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Polskie Archiwum Hydrobiologii existing as such since 1953, is a continuation of *Archiwum Hydrobiologii i Rybactwa* founded in 1926 under the editorship of A. Lityński; during the period 1926 to 1939 and in 1947; thirteen volumes of *Archiwum Hydrobiologii i Rybactwa* have appeared, volume XII, 3, 4, published in September 1939, being almost entirely destroyed due to war action.

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).

The Editorial Board request that the manuscripts conform to the requirements set out below; those manuscripts not conforming to these will be returned to the author for alterantion.

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Authors are requested to be as concise as possible and, in general, papers will be limited to 16 printed pages, including illustrations although in certain cases, longer papers may be accepted provided long tables and lists are avoided. (Irrespective of length of the published paper, authors will be paid for their paper up to 1 quire of type print). Manuscripts should be carefully checked so that proof correction (aparat from printers errors) should be minimal.

Manuscripts, of which the original and one carbon copy complete with tables and figures should be sent, should be typewritten (dobule-spacing) on one side of a sheet only, with a left-band margin of 4 cm and about 30 lines per page; pages should be numbered. The title of the paper (in the language of the text and in the author's native language) should be indicated at the top of the paper together with the author's name (surname and first name), addresse; name and addresse of the laboratory (institute or department) where the work was carried out.

POLSKIE ARCHIWUM HYDROBIOLOGII (Pol. Arch. Hydrobiol.)	16 (29)	1	1—29	1969

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SEASONAL CHANGES IN WATER CHEMICAL COMPOSITION IN SEVEN LAKES

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ABSTRACT

By means of more frequent analyses (carried out every month), seasonal changes and to compare the course of those changes in the lakes which differ among others, in size, depth, and fish yield were investigated. Search has been made for relationship between the chemical composition and the fish yield.

Seasonal changes in temperature, oxygen, transparency, colour, pH, Ca, Na, Mg, K, HCO_3, Cl, SO_4, Fe, PO_4, NO_3, NO_2, SiO_2, oxygen consumption, dry residue, and electrolytic conductivity were investigated in seven lakes in an annual cycle. No relationship has been found between the inorganic fraction of biogenous elements (P, N, Si, and Fe) and the fish yield. It has been found however that the higher the mineral salt contents were, the greater the fish yield was.

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1. Introduction
2. Methods
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1. INTRODUCTION

The available, at present, data on the chemical composition of Mazurian lake water in most cases are results of one or a few series of analyses (OLSZEWSKI, 1953, a, b; PASCHALSKI, OLSZEWSKI 1959; PATALAS, 1960 a, b, c, d; STANGENBERG, 1950; CZECZUGA, 1963; JANUSZKIEWICZ, JAKUBOWSKA, 1963).

The present work aimed at studying in detail seasonal changes by more frequent analyses and then comparison has been made between lakes of different size, depth, and fish yield. Seven lakes were under study: Harsz, Lemięt, Żywy, Arklickie, Upinek, Piecek, and Smolak. Table I presents their limnological characteristics. All those lakes are in the northern part of the Mazurian Lakeland, in the drainage area of the Łyna and Węgorapa Rivers, among Baltic glaciation formations, in a pronouncedly morainal landscape (KONDRACKI, 1952—1953; KONBRACKI, SZOSTAK, 1960).

Table I. Limnological characteristics of lakes under study

Lake	Area[1] in ha	Depth[2]			Limnological type[3]	Thermal stability degree[4]	Primary productivity	Fish yield in kg/ha/ /year
		Max. in m	Average in m	Relative				
Harsz	228.1	48.0	—	—	a-mesotrophic	III/IV	average	16.0
Lemięt	70.5	18.0	5.5	0.021	eutrophic	III/IV	low	11.0
Żywy	115.0	24.5	4.7	0.017	eutrophic	IV	low	12.2
Arklickie	62.0	2.0	1.3	0.002	pond-lake	I	very high	110.0
Upinek	10.0	5.0	2.0	0.016	eutrophic/ pond-lake	II/IV	average	26.8
Piecek	23.3	8.4	3.4	0.017	„suchar"/ eutrophic	IV	low	7.6
Smolak	5.3	5.1	2.4	0.022	„suchar"	II/IV	very low	2.0

[1,2] Surface areas and depths after Olszewski (1953), Kondracki and Szostak (1960).
[3] Limnological types follow the classification by Stangenberg (1936).
[4] Thermal stability degrees and primary production have been given after Patalas (1960 b).

2. METHODS

Seven lakes were studied from March 1961 to April 1962 and then research was carried on on three of them to April 1963.

Water for chemical analyses was sampled as a rule once a month by means of a one-liter Patalas type sampler equipped with a mercurial thermometer.

In deepest parts of the lake water was taken 1 m beneath the surface and 1 m above the bottom apart from the shallow Arklickie Lake, where it was sampled at the depths of 0.5 and 1.8 m.

At the same time water temperature was measured and samples taken for oxygen analyses (every 1 m in shallower lakes and every 2 m, as a rule, in the deeper ones), and the depth of disappearance from view of the Secchi disk checked. (Secchi disk transparency).

When analysing water chemically standard methods were applied (J. Just and W. Hermanowicz 1955, Standard Methods 1955).

Oxygen has been determined by Winkler method (unmodified). pH — by a colour scale after Yamada.

Calcium, potassium, and sodium — by means of a flame photometer.

Magnesium, phosphate phosphorus, ammonium nitrogen, nitrate nitrogen, nitrite nitrogen, silica, and total iron — by colorimetric methods applying a Pulfrich's colorimeter.

Chlorides, oxygen Consumption (with $KMnO_4$) and carbonates — by titration methods.

Sulphates — by the nephelometric method, using a Pulfrich's nephelometer.
Colour — in Nessler tubes according to a dichromate-potassium scale.
Dry residue — by weighing.

Electrolytic conductivity at the temperature of 20°C has been measured with a salinometer, Energopomiar, type GP-2.

3. RESULTS

Temperature (Fig. 3)

A thermal stratification appeared comparatively early in the first year of studies. In June most of the lakes showed their maximum temperature of their surface waters from 19.0° in Lake Harsz to 25.3° in Lake Arklickie. Those high temperatures of the surface water resulted from high air temperatures and weak winds (Figs 1, 2). The greatest temperature differences between surface and bottom waters were observed in June. They amounted to 15.1°C in Lake Piecek and to 13.0°C in Lake Żywy and Lake Smolak.

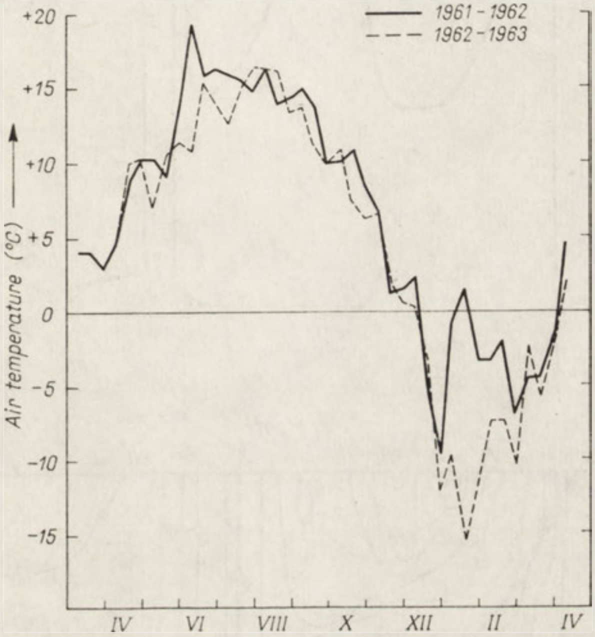


Fig. 1. Seasonal changes in average decadal air temperature

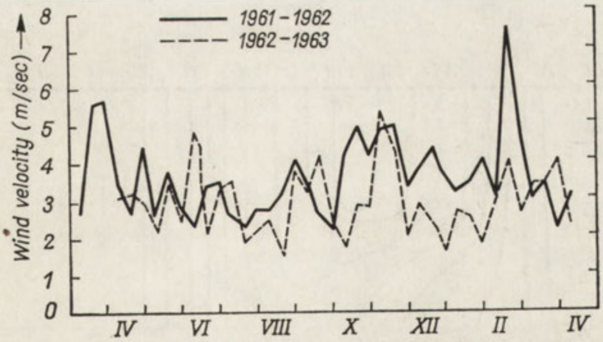


Fig. 2. Seasonal changes in average decadal wind velocities

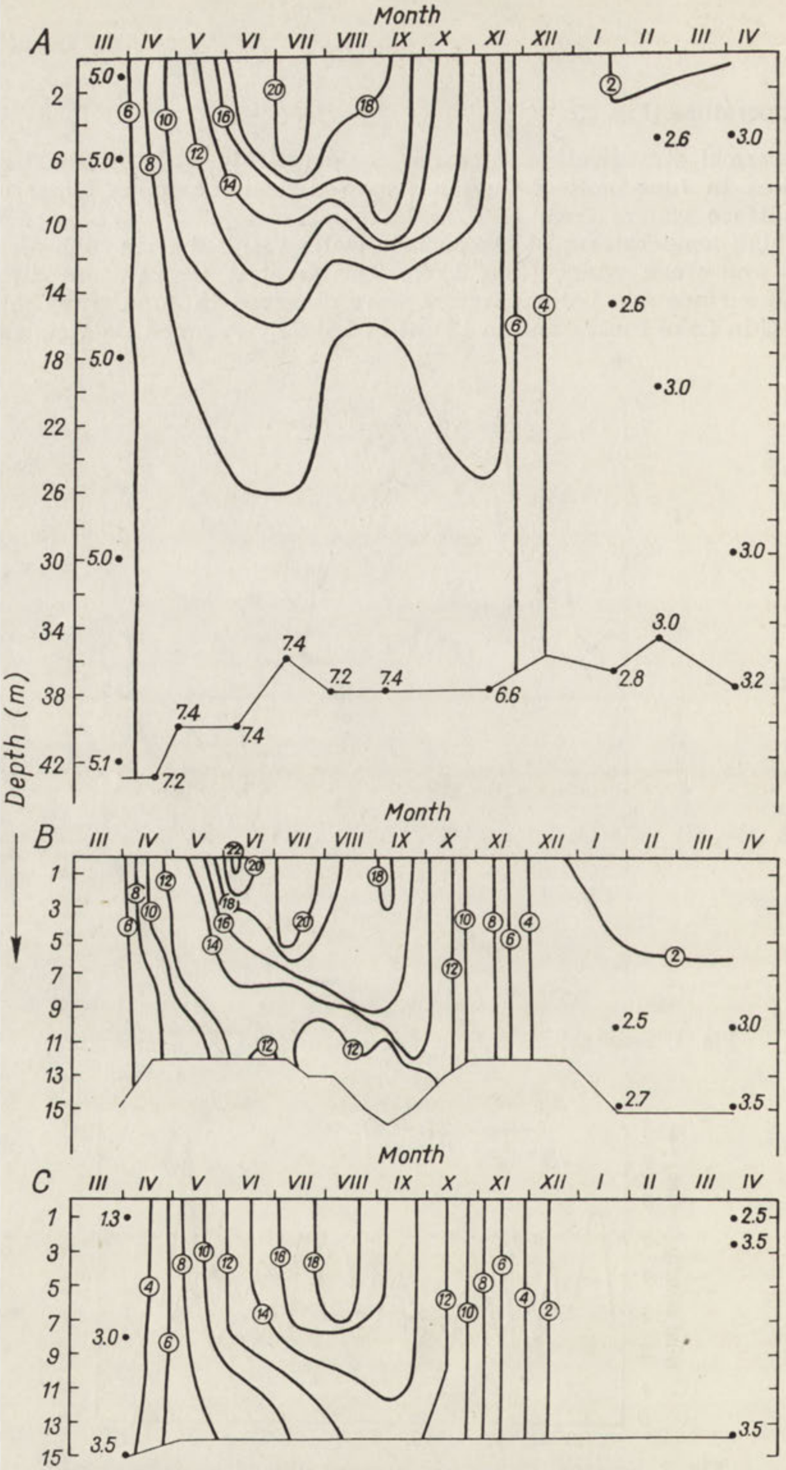
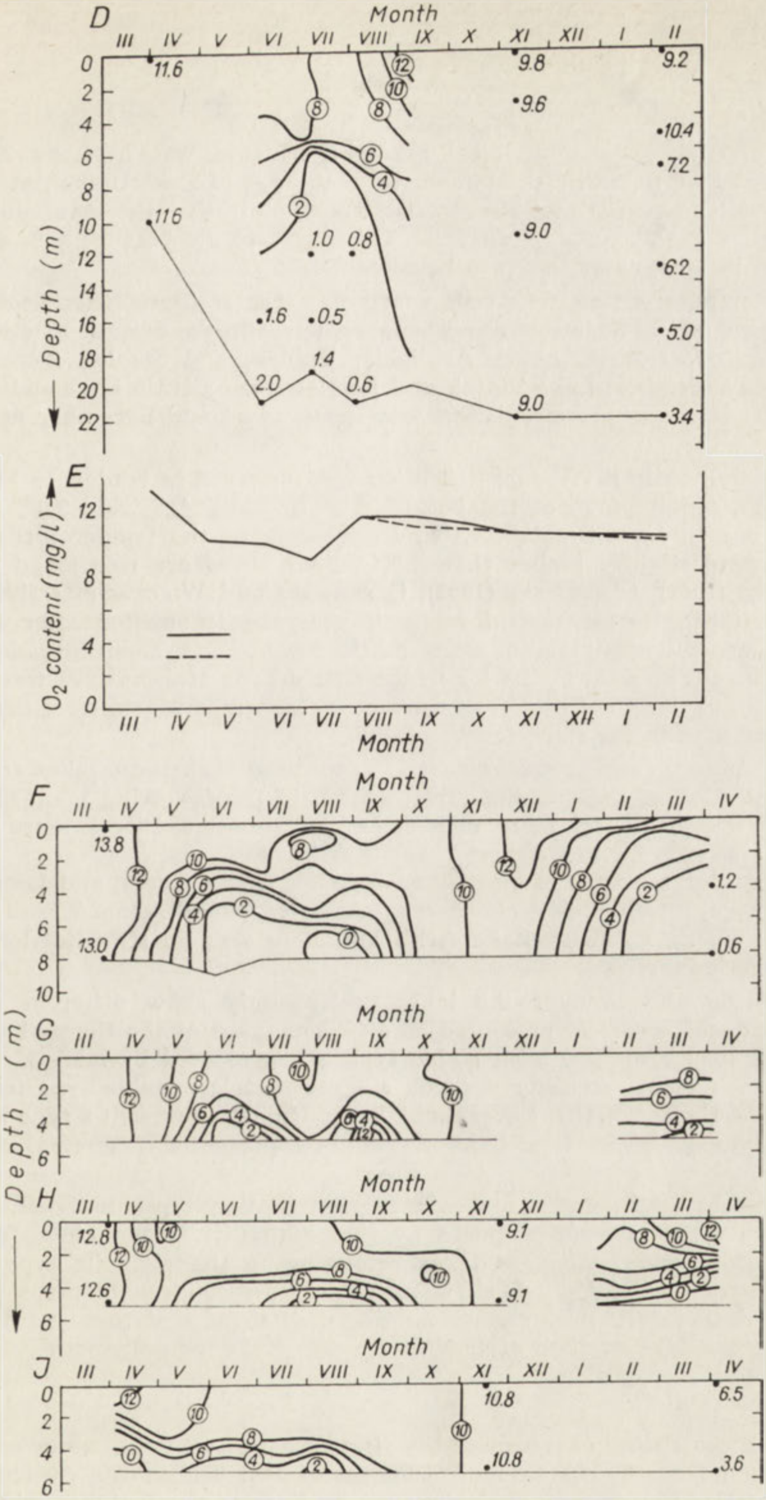


Fig. 3. Seasonal changes in the water temperature of the lakes: A. Harsz (March 1961—April 1962). B. Lemięt (March 1961—April 1962), C. Lemięt (April 1962—April 1963), D. Żywy (March 1961—February 1962),



E. Arklickie (March 1961—February 1962), F. Piecek (March 1961—April 1962), G. Upinek (March 1961—April 1962), H. Smolak (March 1961—April 1962), J. Smolak (April 1962—April 1963)

In July the greatest thermal gradient, 5.2°C/m was in Lake Żywy at a depth of 5—6 m, while the lowest, 0.8°C/m, was in Lake Upinek at a depth of 4—5 m. Olszewski and Paschalski (1959) state that the maximum gradients of the thermoclines in Masurian Lakes studied are between 0.8—8.3°C/m, although in most cases they are between 2—2.5°C/m.

The temperature of the whole mass of water of those lakes became the same at the end of September and October, while in the deepest lake it occurred in mid-November. Lakes Arklickie, Upinek, and Smolak froze in the middle of December; Lake Piecek and Lemięt froze a little later and the last was Lake Harsz where circulation was observed at mid-December at a temperature 4°C.

A pronouncedly reverse stratification was observed in winter. In February the lowest temperature at the bottom was in Lake Arklickie 2.0°, and the highest one in Lake Smolak, 4.4°C. In three lakes the temperatures at the bottom were slightly higher than 4.0°C. Such cases are mentioned also by Mortimer (1941), Olszewski (1953), Olszewski and Więcławska (1965), and Lossow (1965). In the second research year the ice melted later and the surface water temperatures were much lower. The mean decadal daily temperature (Figs 1, 2) of the air in the first decade of June 1962 was by 8.6° lower than in the preceding year. Surface water temperatures were more than 9°C lower than in the same month of 1961.

As it follows from this review it is possible to rank those lakes according to the duration of the summer stratification in the following manner: Harsz almost 7 months, Żywy more than 6, Lemięt almost 6, Piecek more than 5, Smolak almost 5, Upinek almost 2, and Arklickie 0.

Considering the type of stratification Lakes Harsz, Żywy, and Lemięt had three thermal layers: epi-, meta- and hypolimnion, Piecek, Smolak, and Upinek had two layers, while in Lake Arklickie there was no stratification at all (a polymictic lake).

In spring and summer the lakes under study show different thermal conditions which can be presented as different types of the thermal stability (Patalas 1960 b, d). The most stable type is represented by lakes Żywy and Piecek (IV thermal stability degree), a somewhat less stable type by Lakes Lemięt and Harsz (III/IV). Lakes Smolak and Upinek represent a type between II and IV degree. At last, Lake Arklickie represented I thermal stability degree.

Olszewski (1959) distinguishes a few circulation types in lakes. Taking into account the criteria proposed by that author it is possible to describe Harsz, Żywy, and Lemięt as lakes belonging to the eumictic type. Lakes Piecek, Smolak, and Upinek show no clearly distinguishable three thermal strata and therefore they cannot be classified to any of those types. Lake Arklickie can be described after Wiszniewski (1953) as polymictic.

Oxygen (Fig. 4)

During the spring overturn of the first research year the water oxygenation ranged from 89,2% to 106.5% of saturation. The spring overturn had then a similar course with that observed by Stangenberg (1937), when temperatus were different from 4.0°C and the oxygen, saturation varied from 100%.

A clear vertical differentiation in the oxygen content could be seen as early as May and there appeared an oversaturation of the surface layers, whose maximum in most lakes occurred in June (Lake Lemięt 142%, Lake Piecek 127%). At that time quite visible oxygen deficiencies (4.8—47.3% of saturation) could be seen at the bottom, while already at that stage hydrogen sulphide appeared in Lake Lemięt at a depth of more than 8 m. In August hydrogen sulphide was present in three lakes: Lemięt, Piecek, and Smolak.

The rise of oxygen content was the rapidest and most thorough in the bottom water layers of the shallowest lakes. Upinek and Smolak, during the autumn overturn. Differences in oxygen contents between bottom and surface layers could be seen in Lake Lemięt and Lake Piecek, in spite of the disappearance of thermal strata, still in October. A thermal and oxygen stratification could be observed longest, until mid-November, in Lake Harsz. In winter Lake Harsz showed the highest oxygen content (about 50 per cent).

Comparing the results of the following year's studies (1962/1963) on Lake Lemięt and Lake Smolak it should be stated that both in summer as well as in winter the oxygen content was considerably higher and the periods of pronounced deficiency much shorter. Probably it was due to the much colder and windier summer of 1962 in comparison with the summer of the preceding year.

Calcium (Fig. 6)

Ca^{++} ion is as a rule the main cation of inland surface waters (Hutchinson 1957). Of the seven lakes under study in five calcium was the main cation and only in Smolak and Piecek it was surpassed by other cations. Lake Arklickie was the richest in calcium — 67 mg/l Ca, while Lake Smolak contained 1 mg/l of it. Except this last value the remaining ones are within limits, which are given for other Polish lakes by Stangenberg (1936), Olszewski and Paschalski (1959), and Patalas (1960 c).

Lake Arklickie showed seasonal changes in the calcium content most clearly. From the beginning of spring to the end of July there was a sharp decrease in the concentration of calcium, caused by the biological process of water decalcification (Minder 1923). Since that lake is shallow, the entire water mass was decalcified. In autumn and winter there was a gradual increase in the calcium content. In other lakes the differences between the maximum and minimum values were much smaller. As a rule the highest calcium contents were observed in the lakes in autumn and winter and the lowest in summer. An exception is Lake Żywy where for reasons difficult to explain the annual maximum occurred in August.

In most cases higher calcium concentrations were found in the bottom water layers of the lakes under study during the summer and winter stagnation and Lake Lemięt showed the greatest differentiation in the vertical distribution of calcium

In the following research period (1962/1963) seasonal changes in Lake Harsz and Lake Lemięt showed somewhat smaller seasonal variations.

Magnesium (Fig. 6)

In most of the mentioned lakes magnesium was the second most numerous cation after calcium. Only in Lake Smolak it was more numerous than calcium. The highest magnesium concentration was found in Lake Arklickie (30.0 mg/l

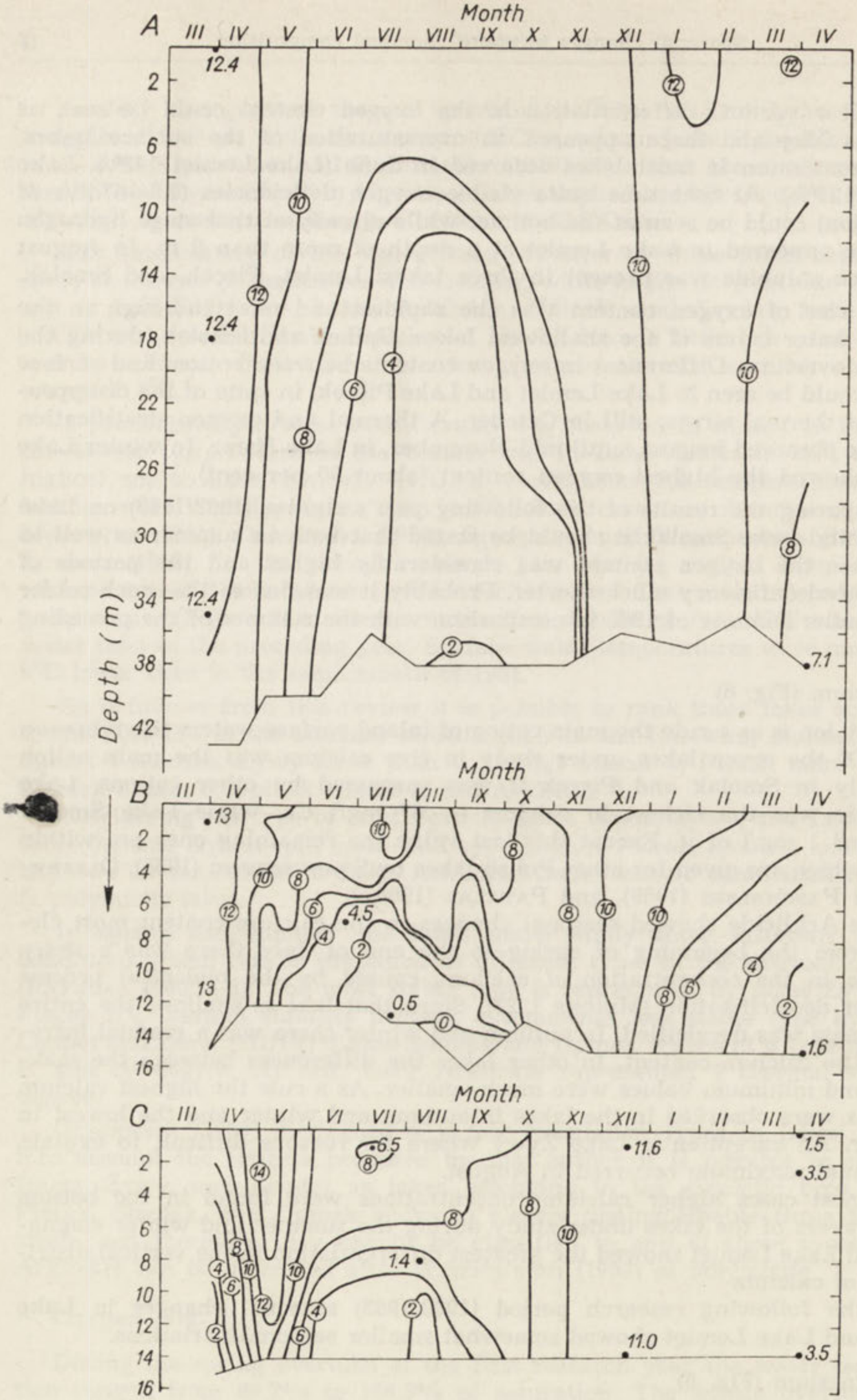
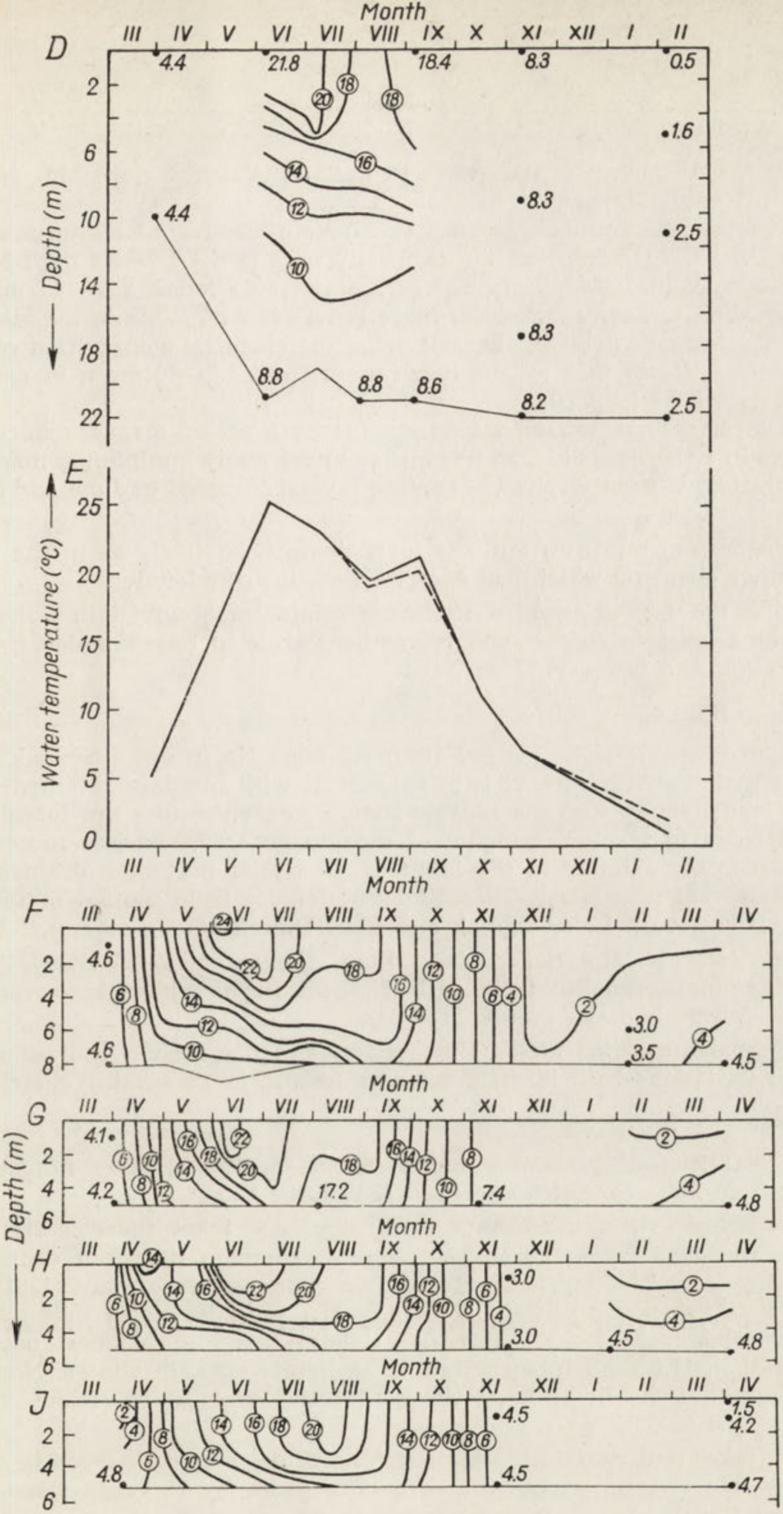


Fig. 4. Seasonal changes in water oxygen content of the lakes: A. Harsz (March 1961—April 1962), B. Lemięt (March 1961—April 1962), C. Lemięt (April 1962—April 1963), D. Żywy (March 1961—February 1962),



E. Arklickie (March 1961—February 1962), F. Piecek (March 1961—April 1962), G. Upinek (March 1961—April 1962), H. Smolak (March 1961—April 1962), I. Smolak (April 1962—April 1963)

Mg) the lowest concentrations were in Lake Smolak (0.3 mg/l Mg) and Lake Piecek (0.9 mg/l Mg).

Januszkiewicz and Jakubowska (1963) state that Lake Klasztorne contains 2.3—11.1 mg/l Mg; according tot Januszkiewicz (1965) 1.9—9.9 mg/l Mg is in Lake Ewingi;; in Lake Wigry Szczepański (1961) found 2.2—16.8 mg/l Mg and according to Niewolak (1966) there is 5.4—22.0 mg/l Mg in the lakes near Iława. Stangenberg (1958), characterizing the chemical composition of Polish river waters, states that magnesium ranges from 1.7—86 mg/l, in most case being between 5—10 mg/l.

The most distinct seasonal changes in the level of magnesium could be seen also in Lake Arklickie. In most lakes under study a minimum magnesium concentration, particularly in the surface layers, occurred in June and November.

A magnesium stratification was most distinct, similarly as in the case of many other elements which had been studied, in Lake Lemięt.

During the second year of studies a minimum occurred in Lake Harsz and Lake Lemięt in August and November, while in Lake Smolak it happened in June and October.

Sodium (Fig. 6)

Sodium cencentrations ranged from 0.5 mg/l Na in Lake Smolak to 14.2 mg/l Na in Lake Arklickie. It is in agreement with the data obtained in 1953 by Patalas (1960 c), that the highest sodium concentrations are found in the lakes situated in the lower region of a drainage area, whereas those values are considerably smaller in the lakes of the upper part of a drainage area (Lake Żywy among others). There is exceptionally little sodium in the lakes having no outlet (in Lake Smolak and Lake Piecek among others).

Lake Arklickie, the richest in sodium, showed also relatively greatest seasonal changes ranging from 11.1—13.4 mg/l Na, while those variations were the lowest in Lake Piecek and Lake Żywy.

In comparison with calcium, potassium, and magnesium sodium showed the least variations both in different seasons and in its vertical distribution.

Potassium (Fig. 7)

The quantities of potassium found in the mentioned lakes ranged from 0.1 mg/l K in Lake Smolak to 8.9 mg/l K in Lake Harsz.

Stangenberg (1956) finds that in most of our lakes there is from 2—6 mg/l K, while as he states (1958) the most common potasium contents in rivers vary from 2—4 mg/l. Similarly Stangenberg-Oporowska (1961) mentioning that fish-ponds contain from 0.7—11.7 mg/l K, states that the most common value is 2—4 mg/l. Patalas (1960 c) found the highest potassium concentration, 11.8 mg/l in a shallow Lake Przerwanki, in winter. Niewolak (1966) finds that the Iława lakes show different levels of potassium, varying from 1.6 mg/l to 12.5 mg/l.

In the lakes under study the highest concentration was observed in winter. On the whole it is in agreement with data given by Patalas (1960 c) and Niewolak (1966).

Lake Piecek showed the greatest seasonal variations, the difference between the maximum and minimum cencentrations being 5.5 mg/l K.

On the whole the bottom water layers contained slightly more potassium than the surface layers. As a rule the potassium concentration resembled that of sodium except Lake Arklickie, where it was only half of the latter.

Ion contents of Lake Piecek considerably varied from the mean values. Potassium was about twice as abundant as sodium and its quantity was even four times higher than that of sodium in winter. Having a very high potassium concentration this lake is at the same time very poor in calcium, magnesium and phosphorus.

Bicarbonates (Fig. 6)

Bicarbonates are most abundant among the anions present in the water of the lakes under discussion. Their content, similarly as that of Ca, undergoes considerable seasonal changes depending on the intensity of assimilation processes or the decomposition of organic matter.

Bicarbonates were most abundant, similarly as calcium, in Lake Arklickie 349 mg/l and Lake Upinek 318 mg/l HCO_3 in winter. In Lake Smolak concentration was very low $<$ 18 mg/l and in Lake Piecek $<$ 43 mg/l HCO_3.

Considerable changes in the concentration of bicarbonates were obserwed in Lake Arklickie and in the bottom water layers Lake Lemięt.

Corbonates (Fig. 6)

In most cases carbonates were found in the surface water layer and rarely at the bottom. Carbonates were not found in Lake Smolak having a very low pH (5.7—7.0). In Lake Piecek carbonates were present only at the surface in June, when pH was 8.6.

The highest carbonates contents, 21.0 mg/l CO_3 at the surface and 24.0 mg/l CO_3 at the bottom, were observed in Lake Lemięt in March 1961 pH of both those water layers was 8.9. Both those layers of Lake Arklickie contained carbonates almost all the year through. Except Lake Upinek, carbonates were not found in the period of the autumn overturn.

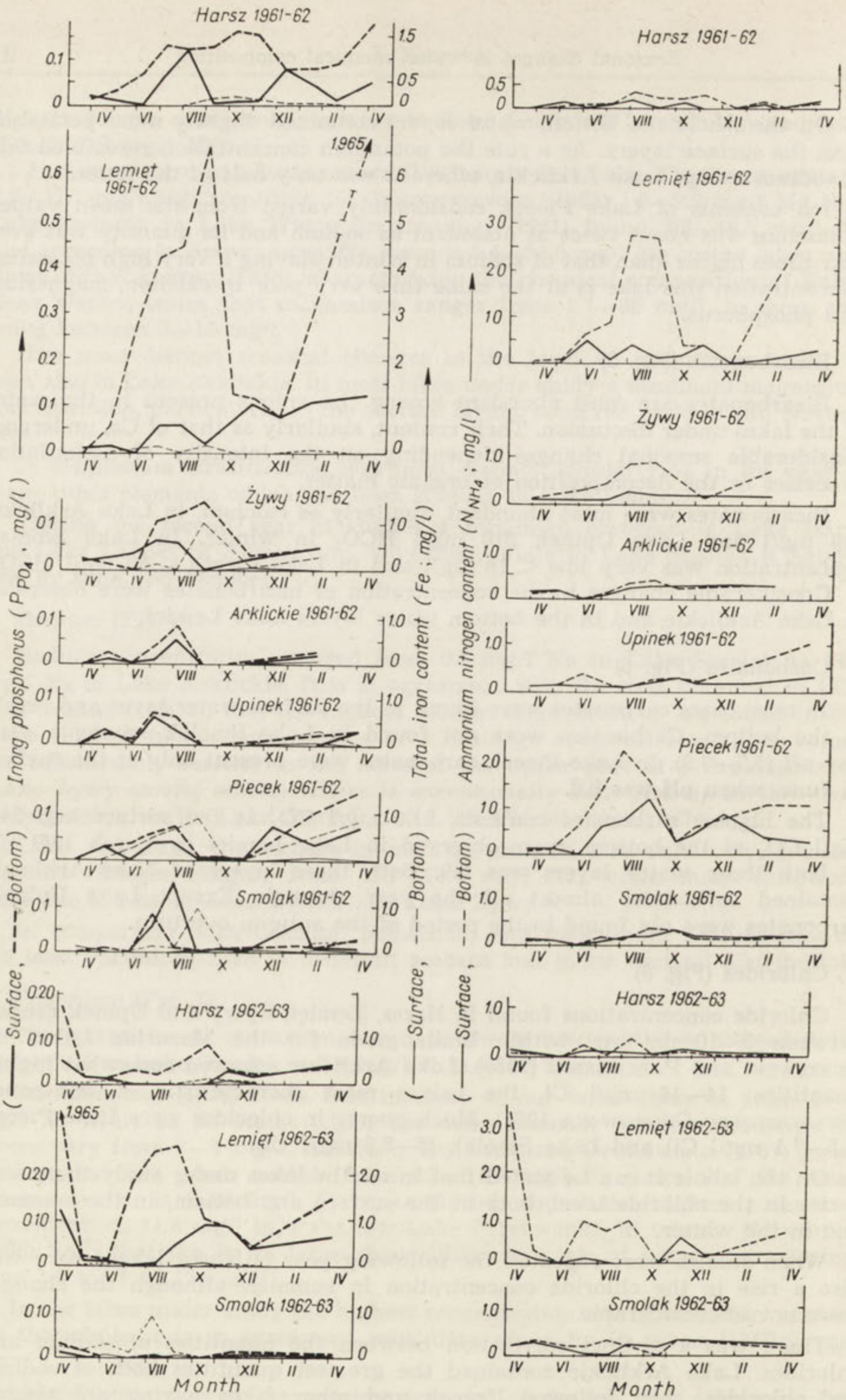
Chlorides (Fig. 6)

Chloride concentrations found in Harsz, Lemięt, Żywy and Upinek ranged between 5—10 mg/l or within limits given for the Mazurian Lakes by Olszewski and Paschalski (1959). Lake Arklickie schowed somewhat higher quantities, 14—19 mg/l Cl, the values most characteristic of fish-ponds (Stangenberg-Oporowska 1961). Much poorer in chlorides were Lake Piecek (2.5—7.1 mg/l Cl) and Lake Smolak (0—3.5 mg/l Cl).

On the whole it can be stated that in all the lakes under study there was a rise in the chloride level, both at the surface and bottom, in the summer, and in the winter.

When studies were repeated the following year on three lakes, there was also a rise in the chloride concentration in summer, although the changes were not so considerable.

There was a distinct correlation between the quantities of sodium and chlorides. Lake Arklickie contained the greatest quantities both of sodium and chlorides, then followed Upinek and other lakes having diminishing concentrations: Harsz, Lemięt, Żywy, Piecek and Smolak (Table III).


Harsz 1961-62
0.1
0
1.5
0.5
0
IV
VI
VIII
X
XII
II
IV
1965
Lemięt 1961-62
0.6
0.5
0.4
0.3
0.2
0.1
0
6
5
4
3
2
1
0
Żywy 1961-62
0.1
0
10
0
Arklickie 1961-62
0.1
0
1.0
0
Upinek 1961-62
0.1
0
1.0
0
Piecek 1961-62
0.1
0
1.0
0
Smolak 1961-62
0.1
0
1.0
0
Harsz 1962-63
0.20
0.10
0
1.0
0
1965
Lemięt 1962-63
0.20
0.10
0
2.0
1.0
0
Smolak 1962-63
0.10
0
1.0
0
Month
(—— Surface, - - - Bottom) Inorg phosphorus (P_{PO_4} ; mg/l)
Total iron content (Fe ; mg/l) (—— Surface, - - - Bottom)
Ammonium nitrogen content (N_{NH_4} ; mg/l) (—— Surface, - - - Bottom)
Harsz 1961-62
0.5
0
Lemięt 1961-62
30
20
10
0
Żywy 1961-62
1.0
0
Arklickie 1961-62
1.0
0
Upinek 1961-62
1.0
0
Piecek 1961-62
20
10
0
Smolak 1961-62
Harsz 1962-63
1.0
0
Lemięt 1962-63
3.0
2.0
1.0
0
Smolak 1962-63
1.0
0
Month

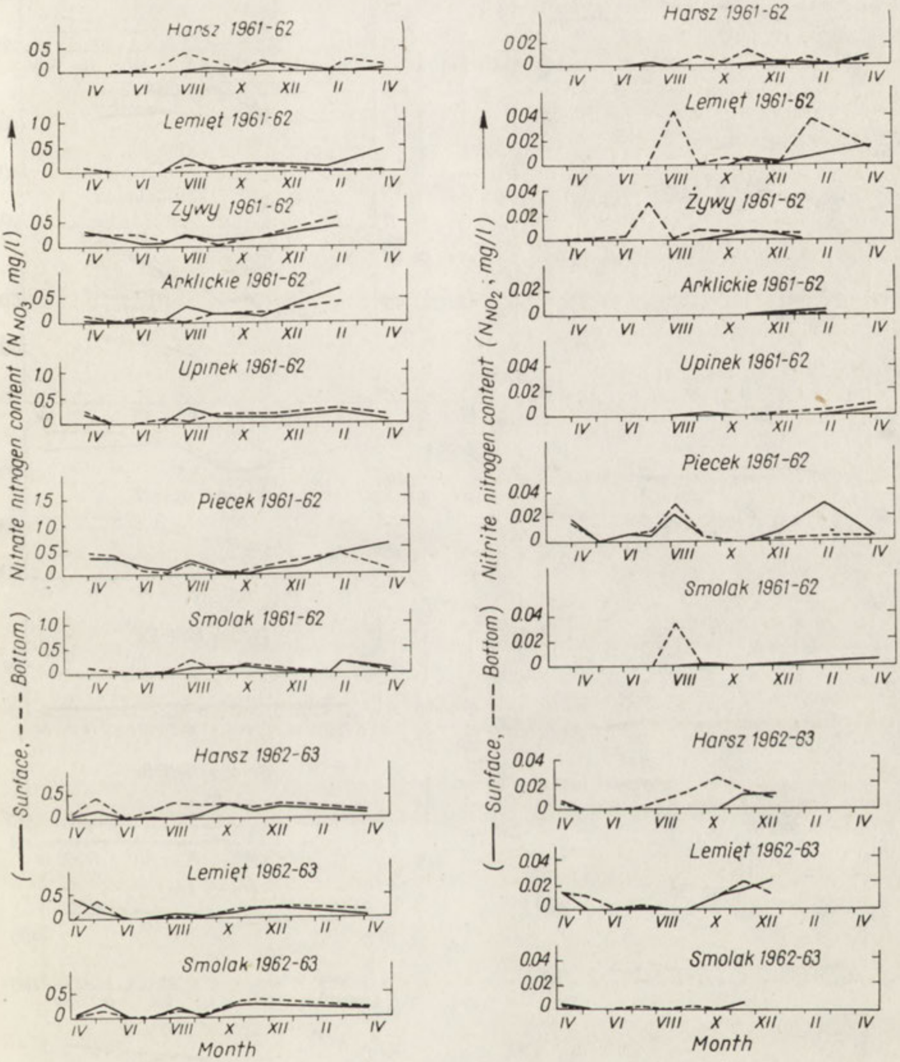
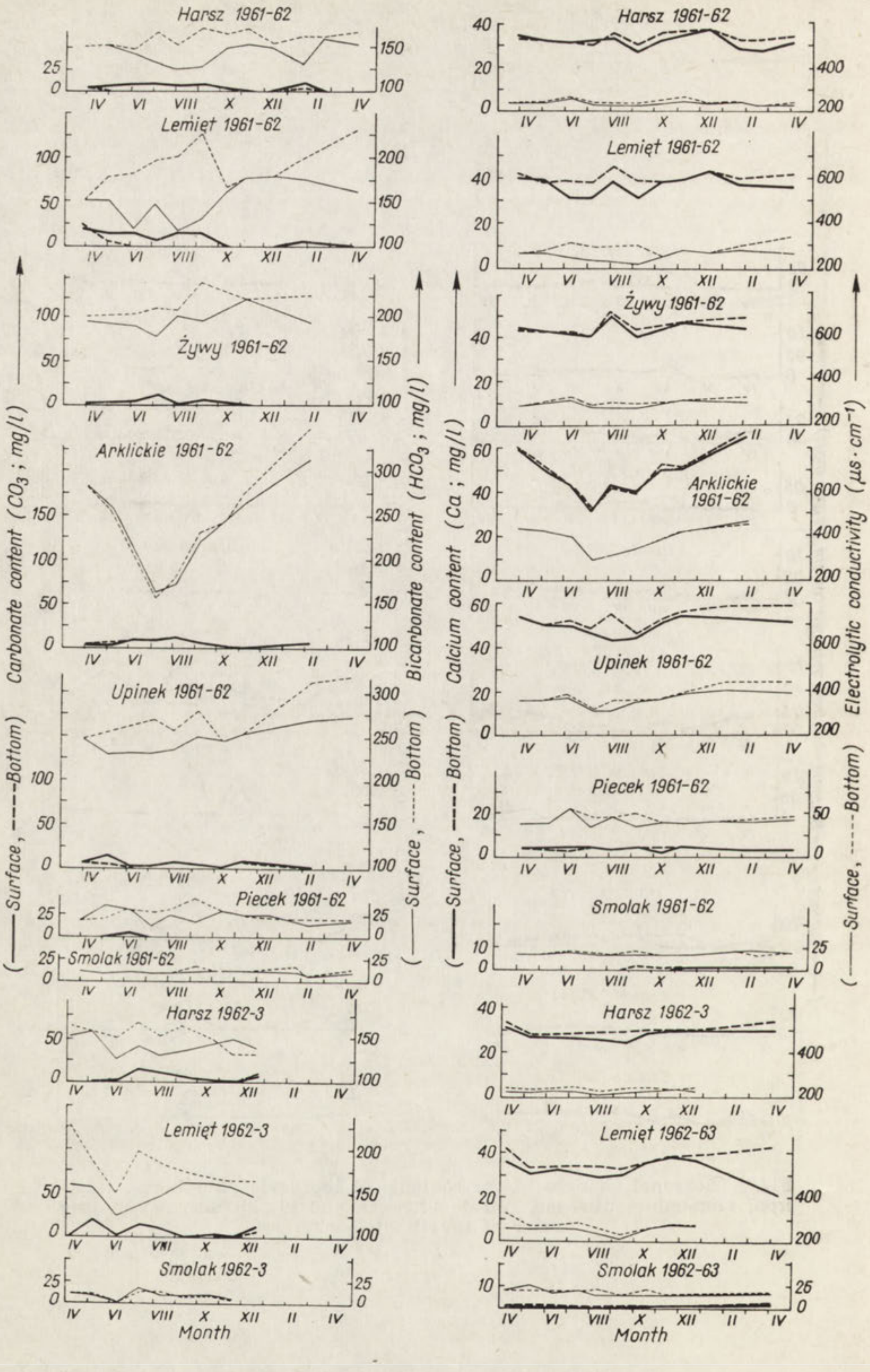


Fig. 5. Seasonal changes in the contents of inorganic phosphorus, total iron, ammonium nitrogen, nitrate nitrogen and nitrite nitrogen in the water of investigated lakes


Harsz 1961-62
Lemięt 1961-62
Żywy 1961-62
Arklickie 1961-62
Upinek 1961-62
Piecek 1961-62
Smolak 1961-62
Harsz 1962-3
Lemięt 1962-3
Smolak 1962-3
Month
Carbonate content (CO3 ; mg/l)
(—— Surface, ---- Bottom)
Bicarbonate content (HCO3 ; mg/l)
(—— Surface, ----- Bottom)
IV VI VIII X XII II IV
Harsz 1961-62
Lemięt 1961-62
Żywy 1961-62
Arklickie 1961-62
Upinek 1961-62
Piecek 1961-62
Smolak 1961-62
Harsz 1962-3
Lemięt 1962-63
Smolak 1962-63
Month
Calcium content (Ca ; mg/l)
(—— Surface, ---- Bottom)
Electrolytic conductivity (µs · cm⁻¹)
(—— Surface, ----- Bottom)

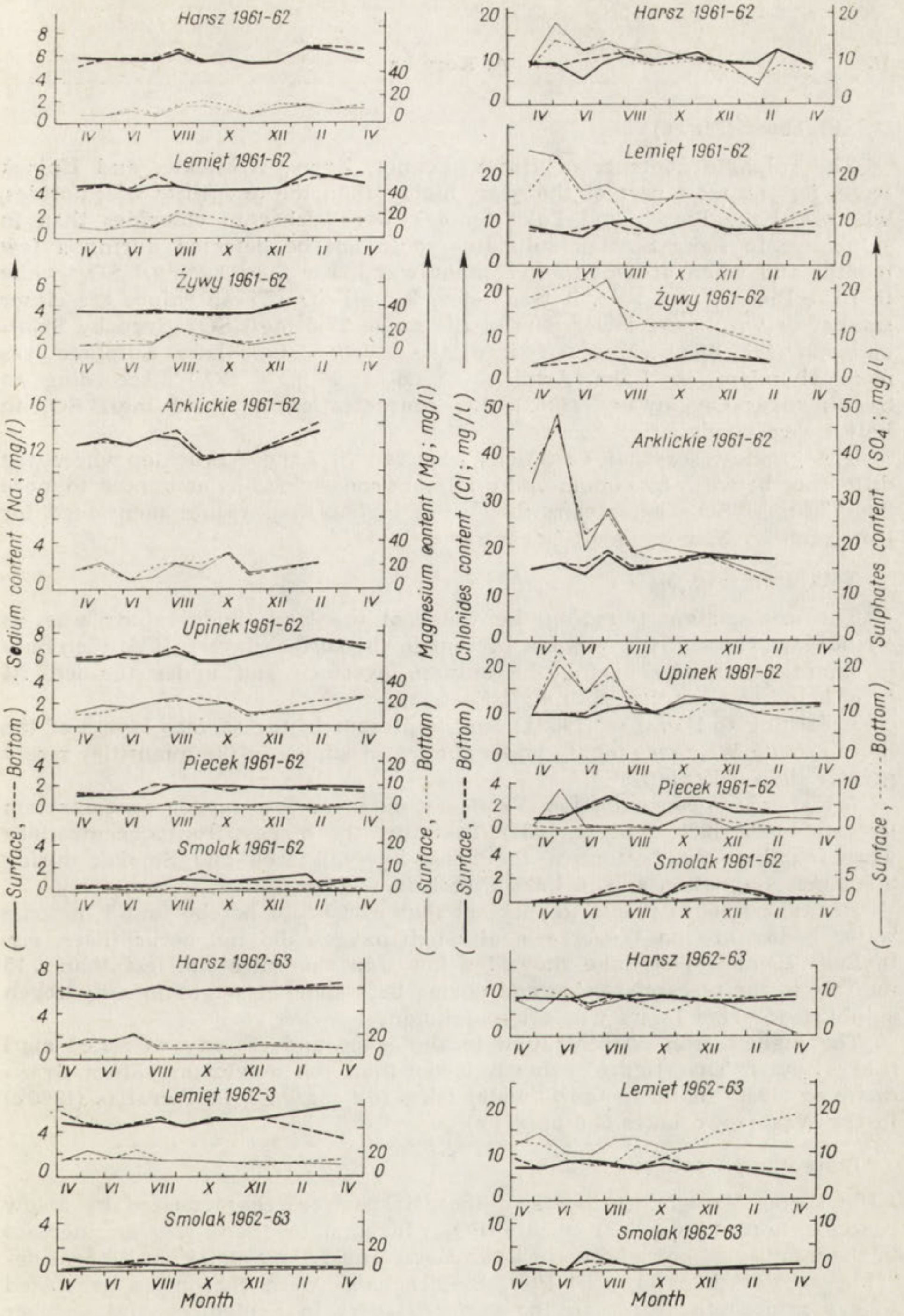


Fig. 6. Seasonal changes in the contents of carbonate, bicarbonate, calcium, sodium magnesium, chlorides and sulphates and electrolitic conductivity in the water of investigated lakes

Sulphates (Fig. 6)

The sulphate contents of Harsz, Lemięt, Żywy, Arklickie, and Upinek were, for the most part of the year, higher than the quantities of chlorides, whereas, Lake Piecek and Lake Smolak were richer in chlorides than in sulphates. In Lake Smolak sulphates could not be detected during a few months and when present their content was lower than 1.2 mg/l SO_4, while in Lake Piecek, as a rule, it was below 3 mg/l SO_4. These values are either smaller or within the lower part of the range 2—5 mg/l SO_4 given by Stangenberg (1937 b) as characteristic of the "suchar" type lake. Sulphate was most abundant in Lake Arklickie (11.6—48.0 mg/l SO_4). According to Stangenberg-Oporowska (1961) this concentration is 7—82 mg/l SO_4 in Polish carp ponds.

The greatest seasonal variations occurred in Lake Arklickie, where the difference between maximum and minimum concentrations amounted to more then 30 mg/l SO_4 that means they were higher than values mentioned for fish-ponds by Stangenberg-Oporowska (1961).

Total iron (Fig. 5)

The iron content found in the water of the lakes under study was, as a rule, low. Generally it was not present in the surface layers, if so then only in minute quantities during the autumn overturn and under the ice, its level being smaller than 0.10 mg/l Fe.

According to Patalas (1960 c) iron is present in the surface layers of the lakes around Węgorzewo only under the ice in winter in the quantities rarely greater than 0.05 mg/l.

A higher iron concentration (Fe^{++}) depends on a low oxygen concentration (Stangenberg 1936, Einsele 1936). Therefore the highest iron concentrations were found at the bottom of the lakes Żywy, Piecek and Smolak during a summer stagnation and in Lake Piecek in winter.

Patalas (1960 c) points to the fact that iron could not be found in some water bodies around Węgorzewo although oxygen did not occur there, e.g. in Lake Lemięt. That lake showed a low iron concentration, less than 0.15 mg/l Fe in the research period and during both summer stagnations hydrogen sulphide occurred in its whole hypolimnion.

The highest iron concentration in the lakes under study was 1.00 mg/l (Lake Żywy). That figure is much lower than the maximum values Stangenberg (1936) found in the Suwałki lakes (6.4 mg/l Fe) or Patalas (1960 c) in the Węgorzewo lakes (4.0 mg/l Fe).

Inorganic phosphorus (Fig. 5)

In spring the surface layers of those lakes were characterized by a low concentration, 0.000—0.031 mg/l $P(PO_4)$. In summer there was an increase in the quanity of phosphorus in Lake Harsz and Lake Smolak, quite considerable, greater than 0.1 mg/l $P(PO_4)$. Phosphates were once more exhausted to a considerable degree in the surface layers in September and October except Lake Lemięt.

The bottom water layers, as a rule, showed higher phosphate concentrations, even in Lake Arklickie, where apart from the period of freezing no thermal stratification was observed. High phosphate concentrations at the bottom of the lakes in summer and winter was usually connected with the absence or a very low concentration of oxygen in that layer. Generally, higher phosphate concentrations occurred with higher iron concentrations (SOLSKI 1964). Lake Lemięt was an exception, in spite of very high phosphate concentrations — 0.655—1.965 mg/l P(PO_4) there were only inconsiderable iron quantities.

The course of changes in the phosphate contents of the lakes: Harsz, Lemięt, and Smolak on the whole was similar. The phosphate quantities found in summer range between the values given by STANGENBERG (1936), OLSZEWSKI and PASCHALSKI (1959), and PATALAS (1960 c). During the autumn circulation the phosphate concentration of the lakes approached the upper values characteristic of the Suwałki lakes (STANGENBERG 1936).

Nitrate nitrogen (Fig. 5)

On the whole the highest quantities of nitrates in the studied lakes occurred in winter, which is in agreement with the data presented by many authors (MORTIMER 1941, STANGENBEG 1950, OLSZEWSKI 1953, PATALAS 1960 c, and others). During the most part of the year the concentration of nitrate nitrogen was usually lower than 0.2 mg/l N(NO_3), being even smaller than 0.1 mg/l in June and July. It was so both in the surface and bottom layers. In the autumn overturn both the surface and bottom water layers contained almost the same amount of nitrates, ranging as a rule from 0.1—0.2 mg/l N(NO_3). Nitrates were most abundant in the lakes: Arklickie, Żywy, and Piecek, while their lowest quantities were present in Lake Harsz in 1961, where they were not found in the surface layers in spring and summer.

Ammonium nitrogen (Fig. 5)

Changes in the contents of ammonium nitrogen as a rule were similar to those of phosphates: small quantities in spring, generally not greater than 0.2 mg/l N(NH_4) and a distinct increase of the concentration in summer, particularly so in the bottom water layer. Considerable ammonium quantities, more than 2.0 mg/l N(NH_4), were present in the bottom water layer of Lake Lemięt and Lake Piecek in August and September 1961. Prolonged periods of oxygen exhaustion occurred in those lakes in summer.

The winter was characterized by a rise in the amonium concentration in the bottom layer. This rise was particularly great in Lake Lemięt — 3.35 mg/l N(NH_4).

As a rule, small amounts of ammonium nitrogen were found in the surface water layers (0.3 mg/l) and only in Lake Piecek a higher concentration had been observed, it amounted to 0.75—1.2 mg/l.

On the whole, more ammonium nitrogen was in Lake Lemięt and Piecek and less in Lake Harsz, Smolak, and Arklickie. Maximum values found were considerably higher than those given by OLSZEWSKI and PASCHALSKI (1959) for the Mazurian lakes; they were slightly lower than those given by PALATAS (1960) for the Węgorzewo lakes — 0.0—4.0 mg/l N(NH_4) and lower than given by STANGENBERG-OPOROWSKA (1961) as characteristic of Polish ponds — 0.02—7.80 mg/l N(NH_4).

Nitrite nitrogen (Fig. 5)

In the lakes under study nitrites were either not present or if so the thousandth parts of mg/l. It is similar as in ponds (STANGENBERG-OPOROWSKA

1961). According to Stangenberg (1958) values from 0.000—0.005 mg/l $N(NH_4)$ are most characteristic of the Polish rivers.

In spring most of the studied lakes did not contain nitrites either in the surface or bottom layers. An exception is Lake Piecek, rich in ammonium and nitrates, where nitrites were present almost all the year through in both layers.

In the summer nitrites were not present in the surface layers, except Lake Piecek. They occurred in that layer in autumn (mainly in November) and were present through the whole winter, when usually their maxima were observed (as thousandths of mg/l), while in Lake Piecek and Lemięt those values were of the order of the hundredth parts. At that time maximum quantities of ammonium could be found in those two lakes.

A second series of studies on lakes Harsz, Lemięt, and Smolak confirmed in general the main trends of seasonal changes.

Silica (Fig. 7)

Surface lake waters of different continents contain from 0 to a few score mg/l SiO_2 (Hutchinson 1957). According to Stangenberg (1961) the silica content of Polish lakes ranges from 0.29—16.0 mg/l SiO_2. In the Wdzydze lakes Patalas (1961) found 2.4—4.5 mg/l SiO_2 in the surface layers and up to 18.0 mg/l in the bottom layers.

The studied lakes contained from 0 to 16.8 mg/l SiO_2 and their maximum values were observed in winter. In the spring of 1961 silica was either absent or present in inconsiderable quantities in the lakes: Harsz, Lemięt, Piecek, and Smolak. In summer a distinct increase in the concentration of silica could be observed, particularly so in the bottom layers of Lake Lemięt, Żywy, and Upinek poor in oxygen. Probably, because of an oxygen deficiency ferrous silicate which formerly had formed in the upper mud layers in the presence of oxygen now was reduced (Mortimer 1941).

During autumn a drop in the silica concentration occurred in most of the lakes and then a new increase took place in winter, particularly in the bottom layers. The greatest seasonal changes were observed in Lake Lemięt which had the most pronounced silica stratification during the two research periods. Lake Smolak and Lake Piecek showed the lowest amounts of silica.

In June 1962, a silica maximum could be observed in the lakes Harsz, Lemięt, and Smolak, which in their surface layers amounted to more than 10 mg/l SiO_2. Probably it was due to a mass dying out of diatoms, as it follows from Półtoracka's materials (in preparation).

Oxygen consumption (Fig. 7)

The highest oxygen consumption was observed in Lake Arklickie 20.5 mg/l O_2 and Lake Żywy 19.2 mg/l O_2 and the lowest one in Lake Smolak 6.4 mg/l. These values approximate those published by Olszewski and Paschalski (1959) for 170 Mazurian lakes (6.9—19.5 mg/l O_2).

An increase in the oxygen consumption was noticed in Lake Arklickie from May to October. In other lakes those changes are not so regular although the oxygen consumption tends to increase there in summer. Water surface layers, as a rule, are characterized by a higher oxygen consumption. The latter drops in late autumn and winter.

Colour (Fig. 7)

Generally the lake water colour was most intensive in summer and least intensive during the autumn overturn and at the end of the winter stagnation period; in most cases the bottom layers showed a stronger colouring. The most intensive colour of the bottom water, 80—90°Pt, was observed in Lake Smolak and Lake Żywy in August and September 1961; the least intensive one, 5°Pt, could be seen in Lake Harsz in the spring 1962. Those values agree with those published by Olszewski and Paschalski (1959) for the majority of lakes in the central part of Mazuria.

Maximum differences in the colouring of the surface and bottom water layers could be seen, as a rule, in summer. In August 1962 they amounted to 70°Pt in Lake Smolak. Equally great differences were observed in Lake Piecek and Lake Żywy at the end of summer 1961. Those differences were the least in Lake Harsz.

According to Mortimer (1941) the hypolimnion water colouration depends among others on the presence of colloidal ferric hydroxide. It should be mentioned that the most intensive water colour, 70—90°Pt, could be seen in Lake Smolak, Żywy, and Piecek at the time when they contained also much iron, i.e. about 1 mg/l Fe.

The most distinct variations in colour were in Lake Smolak, ranging from 15 to 80°Pt at the bottom and in Lake Piecek ranged from 15 to 60°Pt in the surface layer.

The colour of the surface water layers was, on the whole, in a reverse relation to the transparency of water.

Secchi disk transparency (Fig. 7)

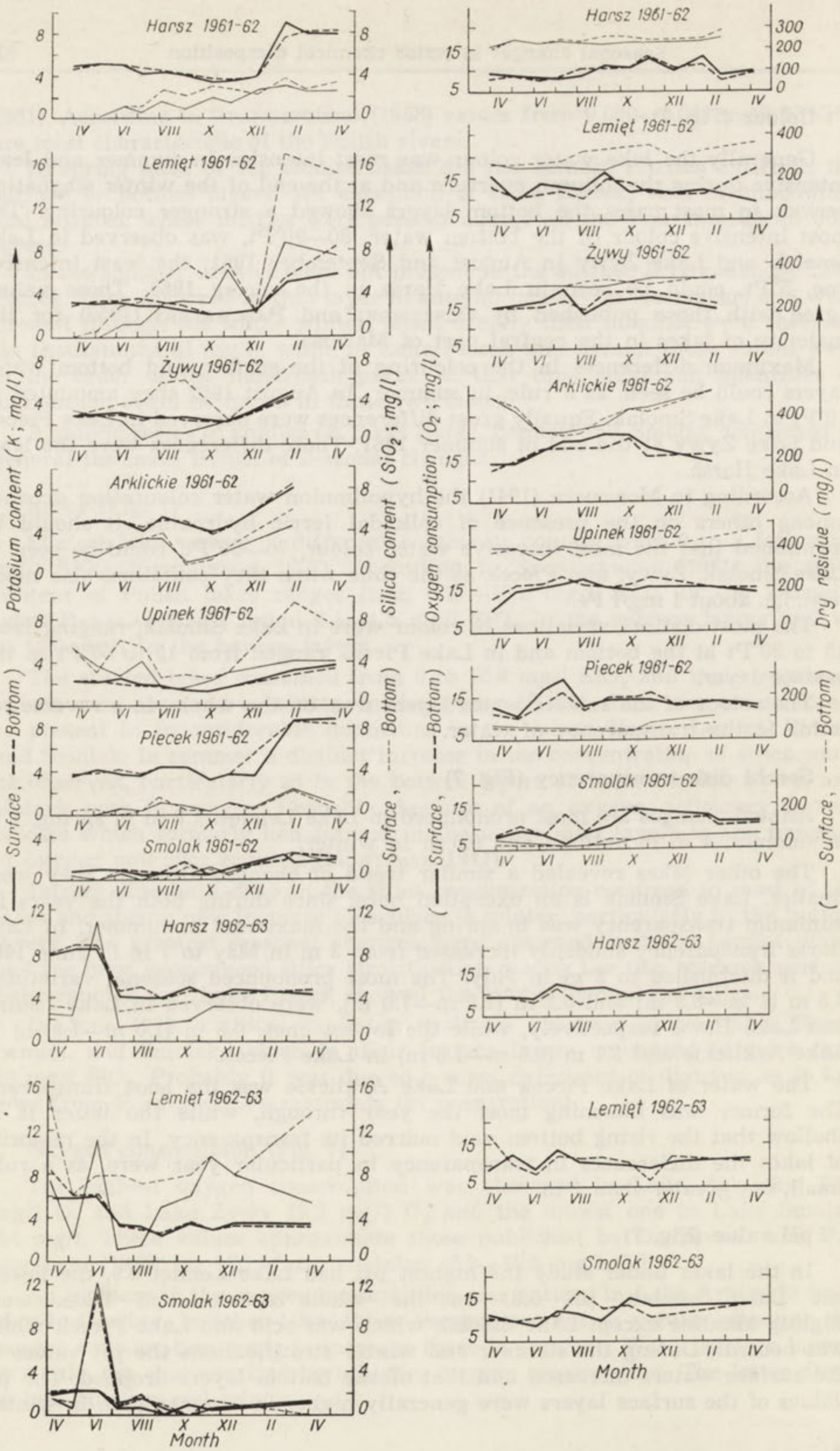
Annual changes are most pronounced in Lake Lemięt: 1.8 m in spring, 1 m in summer, 4 m in autumn and 6.5 m in winter.

The other lakes revealed a similar trend of changes although they were smaller. Lake Smolak is an exception here, since during both the years its minimum transparency was in spring and the maximum in summer. In Lake Harsz transparency suddenly increased from 3 m in May to 7 m in June 1961 and it diminished to 2 m in July. The most pronounced seasonal variations, 5.5 m (1 m—6.5 m) and 5.2 m (1.8 m—7.0 m), were observed in Lake Lemięt and Lake Harsz respectively, while the lowest ones: 0.8 m (1.0 m—1.8 m) in Lake Arklickie and 1.1 m (0.5 m—1.6 m) in Lake Piecek.

The water of Lake Piecek and Lake Arklickie was the least transparent. The former was blooming most the year through, while the latter is so shallow that the rising bottom mud marred its transparency. In the majority of lakes the differences in transparency in particular year were, as a rule, small, not greater than 1 m.

pH value (Fig. 7)

In the lakes under study the highest pH had Lake Lemięt 8.9, the lowest one Lake Smolak, pH 5.3. On the whole the studied lakes were slightly alkaline except Lake Smolak which was acid and Lake Piecek which was neutral. During the summer and winter stratifications the pH values of the surface waters increased and that of the bottom layers dropped. The pH values of the surface layers were generally higher in summer than in winter.



Harsz 1961-62
Lemięt 1961-62
Żywy 1961-62
Arklickie 1961-62
Upinek 1961-62
Piecek 1961-62
Smolak 1961-62
Harsz 1962-63
Lemięt 1962-63
Smolak 1962-63
Potasium content (K; mg/l)
Silica content (SiO2; mg/l)
Oxygen consumption (O2; mg/l)
Dry residue (mg/l)
Surface, ---- Bottom
IV
VI
VIII
X
XII
II
IV
Month
0
4
8
12
16
5
15
0
100
200
300
400

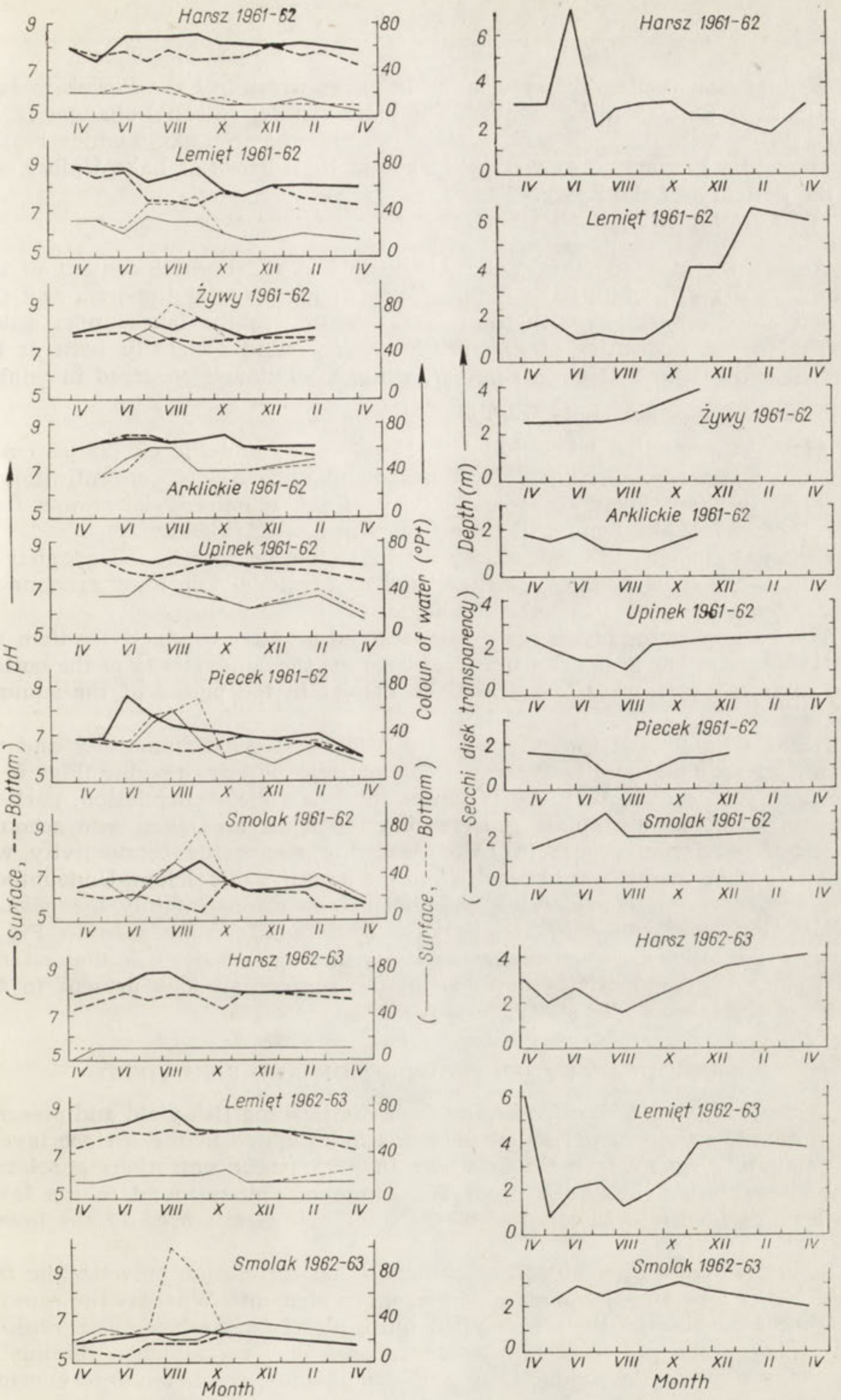


Fig. 7. Seasonal changes in the content of potassium and silica; and oxygen consumption, dry residue, pH, colour and transparency in the water of investigation lakes

A maximum vertical differentiation in pH occurred in Lake Piecek in June and in Lake Smolak in September. The most distinct seasonal changes in pH could be seen in Lake Piecek surface waters and in Lake Lemięt bottom layers, while the least ones were observed at the surface of Lake Upinek and at the bottom of Lake Żywy.

Dry residue (Fig. 7)

Among the studied lakes Lake Arklickie had the highest content of dry residue, 502 mg/l, while Lake Smolak with 21 mg/l was the poorest and this is in a close connection with the mineral content of the lakes under study.

The lowest quantities of dry residue were found generally both at the surface and at the bottom in summer, while a maximum occurred in winter.

Electrolityc conductivity (Fig. 6)

Among the studied lakes, Smolak (15 μS cm^{-1}) and Piecek (35 μS cm^{-1}) had the poorest conductivity. It is connected with a low concentration of minerals in those lakes. The conductivity of the remaining lakes was from 217 μS cm^{-1} in Lake Lemięt to 458 μS cm^{-1} in Lake Arklickie.

Seasonal changes in conductivity resemble the changes in the quantity of principal ions (bicarbonates, calcium) and dry residue. The most pronounced changes were observed in Lake Arklickie.

The bottom water layers, as a rule, showed a better conductivity than the surface waters. The greatest differences between the conductivity of the bottom and surface layers were found in Lake Lemięt in the period of the summer stagnation.

It has been proved that there is a relation between conductivity and the quantity of calcium and between the conductivity and dry residue (Figs 8, 9). It can be seen that in both the instances there is a clear correlation, particularly so when all the points representing the lakes are taken into account. A certain deviation occurs in Lake Arklickie where the conductivity was slightly higher than it would result from the quantity of calcium. Undoubtedly it is so because of considerable amounts of other ions, mainly magnesium, sodium, chloride, and sulphate. Smaller deviations can be seen in Fig. 9 showing a relation between the conductivity and dry reside. It is understandable, since the conductivity depends on the sum of all ions present in the water of the lakes under study.

4. CHEMICAL WATER COMPOSITION AND FISH YIELD

Table II ranks the lakes according their diminishing fish yield and presents mean annual values of particular elements investigated in the surface layers. To compare elements present in water in various concentrations a relative evaluation method has been used. The range of values found in the lakes has been divided into 10 equal classes. The highest class scored 10, the lowest one 1.

It is clear from the Table II that there is no correlation between the fish yield of the lake and the amount of biogenous elements. Whereas the ranking of lakes according to their fish yield quite closely resembles their ranking according to the macroelement contents and that resemblance diminishes when the electrolytic conductivity and dry residue are taken into consideration.

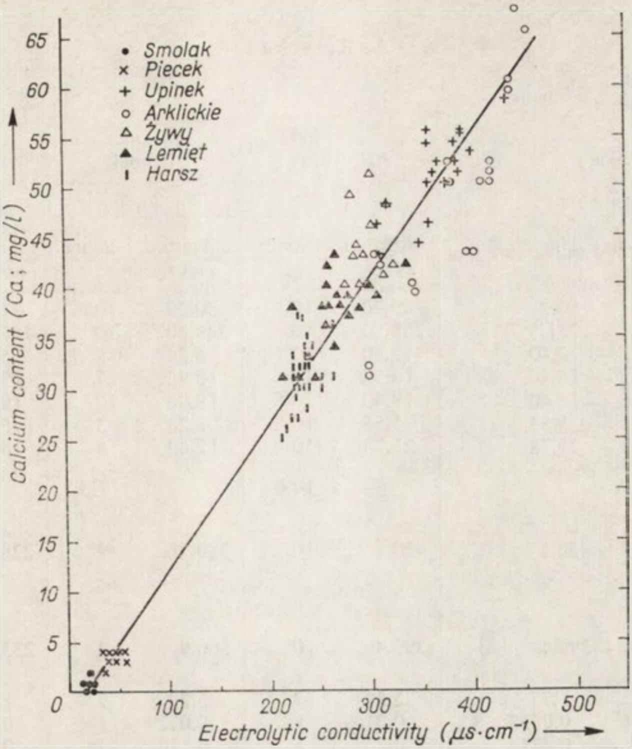


Fig. 8. Relationship between calcium content and electrolytic conductivity of lake water

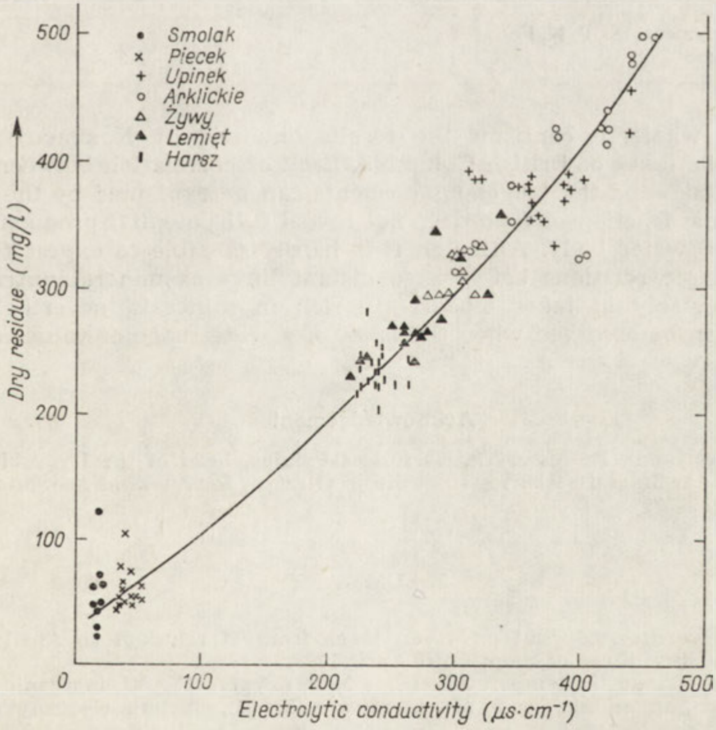


Fig. 9. Relation between dry residue and electrolytic conductivity of lake water

Table II. Mineral

Lake	Arklickie		Upinek		Harsz	
Fish yield in kg/ha/year	110.0		26.8		16.0	
Substance in mg/l	Annual average	Score	Annual average	Score	Annual average	Score
Ca 0.4 — 50.2	49.70	10	50.20	10	31.50	7
HCO_3 10.8 — 251.5	251.50	10	248.60	10	142.70	6
Na 0.85 — 12.40	12.40	10	6.24	5	5.68	5
Cl 1.45 — 16.56	16.56	10	10.92	7	9.25	6
Mg 0.87 — 18.40	18.40	10	18.06	10	10.68	6
K 1.07 — 5.53	5.53	10	2.23	3	5.25	10
SO_4 0.07 — 21.78	21.78	10	12.42	6	10.75	5
Macroelements on average		10.0		7.3		6.4
Dry residue 46.9 —420.1	420.1	10	380.7	9	228.8	5
Electrolytic conductivity in $\mu S cm^{-1}$ 18.0 —399.4	399.4	10	366.9	9	233.0	6
SiO_2 0.77 — 3.77	2.84	7	3.29	9	1.51	3
$P(PO_4)$ 0.0109 — 0.0633	0.0109	1	0.0129	1	0.0344	5
$N(NH_4)$ 0.066 — 0.471	0.228	5	0.170	3	0.066	1
$N(NO_3)$ 0.029 — 0.240	0.240	10	0.126	5	0.029	1
$N(NO_2)$ 0.00057— 0.00862	0.00089	1	0.00057	1	0.00155	2
Fe 0.000 — 0.033	0.007	3	0.005	2	0.000	1
Biogenous elements (Si, P, N, Fe) on average		4.5		3.5		2.1

On the whole, it confirms the results obtained by NORTHCOTE, LARKIN (1956) on the lakes of British Columbia. Lack of correlation between the fish yield of a lake and the biogenous elements can be explained by the fact that the inorganic fraction of food does not reveal full potential production possibilities of a water body. Although it is hardly possible to expect that there will be simple relations between so distant links as mineral nutrients and fish, particularly in lakes moderately rich in minerals, nevertheless such relations can be observed when the lakes of a wide range of values are being compared.

Acknowledgements

I wish to thank Professor Dr Kazimierz Patalas, head of the Hydrobiology Department of the Inland Fisheries Institute in Olsztyn, for his kind help and valuable advice.

5. SUMMARY

Studies were carried out on seven lakes from March 1961 to April 1962 and then continued on three of them until April 1963.

Seasonal changes in temperature (Figs 2, 3), oxygen (Fig. 4), inorganic phosphorus, total iron, amonium (Fig. 5) nitrite, nitrate (Fig. 5), calcium, electrolytic conduc-

contents and fish yield

Żywy		Lemięt		Piecek		Smolak	
12.2		11.0		7.6		2.0	
Annual average	Score	Annual average	Score	Annual average	Score	Annual average	Score
43.50	9	36.70	8	3.60	1	0.40	1
197.40	8	153.40	6	22.60	1	10.80	1
3.83	3	4.62	4	1.72	2	0.85	1
4.62	3	8.50	5	4.35	2	1.45	1
11.76	7	11.70	7	1.99	1	0.87	1
3.12	5	3.36	6	4.57	8	1.07	1
12.93	6	15.05	7	1.99	1	0.07	1
	5.9		6.1		2.3		1.0
309.8	8	255.7	6	73.0	1	46.9	1
293.9	8	255.7	7	40.3	1	18.0	1
2.58	6	3.77	10	0.77	1	0.94	1
0.0347	5	0.0633	10	0.0306	4	0.0318	4
0.166	3	0.187	3	0.471	10	0.175	3
0.239	10	0.104	4	0.213	9	0.072	3
0.00176	2	0.00328	4	0.00862	10	0.00128	1
0.016	5	0.000	1	0.010	4	0.033	10
	5.2		5.3		6.3		3.7

tivity, carbonate (Fig. 6), sodium, magnesium, chlorides and sulphates (Fig. 6), potasium, silica, oxygen consumption and dry residue (Fig. 7), pH, colour and transparency (Fig. 7) were investigated in an annual cycle.

The epi-, meta- and hypolimnion were found in the lakes: Harsz, Żywy, and Lemięt, only the epi- and metalimioh in the lakes: Smolak, Upinek, and Piecek, while Lake Arklickie showed no stratification.

Studies suggest that Lake Arklickie is the richest in the inorganic and organic compounds. That lake, has a very high primary productivity and its first vield was also one of the highest (about 110 kg/ha). Lake Smolak contained the lowest quantities of minerals. Table III lists the lakes according to the diminishing contents of some elements found in those lakes.

Since the lakes have different stability and different oxygen saturation of their bottom waters, it is difficult to compare their contents of nitrogen and

Table III. The lakes lists according to the diminishing contents of some studied elements

Elements	Lakes						
Ca, Mg, HCO_3	Arklickie	Upinek	Żywy	Lemięt	Harsz	Piecek	Smolak
Dry residue	Arklickie	Upinek	Żywy	Lemięt	Harsz	Piecek	Smolak
Electrolytic conduc.	Arklickie	Upinek	Żywy	Lemięt	Harsz	Piecek	Smolak
Na, Cl	Arklickie	Upinek	Harsz	Lemięt	Żywy	Piecek	Smolak
SO_4	Arklickie	Lemięt	Żywy	Upinek	Harsz	Piecek	Smolak
K	Arklickie	Harsz	Piecek	Lemięt	Żywy	Upinek	Smolak

phosphorus. It seems that similar criteria should be accepted when discussing the lake contents of silica. But it is possible to state that Lake Lemięt contained the highest quantities of PO_4, NO_2, NH_4 and SiO_2.

A most untypical minerals contents have been found in Lake Piecek. It is very poor in Ca, Mg, Na, HCO_3, SO_4 and SiO_2, but on the other hand it is rich in NH_4, NO_3, NO_2 and K.

Of the seven lakes five contained calcium as the main cation and only Lake Smolak and Lake Piecek showed a different pattern. The second most numerous cation was magnesium. Only in Lake Smolak there was more magnesium than calcium. On the whole, there was slightly more sodium than potassium in the lakes and only Lake Arklickie had twice as much sodium as potassium. Lake Piecek usually contained twice as much potassium as sodium.

Among anions bicarbonates were most numerous in all the lakes. Sulphates and chlorides occurred in much lower quantities. On the whole the contents of sulphates were higher than those of chlorides apart from Lake Smolak and Lake Piecek.

Lake Arklickie showed the greatest seasonal changes in the contents of Ca, Na, Mg, HCO_3, Cl, SO_4, NO_3, in the conductivity and dry residue, while the same may be said of Lake Lemięt concerning NO_2, NH_4, PO_4 and SiO_2. The greatest seasonal variations in the K concentration have been observed in Lake Harsz.

As a rule, the bottom layers were richer in these substances than the surface waters. The most pronounced differences have been found in Lake Lemięt.

In the second research year the ice melted later and the surface water temperatures were much lower. It had clearly its effects on the seasonal changes in the content of some chemical elements the concentrations of which were much lower in the colder year.

There has also been found a fairly clear correlation between the electrolytic conductivity and the quantity of calcium and between the conductivity and the dry residue.

The fish yield in the mentioned lakes was the higher the greater content of minerals was there (Table II). Whereas no correlation has been found between the fish yield and the quantity of biogenous elements (P, N, Si and Fe).

6. STRESZCZENIE

Badania przeprowadzono na siedmiu jeziorach od marca 1961 do kwietnia 1962 r. i na trzech jeziorach — do kwietnia 1963 r.

Prześledzono w cyklu rocznym zmiany: temperatury (Fig. 2, 3), tlenu (Fig. 4), fosforanów, żelaza, amoniaku (Fig. 5), azotanów, azotynów (Fig. 5), wapnia, przewodności elektolitycznej, węglanów (Fig. 6), sodu, magnezu, chlorków i siarczanów (Fig. 6), potasu, krzemu, utlenialności i suchej pozostałości (Fig. 7), pH, barwy i widoczności (Fig. 7).

Epi- meta- i hypolimnion wykazywały jeziora: Harsz, Lemięt, Żywy; tylko epi- i metalimnion: jez. Smolak, Upinek, Piecek; brak stratyfikacji — jez. Arklickie.

Najbogatszym w związki nieorganiczne i organiczne jest jez. Arklickie. Jezioro to posiada bardzo wysoką produktywność pierwotną, a produkcja rybacka był jedną z najwyższych (około 110 kg/ha). Najmniej zasobne w sole mineralne jest jez. Smolak. Biorąc pod uwagę zasobność jezior w niektóre elementy w tabeli III uszeregowano je według malejących wartości.

Ponieważ badane jeziora posiadają różny stopień statyczności i różne natlenienie wody w przydennych warstwach trudno jest porównywać zasobność jezior w azot i fosfor. Podobne kryteria należałoby także przyjąć oceniając zasobność jezior w krzem. Można jednak stwierdzić, że w jez. Lemięt wykryto największe ilości PO_4, NO_3, NH_4, SiO_2.

Bardzo nietypowy zestaw soli mineralnych posiada jez. Piecek: jest ono ubogie w jony Ca, Mg, Na, HCO_3, Cl, SO_4 i SiO_2, a zarazem bogate w jony NH_4, NO_3, NO_2, K.

Z siedmiu badanych jezior, w pięciu wapń wystąpił jako główny kation, tylko w jęz. Smolak i Piecek ustępował innym kationom. Kolejnym kationem, pod względem ilościowym, był magnez. Jedynie w jez. Smolak wystąpił on w ilościach większych niż wapń. Sodu było w badanych jeziorach na ogół nieznacznie więcej niż potasu, tylko w jęz. Arklickim zawartość sodu przewyższała dwukrotnie zawartość potasu. W jez. Piecek potasu było zwykle dwukrotnie więcej.

Z anionów kwaśne węglany występowały we wszystkich jeziorach w największych ilościach. Znacznie mniej było siarczanów i chlorków. Zawartości siarczanów były na ogół wyższe niż zawartości chlorków, z wyjątkiem jezior Smolak i Piecek.

Największe sezonowe wahania zawartości Ca, Na, Mg, HCO_3, Cl, SO_4, NO_3, przewodności i suchej pozostałości wystąpiły w jez. Arklickim, a w przypadku NO_2, NH_4, PO_4 i SiO_2 — w jez. Lemięt. Największe sezonowe wahania w zawartości K wykazało jez. Harsz.

Na ogół warstwy przydenne były bogatsze w badane elementy niż warstwy powierzchniowe. Największe różnice wystąpiły w jez. Lemięt.

Drugi rok badań charakteryzował się późniejszym terminem zejścia lodów oraz znacznie niższymi temperaturami powierzchniowych warstw. Wpłynęło to wyraźnie na sezonowe zmiany zawartości niektórych elementów chemicznych, które w chłodniejszym roku były znacznie mniejsze.

Stwierdzono dość wyraźną korelację między przewodnictwem elektrolitycznym a ilością wapnia oraz między przewodnictwem elektrolitycznym a suchą pozostałością.

Wydajność rybacka badanych jezior była tym większa, im wyższa była zawartość soli mineralnych (Tab. II). Nie stwierdzono natomiast zależności między zawartością elementów biogennych (P, N, Si, Fe) a wydajnością rybacką.

7. REFERENCES

ALEKIN, O. A. 1956. *Podstawy hydrochemi* [*Principles of hydrochemistry*]. Warszawa (Polish).

CZECZUGA, B., BASZYŃSKI T. 1963. Niektóre dane hydrochemiczne wód Jeziora Rajgrodzkiego. (Some hydrochemical data of the waters of the Rajgród Lake). *Pol. Arch. Hydrobiol.*, 11, 267—274 (Engl. summ.).

EINSELE, W. 1936. Über die Beziehungen des Eisenkreislaufs zum Phosphatkreislauf im eutrophen See. *Arch. Hydrobiol.*, 29, 664—686.

FABER, H. A., Ed. 1955. *Standard methods for the examination of water, sewage, and industrial wastes.* Ed. 10. New York, APHA.

HUTCHINSON, E. G. 1957. *Treatise on limnology.* I. New York.

JUST, J., HERMANOWICZ, W. 1955. *Fizyczne i chemiczne badanie wody do picia i potrzeb gospodarczych* [*Physical and chemical studies of the tap water and for the economical purpose*]. Warszawa, PZWL (Polish).

JANUSZKIEWICZ, T. 1965. Przyczynek do znajomości chemizmu jeziora Ewingi (A contribution to knowledge of chemistry of the Lake Ewingi). *Pol. Arch. Hydrobiol.*, 13, 63—88 (Engl. summ.).

JANUSZKIEWICZ, T., JAKUBOWSKA, L. 1963. Jezioro Klasztorne w Kartuzach — Studium hydrochemiczne (The Lake Klasztorne in Kartuzy — a hydrochemical study). *Pol. Arch. Hydrobiol.*, 11, 274—325 (Engl. summ.).

KONDRACKI, J. 1952—1953. *Katalog jezior polskich* [*Catalogue of Polish Lakes*]. Warszawa.

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.).

LOSSOW, K. 1965. Obserwacje stanu zanieczyszczenia jeziora Bełdany (Observation of State of the polution from Bełdany lake). *Zesz. Nauk. WSR Olsztyn*, 20, 99—119 (Engl. summ.).

MINDER, L. 1923. Über biogene Entkalkung im Zurichsee. *Verh. int. Ver. Limnol.*, 1, 20—32.

MORTIMER, C. 1941. The exchange of dissolved substances between mud and water in lakes. *J. Ecol.*, 29, 280— 329.

NIEWOLAK, S. 1966. The microbiological character of Iława lakes in the years 1960—1963. *Zesz. Nauk. Uniw. Toruń.*, 16, 33—54.

Northcote, T. G., Larkin, P.A. 1956. Indices of productivity in British Columbia Lakes. *J. Fish. Res. Bd. Canada*, 13, 515—540.

Olszewski, P. 1953a. Obserwacje chemiczne z jeziora Tajty (Chemical observations on lake Tajty). *Rocz-i Nauk. roln. Ser. D*, 67, 23—65 (Engl. summ.).

Olszewski, P. 1953b. Kilka przekrojów chemicznych z jezior Pojezierza Mazurskiego (Certain chemical characteristics of Mazurian Lakes). *Ekol. pol.*, 1, 20—47 (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.).

Olszewski, P. 1959. Stopnie nasilenia wpływu wiatru na jeziora (Graduation in the intensity of the wind effects on lakes). *Zesz. Nauk. WSR Olsztyn*, 4, 111—132 (Engl. summ.).

Olszewski, P., Więcławska, M. 1965. Chemizm wód jezior Legińskich (Water chemistry of the Legińskie Lakes). *Zesz. Nauk. WSR Olsztyn*, 20, 279—304 (Engl. summ.).

Patalas, K. 1960a. 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. 1960b. 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, 223—242 (Engl. summ.).

Patalas, K. 1960c. 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. 1960d. 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, 299—326 (Engl. summ.).

Patalas, K. 1961. Limnologiczna charakterystyka jezior kompleksu Wdzydze (Limnological description of lakes in Wdzydze complex). *Rocz-i Nauk roln. Ser. D*, 93, 63—95 (Engl. summ.).

Półtoracka, J. (in preparation). Zbiorowiska planktonu roślinnego w jeziorach różnego typu limnologicznego (Plankton communities in the thre lakes of different types).

Stangenberg, M. 1936. Szkic limnologiczny na tle stosunków hydrochemicznych Pojezierza Suwalskiego (Limnologische Charakteristik der Seen des Suwałki-Gebiets auf Grund der hydrochemischen Untersuchungen). *Rozpr. Spraw. Inst. Bad. Lasów Państw. Ser. A*, 19, 7—54 (Polish and German).

Stangenberg, M. 1937a. Materiały do znajomości przebiegu cyrkulacji wiosennej w jeziorach Suwalszczyzny (Zur Kenntins der Frühlingsvollzirkulation in den Seen des Suwałki —Gebiets). *Rozpr. Spraw. Inst. Bad. Lasów Państw., Ser. A*, 1—14 (German summ.).

Stangenberg, M. 1937b. Fosforany, azotany, siarczany i chlorki jezior Wigierskich w czasie cyrkulacji jesiennej (Phosphate, Nitrate, Sulphate und Chloride der Wigry — Seen Während der Herbstzirkulation). *Rozpr. Spraw. Inst. Bad. Lasów Państw. Ser. A*, 1—20 (Polish, German).

Stangenberg, M. 1956. Przyrodnicze podstawy gospodarstwa jeziorowego [Scientific basis of the lake fishery]. *Pol. Arch. Hydrobiol.*, 3, 363—401 (Polish).

Stangenberg, M. 1958. Ogólny pogląd na skład chemiczny wód rzecznych Polski (A general outlook on the chemical composition of rivers waters in Poland). *Pol. Arch. Hydrobiol.*, 4, 289—359 (Engl. summ.).

Stangenberg, M. 1960. Morfometria i skład chemiczny wody jeziora Charzykowo. (Morphometry and chemical composition of the water of the Charzykowo lake). *In: Jezioro Charzykowo*, 9—42, Warszawa, PWRiL (Engl. summ.).

Stangenberg, M. 1961. Some remarks on the determination and the content of silica in lake waters. *Memorie Ist. ital. Idrobiol.*, 13, 17—42.

STANGENBERG-OPOROWSKA, K. 1961. Studia nad chemizmem wód stawów karpiowych w Miliczu (Studien über chemische Zusammensetzung des Wassers in der Karpfenteichengemeinschaft Milicz). *Pol. Arch. Hydrobiol.*, 9, 37—157 (German summ.).

SZCZEPAŃSKI, A. 1961. Charakterystyka limnologiczna jez. Hańcza. (Limnological characteristic of Hańcza lake). *Pol. Arch. Hydrobiol.*, 9, 9—18 (Engl. summ.).

SOLSKI, A. 1964. Szkic limnologiczny jezior Charzykowskich i jeziora Wdzydze Limnological charakteristic of Charzykowo Lakes and of Wdzydze Lake). *Pol. Arch. Hydrobiol.*, 12, 189—231. (Engl. summ.).

WISZNIEWSKI, J. 1953. Uwagi w sprawie typologii jezior polskich (Remarks on the typology of Polish lakes). *Pol. Arch. Hydrobiol.*, 1, 11—24.

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A COMPARISON OF THE CLOSED-BOTTLE AND FLOWING-WATER METHODS FOR MEASUREMENT OF RESPIRATION IN AQUATIC INVERTEBRATES

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ABSTRACT

Measurements of the oxygen consumption of three species of aquatic invertebrates were carried out simultaneously by the closed-bottle and flowing-water methods. The results obtained from the closed-bottle technique varied with the length of exposition period. On the other hand, results obtained from the flowing-water respirometer were independent of time in carrying out measurements.

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1. INTRODUCTION

During the last few years there has been a great increase in the number of bio-energetic studies for which the measurement of oxygen consumption of animals is an essential requirement. However, the problem of selecting a suitable and adequate method for the measurement of respiratory rate in a particular species is a difficult one and there is very little comparative information available upon which to base such a decision. Pattee (1965) investigated simultaneously the influence of a rapid increase of temperature on the respiratory rate of nine species of freshwater invertebrates by means of a closed-bottle Winkler technique and a manometric technique in which the water was continuously stirred. The oxygen consumption of the control animals as well as the reaction of the experimental animals to heating in many cases varied accordingly to the method used.

The aim of present work is to compare two methods of measuring respiratory rate of the same species. The two methods of measuring oxygen consumption were the closed-bottle Winkler technique, which is a simple and widely used method, and a folowing-water polargraphic method, which is more complicated but has been coming into more general laboratory use in the last few years. To ensure adequate comparison, both methods were opered simultaneously upon each of following three species, *Isoperla buresi* Rauser (Plecoptera), *Cloeon dipterum* (L.)

(Ephemeroptera) and *Bithynia tentaculata*[1] (L.) (Gastropoda). These species were specially selected for their differences in size and to come from different taxonomic and ecological groups (*I. buresi* lives in fast flowing mountain streams whereas the other two species came from shallow lowland standing waters).

2. METHODS

The larvae of *I. buresi* were collected on 29.VI.1967 from the stony bottom of the Olczyski stream in the Tatra mountains; the water temperature was 6.3—6.6°C. As these larvae are aggresive, they were kept separate in glass tubing, 2 cm by 7 cm, together with three small pebbles and with the tube ends covered with netting with holes of 1.5 mm by 1.5 mm. These tubes were placed in an "artificial stream" made of a P.V.C. (polyvinyl chloride) trough, about 90 cm long, 25 cm wide and 15 cm high. This trough had a central partition along its long axis, one end of which was free and the other fixed end of which was pierced by a pipe. In this "stream", the water was continually circulated around the central partition by means of a pump. The "artifical stream" was immersed in a large water thermostat so that its temperature was kept between 7 and 8°C; its water was changed every two days when also the larvae were fed on Tubifex.

The larwae of *C. dipterum* were collected on 7.IX.1967 from amongst the plants growing in the small pools of the Kampinos Forest near Warsaw; the water temperature varied between 19.6 and 22.9°C. All the respiratory measurements by the closed-bottle technique and one of the series using the flowing-water respirometer (19—21.X.1967) were carried out on these larvae. A further series of measurements (15—17.XI.1967) were made on larvae collected on 13.XI. 1967 from the plants growing in a pool on the old glacial river bed of the Vistula, when the water temperature was 5.5°C. In both cases, the larvae together with some plants were placed in glass basins, 18 cm in diameter and with a water depth of 7 cm; the water was ventilated and the basins kept in a thermostat maintaned at a temperature of 20 ± 0.1°C.

The specimens of *B. tentaculata* were collected on 24.X.1967 from among the plants in a pool of the old Vistula river bed; the water temperature was 13°C. The animals were kept in the laboratory under the same conditions of *C. dipterum*.

The level of oxygen concentration in the closed-bottle method was determined chemically by Winkler's method. Usually clear glass bottles, 50 ml volume with ground glass stoppers, were used except in one series with *I. buresi* when 100 ml dark bottles were used. The animals were placed directly into the bottles, usually singly, but in one series with *I. buresi*, two individuals per bottle were used, each separated from the other in a well-perforated perspex tube, 2 cm by 1 cm, one end closed by a perforated perspex plate and the other by coarse netting.

The water used for these respiratory measurements was Warsaw tap water, saturated with air but stood long enough to be rid of the chlorine; it was kept at the temperature of the experiment. To this water was added some antibiotic, 32 mg/l streptomycin and 25 mg/l chloromycetin, in order to inhibit

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[1] Measurements of the oxygen consumption of *B. tentaculata* were made together with Dr. A. F. Alimov from the Zoological Institute, Academy of Sciences, Leningrad, USSR.

as much as possible oxygen consumption by microorganisms. In practice, only a very slight reduction in oxygen concentration occured in the final control bottles compared with the initial control bottles, usually less than 0.8% of air-saturated water.

Before the experiments proper were carried out, some tests were made to determine the best way to flush out and fill the bottles with the experimental water. Richman (1967) connected six bottles by a series of siphons, allowed the experimental water to flow through all the bottles and determined the oxygen concentration in the first and last bottle of the series. This method was checked by connecting only two bottles together; rubber corks were perforated by two tubes, one, the inflow tube, reaching to the bottom of the bottle and the other, the outflow tube, ended just under the cork. The test conditions were made more severe by reducing the oxygen concentration of the test water. Table I present the oxygen concentration determined in the two bottles after they had been flushed once, twice, three, four or five times.

Table I. Changes in the dissolved oxygen content during the flushing of two bottles connected in series

Series	Bottle I		Bottle II		Number of repetitions
	Water analysed (bottle vol.)	Oxygen conc. mg/l	Water analysed (bottle vol.)	Oxygen conc. mg/l	
a	2nd[1]	0.351	1st[1]	0.698	2
b	3rd	0.273	2nd	0.425	2
c	4th	0.277	3rd	0.316	2
c1[2]	4th	0.187	3rd	0.257	6
d1	5th	0.203	4th	0.251	6

[1] Water analysed (bottle vol.). lst means that no water was rejected, 2nd — first bottle volume of water was rejected and the second one was analysed, etc.

[2] Water with another dissolved oxygen concentration was used in the series c1 and d1.

As can be seen in Table I, even in series d1 the amount of oxygen in bottle II is different from that of bottle I and is less than in series c1. The conclusion is that this method of flushing and filling a series of connected bottles gives very uncertain results.

The next test was designed to determine the oxygen concentrations after several flushings and filling of single bottles, unconnected in series. Here, the oxygen concentration was measured in the first, second, third, fourth and fifth bottle volume and was 0.359, 0.242, 0.222, 0.242 and 0.242 mg/l respectively. Therefore, in all the following experiments, bottles were flushed out and filled singly, the first two flushings were rejected and the third re-filling was used for respiratory measurements.

A blank experiment, that is, with water of reduced oxygen concentration treated as described above but without animals, was used to determine the precision of the technique itself. Eleven measurements gave a mean oxygen concentration of 0.196 ± 0.0066 mg/l; this represents a standard error of less than 3.4% of the mean, despite the initial lower dissolved oxygen concentration increasing the possibility of atmospheric contamination during the handling procedure. In fact, the lowest oxygen concentration determined during the whole experiment was 9% air saturation and, even under such conditions, the above standart error would be 0.8% of the mean value. Richman (1967) in a similar test, obtained a standard error which was 10% of the mean. Rebsdorf (1966) compared different medifications of the Winkler method. The precison of the measurement was highest when the Pomeroy-Kirshman variation was used with a pure water sample, giving a standard deviation of 0.02 mg/l; the standard deviation of the measurement reported in the present work is also 0.02 mg/l.

The experimental procedure was as follows: first, the initial control bottle was flushed, filled and fixed immediately. Next, one by one, the experimental bottles, containing animals, and the respective final control bottles were filled and placed in the thermostat for periods of 0 to 50 hours. The water temperature was controlled to ± 0.015°C. Finally, the second initial control bottle was filled and fixed. All bottle volumes were measured, all pipettes and burette scales were checked and re-calibrated and 0.01 N sodium thiosulphate was used for the titration.

In the flowing-water method, the amount of oxygen present was determined polarographically. A detailed description of the apparatus and procedure adopted is given in Klekowski and Kamler (1968).

The interior of the perspex animal chamber was a cylinder placed horizontally with cone-shaped inlet and outlet openings but the lower part of the chamber was occupied by a piece of perspex upon whose upper flat surface were placed the animals. Larvae of *C. dipterum* were placed directly into the chamber, 40 larvae for the experiment of 19—21.X.1967 and 30 larvae for that on 15—17. XI.1967. The length of this chamber was 5.5 cm, the width 1.3 cm and the height 0.65 cm. The speed of water flowing through the chamber was about 0.008 cm/sec. Four specimens of *B. tentaculata* were placed in a chamber measuring 7.5 cm by 1.4 cm by 0.7 cm and the speed of water flow was about 0.006 cm/sec. Two larvae of *I. buresi* were placed separately into two chambers connected one behind the other and divided by a net; each chamber measured 1.6 by 0.7 by 0.35 cm and the speed of water flow was about 0.014 cm/sec. The outflowing water from the respirometer contained about 20% less oxygen that the inflowing water in the cases of *C. dipterum* and *B. tentaculata* and 10% less in the case of *I. buresi*. The error in measurement of oxygen content was never more than ± 1.5%. The causes of these errors is discussed by Klekowski and Kamler (1968).

The dry weights of the animals were determined after previous drying at 100°C to a constant weight. Oxygen consumption by the larval insects is expressed as µl oxygen/g dry body weight · hour whereas it is given as µl oxygen/g dry weight of body plus shell · hour in Bithynia. It proved difficult to separate the body of Bithynia from its shell, either in the dried state or when fresh. Therefore, additional measurements of the dimensions and weights were made on two control series of ten snails in order to calculate the respiratory results in terms of g body weight without shell. The size and living weight of both series of snails were determined; control series 1 of snails were killed in boiling water and digested in a 1% solution of trypsin at 40°C until only shell remained whereas the control series 2 were dried and the dry weight of the body plus shell measured. From the weight of the dried shell, the weight of the body could be determined.

The weights and sizes of the snails belonging to control series 1 and 2 together with those of the experimental snails whose respiration was measured is given in Table II. A comparison of the height and width of the shell, live body weight with shell and dry body weight with shell shows that all three series of snails belonging to the same population so that it is possible to apply the relationships in body measurements of the control snails to the experimental ones. In fact, the standard errors obtained in the control series are greather than those of the experimental snails. This is very useful as, in the control series 1, the shell formed a similar percentage of the total live weight in both large and small snails and this can be applied with some certainty to the experimental snails[2].

Table II. The weights and sizes of a sample of *Bithynia tentaculata* from the old Vistula bed (means and standard errors)

Series	Control series 1 (digested snails)		Control series 2 (dried snails)	Experimental series (respiration was measured)
Number of specimens	10		10	28
Height of shell, mm	8.88±0.378 N[1]		8.61±0.384 N	—
Width of shell, mm	4.97±0.183 N		4.92±0.224 N	—
Live weight of body with shell, mg	119.42±14.75 N		117.92±14.04 N	126.45±8.90 N
Dry weight of body with shell, mg	—		50.11±6.75 N	52.18±3.64 N
Weight of shell, mg	38.85±5.792		—	—
Shell weight as % of total live weight	large snails 5 specimens	small snails 5 specimens	—	—
	34.32 ±2.072 N	28.86 ±1.807 N		

[1] N signifies that the difference between columns is not significant at the 1% level.

It is therefore possible to calculate from the given data the mean dry weight of the body: 50.11 − 38.85 mg = 11.26 mg. If the mean dry weight of the body with shell (50.11 mg) is divided by the mean dry weight of the body alone (11.26 mg), a coefficient of 4.45 is obtained. Thus, the oxygen consumption per g dry weight with shell can be multiplied by 4.45 in order to obtain the results in terms of per g dry body weight without shell.

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[2] Nolan and Brand (1954) found that the percentage shell weight increases, decreases or remains constant with increasing weight in different species of aquatic animals.

In order to obtain additional information on the influence of different experimental conditions on the larvae of *I. buresi*, the presence and absence of "searching movements" was observed and the frequency of respiratory movements per minute was recorded by means of an electrical tapping key whose singals were registred on a kymograph on which was marked a time scale. Fox and Sidney (1953) recorded the frequency of respiratory movements of larval Trichoptera by this means.

3. RESULTS

The rate of oxygen consumption, μl oxygen/g · hour, measured in the flowing-water respirometer, did not vary with time (Figs 1A, 2A and 3A). On the other hand, the rates of oxygen consumption obtained in the closed-bottle method varied considerably depending on the lenght of the experimental period (Figs 1B, 2B and 3B); the shorter the period, the higher the consumption rate, the longer the period, the lower the consumption rate. The empirically obtained results plotted on a logarithmic scale reveal a relationship described by the general formula,

$$Q = a \cdot t^b$$

where Q is the oxygen consumption, μl oxygen/g · hour, t is the time in hours and a and b are constants, which were determined for each species. The measurements of oxygen consumption obtained with the closed-bottle method were always more dispersed than those for the flowing-water respirometer, particularly for short periods of exposition. These general results applied to all three species.

Isoperla buresi

One measurement in the flowing-water respirometer was carried out, which lasted a short time only for technical reasons; the results are shown in Fig. 1A. The mean and standard erorr was 282.8±10.77 μl oxygen/g·hour. No respiratory or searching movements were observed during this experiment.

Table III. The behavioural pattern of *Isoperla buresi* in two series of experiments using closed-bottle method

Series	3—4. VII free larvae	10—12. VII larvae in tubes	Statistical difference between columns
Searching movements per min. (N = 80)			
no. present	19	10	significant ($p = 0.001$)
no. absent	10	41	(χ^2 test)
Respiratory movements per min. (N = 80) mean and standard error	4.8±2.31	36.6±2.94	significant ($p = 0.01$) (analysis of variance)

Two series of measurements were carried out using the closed-bottle method. Figures 1B1 and 1C1 show the results from experiments carried out on 3—4.VII.1967 using free larvae, one per 100 ml dark bottle. Figures 1B2 and 1C2 give the results of other experiments carried out on 10—12.VII.1967,

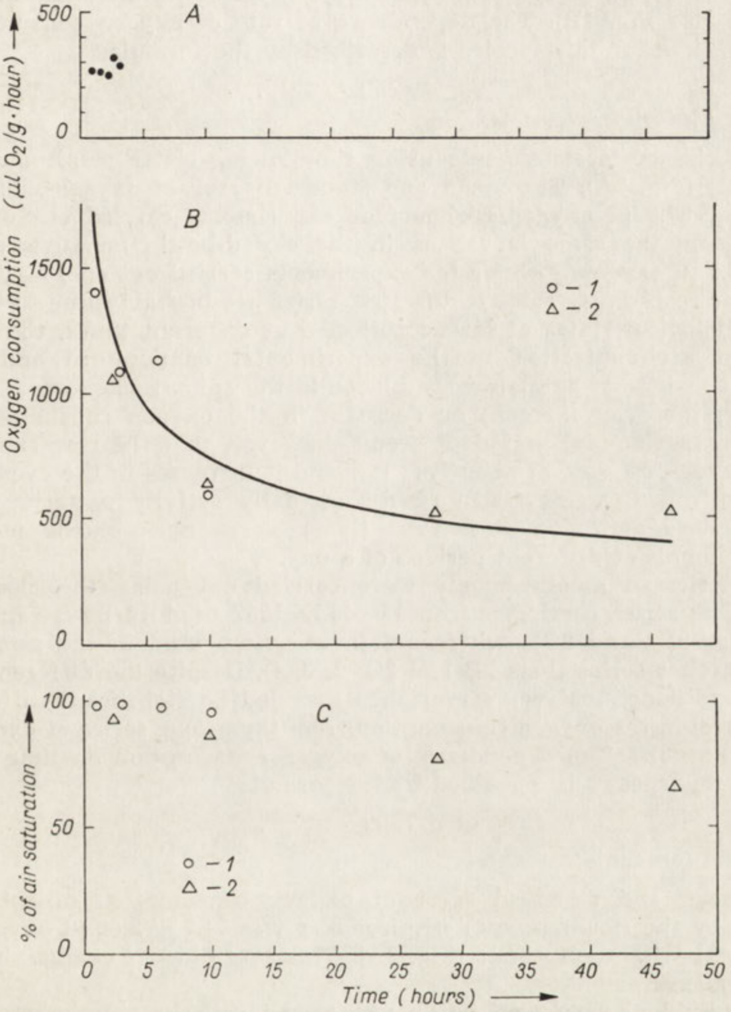

Fig. 1. Oxygen consumption of *Isoperla buresi*, 13 individuals, mean dry weight of one individual 5.34±0.3742 mg; temperature 8±0.015°C. A — flowing-water method; B — closed-bottle method. 1 — 3—4.VII.1967; 2 — 10—12.VII.1967. C — the oxygen content in the bottles after the end of the exposition period. 1 and 2 as in B

using single larvae enclosed in perforated tubes, two larvae per 50 ml clear bottle. Obviously, the oxygen concentration in these bottles were lower at the end of the exposition period, with two larvae in smaller bottles (Fig. 1C2). Table III gives the frequency of respiratory movements per minute and the presence and absence of searching movements, which were recorded in both sets of experiments. The free larvae renewed the oxygen in the boundary layer near their bodies mainly by searching movements whereas the larvae enclosed in tubes by means of respiratory movements. Despite this difference, an analysis of variance (Bailey, 1959) of the oxygen consumption of *I. buresi* in these two series of measurements did not differ significantly at the 1% level (see also Fig. 1B). The dependence of rate of oxygen consumption on exposition time for this species is described by the formula,

$$Q = 1750 \cdot t^{-0.377}.$$

Cloeon dipterum

Two series of measurements using the flowing-water respirometer were carried out (Fig. 2A). The mean and standard error of oxygen consumption was 2655 ± 87.9 μl oxygen/g • hour for experiments carried out on 19—21. X.1967 (using the same larvae as in the closed-bottle measurements) and 1859 ± 60.1 μl oxygen/g • hour for experiments carried out on 15—17.XI.1967. The higher respiratory rates of the first series are probably due to the different physiological states of larvae collected at different times, the different periods of acclimatization to the experimental temperature and because different densities of animals were placed in the animal chambres. In neither series was there an increase or decrease in the oxygen consumption with length of experimental period. It seems, however, that the respiration changes with time of a day, at noon it is low and it increases in the evening. This result confirms Elliot's (1968) results on daily activity patterns of larval Ephemeroptera and also of Pattee (1965) on changes in the metabolism of these animals at different periods of a day.

Four series of measurements were carried out using the closed-bottle method. The series carried out on 14—16.IX.1967 used 10 larvae in a 50 ml bottle (Figs 2B1 and 2C1) whereas 4 larvae were used in the same bottles in all the other series (Figs 2B and 2C: 2, 3, 4). Despite the different experimental conditions, analyses of variance revealed no significant difference at the 1% level in the oxygen consumption from these four series of experiments (see also Fig. 2B). The dependence of oxygen consumption on time of exposition for this species is described by the formula,

$$Q = 7500 \cdot t^{-0.336}.$$

Bithynia tentaculata

The mean and standard error of oxygen consumption of this species measured by the flowing-water respirometer was 74.7 ± 2.62 μl oxygen/g dry body weight with shell • hour (Fig. 3A). This rate did not change during the period of measurement.

One individual per 50 ml bottle was used in all three series of measurements with the closed-bottle method. Two series of experiments were carried out, in which the exposition time was not greater than six hours, on 25.X.1967 (Figs 3B1 and 3C1) and on 30.X.1967 (Figs 3B2 and 3C2) as well as one series with longer periods of exposition, 17—48 hours, on 6—8.XI.1967 (Figs 3B3 and 3C3). However, these differences in the experimental design did not greatly influence the shape of the curve describing the relationship of respiration with time using this method of measurement. This relationship is described by the formula,

$$Q = 192 \cdot t^{-0.450}$$

for all three series, and by the formula,

$$Q = 185 \cdot t^{-0.459}$$

μl oxygen/g dry weight body with shell · hour for the two series of short duration.

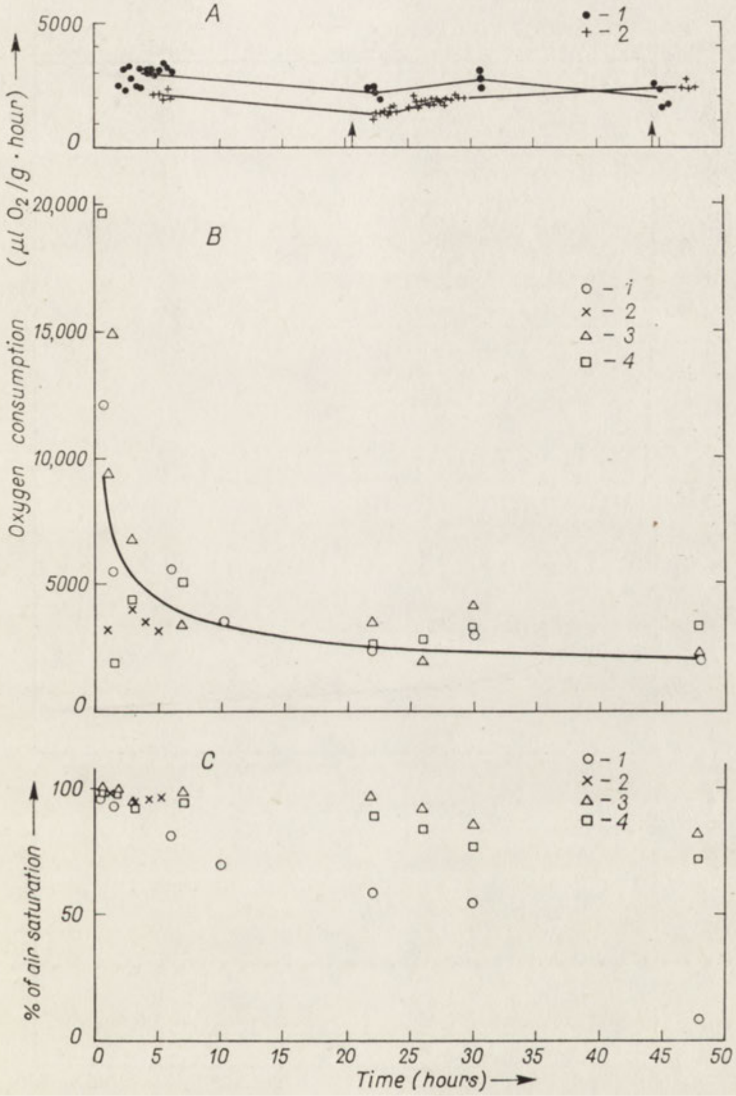

Fig. 2. Oxygen consumption of *Cloeon dipterum*, 215 individuals, mean dry weight of one individual 0.214±0.00445 mg; temperature 20±0.015°C. A — flowing-water method. 1 — 19—21.X.1967; 2 — 15—17.XI.1967; the arrow shows 12 noon. B — closed-bottle method. 1 — 14—16.IX.1967; 2 — 18.IX.1967; 3 — 25—27.IX.1967; 4 — 29—30.IX.1967. C — the oxygen content in the bottles at the end of the exposition period; 1, 2, 3 and 4 as in B

4. DISCUSSION

Ease of measurement and simplicity of equipment in the closed-bottle method compared with the flowing-water respirometer usually influences the decision to use the former method. However, there are several factors causing the results obtained from closed-bottle method to be of little value. Some of these are discussed below.

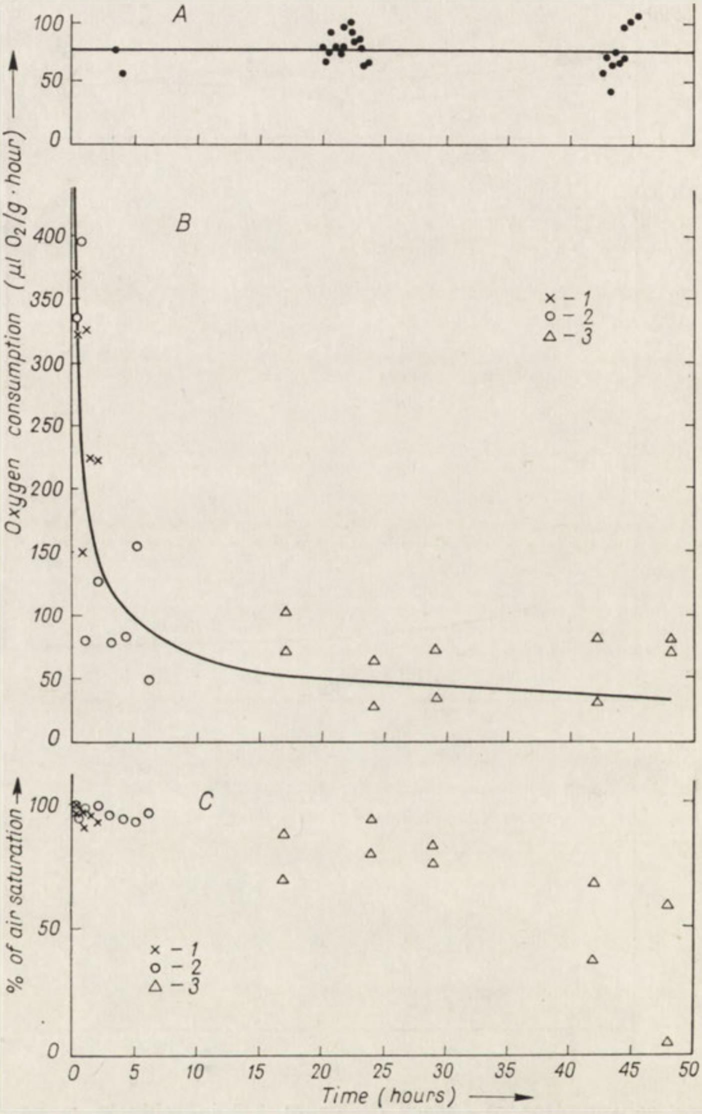

Fig. 3. The oxygen consumption of *Bithynia tentaculata*, 28 individuals, mean dry weight of one individual (body with shell) 52.2±3.64 mg; temperature 20±0.015°C. A — flowing-water method; B — closed-bottle method. 1 — 25.X.1967; 2 — 30.X.1967; 3 — 6—8.XI.1967. C — the oxygen content in the bottles at the end of the exposition period; 1, 2 and 3 as in B

1. In the flowing-water respirometer, conditions are constant and controlled during the experimental period. This is not so in the closed-bottle where conditions change with time of exposition, as the amount of oxygen decreases and that of metabolites increases.

2. The flowing-water respirometer ensures movement of water along the body surface of the animal. Inside the closed bottle which is immersed in a thermostat, there is a complete absence of water movement. It could be said to be an unnatural situation, as in most natural aquatic habitats, even in standing waters, some water movement exists caused by wind, local temperature differences etc. Complete stagnation of water on the body surface of an animal causes the formation of an oxygen gradient. Animals renew these boundary layers by an increase in activity (different kinds of respiratory or searching movements). Dam (1937), Philipson (1954), Ambühl (1959), Knight and Gaufin (1963) all found an increase in frequency of respiratory movements with a fall in the speed of water flow. The results obtained in this paper show a similar relationship, namely, that a lack of respiratory or searching movements in the flowing-water respirometer and their intensification in the closed bottle. In Fig. 4 are given additional observations on changes in the frequency of respiratory movements of two species of Plecoptera in different speeds of water flow. These experiments also show that stagnated water causes a considerable increase in the frequency of respiratory movements.

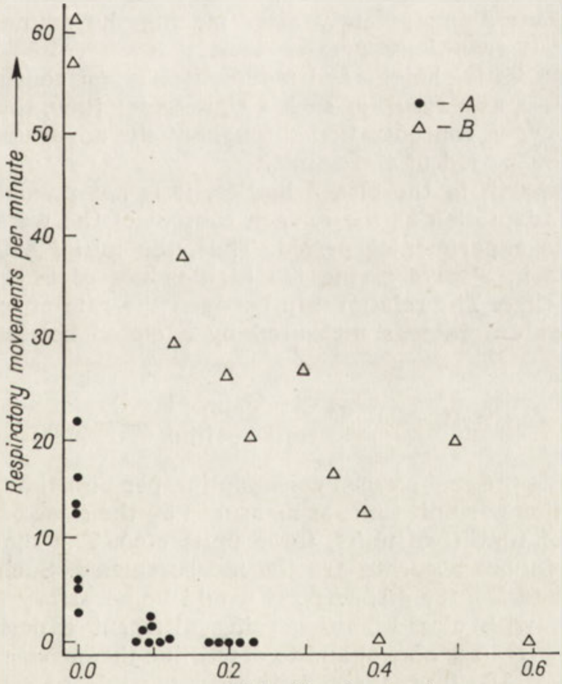

Fig. 4. Frequency of respiratory movements of larval Plecoptera in different speeds of water flow. Room temperature (about 20°C). A — *Arcynopteryx compacta*, 7 larvae, living weight 61—74 mg. B — *Perlodes intricata*, 2 larvae, living weights 103 and 104 mg

3. After placing the animal in the experimental vessel, there follows in general an elevation of the metabolism. Investigating the oxygen consumption in a Barcroft respirometer with water equilibrated with air of larval *C. dipterum* not previously acclimatized to other conditions, Harnisch (1938) found that the first measurement were higher than those of animals which had stayed in the respirometer for some time. Similarly, Pattee (1965) (Fig. 14), using a manometric respirometer, found a heightened metabolism in *Ancylus fluviatilis* and *Asellus aquaticus* during the first five hours. Zeiss (1963), using closed bottles, observed that during an exposition period of 2.5 hours, the oxygen consumption of *Calanus finmarchicus* was twice higher that obtained for a 24 hour period. This heightened metabolism could be the animals, response to handling and being placed in a vessel and is certainly higher than the "normally active state" which Teal (1967) suggests is the only metabolic measurement that is ecologically useful.

In the flowing-water respirometer, there is the possibility of rejecting the measurements of the initial heightened metabolism. In Fig. 4 of Mann's (1965) work, it can be seen that the oxygen consumption of gudgeon in the two hours after placing the fish in flowing-water polarographic respirometer was about three times greater than that after five hours. Mann kept the fish in the respirometer for at least five hours before measuring their oxygen consumption. Kamljuk (1964) measured the oxygen consumption of *Lebistes reticulatus* using also a flowing-water polorographic respirometer. The oxygen consumption measured immediately after placing the animals in the respirometer was about two times greater than that after 1.5—2 hours. In the present study, the initial heightened metabolism is not conspicuous (Fig. 1A, 2A and 3A) because, as a result of such a slow water flow, the time needed to equilibrate the oxygen concentration throughout the apparatus is longer than the acclimatization period of the animal.

On the other hand, in the closed bottles, it is not possible to reject this initial period of adaptation as the oxygen content of the water is determined at the end of the experimental period. Thus, the initial heightened oxygen utilisation results in always giving too high values of oxygen consumption over a period of time. The relationship between the rate of oxygen consumption and the apparent rate as measured by a closed bottle respirometer is described by

$$R_{(t)} = \frac{Q_{(t)} \cdot t - Q_{(t-1)} \cdot (t-1)}{\text{unit of time}}$$

where R represents the real oxygen consumption per unit time, Q the apparent oxygen consumption per unit time, as measured by the closed-bottle technique, and t is a unit of time (two units, three units etc.). The shorter the unit of time utilised, the more accurate are the measurements. Such a formula can be used to calculate $R_{(t)}$ for a species. It would be necessary to make a series of measurements with closed bottles using different experimental periods, to calculate $Q = a \cdot t^b$, (see above) and to determine the curve analogical to that in Figs 1B, 2B and 3B; from these, it is then possible to calculate $R_{(t)}$. This involves a great deal of work and it might be simpler to construct a flowing-water respirometer.

The above relationship is illustrated in the following theoretical example. Let us suppose that four larval *C. dipterum* are placed in each of four bottles;

four control bottles without animals are exposed simultaneously as final controls. In each bottle is placed an oxygen electrode recording the oxygen content every hour. The first pair of bottles are exposed for two hours, the second pair for five hours, the third for ten hours and the fourth pair for twenty hours. After the end of the exposition period, the oxygen content in each bottle is determined by Winkler's method. For simplicity, let us suppose a) there is no individual difference in oxygen consumption between individual animals, b) the dry weight of all individuals is the same, i.e. one individual weighs 0.0002 g, for individuals weigh 0.008 g, c) that only the animals use oxygen and the oxygen content of all final rontrol bottles is the same, that is, equal to $100^{0}/_{0}$ air saturation, which is 6.36 ml oxygen/l at 20°C, d) the volume of all bottles is the same, 50 ml, e) the measurement error is zero, f) the adopted unit of time is one hour and is synonymous with an infinitely small unit of time. Figure 5A present the results from these "theoretical" measurements of oxygen concentration in bottles with animals. In all the bottles events proceeded identically; the points on the curve illustrating the electrode readings after one hour really represent four super-imposed points from all four bottles, but because each of the four Winkler determinations used up one bottle, the electrode readings after the sixteenth hour come from only one bottle, the fourth one exposed for the longest time.

From this information, it is possible to calculate two kinds of oxygen consumption, $R_{(t)}$ and $Q_{(t)}$. In Fig. 5B, the curve 5B1 shows the real oxygen utilisation, $R_{(t)}$, in µl oxygen/g•hour, calculated from the electrode readings with the help of the following formula,

$$R_{(t)} = \frac{(C_{(t-1)} - C_{(t)}) \cdot 50\,\mathrm{ml}}{0.0008\mathrm{g} \cdot 1\,\mathrm{hour}}$$

where C represents oxygen concentration in ml/l. Thus for example, for the second hour, $R_{(2)} = \frac{(6.239-6.169) \cdot 50}{0.0008 \cdot 1} = 4375$. Whereas curve 5B2 presents apparent oxygen consumption, $Q_{(t)}$, in µl oxygen/g•hour during time t, calculated from the Winkler determinations of the oxygen content at the end of the exposition period with the help of the formula,

$$Q_{(t)} = \frac{(6.360 - C_{(t)}) \cdot 50\mathrm{ml}}{0.0008g \cdot t}.$$

Thus, for the second hour, $Q_{(2)} = \frac{(6.360-6.169) \cdot 50}{0.0008 \cdot 2} = 5968$. Curve 5B1, presenting the real oxygen consumption, shows its initial high level followed by an uniform rate after longer exposition, about 2200 µl oxygen/g•hour, which is close to flowing-water method results, 1859 and 2655. Curve 5B2 shows a consistently higher level than 5B1. This curve 5B2 is exactly the same curve as that given in Fig. 2B for *C. dipterum* and is analogical to those curves in Figs 1B and 3B for the other species.

It is necessary not to forget that the circulating type of flowing-water respirometer such as Ambühl (1959) and Eriksen and Feldmeth (1967) used prevents only those arrors mentioned above in point 2 and not those described in points 1 and 3 unless there is continuous registration of the decrease in oxygen concentration and so the initial heightened metabolism can be rejected.

4. Both methods discussed in this work have their own specific errors. Error involved in determination of oxygen content was discussed earlier in the section on methods. The scatter of results in determination of oxygen consumption by the flowing-water respirometer were not great and were constant. The standard error as percentage of the mean was 3.2% for *C. dipterum* from November and 3.3% from October, 3.5% for *B. tentaculata* and 3.8% for *I. buresi*. Fischer (unpublished data) measured respiration of a fish, *Ctenopha-*

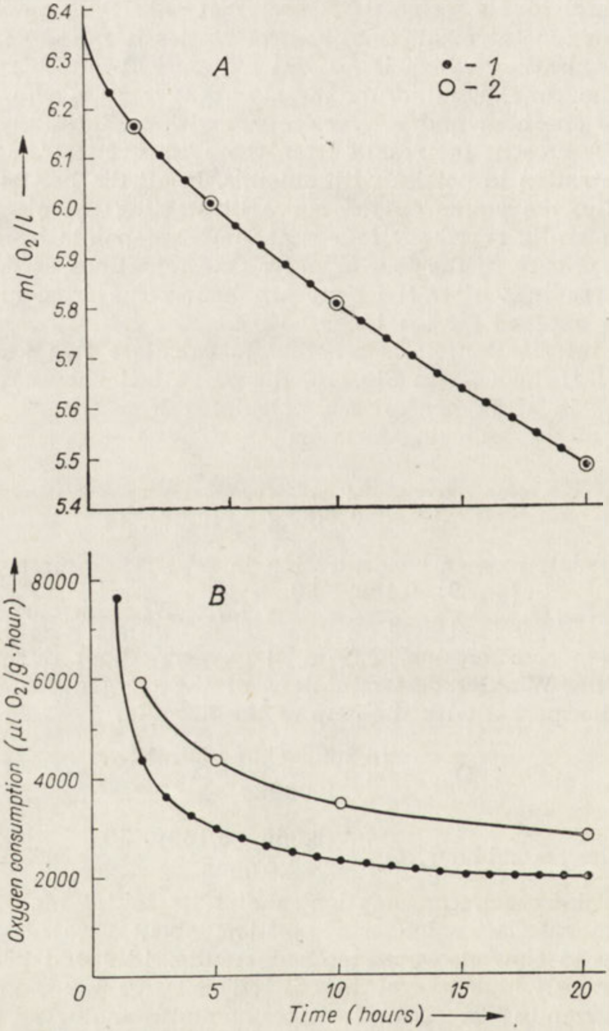

Fig. 5. A theoretical example of oxygen consumption measured by the closed-bottle method. A — changes in the oxygen concentration in the bottles with animals; 1 — "continuous" results obtained from the recorded readings of the oxygen electrode (every hour); 2 — results obtained by the Winkler method (after 2, 5, 10 and 20 hours). B — oxygen consumption by animals; 1 — the real oxygen consumption $R_{(t)}$ calculated from the "continuously" recorded readings of the oxygen electrode; 2 — the apparent oxygen consumption $Q_{(t)}$ calculated from Winkler analyses

ryngodon idella with an another type of flowing-water respirometer; the standard error of her results was 3.5% of the mean. Whereas the scatter of results in the closed-bottle method was always important, particularly when the exposition time was short and so the differences in oxygen concentration small (Figs 1B, 2B and 3B). It may be that here we are dealing not only with errors associated with the method but also due to various specific individual reactions associated with handling and placing into vessels.

Until now our knowledge of recently described species *I. buresi* (Raušer, 1962) has been limited to descriptions of its morphology and distribution. There is therefore no data with which to compare the rates of oxygen consumption obtained in the present work.

The magnitude of oxygen utilisation by larval *C. dipterum* in water equilibrated with air is given in several papers by Fox and his co-workers. This information can be compared with the results obtained here only with the greatest care, because the experimental conditions were different. Fox and Simmonds (1933) investigated animals with a mean dry weight of 0.28 mg per individual in January. The animals were narcotised and the measurements were carried out with a Barcroft manometric respirometer. At 10°C the mean oxygen consumption was 600 µl oxygen/g dry weight•hour. In Fox, Simmonds and Washbourn (1935) similar level is given, 606 at 10°C, under similar experimental conditions. The value for Q_{10} for *C. dipterum* recorded by Pattee (1965) was near to 3. It is possible to calculate that the oxygen consumption of narcotised larvae at 20°C is 1800 or 1818 µl/g•hour on the basis of the information given above. This level is similar to that obtained in the present work when the heightened metabolism associated with the animals' adaptation to the vessel is rejected, that is, to the results obtained when flowing-water method is used (2655 in October, 1859 in November). Results of measurements using the closed-bottle method are contained in the works of Fox, Wingfield and Simmonds (1936, 1937). Un-narcotised larvae exposed for one to two hours at 10°C during the month of November gave a mean oxygen consumption of 1310 µl/g•hour. Therefore, one can expect that the level of 1310 µl/g•hour at 10°C converted to 20°C would give the level of 3930 µl/g•hour. Such level of oxygen consumption is considerably higher than the results discussed above and it is possible to consider that it is heightened by inclusion of the metabolism of the adaptation period, similarly, as in the results for the closed-bottle method of the present work.

Winberg (1956) investigated the dependence of oxygen consumption of larval *C. dipterum* and *C. praetextum* on weight. He employed the closed-bottle technique, with an exposure period of two hours and converted the results to 20°C. The oxygen consumption (Q) as µl oxygen/individual•hour was defined by the formula $Q = 0.872 \cdot {}_{w}0.88$ where w is living weight of one individual, mg. In the larval *C. dipterum* used in the present work, the percentage water content of the body was approximately 85%, obtained from rather a small number of measurements. The mean dry weight of an individual was 0.214 mg, giving a mean living weight of about 1,43 mg. Substituting this value in the above formula gives a rate of 1.195 µl oxygen/individual•hour or a rate of 5584 µl oxygen/ g dry weight•hour. This level is similar to that obtained in the closed-bottle results obtained in this work after two hours exposure (5943 ml oxygen/g•hour in Fig. 2B). It appears that both of these results are too high.

Winberg and Beliazkaya (1958, 1959) carried out measurements of the oxygen consumption of ten freshwater Gastropoda species including *B. tentaculata* whose living weight of body without shell was 0.001—0.090 g. The oxygen consumption as ml oxygen/individual•hour at 20°C (Q) for all species was described by one formula, $Q = a \cdot w^{0.75}$, where a refers to the axygen consumption of one gram weight, w — is living weight of body without shell (in g). These authors carried out their studies on animals kept in the laboratory for about 24 hours and on freshly collected animals. The oxygen consumption of the latter were always higher. In the present work, animals were always kept in the laboratory for 24 hours or more before measurements were made. Thus these results can be compared with those of Winberg and Beliazkaya, using their minimal values for a, $a^{\min} = 0.05$ ml oxygen/g•hour. From Table II, the mean living weight without shell of one experimental animal is 126—39 = 87 mg or 0.087 g; substituting in the above formula, the oxygen consumption obtained is 8 μl oxygen/individual•hour. The mean dry weight of body with shell was 0.0522 g (Table II); thus the oxygen consumption, calculated by means of Winberg and Beljazkaya's formula, for an animal of similar weight as those used in the present works is 8/0.0522 = 153.2 μl oxygen/g dry weight of body with shell•hour. The cited authors carried out their measurements by means of the closed-bottle method and the exposition period varied from one to four hours. In the present work the oxygen consumption at 20°C of *B. tentaculata* using the closed-bottle method for a one hour and a four hour exposure period was 192 and 103 μl oxygen/g dry weight of body with shell•hour respectively (Fig. 3B). These are very similar results. Undoubtedly, both one and the other are higher values than occur under natural conditions.

Berg (1961) also measured the oxygen utilisation of freshwater snails using closed-bottle technique he does not give the period of exposure but judging from the remarks given in Berg's 1953 work, it seems likely that the exposition period was a short one. Figure 2 in the 1961 paper presents respiratory results for *B. tentaculata* whose living weight without shell was 80 mg which is very close to the weights of animals used in this paper. The temperature (18°C) and dissolved oxygen content (about 18.5% of gas mixture) was also rather similar to those used here. The oxygen consumption by Berg's Bithynia was 8 μl oxygen/individual•hour which is also very similar to that measured in the present work by means of closed-bottle technique.

5. CONCLUSIONS

In the present work, the closed-bottle technique was used in a way that is widely applied, that is, the closure of the bottles and the start of the exposition follows immediately after the placing of the animals in the bottles; the calculation of oxygen consumption is based on the decrease of oxygen caused by the animal during the whole period of exposition. The results obtained suggest that the levels of oxygen consumption from such an application of the closed-bottle method are much higher than the real values and cannot be used as an element in energy balance studies. Besides this, results differ according to the manner of carrying out the measurements, that is, according to the time of exposition utilised. This phenomenon occurs particularly clearly when the exposition time is short.

It seems that this method can be used in comparative investigations, for example, in studies on the influence of different temperatures on an organism when other methods are not available. Then it is necessary to take a suitable period of exposition time. It should be sufficiently long but not so long that the fall in oxygen concentration and the accumulation of metabolites in the bottle can influence the animal being investigated. The exposition time has to be equal in a whole set of measurements. Results so obtained certainly permit inquiry into the dynamics of phenomena, however it is necessary to treat them only as relative values.

Results from the flowing-water method can be applied to both types of investigation. However, there is difficulty in applying this method to certain subjects, for example, to Rotifera. The flowing-water technique can be used also for investigations of the metabolism of benthic communities in the field (Pamatmat, 1965).

Acknowledgements

The carrying out of this work would have been impossible without the active assistance of Miss Jadwiga Weber; I thank her most sincerely.

6. SUMMARY

1. In order to compare two methods of measuring the respiratory rate of freshwater organisms, namely the closed-bottle-Winkler technique and the flowing-water polarographic technique, a series of long term measurements of the oxygen consumption of three species of aquatic invertebrates was carried out, both methods being applied simultaneously.

2. The test organisms were *Isoperla buresi* (Plecoptera), *Cloeon dipterum* (Ephemeroptera) and *Bithynia tentaculata* (Gastropoda). These species differ taxonomically, ecologically and in their size.

3. The measurements of oxygen consumption obtained by the flowing-water respirometer showed no changes in relation to how long the experiment lasted and revealed very little variation. The elevated metabolism due to the animal's adaptive period did not affect the measurements made after the end of adaptation. On the other hand the results from the closed-bottle method were very variable in relation to exposition period; this relationship can be defined by the formula $Qa \cdot t^b$. All the results obtained by the closed-bottle method include the errors resulting from incorporation of the period of elevated metabolism due to the period of adaptation. The results obtained are higher than the real oxygen consumption of the organism after the passing of the same time from the start of the exposition. This error varies with the length of the period of exposition. The scatter in the results is great.

4. The above relationship between oxygen consumption as measured by closed-bottle technique and length of exposition time occurred in all series of experiments irrespective of species studied or modification in the procedure of the experiment.

5. The following additional measurements were made:

a. Measurements aimed at increasing the accuracy of determination of oxygen concentration.

b. Measurements of the frequency of respiratory movements and the occurrence of searching movements in larval Plecoptera in order demonstrate the changing conditions occurring in the experimental series and the importance of the water movement.

c. Measurements of the size and weight of *B. tentaculata* to permit the oxygen consumption to be expressed in terms of g dry weight of body without shell.

7. STRESZCZENIE

1. Dla porównania metody butelek zamkniętych i metody przepływowej wykonano serie długotrwałych pomiarów zużycia tlenu przez 3 gatunki wodnych bezkręgowców. Obie metody były stosowane równolegle.

2. Jako organizmy testowe wybrano *Isoperla buresi* (Plecoptera), *Cloeon diptrum* (Ephemeroptera) i *Bithynia tentaculata* (Gastropoda). Gatunki te różnią się pozycją systematyczną, wymaganiami ekologicznymi i wielkością.

3. Wyniki pomiarów zużycia tlenu metodą przepływową nie zmieniają się w zależności od tego, jak długo zwierzę przebywało w respirometrze i są mało zmienne. Podniesiony metabolizm okresu adaptacji zwierzęcia do respirometru nie obciąża wyników pomiarów przeprowadzonych po ukończeniu adaptacji. Natomiast wyniki uzyskane metodą zamkniętych butelek zmieniają się w zależności od czasu ekspozycji butelek. Zależność zmierzonej wielkości zużycia tlenu od czasu ekspozycji określa wzór $Q=a \cdot t^b$. Wszystkie wyniki uzyskane metodą butelek zamkniętych są obciążone błędem wynikającym z podwyższonego metabolizmu okresu adaptacji. Uzyskane wyniki są wyższe, niż prawdziwe zużycie tlenu przez zwierzę po upływie tego samego czasu od początku doświadczenia. Ten błąd jest różny w zależności od tego, jak długo trwa ekspozycja. Rozrzut wyników jest duży.

4. Powyższe zależności wystąpiły we wszystkich seriach eksperymentów, niezależnie od badanego gatunku i od modyfikacji w sposobie przeprowadzania pomiaru.

5. Przeprowadzono pomiary dodatkowe:

a. Pomiary, mające na celu zwiększenie dokładności oznaczeń stężenia tlenu.

b. Pomiary częstotliwości ruchów oddechowych i występowania ruchów szukających larw Plecoptera dla zilustrowania odmiennych warunków występujących w seriach eksperymentów i znaczenia ruchu wody.

c. Pomiary wielkości i wagi *B. tentaculata* dla umożliwienia przeliczeń uzyskanych wyników zużycia tlenu.

8. REFERENCES

Ambühl, H. 1956. Die Bedeutung der Strömung als ökologischer Faktor. *Schweiz. Z. Hydrol.*, 21, 133—264.

Berg, K. 1953. The problem of respiratory acclimatization. *Hydrobiologia*, 5, 331—350.

Berg, K. 1961. On the oxygen consumption of some freshwater snails. *Verh. int. Ver. Limnol.*, 14, 1019—1022.

Dam, L. van 1937. Über die Atembewegungen von Phryganea-Larven, *Arenicola marina* und *Nereis virens*, sowie über die Sauerstoffausnutzung bei *Anodonata cygnea*, *Arenicola marina* und *Nereis virens*. *Zool. Anz.*, 118, 122—128.

Elliot, J. M. 1968. The daily activity patterns of mayfly nymphs (Ephemeroptera). *J. Zool. Lond.*, 155, 201—221.

Eriksen, C. H., Feldmeth, C. R. 1967. A water-current respirometer. *Hydrobiologia*, 29, 496—504.

Fox, H. M., Sidney, J. 1953. The influence of dissolved oxygen on the respiratory movements of caddis larvae. *J. exp. Biol.*, 30, 235—237.

Fox, H. M., Simmonds, B. G. 1933. Metabolic rates of aquatic arthropods from different habitats. *J. exp. Biol.*, 10, 67—74.

Fox, H. M., Simmonds, B. G., Washbourn, R. 1935. Metabolic rates of ephemerid nymps from swiftly flowing and from still water. *J. exp. Biol.*, 12, 179—184.

Fox, H. M., Wingfield, C. A., Simmonds, B. G. 1936. Oxygen consumption of mayfly nymphs in relation to available oxygen. *Nature, Lond.*, 138, 1015.

Fox, H. M., Wingfield, C. A., Simmonds, B. G. 1937. The oxygen consumption of ephemerid nymphs from flowing and from still waters in relation to the concentration of oxygen in the water. *J. exp. Biol.*, 14, 210—218.

Harnish, O. 1938. Zur Analyse der Sauerstoffverbrauchs der Larven von *Cloeon dipterum* and *Ephemera vulgata*. *Z. vergl. Physiol.*, 26, 548—569.

[Kamljuk, L. V.] Камлюк, Л. В. 1964. Применение полярографического метода при измерении скорости потребления кислорода водными животными [Application of polarographic method for the measurements of aquatic animals respiration]. *Naučn. Dokl. vysš. Školy, Biol. Nauki*, 3, 49—53 (Russian).

Klekowski, R. Z., Kamler, E. 1968. Flowing-water polarographic respirometer for aquatic animals. *Pol. Arch. Hydrobiol.*, 15, 121—144

Knight, A. W., Gaufin, A. R. 1963. The effect of water flow, temperature, and oxygen concentration on the Plecoptera nymph, *Acroneuria pacifica* Banks. *Proc. Utah Acad. Sci.*, 40, 175—184.

Mann, K. H. 1965. Energy transformations by a population of fish in the river Thames. *J. Anim. Ecol.*, 34, 253—275.

Nolan, M. O., Brand, T. von 1954. The weight relations between shell and soft tissues during the growth of some fresh-water snails. *J. Wash. Acad. Sci.*, 44, 251—255.

Pamatmat, M. M. 1965. A continuous-flow apparatus for measuring metabolism of benthic communities. *Limnol. Oceanogr.*, 10, 486—489.

Pattee, E. 1965. Sténothermie et eurythermie les invertébrés d'eau douce et la variation journalière de température. *Annls Limnol.*, 1, 281—434.

Philipson, G. N. 1954. The effect of water flow and oxygen concentration on six species of caddis-fly (Trichoptera) larvae. *Proc. zool. Soc., Lond.*, 124, 547—567.

Raušer, J. 1962. *Plecoptera bulgarica*. I. *Sb. faun. Praci ent. Odd. nar. Mus. Praha*, 8 (70), 67—81.

Rebsdorf, A. 1966. Evaluation of some modifications of the Winkler method for the determination of oxygen in natural waters. *Verh. int. Ver. Limnol.*, 16, 459—464.

Richman, S. 1967. Laboratory measurements of zooplankton respiration by the Winkler method. *IBP Meeting on Methods on assessment of secondary production in freshwaters.* Prague, 6pp. (Mimeographed copy).

Teal, J. M. 1967. Respiration and energy flow. *IBP Meeting on Methods on assessment of secondary production in freshwaters.* Prague. 8pp. (Mineographed copy).

[Winberg, G. G.] Винберг, Г. Г. 1956. О зависимости интенсивности обмена членистоногих от величины тела [On dependence of metabolic rate on body dimension in arthropods]. *Uč. zap. Belorussk. gos. Univ.*, 26, 243—254 (Russian).

[Winberg, G. G., Beliazkaya, J. S.] Винберг, Г. Г., Беляцкая, Ю. С. 1957/1958. Зависимость интенсивности обмена от общих размеров тела у пресноводных брюхоногих моллюсков [Dependence of metabolic rate on total body dimensions in mollusca, Gastropoda]. *Bjul. Inst. Biol. Akad. Nauk Belorussk. SSR*, 3, 273—276 (Russian).

[Winberg, G. G., Beliazkaya, J. S.] Винберг, Г. Г., Беляцкая, Ю. С. 1959. Соотношение интенсивности обмена и веса тела у пресноводных брюхоногих моллюсков [Relation between metabolic rate and body weight in freshwater gastropods]. *Zool. Ž.*, 38, 1146—1151 (Engl. summ.).

Zeiss, F. R. 1963. Effects of population densities on zooplankton respiration rates. *Limnol. Oceanogr.*, 8, 110—115.

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ROTIFÈRES (ROTATORIA) DE TROIS LACS À TROPHISME DIFFÉRENT

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RÉSUMÉ

Les 3 lacs Sosnowickie (Białe, Bialskie et Czarne), appartenant au complexe de lacs Łęczyńsko-Włodawskie, voïvodie de Lublin, ont été étudiés du point de vue de leur composition en rotifères. Les recherches furent accomplies entre octobre 1961 et décembre 1963. Les résultats obtenus ont permis de constater certaines différences entre les complexes pélagiques des rotifères de ces lacs. Les espèces appartenant à l'héléo- et au telmatoplancton dominent dans la zone pélagiale du lac Białe, tandis que le pélagial des lacs Bialskie et Czarne se caractérise par la domination d'espèces typiquement eulimnétiques. Les lacs Sosnowickie possèdent une faune de rotifères assez riche et bien différenciée du point de vue écologique.

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9. Bibliographie

1. INTRODUCTION

Les recherches effectuées concernaient les 3 lacs Sosnowickie qui se trouvent dans la partie nord du complexe des lacs Łęczyńsko-Włodawskie. On entreprit des recherches sur la faune de ces lacs qui, en dehors de la mention de Lityński (1919) de la présence d'une espèce et de deux genres dans ce complexe de lacs, n'y fut nullement étudiée. En outre, dans les régions de la Polésie Lubelskie, Wyżyna Lubelska et Roztocze, si riches pourtant en toutes sortes de réservoirs aquatiques, on ne trouva jusqu'à présent que quelques espèces des plus communes des rotifères. On essaya également d'estimer les changements s'effectuant dans la composition des espèces des rotifères en dépendance de la saison ainsi que d'établir, tout au moins de façon estimative, les rapports quantitatifs entre les différentes espèces. En 1963, après le prélèvement du matériel pour ce travail, les lacs Sosnowickie furent reliés au système du canal Wieprz-Krzna. Les résultats de ce travail pourront servir de base à des travaux comparatifs sur l'évolution de la biocénose des rotifères de ces lacs sous l'influence de l'introduction des eaux fertiles et alcaliques des rivières. Les rotifères rares et intéressants de la faune des lacs Sosnowickie, leur répartition et leur spectre écologique furent l'objet d'une étude séparée (Radwan 1968).

2. CARACTÉRISTIQUE LIMNOLOGIQUE DES LACS SOSNOWICKIE

Le groupe des lacs Sosnowickie, nommés aussi Libiszowskie, comprend 3 lacs d'étendue relativement faible: Białe, Bialskie et Czarne, situés dans le partie nord du complexe de lacs Łęczyńsko-Włodawskie dans la voïvodie de Lublin. Tout comme les autres lacs de cette région, ils ressemblent aux lacs de la Polésie propre qui se trouve sur la rive droite du Bug. Ils sont entourés de plaines abondant en marécages et tourbières (Wilgat 1954). Depuis décembre 1963 cas lacs communiquent aves le canal Wieprz-Krzna et en certaines périodes de l'année on y détient les eaux de la rivière Wieprz en tant que réserve pour des étangs piscicoles. Lac Białe — c'est un bassin de 144,8 ha de surface et d'une profondeur maximale de 2,7 m (Wilgat 1954). Ses rives sont marécageuses et en général inaccessibles et son fond est couvert d'une couche de vase de deux mètres. Au milieu du lac se trouvent deux'îles. Sa vegétation émergée est constituée dans sa majorité par *Scirpus lacustris* L., *Phragmites communis* Trin. et *Typha angustifolia* L. Tout autour du lac la rive est couverte par le Sphagnum et le complexe Saliceto-Franguletum. La flore immergée est pauvre et répartie en îlots. Entre les îlots de joncs on trouve le plus fréquemment. *Myriophyllum alterniflorum* DC, *M. spicatum* L., *Potamogeton lucens* L. et *Potamogeton crispus*. L. Cette derniėe espėce est répartie dans tout le lac. Les deux îles sont également entourées de jonics.

Dans la partie sud et ouest du lac on trouve parmi les joncs de nombreux groupements de *Nuphar luteum* Smith et de *Nymphaea candida* Presl (Fijałkowski 1960). Le phytoplancton aussi bien du pélagial que de la zone littorale est formé principalement par deux espèces de Cyanophyceae; *Gomphosphaeria naegeliana* (Unger) et *Microcystis wesenbergi* Komarek, ainsi que par *Melosira* sp. et *Pediastrum* sp.

Sauf durant la période estivale *Eudiaptomus graciloides* Lilljeborg est l'espèce dominante des crustacés du plancton du pélagial.

Le gradient thermique ainsi que la teneur en oxygène durant l'année étaient caractéristiques pour les bassins peu profonds; on observait de faibles différences entre les couches du fond et celles de la surface. Le pH de l'eau variait, en dépendance de la période de l'année, entre 7,0 et 8,3. I'eau du lac était trouble, de couleur jaune-verdâtre en été et jaune-brunâtre en automne et en hiver. La visibilité était très faible, de 0,23 m en été à 1,74 m en hiver. La glace s'y maintenait dès le début de décembre jusqu'à la moitié de mars.

D'après Brzęk (1964) le lac Białe appartient au groupe de lacs fortement eutrophiés.

Le lac Bialskie est le moins étendu des lacs étudiés — 31,7 ha mais aussi le plus profond — 18,2 m (Wilgat 1954). Sa cuvette a la forme d'un entonnoir régulier. Les rives du côté sud et est sont élevées et possèdent une large plage sablonneuse, tandis que celles du nord et de l'ouest sont basses et, donnant sur des tourbières, sont inaccessibles. Le fond du bassin est couvert d'une mince couche de vase. La végétation émergée de la rive sud-ouest est consaituée en majeure partie par *Typha angustifolia* L., *Phragmites communis* Trin, et

Scirpus lacustris L., tandis que le reste de la rive est couvert par le complexe Caricetum inflatae vesicariae avec *Heleocharis palustris* (L.) en tant que dominant. Les couches plus profondes de la zone littorale sont couvertes par *Myriophyllum alterniflorum* DC, remplacé an allant vers le fond par une large ceinture de *Myriophyllum spicatum* L., et ensuite, dans le sublittoral par de vastes près de *Ceratophyllum demersum* L. (Fijałkowski 1960).

De nombreuses floraisons de *Oscillatoria agardhii* Gom. ainsi que des quantités considérables de *Tabellaria flocculosa* var. *asterionelloides* sp. et *Pediastrum* sp. furent notées dans les deux zones de ce lac. En outre la présence en grand nombre de *Melosira* sp. et de *Pediastrum* sp. fut notée dans son littoral. Quant aux crustacés du zooplancton ils formaient dans le pélagial un complexe constitué par *Eudiaptomus graciloides* Lilljeborg, *Daphnia cucullata kahlbergensis* Schödler et *Bosmina coregoni kessleri* Uljanin.

Le gradient thermique et la teneur en oxygène étaient ceux des lacs profonds car durant la période de stagnation on notait des différences considérables entre la température et la teneur en oxygène de la surface et du fond. En septembre et en octobre ainsi qu'en mars les couches du fond contenaient fréquemmant du H_2S. L'eau du lac avait un pH de 6,8—7,8. La couleur de l'eau allait du vert en hiver au vert d'olive en été. La visibilité y était bonne, de 3,01 m en été à 7,42 m durant la période hiverno-printannière. A partir de décembre jusqu'à mars le lac était couvert de glace.

D'après Brzęk (1964) le lac Bialskie étant probablement le plus jeune des 3 lacs, est peu eutrophié et possède quelques traits d'oligotrophie.

Le lac Czarne, bassin de 41,13 ha de superficie de 15,6 m de profondeur maximale est ceinturé par une fôret. Sa rive Sud et Sud-Ouest touche une veste turbière élevée appelée Czarne Bagno avec laquelle il se relie par deux fossés d'amélioration (Wilgat 1954). A part la partie de ces rives adjacentes à la tourbière le reste de la rive Sud et Sud-Ouest est élevé et sablonneux. Le fond du lac couvert d'une couche assez épaisse du type tyrphopélique. La rive sud-ouest est couverte par *Phragmites communis* Trin. et *Heleocharis palustris* L., la végétation de la rive nord est composée principalement par *Scirpus lacustris* L., tandis que celle de la rive Est est constituée en majeure par *Typha angustifolia* L. Les couches plus profondes de l'eau sont occupées par une large ceinture de *Myriophyllum alterniflorum* DC (Fijałkowski 1960). Le phytoplancton du pélagial se compose de deux espèces appartenant aux Cyanophycea: *Gomphosphaeria naegeliana* (Unger) et *Oscillatoria agardhii* Gom., tandis que dans la zone littorale on notait fréquemment *Oscillatoria agardhii* Gom., *Tabellaria flocullosa* (Roth) ainsi que *Pediastrum* sp. Quant aux crustacés du pélagial les espèces dominantes pendant toute l'année étaient, tout comme dans le lac Bialskie, *Eudiaptomus graciloides* Lilljeborg, *Bosmina coregoni kessleri* Uljanin et *Daphnia cucullata kahlbergensis* Schödler.

Le gradient thermique tout comme la teneur en oxygène sont similaires à ceux du lac Bialskie. Dans l'hypolimnon profond du lac Czarne on nota également du H_2S (IX—XI, III). Le pH de l'eau allait de 6,8, à 7,8. La couleur de l'eau orange-clair en été et en automne devenait orange-brun en hiver. La visibilité y était considérable, de 1,27 au début de l'automne à 4,20 m en hiver.

Brzęk (1964) considère ce lac comme eutrophe avec des éléments de distrophie.

3. MATÉRIEL ET MÉTCHODES

La matériel était collecté en 1961—1963 durant toute l'année toutes les 6 semaines. A chaque fois un échantillon était prélevé aussi bien dans la zone riveraine que dans le pélagial. On employait des filets de gaze de moulin nr. 25 (0,055 mm de diamétre des mailles). Au milieu du lac on prélevait deux échantillons: l'un en vertical au lieu le plus profond du lac en tirant le filet à 5 reprises travers toute la couche de l'eau, l'autre en horizontal en tirant le filet derrière une barque, à 3 emplacements différents du lac. Le filet était situé dans ce cas 1 mètre en dessous de la surface de l'eau. Les échantillons provenant du littoral étaient prélevés dans de différents biotopes. En hiver les échantillons étaient prélevés dans les deux zones du lac par des trous percés dans la glace. Les échantillons étaient fixés immédiatement après avoir été prélevés à l'aide de formaline à 4%. Simultanément on prélevait des échantillons destinés à des analyses „in vivo" pour pouvoir déterminer les rotifères déformables par la formaline. En total on collecta et on analysa 254 échantillons provenant aussi bien du littoral que du pélagial.

4. COMPARAISON DE LA FAUNE DES ROTIFÈRES PROVENANT DES 3 LACS ÉTUDIÉS

Au total on trouva 137 formes de rotifères dans les deux zones des lacs Sosnowickie. Entre elles les espèces suivantes ne furent trouvées que dans le pélagial: *Asplanchna brightwelli* Gosse, *Ascomorpha cf. minima* Hofsaen. *Cephalodella obvia* Donner, *Conochilus dossuarius* (Hudson), *Filinia terminalis* (Plate), *Keratella quadrata reticulata* Carlin, *Monostyla stenroosi* Meissner, *Polyarthra dolichoptera brachyptera* Bartoš, *Polyarthra dolichoptera aptera* Hood. 65 formes, par contre ne furent constatées que dans le littoral tandis que le reste, 63 formes habitaient les deux zones des lacs (Table 1).

Les lacs Bialskie et Czarne se ressemblent du point de vue de leur composition en rotifères mais différent du lac Białe. Dans les deux premiers les espèces communes durant toute l'année étaient: *Asplanchna priodonta* Gosse, *Conochilus unicornis* Rousselet, *Gastropus stylifer* Imhof, *Filinia maior* (Colditz), *Kellicottia longispina* (Kellicott), *Keratella hiemalis* Carlin *Keratella cochlearis* (Gosse) et *Polyarthra vulgaris* Carlin. Durant la période chaude de l'année à ces espèces s'ajoutait *Polyarthra euryptera* (Wierzejski). Il y manquait par lontre certaines formes qu'on ne trouvait que dans le lac Białe: *Asplanchna brightwelli* Gosse, *Brachionus angularis* Gosse, *Brachionus angularis bidens* Plate, *Brachionus diversicornis homoceros* (Wierzejski), *Brachionus diversicornis* (Daday). Les formes communes présentes durant toute l'année dans le pélagial du lac Białe étaient des formes caractérisaiques pour les petits bassins aquatiques: *Brachionus angularis* Gosse, *Keratella quadrata* (Müller), *Keratella cochlearis tecta* (Gosse), *Keratella cochlearis* (Gosse) et *Polyarthra vulgaris* Carlin. Au printemps et en été on y notait également en grandes quantités *Trichocerca cylindrica* (Imhof) et *Trichocerca similis* (Wierzejski). Par contre des espèces comme: *Conochilus unicornis* Rousselet et *Kellicottia longispina* (Kellicott), caractéristiques pour les lacs profonds n'y apparaissaient qu'en petites quantités et de façon sporadique. *Gastropus stylifer* Imhof, une des espèces les plus communes dans les lacs Bielskie et Czarne ainsi que *Polyartha euryptera* (Wierzejski) ne purent être décelées dans la lac Białe.

La zone littorale dans les étudiés était habitée par différentes espèces qui apparaissaient de façon sporadique en exemplaires isolés.

Un prélèvement contenait de 20 à 40 espèces mais en général on y en trouvait de 8 à 17. Dans le pélagial tout comme dans le littoral on trouvait en général mons de rotifères en janvier, février et mars. La plus grande quantité de formes était constatét de juillet à octobre (Fig. 3). D'après la fréquence des rotiféres dans les deux zones des lacs étudiés on peut les classer en 4 groupes:

a) Espèces très fréquentes, constatées dans plus de 40% des prélèvements. A ce groupe appartiennent 10 espèces euplanctoniennes et une espèce, *Euchlanis dilatata* Ehrenberg, qui est une forme epiphyte.

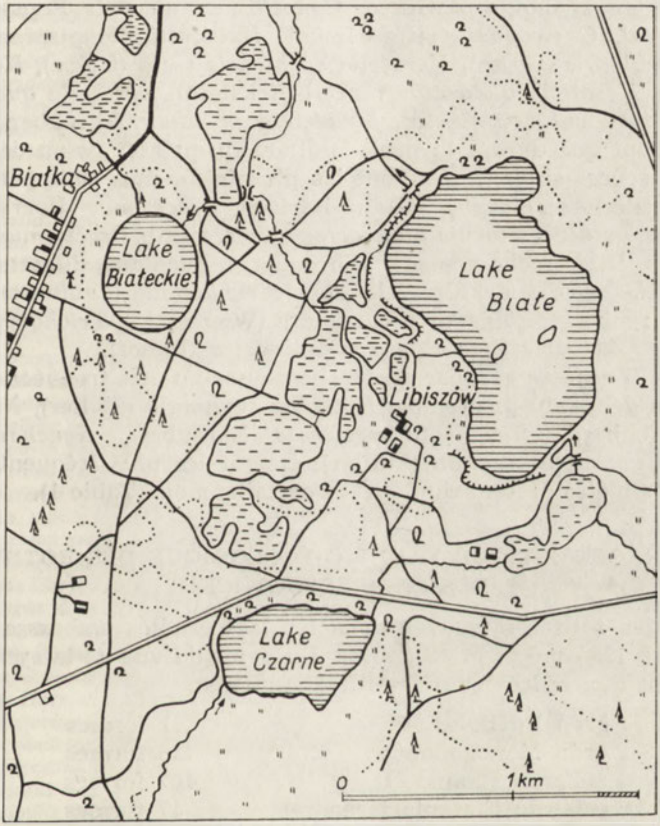

Fig. 1. Plan de situation des lacs de Sosnowica

b) Espèces fréquentes, constatées dans 15—40% des prélèvements. Ce groupe compte 20 formes dont 7 sont des épiphytes le restant étant des euplanctonies typiques.

c) Espèces assez fréquentes, se trouvant dans 5—15% des prélèvements Ce groupe est constitué par 29 formes: 15 épiphytes et 14 euplanctoniennes.

d) Espèces rares, dont la fréquence ne dépasse pas 4% des prélèvements. On y compte 78 formes dont seules 14 sont des formes euplanctoniennes et 64 des rotifères épiphytes.

Les formes communes présentes en général en grand nombre dans les lacs Sosnowickie étaient les suivantes: *Asplanchna priodonta* Gosse, *Brachionus angularis* Gosse, *Conochilus unicornis* Rousselet, *Filinia maior* (Colditz), *Gastropus stylifer* Imhof, *Kellicottia longispina* (Kellicott), *Keratella cochlearis* (Gosse), *Keratella cochlearis hispida* (Lauterborn), *Keratella cochlearis tecta* (Gosse), *Keratella hiemalis* Carlin, *Polyarthra vulgaris* Carlin, *Polyarthra dolichoptera* (Idelson), *Pompholyx sulcata* Hudson, *Synchaeta pectinata* Ehrenberg, *Trichocerca cylindrica* (Imhof).

Certaines formes étaient présentes durant toute l'année, d'autres n'apparaissaient que pendant certaines périodes (Table 1).

Les espèces présentes durant toute l'année étaient: *Asplanchna priodonta* Gosse, *Brachionus angularis* Gosse, *Conochilus unicornis* Rousselet, *Filinia maior* (Colditz), *Gastropus stylifer* Imhof, *Kellicottia longispina* (Kellicott), *Keratella cochlearis* (Gosse), *Keratella cochlearis tecta* (Gosse), *Keratella hiemalis Carlin*, *Keratella quadrata frenzeli* (Eckstein), *Keratella quadrata* (Müller), *Polygarthra vulgaris* Carlin, *Synchaeta pectinata* Ehrenberg. 62 formes n'apparaissaient que durant la période allant du printemps au début de l'automne. Les espèces suivantes étaient les plus fréquentes et apparaissaient en grande quantité: *Ascomorpha saltans* Bartsch, *Brachionus diversicornis* (Daday), *Brachionus diversicornis homoceros* (Wierzejski), *Brachionus quadridentatus* Herman, *Dissotrocha aculeata* (Ehrenberg), *Euchlanis dilatata* Ehrenberg, *Euchlanis lucksiana* Hauer, *Keratella cochlearis hispida* (Leuterborn), *Mytilina ventralis* (Ehrenberg), *Polyarthra euryptera* (Wierzejski), *Trichocerca capucina* (Wierzejski et Zacharias), *Trichocerca cylindrica* (Imhof).

Parmi les 21 espèces qui, par contre, ne pouvaient être trouvées que pendant l'hiver ou au début du printemps: *Notholca squamula* (Müller), *Notholca acuminata* (Ehrenberg), *Synchaeta pectinata* Ehrenberg, *Synchaeta oblonga* Ehrenberg, *Synchaeta tremula* (Müller), étaient les plus fréquentes. Le reste des 42 formes n'étai présent que durant certains mois (Table 1).

5. CARACTÉRISTIQUE FAUNICO-ÉCOLOGIQUE DES ROTIFÈRES DES LACS SOSNOWICKIE

La liste des rotifères trouvés dans les lacs étudiés embrasse 137 formes appartenant à 120 espèces et 48 genres. Du point de vue de la systématic elles appartiennent aux ordres et sous-ordres suivants:

ordo Bdelloidea	11 formes
ordo Monogononta	126 formes
subordo Ploima	107 formes
subordo Flosculariacea	17 formes
subordo Collothecacae	2 formes

Parmi ces formes 15 se sont avérées nouvelles et 30 rares pour la Pologne. Les nouvelles formes sont[1]: *Ascomorpha cf. minima* Hofsten, *Cephalodella biungulata* Wulfert, *Cephalodella stenroosi* Wulfert, *Cephalodella sterea dentáta* Donner, *Collotheca calva* (Hudson), *Dissotrocha aculeata crystallina* (Murray), *Keratella quadrata frenzeli* (Eckstein), *Keratella quadrata reticulata* Carlin, *Lecane stokesi* (Pell), *Mniobia punctulata* Bartoš, *Polyarthra dolichop-*

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[1] Une revue détaillée de ces formes nouvelles pour la Pologne a été publiée séparément (Radwan 1966).

Table I. Liste systématique de rotifères (Rotatoria), leur fréquence et règion de leur apparition dans les lacs de Sosnowica

Espèces	Lac					Saison		
	Białe	Bialskie	Czarne	Zone	fréquence	durant toute l'année	printannières et estivales	hiverno-printan-nières
Rotaria rotatoria (Pall)	+	+	+	PL	2		+	+
Rotaria tardigrada (Ehrb.)	+	+	+	L	3		+	+
Mniobia punctulata Bart.	+			L	4			+
Dissotrocha aculeata (Ehrb.)	+	+	+	PL	3		+	
Dissotrocha a. crystallina (Murray)		+		L	4		+	
Dissotrocha macrostyla (Ehrb.)	+	+	+	PL	3		+	+
Dissotrocha m. tuberculata (Gosse)	+	+		L	4		+	+
Philodina citrina Ehrb.		+		L	4		+	
Philodina megalotrocha Ehrb.		+	+	PL	4		+	+
Philodina roseola Ehrb.		+		L	4		+	
Adineta gracilis Jans.		+		L	4		+	
Notommata collaris Ehrb.			+	L	4		+	
Notommata copeus Ehrb.		+		L	4		+	
Notommata cyrtopus Gosse	+	+	+	L	4		+	
Pleurotrocha petromyzon Ehrb.	+			L	4			+
Cephalodella biungulata Wulf.	+			L	4			+
Cephalodella catellina (Müll.)	+			L	4			+
Cephalodella delicata Wulf.			+	L	4		+	
Cephalodella gibba (Ehrb.)	+	+	+	PL	4		+	+
Cephalodella obvia Donn.	+			P	4		+	
Cephalodella stenroosi Wulf.			+	L	4			+
Cephalodella sterea dentata Donn.			+	L	4			+
Cephalodella s. minor Donn.			+	L	4		+	
Cephalodella s. mutata Donn.	+	+	+	L	3		+	+
Monommata longiseta (Müll.)	+	+	+	L	4		+	+
Eosphora najas Ehrb.	+			L	4		+	
Pseudocharringia similis Fad.		+		L	4		+	
Proales minima Mont.			+	L	4		+	
Proales sordida (Gosse)		+		L	4		+	
Tetrasiphon hydrocora Ehrb.			+	L	4			+
Lindia pallida Harr. et Myers			+	L	4		+	
Trichocersa capucina (Wierz. et Zach.)	+	+	+	PL	2		+	
Trichocerca cylindrica (Imhof)	+	+	+	PL	2		+	
Trichocerca porcellus (Gosse)	+	+	+	PL	3		+	+
Trichocerca rattus carinata Ehrb.	+	+	+	L	3		+	+
Trichocerca similis (Wierz.)	+	+	+	PL	2		+	+
Trichocerca tigris (Müll.)	+	+	+	PL	2		+	
Elosa spinifera Wiszn.		+	+	L	4		+	+
Gastropus hyptopus (Ehrb.)		+		PL	4		+	
Gastropus stylifer Imhof		+	+	PL	1	+		
Ascomorpha saltans Bartsch	+	+	+	PL	3		+	
Ascomorpha cf. minima Hofst.		+		P	4		+	
Chromogaster ovalis (Berg.)		+	+	PL	3		+	+
Chromogaster testudo Laut.		+	+	PL	3		+	+
Harringia eupoda (Gosse)			+	L	4			+
Asplanchna brigthwelli Gosse	+			P	4		+	+
Asplanchna priodonta Gosse	+	+	+	PL	1	+		
Synchaeta pectinata Ehrb.	+	+	+	PL	1			+

Table I, cont.

Espèces	Lac					Saison		
	Białe	Bialskie	Czarne	Zone	fréquence	durant toute l'année	printannières et estivales	hiverno-printannières
Synchaeta oblonga Ehrb.	+	+	+	PL	2			+
Synchaeta tremula (Müll.)	+	+	+	PL	2			+
Polyarthra dolichoptera (Idelson)	+	+	+	PL	2		+	+
Polyarthra d. aptera (Hood)	+			P	4			+
Polyarthra d. brachyptera Bart.	+	+	+	P	4			+
Polyarthra euryptera (Wierz.)		+	+	PL	3		+	
Polyarthra vulgaris Carlin	+	+	+	PL	1	+		
Epiphanes brachionus (Ehrb.)		+		L	4			+
Cyrtonia tuba (Ehrb.)		+		L	4		+	
Rhinoglena frontalis Ehrb.		+	+	PL	4			+
Brachionus angularis Gosse	+			PL	2	+		
Brachionus a. bidens Plate	+			PL	4		+	+
Brachionus diversicornis (Dad.)	+			PL	3		+	
Brachionus d. homoceros (Wierz.)	+			PL	4		+	
Brachionus quadridentatus Herm.	+	+	+	L	4		+	
Platyas quadricornis pentagona Wulf.		+		PL	4		+	
Keratella cochlearis Gosse	+	+	+	PL	1	+		
Keratella c. hispida Laut.	+	+	+	PL	2		+	
Keratella c. tecta (Gosse)	+	+	+	PL	2	+		
Keratella hiemalis Carl.	+	+	+	PL	2	+		
Keratella quadrata (Müll.)	+	+	+	PL	1	+		
Keratella q. frenzeli (Eckst.)	+	+	+	PL	2	+		
Keratella q. reticulata Carl.		+	+	P	4			+
Keratella valga (Ehrb.)		+	+	PL	4		+	+
Kellicottia longispina (Kell.)	+	+	+	PL	1	+		
Notholca acuminata (Ehrb.)		+		PL	3			+
Notholca labis Gosse	+	+	+	PL	3		+	+
Notholca squamula (Müll.)	+	+	+	PL	3			+
Argonotholca foliacea (Ehrb.)	+	+		PL	3		+	+
Euchlanis calpidia Myers		+	+	L	4		+	+
Euchlanis deflexa Gosse	+	+	+	L	2		+	+
Euchlanis dilatata Ehrb.	+	+	+	PL	1		+	
Euchlanis incisa Carl.		+		L	4		+	
Euchlanis lucksiana Hauer		+	+	P	3		+	
Euchlanis lyra Huds.	+	+	+	L	3		+	+
Euchlanis meneta Myers			+	L	4		+	
Euchlanis oropha Gosse	+			L	4		+	
Euchlanis pyriformis Gosse			+	L	4		+	
Euchlanis triquetra Ehrb.		+	+	PL	2		+	+
Mytilina ventralis (Ehrb.)	+			L	3		+	
Mytilina mucronata spinigera (Ehrb.)	+	+	+	L	3		+	
Lophocharis oxysternon (Gosse)	+	+	+	PL	4		+	+
Lophocharis salpina (Ehrb.)			+	L	4		+	
Trichotria pocillum (Müll.)	+	+	+	PL	2		+	+
Trichotria tetractis (Ehrb.)		+	+	PL	3		+	+
Lepadella acuminata (Ehrb.)			+	L	4		+	
Lepadella ovalis (Müll.)	+			L	4		+	
Lepadella patella (Müll.)	+	+	+	PL	3		+	
Lepadella quadricarinata (Stenr.)			+	L	4		+	

Table I, cont.

Espèces	Lac					Saison		
	Białe	Bialskie	Czarne	Zone	fréquence	durant toute l'année	printannières et estivales	hiverno-printan-niéres
Lepadella rhomboides (Gosse)		+		PL	4		+	
Lepadella triptera Ehrb.		+		L	4		+	+
Squatinella rostrum (Schm.)			+	L	4		+	
Colurella adriatica Ehrb.	+	+	+	L	4		+	+
Colurella bicuspidata (Ehrb.)		+		L	4		+	
Lecane lauterborni Hauer		+		L	4		+	+
Lecane ludwigi (Eckst.)		+	+	L	4			+
Lecane luna (Müll.)	+	+	+	PL	2		+	
Lecane mira (Murr.)	+	+		L	4		+	
Lecane stichea Harr.	+	+	+	L	4		+	+
Lecane stokesi (Pell)		+	+	L	4		+	
Lecane subtilis Harr. et Myers				L	4			
Lecane ungulata (Gosse)	+	+	+	PL	3		+	
Monostyla bulla Gosse	+	+	+	PL	3		+	+
Monostyla closterocerca Schm.		+	+	L	4		+	+
Monostyla hamata Stok.		+	+	L	4		+	+
Monostyla lunaris Ehrb.	+	+	+	PL	2		+	+
Monostyla pygmaea Dad.		+		L	4		+	
Monostyla scutata Harr. et Myers		+		L	4		+	
Monostyla stenroosi Meiss.	+			P	4		+	
Monostyla subulata Harr. et Myers		+		L	4		+	
Testudinella incisa (Tern.)		+		L	4		+	
Testudinella parva (Tern.)		+	+	PL	3		+	
Testudinella p. bidentata (Tern.)			+	L	4		+	
Testudinella patina (Herm.)			+	L	4		+	
Testudinella p. intermedia (And.)		+		L	4		+	
Testudinella p. trilobata (And. et Shep.)		+		PL	4		+	
Testudinella truncata (Gosse)	+			L	4		+	
Pompholyx complanata Gosse			+	PL	4		+	+
Pompholyx sulcata Huds.	+	+	+	PL	2		+	+
Filinia longiseta (Ehrb.)	+		+	PL	2		+	+
Filinia maior (Cold.)	+	+	+	PL	1	+		
Filinia terminalis (Plate)	+			PL	4			+
Sinantherina socialis (L.)		+	+	PL	3		+	+
Conochilus hippocrepis (Schr.)		+	+	PL	3		+	
Conochilus unicornis Rouss.	+	+	+	PL	1	+		
Conochiloides dossuarius (Huds.)		+	+	P	4		+	+
Conochiloides natans (Seligo)	+		+	PL	3			+
Collotheca calva (Huds.)	+	+	+	PL	3		+	+
Collotheca mutabilis (Huds.)	+	+	+	PL	3		+	+

P — pelagial. L — littoral. 1 — formet tres frequentes, 2 — formes frequentes, 3 — formes assez frequentes. 4 — formes rares.

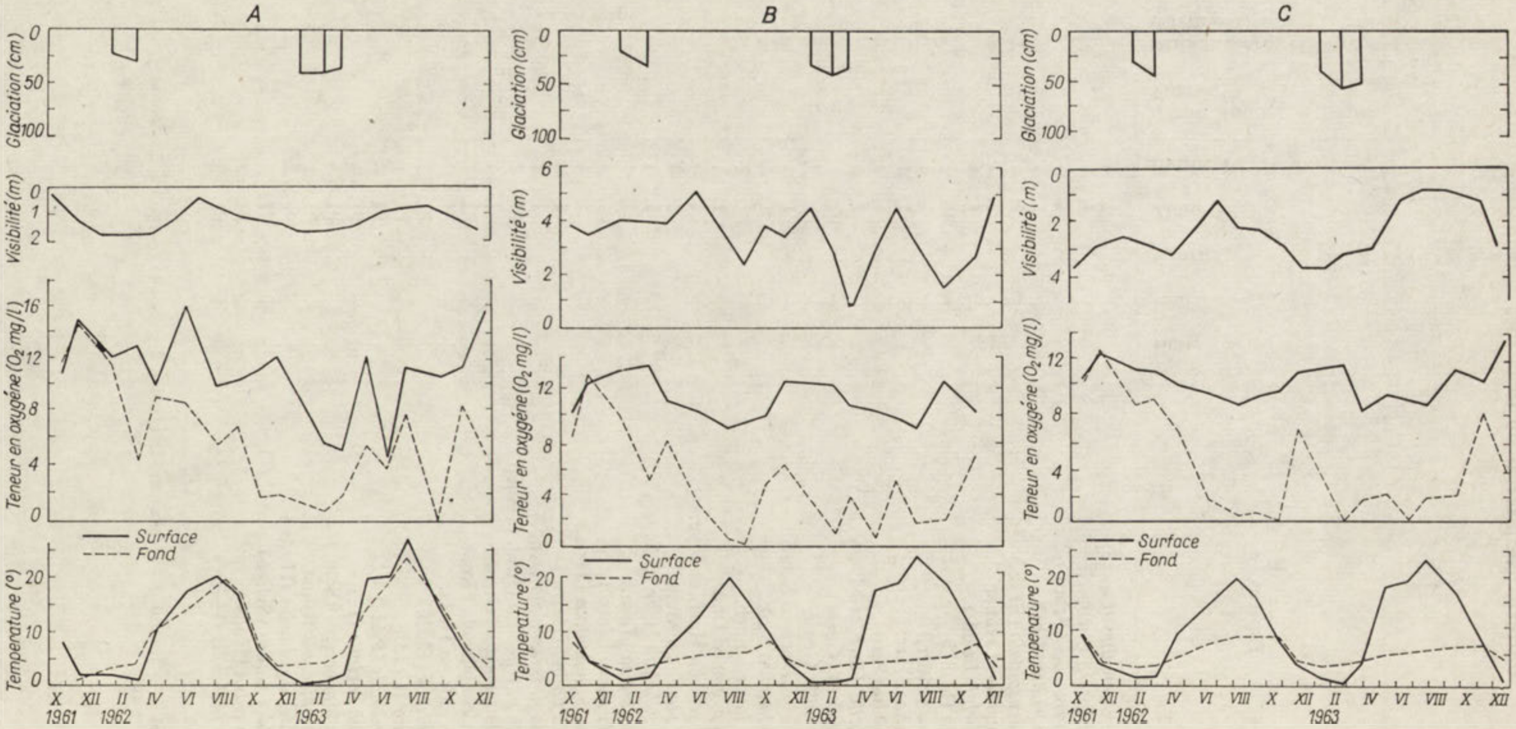

Fig. 2. Changements annuels des teneurs en oxygène, de la température d'eau de visibilité et de la glaciation de la surface des lacs de Sosnowica. A — Lac Białe, B — Lac Bialskie, C — Lac Czarne

tera brachyptera Bartoš, *Pseudoharringia similis* Fadeev, *Squatinella rostrum* (Schmarda), *Testudinella parva* (Ternetz), *Testudinella patina trilobata* Anderson et Shepard.

Presque toutes les formes constatées dans les lacs Sosnowickie sont nouvelles pour la voïvodie de Lublin, car seules 11 formes de rotifères furent jusqu'à présent trouvées dans cette partie de la Pologne (Cabejszek, Malanowski et Włodek 1956, Kulmatycki, Gabański 1931, Lewandowska 1963, Lityński 1918, 1919). Ce sont: *Asplanchna priodonta* Gosse, *Asplanchna herricki* de Guerne, *Brachionus angularis* Gosse, *Brachionus calyciflorus* Pallas, *Brachionus calyciflorus dorcas* (Gosse), *Brachionus diversicornis homoceros* Wierzejski, *Brachionus urceus* Linne, *Filinia longiseta* (Ehrenberg), *Kellicottia longispina* (Kellicott), *Keraaella cochlearis* (Gosse), *Keratella quadrata* (Müller). Les espèces suivantes, appartenant à ce groupe, n'y furent pas retrouvées: *Asplanchna herricki* de Guerne, *Brachionus calyciflorus dorcas* (Gosse), *Brachionus calyciflorus* Pallas, *Brachionus urceus* Linne. On distingue quelques groupes écologiques. La caractéristique écologique a été basée sur les travaué suivants: Beauchamp (1909), Rylov (1935), Wiszniewski (1934), Galliford (1946) et Pawłowski (1958).

ROTIFÈRES DE LA ZONE PÉLAGIALE

Parmi les 72 formes constatées dans la zone pélagiale 48 sont des organismes euplanctoniens dont les rotifères eulimnétiques (propres au plancton des grand lacs) sont constitués par: *Asplancha priodonta* Gosse, *Conochiloides natans* (Seligo), *Conochilus unicornis* Rousselet, *Gastropus stylifer* Imhof, *Kellicottia longispina* (Kellicott), *Polyarthra euryptera* (Wierzejski), *Trichocerca capucina* (Wierzejski et Zacharias).

Le reste des 41 formes peut être considéré comme propre pour les petits bassins aquatiques (présent aussi bien dans le héléoplancton que dans le telmatoplancton) mais la majorité de ces formes peut se trouver également dans le plancton des lacs. Les espèces suivantes sont caractéristiques pour le héléoplancton de ce groupe: *Ascomorpha saltans* Bartsch, *Brachionus angularis bidens* Gosse, *Brachionus angularis* Plate, *Brachionus diversicornis* (Daday), *Brachionus diversicornis homoceros* (Wierzejski), *Conochiloides dossuarius* (Hudson), *Pompholyx complanata* Gosse, *Trichocerca cylindrica* (Imhof). On ne trouva par contre dans ce groupe aucune forme typique uniquement pour le telmaplancton.

24 espèces de rotifères du pélagial des lacs étudiés peuvent être considérées comme accidentelles (tychoplancton) pour cette zone: *Euchlanis dilatata* Ehrenberg, *Lecane luna* (Müller), *Monostyla lunaris* Ehrenberg, *Totaria rotatoria* (Pallas), *Trichocerca tigris* (Müller) on étaient les espèces les plus fréquentes.

ROTIFÈRES DE LA ZONE LITTORALE

En comparaison avec le pélagial le littoral est beaucoup plus riche en quantité de formes de rotifères: on y constata 127 formes qui furent classées en quelques groupes écologiques.

Les espèces les plus nombreuses représentées par 75 formes étaient les rotifères épiphytiqueliés à différent degré à la végétation aquatique. *Euchlanis* *dilatata* Ehrenberg et *Monostyla lunaris* Ehrenberg en étaient les représentants les plus nombreux et les plus fréquents. 19 espèces, dont seules *Adineta gracilis* Janson et *Mniobia punctulata* Bartoš sont considérées comme bryophyles typiques, étaient trouvées dans la mousse.

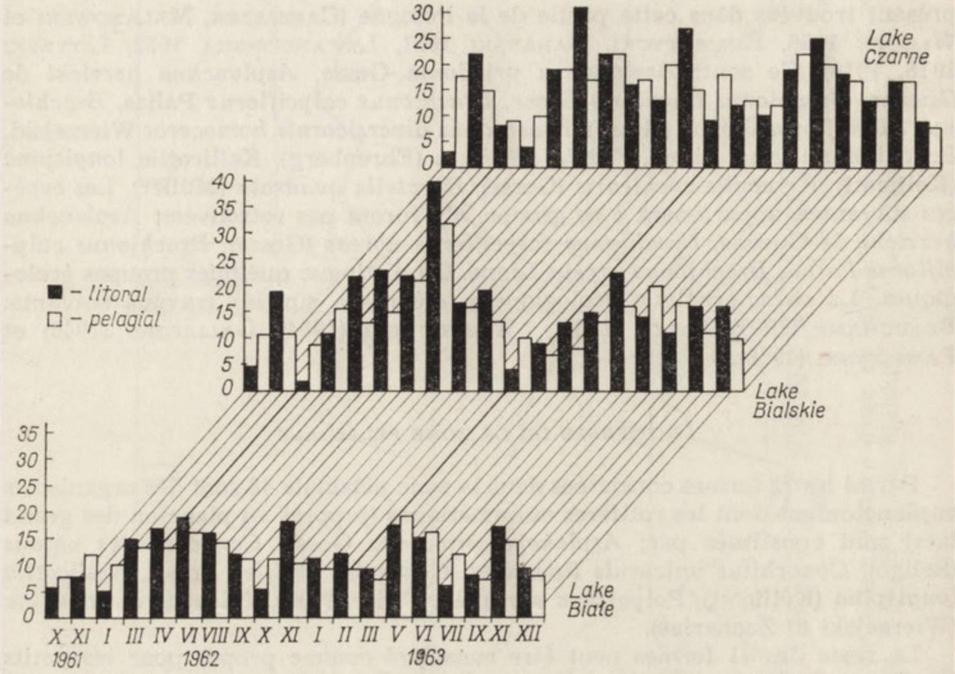

Fig. 3. Nombre des espèces de Rotifères constatées dans la zone pélagique et dans la zone littorale des lacs de Sosnowica dans les mois particuliers

30 espèces appartenaient au psammon mais uniquement *Elosa spinifera* Wiszniewski représentait les psammonbiontes. Les espèces psammophyles étaient les suivantes: *Adineta gracilis* Janson, *Cephalodella catellina* (Müller), *Cephalodella gibba* (Ehrenberg), *Cyrtonia tuba* (Ehrenberg), *Monostyla closterocerca* Schmarda, *Notholca labis* Gosse, *Philodina megalotrocha* Ehrenberg, *Rotaria tardigrada* (Ehrenberg). La présence dans le psammon de 21 espèces restantes est considérée comme accidentelle.

3 espèces peuvent être considérées comme épibiontes. L'une d'elles, *Pleurotrocha petromyzon* Ehrenberg est une épibionte facultative, tandis que les deux autres: *Cephalodella gibba* Ehrenberg et *Lepadella acuminata* Ehrenberg ne se trouvent sur les animaux que d'une façon accidentelle. Certaines espèces appartenant aussi bien aux rotifères du psammon qu'aux bryophyles ou aux épibiontes peuvent se trouver en liaison étroite avec la végétation aquatique.

Le dernier groupe, relativement nombreux et abondant en quantité d'espèces est formé par les rotifères accidentels dans le littoral. Ce groupe compte 43 formes dont les plus fréquentes sont: *Asplanchna priodonta* Gosse, *Conochilus unicornis* Rousselet, *Filinia maior* (Colditz), *Kellicottia longispina* (Kellicott), *Keratella cochlearis* Gosse, *Keratella hiemalis* Carlin, *Keratella quadrata* (Müller), *Polyarthra vudgaris* Carlin.

6. DISCUSSION

La composition en espèces des rotifères pélagiaux des lacs Sosnowickie était différenciée. Les formes fréquentes dans les lacs Bialskie et Czarne étaient avant tout des espèces caractéristiques pour les lacs profonds: *Asplanchna priodonta* Gosse, *Conochilus unicornis* Rousselet, *Gastropus stylifer* Imhof, *Kellicottia longispina* Kellicott et autres. Dans le lac Białe, par contre, dominaient des espèces caractéristiques pour les petits bassins aquatiques: *Branchionus angularis* Gosse, *Keratella quadrata* (Müller), *Keratella cochlearis* tecta (Gosse) et autres. Cette différence entre les deux types de lacs en ce qui concerne leur faune de rotifères peut bien s'expliquer par une certaine différence entre leurs propriétés limnologiques. Le lac Biała est peu profond et ressemble plutôt à un étang ce qui fait que les espèces eulimnétiques n'y trouent pas de conditions favorables à leur existence. Les deux autres lacs, par contre, possèdent une zone limmétique assez bien formée où peuvent vivre des formes caractéristiques pour les grands lacs.

La présence de l'euplancton dans le littoral et du tychoplancton dans le pélagial des lacs Sosnowickie s'explique par la faible étendue de ces lacs ce qui permet la migration des nombreuses espèces pélagiales vers le littoral et rend également possible le déplacement actif ou passif vers le pélagial de certaines formes du littoral.

Remerciements

Je m'empresse à l'occasion de ce travail d'exprimer ma profonde reconnaissance à M. le professeur G. Brzęk qui me suggéra ce travail et veilla à sa réalisation. Je tiens également à remercier M. le professeur L. K. Pawłowski d'avoir vérifié la détermination des espèces ainsi que pour ses valables remarques concernant la systématique et l'écologie des rotifères. Je remercie également M. le professeur K. Matusiak, M. I. Wojciechowski et M. K. Sasak pour l'aide qu'ils m'ont accordée durant le prélévement des échantillons, ainsi que M. le docteur Cz. Kowalczyk pour la détermination des Cladocera et Copepoda cités dans ce travail.

7. RÉSUMÉ

Ce travail représente le résultat d'études sur la faune de rotifères des 3 lacs Sosnowickie (Białe, Bialskie, Czarne). Le matériel, 254 prélévements provenant du pélagial et du littoral de ces lacs, fut collecté durant tout le cycle annuel entre octobre 1961 et décembre 1963. 137 formes appartenant à 120 espèces y furent déterminées. La présence de 15 de ces formes fut constatée pour la première fois en Pologne et de 130 formes pour la voïvodie de Lublin.

Les lacs Bialskie et Czarne possèdent une composition en rotifères différent nettement de celle du lac Białe. Des espèces caractéristiques pour les lacs profonds (*Asplanchna priodonta* Gosse, *Conochilus unicornis* Rousselet, *Gastropus stylifer* Imhof. *Kellicottia longispina* (Kellicott) et autres, dominaient dans les deux premiers cas tandis que le lac Białe abondait en espèces communes dans les petits bassins aquatiques (*Brachionus angularis* Gosse, *Brachionus diversicornis* (Daday), *Keratella quadrata* (Müller) et autres.

On nota une certaine dépendance saisonnale de la composition en espèces Rotatoria. 13 formes étaient présentes durant toute l'année, 62 durant la saison allant du printemps au début de l'automne, 21 appartenaient aux formes hivernales.

La faune des lacs étudiés était différenciée du point de vue écologique. Le pélagial contenait aussi bien des espèces typiques pour la zone limnétique des grands lacs que des espèces associées en général aux petits bassins aquatiques.

A ce groupe appartenait une population nombreuse de tychoplancton. En outre des espèces caractéristiques pour le littoral on constata dans cette zone un grand nombre d'autres espèces, ne s'y trouvant que d'une façon accidentelle.

8. STRESZCZENIE

Celem pracy było poznanie fauny wrotków 3 jezior Sosnowickich (Białego, Bialskiego i Czarnego). Materiały gromadzono w cyklu całorocznym w okresie od października 1961 do grudnia 1963 r. 254 próby, pochodzące ze strefy pelagicznej i litoralnej. Stwierdzono 137 form wrotków należących do 120 gatunków; spośród nich 15 form po raz pierwszy w faunie Polski, a 130 form w faunie woj. lubelskiego.

Jeziora Bialskie i Czarne mają skład jakościowy wrotków pelagicznych dość wyraźnie różny od jeziora Białego. W pierwszych dwu dominowały gatunki charakterystyczne dla jezior głębokich (*Asplanchna priodonta* Gosse, *Conochilus unicornis* Rousselet, *Gastropus stylifer* Imhof, *Kellicottia longispina* (Kellicott) i inne, zaś w jeziorze Białym pospolite były wrotki typowe dla drobnych zbiorników wodnych (*Brachionus angularis* Gosse, *Brachionus diversicornis* (Daday), *Keratella quadrata* (Müller) i inne.

Rejestrowano również zmiany sezonowe w składzie gatunkowym Rotatoria. Do całorocznych zaliczono 13 form, do wiosenno-letnich i wczesno-jesiennych 62 formy, do zimowych zaś i wczesno-wiosennych 21 form.

Fauna wrotków badanych jezior wykazuje duże zróżnicowanie ekologiczne. W pelagialu notowano zarówno gatunki typowe dla strefy limnetycznej wielkich jezior, jak też gatunki właściwe dla drobnych zbiorników i stawów. Dość liczną grupę stanowiły w tym zespole wrotki tychoplanktonowe. W litoralu obok form typowych dla strefy przybrzeżnej stwierdzono bardzo liczny zespół gatunków przypadkowo występujących w tej strefie.

9. BIBLIOGRAPHIE

Beauchamp. P. de, 1909. Recherches sur les Rotifères: les formations tégumentaires et l'appareil digéstif. *Archs Zool. exp. gen.*, 4, 1—140.

Brzęk, G. 1964. *Charakterystyka limnologiczna jezior Libiszowskich* [*Limnological characteristics of Libiszowskie lakes*], (type-script) /En polonaise/.

Cabejszek, J., Malanowski, Z., Włodek, S. 1956. Plankton rzeki Bugu (Plankton of the Bug river). *Pol. Arch. Hydrobiol.*, 3, 189—202 /Rés. angl./.

Fijałkowski, D. 1960. Szata roślinna jezior Łęczyńsko-Włodawskich i przyległych do nich torfowisk (Plant associations of lakes situated between Łęczna and Włodawa and of peat-bogs adjacent to these lakes). *Ann. UMCS, sect.* B, 14, 131—206 /Rés. angl./.

Galliford, A. L. 1946. A contribution to the Rotifer fauna of the Liverpool ares. *Proc. Lpool Nat. Fld Club*, 1945, 10—16.

Kulmatycki, W., Gabański, J. 1931. O zanieczyszczeniu rzeczki Jankowej przez ścieki cukrowni [On pollution of Jankowa rivulet by sugar plant sewage]. *Inż. rolna*, 3, 119—137 /En polonaise/.

Lewandowska, B. 1963. Przyczynek do poznania zmienności składu zooplanktonu stawów rybnych RZD WSR Czesławice w cyklu rocznym (On the instability recognition of the zooplankton composition of the fish ponds RZD Czesławice in a year's cycle). *Rocz-i Nauk roln. Ser. B.* 82, 678—690 /Rés. angl./.

Lityński, A. 1918. Jeziora Firlejowskie. Zarys limnologiczno-biologiczny (Recherches limnobiologiques sur les lacs de Firlej). *Pam. fizjogr.*, 25, 1—20 /Rés. allem./.

Lityński, A. 1919. Sprawozdanie tymczasowe z badań na Pojezierzu Łęczyńsko-Włodawskim, dokonanych w lipcu i sierpniu 1919 r. [Preliminary report on investigations carried out in July and August 1919 in Łęczyńsko-Włodawski lake district]. *Przegl. ryb.*, 1,173—181 /En polonaise/.

Pawłowski, L. K. 1958. Wrotki (Rotatoria) rzeki Grabi. Cz. I. — faunistyczna (Les Rotifères de la rivière Grabia. I — Partie faunistique). *Pr. Łódź. Tow. Nauk.*, *Sect. III*, No. 50, 1—439 /Rés. franc./.

RADWAN, S. 1966. Nowe dla Polski gatunki wrotków (Rotatoria) ich występowanie i ekologia (Espèces des Rotifères-Rotatoria-nouvelles pour la faune de la Pologne, leur distribution et écologie). *Ann. UMCS, sect. C*, 21, 121—130 /Rés. franc./.

RADWAN, S. 1968. Espèces rares et intéressantes de rotifères des lacs Sosnowickie. *Pol. Arch. Hydrobiol.*, 15, 237—249.

RYLOV, V. M. 1935. Das Zooplankton der Binnengewässer. *Die Binnengewässer*, 15, 36—96.

WILGAT, T. 1954. Jeziora Łęczyńsko-Włodawskie (Lakes between Łęczna and Włodawa). *Ann. UMCS, sect. B*, 8, 37—121 /Rés. angl./.

WISZNIEWSKI, J. 1934. Recherches écologiques sur la psammon et spécialement sur les rotifères psammiques. *Arch. Hydrobiol. Ryb.*, 8, 149—272.

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DISTRIBUTION AND AGE STRUCTURE IN POPULATION OF *PELOPIA KRAATZI* KIEFF. (TENDIPEDIDAE, PELOPIINAE) IN LAKE WILKUS*

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ABSTRACT

Studies were made of seasonal changes in distribution of *Pelopia kraatzi* Kieff. in sublittoral and so-called mid-lake zone as well as in different parts of the lake. The age structure of the population, as based on the length data, was also analyzed. It was found that in spite of some differentiation in distribution of the larvae, the population showed features similar in the two zones of the lake with a peak of abundance occurring in early June. The population consisted of several, overlapping generations.

CONTENTS

1. Introduction
2. Terrain description and methods
3. Results
   A. Seasonal and spatial changes in occurrence
   B. Age structure
4. Discussion
5. Summary
6. Streszczenie
7. References

1. INTRODUCTION

Species belonging to sub-family of Pelopiinae occur in various aquatic environments, both of stagnant and running water (Wesenberg-Lund 1943, Černovskij 1949, Thienemann 1954, and others). Tarwid and others (1953) have reported that Pelopiinae of lake Tajty occurred at the border of littoral and sublittoral as well as in deep sublittoral and upper profundal. The larvae were abundant in a shallow part of the lake, but rarely found in deep profundal. Borutzky (1939) has reported on the Tanypi larvae occurring in all zones of lake Beloie, USSR.

Considering these data, it seems interesting to trace the occurrence of *Pelopia kraatzi* Kieff. in an eutrophic lake and to show whether there are some differences in distribution of this species between sublittoral and "profundal" in spite of a close morphometric similarity of these two zones. Besides, a possible differentiation in occurrence of the larvae in connection with the flow factor in the lake will be described. In addition, a trial will be made to depict the age structure of this species basing on the body length measurements. This will supply the information about the number of generations and will permit to infer about the time and intensity of flights.

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* The paper has been prepared in the Institute of Ecology.

2. TERRAIN DESCRIPTION AND METHODS

The studies were carried out on lake Wilkus, Olsztyn voievodship, Węgorzewo district (54°10' of N longitude, 21°43' of E latitude). The lake is situated in the basin of river Węgorapa, being the second in the sequence of lakes connected with river Sapina. Its morphometric data are the following: surface — 94.4 ha, max. depth of 7 m, max length of 3 km, max. width of 0.9 km. The lake is elongated in the NS direction and has a lacustrine bay in its south part. The basin of the lake is not of a typical shape, the profundal zone is lacking. In its place there is a shallow, muddy bottom void of vascular plant vegetation. This zone will be called further the mid-lake. The sublittoral has no typical slope, but the layer of dead mollusc shells is well developed.

The flow of water throught the lake is a factor which has an important role in determining the physical and chemical properties of the lake water. Especially in spring these properties are dependent to a greater extent on those in lake Gołdapiwo, which supplies water to lake Wilkus through a sluice. The concentrations of certain nutrients in water from the surface samples collected on August 24, 1956 at different points of lake Wilkus varied slightly; CaO: 58.0—59.0 mg/l, Na_2O: 6.6—6.9 mg/l, K_2O: 3.2—3.6 mg/l, Fe: 0.0 mg/l, P_2O_5: 0.0 mg/l, NH_3: 0.10—0.16 mg/l, NO_3: 0.0 mg/l, Cl: 4.9—5.4 mg/l [1].

The water is rich in oxygen. Even during the summer stagnation there was no oxygen shortage and thermal stratification, except for a small deeper part of the lake [1].

Littoral is typical of small lakes. The shore line is, in general, well developed. Emerged vegetation, growing compactly along the shore, consists mainly of *Phragmites communis* Trin. *Typha angustifolia* L. and *Scripus* spp. are clearly less abundant. Submerged vegetation with floating leaves is represented by *Nuphar luteum* Smith, which grows abundantly in the bay.

Sublittoral, with a smooth slope in the most of sampling sites, covers a bottom surface of 2—3 m of depth. The bottom sediments contain plenty of dead mollucs shells, mainly of *Dreissensia polymorpha* Paal. In the part close to littoral, submerged vegetation occurs abundantly, but in patches, and is represented by *Ceratophyllum* spp, *Myriophyllum* spp., *Ranunculus circinatus* Sibthrop, and *Potamogeton* spp.

Mid-lake shows no higher differentiation both in depth and in the character of bottom sediments. The majority of its surface is flat, about 3 m of depth with a hollow in the southern part, down to 7 m. The superficial layer of the bottom consists of the colloidal mud which has similar colour and consistency in all parts of the lake.

Four parts were distinguished in the lake, basing on morphometric differences, on differences in the wind effect, water flow, and vegetation divergence. The rightness of such partition finds corroboration in different transparency of water in the distinguisched parts of the lake (Tarwid 1967).

Bay is situated aside of the main water current, highly eutrophic and characterized by a weak wind action and atypical for the lake vegetation (*Nuphar luteum* Smith). The individuality of such environments has been reported in the literature (Szczepańska 1967).

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[1] After unpublished data of the Inst. of Inland Fisheries, Olsztyn.

Part I, southern, open to wind, inlet of river Sapina; includes the deepest part of the lake and borders with the bay on the west.

Part II, middle, narrower than the latter, protected from wind. Two streams discharge on its east shore.

Part III, northern, elongated in north-west direction, with strong winds along its longer axis, connected with the farther lake Przyleśne.

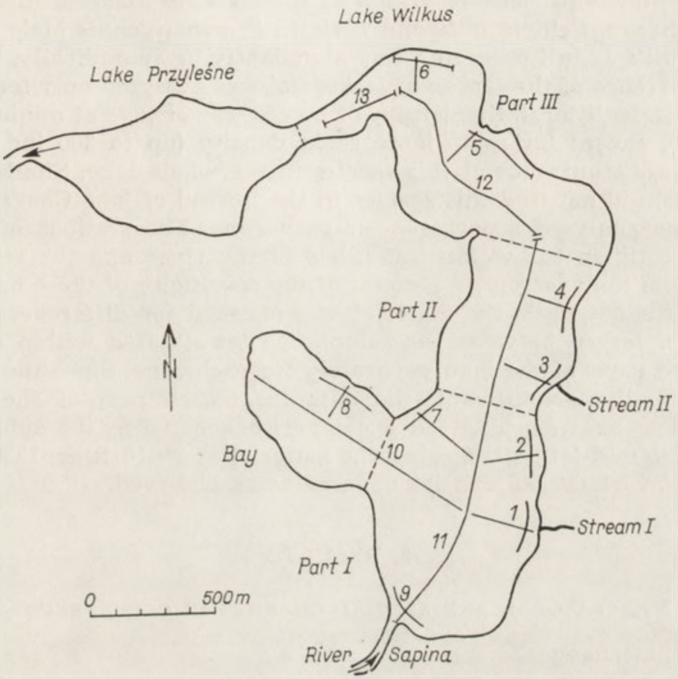

Fig. 1. The map of lake Wilkus
1—13 — sampling sites

The samples were collected with a tube bottom sampler with sampling surface of 10 cm². The apparatus was lowered 15—20 cm down in the mud, or a little less, when the substrate was hard. In general, 2,094 samples were taken in 8 series, each consisting of about 260 samples. The series were taken at about 20-day intervals with one collection lasting for 2—3 days. There were 13 sites of sampling chosen. The samples were arranged in a line (for directions of the lines see Fig. 1). Such pattern of sampling allowed to explore almost the whole lake with a relatively small number of samples, and to eliminate, in a greater extent, the mosaic character of the environment.

Three types of profiles were taken.

1. Centripetal profiles (through littoral, sublittoral, and mid-lake), perpendicular to the shore, including 3, 4, and 6 samples in each zone, respectively (13 in total). The line ended in the middle of the lake (at the longest axis of the lake).

2. Parallel profiles, (through the sublittoral), parallel to the shore (12—13 samples). The crossing of centripetal and parallel lines formed one site. There were 9 such sites chosen besides 5 mid-lake profiles.

3. Mid-lake profiles, arranged in 4 sections of one line going through the middle of the lake, along its longer axis, and one section through the bay.

The samples were washed on a wire sieve, the material was preserved and sorted later in the laboratory. The tendipedid larvae were identified acc. to the keys of Černovskij (1949) and Goetghebuer (1936). Besides *Pelopia kraatzi* Kieff., the following species or groups of species were found of the Pelopiinae; *Procladius* Skuze, *Pelopia villipennis* Kieff., *P, punctipennis* Meig., and *Ablabesmya monilis* L., all occurring less abundantly or sporadically.

The occurrence of the larvae of *P. kraatzi* was analyzed only for sublittoral and mid-lake. In littoral, the density of larvae was always at minimum (below 100 ind./m²), except for some increase in density (up to 300 ind./m²) in the period of mass occurrence of this species in the whole lake. Similarly, Romaniszyn (1953) did not find this species in the littoral of lake Charzykowo. The material was analyzed separately for each zone. The sections of sublittoral situated directly in the vicinity of inlets of the river and the streams were excluded from the analysis on account of the specificity of these habitats.

Using t-student tests, the material was checked for differences in density of *P. kraatzi* larvae between the sampling sites situated within each of the distinguished parts of the lake, separately for each zone. Since the differences were statistically insignificant, the data from each part of the lake were combined. The analysis involved 6 comparisons between the sublittoral and 6 between the mid-lake sites, using the material of 8—10 June, 1956, when the maximum of variation in density of larvae was observed.

3. RESULTS

A. SEASONAL AND SPATIAL CHANGES IN OCCURRENCE

a. Seasonal changes

The occurrence of the larvae in different parts of the lake is shown in Fig. 2A for sublittoral and in Fig. 2B for mid-lake.

In sublittoral, on May 17, the density of larvae was similar for all the parts of the lake and ranged from 50 to 100 ind./m². Within a short period, the numbers of the larvae were found to increase several times, reaching a maximum of 800—1,100 ind./m² in the bay and in parts I and III, on June 10. In part II the maximum was somewhat lower, 550 ind./m², and lasted to the end of June. After the period of maximum occurrence, a rapid decrease in numbers followed so that in the end of June rather uniform and low density was observed throughout the lake, 300—500 ind./m². Further changes in density of the larvae differed somewhat in the lake parts. In the bay, the numbers of larvae were continuously decreasing, resulting in a low density of less than 100 ind./m² in the second half of August and the first half of September. In the remaining parts, however, another not conspicuous increase in density was observed in July (part III) and in the first half of August (parts I and II). From that time on, the *P. kraatzi* larvae occurred in minimal numbers with an inconsiderable increasing tendency in the end of September, observed in the bay and part II.

In general, it can be said that the distribution of *P. kraatzi* larvae in the sublittoral of different parts of the lake was relatively uniform, showing a spring maximum in early June, typical for the entire sublittoral and a considerably lower peak of abundance either in July or in the first half of August, depending on the part of the lake.

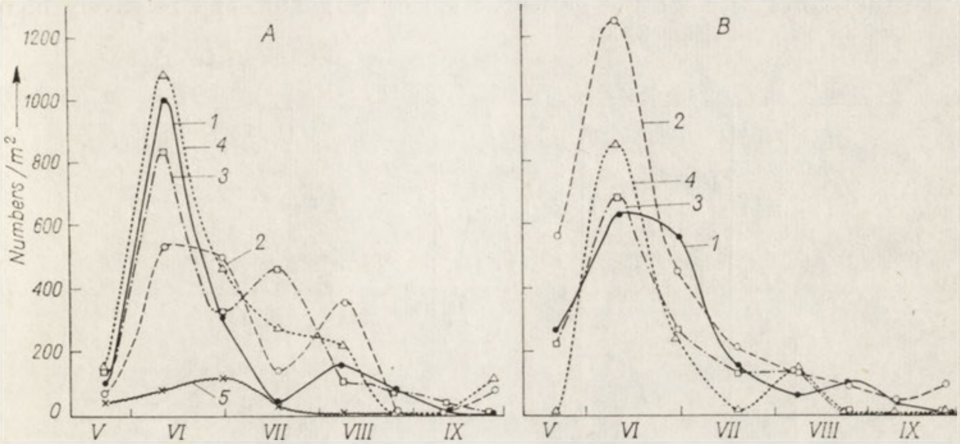

Fig. 2. Seasonal changes in numbers of larvae of *P. kraatzi*
A — sublittoral, B — mid-lake, 1 — Part I, 2 — Part II, 3 — Part III, 4 — Bay, 5 — at inlets

In mid-lake, the changes in density of *P. kraatzi* followed the similar pattern as that in the sublittoral. The maximum of occurrence was observed in the beginning of June (8—10.VI), it lasted shortly and disappeared as early as in the end of June, except for part II, where the maximum was postponed to the end of June. A relatively high density (reaching 1,300 ind./m²) was observed in part II of the lake in the period of 17—19 of July. The second increase in numbers was not observed. In general, the density of the larvae in the mid-lake showed higher differentiation between the lake parts than that in sublittoral, but the trend of changes was similar for the whole zone.

b. Spatial changes

Bay. The density of larvae was always higher in the sublittoral than in the mid-lake (Fig. 3). Such situation could be connected with unfavourable oxygen conditions in the middle part of the bay, situated beyond the flow. The sublittoral of this part showed somewhat higher density of larvae as compared with that in the sublittoral of other parts.

Part I. During the spring maximum, the density of larvae in the sublittoral was higher than in the mid-lake, where the peak of abundance was prolonged. The mid-lake zone of this part showed lower numbers of larvae than the other parts and was characterized by a longer maximum in June (Figs 2, 3).

Part II. At the beginning of sampling (may and first half of June), clear preponderence of the larvae was observed in the mid-lake zone, later on the numbers of larvae in both zones became uniform due to decreasing tendency in the mid-lake and a prolonged maximum in the sublittoral which lasted to the end of June. In the first half of August, the larvae of *P. kraatzi* were more abundant in sublittoral on account of their second peak of occurrence found in this zone with a simultaneous decrease following further in the mid-lake. The latter zone differed from the mid-lake of the other parts of the lake in almost twice as high density of the larvae in May, June and July. The sublittoral revealed the prolonged spring maximum and relatively high density in August (Figs 2, 3).

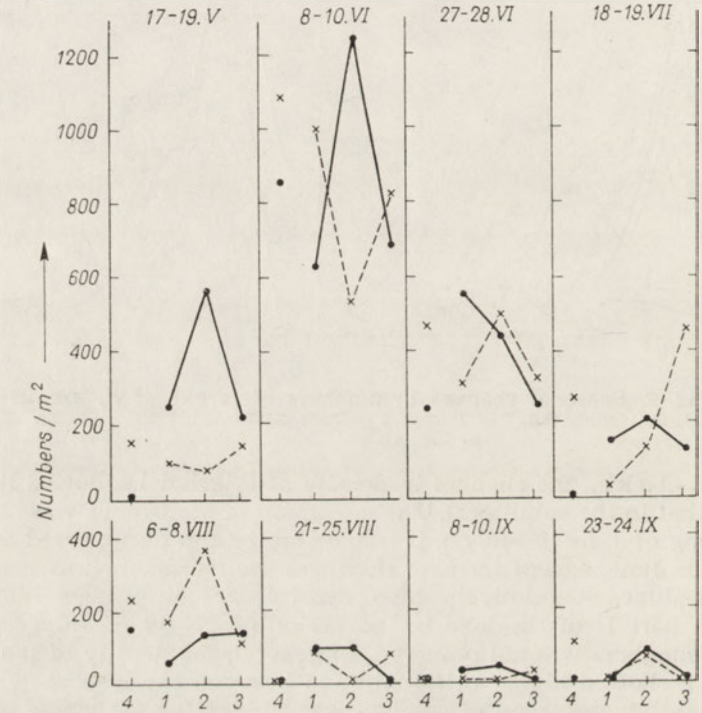

Fig. 3. The distribution of larvae of *P. kraatzi* in the two zones of lake parts. 1—4 — as in Fig. 2. Broken lines — sublittoral, solid lines — mid-lake

Part III. During the period of maximum abundance in June the larvae were more abundant in sublittoral than in mid-lake; later on the numbers in mid-lake were diminishing, whereas in the sublittoral another peak of abundance was observed in early July. Thus the sublittoral of this part differed from the other parts of the lake in a relatively early and rather high second peak of occurrence, whereas the changes in the mid-lake were similar to those in the other parts of the lake (Figs 2, 3).

c. Flow *versus* occurrence of larvae

From the review of seasonal and spatial changes in the distribution of larvae of *P. kraatzi* in the lake it is difficult to find any dependence between the flow of water and the distribution of the larvae. The comparison of larval density in parts I, II, and III, through which the water flows (Fig. 1). did not show any regular change in density which could be attributed to the flow effect. During the maximum abundance, the mid-lake zone of the central part seemed to be favoured by the Pelopia larvae. It would also seem that somewhat later (the second half of June), a certain decreasing tendency in density, parallel to the direction of flow, had been established, however, this picture disappeared soon after, and the new distribution resembled that of the spring. The regularly higher densities were observed in the mid-lake zone of part II as compared to those in part III, but a high similarity in the occurrence of larvae between mid-lake zones of part I and II does not permit to draw any definite conclusion about the effect of flow on the distribution of the larvae.

B. AGE STRUCTURE

From the distribution of the larvae, it can be said that although the numbers of larvae showed certain differentiation of occurrence in various parts of the lake, the general trend of numerical changes seems to be common in each zone of the lake. This is inferred from the convergent spring maximum in the lake and a rather regular diminishing numbers of the population during the season. From this, one can suppose that the life cycle of the larvae should have a similar course in all the parts of the lake. This is why the analysis of age structure was carried out for the whole lake, with distinguishing, however, the two zones.

The analysis was based on the length data on account of lacking information on the number of molts and the size of molting larvae in *P. kraatzi*. The larvae which were found in lake Wilkus had the maximum length of 10—11 mm, sporadically 13 mm. During the whole period of sampling, a relatively low numbers of the smallest individuals, 2—3 mm in length, were observed (Fig. 4). This fact can be explained either by a faster growth of the youngest larval stage so that at the applied frequency of sampling the probability of capture

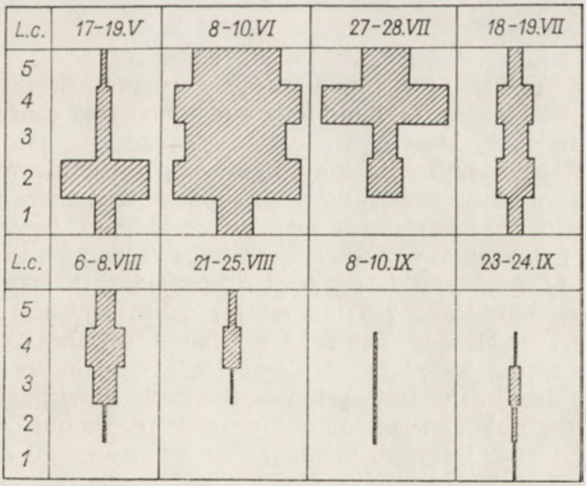

Fig. 4. The age structure of population of *P. kraatzi* in lake Wilkus
L.c. — Length classes. 1 — 2—3 mm, 2 — 4—5 mm, 3 — 6—7 mm, 4 — 8—9 mm, 5 — 10 and more mm. 0,25 cm^2 = 50 ind./m^2

was rather low, or by the loss of these larvae while washing or sorting the material. This latter reason is supported by the literature data concerned with the methods of sampling and collecting the larvae of Chironomidae (Kajak 1954). Thus the obtained picture of the abundance of the smallest larvae did not carrespond with the real one and this age class was excluded from the analysis.

The following groups of larvae were distinguished; young — to 6 mm in length and old — above 6 mm in length. Such dividion resulted in a natural way from a regular drop in abundance of larvae 6 mm long, caused apparently by the molting and a leap in length of these individuals.

The material gathered allows to describe only a part of the life cycle of *P. kraatzi*, i.e., the development of larvae from 3 mm of length to 10—11 mm, that is, to the pupal stage. The changes in age composition of population were inferred from the shifts of peaks on the length co-ordinate with the elapse of time in Figures 5A—H. The possibility of precise comparison between the incidence of the two age classes was obtained by planimetering (integrating) the areas under the curves. Obtained values in squere centimeters were then converted to numbers of a given age class, as presented in Table I.

Table I. The incidence of larvae of *P. kraatzi* in lake Wilkus in 1956

Date	Sublittoral		Mid-lake	
	young (<6 mm)	old (>6 mm)	young (<6 mm)	old (>6 mm)
17—19 V	72	0	217	62
8—10 VI	245	243	289	526
27—28 VI	69	316	46	332
18—19 VII	60	110	68	85
6—8 VIII	7	110	15	95
21—25 VIII	0	36	0	53
8—10 IX	0	0	0	13
23—24 IX	31	10	9	10

In the middle of May, the young larvae were prepodering over the older ones in the mid-lake zone (217 ind./m^2) and much less conspicuously in the sublittoral (72 ind./m^2). Most of these larvae were 4—5 mm long (Fig. 5A). The absence of older larvae in that time (some insignificant numbers were observed in the mid-lake zone) allows to suppose that there must have been an earlier flight of adults from the lake before May, 17. This flight coincided probably with favourable wheather conditions (sunny, warm and windless days), thus the progeny of this generation appearing in lake in June (8—10. VI.) was numerous (245 and 289 ind./m^2 for sublittoral and mid-lake zones, respectively — Fig. 5B and Table I.) It should be also expected that the flight of these adults lasted for 2—3 weeks, giving in its first period the May generation and in the last period — the early June generation. In early June, some of the older larvae, those 10 mm long, should correspond to the group of young larvae recorded in May. The density of all older larvae was then very high (Fig. 5B and Table I). Thus the spring maximum of numbers consisted of large numbers of young individuals and equally large numbers of older larvae. The flight of the latter occurred probably before the following sampling, i.e, between 8 and 28 of June. These adults gave rise to the next young generation, observed in the end of June (Fig. 5C).

The young generation from the first half of June gave the peak of older larvae in the end of June (Table I, Fig. 5C). The flight of this generation have occurred probably in the first half of July, and, considering the high densities of older larvae, it should have been similarly abundant as that in June.

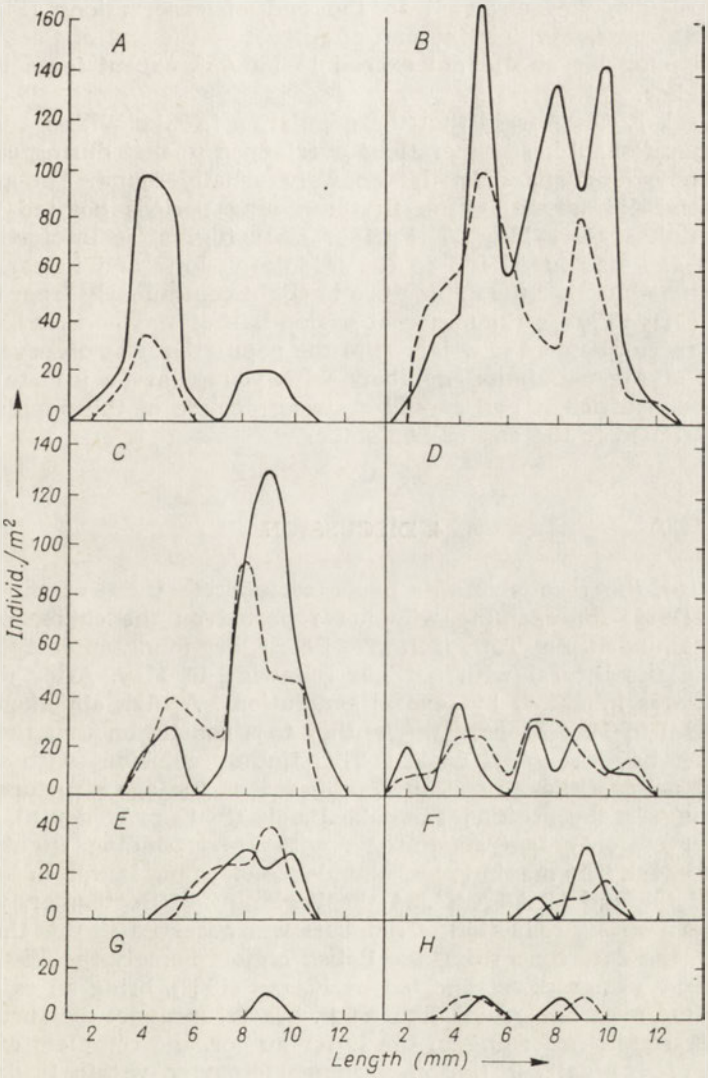

Fig. 5. The length distribution in larvae of *P. kraatzi* in the two zones of lake Wilkus Sampling dates; A — 17—19 V, B — 8—10 VI, C — 27—28 VI, D — 18—19 VII, E — 6—8 VIII, F — 21—25 VIII, G — 8—10 IX, H — 23—24 IX 1956. Broken lines — sublittoral, solid lines — mid-lake

The young generation as sampled on 27—28 of June was not abundant (Fig. 5C, Tab. I). So the total density of larvae decreased, the population being represented mostly by the older larvae of previous generations. In consequence, the insufficient replenishment of the population with young larvae in the end of June caused the population decline. The values of density of young larvae on 17—18 July (Fig. 5D, Table I) did not indicate any restoration of the population. The population numbers stayed low even though the appearance of a few small larvae (up tot 3 mm of length) in both the zones in this time suggests that the population shawed some tendency of such restoring. The depression of population lasted to the end of observations (Fig. 5F—H). During three last samplings (the end of August — the end of September) the density of young larvae did not exceed 15 ind./m², except for sublittoral in late September.

In general, it can be said that the population in lake Wilkus consistent of several generations. These generations overlapped so that during each sampling both the young and older larvae were usually found. The proportions of young and old larvae in the first sampling periods pointed to a mass flight of adults before May 17. Further mass flights, as inferred from the subsequent age structures, fell in the middle of June and in early July. It is however possible that the adult were in flight continuously from the middle of June to early July. In the period of second half of May — first half of July, an intense recruitment of new larvae to the population was observed. Further restoration of the population numbers with young larvae in late June and in July was insufficient and caused a strong decline of the population. This decline continued to the end of September.

4. DISCUSSION

In general, the results of this paper corroborate those of the literature. Borutzky (1939) for example who has reported on the course of seasonal changes in abundance of Tanypi in lake Beloie, has found an early generation occurring in the littoral with a flight following in May. After this period, the littoral was inhabited by several generations. A high abundance of eggs in the littoral in May brought this author to a conclusion that the adults of Tanypi must have occurred earlier. This finding coincides with the one of the present paper although the latter is based on the age structure of larvae in late spring. In the profundal of lake Beloie (to 13 m of depth), Borutzky (1939) observed only two generations with corresponding flights in June and July-August. The maximum of abundance of young larvae in lake Biełoje occurred in the end of August and the beginning of September, whereas in lake Wilkus a strong reduction of numbers was observed in this time. On the other hand, the data concerning the Polish region, namely the Vistula lateral branch near Wyszogród, as reported by Kajak (1960), bring an evidence that except for the most numerous flight of *P. kraatzi* in June, the further flights were rather small. According to the latter author, the complete exchange of population of *P. kraatzi* in that environment occurred within 16 days.

It is possible to attribute the differences found in seasonal occurrence of this species by various authors to different conditions in the environments examined.

5. SUMMARY

The occurrence of *P. kraatzi* in the bottom layer of lake Wilkus has been analyzed for the sublittoral and so-called mid-lake zone, as based on the material of 2,094 samples collected in the period of May 17 — September 24, 1956.

1. The maximum of occurrence was recorded in the first half of June, reaching densities of 600 — 1,200 ind./m^2. The maximum was rather short, followed by a sharp decrease in larval density observed from the middle of June. A further decrease in numbers followed in July, August, and September to the values untraced with the applied method of sampling.

2. The differences in occurrence of the larvae in parts of the lake (Fig. 1) point to a certain individuality of these environments, however, the common and similar trend of changes in density allows to infer about the homogeneity of the population.

3. No dependence was found between the flow through the lake and the density of larvae in the lake parts exposed to flow. In the spots of sublittoral open directly to the current (inlets of the river and streams), *P. kraatzi* occurred scarsely (below 100 ind./m^2).

4. The population examined consisted of several, overlapping generations. Mass flights of adults occurred probably in the first half of May, in the middle of June, and in early July. In late spring (second half of May, first of June), the population was intensely restored by young larvae. Both the adult flights and meagre supply of young larvae in the end of June and July brought about a further permanent decline of the population.

5. A similar trend of changes in density of larvae and similar age structures in both the zones are the evidence of a common type of occurrence of population of *P. kraatzi* in lake Wilkus.

6. STRESZCZENIE

W oparciu o materiał z 2094 prób zebranych w okresie od 17.V.—24.IX.1956 r. zanalizowano występowanie *P. kraatzi* w warstwie dennej jeziora Wilkus, wyróżniając w niej strefy sublitoralu i śródjezierza.

1. Maksymalne występowanie gatunku miało miejsce w pierwszej połowie czerwca, osiągając zagęszczenia 600—1200 osob./m^2. Maksimum trwało raczej krótko, po czym od połowy czerwca nastąpił ostry spadek liczebności larw, trwający w lipcu sierpniu i wrześniu, do ilości niewykrywanych stosowaną metodą połowu.

2. Różne występowanie w 4 wyróżnionych częściach jeziora (Fig. 1) wskazuje na pewną odrębność środowiskową tych części, jednakże wspólny kierunek zmian zagęszczeń larw pozwala sądzić o jednorodności całej badanej populacji.

3. Nie stwierdzono zależności między przepływem wody przez jezioro a zagęszczeniem larw w częściach jeziora wystawionych na działanie przepływu. W odcinkach sublitoralu narażonych na bezpośrednie działanie prądu wody (ujścia rzeki i strumieni) *P. kraatzi* występowała w minimalnych ilościach (poniżej 100 osób./m^2).

4. Opisywana populacja składała się z kilku kolejnych pokoleń, które zachodziły na siebie w czasie. Masowe wyloty imago występowały przypuszczalnie w maju, w połowie czerwca i na początku lipca. Zarówno wylot imago jak i niedostateczne uzupełnienie populacji larwami młodymi w końcu czerwca i w lipcu spowodowały trwałe załamanie się populacji.

5. Podobny przebieg zmian zagęszczeń oraz zbliżona struktura wiekowa w obu strefach jeziora wskazują na wspólny typ występowania populacji *P. kraatzi* w całym jeziorze Wilkus.

7. REFERENCES

[Borutzky, E. V.] Боруцкий, Е. В. 1939. Динамика общей биомассы бентоса профундали белого озера [Dynamics of the total benthic biomass in the profundal of lake Beloie]. *Trudy Limnol. St. Kosino*, 22, 196—218 (Engl. summ.).

[Černovskij, A. A.] Черновский, А. А. 1949. Определитель личинок комаров семейства Tendipedidae [Key of larvae of mosquitoes of family of Tendipedidae]. *Opredeliteli po faune SSSR*, 31, pp. 185, Leningrad.

Goetghebuer, M. 1936. Tendipedidae (Chironomidae) subfamilie Pelopiinae (Tanypodinae). In Lindner E. (edit.) *Die Fliegen der palearktischen Region*, 13b Lieff. 97, Stuttgart.

Kajak, Z. 1954. Uwagi w sprawie ilościowej aparatury i metodyki bentosowej (Remarks on the quantitative apparatuses and benthic methods). *Biul. Komitetu Ekol. PAN*, 1, 13—22 (Polish).

Kajak, Z. 1960. Dynamika liczebności Tendipedidae bentosowych na terenie mulistych odcinków łachy Konfederatka (Quantitative dynamics of benthic Tendipedidae in the muddy sections of the "Konfederatka" — old branch cut off from the Vistula) *Ekol. pol. ser. A*, 8, 229—260 (Engl. summ.).

Romaniszyn, W. 1953. Analiza ilościowa fauny ochotkowatych (Tendipedidae, Diptera) w strefie brzeżnej jeziora Charzykowo (Quantitative analysis of the Tendipedid fauna [Tendipedidae, Diptera] in the littoral zone of the lake Charzykowo). *Pol. Pismo entomol.*, 23, 1—52 (Engl. summ.).

Szczepańska, W. 1967. Limnological individuality of small lacustrine bays. *Pol. Arch. Hydrobiol.*, 14 (27), 39—52.

Tarwid, K., Dobrowolski, K., Fic, E., Hillbricht, A., Kajak, Z., Sosnowska, J., Szczepańska, W., Szczepański, A., Sztuke, I. 1953. Fauna pokarmowa ryb w jeziorze Tajty (The quantitative relation of fauna serving as feed for fish in lake Tajty). *Rocz-i Nauk roln. Ser. D*, 67, 85—153 /Engl. summ./.

Tarwid, K. 1967. Krótkotrwałe, periodyczne wahania przezroczystości wody w jeziorze (Short-lasting, periodical variation in transparency of water in a lake). *VII Zjazd Hydrobiol. Polskich w Świnoujściu*, 20—23.IX.1967, Streszczenia referatów, 125—126.

Thienemann, A. 1954. Chironomus, Leben, Verbreitung und wirtschaftliche Bedeutung der Chironomiden. *Die Binnengewässer*, 20, Stuttgart, pp. 834.

Wesenberg-Lund, C. 1943. *Biologie der Süsswasserinsekten*. Kopenhagen, Gyldendalske Boghander.

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THE DESICCATION OF EPHEMERAL POOLS AND THE RATE OF DEVELOPMENT OF *AEDES COMMUNIS* LARVAE

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ABSTRACT

The influence of water-medium dilution with distilated water desiccation and population overcrowding on the development rate of *Aedes communis* larvae was studied in the sylvatic ephemeral pools of the Kampinos Forest near Warsaw. The dilution of water-medium retards by about 8% the development rate of larvae. Both the drying up of the pool and the overcrowding of population accelerate this process, the former slightly the latter greatly.

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1. INTRODUCTION

It is generally known that the development of some species of ephemeral pool fauna is quickened during the drying up of a pool (Zernow 1949, Allee, Schmidt, 1951, Clarke, 1954) not only because of the typically favourable thermic conditions, but also because of the increase in nutritional organic and mineral substances occurring during desiccation (Žadin 1950, Paschalski 1958, Chodorowski 1961, Nourisson 1964). A quick reduction in the pool's water volume results in an increased density of organisms which in turn causes the accumulation of metabolites during the period prior to drying up Fischer (1960) established that this augmenta-

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tion of metabolites during desiccation inhibits the development of the *Daphnia magna* population. The investigation of other habitats indicates that overcrowding often has a negative influence on the growth rate of the organisms (Winsor, Winsor 1935, Foerster 1944), lowers their fertility (Pearl, Parker 1922) and stops the division of Protozoa (Woodruff 1911). Allee and others have shown 1950 that hypodensity of organisms is likewise harmful. It has been shown by Klekowski (1959) that a rise in density causes an increase in snails' resistance to desiccation. During the drying up — period some changes in the osmotic pressure of this medium occur (Klekowski 1961).

2. MATERIALS AND METHODS

The Aedes communis are the basic early-vernal component of sylvatic ephemeral pools. These larvae are mentioned by Menčadskij (1951) and Kramař (1955) as the typical organism in the fauna of the early-vernal sylvatic pools which are filled with water from thawing snow and are rich in fallen leaves. The *Aedes communis* and the *Aedes punctor* are dominant species in the vernal association of mature mosquitoes in the Kampinos Forest. They recede however when the next pair of dominants *A. excrucians* and *A. annulipes* (Tarwid 1952), appears. Some preliminary results of the investigation on the *Aedes communis* larvae development have been published (Chodorowki 1958).

The sylvatic pools of the Kampinos Forest are small water filled woodland depressions. The bottom of which are abounding in fallen leaves. Their annual duration does not exceed 2.5 months. They are very shaded and thus protected from over-warming in the spring (Chodorowski 1961)[1]. Similar reservoirs have been described in the papers of Brandt (1935, 1936) and Bick (1958).

Special methods have been required for a biocoenotical investigation of the small pools. The chief rule which has been observed was to experiment on small, isolated sections of the real biocoenosis and not on the artificially grown populations. Sections as large as possible of small pools biocoenosis, have been carried to the laboratory or were isolated in the station and were subjected to various experimental conditions. No such cultivating precesses as extra-feeding, changing of water, etc. have been employed. Similar methods were used when hay infusion was observed by Woodruff (1912).

In experiments of this kind difficulties arise connected with the great number of species coexisting in a given biocoenosis. To avoid these difficulties Gause (1934) in the hay infusion, formed a model biocoenosis of a very simple structure. In our case, we have chosen the sylvatic ephemeral pools as the subject of investigation because they posses a small number of existing species which species are significant determiners in the year succesion of a pool.

A. LABORATORY EXPERIMENTS

Samples from the pool have been taken. They consisted of 10—100 litres of water, together with the substratum. They were transported in 10 l glass-containers. In the laboratory the water and leaves were distributed with

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[1] For detailed description of these pools and climatic and hydrographic conditions in the Kampinos Forest see Chodorowska, Chodorowski, (1958).

a pint container in such a way as to ensure rather proportional distribution of the material.

The experiments included a study of the influence on the biocoenosis of such factors as a) water-medium dillution with distilled or tap water, b) artificial increase of density of organisms, and c) desiccation. In all cases parallel control experiments series were carried on. Comparison were made using the mean value obtained from the 4—12 aquaria in a serie.

a. Influence of water amount medium dilution

Distilled or tap water was added to the water samples from ephemeral water-bodies. Dilution with distilled water diminishes the mineral salts concentration, and it may cause greater acidity because carbon dioxide dissolves in distilled water. On the other hand, addition of tap water causes some changes in mineral salts composition. The aquaria in 2 series, 8 aquaria in each, were situated in the laboratory out of the reach of direct sun-rays. Air temperature was subject to small changes and it was in the range 15—18°C.

b. Influence of an artificial increase in density

The samples vere made 5 times more dense by means of a plankton net. Control series with normal organism density were prepared. The aquaria were main tained under the previously described conditions.

c. Influence of desiccation (Fig. 1)

The material was poured into shallow vessels developing dishes. They were placted on window sills. The windows were directed towards the south, thus ensuring greater evaporation. When the evaporation was too rapid and too intense especially in the final stage of the experiment, the dishes were covered with glass plates in order to decrease the water loss. In control series the evaporation was lessened by a partial covering with glass plates. This, however, caused the conditions to differ considerably from those in the experimental series bacause of some difficulties in air-flow, a greater air-humidity immediately above the water-surface, and a higher temperature when they were warmed by direct sun-rays. In order to lessen the negative effects caused by covering the vessels in the experimental as well as in the control series the developing dishes were placed in large aquaria. However, this caused

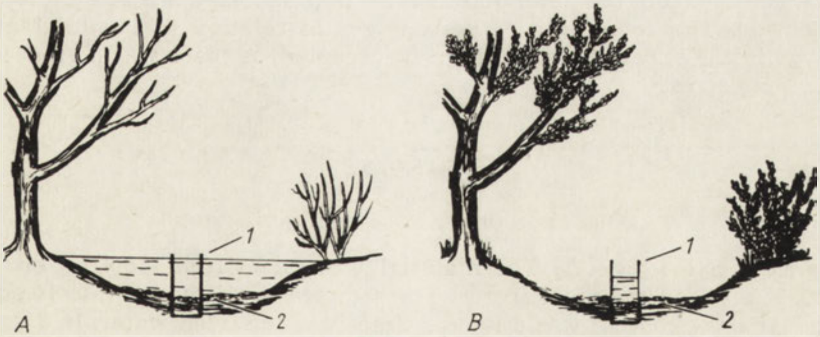

Fig. 1. Field experiments in the prolonged existence of isolated biocoenosis sections of a small water-body. A — beginning and B — end of an experiment; 1 — an aquarium placed in the pool; 2 — fallen leaves

the distinct decrease in desiccation of the experimental series. Thus relatively best method employed was to add frequently small amounts of distilled water and, at the same time, to stir the water in the second, experimental series, in order to avoid differences in oxygen-saturation and the formation of bacterial surface films.

Experiments on the influence of desiccation were subject to great thermal changes. The range of temperature on the window-sill reached 10.5°C. During the day, the air temperature reached its maximum, 26.5°C, under the direct sun-rays exposure. In uncovered vessels the water temperature reached 24.6°C, in the covered ones 28.7°C.

B. FIELD EXPERIMENTS

Some experiments were performed concerning the prolonged existence of sections of small pools biocoenosis have been carried on. The sections were isolated from the reservoir in aquaria put into the pools (Fig. 1). Early in spring (Figs 1, 6) deep glass vessels were placed on the bottom of the pool. The containers were filled with layers of plant debris and with water from the reservoirs. Water level lowered more slowly in the vessels because of reduced evaporation, and the lack of absorption by the substratum, thus water remained there for several months longer than it did in the pool itself (Figs 1, 7). Changes in the aquaria were observed and quantitative samples from them were taken.

Employing the preceding methods, were evaluated a) changes of maturation rate of *Aedes communis* larvae due to water medium dilution, b) desiccation, c) increase of density of organisms and d) prolonged existence of small pools biocoenosis. Some attempts were made to estimate the ability of the larvae and pupae to survive a completely waterless period. According to the accepted rules, mosquito larvae were not isolated from the biocoenoses sections. They were brought into the laboratory and they did not receive any additional food during the experiment. In some cases the predators were removed to prevent a decrease in the mosquito population. The acceleration or retardation of their pupation has been accepted as an indicator of the mosquito development-rate. The calculation of percentage of pupated mosquitoes was based on the total number of individuals undergoing the whole larval cycle. The computing of percentages in relation to the total number of larvae in the experiment could not be accepted, as there was a great mortality in some cases.

3. RESULTS

INFLUENCE OF WATER-MEDIUM DILUTION

Experiment no. 1. The material was taken from pool C_6 on March 3, 1955. The water body was frozen. The samples were divided into 10 aquaria. In 5 aquaria the content was diluted 2 times with distilled water. In 3 days the first *Aedes communis* larvae appeared; in 11 days the first pupae in the aquaria with undiluted water were observed (Table I). The diagram in Fig. 2 shows the changes of the pupae and imagines numbers in both the experimental series. The culmination of pupation was on the 12th day of the experiment in the aquaria with diluted water medium and on the 11th day in those with undiluted medium.

Table I. The influence of dilution of aquatic medium on the maturation rate of the *Aedes communis* larvae

Experiment no. 1

Aquatic medium	% of pupated mosquitoes in days			
	11	12	13	14
Undiluted	10	60	97	100
Double diluted	0	33	89	100

Experiment no. 2

Aquatic medium	% of pupated mosquitoes in days					
	9	10	11	12	13	14
Undiluted	33	44	56	100		
Triple diluted	0	12,5	25	50	87.5	100

Experiment no. 2. The material was collected on March 22, 1955 from pool C_6. It consisted of *Aedes communis* larvae and the water in which they lived. The material was placed into 16 aquaria. The experimental series, consisting of 8 aquaria, was diluted 3 times with distilled water. In 9 days the first pupae in the control series appeared and on the next day, those in the experimental series were hatched (Table I). The culmination of larval pupation took place one day later in the aquaria with diluted water than in those of the control series (Fig. 2)

It follows from the experiments described above the dilution of the medium with distilled water usually retards by about one day the development of *Aedes communis* larvae in comparison with the development rate in undiluted media, this amount to an 8% retardation if one considers the length of the larval development period under experimental conditions to be 12—13 days.

INFLUENCE OF DESICCATION

Experiment no. 3. The material was taken on 6th of April from pool M_{17} and it was distributed into 14 developing dishes. Experimental series were permitted to desiccate. In order to avoid desiccation in the control series, destilled water was added daily to compensate for the water lost by evaporation. Desiccation occured rather quickly; consequently after 15 days, the evaporation had to be diminished by a partial covering of the dish with a glass plate. In 6 days the pupation period began. It was of long duration lasting: up to 18 days in the control series (Fig. 3). Mortality was rather high in the drying series up to 80% and in the control, up to 60%. In the dishes a lot of faeces and metabolites accumulated and the lack of food was observed. In the drying dishes a distinct acceleration of the development was observed at the begining of the experiment up to the 12th day; later, the retardation of development followed, especially from the moment when only a small amount of water remained.

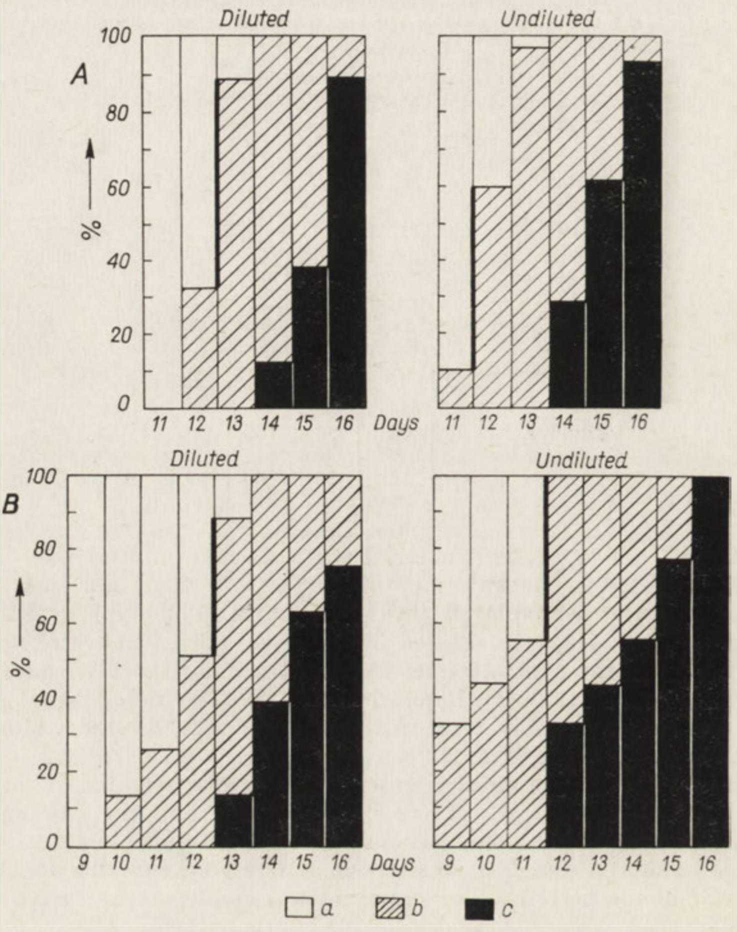

Fig. 2. Pupation and hatching of *Aedes communis*, depending on aquatic medium dilution. A — Experiment no. 1: duble dilution; B — Experiment no. 2: triple dilution. a — larvae, b — pupae, c — imagines; thick line marks the culmination point — larval pupation

Experiment no. 4. The material was collected on April 12, 1955 from pool M_{17} and it was placed in developing dishes, as in the previous experiment. The pupae appeared on the 5th day of the experiment in the non-drying medium. The whole pupation period was considerably extended, as in the previous experiment, and lasted up to 14 days (Table II, Fig. 4A, B). In desiccating dishes pupation-rate was greater, the pupation period lasting a total of 10 days. There was no distinct culmination which would enable us to determine the acceleration in relation to non-drying medium. Mortality

Table II. The influence of desiccation and density-increase of population on the maturation-rate of *Aedes communis* larvae
Experiments no. 4 and 6

Density of population	Aquatic medium	% of pupated mosquitoes in days							
		6	8	10	12	14	16	18	20
Normal 20—30 ind./l	drying	9	18	36	55	82	100		
	non-drying	8	41	41	41	42	58	75	100
5 × greater 100—150 ind./l	drying	32	56	64	72	80	92	100	
	non-drying	30	50	65	65	70	85	100	

in both series was great, and in egaled 81% in non-drying dishes and 82% in drying ones.

Experiment no. 5. February 19, 1957 the material was collected from pool C_6 and was distributed in 24 developing dishes 12 of them were drying dishes, and 12 non-drying ones. The pupae appeared in 15 days. On the 23rd day experiment had to be interrupted because the experimental dishes dried up. Initially there was a slightly greater percentage of pupated larve in the desiccating series (Table III); later, however the number of pupae in the non-drying dishes increased.

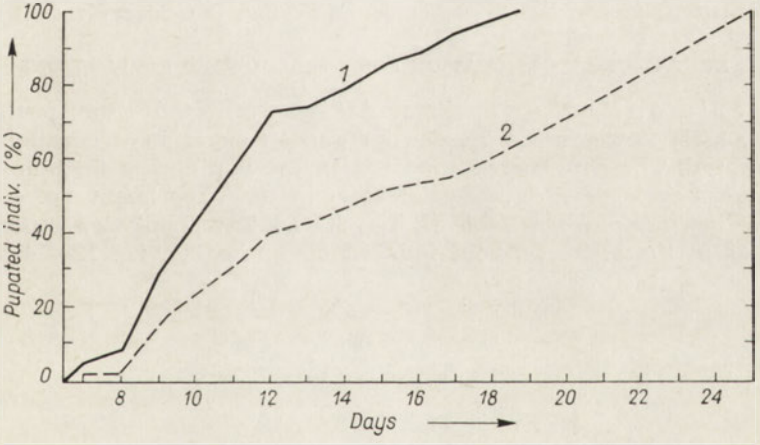

Fig. 3. Experiment no. 3. The influence of desiccation on pupation of *Aedes communis*. 1 — drying environment; 2 — non-drying environment

Comparing the results of the above experiments one might say that the influence of desiccation on the development-rate of *Aedes communis* larvae is less distinct than that of dilution (as mentioned before). The process of pupation lasts for a longer period of time than typical of field conditions. Mortality rate increases oscillating between 60% and 85% in particular experiments. Both these phenomena seem to be influenced by accumulation of metabolites and, in some cases, by the lack of food-stuffs. A slight acceleration of growth in the experimental series was observed when there was still a considerable amount of water in the dishes, but when water amount had diminished to such a degree as to hamper the larval movements, their development-rate decreased in comparison with non-drying developing dishes.

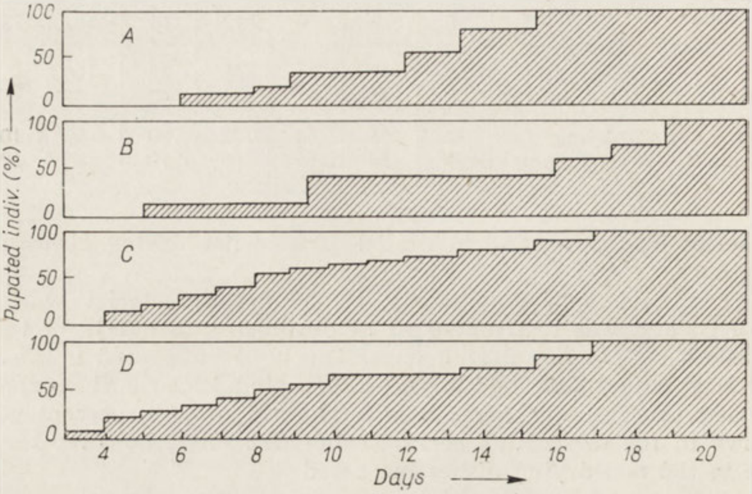

Fig. 4. Experiments nos 4 and 6. The influence of desiccation and density of organisms on pupation rate of *Aedes communis*: A — normal density-drying up; B — normal density, non-drying; C — over-dense, drying, D — over-dense, non-drying

INFLUENCE OF DESICCATION FOR OVERCROWDED POPULATIONS

Experiment no. 6. The material was collected from pool M_{17} on April 12, 1955. It was made 5X densier and an experiment parallel to no. 4 was prepared. The first pupae appeared in the non-drying medium in the 3 days; thus they were 2 days earlier than in the experiment no. 4 (without *overcrowding* induced -see Table II, Fig. 4C, D). The population process lasted as long as in the series without induced *overcrowding*, i.e. 12—14 days, the mortality was slightly greater: 80—84$^{0}/_{0}$. Pupation-rate was higher than in the experiments with normal density, especially et the beginning of the experiment. The influence of masquito population *overcrowding* on the development of mosquitoes is so strong that it eliminates the differences between the desiccating (Fig. 4C) and non-drying series (Fig. 4D).

Table III. The influence of desiccation on the maturation rate of *Aedes communis* larvae
Experiment no. 5

Aquatic medium	% of pupated mosquitoes in days		
	15	19	23
Drying	9	18	33
Non-drying	8	15	39

INFLUENCE OF DESICCATION-DECREASE UNDER FIELD CONDITIONS

Experiment no. 7 carried out in the Kampinos Forest. On April 12, 1955 the experiment was prepared in pool M_3 as described before (Figs 1, 6, 7). Both in the reservoir and in the aquaria the larvae of the 1-st development phase were recorded. From the middle of May the water body dried considerably. In the aquaria water quantity did not decrease, but, on the contrary, it increased slightly because of rain. The hatching of *Aedes communis* imagines began on May 10 and was finished on May 16 (Fig. 5). In certain experimental aquaria the pupation appeared, in general, later. In nearly all of them the pupae were recorded 4 days after hatching of the *Aedes communis* imagines in the pool.

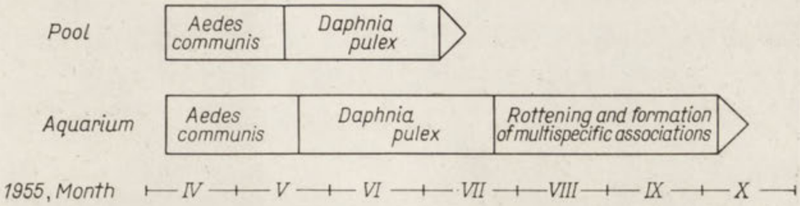

Fig. 5. A comparison of consecutive domination systems in the pool M_3 and in the aquaria, placed in it

Fig. 6. Pool M_3. Field experiments on prolongation of isolated biocoenosis section in aquaria placed in to the pool 18.V.1958

ABILITY OF LARVAE AND PUPAE TO SURVIVE WATERLESS PERIODS

During the experiment it was observed that pupae have a greater ability to survive a short waterless period than do the larvae. The ability to survive even a very short waterless period is of a considerable importance to *Aedes* *communis*. Since it enables them to either undergo the development cycle in the wet leaves which remain after drying up of a pool, or to wait in this environment for an innundation. KRAMÁŘ (1955) presented some examples of mosquito survival and partial maturation on the bottom of dried up pools.

Fig. 7. Pool M_3. Field experiments on prolongation of isolated biocoenosis sections in aquaria placed into the pool 19.VI.1958

Experiment no. 8. The material was collected from pool C_6 on April 2, 1959. It consisted of water and the *Aedes communis* larvae and some leaves from the pool bottom and it was placed into 14 developing dishes (6—9 *Aedes communis* larvae in a dish). Later, the dishes were completely dried up. 4 dishes immediately before their desiccation were placed into covered aquaria (relative humidity — about 90%). The remaining aquaria were kept in a place where the relative humidity was 60%. Afterwards the dishes with their dry contents were filled with distilled water. The water was poured into some dishes immediately after drying up, into others either 6, 12 or 18 hours after desiccation (Table IV). The percentages of larvae and pupae which survived were recorded. The percentages of "reviving" *Mochlonyx culiciformis* larvae were also recorded.

Table IV. Abilities of *Aedes communis* larvae and pupae and *Mochlonyx ciliciformis* larvae to survive waterless periods
Experiment no. 8

Inundated	Relative humidity 60%			Relative humidity 90%		
	Aedes communis		*Mochlonyx culiciformis*	*Aedes communis*		*Mochlonyx culiciformis*
	larvae	pupae	larvae	larvae	pupae	larvae
Immediately after desiccation	92%	100%	50%	100%	100%	100%
In 6 hours	45%	100%	25%	—	—	—
In 12 hours	12%	100%	0%	37%	100%	66%
In 18 hours	0%	—	—	25%	—	—

In a relative humidity of 60%, very different from that which is prevaling in shaded ephemeral pools when they are drying up, some of the larvae survived up to 12 hours under waterless conditions; however, most of them tailed to survive beyond a very short desiccation period (up to 1 hour). Under conditions more closely resembling the normal (relative humidity 90%), the number of surviving larvae was greater: in 18 hours about 25% of the larvae were still alive. The pupae had survived (100% survival) for 2—18 hours and their development afterwards was not disturbed. The *Mochlonyx culciformis* larvae could not survive desiccation as well as *Aedes communis.*

4. DISCUSSION

It is very difficult to discuss the above results for there is lack of complete knowledge of the physical and chemical properties of water during desiccation. The development of *Aedes communis* larvae takes place in sylvatic ephemeral pools of the Kampinos Forest in the period of their low electrolytic conductivity accompanied by their decreased total mineral solids quantity (TDS) and the lowest chemical oxygen demand (COD) of their water (Chodorowski 1961). The great increase of COD begins at the end of the mosquito domination phase because of accumulation of moultigins and under the influence of detri tus-eating larvae, which crumble the rotting remnants (detritus). Physical and chemical changes in the Kampinos Forest pools are complicated by the phenomenon of "periodic disappearance" of water bodies, caused mainly by soaking of water into the substratum and not only by evaporation itself.

Experimental results show that the aquatic medium dilution in the case of biocoenoses characterized by "normal" density, diminishes the development rate of *Aedes communis* larvae. The date referring to the influence of desiccation itself on the larval development-rate are not completely reliable because the drying processes took place under different conditions than those in the natural medium (too high temperature, desiccation rate rather accelerated, environment at humidity too low, etc). This abnormality is made evident by the rather great mortality of larvae and pupae, as well as by their prolonged pupation (much longer than in the natural pond). Slight and very variable acceleration of larval development-rate in the desiccating series occurs only up to the moment when the amount of water in vessels is sufficient to continue the vital functions of the larvae. In the final stage of desiccation, when the water amount is too small and the accumulation of metabolites is too great, the development-rate pupation rate decreases.

When the additional factor, mosquito population overcrowding, is introduced during desiccation, it accelerates maturation-rate (especially at the beginning of the experiment). The influence of overcrowding is so great that it overshadows the difference between drying and non-drying series. In the final stage of pupation processes a diminution of appearance of pupae is observed, caused by the lack of food-stuffs, and probably by accumulation of faeces and metabolites. These conditions may occur at the end of the experiment.

Field experiments in which the processes of water absorption by the substratum were stopped, and in which evaporation distinctly diminished, show that pupation under these conditions is slightly retarded in comparison with those of a normally disappearing water body. There may be also other causes of this phenomenon connected with the isolation of biocoenoses sections from the pool. One may suppose that under field conditions the ability of mosquito larvae and pupae to survive short waterless periods, and even to undergo metamorphosis in the environment of wet leaves, is of greater importance for species survival then an acceleration of development rate by desiccation.

Acknowledgements

I would like to express my gratitude to Docent R. Z. Klekowski for his critical evaluation of this paper and also to all other persons from the Department of Experimental Hydrobiology of Nencki Institute to whom I am indebted for their help.

5. SUMMARY

Dilution of aquatic medium of sylvatic ephemeral pools retards the development rate of *Aedes communis* larvae about 1 day (24 hours) i.e. about 8% of their larval development period (Tables I, Fig. 2).

Drying of a pool slightly accelerates the development of *Aedes communis* larvae. This relationship breaks down when the water level reaches the maximum amount required for larval development (Tables II, III, Figs 3, 4). Overcrowding of the population, during drying up, accelerates larval development eliminates the differences between development rate in a drying and in a non-drying environment (Table III, Fig. 4).

The larvae and pupae of *Aedes communis* have abilities to survive short waterless periods in the environment of wet leaves (Table IV).

6. STRESZCZENIE

Rozcieńczenie środowiska wodnego leśnych zbiorników efemerycznych powoduje zwolnienie tempa rozwoju larw *Aedes communis* przeciętnie około 1 doby, co stanowi ca 8% rozwoju larwalnego (Tab. I, Fig. 2).

Wysychanie zbiornika wpływa nieznacznie przyspieszająco na rozwój larw *Aedes communis* tylko do pewnego punktu krytycznego, którym jest minimalna ilość wody potrzebna do ich rozwoju (Tab. II, III, Fig. 3, 4). Dodatkowe zagęszczenie populacji przy wysychaniu wyraźnie przyśpiesza rozwój larw, zacierając równocześnie różnice między tempem rozwoju w środowisku wysychającym i niewysychającym (Tab. III, Fig. 4).

Larwy i poczwarki *Aedes communis* posiadają zdolność przetrwania krótkotrwałych okresów bezwodnych w środowisku wilgotnych liści (Tabl. IV).

7. REFERENCES

Allee, W. C., Emerson, A. E., Park, O., Park, T., Schmidt, K. P. 1950. *Principles of animal ecology*. Philadelphia, W. B. Saunders.

Allee, W. C., Schmidt, K. P. 1951 *Ecological animal geography*. New York, J. Wiley.

Bick, H. 1958. Ökologische Utersuchungen an Ciliaten fallaubreicher Kleingewässer. *Arch. Hydrobiol.*, 54, 506—542.

Brandt, A., von 1935. Hydrographische Untersuchungen am kleinen Waldgewässern unter besonderer Berücksichtigung der jahreszeitlichen Schwankungen. *Ber. westpr. bot.-zool. Ver.*, 57, 61—154.

Brandt, A., von 1936. Temperaturschwankungen in kleinen Waldgewässern. *Arch. Hydrobiol.*, 30, 132—141.

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. Wpływ wysychania zbiorników okresowych na tempo rozwoju larw komarów z rodzaju Aedes (Influence of the drying-up of temporarily formed pools on the rate of development of mosquito larvae of the Aedes genus). *Ekol. pol. ser. B*, 35—39 (Engl. summ.).

Chodorowski, A. 1961. Niektóre cechy termiczne drobnych zbiorników Puszczy Kampinoskiej w okresie wiosennym (Some chemical and thermal properties of the small pool in the Kampinos Forest in the spring-time). *Pol. Arch. Hydrobiol.*, 9, 287—317 (Engl. summ.).

Clarke, G. I. 1954. *Elements of ecology*. New York, J. Wiley.

Fischer, Z. 1960. The influence of some changes of environment on the development of *Daphnia magna* Straus and the larvae of the dragon-fly Lestes nympha Se. *Pol. Arch. Hydrobiol.*, 7, 125—142.

Foerster, R. E. 1944. The relation of lake population density to size of sockeye salmon, *Oncorynchus nerka*. *J. Fish. Bd. Canada*, 5, 315—336.

Gause, G. H. 1934. О процессах уничтожения одного вида другим в популяциях инфузории (Destruction of one species by another in populations of Protozoa). *Zool. Ž., Mosk.* 13, 18—26 (Engl. summ.).

Klekowski, R. Z. 1959. Przeżywalność wysychających ślimaków *Planorbis planorbis* L. w zależności od niektórych warunków środowiska (Survival of desiccating molluscs *Planorbis planorbis* L. in dependence on some environmental conditions). *Pol. Arch. Hydrobiol.*, 5, (2) 71—89 (Engl. summ.).

Klekowski, R. Z. 1961. Survival of *Planorbis planorbis* (L.) and other snails in diluted sea-water and during the following desiccation. *Pol. Arch. Hydrobiol.*, 9, 383—406.

Kramář, J. 1955. Komáři rodu Aedes v ČSR. *Rozpr. českoslov. Akad. Ved., Řada MPV*, 65, (9), 1—67.

[Mončadskij, A. S.] Мончадский, А. С. 1951. Личинки кровососущих комаров СССР и сопредельных стран. (Подсем. Culicinae) [Larvae of blood-sucking mosquitoes of USSR and adjected countries]. *Opredeliteli po faune SSSR*, 37, pp. 290 (Russian).

Nourisson, M. 1964. Recherches écologiques et biologiques sur le Crustacé *Chirocephalus diphanus* Prév.; étude expérimentale du determinisme du développement de l'oeuf. These sci. Nancy, pp. 154.

Paschalski, J. 1958. Zmiany obrazu chemicznego drobnych zbiorników wodnych [Changes of chemical properties of the small waterbodies]. *IV Zjazd Pol. Tow. Hydrobiol.*, Kraków 1958, Streszcz. referatów, 119—120 (Polish).

Pearl, R., Parker, S. L. 1922. Experimental studies on the duration of life. IV. *Am. Nat.*, 56, 312—321.

Tarwid, K. 1952. Próba charakterystyki zespołów komarów Puszczy Kampinoskiej (An attempt at characterization of the association of mosquitoes in the Kampinos Forest near Warsaw). *Studia Soc. Sci. torun., Sectio E*, 3 (2), 1—28 (Engl. summ.).

Winsor, C. P., Winsor, A. A. 1935. Lengevity and fertility in the pond small *Lymnea columella*. *J. Wash. Acad. Sci.*, 25, 302—307.

Woodruff, L. L. 1911. The efect of excretion products of Paramaecium on its rate reproduction. *J. exp. Zool.*, 10, 551—581.

Woodruff, L. L. 1912. Observations on the origin and sequence of the protozoan fauna of hay infussions. *J. exp. Zool.* 12, 205—264.

[Žadin, V. I.] Жадин, В. И. 1950. *Жизнь в реках* [*Life in the rivers*]. *Žizn presnych vod.* 3, p. 113—256 (Russian).

[Zernov, S. A.] Зернов, С. А. 1949. *Общая гидробиология* [*General hydrobiology*]. Moskva, Izdat. A. N. SSSR (Russian).

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THE PROBLEM OF PARASITISM OF THE SPECIES OF THE GENUS BRANCHIOBDELLA ODIER, 1823

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ABSTRACT

Differences of opinions on the degree of parasitism of the genus Branchiobdella induced the author to check whether *Branchiobdella parasita* (Braun, 1805), Henle, 1835 and *B. hexodonta* Gruber, 1883 found on *Astacus astacus* (L.) lead in fact a parasitic way of life. Biological observations and histological studies together with experiments with the use of ^{51}Cr have shown that *B. hexodonta* is a parasite of the crayfish, whereas *B. parasita* is not.

CONTENTS

1. Introduction
2. Material and methods
3. Results
4. Discussion
5. Conclusions
6. Summary
7. Streszczenie
8. References

1. INTRODUCTION

Species of the genus Branchiobdella Odier, 1823 were very rarely mentioned in literature although they are widespread on the polish territories. Till recently only one species of *Branchiobdella parasita* (Braum, 1805) Henle, 1835 [1] was reported to occur. It was known from two places (Moszyńska 1962). It is only Wojtas in the year 1964 when studying river crayfish (*Astacus astacus* L.) from the river Grabia (Łask district) who has reported the occurence of four species of this genus. Among others the author mentiones *B. parasita* and single specimens of *B. hexodonta* Gruber, 1883.

In literature available most workers mentioned Branchiobdella as external parasites of crayfish (Ude 1929, Moszyński 1937, Moszyński and Moszyńska 1957, Pop 1965 and others). Only Nurminen (1966) is of the opinion that the species he found is not a parasite. Much earlier Smallwood (1906) observed that some american species of the family Branchiobdellidae are not parasites and do not feed on the body of the crustacean.

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[1] Most authors reported this species as *B. parasita* Henle, 1835.

Observations made in spring 1967 seemed also to show that the ranking of all the representatives of the genus Branchiobdella among parasites is not correct. In relation to this it has been attempted to conduct exact observations and biological studies together with experiments with the use of ^{51}Cr in order to determine whether the available species from the family Branchiobdellidae are in fact parasites.

2. MATERIAL AND METHODS

Two species of Oligochaeta: *Branchiodbella parasita* and *B. hexodonta* were found on the crayfish (*Astacus astacus* L.) from Czarci Jar province of Olsztyn. The material was collected in the spring-summer period as well as in autumn 1967. The examination in April was accomplished on crayfish kept during winter in aquaria with a constant flow of lake water.

In order to establish whether the Oligochaeta are closely connected with the crustaceans about 50 specimens of *B. parasita* were collected in July and placed in a small dish into an aquarium with crayfish. The isolated *B. hexodonta* were put in dark containers in the end of November: 25 specimens in a black vessel and 19 in a small brown and then placed in the aquarium with crayfish.

In order to ascertain whether *B. parasita* can live without the crayfish for a long time 10 specimens were isolated and kept from July till December in a small dish with lake water, plants and stones. Every few weeks plankton was added to the vessel and the survival of Branchiobdella was tested.

In order to establish to what extent the Oligochaeta feed on plankton crustaceans an experiment with *B. parasita* in three vessels was accomplished at the beginning of August:

1. 10 Oligochaeta without crayfish were placed in a small dish with a high density of plankton.

2. In a small aquarium one crayfish with *B. parasita* was kept plankton was also added but its density was smaller than in the first vessel.

3. In a large aquarium plankton was not added to the crayfish with the Oligochaeta but this aquarium was provided with a constant flow of lake water. After two days the filling of the intestinal tract of Branchiobdella was tested on live specimens.

Once more a similar experiment has been conducted at the beginning of November. Fifteen specimens of *B. parasita* and 36 specimens of *B. hexodonta* were placed in small dishes with a high density of plankton in lake water. Two crayfish with Oligochaeta were put into an aquarium with a similar density of plankton crustaceans. A part of the material was fixed after two days, the rest after six days.

The Oligochaeta were partly examined in live state but the majority after flattening were fixed in 75% alcohol. Total preparations were stained in alum carmine and embedded in resin. Specimens of *B. hexodonta* that were destined for examination of content of intestine tract by means histological method were fixed in alcohol-formol and 10% neutral formaline. Sections were stained in alum haematoxylin after Mayer and water soluble eosin.

Experiments with the use of ^{51}Cr were conducted on 14 crayfish at the beginning of November. A determined dose of the isotope (4 μC) in the form of an isotonic solution of Na_2 $^{51}CrO_4^2$ was introduced into the body cavity. The aquarium in which the crayfish with Branchiobdella were placed had a continuous flow of lake water. After a few hours an apparent weakening of the crayfish was observed and the next day 11 specimens were found dead (the crayfish used in this experiment were relatively weak). Samples of tissues were taken from 4 dead specimens[3]. The remaing 3 live crayfish were kept during four days and after this period their Oligochaeta were collected together with samples of the basic tissues with the Branchiobdella could have direct contact. From the Oligochaeta living on the crustaceans 82 specimens of *B. parasita* were collected from the external integuments of the crayfish as well as additional 25 specimens during the post mortem. From the branchial cavity 75 specimens of *B. hexodonta* were isolated. The Oligochaeta were washed three times with lake water before counting. Also the radioactivity of the water and aquarium sediments were counted.

3. RESULTS

A. *BRANCHIOBDELLA PARASITA* (BRAUN, 1805) HENLE, 1835

This species occured in a fairly great number. The number of Oligochaeta on crayfish from the lake reached 45 on one specimen.

In summer in the aquaria the occurence of *B. parasita* has been established most often on the armature of the crayfish in the region of the eyes, on the pincers and walking legs. On the lower part of the abdomen rarely only single specimens were found. When conducting observations in October a relative increase in number of *B. parasita* on the abdomen from the ventral side has been found to occur. During the post-mortem this Oligochaeta has not been found to occur in the gills of the crayfish.

The Oligochaeta do not live permanently on the crayfish. They were found on tiles[4] placed in the aquaria with crayfish and on the walls of the aquarium. Once 27 specimens were observed an a tile. After the molting of the crustacean the Oligochaeta do not leave the exuviae at once but live on it during a few days. Similarly after the death of the crayfish the stay on it still the beginning of decomposition.

B. parasita put in dish and placed into an aquarium with crayfish partly migrated from the vessel after a few days, the remaining specimens stayed there for about a week, single ones even longer. Intentional crowding consisting in the placing of 150 specimens on one crayfish has also shown that the Oligochaeta do not live permanently on the crustacean but part of them migrates to the artificial substratum.

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[2] Produced by the Department of Production and Distribution of Izotopes at the Institute of Nuclear Research in Świerk near Otwock.

[3] Radioactivity was measured by means of a scintillation counter type SE2 produced by the Experimental Department of the Bureau for Nuclear Technique Equipment BUTI in Służewiec with the scintillation crystal NaJ of the type vell produced by Tesl of dimension 45×50 mm, the well 19×37 mm, electronic computer of the type PLE5A and stabilized feeder of the type PZS5A produced by ZOPAW in Warsaw.

[4] Tiles were used in order to create hiding places.

The isolated *B. parasita* in the vessel without crayfish lived for a fairly long time. After 24 days one specimen was found dead with a mechanical damage of the sucker and after about two months the next two specimens perished. At the closing of the experiment after more than four months 40% of the Oligochaeta were still alive.

When conducting the analysis of the intestine tract content of *B. parasita* it has been observed that their food is very differentiated and belongs to various systematic groups. Diatoms have been found there (different species) in numbers ranging from single specimens up to mass occurence, algae (thread-like) ranging from single specimens to a fairly numerous occurence, plankton crustaceans 1—4 specimens in one intestinal tract and single larvae of Chironomidae. Besides the detritus has been found to occur in different amounts. Sometimes nearly all the above mentioned types of food were simultaneously encountered in one specimen. The Oligochaeta from the aquaria examined in April fed actively and only single specimens had empty intestinal tracts (Table I). In October, food has been found to occur in 48 per cent of *B. parasita* found on crayfish from the lake.

Table I. *Branchiobdella parasita* (Braun) collected from *Astacus astacus* (L.)

Date of examination	Number of specimens examined	With food in the intestinal tract	
		number of specimens	%
IV. 1967 from the aquarium	73	69	94.5
2.X. 1967 from the lake	50	24	48.0

The food encountered most often consisted of Diatomeae. They were observed in 93.1 per cent of the specimens caught in April and in 48 per cent of the specimens caught in October (Table II). They often occured as fairly numerous or numerous, whereas algae were found as single forms. Among the plankton organisms Cladocera[5] (Fig. 1) which are organisms more easily accessible to Oligochaeta than Copepoda (Fig. 2, 3), clearly dominated.

When comparing the material from the aquaria and from the lake it has to be said that qualitatively the food was very similar. The main difference was the finding of single larvae of Chironimidae only in Oligochaeta from the lake.

The size of the *B. parasita* examined was various, they had gonads developed to a different degree. When examining the preparations no correlation between the degree of maturity of *B. parasita* and their feeding with Diatomeae and even plankton has been observed.

The experiments conducted in three vessels with a different density of plankton have shown that in *B. parasita* living separately from the crayfish in 80 per cent of the specimens examined plankton has been found numbering

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[5] The genus the most often encountered were Chydorus Leach and Alona Baird.

Table II. The per cent composition of food of *Branchiobdella parasita* (Braun) collected from *Astacus astacus* (L.)

Date of examination	The number of Oligochaeta	Diatomeae					Algae			Plankton crustaceans			Larvae Chironomidae	Detritus
		Total	Single[1]	Fairly numerous[2]	Numerous[3]	Mass numbers	Total	Single[1]	Fairly numerous[2]	Total	Copepoda	Cladocera		
IV. 1967 from the aquarium	73	93.1	31.5	34.3	26.0	1.3	39.7	35.6	4.1	21.9	4.1	20.5	—	94.5
2.X. 1967 from the lake	50	48.0	22.0	18.0	8.0	—	6.0	6.0	—	4.0	—	4.0	6.0	46.0

[1] Up to 10 specimens.
[2] From 10 to 50 specimens.
[3] Above 50 specimens.

from 1—4 specimens in one intestinal tract. In the Oligochaeta living on crayfish in a small aquarium in 33.3 per cent of the specimens the intestinal tracts were filled with crustaceans, which were found in numbers ranging from 1—2 specimens. In the large aquarium only 12.5 per cent, of the Oligochaeta had plankton in the intestinal tract, and by only one crustacean.

Fig. 1. Cladocera in the intestinal tract of *Branchiobdella parasita* (Braun, 1805)

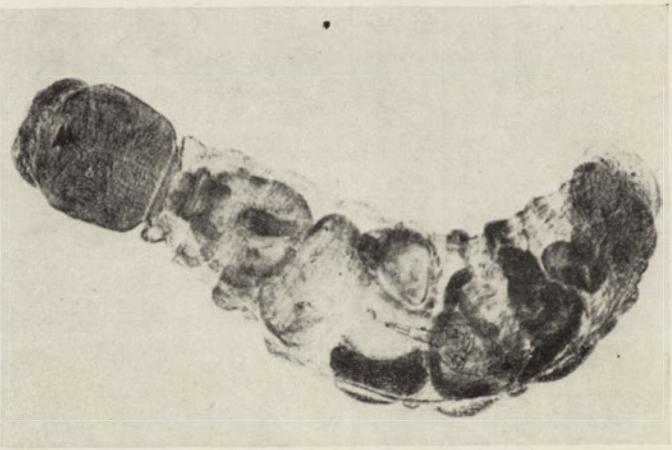

Fig. 2. *Branchiobdella parasita* (Braun, 1805) with a single specimen of Copepoda in the intestinal tract

The experimental with the plankton crustaceans with two vessels of a possibly similar density conducted later, showed that the intestinal tracts of *B. parasita* placed without the crayfish after a period of two days were filled with plankton in 60 per cent, the number of crustaceans ranging from 1—2 specimens. Among 33 specimens collected from one crayfish plankton was found also in 60.6 per cent. In their intestinal tracts 1—6 plankton specimen were encountered. After 6 days in 27 *B. parasita* from the second crayfish food occured in 77.8 per cent and 1—4 crustaceans in one intestine tract were found. In the Oligochaeta found on crayfish in the majority of cases the whole plankton was found to be eaten. Generally Cladocera dominated in the intestine tracts.

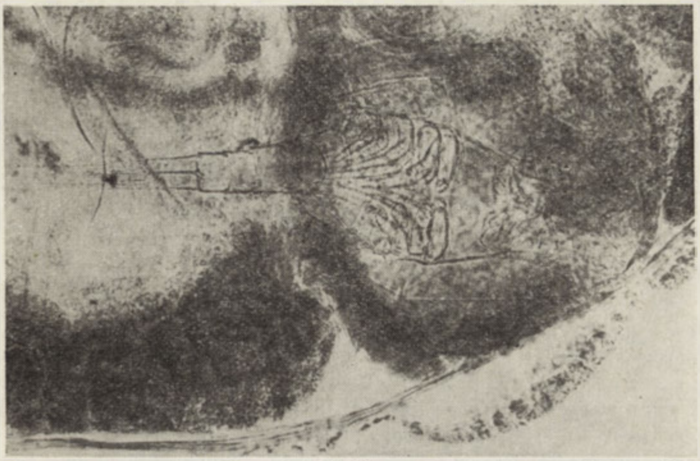

Fig. 3. An enlarged segment of *Branchiobdella parasita* (Braun, 1805) with a specimen of Copepoda visible in the intestine. All the photographs were acomplished by J. Waluga

B. *BRANCHIOBDELLA HEXODONTA* GRUBER, 1883

Oligochaeta were found exclusively in the branchial cavity and on the gills 2—38 specimens on one crayfish. During the observation in aquaria no *B. hexodonta* on artificial substratum has been encountered. After the death of a crayfish these oligochaeta leave him significantly faster than *B. parasita*.

B. hexodonta placed in a dark vessel in an aquarium with crayfish migrated during four days. They stayed longer in the bottle and after six days three specimens were still found there, one of them was dead. The next day only one specimen was found, who stayed there for about a week. The results obtained could not give a real biological image because of the winter season and a slightly lowered water temperature (up to 15°C).

In the majority of total preparations of the 95 specimens of *B. hexodonta* under study the food that occured in great amounts was difficult to identify. Most often it was accompanied by a small amount of detritus. In the same specimens sometimes single or fairly numerous diatoms were encountered. They were found in 10.5 per cent of the Oligochaeta including single specimens in 6.3 per cent and fairly numerous in 4.2 per cent.

In the intestinal tracts of *B. hexodonta* examined by means of the histological method most often completely digested food was found. This formed a structurclass mass (without structure) mainly brownish-gray in color. Besides that in a small number of specimens single cells digested to a significant extent were encountered together with larger fragments of the character of epithelium and of connective tissue. These fragments were irregular in shape, tattered and had a highly vacuolized cytoplasm pink-gray in colour. On a few microtome sections very well conserved nuclei of epithelial cells were observed, coloured intensely violet-blue, nearly circular in shape with the clear structure of the chromatin net. Around the nuclei usually a delicate cytoplasm was seen partly changed into a granular mass. Also single well conserved oval nuclei were observed with a very dense chromatin resembling the connective tissue cell nuclei. They were intensely coloured violet-blue and were surrounded by remmants of the cytoplasm. More often only nuclei fragments were encountered or their outlines.

The experiment with plankton crustaceans in vessels with density as in previous experiments showed that isolated *B. hexodonta* did not feed on plankton. In the intestine tracts of Oligochaeta collected on crayfish indeterminable remmants of crustaceans were found. After two days out of 14 specimens examined these remnants were found in two (14.3 per cent) and after 6 days out of specimens examined the plankton remnants were found also in two Oligochaeta (5.7 per cent).

C. RESULTS OF THE ISOTOPE EXPERIMENTS

A separate experiment showed that tissues from crayfish treated with ^{51}Cr were highly radioactive. The number of counts per min was high. The mean results per gram are illustrated in Table III. The greatest number of counts was noted in the liver of the dead crayfish and gills.

Table III. The radioactivity of chosen tissues of *Astacus astacus* (L.)

Type of tissue	Number of counts per g	
	dead crayfish	live crayfish
The armature of the cephalothorax (separated from the epithelium as possible)	21 895	17 550
Chitin from the ventral side of the abdomen	25 207	38 717
Gills	51 251	100 990
Liver	139 571	—

The radioactivity found in the species of Branchiobdella under study living on the same crayfish differed widely and was 16 counts in the case of 100 specimens of *B. parasita* collected before the post-mortem whereas in the case of *B. hexodonta* it reached 1353 counts. In specimens of *B. parasita* found during the post-mortem 96 counts per min, were obtained from 100 specimens. 1 ml of the water from the testtubes in which *B. parasita* had stayed for about 3 hours gave 5 counts per min, in the case of *B. hexodonta* it was 15 counts whereas 1 ml of water with the sediments from the aquarium in which the experiment had been conducted displayed a radioactivity of 210 counts per min.

4. DISCUSSION

When comparing the location on the crayfish of *Branchiobdella parasita* with the literature available no significant differences have been observed. UDE (1929), SCHÄPERCLAUS (1954) and POP (1965) report that this species occures on the surface of the body of crayfish. Also Berger (1953/1954) has found these Oligochaeta at the base of the abdominal appendages.

The finding that *B. parasita* do not live on the crustacean permanently they often stay on the artificial substratum and when isolated from the crayfish they live during a longer period of time, seems to be significant. Similar observations have not been encountered in the literature available.

The species of the genus Branchiobdella were reported to be parasites till recently in papers and popular publications. Wesenberg-Lund (1939) and Boldt (1940) consider the family Branchiobdellidae as parasites river crayfish which out their host with their maxilla in the articulated points. Basing on the data of Boldt (1940), Berger (1953/1954) assumes that *B. parasita* is a parasite. Schäperclaus (1954) is of the opinion that the species of Branchiobdella described by him destroy as mature specimens the soft parts of the crayfish or the gills and feed with the tissue fluids and blood. However the young Oligochaeta feed on the mucus of the host and do not cause any harm. Also Wojtas (1964) is of the opinion that the species under discussion is a parasite. Basing probably on the data of other this author claims that Branchiobdellidae are permanent external parasites of fresh water crayfish, they damage their epithelium, suck the blood and feed on its eggs.

The results of the present experiments concerning *B. parasita* are contradictory to the above mentioned opinions. First of all a very differentiated food and not originating from the crayfish has been found in the intestinal tract of this species. The Oligochaeta from the lake and the aquarium ingested a qualitatively similar food. A lower per cent of filling of the intestinal tract in specimens from the lake can be probably explained by the keeping of crayfish in passage containers and during 24 hours in tap water before they were supplied to the laboratory or by a smaller accessibility of food. A relatively high percentage of diatoms, fairly numerous and numerous in intestine tracts and sometimes occurring even in mass numbers favours rather the opinion that they did not appear there incidentally. This view is supported by the fact that together with the diatoms also algae and plankton crustaceans were encountered in the same specimens. No correlation has been observed between the degree of maturity of *B. parasita* and the intensity of its feeding on unicellular organisms and plankton. It is possible that the reason for finding mainly single algae in the intestine tract is the relatively poor development of these organisms in aquaria as well as the keeping of crayfish from the lake before the experiment.

Experiments with plankton crustaceans of various density have shown that *B. parasita* feed most intensely with plankton in a environment of a higher density, where probably they have a greater possibility of contact with the food. However it resulted from the experiment with a similar density of plankton that the Oligochaeta living on the crayfish uptook even a slightly greater number of crustaceans than those placed in similar conditions in a dish. These observations would favour the opinion that the crayfish is only the means of transport and a substratum producing a current of water owing to which food can be obtained more easily.

Analogical results were obtained by Smallwood (1906). The author when examining crayfish from the lake Clear (N.Y.) has found in the alimentary tracts of *Xironogiton instabilius* (Moore, 1893) Ellis, 1919 and *Xironodrilus pulcherrimus* (Moore, 1893) Ellis, 1919 great numbers of alage and diatoms even in mature specimens. Basing on these facts he considered that the species he described were not parasites of crayfish but rather its symbiotonts. Also it is esential that these Oligochaeta occurred similarly to *B. parasita* on the external integuments of the crustaceans. Also NURMINEN (1966) stresses the fact that *Branchiobdella pentodonta* Whitman, 1882 is only an epibiont of the crayfish.

An interesting note on the feeding of Branchiobdellidae can be found in the paper of HALL (1914/1915), who reports that young organisms are not parasites but feed on detritus and small animals. In this case the present results concerning *B. parasita* are in accord with the data of HALL. Further on this author states that in the mature stage the specimens of the species under discussion turn to a parasitic way of life. During his investigations he has found fragments of the striated muscle in a mature specimen of the species described by him as *Ceratodrilus thysanosomus* Hall, 1914 occurring on crayfish and coming from Utah near Salt Lake City.

Biological observations of *B. hexodonta* suggest that this species, in accord with the previously mentioned literature (MOSZYŃSKI 1937, UDE 1929, WOJTAS 1964 and others) leads a parasitic way of life. The finding of the occurrence of these organisms on the gills is substantially also in accord with the data of UDE (1929) and SCHÄPERCLAUS (1954). It should be however added that these Oligochaeta live not only on the more gills but also in the branchial cavity, whereas POP (1965) pointed to the occurrence of this parasite also on the armature of live crayfish. It results from the present experiments that this species is no doubt more closely linked to the crayfish than *B. parasita*. Also the fact that partly digested fragments of crayfish tissues were found in the intestinal aract of *B. hexodonta* favours the opinion that this species is a prasite. However the finding of small numbers of diatoms and remnants of plankton crustacean could lead to the conclusion that they are not the basic food. They rather reached this place together with an other type of food and can be eventually used as an additional sort of food. It seems essential that specimens of this species when isolated fram the crayfish did not feed on plankton.

The results of the isotope method were in full accord with biological observations. The radioactivity of *B. parasita* was very low. It fell within the limits of error and this could not be considered as a proof of parasitism of this species. The sediments from the aquarium which displayed a certain amount of radioactivity could be the reason for the trace radioactivity shown by *B. parasita*. A very important factor in the estimation of the experiment at result is the purity of samples. In the specimens of *B. parasita* collected during the post-mortem a slightly greater number of counts has been found. This was probably caused by the uptake of minimal amounts of labeled solution by these very motile organisms. As *B. hexodonta* were also collected during the post-mortem perhaps it would be appropiate to substract about 100—200 counts from the results obtained. However the part that remains more than 1000 counts decidedly points to the feeding on food originating from the labeled crayfish. The radioactivity of the water in which the Oligochaeta stayed is very low and could not influence the results.

5. CONCLUSION

The results obtained allow the revision of up to date opinions and the drawing of the following conclusions *Branchiobdella hexodonta* living permanently in the branchial cavity feed mainly of the tissues of the crayfish and thus are decidedly its parasite. However the Oligochaeta of the species *B. parasita* are not closely linked to the crayfish and are not parasites. They feed on food from the external environment.

Acnowledgements

We wish to thank Dr J. Czarnocki for valuable remarks and for his help in the application of isotopes.

6. SUMMARY

The difference in opinions on the question of parasitism of Oligochaeta from the genus Branchiobdella have induced the authors to check whether the species encountered during observations on the crayfish (*Astacus astacus* L.) are really its parasites. Two species were found: *B. parasita* (Braun, 1805) Henle, 1835 and *B. hexodonta* Gruber, 1883. A number of observations and experiments, also with the use of ^{51}Cr and with histological examinations were conducted. All the above mentioned methods have shown that for *B. parasita* the crayfish is only a means of transportation producing currents of water facilitating the achievement of food. This species is not closely linked to the crustacean and feeds on very differentiated food from the external environment. However the Oligochaeta of the species *B. hexodonta* living permently in the branchial cavity are typical crayfish parasites and feed mainly on its tissues.

7. STRESZCZENIE

Rozbieżność poglądów na pasożytniczy tryb życia skąposzczetów rodzaju Branchiobdella skłoniły do sprawdzenia czy spotkane w czasie badań gatunki na raku szlachetnym (*Astacus astacus* L.) są rzeczywiście pasożytami tego skorupiaka. Znaleziono dwa gatunki: *B. parasita* (Braun, 1805) Henle, 1835 i *B. hexodonta* Gruber, 1883. Przeprowadzono szereg obserwacji i doświadczeń również z użyciem izotopu ^{51}Cr oraz badania metodą histologiczną. Wszystkie wyżej wspomniane metody wykazały, że dla *B. parasita* rak jest jedynie środkiem lokomocji wytwarzającym prądy wody ułatwiające zdobycie pokarmu. Gatunek ten nie jest ściśle związany ze skorupiakiem i odżywia się pokarmem bardzo zróżnicowanym pochodzącym ze środowiska zewnętrznego. Natomiast skąposzczety gatunku *B. hexodonta* przebywające stale w jamie skrzelowej są typowymi pasożytami raka i odżywiają się głównie jego tkankami.

8. REFERENCES

Berger, H. 1953/1954. Beitrag zur Verbreitung und Ökologie der Süsswasseroligochäten um Jena. *Wiss. Z. F. Schiller Univ. Jena, Math. naturw.*, R. 3, 453—458.

Boldt, W. 1940. Oligochaeta. In: P. Schulze (Hrsg.) *Biologie der Tiere Deutschlands*, 12a, 1—39. Berlin.

Hall, M. C. 1914/1915. Descriptions of a new genus and species of the discodrilid worms. *Proc. U. S. natn. Mus.*, 48, 187—193.

Moszyńska, M. 1962. Skąposzczety (Oligochaeta). In: *Katalog Fauny Polski* (*Catalogus faunae Poloniae*), 11, 2, Warszawa, PWN (Polish).

Moszyński, A. 1937. Oligochètes parasites de l'Ecrevisse (*Potamobius astacus* L.) de la Yougoslavie. *Glasn. Skops. anuč. Društ. Sect. Sci. Nat.*, 18, 69—75.

Moszyński, A., Moszyńska, M. 1957. Skąposzczety (Oligochaeta) Polski i niektórych krajów sąsiednich (Oligochaeta of Poland and several neighbour countries). *Pr. Kom. biol. Pozn. TPN*, 18, No. 6, 1—202 (Polish).

Nurminen, M. 1966. Notes about *Acanthobdella peledina* Grube and *Branchiobdella pentodonta* Whitman (Annelida). *Annls zool. Fenn.*, 3, 70—72.

Pop, V. 1965. Systematische Revision der europäischen Branchiobdelliden (Oligochaeta). *Zool. Jb., Syst.*, 92, 219—238.

Schäperclaus, W. 1954. *Fischkranheiten.* 3 Aufl., Berlin. Akademie Verlag.

Smallwood, W. M. 1906. Notes on Branchiobdella. *Biol. Bull.*, 11, 100—111.

Ude, H. 1929. Oligochaeta. In: F. Dahl, *Die Tierwelt Deutschlands und der angrenzenden Meeresteile nach ihren Merkmalen und nach ihrer Lebensweise*, 15, 1—132. Jena. G. Fischer.

Wesenberg-Lund, C. 1939. *Biologie der Süsswassertiere.* Wien.

Wojtas, F. 1964. Materiały do poznania skąposzczetów Branchiobdellidae rzeki Grabi (Notes on the Family Branchiobdellidae [Oligochaeta] of the river Grabia). *Przegl. zool.*, 8, 149—152. (Engl. summ.).

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HATCHABILITY OF EGGS OF *TRIOPS CANCRIFORMIS* (BOSC) IN SOLUTION OF CHLORIDES AND SULFATES

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ABSTRACT

Eggs of *Triops cancriformis* (Bosc) were developing in solutions of NaCl, KCl, $CaCl_2$, K_2SO_4, $MgSO_4$, at concentrations from 5‰ to 50‰. Solutions of K_2SO_4 and $MgSO_4$ were most suitable for hatching, the least suitable were NaCl and KCl. The shorter the period of exposure of the eggs to solutions, the higher the level of their hatchability.

CONTENTS

1. Introduction
2. Material and methods
3. Results
4. Discussion
5. Conclusions
6. Summary
7. Streszczenie
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1. INTRODUCTION

Eggs of Branchiopoda, being simultaneously the resting stage, show very broad possibilities of adaptation to varying factors of the environment; they possess membranes which insulate markedly the embryo from external environment. Due to these properties, a high resistance of eggs to unfavourable external conditions was often ascertained in contrast with post-embryonic stages of a narrow adaptative ability (review of literature: Dutrieu 1960, Nourisson 1964, Hempel-Zawitkowska 1967).

The experiments on hatchability of eggs of *Triops cancriformis* (a freshwater species) at different concentrations of sea water (Klekowski, Hempel-Zawitkowska 1968), brought still further the evidence of these properties. In that paper, certain analogy was found between the effect of saline external environment and desiccation, which confirmed earlier supposition (Mathias, Bouat 1934).

The present paper aimed at explaining whether the saline environment affects the eggs only through changes in osmotic pressure of the environment, or whether the development of eggs also depends on the ion composition of is environment.

2. MATERIAL AND METHODS

The eggs for the experiments were collected from parthenogenetic females accurring in a fish pond, fry transfer I, at "Łąki Jaktorowskie" near Warsaw. Each year this pond has been filled with water for 6—8 weeks, from May to

July, and the species occurred there mass appearances abundantly every year. The animals were caught in June. The eggs had been removed from egg pouches of females (for the method see HEMPEL 1962) and later they were kept in the pond water until the experiment began.

Solutions of the following salts were used in the experiments: NaCl, KCl, $CaCl_2$, $MgSO_4$, $MgCl_2$, K_2SO_4. Each salt was dissolved in tap-water, resulting in the following concentrations: 5‰, 10‰, 15‰, 20‰, 25‰, 30‰, 35‰, 40‰, 45‰, 50‰. The eggs, 4—6 hours after they had been removed from egg puches, were arranged in groups of several hundred individuals each placed into containers, 50 ml of volume, and the above salt solutions were poured into them. The eggs were left to develop at room temperature.

Losses of water due to evaporation were supplemented daily with tap water up to a certain volume, so as to maintain the constant concentration of salts in containers.

The experiments were run of three stages (Table I).

Table I. Cumulated hatchings of *Triops cancriformis* eggs at different concentrations of salts

	Type of salt	Concentration in ‰										
		0	5	10	15	20	25	30	35	40	45	50
Continuous stay	NaCl	88	65	45								
	KCl	79	81	11	2							
	$CaCl_2$	88	87	63	14							
	$MgCl_2$	79	88	86	56	26	3					
	K_2SO_4	79	91	88	68	34	12	1				
	$MgSO_4$	79	91	89	89	76	49	26	12	14		
Temporary stay 7—8 days	NaCl	88	60	53	2							
	KCl	79	69	26	8							
	$CaCl_2$	88	88	54	41		1					
	$MgCl_2$	79	74	89	51	50	24	18	1			
	K_2SO_4	79	91	+88	+68	63	44	19	7			
	$MgSO_4$	79	+91	+89	+86	+76	+49	57	45	22	10	1
Temporary stay, 3 days	NaCl	88	64	56	3							
	KCl	79	67	34	13	6						
	$CaCl_2$	88	92	64	40							
	$MgCl_2$	79	86	90	53	42	48	12				
	K_2SO_4	79	89	73	71	39	48	30	11			
	$MgSO_4$	79	87	74	88	74	64	45	51	29	29	12

+ = series of eggs that hatched in salt solutions and were not transferred into tap-water.

Stage I — the development of eggs has followed in the salt solutions for 40 days (to the cessation of hatching).

Stage II — after 3 days the eggs has been kept in the solutions, a portion of about 100 eggs was transferred from each container to another one with aerated tap water (for the time as indicated for stage I).

Stage III — after elapse of 7—8 days from the beginning of the experiment, the next portion of eggs was transferred from containers with salt solutions to those with tap-water for the period as indicated for stage I.

Stages II and III of the experiments aimed at defining the effect of temporary stay of eggs in salt solutions (for 3 and 7—8 days) on their development. Only in stage III the eggs from some containers with K_2SO_4 and $MgSO_4$ were not transferred to tap-water (marked with crosses in Table I) since they started hatching before 7—8 days.

Throughout the period of experiments, the numbers of eggs hatching in each container were recorded and later the percentages of eggs that had hatched in subsequent days, were calculated. The eggs developing in aerated, tap-water were used as control. Since the eggs for experiments had been collected on two different days (portion I for experiments with NaCl and $CaCl_2$ and portion II for the remaining salts), there were also set two control series, one for each portion of eggs.

The hatching completed, all the eggs which had not hatched were dried up for 3 weeks, (after washing) and then submerged again in tap water. This desiccation was meant to break a possible diapause of eggs and after rehydration to cause their further development and hatching which was the case in the previous experiments run in sea-water (KLEKOWSKI, HEMPEL-ZAWITKOWSKA 1968). This procedure has brought about only a partial hatching in the control series. The eggs which had been kept in salt solutions did not hatched, thus they were considered as dead ones.

3. RESULTS

Stage I fo the experiment, or continuous stay of eggs in salt solutions.

Out of all salts used, the least favorable conditions for hatching were found in solutions of NaCl (Fig. 1). The eggs were hatching only at 5‰ and 10‰ concentrations of this salt. In both concentrations the percentage of hatching was lower and the time of development was longer than in the controls.

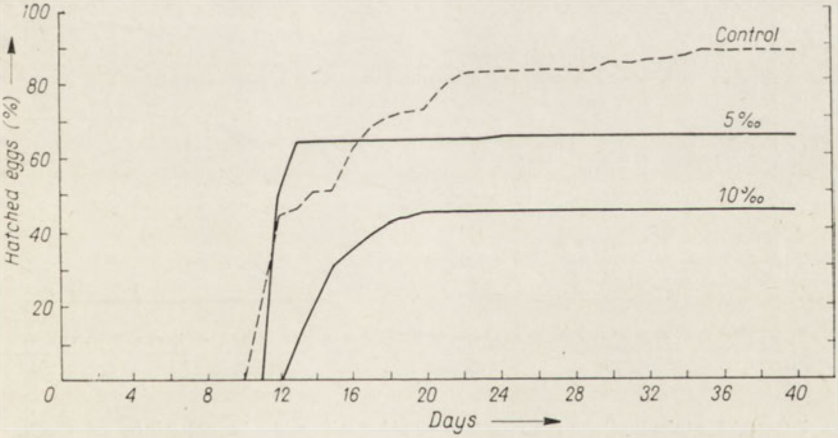

Fig. 1. Hatchability of *Triops cancriformis* eggs in solutions of NaCl

Somewhat better hatching conditions were observed in solutions of KCl (Fig. 2), where, at concentration of 5‰, the hatchability was higher (81%) than in the control (79%). A low egg hatchability was also observed at concentrations of

10‰ and 15‰. In solutions of $CaCl_2$ (Fig. 3), the eggs were hatched at the same three concentrations, differing however in clearly higher percentages of hatching at concentrations of 10‰ and 15‰, as comparing with the analogous concent rations of the previous salt.

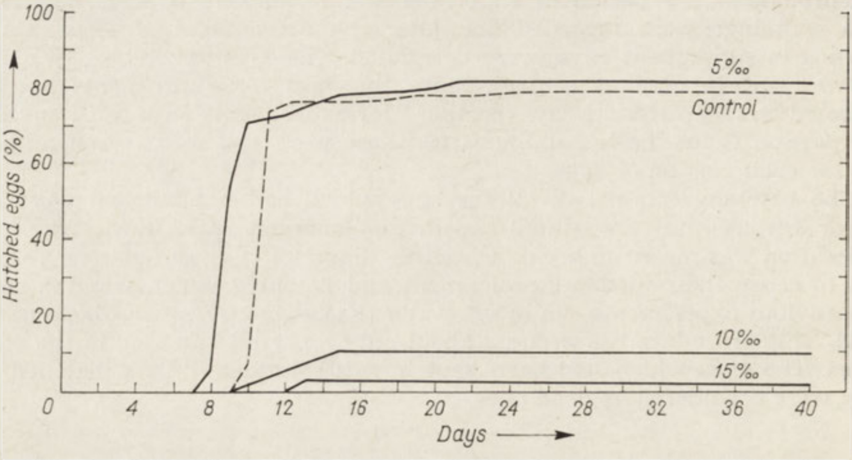

Fig. 2. Hatchability of *Triops cancriformis* eggs in solutions of KCl

Solutions of the three remaining salts: $MgCl_2$ (Fig. 4), K_2SO_4 (Fig. 5), and $MgSO_4$ (Fig. 6) proved to be clearly less toxic for the eggs. In $MgCl_2$ and K_2SO_4, at concentrations of 5‰ and 10‰ the eggs started hatching 2 days earlier

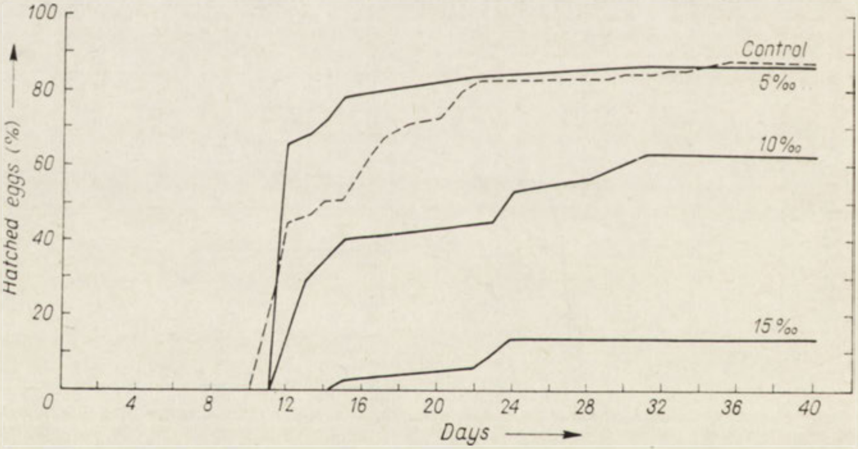

Fig. 3. Hatchability of *Triops cancriformis* eggs in solutions of $CaCl_2$

and in higher percentage (for 5‰ of both salts — 91%, for 10‰ — 88% and 89%, respectively) as compared with the cantrols (79%). In $MgCl_2$, the eggs has hatched at lower concentrations including 25‰, but in K_2SO_4 at concentrations including 30‰.

The most intense hatching was observed in $MgSO_4$ solutions where at three first concentrations (5‰, 10‰, 15‰) the percentage of hatching was uniform and reached 90%, surpassing thus by 10% the control hatching, and at 20‰ concentration, the hatching was almost equal to that in the control series. At four first concentrations, the eggs started hatching earlier than in the controls. The highest concentration at which the eggs were still hatching was 40‰.

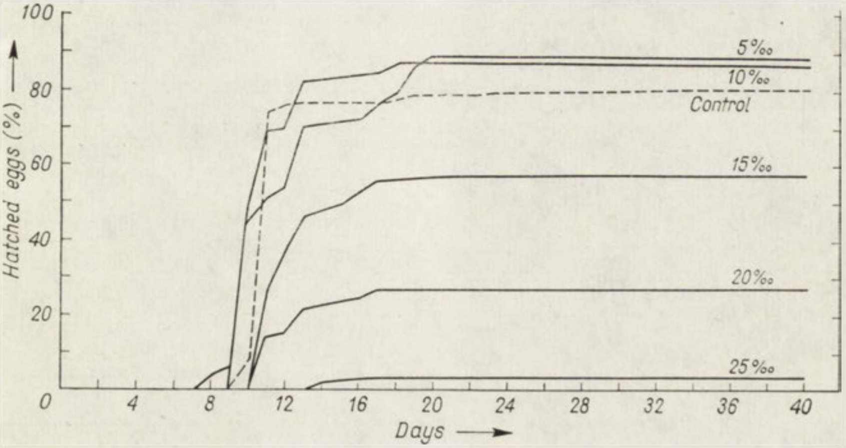

Fig. 4. Hatchability of *Triops cancriformis* eggs in solutions of $MgCl_2$

There was a regularity observed for all salts used (with rare exceptions) that the percentage of hatching was diminishing proportionally with increasing concentration.

Stage II and III of the experiments — temporary stay of eggs in salt solutions.

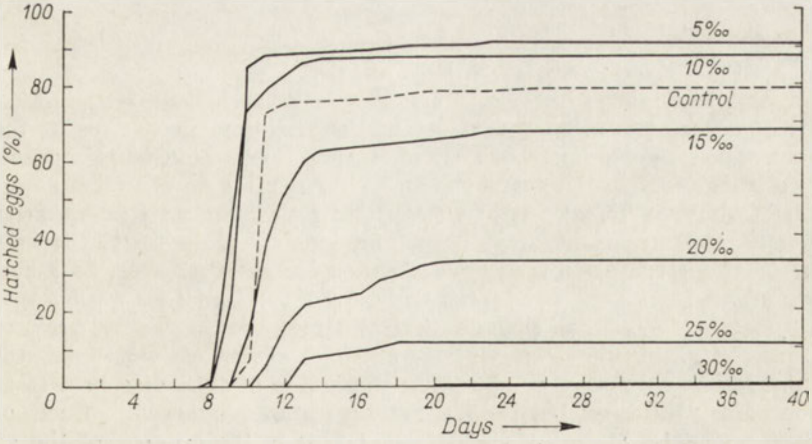

Fig. 5. Hatchability of *Triops cancriformis* eggs in solutions of K_2SO_4

The hatching of eggs which had stayed for 3 or 7—8 days in salt solutions and then were transferred to tap-water, had a similar trend to that of the eggs continuously kept in salt solutions. The sequence of salts from the most favourable to the least favourable for hatching was the same as in experiments with a stay in salt solutions: NaCl, KCl, CaCl$_2$, MgCl$_2$, K$_2$SO$_4$, and MgSO$_4$ (Table I). Similarly as for the continuous stay, the intensity of hatching and the rate of development are negatively correlated with concentration of all the salts listed.

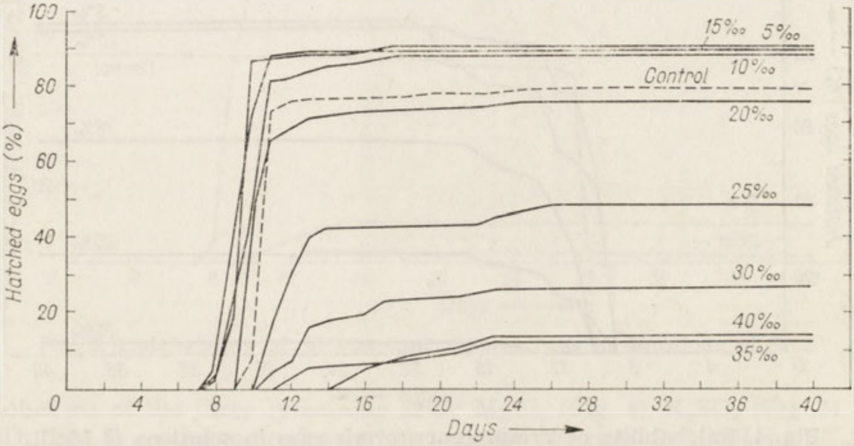

Fig. 6. Hatchability of *Triops cancriformis* eggs in solutions of MgSO$_4$

From the comparison of hatchings at three different periods of stay in particular solutions, continuous 7—8 days, 3 days-stay it resulted was concluded that the intensity of hatching was diminishing with increasing duration of stay in the salt solution. These differences were quite conspicuous for these salts in with the conditions for hatching were generally most favourable, i.e., in K$_2$SO$_4$ and in Mg SO$_4$.

4. DISCUSSION

The previous works on the effect of the chemical properties of the environment on the development of eggs of Branchiopoda pointed to a great complexity of this problem. Dutrieu (1960), in her studies on chemical composition of eggs of *Artemia salina* kept in NaCl and KCl solutions has found that the egg membranes are impermeable for the ions of these salts. Closer examination of the structure of egg membranes in other species — *Triops cancriformis* and *Lepidurus productus* (Hempel 1965), and *Chirocephalopsis bundyi* (Linder 1960) — has proved that the membranes had a very complex structure containing large amounts of chitin, a substance with insulating properties. This would rather suggest that the action of salts dissolved in external environment would be been of a rather osmotis character. Such opinions were expressed by Mathias and Bouat (1934) in their paper of the effect of higher concentrations of salts and saccharides on the eggs of *Branchiopus* *stagnalis*. These authors reported that the solutions in question acted similarly as desiccation through osmotic dehydration, bringing the eggs to normal for these arthropods diapause, after wich the further development and hatching are observed at appropiate conditions of hydration and temperature.

Their results have been confirmed by experiments on the effect of various solutions of artifical sea-water on the development of eggs of *Triops cancriformis* (Klekowski, Hempel-Zawitkowska 1968), where at higher concentrations of sea-water the eggs did not hatch, however, after being transferred to fresh water they hatched in a high percentage.

The present paper did not aim at confirming the analogy between „osmotic" and atmospheric desiccation, but at answering the question how ions of salts which were most often found in external environment affected the development of eggs after their oviposition. That is why the eggs were exposed to salt action in a possibly shortest time after their removal from egg pouches, (4—6 hrs later), and not after one day as it was the case with experiments on the effect of sea-water. This results in incomparability of both the experiments as concerning the differences between series of eggs which were continuously kept in salt solutions and those which after temporal stay in the salts were transferred to fresh water. In the present experiments, the differences in percentage of hatching eggs between series of eggs which were kept continuously and temporarily in particular salts, were inconspicuous. Only a certain proportion of eggs (characteristic for a given salt and its concentration) hatched. However the rest of eggs did not enter the diapause period as they did in the case of sea-water experiments, and they died. The eggs were proved to be dead by the fact that they did not reveal any hatchings after being kept in salt solutions, then dried up after completed experiments and submerged in water again.

The fact described above speaks in favour of the hypothesis put forward elsewhere (Hempel 1965) about the stages in development of *Triops cancriformis* eggs. According to this hypothesis, the eggs just after they have been laid are not able to reach the diapause stage and the desiccation is lethal for them. Similar results were obtained in the experiments dealing with the effect of desiccation at various relative humidities of the air on hatchability of the eggs of *T. cancriformis* (Klekowski, Hempel-Zawitkowska 1968). The same holds for other environmental factors, e.g., lower temperature (Hempel, Dutrieu 1965). The eggs used in the present paper were accurately at this first stage of development. Only these eggs which had found favorable conditions developed. The rest of them was not able to enter diapausing, and died.

As it results from the comparison of intensity of hatching and the duration of the development in particular salts and their concentrations (Figs 1—6), the action of these salts was not only of the osmotic character.

Similar conclusions were reached by Baas Becking, Karstens and Kanner (1936), who studied the combined effect of NaCl, KCl, $CaCl_2$, and $MgCl_2$ on hatchability of eggs in *Artemia salina*. At the same molar value, the hatchability varies with the ion composition of the environment.

On the other hand, estimation of toxic properties of ions of salts mentioned differs for the eggs of *Triops cancriformis* and for those of *Artemia salina*, namely, ion Na is least toxic for *A. salina*, and in addition it neutralizes the toxic effect of ions K, Ca and Mg. Similar effect of ion Na was reported by

Croghan (1958) in his studies on survival of maturated individuals of *Artemia salina* in solutions of various inorganic compounds.

As it results from the comparison of hatchability rates of *Triops cancriformis* eggs kept at 6 salts, the solutions of NaCl proved to be the least suitable environment — no hatching was observed at concentrations higher than 10‰ (Fig. 1). Different respond of the eggs of *Artemia salina* and those of *Triops cancriformis* to the ion Na can be explained by a specific adaptation of this species to NaCl — the most abundant salt in the environment inhabited by this species. This supposition can be supported by the results of studies on the effect of inorganic water soluble compounds on survival in *Paramecium caudatum* (Grębecki, Kuźnicki 1955). The latter experiments showed that for freshwater protozoans the toxic properties of beryllium group elements (e.g. Mg and Ca) were approximately equal to those of the lithium group elements (e.g. Na and K).

According to these authors, the effect of anions on survival of *Paramecium caudatum* is inconspicuous as compared with that kations. This conclusion was not affirmed in *Triops cancriformis* eggs since from the comparison of hatchings in KCl, K_2SO_4 with those in $MgCl_2$ and $MgSO_4$ it was evident that the intensity of hatching at particular concentrations was clearly higher in sulfates than in chlorides.

The hatchability of *Triops cancriformis* eggs in sea-water (Klekowski, Hempel-Zawitkowska 1968), where NaCl constitutes 78% of dissolved salts was higher than in NaCl solution and it reached 13% at concentration of 15‰. This would support the data obtained by Baas Becking et al. (1936) and those by Croghan (1958) on diminished toxicity of ion Na by the presence of other ions in solution.

According to Pora (1962), favourable environmental conditions are attained not only by presence or lack some ions, but also by their particular proportions. The equilibrium between anatgonistic action of particular ions on an organism (e.g. diminishing permeability of membrans by ion Ca and increasing of it K), called "facteur rapique" is an inportant feauture of the environment.

5. CONCLUSIONS

1) The eggs of *Triops cancriformis* (Bosc) kept in soultion of salt examined hatched at concentrations from 5‰ to 40‰, in different proportions depending on type of salt used. The intensivity of hatching at these concentrations was observed to decrease usually with increasing concentration of dissolved matter. The sequence of the salts arranged according to their increasing toxicity is as follows $MgSO_4$, K_2SO_4, $MgCl_2$, $CaCl_2$, KCl and the most toxic NaCl. The percentage of hatching was higher at low concentrations of the four first salts than in the controls.

2) The duration of development of eggs in the salt solutions did not differed substantially from the control one. No clear difference was found in hatchability of eggs kept continuously and temporarily in salt solutions.

3) It was found that salinity affected the eggs not only through the change in osmotic pressure of the environment but also through the ion composition.

When the eggs were at a very early stage of development, the salinity prevented their diapause, and those eggs which had not found suitable conditions for hatching died.

6. SUMMARY

The eggs of *Triops cancriformis* (Bosc) collected in the fish pond situated near Warsaw, were placed in solutions of various salts at concentrations from 5 to 50‰. The duration of development and the percentage of hatching were recorded. After 3 or 7—8 days following the start of the experiment, portions of eggs were transferred from salt solutions to tap-water in order to ascertain the differences in continuous and temporal action of the salts on the egg hatchability. The intensity of hatching is usually higher when the eggs stay shorter in salt solutions.

Toxicity of the salts examined was uniform and was increasing in the following suquence: $MgSO_4$, K_2SO_4, $MgCl_2$, $CaCl_2$, KCl and NaCl (Figs 1—6). At low concentrations of the 4 first salts, the hatchability was higher than in the controls (Table I).

The eggs which had not hatched in the salts examined, did not enter the diapause stage, and died.

7. STRESZCZENIE

Jaja *Triops cancriformis* (Bosc), pochodzące ze stawu rybnego z okolic Warszawy, umieszczano w roztworach różnych soli o koncentracjach od 5‰ do 50‰ i obliczano czas i procent wylęgu. Po 3 oraz 7—8 dniach od rozpoczęcia doświadczeń część jaj przekładano z roztworów soli do wody wodociągowej, celem wykrycia różnic między ciągłym i okresowym działaniem roztworów soli na wyląg. Intensywność wylęgów jest na ogół większa im krócej jaja przebywały w roztworach soli.

Toksyczność badanych soli okazała się różna i wzrasta ona w następującej kolejności: $MgSo_4$, K_2SO_4, $MgCl_2$, $CaCl_2$, KCl i NaCl (Fig. 1—6). W niskich koncentracjach pierwszych czterech soli intensywność wylęgu była większa, niż w kontroli (Tab. I.).

Jaja, które nie wylęgały się w badanych roztworach soli, nie przeszły w stan diapauzy i okazały się martwe.

8. REFERENCES

Baas Becking, L., Karstens, W., Kanner, M. 1936. Salzeffekte und Milieu bei *Artemia salina* L. nebst Bemerkungen über Ionenantagonismus. *Protoplasma*, 25, 32—40.

Croghan, P. C. 1958. The survival of *Artemia salina* in various media. *J. exp. Biol.*, 35, 213—218.

Dutrieu, J. 1960. Observations biochimiques et physiologiques sur le développement d'*Artemia salina* Leach. *Archs. Zool. exp. gen.*, 99, 1—134.

Grębecki, A., Kuźnicki, L. 1955. Stosunek *Paramecium caudatum* do chemizmu środowiska i ochrony wpływ skupienia wobec substancji nieorganicznych (The relation of *Paramecium caudatum* to chemical properties of its medium and the protective effect of aggregation against inorganic substances). *Folia biol. Kraków*, 3, 127—158. (Eng. summ.).

Hempel, J. 1965. Some remarks concerning chemical composition of eggs convenings and cuticle in *Triops cancriformis* (Bosc) and *Lepidurus productus* (Bosc). *Zoologica Pol.*, 15, 143—146.

Hempel, J., Dutrieu, J. 1965. Rôle de la température et de la dessiccation sur le développement des oefs de *Triops cancriformis* (Bosc). *C. r. Séanc. Soc. Biol.*, 159, 146—149.

Hempel-Zawitkowska, J. 1966. L'influence de la dessiccation sur l'éclosion des oeufs de *Triops cancriformis* (Bosc). *Verh. int. Ver. Limnol.*, 16, 571—576.

Hempel-Zawitkowska, J. 1967. Natural history of *Triops cancriformis* (Bosc). *Zoologica* Pol., 17, 173—239.

Hempel-Zawitkowska, J., Klekowski, R. 1968. The influence of different air humidity on hatchability of *Triops cancriformis* (Bosc) eggs. *Pol. Arch. Hydrobiol.*, 15, 183—189.

Klekowski, R., Hempel-Zawitkowska, J. 1968. The influence of water salinity on hatchability of the eggs of *Triops cancriformis* (Bosc). *Pol. Arch. Hydrobiol.*, 15, (in press).

Linder, H. J. 1960. Studies on the fresh water fairy shimp *Chirocephalopsis bundyi* (Forbes). II. Histochemistry of egg-shell formation. *J. Morph.*, 107, 259—284.

Mathias, P., Bouat, M. 1934. Sur la développement de l'oeuf de *Branchipus stagnalis* L. (Crustacé, Phyllopode). *C. r. hebd. Séanc. Acad. Sci., Paris*, 199, 320—322.

Nourisson, M. 1964. Recherches écologiques et biologiques sur le Crustacé Branchiopode *Chirocephalus diaphanus* Prév.: Etude experimentale du déterminisme du développement de l'oeuf. *Bull. Acad. Lorraine Sci.*, 4, 9—154.

Pora, E. A. 1962. Considération sur l'importance du facteur osmotique et du facteur rapique dans le développement de la vie dans la Mer Noir. *Acta biotheor. ser.. A*, 15, 161—174.

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THE INFLUENCE OF ACTIVE WATER REACTION ON THE FILTRATION RATE OF CLADOCERA

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ABSTRACT

The effect of water reactions on the filtration rate of cladocerans in short-time experiments was examinated. The filtration rate showed two maxima in relation to the changes in pH values, the minimum between them pointing to an optimal pH which usually corresponds to natural conditions of the aquatic environment. Some conclusions are drawn on the possibility of defining eurytopic properties of crustaceans from pH-filtration rate dependence.

CONTENTS

1. Introduction
2. Materials and methods
3. Results
4. Discussion
5. Conclusions
6. References

1. INTRODUCTION

Ecological and physiological studies of different species of aquatic animals are becoming at present more and more important. The elucidation of relations between animals of a given species and a given factor of the environment is often necessary when a more accurate determination of the species is needed, or in cases of acclimatization. The method used currently in hydrobiology, in which the species spectrum of animals encountered in different waterbodies is established, can not always give a satisfactory answer to the question which conditions can be considered as optimal for these organisms in view of the inacuracy of the description of water body conditions and species determination.

The studies concerning the reaction of aquatic animals to changes in a given environment factor and the determination of the optimal value of this factor can be achieved a in two ways: 1) by studies on the distribution of animals in conditions where there is a gradient of the factor in question and 2) by measurement of the feeding rate or respiration in different conditions. The temperature optimum for animals is known best, the influence of water reaction is considerably less well known. The limits of pH between 4 and 9.5 can be considered as the survival range of aquatic animals (Skadovskij 1928, Bogatova 1962). However, there are several data in literature showing that the pH value within the above mentioned limits is not indifferent to animals. The distribution of several species corresponds to determined values of the water reaction, e.g. in *Holopedium gibberum*, which can be encountered only in huminificated water bodies with an acidic reaction of the environment (Manujlova 1964). The fact that widespread forms become smaller in lakes with low pH values is well known (Skadovskij, Ščerbakov, Vinberg 1928, Manujlowa 1949, Salazkin 1966). Finally, there is some information cencerning the influence of pH on the intensity of general metabolism, the rate feeding and multiplication. Besides the papers mentioned by Skadovkij in his review (1955) only a few shall by mentioned: A. T. Jačenko (1928) in her experiments with *Chydorus sphaericus* and *Ch. ovalis* has found that hydrogen ion concentration has an influence on the rate of oxygen utilization by these crustaceans as well as on the rate of multiplication. Hefco and Miron (1965) have shown the influence of water reaction on gas exchange of larvae of aquatic parasites, Alimov (1967) has obtained similar results in experiments where the filtration rate of a mollusc, *Sphaerium corneum*, was determined.

The gaim of the present paper was to determine the optimal pH value for some species of Cladocera by means of examining the filtration rate in environments with different water reaction as well as to define the degree of their euryoky in relation to this factor. Filtration rate was chosen as an indicator of the physiological state of the animals in view of the fact that this phenomenon is closely correlated to such important processes as feeding and respiration of animals. Studies on the physiological state of the animals from different types of water bodies can possibly contribute to the elucidation of the nature of phenotypic variability.

2. MATERIALS AND METHODS

Materials for the experiments consisted of crustaceans collected in Lakes Otradnoe and Svietloe near Ladoga, in ponds and temporary water bodies of the Leningrad district. The experiments were conducted in the laboratory of the Institute of Zoology, the Soviet Academy of Sciences, and under field conditions in Lake Otradnoe. The crustaceans were collected from water bodies by means of a Apstein net, then they were transfered to aquaria filled with water from the same water body from which they had been taken. After some time (not less than 24 hours) the individuals adaptated themselves to room temperature. Selection of material for experiments was accomplished with the aid of a binocular and special attention was payed to use in experiments only active and healthy specimens. The crustaceans were transferred from one vessel to another by means of a soft small brush in order to avoid wounding that could have happened if the fishing had been done with a pipette.

All the experiments were conducted by day light, at temperature ranging from 19—20°C. It is known that maximal filtration rate occurs at 20—22°C (Krjučkova and Kandratjuk 1966). Beakers and test-tubes were used as experimental vessels in which the filtration rate was measured. Water volume in the test-tube was 10 ml. Water volume in the experimental vessels influenced significantly the filtration rate calculated. It is known that the greater is the volume of the vessel, the greater volume of water is filtered (Rigler 1967). The data concerning the volume of water per 1 g wet weight of crustacean obtained in the present experiments are given in Table I. As the experiments aimed at comparing the filtration rate in crustaceans of one species at different pH values, a special attention was payed to the constancy of conditions within a series of experiments. That is why there was no attempt made to establish equal conditions for different species, nor the filtration rates of different forms will be compared. Since due to the fact that in experiments with large individuals the water volume per 1 mg weight was smaller the filtration rates obtained for these forms were slightly underestimated as compared to those obtained for smaller forms. Dry pond clay was used as filtered suspension. The dimensions of its particles were 1—10 μ. Clay concentration in experiments was 180—200 mg per 1, bichromic axidasibility of water was about 30 mg oxygen per liter. Suspended clay concentration was determined by means of a photocolorimeter FEK M-56.

Table I. Weight of the crustaceans, their number in the experiments, the quantity of water with clay suspension per mg wet weight

Species	Number of animals in the experiment	Wet weight[1] of one crustacean mg	Water volume ml per mg wet weight of crustacean
Simocephalus expinosus	10	0.070	14.2
Daphnia longispina	5	0.060	33.3
D. longispina	5	0.140	14.2
D. pulex	40	0.008	31.2
D. pulex	10	0.180	5.6
D. pulex	20	0.430	3.0
Bosmina longirostris	30	0.006	55.6
Sida cristallina	3	0.460	7.2
Ceriodaph. reticulata	10	0.012	83.3
Scapholeberis mucronata	10	0.40	25.0

[1] Wet weight given according to tables of standard weights, length measured under a binocular.

The experiment was conducted in the following way. Dry clay was placed in a can of water mixed up and left for 24 hrs. During that time a sediment composed of greater particles of clay was formed and over this stratum there was a suspension of fine clay. The concentration of suspension was determined by means of FEK and, if necessary it was diluted with aged water. After the concentration, determining the clay suspension was poured into 0.5 l cans. In these cans the pH needed was established directly before the experiment. The hydrogen ion concentration was changed by addition of a few drops of 0.1 sulfuric acid and 1 per cent Na_2CO_3. Sulfuric acid for the acidifying of the environment was chosen basing on the data of S. N. SKADOVSKIJ (1928) who stated that acidic water reaction in humificated water bodies was caused by a small amount of sulfuric acid evolved into the water by sphagnum moss.

Water reaction was measured by means of a pH meter at the beginning and at the end of the experiment. During the experiment (4 hours) there was no change in the pH value. The sedimenting of clay by filtratore ran at different rates depending on the pH value, the difference between the initial and final concentration did not exceed 40 per cent of the initial one. Each variant of the experiment was repeated 3 to 5 times and thus each point on the curve represents a mean value from 3—5 measurements. Controls without animals for the determination of the non biological clay sedimentation were carried out 3 times. Non biological clay sedimentation constituted on the average, 15 to 20 per cent of the initial concentration. Water reaction did not influence clay sedimentation a significant way (Table II).

Table II. Clay sedimentation in control vessels (belonging to the series) at different pH values

pH	E_0	E_k/E_0	Mean E_0	Mean E_k/E	C E_k/E_0
4.5	0.230	0.96	0.245	0.86	8.6%
5.0	0.218	0.85			
5.5	0.210	0.91			
6.5	0.250	0.88			
7.5	0.280	0.80			
8.5	0.280	0.80			
8.9	0.245	0.83			
4.8	0.230	0.84	0.234	0.82	4.5%
6.0	0.235	0.84			
6.9	0.235	0.80			
8.0	0.235	0.80			
4.8	0.235	0.81	0.235	0.83	2.8%
6.0	0.235	0.81			
6.9	0.235	0.86			
8.0	0.237	0.84			

E_0 — extinction of the initial suspension, E_k — light absorption after a 4 hours experiment, C — variation coefficient. Lenght of FEK cuvettey 10 mm.

Calculations were accomplished according to the following formulas:

$$F = \frac{m(\ln E_0 - \ln E_t)}{t} - a; \qquad a = \frac{m(\ln E_0 - \ln E_k)}{t}$$

F — filtration rate, E_0 — initial extinction of the suspension, E_t — final extinction of the suspension in the experiment, E_k — final extinction of the control, t — duration of the experiment, m — water volume in the experiment, a — correction accounting for the non biological sedimentation.

3. RESULTS

1. *Sida crystallina* (D. F. Müller) — (Fig. 1, curve 1). The crustaceans were collected from Lake Otradnoe where they were encountered in great numbers among reeds, the water pH being there 6.8—7.0. As it has been shown by experiments, *S. cristallina* does not display great sensitivity to pH changes ranging from 5.8 to 8.5.

2. *Daphnia pulex* (De Geer) (Fig. 2). Material was collected in ponds in one of Leningrad parks, water pH being about 7.0. The changes in water reaction influenced rather strongly the filtration rate in Daphnia (Ivanova 1965). Daphnia of three size groups were taken for the experiment: newly — born individuals weighing 0.003 mg, immature sexually of Daphnia weighing 0.180 mg and sexually mature females, weighing 0.430 mg (Fig. 2). The reaction of Daphnia differed in these groups, in sexually mature Daphnia, the greatest filtration rate was observed at pH 6.0 and 8.0, when pH was about 7.0 the filtration rate considerably decreased. Sexually immature individuals filtrated at the greatest rate at neutral water reaction. It is worth mentioning that

according to data from literature (Manujlova 1964), *D. pulex* cannot be found in acidic waters.

3. *Daphnia longispina* (O. F. Muller) (Fig. 3, curve 1). Individuals of this species were collected from two water bodies Lake Otradnoe and a forest pool. In Lake Otradnoe, *D. longispina* can be encountered in the pelagial as well as in the coastal zone, less often within the scrub, where the animals are being evidently, brought, from the open part of the lake. Water reaction in the lake pelagial during the whole summer is about. 7.0. The greatest filtration rates in the lake population of Daphnia were observed at pH 6.0 and 8.0, in experiments with a neutral environment a decrease in the filtration rate was observed. The forest pool from which Daphnia were collected was about 0.5. m deep, had 4 m in diameter, was completely covered with duckweed, the water was brown in colour with a great quantity of humus substances, its reaction was rather acidic, pH 5.8—6.0. The highest rates of filtration in Daphnia of the post population were those at pH 5.5 and 8.5 (Fig. 3, curve 2). According to the data given by E. F. Manujlova (1964) this species prefers slightly alcalinic or acidic water bodies.

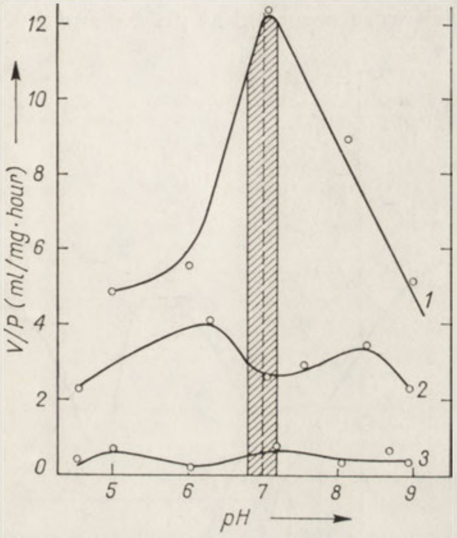

Fig. 1. The changement in the filtration rate under the influence of pH: 1. *Ceriodaphnia reticulata*, wet weight (W) 0.012 mg; 2. *Bosmina longirostris*, wet weight (W) 0.006 mg; 3. *Sida cristallina*, wet weight (W) 0.46 mg. The hatchet zone on Fig. 1, 2, 3 and 4 corresponds to pH values at which the crustaceans lived in the water body

4. *Ceridodaphnia reticulata* (Jurine) (Fig. 1, curve 1). The animals were collected in a shallow swamp of Lake Otradnoe, water pH in it being about 7.0. In the experiment, this species responded much more acutely to the pH value than the other forms. Maximal filtration rate was observed at water reactionclose to neutral; the filtration rate decres when the pH deviated to the acidic or basic values. No reports have been found in literature concerning the influence of water reaction on the distribution of *C. reticulata*, except for the data of S. N. Skadovskij (1928), acc. to which this species has been found in a water body at pH of 8.4—7.0 and was missing in more acidic waters.

5. *Simocephalus expinosus* (Koch). The individuals of this species were collected in Lake Svietloe, where they occurred abundantly in the shore zone. Lake Svietloe is very specific on account of its physico-chemical characteristics. Its water is poorly mineralized with colouration close to zero; pH falls within the range from 6.0 to 6.8. The experiments showed a weak responce of Simocephalus to pH ranging from 5.0 to 8.0 This species has been also found to occur in a forest pool whose living conditions have been described earlier; experiments with specimens from the forest pool involved at smaller pH intervals. In this case a decrease in the filtration rate was observed at pH 6.0 and the highest rates were recorded at pH 5.4 and 6.9.

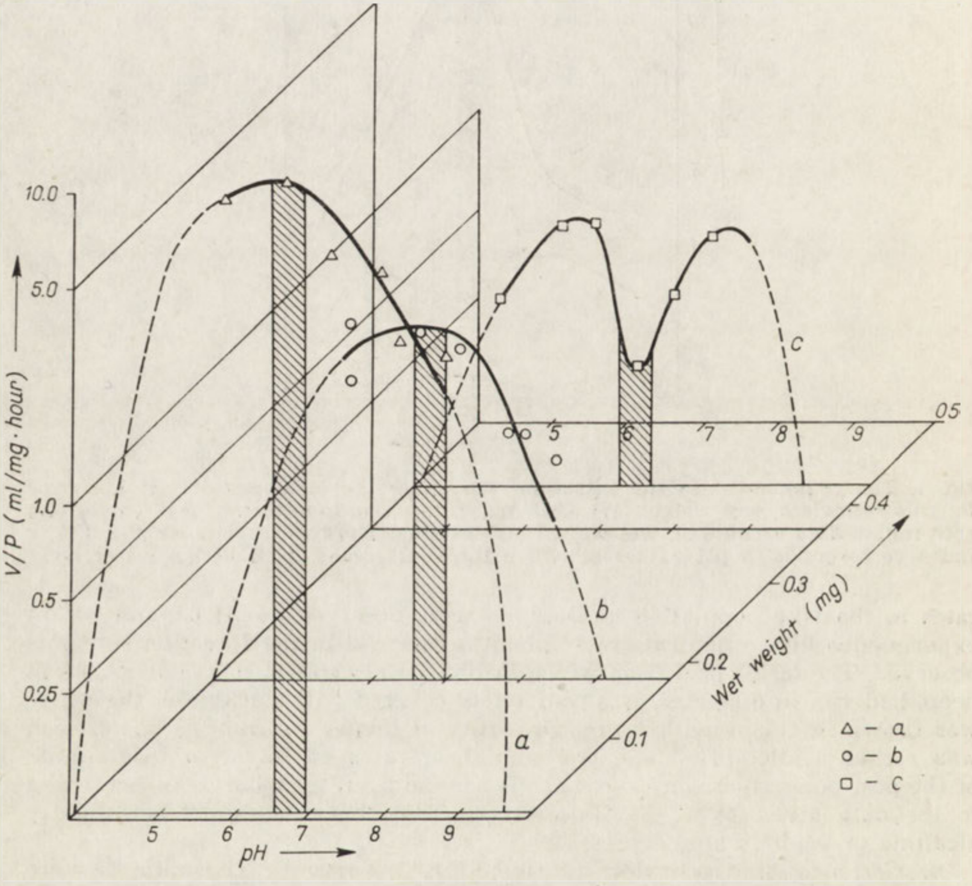

Fig. 2. The changement in the filtration rate under the influence of pH: a — *Daphnia pulex*, W = 0.008 mg; b — *D. pulex*, W = 0.18 mg; c — *D. pulex*, W = 0.430 mg

6. *Scapholeberis mucronata* (O. F. Müller) (Fig. 4, curve 2). The material was collected from one of the swamps of Lake Otradnoe in which the conditions differed significantly from the other parts of the lake because of the presence of humic substances. The pH of water in the swamp ranged from 6.2 to 6.4. The determination of the filtration rate in media with different pH

showed that Sc. mucronata filtered with the greatest rate at pH 7.0 and 5.5 decrease in the region of pH of 6.5 a decrease of the filtration rate was observed.

7. *Bosmina longirostris* (O. F. Müller) (Fig. 1, curve 2). Specimens of this species were collected in Lake Otradnoe, where they could be found in great numbers in the pelagial as well as in the shore zone. The greatest filtration rates were observed at pH 6.5 and 8.5. This species is related to widely spread for it can be encountered in neutral, slightly basic and slightly acidic waters (Manujlova 1964, Järnefelt 1956—1958) it lives in Finnish oligotrophic and eutrophic lakes with transparent or slightly huminificated water, at pH from 6.5 to 7.5.

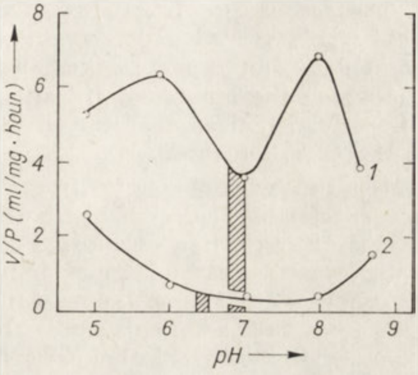

Fig. 3. The changement in the filtration rate under the influence of pH: 1 — *Daphnia longispina* from the Otradnoe Lake, W = 0.065 mg; 2 — Forest pool *D. longispina*, W = 0.190 mg

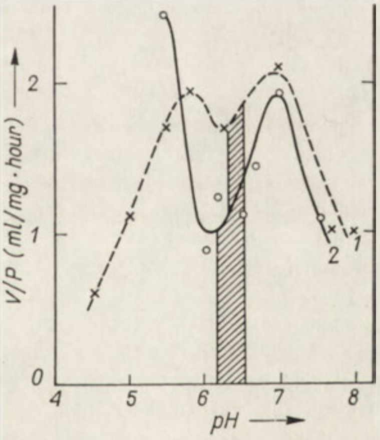

Fig. 4. The changement in the filtration rate under the influence of pH: 1 — *Simocephalus expinosus*, W = 0.350 mg; 2 — *Scapholeberis mucronata*, W = 0.04 mg

4. DISCUSSION

After comparing the data obtained for the filtration rates of Cladocera at different pH values the Cladocera species can be divided into two groups. The first group consists of the species for which a decrease in the filtration rate was observed at the pH value close to that of the water bodies from which they had been taken: *Sida crystallina*, *Daphnia longispina*, *D. pulex* (sexually mature females, *Simocephalus expinosus*, *Scapholeberia mucronata*, *Bosimina longirostria*. Also two species of Chydorus should be included in this group (Jačenko 1928). The second group consists of crustaceans for which a maximal filtration rate was observed under conditions similar to those in nature: *Ceriodaphnia reticulata* and young *Daphnia polex*. The intervals between the pH values at which the maximum filtration rates were observed can vary widely and it can be noticed that the greater the difference the smaller the increase in the filtration rate.

The increase in filtration rate with deviations from the environmental conditions to which a given species of Cladocera had been adapted, can be evidently explained by the disturbing action of unusual concentration of hydrogen ion which acts in this case as a stimulator of activity. This makes clear the fact reported by Skadovskij (1928) and Jačenko (1928) that the action of pH, as it can be concluted from their results, is similar to the action of several other irritating agents, especially ethyl alcohol, Filipčenko (1932) that any change in the external conditions can act as an irritating agent on organisms. He gave a schematic representation of the increase in the irritation intensity when the factor was intensified or diminished, according to which the optimal conditions environmental corresponded to no irritation at all and maximal irritation could be observed when the environmental conditions were close to the lethal limits. Thus it be concluded that the decrease in filtration rate at experimental conditions similar to those of the cladoceran habitat, and to which the animals had adapted themselves, corresponds to the region of their minimal irritation and minimal activity.

When great sensitivity of the animals to pH changes is observed the maxima come close to one another to such an extent that when great intervals in pH measurements are used the curve seems to have one maximum. This phenomenon was observed by the author in the case of young *Daphnia pulex*, *Ceriodaphnia reticulata* and by Alimov (1967) in the case of molluscs of the genus Sphaerium. It is possible that with more narrow pH changes it would be possible to discover two maxima closely together. Basing on the hypothesis that the more the conditions differ from optimal the greater the intensity of motoric reactions (Ivlev 1963) it can be interred from the decrease in the filtration rate which pH is optimal for a given group of animals, as well as the degree of their euryoky in relation to this factor.

When considering the data obtained for the filtration rate of Cladocera at different pH values the following sequence in the increase of euryoky can be given *Ceriodaphia reticulata* young *Dephnia pulex*, *Simocephalus expinosus*, *Scapholeberis mucronata*, lake *Daphnia longispina* and from the forest pool, *Daphnia pulex*, *Sida crystallina*. *Sida crystallina* prowed to be most indifferent to pH changements, a fact that suits well the reports concerning the distribution of this species in water bodies of different types (Manujlova, 1965). Also different curves for *Daphnia longispina* from the forest pool and from the lake can be noticed, a fact that is evidently correlated with the adaptation of these populations to the conditions of their habitats. Daphnia from a forest pool with an acidic water reaction proved to be less sensitive to pH changements in the experiment.

5. CONCLUSIONS

1. Water reaction has a visible influence on the filtration rate of cladocerans in short — term experiments.
2. The curve illustrating the pH — filtration rate dependence in most cases has two maxima with a minimum between them. The minimum talls at these pH values which correspond to the living conditions in the water body and can be considered as optimal. When a great sensitivity to changes in water reaction is observed, the maxima may come closer and the curve seems to have but one maximum.
3. From the position of the maximal filtration rates on the pH scale, conclusions can be drawn concerning the degree of euryoky of given animals.

REFERENCES

[Alimov, A. F.] Алимов, А. Ф. 1967. Влияние некоторых факторов среды на фильтрационные способности моллюсков *Sphaerium corneum* (L.) (Effect of certain environmental factors on filtration by *Sphaerium corneum* (L.). *Gidrobiol. Ž. Kiiv*, 3 (2), 26—32 (Engl. summ.).

[Bogatova, I. B.] Богатова, И. Б. 1962. Летальные границы содержания кислорода, температуры и pH для некоторых представителей семейства Chydoridae (Lethal ranges of oxygen content, temperatures and pH for some representatives of the family Chydoridae). *Zool. Ž., Mosk.*, 41, 58—62 (Engl. summ.).

[Filipčenko, Ju. S.] Филипченко, Ю. С. 1932. *Экспериментальная зоология* [*Experimental zoology*]. Leningrad, Gosmedizdat. (Russian).

Hefco, V., Miron, I. 1965. Consumul de oxigen la citeva larve acvatice de insecte şi influenţa reacţiei acido-bazice a mediului. *Anal. ştiint. Univ. Al. I. Cuza, Iasi*, Sect. 2a, 11, 33—38.

[Ivanova, M. B.] Иванова, М. Б. 1965. Влияние температуры и активной реакции воды на дыхание и скорость фильтрации *Daphnia pulex* (Effect of temperature and active reaction of water on the respiration and rate of filtration of *Daphnia pulex*). *Gidrobiol. Ž., Kiiv*, 1 (5), 15—19 (Engl. summ.).

[Ivlev, V. C.] Ивлев, В. С. 1963. Изучение распределения животных в градиентных условиях среды как метод эколого-физиологического анализа [Studies on distribution of animals under gradient conditions of the environment as a method of ecological and physiological analysis]. *Trud. sevastopol. biol. Sta*, 16, 277—281 (Russian).

[Jacenko, A. T.] Яценко, А. Т. 1928a. Комбинированное влияние активной реакции, температуры и света на размножение *Chydorus sphaericus* [The combined effect of active reaction, temperature and light on reproduction in *Chydorus sphaericus*]. *Trud. Zvenigorod. Gidrofiziol. Sta*, 1928, 97—111 (Russian).

[Jacenko, A. T.] Яценко, А. Т. 1928b. Активирование культуры *Chydorus ovalis* этиловым алкоголем [Activation of the culture of *Chydorus ovalis* by ethyl alcohol]. *Trud. Zvenigorod. Gidrofiziol. Sta*, 1928, 112—123 (Russian).

Järnefelt, H. 1956—1958. Zur Limnologie einiger Gewässer Finnlands. Part XVI—XVIII. *Ann. Zool. Soc. Zool. Bot. Fenn. Vanamo*, 17 (1), 1—201, 18 (2), 1—61, 19 (5), 1—52.

[Krjučkova, N. M., Kondratjuk, V. G.] Крючкова, Н. М., Кондратюк, В. Г. 1966. Зависимость скорости фильтрационного процесса от температуры у некоторых представителей отряда ветвистоусых ракообразных [Dependence of the filtration process from temperature in some representatives of Cladocera]. *Dokl. Akad. Nauk BSSR*, 10, 120—123 (Russian).

[Manujlova, E. F.] Мануйлова, Е. Ф. 1949. К вопросу о влиянии дистрофности водоемов на фауну Cladocera [On the effect of distrophy of water-bodies on the fauna of Cladocera]. *Trud. I naučn. sesii Karelo-fin. Univ.*, 2, 86—93 (Russian).

[Manujlova, E. F.] Мануйлова, Е. Ф. 1964. Ветвистоусые рачки (Cladocera) фауны СССР [Cladocerans (Cladocera) of the fauna of USSR]. Moskva, Izdat. „Nauka" (Russian).

Rigler, F. H. 1967. *Quantitativ methods for studying the feeding of planktonic Crustacea.* Toronto, Dept. of Zool. Univ. Toronto.

[Salazkin, A. A.] Салазкин, А. А. 1966. О влиянии гумификации водоема на размеры, вес и некоторые морфологические особенности планктонных ракообразных (Cladocera и Copepoda) [On the effect of waterbody humification upon the size, weight and some morphological peculiarities of plankton crustaceans (Cladocera and Copepoda)]. *Zool. Ž., Mosk.*, 45, 1476—1480 (Engl. summ.).

[Skadovskij, S. N.] Скадовский, С. Н. 1928. Активная реакция среды в пресных водоемах и ее биологическое значение [Active reaction of the environment in freshwater reservoirs and it biological significance]. *Trud. Zvenigorod. Gidrofiziol. Sta*, 11—74 (Russian).

[Skadovskij, S. N.] Скадовский, С. Н. 1955. *Экологическая физиология.* [*Ecological physiology*]. Moskva (Russian).

[Skadovskij, S. N., Ščerbakov, A. P., Vinberg, G. G.] Скадовский, С. Н., Щербаков, А. П., Винберг, Г. Г. 1928. Предварительное сообщение о результатах гидробиологического и физико-химического исследования Петровских озер Тверской группы [Preliminary report on results of hydrobiological and physicochemical studies of Tverska group of Petrovske lakes]. *Trud. Zvenigorod. Gidrofiziol. Sta*, 215—239 (Russian).

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1. Reynoldson, 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, E. 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. soveśč. 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. 77—78. Warszawa, Komitet Hydrobiol. PAN.
5. Ekman, S. 1953. *Zoogeography of the sea.* London, Sidgwick and Jackson.
6. Beeton, A. M., Chandler, D. C. 1963. The St. Lawrance Great Lakes. In: Frey, D. C. (ed.) *Limnology in North America.* 535—558. Madison, The University of Wisconsin Press.

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