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Z. FISCHER

FOOD SELECTION IN GRASS CARP (CTENOPHARYNGODON IDELLA VAL.) UNDER EXPERIMENTAL CONDITIONS

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ABSTRACT

Study was made of food selection in grass carp against 10 plant species under experimental conditions with the availability of food at its maximum. The fish revealed rather slight preference towards any of plants examined. Three groups of food were distinguished: 1 preferable food (*Lemna minor*, *Lactuca sativa*, *Glyceria fluitans* — soft plants), 2 food evoking variable selection depending on cooccurring species (*Juncus effusus*, *Hottonia palustris*, *Potamogeton natans*), 3 avoided food (*Carex hudsonii*, *Galium palustre*, *Typha latifolia* — hard plants). It is assumed that the morphological structure of plants and the development of mouth apparatus of feeders are the factors responsible for food selectivity in young fish. The rate of consumption varies with different plants from 661.90 to 9,786.27 calories per fish per 24 hrs.

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1. INTRODUCTION

This study aims at obtaining rough data on food selection in grass carp, *Ctenopharyngodon idella* Val., against most common aquatic plants occurring in shallow waters of Poland.

The term "food selection" accepted after IVLEV (1955) is understood as a resultant of animal's preference towards a certain food as well as of the availability of this food in the environment occupied by the animal. Effort was made to eliminate the factor of availability from the experiments as much as possible in order to assess food selection which would correspond closely to pure preference.

2. MATERIAL AND METHODS

Food selection was tested in terms of IVLEV's selection index (1955), according to the formula:

$$K_i = \frac{r-p}{r+p},$$

where: r = percentage occurrence of a given food item in the total food eaten; p — percentage occurrence of this food in the food supplied to animal (or occurring in the environment when one considers the field observations).

Two types of experiments were carried out: two-plant experiments and three-plant experiments, i.e., the food consisted either of two or three plant species exposed to the fish simultaneously. In order to complete all possible combinations of 10 plants tested, 45 experiments should have been performed in the two-species series, and 120 in the three-species series*. General formulae for the numbers of combinations are as follows:

Two-species series

$$K_x = \sum_1^{x-1} n$$

Three-species series

$$K_x = (x-1) \sum_1^{x-2} n - \sum_1^{x-2} n^2$$

where x is the number of plant species (10), and n — subsequent numerals from 1 to $x-2$.

Ten treatments were made of the two-species series and 16 of the three-species series. The design of experiments is presented in Table I.

Preliminary experiments were made in order to eliminate the availability factor from the study. They aimed at defining which of various positions of plants in water is more desirable to the fish. Four variants were made with two plants, *Typha latifolia* and *Carex hudsonii*. First — both the species floated at the water surface, second — both in their natural position, third and fourth — one species in vertical position, another in horizontal. It was found that the fish fed most preferably on plants floating at the water surface. Thus this position of food was used in all further experiments.

The experiments were carried out at ambient temperatures (20—22°C) on the fish which hatched in June 1965 in fish ponds at Żabieniec near Warsaw**.

In the autumn 1965 they were brought to the laboratory, where they have been kept for the recent year in a big aquarium, 300 l of volume. During this time the fish were fed mainly with lettuce, *Lactuca sativa*, and also with *Lemna minor*, *Glyceria fluitans*, *Typha latifolia*, *Carex hudsonii*, and *Potamogeton natans*. The live weight of experimental fish ranged from 22.2 to 37.6 g. Their food selection was tested against ten commonest species of shallow waters of Poland, namely *Carex hudsonii* Rennet, *Typha latifolia* L., *Potamogeton natans* L., *Sphagnum* sp., *Juncus effusus* L., *Lemna minor* L., and *Lactuca sativa*. In spite of the fact that the latter species is not a natural food of this fish, it has been included in the diet since before the experiment the fish were fed abundantly with this plant, thus they were habituated to this food. During

* Transformation of Newton's symbol.

** I wish to express my sincere gratitude to docent Dr. P. WOLNY and K. OPU-SZYŃSKI, B.Sci. for supplying the fish for the experiments.

the experiments the fish were kept separately one from another in 15 l aquaria, well aerated. The water was changed every second day.

Table I

The consumption rates of different food components

No.	Plants			mg dry weight eaten				calories eaten			
	1	2	3	1	2	3	total	1	2	3	total
1	<i>Lactuca</i>	<i>Lemna</i>	<i>Glyceria</i>	515	748	1231	2494	1986	2737	5063	9786
2	<i>Carex</i>	<i>Juncus</i>	<i>Lactuca</i>	92	1175	504	1771	373	4617	1944	6934
3	<i>Carex</i>	<i>Lemna</i>	<i>Juncus</i>	237	253	1189	1679	961	926	4673	6560
4	<i>Juncus</i>	<i>Typha</i>	—	918	468	—	1386	3607	1983	—	5590
5	<i>Galium</i>	<i>Sphagnum</i>	<i>Juncus</i>	73	37	1076	1186	295	148	4228	4671
6	<i>Galium</i>	<i>Sphagnum</i>	<i>Glyceria</i>	1	81	1013	1095	4	323	4166	4493
7	<i>Hottonia</i>	<i>Lemna</i>	—	97	700	—	797	393	1993	—	2386
8	<i>Typha</i>	<i>Lemna</i>	—	59	835	—	894	25	3054	—	3079
9	<i>Lemna</i>	<i>Potamoget.</i>	—	749	54	—	803	2740	219	—	2959
10	<i>Typha</i>	<i>Potamoget.</i>	—	196	601	—	797	829	2460	—	3289
11	<i>Lemna</i>	<i>Juncus</i>	—	335	440	—	775	1226	1728	—	2954
12	<i>Sphagnum</i>	<i>Glyceria</i>	<i>Potamoget.</i>	16	354	397	767	64	1456	1625	3145
13	<i>Glyceria</i>	<i>Juncus</i>	—	432	276	—	708	1775	1085	—	2860
14	<i>Glyceria</i>	<i>Carex</i>	—	683	4	—	687	2809	15	—	2824
15	<i>Lactuca</i>	<i>Hottonia</i>	<i>Potamoget.</i>	398	37	225	660	1535	150	920	2605
16	<i>Carex</i>	<i>Galium</i>	<i>Potamoget.</i>	233	47	349	629	945	189	1430	2564
17	<i>Galium</i>	<i>Sphagnum</i>	<i>Lactuca</i>	0	320	293	613	0	1279	1130	2409
18	<i>Juncus</i>	<i>Hottonia</i>	—	354	251	—	605	1391	1021	—	2412
19	<i>Galium</i>	<i>Sphagnum</i>	<i>Lemna</i>	75	85	364	524	303	340	1331	1974
20	<i>Sphagnum</i>	<i>Glyceria</i>	<i>Typha</i>	73	394	39	506	292	1620	165	1077
21	<i>Galium</i>	<i>Sphagnum</i>	<i>Carex</i>	7	108	369	484	28	432	1495	1955
22	<i>Lactuca</i>	<i>Hottonia</i>	<i>Typha</i>	381	30	94	505	1470	124	398	1992
23	<i>Potamoget.</i>	<i>Juncus</i>	—	103	322	—	425	421	1264	—	1685
24	<i>Carex</i>	<i>Galium</i>	<i>Typha</i>	220	86	68	374	892	350	288	1530
25	<i>Sphagnum</i>	<i>Glyceria</i>	<i>Hottonia</i>	40	301	15	356	159	1238	61	1458
26	<i>Carex</i>	<i>Galium</i>	<i>Hottonia</i>	80	7	76	163	324	29	308	661

The food intake was measured as follows: at a given time (9:00 a.m.) a known amount of plants (their weight) was exposed to the fish. The food was supplied in excess. The similar portion was placed into another aquarium holding no fish to check whether calorific values of the plants change during the experiments. After 24 hrs, remaining plants were removed from the aquarium and for each species the following records were taken: dry weight, calorific value, and ash content. Dry weight — by drying to constant weight at 50°C, ash content — by burning in a muffle oven, calorific value — by burning in Phillipson's miniature bomb calorimeter (PHILLIPSON 1965). Similar measurements were made of the control plants. Then the portion of a given plant species eaten by fish was related to the total amount of plants eaten and expressed as percentage, finally the calorific value of this portion was calculated.

Each treatment was repeated on 10 fish simultaneously, then the results were averaged. There were 26 such treatments which allowed to infer about the food selection of the fish towards each plant species against the remaining ones.

3. RESULTS

Means of the food selection index (based on about 60 records) and those of food calorific values are shown in Table II. Grass carp revealed food preference towards only three species of the plants examined, namely to

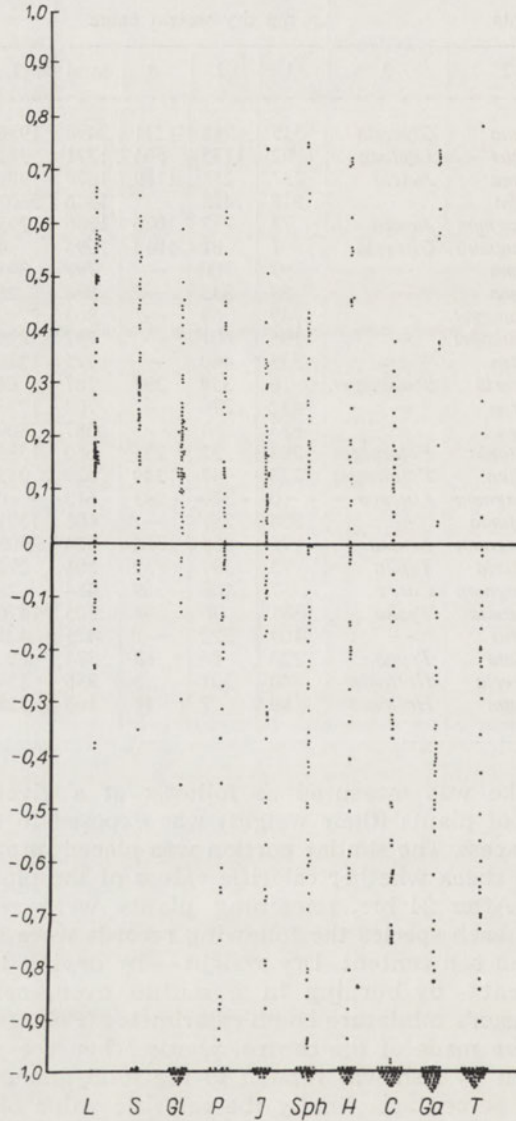


Fig. 1. Ivlev's index of preference

Each point denotes the index value for one particular experiment. L. — *Lemna minor*, S. — *Lactuca sativa*, GL — *Glyceria fluitans*, P — *Patomogeton natans*, J — *Juncus effusus*, Sph — *Sphagnum* sp., H — *Hottonia palustris*, C — *Carex hudsonii*, Ga — *Gallium Palustre*, T — *Typha latifolia*

Lemna minor, *Lactuca sativa*, and *Glyceria fluitans*, the latter being hardly selected. The fish avoided the remaining plants. From Table II it can be easily seen that there was no specially preferable food in the grass carp diet. The values of Ivlev's food selection index oscillate around zero, thus the food selection is not conspicuous. There is no correlation between selected food and its calorific value.

From the data presented in Figure 1 (which comprises the results of all of the individual experiments) three groups of plants similarly preferable to the fish can be distinguished. 1. *Lemna minor*, *Lactuca sativa*, and *Glyceria fluitans* — plants selected; 2. *Potamogeton natans*, *Juncus effusus*, *Sphagnum* sp., and *Hottonia palustris* — plants differently selected, depending on the set of other species with which they were exposed to the fish; 3. *Carex hudsonii*, *Galium palustre*, and *Typha latifolia* — plants which are generally avoided. They are eaten only when exposed with the non-preferable food.

Rough data were also obtained concerning the consumption rates of different food components (tab. I).

In order to assess what percentage of the fish body is daily consumption by weight and in calories, wet weight of fish was related to dry weight of fish in a parallel culture. This culture supplied also the data on calorific value of 1 mg dry weight of grass carp body. The calculated averages for one individual were the following: wet weight — 21.690 g, dry weight — 40.508 g, calorific value — 163.016 cal. Depending on the set of food components the daily food intake as percentage of body weight varied conspicuously from 4.2% to 61.5%, and in terms of calories from 4.5% to 60.0%.

4. DISCUSSION

Previous studies on feeding behaviour of grass carp dealt mainly with qualitative composition of its food (BORUCKI 1952, JÄHNICHEN 1967, KRUPAUER 1967, STROGANOV 1955, VERIGIN 1961, 1963, and others). Few authors (STROGANOV 1955, ŁUKANIN 1959, and others) reported on the rate of consumption most often expressed as percentage of the body weight to the food eaten. The problem of food selection has been rarely dealt with, mostly on the basis of analysis of intestine contents of fish taken from natural environment. It is obvious that the selection of food will depend on many factors, such as degree of satiation of fish with food, and in the first place on the composition of food available. It is often found that under unfavourable food conditions, the food which normally has been avoided becomes a main diet component. That is why experiments on food selection should be carried out under possibly optimal feeding conditions.

The present experiments proved rather weak selection in the fish examined. *Lemna minor*, *Lactuca sativa*, *Glyceria fluitans* were the only preferable plants. VERIGIN (1961) JÄHNICHEN (1967), and KRUPAUER (1967) have mentioned the feeding behaviour of grass carp; and GAJEVSKA (1966 — after NAKAMURA 1958), JÄHNICHEN (1967) and KRUPAUER (1967) reported on *Glyceria fluitans* as food of these fish. The authors mentioned above considered these plants as food eaten thoroughly and eagerly.

Although the experiments in this paper were designed to eliminate food availability, nevertheless this factor had some effect on the results of this study. Since the availability of food depends to a certain extent on morpho-

logical features both of the mouth apparatus and of the plants eaten. This appears to be a main reason for relatively high selection of *Lemna minor*. The experimental fish were rather small as compared with adults of this species, and their pharyngeal teeth were weak and small so that most preferable food were soft plants. Similar soft structure was of the remaining preferable plants: *Lactuca sativa* and *Glyceria fluitans*. JÄHNICHEN (1967) wrote that the morphological structure of plants, their hardness or softness, is decisive whether a given species is eaten or avoided. He emphasized that young reeds are most willingly eaten as compared to old ones. This factor is, however, not the only one which affects food selection of grass carp. Structure of *Sphagnum* sp. and *Hottonia palustris* is also delicate but these plants were not chosen by fish. (Fig. 1). Hard plants such as *Carex hudsonii* and *Typha latifolia* were eaten unwillingly. One can find very often in the literature that fish feeds on such aquatic plants as *Typha latifolia*, *Potamogeton natans* and *Carex hudsonii* (VERIGIN 1961). Especially *Typha* is often mentioned as preferable food. It is well known that food of grass carp changes with its development, (SCHEER, JÄHNICHEN, GRAHL 1967, PENZES and TÖLG 1966), as well as with temperature, and feeding conditions (STROGANOV 1963).

It is often the case that authors who deal with feeding habits of grass carp do not specify neither biology of fish, nor conditions of their habitat. That makes their data uncomparable.

The tentative results of food intake of grass carp, given in Table I, are similar to those obtained by ŁUKANIN (1959) in spite of the fact that Łukanin expressed the food intake in terms of wet weight and as the ratio of this weight to the wet weight of feeder's body. The consumption rate in present study when expressed in terms of wet weight varies from 15% to 180% of the wet weight of fish body, and in Łukanin's data: 80—120%.

In general, the consumption rate of grass carp is high, which corresponds to the data available in literature on this subject (STROGANOV 1955), but one should presume that food assimilation is low (HICKING 1966). This renders to this species a special importance as a rotator of energy in natural environment. This role of grass carp was stressed by PENZES and TÖLG (1966).

Table II

Food selection, calorific value and ash content of different food components

Plant	Ivlev's index (mean) K	Standard error	Calorific value of 1 mg dry weight	Ash content (%)
<i>Lemna minor</i>	+0.222	0.0342	3.6582	17.0
<i>Lactuca sativa</i>	+0.217	0.0445	3.8570	15.0
<i>Glyceria fluitans</i>	+0.008	0.0497	4.1128	10.0
<i>Potamogeton natans</i>	-0.109	0.0572	4.0925	17.0
<i>Juncus effusus</i>	-0.128	0.0485	3.9294	13.0
<i>Sphagnum</i> sp.	-0.232	0.0583	3.9963	7.3
<i>Hottonia palustris</i>	-0.346	0.0727	4.0630	10.0
<i>Carex hudsonii</i>	-0.498	0.0564	4.0542	3.0
<i>Galium palustre</i>	-0.540	0.0615	4.0542	10.0
<i>Typha latifolia</i>	-0.610	0.0524	4.2368	5.7

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5. SUMMARY

Analysis was made of the food selection of grass carp against 10 plant species under experimental conditions with the availability of food being at its maximum. Ivlev's method was applied. Young fish (about 1 year old) weighing about 21 g each showed a slight selection towards the plants examined (Tab. 1). The highest selectivity was found towards plant species of soft structure (*Lemna minor*, *Lactuca sativa*, and *Glyceria fluitans*). Variable selectivity was shown by fish towards: *Juncus effusus*, *Hottonia palustrae*, *Potamogeton natans*, and *Sphagnum* sp., depending on set of species with which they were exposed to fish at a given experiment. On the other hand, plants with hard and rigid structure: *Carex hudsonii*, *Galium palustrae*, and *Typha latifolia* — were clearly avoided. It can be assumed that the morphological structure of food and the degree of development of mouth apparatus of young fish are the important factors in food selection.

Rate of consumption was ascertained for grass carp with different plants species fed to the fish. The daily consumption varies from 661.90 to 9,786.27 calories, 5,224.85 on the average.

6. STRESZCZENIE

Badano wybiórczość pokarmową białego amura wobec 10 gatunków roślin w warunkach eksperymentalnych, przy maksymalnej dostępności pokarmu. Wybiórczość pokarmową określano metodą Ivleva. Młode ryby (wiek około 1 roku) wagi około 21 g wykazują małą wybiórczość pokarmową wobec użytych do doświadczeń roślin. (tab. 1) Największa wybiórczość wystąpiła wobec roślin o miękkiej strukturze (*Lemna minor*, *Lactuca sativa*, *Glyceria fluitans*). Wybiórczość zmienna, zależna od zestawu gatunków roślin współpodanych występowała u: *Juncus effusus*, *Hottonia palustris*, *Potamogeton natans*, *Sphagnum* sp. Natomiast rośliny o strukturze twardej i sztywnej — *Carex hudsonii*, *Galium palustre*, *Typha latifolia* — były wyraźnie unikane. Można przypuszczać, że u młodych ryb jednym z czynników decydujących o wybiórczości jest budowa i stopień wykształcenia aparatu gębowego.

Uzyskano też dane dotyczące się racji pokarmowej białego amura przy pokarmie składającym się z różnych gatunków roślin. Wielkość oznaczonej racji dobowej wynosi od 661.90 do 9786.27, średnio 5224.85 cal.

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K. WIKTOR

SEASONAL MODIFICATIONS IN FERTILITY OF SOME ROTIFERA SPECIES

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ABSTRACT

An analysis is given of the seasonal changes in mean number of eggs attached to the female as well as the incidence of egg-carrying females in the total population of various species of rotifers. Changes in fertility recur regularly from year, and are rather specific to each species. In *Keratella quadrata* and *K. cochlearis* and less distinctly in *Brachionus angularis* and *B. calyciflorus* the highest fertility occurred in spring, accompanied by both an increase in the number of eggs carried by one female and a larger incidence of egg-carrying females in these populations. At the highest population density, the incidence of egg-carrying females diminished. Changes in population numbers in the remaining seasons could not be paralleled with modified fertility.

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1. INTRODUCTION

Rotifera, though they occur as mass-population of eutrophic pools and ponds, have been subjected as yet to only few investigations. Recently, however, this group seems to have awakened some interest, though investigations mostly focussed on such problems as the species composition of the population or seasonal changes taking place in its concentration in water bodies of various types; investigations on the biology of rotifera as well as of the reaction of particular species to various environmental factors are still scarce.

The present paper may constitute a contribution to the elucidation of the role of rotifera in water biocenoses by presenting the results of observations of seasonal changes in fertility of some Rotifera species.

2. MATERIAL AND METHODS

The observations were performed on materials collected in 1956, as well as in 1962—1964, in the central basin of the Szczecin Bay. Those materials were gathered at the time mostly in order to follow the development variations in

zooplankton of particular years, but they also supplied bases for certain observations relating to the fertility of some Rotifera species. Sampling was done by means of a plankton net, Apstein type (of inlet: 20 cm., length of filtering part: 75 cm., material: milling gauze No. 20), every year from april to december, at fortnight long intervals. The coefficient of filtration was estimated three times in the course of the year, and results compared between sampling obtained by means of the plankton net and those obtained from a Patalas sampler.

Investigations were applied to merely a few Rotifera species, namely to those which fulfilled three main conditions: that of mass occurrence in the Szczecin Bay, of presence in these waters during the major part of the year (in spite of important seasonal numerical changes) and of carrying by the females of their summer eggs attached to the faecal exit. These conditions are fulfilled in the Szczecin Bay by the following species: *Keratella cochlearis* (GOSSE), *Keratella quadrata* (MULLER), *Keratella cochlearis tecta* (GOSSE), *Brachionus angularis* (GOSSE) and *Brachionus calyciflorus* Pallas.

Following items were taken into account while preparing the materials:

- 1) the mean number of eggs carried by one female
- 2) the percentual amount of females with eggs in one given sample
- 3) the mean number of eggs carried by one thousand females in the given sample.

Attention was also focused on the question, whether any correlation exists between the three above mentioned parameters and numerical changes in representatives of the particular species.

3. RESULTS

A. NUMBER OF EGGS CARRIED BY ONE FEMALE

The number of eggs attached to the mother organism oscillates in wide limits in rotifera, not only in dependence of the species but also within boundaries of single species, where females may be found with various amounts of attached eggs.

Females of the three above mentioned species from the *Keratella* genus, namely *K. cochlearis*, *K. quadrata* and *K. cochlearis tecta* carry as a rule no more than one egg, attached to the faecal exit. Sometimes, however, it is possible to meet a certain per cent of females of these species carrying a larger amount of eggs. (Fig. 1, Fig. 2). The maximum amount of eggs carried by one female of *K. quadrata* did not exceed 4 in my own experiments, in *K. cochlearis* it was 3, and in *K. tecta* — 2. In the waters of the Szczecin Bay females of *Keratella quadrata* and *K. cochlearis* carrying more than one egg are met mostly in the spring months, from the end of march to the middle of may, at the starting development period of the population (table I). At that time, the per cent of females carrying more than 1 egg amounted from 0.8 to 75%.

Beside, I happened to meet single *K. quadrata* females with the eggs attached to the faecal exit in the autumn (September — December). The eggs are then placed one above the other between the lower processes of the crust.

In case when the females as well of *K. quadrata* as of *K. cochlearis* carry more than one egg, those eggs differ by their stage of development, as may be seen in Fig. 1.

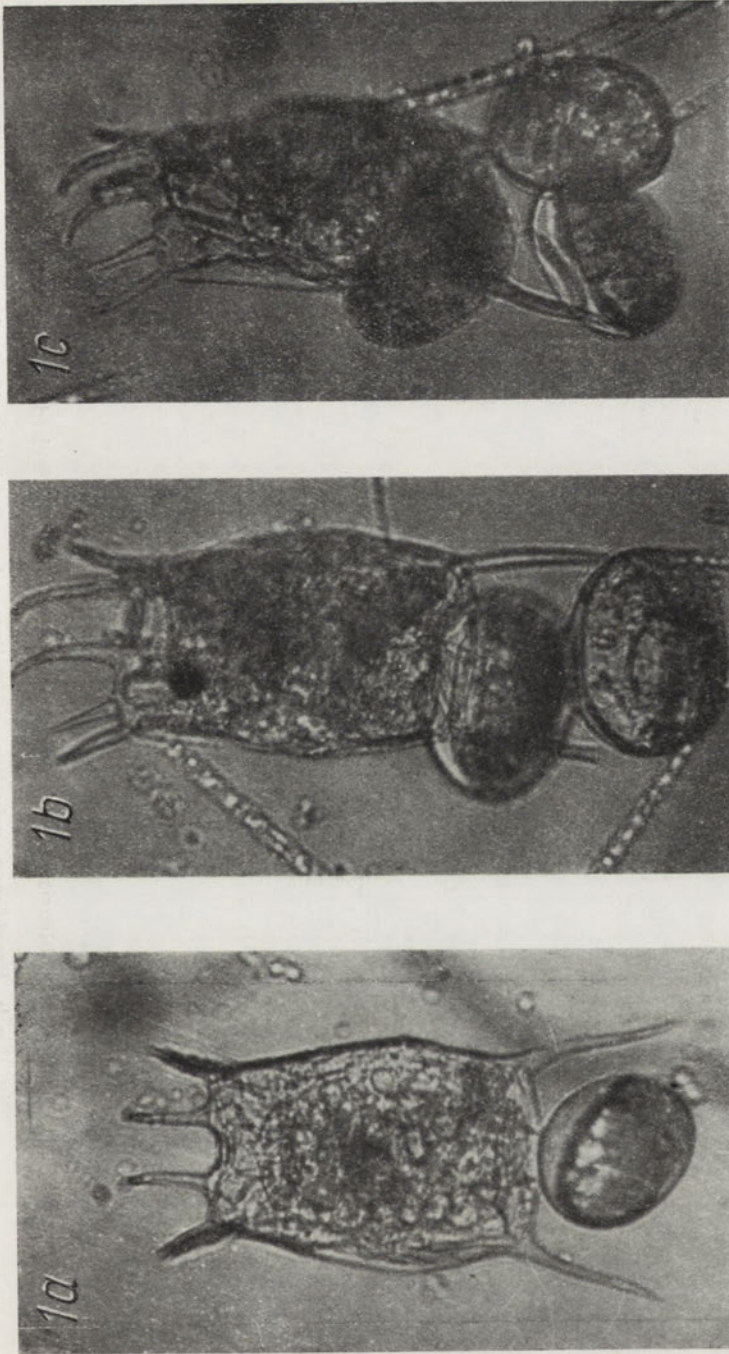


Fig. 1 a, b, c *Keratella quadrata* (Müller) female carrying eggs attached to the faecal exit (photo J. Wiktor)

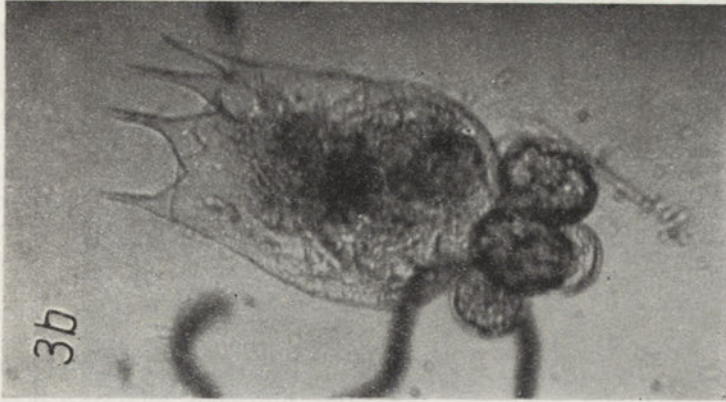
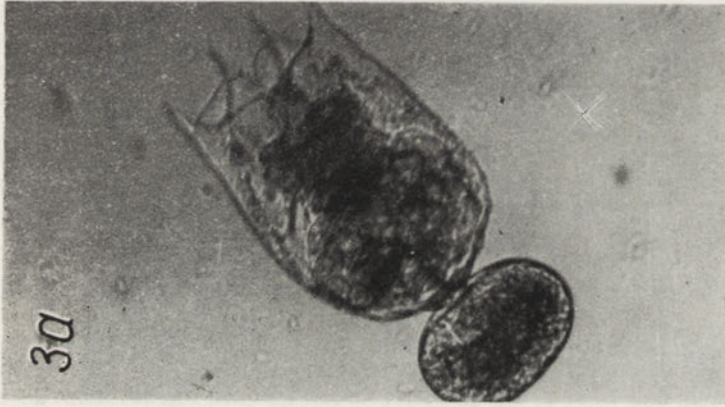
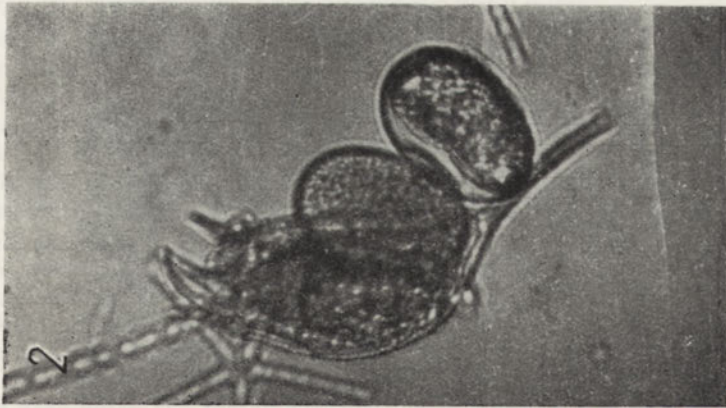


Fig. 2. *Keratella cochlearis* (Gosse) female with two eggs attached to the faecal exit (photo. J. Wiktor).

Fig. 3 a, b *Brachionus calyciflorus* (Pallas) — female with attached eggs (photo J. Wiktor).

The highest number of eggs carried by one female of *Keratella cochlearis tecta* amounted to 2. The per cent of females carrying more than one egg was, however, very small (0.8—1.5). Moreover, they appeared exclusively at the end of June or in the first half of July, at the time when the population had already reached an important number.

A comparatively large number of eggs, sometimes up to 8, are met with in females of *Brachionus calyciflorus* (table I). In one and the same sample, however, it is possible to meet individuals with various amounts of eggs (Fig. 3). Females of that species, carrying numerous eggs, may be met with in the waters of the Szczecin Bay as a rule at periods of large concentration of the population, in spring and summer months (May, June, July). In autumn months (September—December) the females of this species carry only one egg as a rule, of rather large dimension (Fig. 3). These could be mainly durable eggs.

The number of eggs attached to the body of the female in *Brachionus angularis* amounts to from 1 to 5, increasing in spring months (April, May) as compared with the remaining seasons of the year (table I). This, however, is not the absolute rule, as it was observed in 1962 that samples collected in August and September, contained females carrying from 2 to 5 eggs, where as the females of this species caught in the spring of the same year carried only a single egg each.

The performed investigations permit to establish that the largest of eggs attached to the mother organism are noted in the above mentioned species in the spring or early summer, i.e. in the first developmental phase of the given year's population. These observations are in good agreement with those concerning seasonal changes in the number of eggs carried by other plankton individuals, met with in our waters, as e. g. *Copepoda* (CZECZUGA 1960), *Cladocera* (WIKTOR 1961), *Neomysis vulgaris* (WIKTOR 1960).

It is difficult to decide presently which factor regulates the amount of eggs laid, or carried by one female of the given species at a given time. It is not the temperature of the water which could play here a decisive role. It is true that the temperature of water (as experienced by EDMONDSON 1960) plays a major role as to the speed of development and frequency of laying. However, it is not the only factor involved.

As was mentioned before, the females of *Brachionus calyciflorus*, or *B. angularis* carrying several eggs as well in May, when the water temp. is relatively low (12°—14°C), as in July, a month of much higher water temp. (18°—22°C. — Fig. 4). (WIKTOR, ZEMBRZUSKA 1959). EDMONDSON (1960) suggests that a certain effect on egg-laying and their number in rotifers may be exerted by the kind and amount of food they can dispose of, analogically to what was established in respect to other groups of plankton animals, like *Calanoida* (MARSHALL ORR 1952), or *Cladocera* (MANUILOVA 1953). No observations, however, have been made as yet conforming this assumption in relation to rotifera.

The species of rotifers discussed here present heterogeny, and the summer eggs laid by amictic females do not differ outwardly (if not by size) from eggs yielding males. Sometimes only, the number of the latter, attached to the mother-organism is larger than that of eggs, producing females (REMANE 1962). I did not check in my own materials the appearance of males of the above species, though it might have been possible that they appeared in the plankton, but were not put down. This may happen, as the dimensions of

the males are much smaller than those of females, and their life-span is much shorter (a few to several days). It may therefore not be excluded, that they were not represented in the material collected with a plankton net,

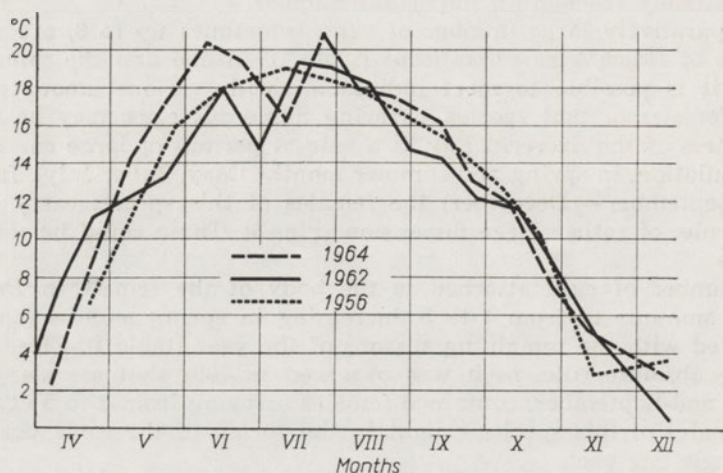


Fig. 4. Temperatures of surface waters of the Szczecin Bay in 1956, 1962 and 1964.

because of their minute size, or else — which is less probable — the frequency of sampling was insufficient, in so far that the total life — span of males remained within the limits of the period contained between two successive samplings. Males make their appearance at various seasons. According to WISZNIEWSKI (1953) the *Brachionus angularis* males appear in April, those of *B. calyciflorus* — in June and in the autumn.

B. PERCENTUAL PARTICIPATION OF FEMALES WITH ATTACHED EGGS IN THE POPULATION

The per cent of females carrying attached eggs varies in the populations of above mentioned Rotifera species. In the *Keratella quadrata* and *K. cochlearis* populations, which in the waters of the Szczecin Bay present usually two numerical peaks in the year, the highest per cent of eggs-carrying females is found as a rule in the spring months, at the period preceding the first numerical peak (Fig. 5, 6). These females constitute at that time 35—50% of the total amount of *Keratella quadrata* individuals, as well as 77% of all the *K. cochlearis* individuals. At the period of highest concentration of the population, the per cent of eggs-carrying females diminishes. It increases again in the autumn, regardless of occurrence or non — occurrence of a second, autumnal maximal concentration.

In the population of *Keratella cochlearis tecta* (Fig. 7), a species which in the Szczecin Bay attains only one numerical maximum in summer, mostly taking place in July, the highest per cent of eggs-carrying females could be established at the period preceding a rapid increase of population concentration.

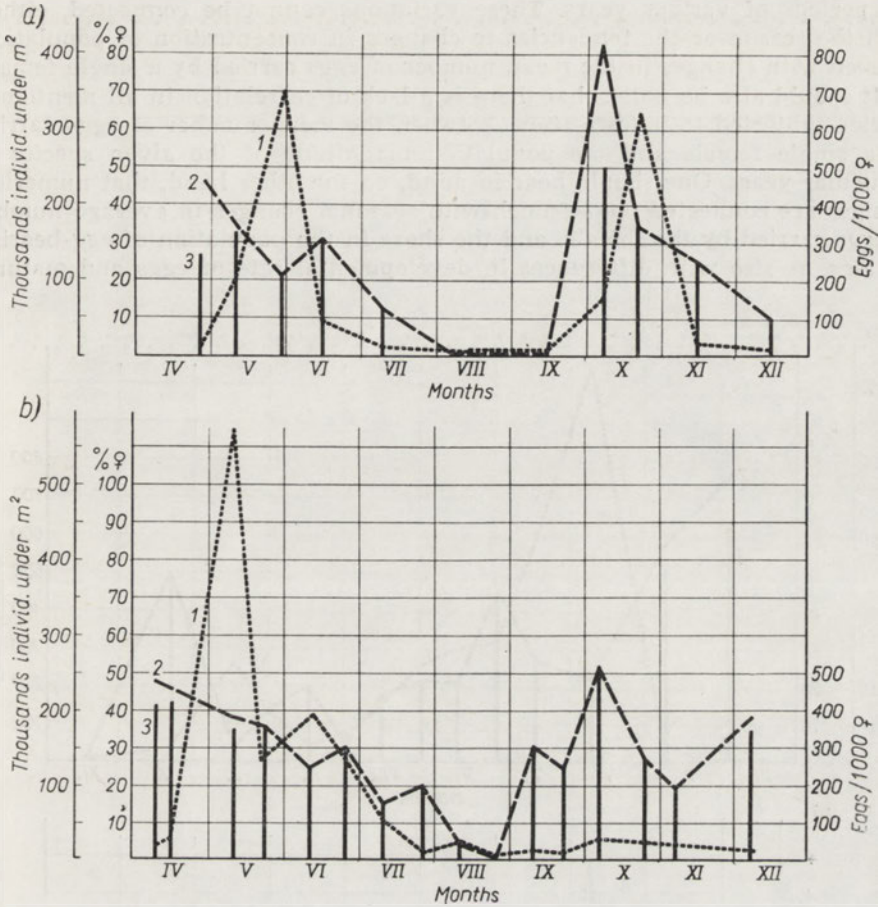


Fig. 5. Numerical seasonal changes in share of egg-carrying females, and number of eggs per one thousand females of the population *Keratella quadrata* (Müller) a) in 1956 b) in 1964; 1 — concentration of population, 2 — mean number of eggs per one thousand females, 3 — share of egg-carrying females (in per cents)

The tendencies characterizing these changes, recur fairly regularly every year, notwithstanding differences observed in climatic or physical conditions. They are presented in Figs 5, 6, 7, as exemplified by the years 1956, 1962 and 1964, of various thermal conditions (cold summer in 1956 and 1962, and hot summer in 1964 — Fig. 4).

Brachionus angularis and *Brachionus calyciflorus* (Figs 8 and 9) belong in the waters of the Szczecin Bay to species, of which the numerical changes have an irregular course. They present from one to three numerical peaks in the course of the year, varying not only from year to year but from month to month. These changes could not possibly be connected so far with physico-chemical environmental factors.

The per cent of egg-carrying females is greatly variable in populations of both these species, as well in the course of one year, as in regard to correspond-

ing periods of various years. These variations cannot be connected, either, with the season or the tendencies to changes in concentration of population, or even with changes in the mean number of eggs carried by a single female.

It should also be noted that there is a lack of correlation in all mentioned species subjected to investigation, between the mean number of eggs carried by a single female and the population magnitude of the given species in particular years. One should bear in mind, on the other hand, that numerical changes are connected not so much with seasonal changes in average number of eggs carried by the female, and the share in the population of egg-bearing females, as also with differences in developmental rate of eggs and matura-

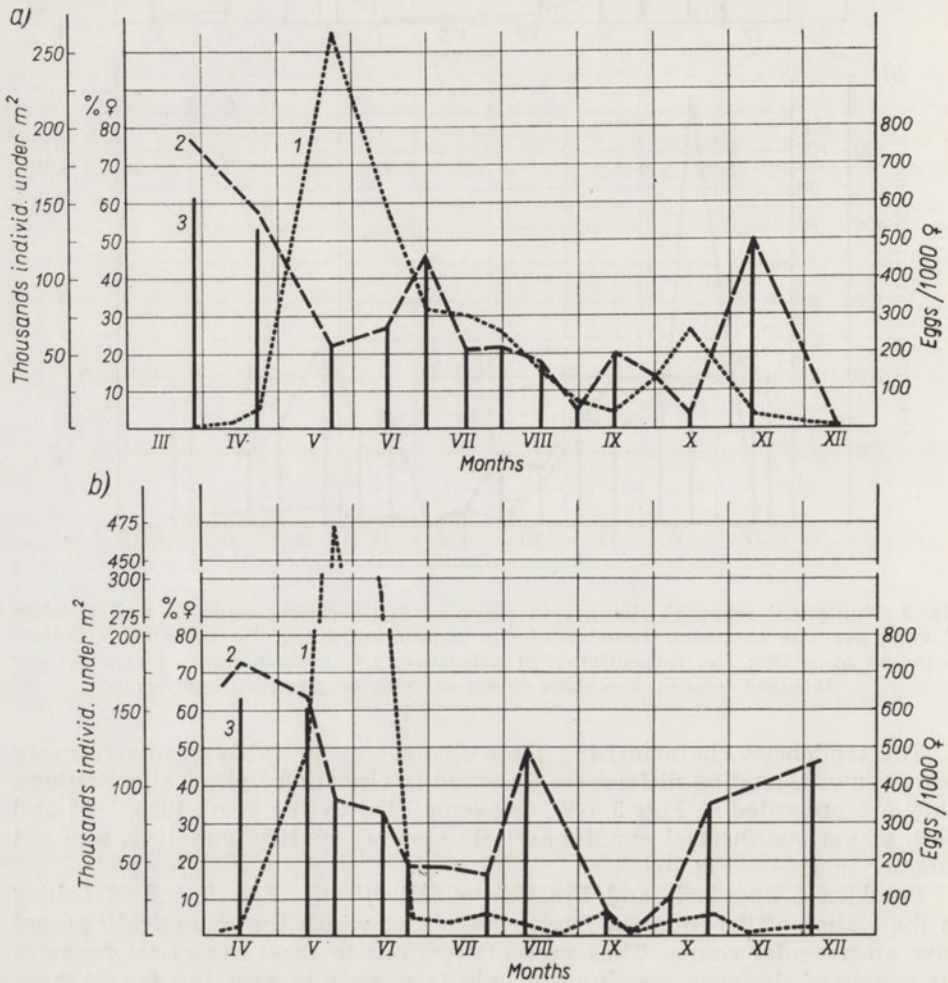


Fig. 6. Seasonal numerical changes of egg-carrying females share, as well as number of eggs per one thousand females of the *Keratella cochlearis* (Gosse) population

a) in 1962 b) in 1964 (denotations as in Fig. 5)

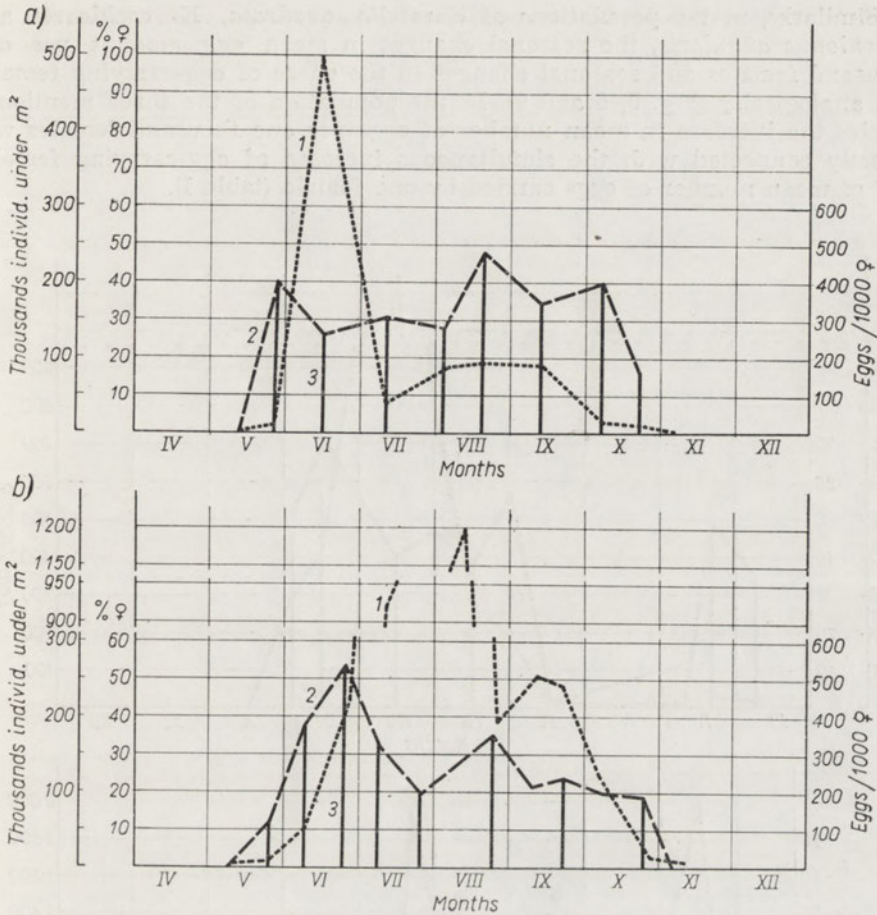


Fig. 7. Seasonal numerical changes of egg-carrying females share, as well as number of eggs per one thousand of *Keratella cochlearis tecta* (Gosse) population a) in 1956 b) in 1964 denotations as in Fig. 5)

tion of individuals, which properties depend in a high degree on factors of external environment.

C. AVERAGE NUMBER OF EGGS PER ONE THOUSAND FEMALES

The mean number of eggs per one thousand individuals in a given sample may be considered as the index of progenitive strength of the population.

In the case of *Keratella cochlearis tecta*, a species whose females carry as a rule merely one egg, attached to the mother-organism, the mean number of eggs per one thousand females depends entirely upon the share in the population of egg-carrying females. Thus the seasonal changes in both these parameters have an analogous course (Fig. 7.).

Similarly, in the populations of *Keratella quadrata*, *K. cochlearis* and *Brachionus angularis*, the seasonal changes in mean egg amount per one thousand females and seasonal changes in the share of egg-carrying females run analogically (Fig. 5, 6 and 8). In the population of the three mentioned species the increase in mean number of eggs per one thousand females was directly connected with the simultaneous increase of egg-carrying females and of mean number of eggs carried by one female (table I).

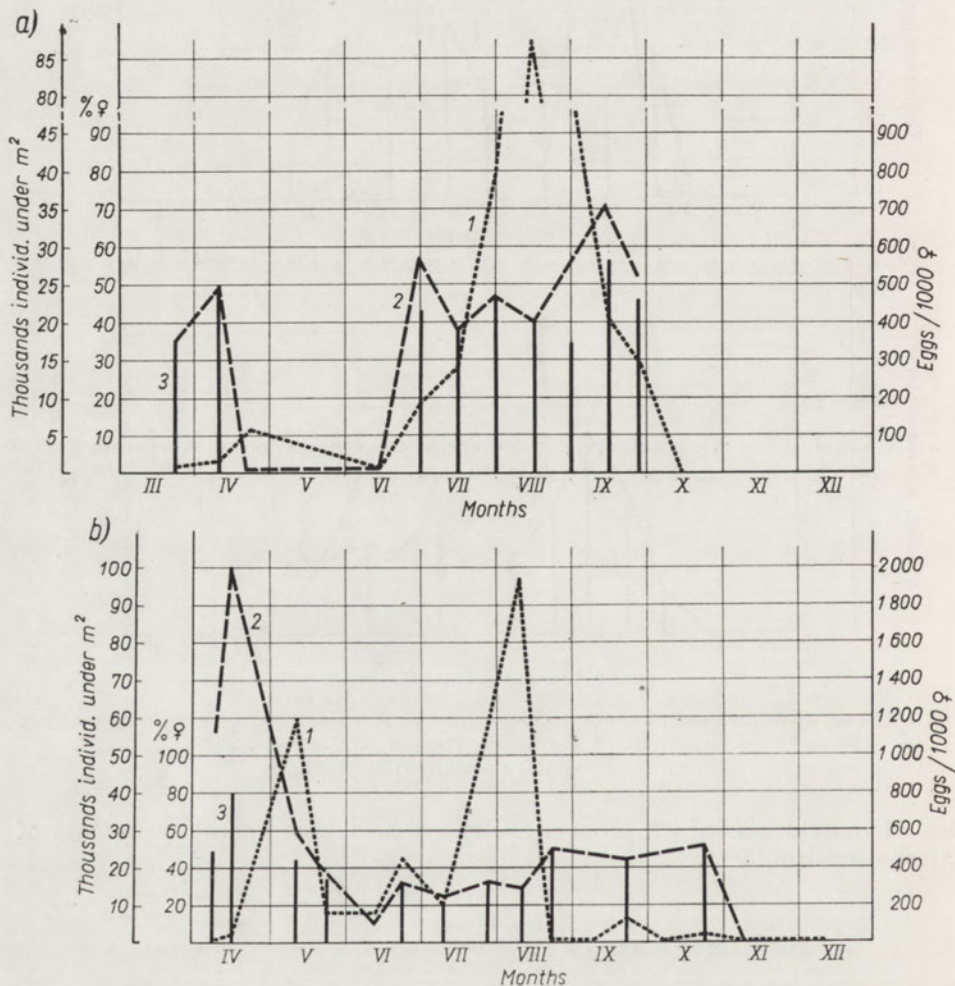


Fig. 8. Seasonal numerical changes in egg-carrying females as well as number of eggs per one thousand females of *Brachionus angularis* (Gosse) population
a) in 1962 b) in 1964 (denotations as in Fig. 5)

In the populations of both species of the genus *Keratella* i.e. *Keratella quadrata* and *Keratella cochlearis*, the index: mean number of eggs per one thousand females reached its greatest importance in the spring months, at

the period preceding the first yearly peak of concentration of the population. In *K. quadrata* population a renewed increase of the mentioned index could be observed also in the autumn (September — October).

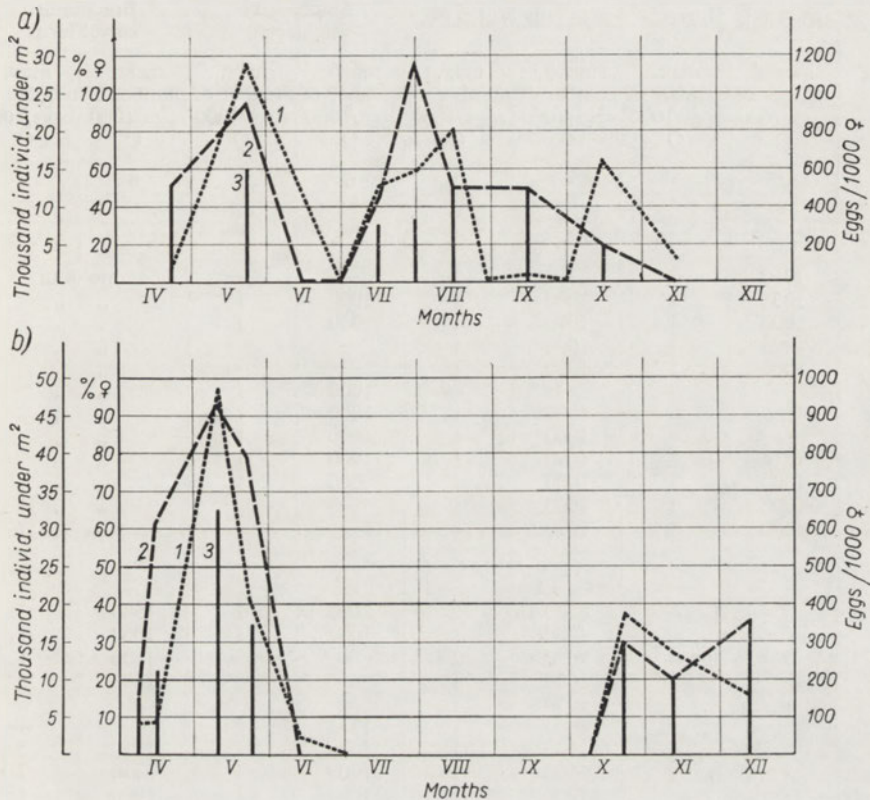


Fig. 9. Seasonal numerical changes of egg-carrying females share as well as number of eggs per one thousand females of *Brachionus calyciflorus* (Pallas) population a) in 1962 b) in 1964 (denotations as in Fig. 5)

Things take a slightly different course (as compared with the above discussed species) in *Brachionus angularis* with respect to seasonal changes concerning the mean number of eggs per one thousand females, varying from year to year. It is true that the index: number of eggs per one thousand females continually reached high values in the spring months (April — May), but in the summer it oscillated within wide limits, attaining maximal values in successive years in various seasons (Fig. 8).

In the case of *Brachionus calyciflorus*, a species of which the female carries often a large amount of eggs (Fig. 7—8, table I), the index of number of eggs per one thousand females reaches often the highest values at times when the share of egg-bearing females decreases. This indicates that in that size of the index related rather to the average amount of eggs borne by one female, than to the share in the population of eggs-bearing females (Fig. 9), and in the population of this species in the waters of the Szczecin Bay it reaches:

Table I

Seasonal changes in mean and maximal number of eggs carried by a single female of some Rotifera species

Data	Keratella quadrata		Keratella cochlearis		Brachionus angularis		Brachionus calyciflorus	
	mean number of eggs/1000	max. number of eggs/1000	mean number of eggs/1000	max. number of eggs/1000	mean number of eggs/1000	max. number of eggs/1000	mean number of eggs/1000	max. number of eggs/1000
	♀	♀	♀	♀	♀	♀	♀	♀
1	2	3	4	5	6	7	8	9
1956								
26.4.	1750	2	1362	2	—	—	no data	
11.5.	1035	2	1000	1	1000	1	''	''
28.5.	1000	1	1000	1	1000	1	''	''
14.6.	1000	1	1000	1	—	—	''	''
10.7.	1000	1	1000	1	—	—	''	''
5.8.	—	—	—	—	1000	1	''	''
23.8.	—	—	1000	1	1000	1	''	''
14.9.	—	—	1000	1	1000	1	''	''
6.10.	1214	2	1000	1	1000	1	''	''
22.10.	1000	1	1000	1	1000	1	''	''
16.11.	1000	1	1000	1	—	—	''	''
16.12.	1000	1	1000	1	—	—	''	''
1962								
24.3.	no data		1200	2	1000	1	1500	3
11.4.	''	''	1000	1	1000	1	1000	1
24.4.	''	''	1070	2	—	—	1000	1
25.5.	''	''	1000	1	—	—	1583	5
15.6.	''	''	1000	1	—	—	—	—
30.6.	''	''	1000	1	1333	2	—	—
16.7.	''	''	1000	1	1000	1	1750	5
30.7.	''	''	1000	1	1000	1	2666	7
14.8.	''	''	1000	1	1000	1	1000	1
30.8.	''	''	1000	1	1555	5	—	—
15.9.	''	''	1000	1	1250	2	1000	1
28.9.	''	''	1000	1	1166	2	—	—
15.10.	''	''	1000	1	—	—	1000	1
13.11.	''	''	1000	1	—	—	—	—
17.12.	''	''	—	—	—	—	—	—
1963								
28.4.	—	—	—	—	—	—	—	—
24.4.	1038	2	1000	1	—	—	1571	2
8.5.	1236	2	1000	1	1055	2	2350	8
24.5.	1000	1	1000	2	1000	1	2666	7
14.6.	1000	1	1000	1	1000	1	1366	2
28.6.	1043	2	1000	1	1000	1	1250	2
12.7.	1000	1	1000	1	1250	2	1250	2
13.8.	1000	1	1000	1	1000	1	—	—
27.8.	1000	1	1000	1	1000	1	—	—
10.9.	1000	1	1000	1	1000	1	—	—
10.10.	1000	1	1000	1	—	—	—	—
18.10.	1000	1	1000	1	—	—	—	—
26.11.	1000	1	—	—	—	—	—	—

1	2	3	4	5	6	7	8	9
1964								
9.4.	1200	3	1000	1	2333	5	1000	1
15.4.	1090	2	1142	2	2500	3	2666	4
11.5.	1092	4	1036	2	1388	3	1434	5
24.5.	1000	1	1015	2	1000	1	2250	4
12.6.	1000	1	1014	2	1000	1	—	—
26.6.	1000	1	1000	1	1000	1	—	—
9.7.	1000	1	1000	1	1000	1	—	—
27.7.	1000	1	1000	1	1000	1	—	—
10.8.	1000	1	1000	1	1035	2	—	—
26.8.	—	—	—	—	1000	1	—	—
11.9.	1000	1	1000	1	—	—	—	—
24.9.	1000	1	—	—	1333	2	—	—
9.10.	1000	1	1000	1	—	—	—	—
27.10.	1000	1	1000	1	1000	1	1000	1
9.11.	1000	1	1000	1	—	—	1000	1
10.12.	1083	2	1000	1	—	—	1000	1

its highest values at times of greatest thickening of population. The highest values are commonly reached in May, and later, in connection with numerical changes — also in July and October (Fig. 9).

It is difficult to ascertain in how far seasonal changes in fertility of the above mentioned rotifera species, noted in the Szczecin Bay are typical for populations of these same species in eutrophic waters of the temperate zone and in how far they are specific for the waters of the Szczecin Bay, considering the lack of analogous investigations performed in other water — bodies. The Szczecin Bay, in spite of bearing the features of an eutrophic water — body of our latitudes, is still, however, a brackish — water pool and it is well known that a certain salinity — if not approximating values, critical for the given species — is rather a stimulating factor in procreation, development and growth of individuals. In consideration, however, of the fact that the salinity of the Szczecin Bay is very low (mean salinity 0,4—0,5‰ — J. WIKTOR 1960, K. WIKTOR, D. ZEMBRZUSKA 1959) so that the majority of fresh — water species find here favourable life and development conditions, it does not seem to affect basically the life functions of the representatives of the discussed Rotifera species.

4. SUMMARY

Investigations bore on the following Rotifera species: *Keratella quadrata* (MÜLLER), *Keratella cochlearis* (GOSSE), *Keratella cochlearis tecta* (GOSSE), *Brachionus angularis* (GOSSE) and *Brachionus calyciflorus* (PALLAS). Investigations were performed on materials collected in 1956 as well as in 1962—1964 in the central basin of the Szczecin Bay. Seasonal changes have been taken into consideration concerning the mean number of eggs attached to the female, as well as the share of egg-carrying females in the population of the given species and changes in the mean number of eggs per one thousand females of the given species.

Trends in fertility modifications recur fairly regularly from year to year, and are rather specific for the species. The greatest fertility is generally noted in the spring. The first numerical peak in the given species is preceded as a rule by an increase in the number of eggs carried by one female and by a larger share of egg-carrying females in the population. At the time when the population attains

its highest concentration, the share of egg-carrying females in the population diminishes. This phenomenon is distinct in *Keratella quadrata* and *K. cochlearis*, and less distinct in *Brachionus angularis* and *B. calyciflorus*. Numerical changes in population taking place in the remaining periods of the year could not be paralleled with modified fertility.

5. STRESZCZENIE

Badaniami objęto następujące gatunki wrotków: *Keratella quadrata* (MÜLLER), *Keratella cochlearis* (GOSSE), *Keratella cochlearis tecta* (GOSSE), *Brachionus angularis* (GOSSE), oraz *Brachionus calyciflorus* (PALLAS). Badania przeprowadzone na materiałach zebranych w latach 1956 oraz 1962—1964 w centralnym basenie Zalewu Szczecińskiego. Uwzględniono zmiany w średniej liczbie jaj przyczepionych do samicy, udział samic noszących jaja w populacji danego gatunku, oraz zmiany w średniej ilości jaj przypadających na 1000 samic danego gatunku.

Tendencje zmian w płodności powtarzają się dosyć regularnie z roku na rok i są raczej specyficzne dla gatunku. Na ogół największą płodność obserwuje się na wiosnę. Pierwsze w danym roku maksimum liczebności danego gatunku poprzedza zwykle wzrost średniej ilości jaj znoszonych przez jedną samicę i zwiększony udział w populacji samic noszących jaja. W okresie gdy populacja osiąga maksimum zagęszczenia, udział w populacji samic, noszących jaja maleje. Zjawisko to jest wyraźne u *Keratella quadrata* i *K. cochlearis*, słabiej występuje u *Brachionus angularis* i *B. calyciflorus*. Zmian w liczebności populacji zachodzących w pozostałych okresach roku nie da się powiązać ze zmianami w płodności.

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RESPIRATION OF THE EMBRYOS OF *SALMO TRUTTA* L.
AND *SALMO GAIRDNERI* RICH. IN MEDIA DIFFERING IN GASEOUS
DIFFUSION RATE

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ABSTRACT

In studies on the embryonic respiration in the brown trout and in the rainbow trout the highest rate of gaseous exchange was found for embryos on a wet substratum; embryos developing in non-flowing water showed a slower, and those in paraffin oil — the slowest gaseous exchange. It has been found that the exchange rate depends on the rate of O₂ and CO₂ diffusion through the medium. A lowered O₂ supply and especially an impeded release of CO₂ cause a considerable elongation of the embryonic period, and may even, as in the case paraffin oil, become the cause of the death of embryos.

For a normal course of their respiration and growth the eggs of the two fish species considered do not require large quantities of water or its flowing; they may develop even outside the aqueous medium, provided that their surface is kept permanently wet.

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1. INTRODUCTION

In the numerous studies, hitherto published, on the respiration of fish during their embryonic development little attention has been given to the importance of the thickness of the water layer above the embryos. Most often the subject of investigations was the intensity of O₂ consumption at the different embryonic stages (BATAILLON 1896, 1897; SCOTT and KELLCOTT 1916; HYMAN 1921; GRAY 1927; HAYES 1930; WOOD 1932; SCHLENK 1933; LECHLER 1933; TRIFONOVA 1935; PRIVOLNEV 1938; TRIFONOVA et al. 1939), and the exchange of O₂ and CO₂, for which the respiratory quotient (RQ) was determined at the different embryonic stages (BURFIELD 1928; AMBERSON and ARMSTRONG 1933; PRIVOLNIEV 1938). During the last 30-year period most attention was given to studying the differences in respiratory processes between the embryos, in relation to the different environmental conditions. Studies of this group were aimed primarily at establishing the optimum O₂ and CO₂ partial pressure which determines the maximum consumption of O₂ at each of the different embryonic stages (LEINER 1937; PRIVOLNIEV 1940; LINDROTH 1942; ALDERDICE et al. 1958).

Bataillon (1896), and then all the other investigators were in agreement in their views that the gaseous exchange varies with the embryonic stages (SCOTT and KELLICOTT 1916; HYMAN 1921; GRAY 1927; BURFIELD 1928; HAYES 1930; WOOD 1932; AMBERSON and ARMSTRONG 1933; LECHLER 1933; SCHLENK 1933; TRIFONOVA 1935; LEINER 1937; PRIVOLNIEV 1938, 1939, 1940; TRIFONOVA et al. 1939; HAYES 1949; HAYES et al. 1951; MARCKMANN 1958). There are some discrepancies in the opinions concerning the intensity of the embryonic exchange of O_2 and CO_2 . Some authors maintain that the rate of gaseous exchange grows steadily until the time of hatching out (GRAY 1927; WOOD 1932; LECHLER 1933; SCHLENK 1933; PRIVOLNIEV 1938, 1939), while others think that the oxygen consumption curve turns down at the stage of blastopore closure (KAVAJIRI 1925; TRIFONOVA 1935; TRIFONOVA et al. 1939) or at the time when blood circulation is being established (HYMAN 1921; AMBERSON and ARMSTRONG 1933), and then in the period immediately before hatching (HAYES 1930; AMBERSON and ARMSTRONG 1933; HAYES et al. 1951).

According to TRIFONOVA (1935), the absolute O_2 consumption in *Perca fluviatilis* L. embryos does not increase steadily, but abruptly, lowering rapidly during gastrulation and immediately after blastopore closure. An identically abrupt change in O_2 consumption was observed in the embryos of other fish species by TRIFONOVA et al. (1939), KOROLIEVA a. FIODOROVA (1951), and by VERNIDUB (1956). The above authors relate this situation to the critical moments in the embryonic growth, connected with an intensified morphogenesis.

In their studies LINDROTH (1942), DYK (1942), HAYES et al. (1951), MARCKMANN (1958), KORZUJEV et al. (1960) did not find such relationships to support this view.

The removal of CO_2 by the embryos was less extensively studied. The knowledge of this side of the turnover of gas is important in as much as it permits the determination of the respiratory quotient.

BURFIELD (1928) determined RQ in *Platessa platessa* (L.) obtaining a value of 0.75. SCHLENK (1933) has found that the RQ value at the morula stage of *Salmo gairdneri* Rich. exceeds unity. PRIVOLNIEV (1939, 1940) reports that in his experiments with 5 fresh-water fish species, whose development he studied, the RQ value immediately after fertilization was relatively low and appeared to grow with the growth of the embryos. The results reported by AMBERSON and ARMSTRONG (1933) from *Fundulus heteroclitus* (L.) have shown that on the first day after fertilization RQ value was 0.90, during the establishing of blood circulation — 0.77, during the mobile-embryo stage — 0.70, and at the end of the embryonic growth — 0.74 and more.

Experiments have also been carried out to describe the effect of an increased O_2 partial pressure on the consumption of O_2 .

LEINER (1937) found in the eggs of *Hippocampus europaeus* (Ginsburg) an increased O_2 consumption, directly proportional to the partial pressure of O_2 in the medium.

In his experiments with 3 fish species PRIVOLNIEV (1938, 1940) found that embryos kept in pure oxygen took more O_2 than did those which developed in the normal air. This finding has further been confirmed by the experiments carried out by LINDROTH (1942) with the eggs of *Salmo salar* L. and *Esox lucius* L.

The other side, as it were, of this problem is the respiration of fish embryos in a medium with a decreased oxygen content.

As has been proved by KULMATYCKI (1925), *Salmo trutta m. fario* may hatch from eggs incubated in sealed vessels with a limited amount of water, but the growth under these conditions is longer than under the normal ones (up to 600 degree-days or more), and the larvae that hatch from these eggs are much smaller than those hatched from eggs incubated in flowing water. The total amount of O_2 taken up by the embryo during its growth is much smaller than reported by WOOD (1932) and SCHLENK (1933). Similar results were obtained from studies on *Salmo gairdneri* Rich. eggs by DOMURAT (1948), who kept the eggs in non-flowing water in open vessels. He found that the thinner the water layer above the eggs was, the faster and better the growth proceeded.

It might, therefore, be presumed that this relationship is connected with the rate of O_2 diffusion through the layer of water. As the O_2 diffusion from the oxygenated surface water is slow (acc. Krogh's calculation, the oxygen diffusion in water is about 300 000 times slower than in the air (KROGH 1941), the O_2 content in the water around the egg surface decreases rapidly and there develop conditions affecting the intake of this gas by the embryo.

It seems likely that eggs placed on a wet substratum, i.e. covered by only a thin layer of adhesive water, which protects them from drying out, would have optimum conditions of O₂ access to their surface and CO₂ release into the atmosphere.

BADER (1937), LEDEBUR (1939), VOYNAROVICH (1955), HARRINGTON and HAEGER (1958), and BIELYJ (1959) reported that the development of fish eggs could go on outside the aqueous medium, provided their surface was kept wet. They did not, however, study the gaseous exchange. WINNICKI (1959) succeeded in hatching the brown trout and the rainbow trout from eggs incubated on a wet substratum.

2. MATERIAL AND METHODS

Since by Winkler method, used for studying the gaseous exchange in fish, it is only possible to determine the O₂ consumption, and in the Warburg method only a relatively small number of eggs can be examined for only a short time, not to mention the main disadvantage of this method — the shakes and the necessity to handle the eggs, it was decided to work out a method that would allow of: a) a simultaneous determination of oxygen consumption and carbon dioxide removal; b) using large material for experiments; c) continuation of experiments with the same material without having to handle the eggs in connection with transferring them to the respiratory chambers; d) a longterm study of the gas turnover (for periods of over 20 hours instead of for several hours).

The method worked out by the author of the present paper fulfils all the above conditions. It is based on a system of closed respiratory chambers, and on the use of Haldane apparatus for the determination of O₂ and CO₂ contents in the air contained in the chambers. The respiratory chambers used were rectangular plexiglass boxes, about 1200 cm³ in volume. Before covering a chamber with a glass plate the ground surfaces of its top edges were covered with vaseline.

In the chambers with eggs incubated in paraffin oil the layer of oil covering the floor was 1 cm thick.

To prevent the eggs from lying too close together and from rapid rolling during the tilting of the chamber, each of the chambers with eggs incubated in water was partitioned into 6 compartments. Partitions were not needed in the chambers with paraffin oil on account of the considerable viscosity of the latter. In chambers with waterincubated eggs the water layer covering the floor was 1 cm thick.

In the third group (wet substratum) the floor of the chambers was covered by a 1 cm-thick layer of water on which a float was placed with a piece of filter paper on it. The ends of the paper on both sides of the float were immersed in the water.

In groups 1 and 2 (paraffin oil and water, respectively) the brown trout eggs were lying on the floor of the chambers with a 5–6 cm thick layer of the liquid above them. In the third group the eggs were placed on the filter paper that covered the float. They had, therefore, sufficient humidity throughout the embryonic growth. Before being placed in paraffin oil eggs were dried by being rolled several times over a sheet of dry filter paper.

In the experiments with the rainbow trout the same procedure was used except that the liquid layer above the eggs was here thicker (6–6.5 cm), as a result of the smaller size of the eggs of this species.

At the beginning, gas samples for analysis were taken at intervals of several days, and at the end of the experiments — every day, because towards the end of the embryonic growth the respiratory exchange is many times greater than during the first stages.

The gas analysis was carried out by the method described by Haldane, using potassium base (for CO_2) and the alkaline solution of pyrogallol (for O_2) as absorbers. The determined amount of oxygen, and the amount of carbon dioxide expelled by all the eggs in the chamber were then calculated per one egg per hour, and per 24 hours.

In the experiments with the brown trout eggs the temperature varied from 8.5 to 11°C (mean 9.5°C), and in the experiments with the rainbow trout — 9.5—11.5°C (mean 10°C).

In the spring of 1960 Warburg method was used for estimating the oxygen consumption in the experiments with the rainbow trout eggs. This method allowed of a more precise description of the respiratory turnover during the period of blastopore closure, and immediately after it, which could not be done with the method of Haldane.

The eggs were placed in 30 ml basins with 1 cm-thick layers of water or paraffin oil, 30 eggs in each basin. In one of the series, instead of the liquid-layer strips of soaked filter paper were used and the eggs were put upon these. The basins were not shaken.

The experiments were carried on during the autumn and winter of 1959 and in the spring of 1960, at the hatchery of the Department of Fish Physiology, College of Agriculture, Olsztyn. In the first series the brown trout (*Salmo trutta* L.) roe, supplied by a fishing farm at Słupsk, was used, and in the second series — the rainbow trout (*Salmo gairdneri* Rich.) roe, obtained from the Experimental Fishery Establishment at Mydlniki near Kraków.

In both cases an artificial on-the-spot spawning was performed, and the eggs, fertilized under dry conditions, were brought in thermos flasks with ice in them to the laboratory hatchery at Olsztyn. Twenty-four hours after fertilization the eggs were already in the respiratory chambers. In each experimental series 9 respiratory chambers were used. Three of the chambers contained eggs incubated in paraffin oil, three were with eggs in water and three contained eggs on a wet substratum.

In each chamber 300 eggs were placed. Each of the series consisted of 3 chambers so in each of the media used a total of 900 eggs were subjected to the experiments.

3. RESULTS

Table 1 contains values of O_2 consumed and CO_2 released, as determined by Haldane method, throughout the embryonic growth by one embryo of each of the two fish species studied. The results from determinations by this method of the oxygen consumption and carbon dioxide removal by the embryos during the period between the appearance of the first blastomeres and the hatching of larvae are shown in Graphs 1a, 1b — for the brown trout, and in 2a, 2b — for the rainbow trout. The values given in the graphs correspond with the amount of O_2 taken up and CO_2 released at the given stage by one embryo during an hour.

A comparison of the graphs illustrating the respiration of the embryos of the two species studied reveals considerable differences, depending on the medium used for incubation. Eggs incubated in paraffin oil appeared to

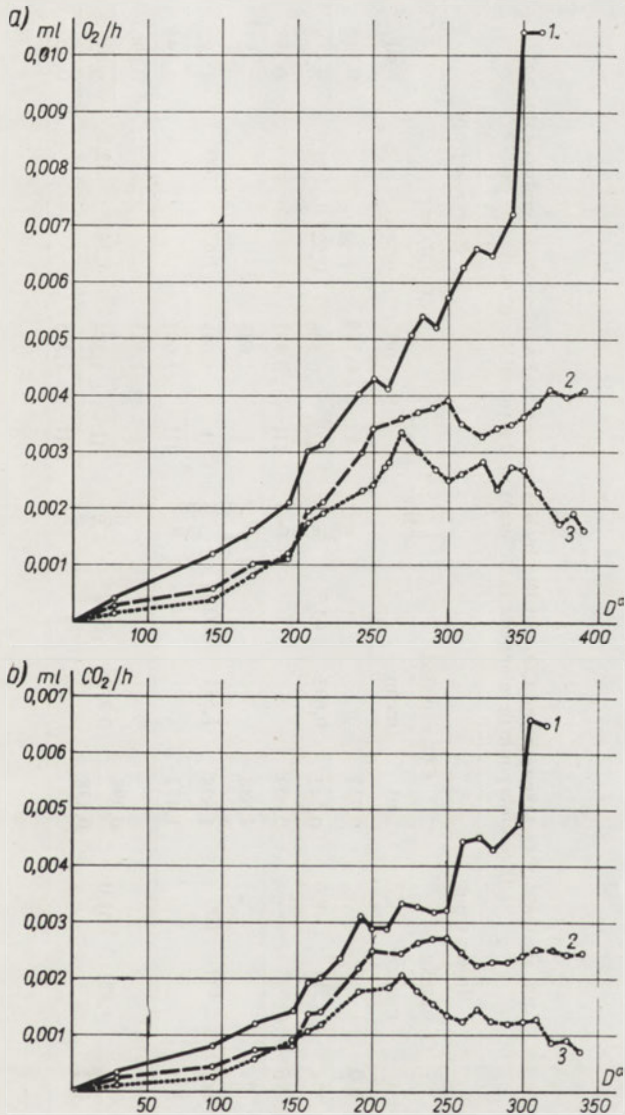


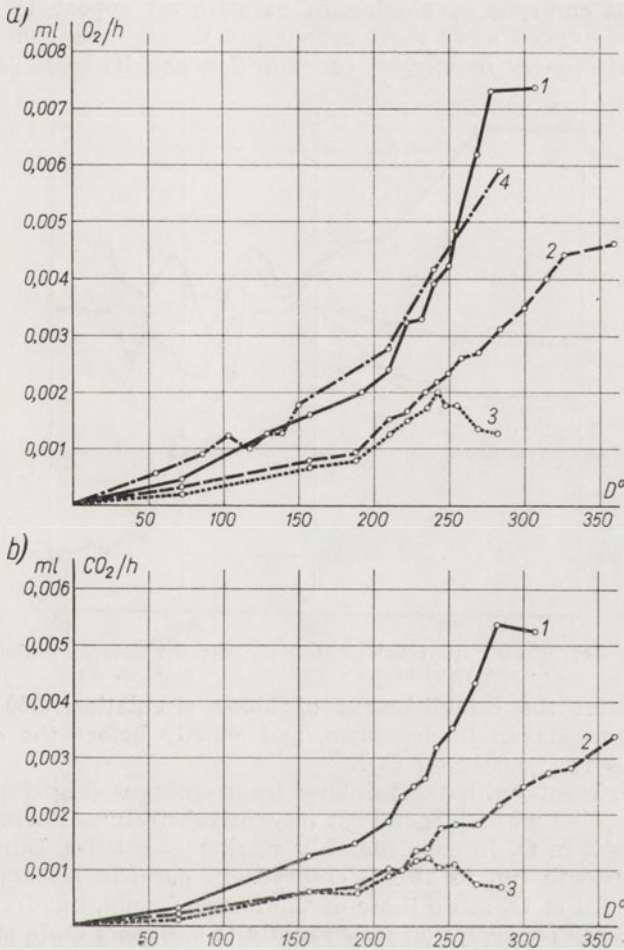
Fig. 1a. O₂ consumption by 1 *Salmo trutta* L. embryo
 Fig. 1b. CO₂ expulsion by 1 *Salmo trutta* L. embryo
 1 — wet substrate; 2 — water; 3 — paraffin oil

have consumed the smallest amount of oxygen, those incubated in non-flowing water took up considerably more, and those placed on the wet substratum the most.

Table 1

Total amounts of O₂ taken-up and CO₂ expelled by brown-trout and rainbow-trout embryos during their embryonic development in different media (in ml/1 embryo)

		Brown trout						Rainbow trout							
medium	series	O ₂ uptake			CO ₂ expelled			medium	series	O ₂ uptake			CO ₂ expelled		
		ml	mean	%	ml	mean	%			ml	mean	%	ml	mean	%
paraffin oil	I	1,260	1,213	48,6	0,723	0,693	43,7	paraffin oil	I	0,544	0,521	31,9	0,346	0,324	28,1
	II	1,294			0,747				0,329						
	III	1,086			0,609				0,298						
wet substrate	I	2,724	2,493	100	1,688	1,591	100	wet substrate	I	1,688	1,631	100	1,187	1,153	100
	II	2,461			1,608				1,127						
	III	2,295			1,477				1,144						
water	II	1,631	1,521	61,0	0,998	0,918	57,7	water	I	1,333	1,341	82,2	0,896	0,900	78,0
	III	1,412			0,838				0,867						

Fig. 2a. O_2 consumption by 1 *Salmo trutta* L. embryoFig. 2b. CO_2 expulsion by 1 *Salmo trutta* L. embryo

1 — wet substrate; 2 — water; 3 — paraffin oil; 4 — Warburg method

In experiments with the brown trout eggs, before the establishment of blood circulation, the oxygen consumption grew steadily in all the three series. The curves for eggs developing in water and for those in paraffin oil are less steep than the curve illustrating the O_2 consumption by embryos developing on the wet substratum. From the establishment of blood circulation ($200-220 D^\circ$) this last curve begins a steep rising which is continued until shortly before hatching ($\pm 340 D^\circ$) when the O_2 consumption slows down a little, having a value of about $0.0011 ml O_2/h$.

In non-flowing water, before the establishment of blood circulation ($220-240 D^\circ$), the O_2 consumption rate grows steadily, but it decreases after the establishment of blood circulation ($300-320 D^\circ$). The oxygen consumption is then maintained, with only slight variations, at from 0.0033 to $0.0041 ml O_2/h$ until the time of hatching.

Brown trout embryos developing in paraffin oil appear to take up the same amount of oxygen as do those growing in water, except the early stages when slight differences in oxygen consumption can be seen between these

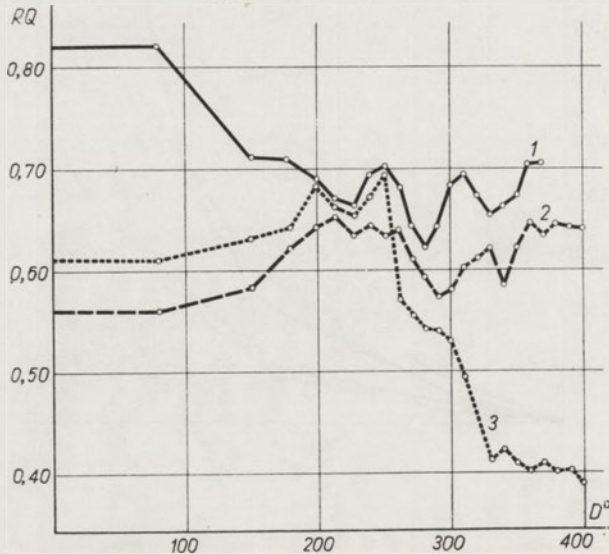


Fig. 3. Respiratory quotient (R. Q.) of *Salmo trutta* L. embryos
1 — wet substrate; 2 — water; 3 — paraffin oil

two groups. After the establishment of blood circulation (250—270D°) the amount of oxygen taken in decreases, and shortly before the death of the embryos it falls to ± 0.0017 ml O₂/h.

In the experiments with the rainbow trout embryos (Fig. 2a) the highest oxygen consumption was by eggs kept on wet substratum. Embryos developing in water took in O₂ in considerably smaller quantities. During the first half of their growth (up to 240D°) embryos in paraffin oil appear to take almost the amount of O₂ as do those of the former group, but from 250D° onwards their oxygen consumption falls rapidly to 0.0014 ml O₂/h, at the time of their death.

The O₂ consumption by embryos on the wet substratum and in the non-flowing water increases continuously; this increase is slowed down only 25—30D° before hatching. Sometimes in embryos on the wet substratum a considerable fall in the O₂ consumption can be seen.

Figure 2a shows values of oxygen consumption, determined by Warburg method, for embryos on wet substratum. The curve resembles the O₂ consumption curve obtained by using Haldane method, except that by the Warburg method somewhat higher values were obtained at the beginning and slightly lower at the end of the embryonic growth. A decrease of respiration rate was also observed after blastopore closure.

Release of carbon dioxide and the respiratory quotient (RQ).

The CO₂ removal curves in Graphs 1b and 2b have a course similar to that of the O₂ consumption curves except that the values are much lower than in the case of the O₂ curves. In Graphs 3 and 4 are shown the mean values of the successive determinations of RQ during the embryonic growth of the brown trout and the rainbow trout.

They indicate that for the eggs incubated in non-flowing water the RQ value is the lowest at the beginning and intermediate at the end of the embryonic growth. The RQ value of the embryos in paraffin oil is only at the beginning similar to that of the embryos in water, but it decreases towards the end the development, and shortly before death it has a value of 0.38 in the brown trout, and 0.55 in the rainbow trout embryos.

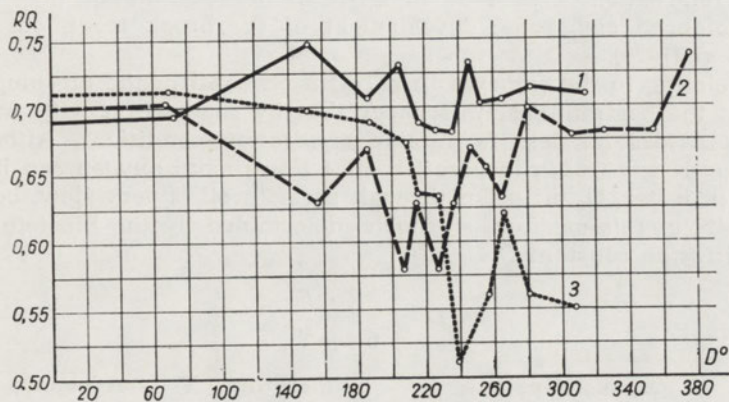


Fig. 4. Respiratory quotient (R. Q.) of *Salmo gairdneri* Rich
1 — wet substrate; 2 — water; 3 — paraffin oil

For the eggs on the wet substratum the highest rate of growth (total embryonic growth lasting only 368 D° — in brown trout, and 326 D° — in rainbow trout), the lowest mortality (28.5% — brown trout, 22.1% — rainbow trout), and the largest size of larvae (15.23 mm — brown trout, 14.6 mm — rainbow trout) were found. Embryos kept in non-flowing water revealed a retardation of particular stages, a longer embryonic period (395 D° — brown trout, 360 D° — rainbow trout), and a higher mortality (50.6% — brown trout, 43% — rainbow trout). Embryos in paraffin oil showed a still more retarded growth and they all died before hatching.

4. DISCUSSION

The results indicate rather clearly that the eggs on the wet substratum developed under the best conditions for gaseous exchange. It may be presumed that the adhesive water layer is at any time in the condition of maximum oxygenation, due to which a considerable difference in partial pressure of oxygen is found in the space between the water layer covering the egg and the perivitelline fluid. Oxygen can, therefore, diffuse fast into the perivitelline space and therefrom into the growing embryo. The same would apply to the carbon dioxide removed by the embryo.

The slower increase in the rate of gaseous exchange in the embryos kept in non-flowing water, the lowered exchange after the establishment of blood circulation and the considerably lower total embryonic consumption of oxygen and removal of carbon dioxide seem to prove that in this medium respiration is difficult. The impeded gaseous exchange in non-flowing water

may be explained by the slow diffusion of oxygen from the air through the water layer above the eggs, and by the accumulation of CO_2 in the water around the eggs. After saturating the buffers this gas acidifies the medium and thereby impedes respiration. The low rate of gaseous exchange and the considerably lower total consumption of O_2 and removal of CO_2 in this medium account for the weak condition of the larvae, as well as for the considerable retardation of their hatching. A similar explanation may be given to the prolonged embryonic development of the brook trout, observed by KULMATYCKI (1925).

Data relating to the embryos in paraffin oil confirm the presumption expressed at the beginning of this paper that by comparison with water this medium provides for less favourable respiration conditions. Although, as reported by KUBIE (1927), in paraffin oil 4 times more oxygen can be dissolved than in water, O_2 diffusion through paraffin oil is very slow, because of the viscosity of this medium, as can be determined by the Einstein formula for the diffusion constant D :

$$D = \frac{R \cdot T}{6 \pi \eta \rho N}$$

where: R — gaseous constant, T — temperature, N — Avogadro number, η — viscosity, ρ — O_2 molecular radius. It follows that gas diffusion is inversely proportional to the viscosity of the medium. As shown by the determinations carried out by the author, the viscosity of paraffin oil at 10°C is 449; the O_2 diffusion constant for this medium will, therefore, be 367 times smaller than for water. From Höffner's formula for the calculation of the rate of diffusion through a liquid:

$$V = K \frac{a(p_1 - p_2) \cdot \sqrt{273 + t}}{d \cdot 760 \sqrt{m}}$$

where K — gaseous constant, a — Bunsen absorption coefficient, m — molecular weight of gas, $p_1 - p_2$ — decrement in pressure, t — temperature, d — thickness of liquid-layer, it follows, among other things, that diffusion rate is inversely proportional to the molecular weight of the diffusing gas. The above throws more light upon the gaseous exchange in paraffin oil, indicating clearly that because of its greater molecular weight CO_2 diffuses more slowly than O_2 . This situation makes the respiration of the embryos in paraffin oil still more difficult. As a result of the gradual accumulation of CO_2 around the egg, the difference in CO_2 partial pressure between the perivitelline fluid and the oil decreases steadily. Due to this, having bonded all the buffers of the perivitelline fluid CO_2 remains in it in the free condition, causing its acidification, which impedes the respiration of the embryos to a larger extent than observed in non-flowing water.

The embryonic respiration curves for the different media, from the beginning to the establishment of blood circulation, do not differ much in their course, and only the respiration curves for water and paraffin oil have, by comparison to those for the wet substrate, a flatter course.

At the beginning of the embryonic development, when the gaseous exchange rate is still low, the atmospheric O_2 diffuses into both the water and paraffin oil in sufficient quantities to meet the requirements of the embryo.

Therefore the first portion of the curve showing the amounts of O_2 consumed by the embryos in paraffin oil follows the course, (though with an ever-increasing retardation) of the curve illustrating the consumption of oxygen by embryos in non-flowing water.

A different situation is seen when with the establishment of blood circulation a rapid increase in the oxygen consumption begins. Embryos on the wet substratum, which are growing under optimum conditions for gaseous exchange, may then take up as much oxygen as they need, while the embryos in non-flowing water begin to suffer from the O_2 deficiency, mainly because the diffusion of this gas through the thick layer of water is slow. This leads to a restriction of the biochemical processes and the subsequent decrease of the growth rate. The larvae that hatch under these conditions will be much smaller than those which hatch under better oxygen supply.

In paraffin oil the embryos at first breathe at the same rate as do the embryos developing in water. Later on, however, due to the oxygen deficiency (not to speak about the difficulties with the removal of CO_2), their gaseous exchange is slowed down so considerably that the embryos die before hatching. If eggs, previously kept in paraffin oil for about 260—280 D° , are transferred to water, the larvae will hatch but the hatching will be delayed by about 200 D° , as compared with the eggs developing in water (WINICKI, 1958).

The above consideration may be useful in the interpretation of the respiratory quotient values obtained in the present experiments. Both in the brown trout and in the rainbow trout (Graphs 3 and 4) the highest was the value of the RQ of the embryos developing on the wet substratum. The RQ values for embryos kept in water were slightly lower due, most probably, to the fact that an amount of CO_2 is bound by the buffers of the water, and some of it (a relatively small quantity) is used for the saturation of the water, and only the remainder is released into the atmosphere.

In paraffin oil, at the (—) beginning when the respiration rate is still low RQ is maintained at a fairly high level, but when at a later stage the embryo begins to remove more CO_2 than can be diffused, at a given time, through the oil layer, the RQ value falls. As a result, an amount of CO_2 remains in the perivitelline fluid, which in turn leads to an acidification of the internal medium of the embryo and thus to a restriction of the gaseous exchange.

From the above it may be inferred that only in the case of eggs incubated on a wet substratum the RQ values represent the real extent of gaseous exchange.

In the non-flowing water and in paraffin oil the RQ values are lowered by the amount of CO_2 remaining in both the internal and the external medium of the egg. The RQ values obtained for the eggs on the wet substratum indicate that during the embryonic growth of both the brown and the rainbow trouts the source of energy are fats. This presumption agrees with the view of HAYES (1949) and disagrees with the theory published by NEEDHAM (1931, 1950).

The O_2 consumption and CO_2 removal curves obtained during the present study do not confirm the view that the changes in respiratory processes, taking place before the closure of the blastopore, are abrupt in nature (TRIFO-

NOVA 1935; TRIFONOVA et al. 1939). It should be pointed out, that the situation described by the above authors may have resulted from the great sensitivity of the embryos, at this stage, to mechanical factors, due to which some of them may have died. Death of embryos, resulting from, for instance, the handling connected with the transferring of the eggs to the respiratory chamber, or during the determination of O_2 by Warburg respirometer (shaking), is not always at once noticed. This fact has been pointed out by PRIVOLNIEV (1938), who succeeded in eliminating shaking. In his experiments eggs were placed in basins with humid air and so the Warburg respirometer could be immobilized. The data reported by PRIVOLNIEV (1938, 1940) do not confirm the existence of abrupt falls in the O_2 consumption at critical moments, described by TRIFONOVA et al. (1939).

The present experiments have shown considerable differences in O_2 consumption and CO_2 removal between the brown trout and the rainbow trout embryos, as also between embryos of the same species developing in different media. The values expressed as percentages of the respective values for the wet-substratum embryos are different each of the two species studied. The larger quantities of O_2 consumed, and the larger amounts of CO_2 removed by the brown trout embryos, as compared with the rainbow trout, might be the result of the difference in egg size between these two fish species. The average radius (r) of the brown trout egg in the present experiments was 2.25 mm, and that of the rainbow trout — 1.75 mm, so the volume (V) of the brown trout eggs is 44.38 mm³, and of the rainbow trout — only 22.5 mm³.

The differences in O_2 consumption and CO_2 removal between individual embryos kept in the water were greater in the brown trout than in the rainbow trout. This situation can partly be explained by the fact that in the brown trout the surface (S) to volume (V) ratio of the egg is less favourable than in the rainbow trout. In the present experiments the S/V ratio was higher in the rainbow trout, as compared with the brown trout, by 19.2%. Even if we assume that, in accordance with the Hüffner formula given above, the rate of diffusion through the thicker (by 1 mm) water-layer above the rainbow trout egg is lower by 15.4%, the rainbow trout eggs will still appear to be in more favourable conditions for respiration.

A reversed situation is seen in the groups of embryos kept in paraffin oil, where the difference between individual embryos were much smaller in the brown trout than in the rainbow trout.

This seemingly paradoxical situation may be explained by an additional factor, namely carbon dioxide which diffuses in water at a considerable rate and does not exercise any significant influence on gaseous exchange. In paraffin oil, however, its diffusion is impeded considerably by the higher viscosity of the medium. Since the rainbow trout eggs lies deeper than the brown trout egg, the release of CO_2 to the atmosphere is more difficult than in the experiments with the brown trout egg, regardless of the more advantageous surface to volume ratio.

5. SUMMARY

Experiments were carried out to measure the respiration rate in embryos of *Salmo trutta* L. and *Salmo gairdneri* Rich. in three different media. Embryos developing on a wet substratum had the highest rate of gaseous exchange, the

lowest mortality, the shortest developmental period, and they developed into larvae which appeared to be the largest of all the larvae in the experimental series. In non-flowing water a slower, as compared with the former group, rate of gaseous exchange was seen; the particular stages lagged behind, due to which the embryonic period was prolonged. The mortality rate also was higher there, and the larvae that hatched out were smaller and weaker. The smallest rate of gaseous exchange was seen in paraffin oil; after the establishment of blood circulation this exchange became slower still. In this group a considerable retardation of growth was observed and all the embryos died before hatching.

The results obtained indicate that the exchange of O_2 and CO_2 by the growing embryos depends on the rate of diffusion of these gases through the medium. The thin layer of the adhesive water that covers the eggs incubated on a wet substratum creates the best conditions for gas diffusion and allows of the highest rate of external respiration.

A lowered O_2 supply to the developing eggs, and particularly an impeded removal of CO_2 cause a considerable prolongation of the embryonic period (non-flowing water), and they may cause the death of the embryos (paraffin oil).

The rate of gaseous exchange, and the effect of O_2 deficiency, or the accumulation of CO_2 in the medium are different in each of the two fish species studied, the differences being the result of differences in egg size. The rainbow trout eggs possess an advantageous surface to volume ratio so they more easily resist a lack of oxygen.

For a normal course of their respiration and growth the eggs of the brown trout and of the rainbow trout do not require large amounts of water or its fast flowing. They may even remain outside the aqueous medium, provided that their surface is always wet.

6. STRESZCZENIE

Doświadczenia przeprowadzono w celu zbadania warunków oddychania zarodków *Salmo trutta* L. i *Salmo gairdneri* Rich. rozwijających się w trzech środowiskach. Wykazały one u zarodków rozwijających się na zwilżonym podłożu najintensywniejszą przemianę gazową, najmniejszy procent śmiertelności. Najkrótszy okres rozwoju i największe oraz najlepiej wykształcone larwy. U zarodków rozwijających się w wodzie stojącej intensywność przemiany gazowej mniejsza niż w grupie poprzedniej, opóźnienia poszczególnych stadiów i dłuższy okres całkowitego rozwoju, a także większy procent śmiertelności i mniejsze oraz słabsze larwy po wylęgu. U zarodków rozwijających się w oleju parafinowym intensywność przemiany gazowej była najmniejsza, a po ustaleniu się krążenia jeszcze się zmniejszyła. Rozwój zarodków w tej grupie był znacznie opóźniony i wszystkie zarodki zamierały nie osiągając momentu wyklucia.

Na podstawie otrzymanych wyników i przeprowadzonej dyskusji autor wyciąga następujące wnioski: 1. Przemiana O_2 i CO_2 rozwijających się zarodków uzależniona jest w warunkach przeprowadzonych doświadczeń od możliwości dyfuzji tych gazów badanym środowisku. 2. Cienka warstewka wody adhezyjnej otaczająca zarodki rozwijające się na zwilżonym podłożu, stwarza najlepsze warunki dyfuzji gazów i umożliwia najintensywniejsze oddychanie zewnętrzne. 3. Warunki wymiany gazowej w danym środowisku wpływają na długość okresu rozwoju zarodkowego. Ograniczenie dostępu tlenu do rozwijających się jaj, a szczególnie trudności w ewakuacji dwutlenku węgla, w znacznym stopniu przedłużają okres embrionalny, a nawet mogą powodować śmierć zarodków. 4. Intensywność przemiany gazowej i reakcja na brak tlenu, czy nagromadzenie dwutlenku węgla w środowisku są różne u badanych gatunków ryb. 5. Pstrąg tęczowy posiadający korzystniejszy stosunek powierzchni do objętości jaja łatwiej dostosowuje się do gorszych warunków tlenowych. 6. Jaja troci „bałtyckiej” i pstrąga tęczowego dla prawidłowego przebiegu procesów oddechowych i dla normalnego rozwoju nie wymagają dużych ilości wody ani szybkiego przepływu, a nawet mogą pozostawać poza wodą, pod warunkiem, że ich powierzchnia będzie stale zwilżana.

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S. GOŁOWIN

DIE BEZEICHNUNG DES VEKTORS DER SAPROBITÄT \bar{S} ALS
EINE NEUE METHODE DER INTERPRETATION DER HYDROBIOLOGISCHEN
FORSCHUNGEN BEI DER SCHÄTZUNG DES STANDES
DER WASSERVERUNREINIGUNG

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ABSTRACT

Der Autor stellt eine neue Methode der Interpretation der Ergebnisse der hydrobiologischen Forschungen vor, die bei der Beurteilung des Standes der Wasserverunreinigung angewendet wird. Die Methode beruht auf dem Prinzip des Summirens der Vektore dessen Grösse durch die absolute Zahl der Leitorganismen bestimmt wird, die für die einzelnen Zonen der Verunreinigung festgestellt wurden, oder auf Grund des prozentsatzigen Anteiles der einzelnen Gruppen der Leitorganismen die auf dem Wege der mikroskopischen Analyse bestimmt wurden. Die Winkelneigung des Resultante-Vektors \bar{S} bezeichnet den saprobiontischen Wert der geprüften Ansammlung. Die Bezeichnung der saprobiontischen Spektra, als eine Möglichkeit der Ausnutzung der Interpretation dieser Methode wurde gegeben. Der Vergleich der Ergebnisse die auf dem Wege der Bezeichnung des Vektors der Saprobität \bar{S} und nach der Methode von Pantle und Buck erhalten wurden mit den Ergebnissen der physikalisch-chemischen Forschungen spricht für die Richtigkeit der Vektor-Methode und beweist, dass die Resultate die auf diesen Wege erhalten wurden als massgebend zu betrachten sind.

INHALT

- | | |
|-----------------------------|-----------------|
| 1. Einleitung | 4. Streszczenie |
| 2. Resultate und Diskussion | 5. Literatur |
| 3. Zusammenfassung | |

1. EINLEITUNG

Die biologischen Forschungen im Bereiche der Probleme des Wasserschutzes vor der Verunreinigung, der Selbstreinigung der Gewässer sowie des Standes der Verunreinigung wurden schon als eine notwendige Ergänzung der physikalisch-chemischen Arbeiten anerkannt. In Polen wird zum praktischen Zwecken am häufigsten die Methode der Interpretation der diesbezüglichen biologischen Forschungen von PANTLE und BUCK (1955) angewendet. Diese Methode ist auch, neben der von LIEBMANN (1953) gegebenen am klarsten und übersichtlichsten.

Ein prinzipieller Fehler der Methode von Pantle und Buck liegt jedoch darin, dass zu einer exakten, mathematischen Formel eine schätzungswertige Zahl der vorträtenden Organismen unterstellt wird; eine Zahl also die in der Wirklichkeit

sehr subjektiv ist und eine ungenaue Skala aufweist. Dies bedingt, dass die für die gegebene Ansammlung untypischen, in der geprüften Probe nur zufällig und in unbedeutender Zahl vorkommenden Leitformen überschätzt werden da sie für die Bedingungen des geforschten Millieu nicht massgebend sein können. In manchen Fällen wirkt sich das auf der Richtigkeit des Saprobität-Indexes aus, der auf diese Weise berechnet wurde und führt zur unrichtigen Interpretation der erhaltenen Resultate.

Die vorgestellte Arbeit schlägt eine neue Methode der Interpretation und der Angabe der hydrobiologischen Resultate vor, die bei der Beurteilung des Grades der Verunreinigung angewendet wurden. Die Methode beruht auf dem Prinzip des Summieren der Vektore; ihre Anwendung wurde am Beispiel der Interpretation der biologischen Forschungen vorgestellt die am Sommer-Bioseton der Krasowska Struga, eines linken Zuflusses des Flusses Widawa unternommen wurden.

2. RESULTATE UND DISKUSSION

Auf Grund der mikroskopischen Analyse der Wasserproben die am acht ausgewählten Stellen entlang der Krasowska Struga entnommen worden sind, wurde im Sommerseston dieses Wasserlaufes das Vorträten von 127 Arten festgestellt. Um die Anwendung der vorgestellten Methode bildlich zu besprechen wurden nur diese Daten betreffend des quantitativen Vorträgens entnommen die von Liebmann (1953) in seinen revidierten Saprobien-system als Leitorganismen für einzelne Verunreinigungs-zonen bezeichnet wurden. Die Daten wurden in der Tabelle I zusammengestellt.

Die Zahlen der Leitorganismen die für jede Zone charakteristisch sind und die in 1 l des Flusswassers vorgefunden worden sind, wurden in der Tabelle II zusammengestellt. Die summarischen Zahlen die in der einzelnen Probe für die Leitorganismen der betreffenden Verunreinigungszone zufallen, wurden in dem System dargestellt der auf der Abb. 1 gezeigt wurde; die entsprechenden Abschnitte wurden also auf der betreffenden Achse vorgenommen. Für jeden Diagramm, also für jede Probe soll dabei die gleiche Skala angewendet werden, zum Beispiel: 1 mm = 1;5 bzw. 10 Einzelwesen. Die absoluten Zahlen der Organismen können durch den prozensatzigen Anteil der Leitorganismen ersetzt werden; die für jede Zone festgestellte Zahl der Organismen wird proportionell zu der Gesamtzahl der Leitorganismen (als 100% angenommen) vorgestellt — analogisch wie es in der Pollen-Analyse üblich ist. Für die Bearbeitung von Periphyton ist auch dieses Verfahren viel bequemer.

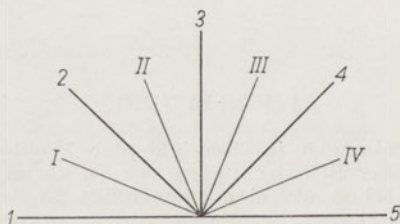


Abb. 1. Koordinatensystem der Achsen und die Grenzen der Saprobität-Zonen I. Achse der Oligosaprobionten; II. Achse der β -Mezosaprobionten; III. Achse der α -Mezosaprobionten; IV. Achse der Polisaprobionten. 1,2-die Grenze der oligosaprobien Zone, 2,3-die Grenze der β -mezosaprobien Zone, 3,4-die Grenze der α -mezosaprobien Zone, 4,5-die Grenze der polisaprobien Zone

Tabelle 1

Zahlenmässiges Verzeichniss der Leitarten die im Seston der Krasowska Struga festgestellt wurden

1	Art	Indikator	Zahl der Einzelwesen in 1 l Wasser							
			Stelle							
			1	2	3	4	5	6	7	8
2	3	4	5	6	7	8	9	10	11	
1	<i>Zoogloea ramigera</i> Itzigs.	Ps	—	790	800	150	5	—	—	5
2	<i>Microcoleus subtorulosus</i> Gomont	Os	120	—	10	5	—	—	10	20
3	<i>Oscillatoria agardhii</i> Gomont	BMs	740	—	50	5	—	20	20	150
4	<i>Oscillatoria princeps</i> Vaucher	AMs	—	—	70	20	10	20	20	—
5	<i>Oscillatoria putrida</i> Schmidle	Ps	—	90	50	5	5	—	—	5
6	<i>Oscillatoria tenuis</i> Agardh.	AMs	—	140	140	100	70	70	70	5
7	<i>Euglena viridis</i> Ehr.	Ps	—	5	—	—	5	—	—	5
8	<i>Melosira varians</i> Agardh.	BMs	1640	—	80	130	180	600	710	800
9	<i>Melosira granulata</i> (Ehr.) Ralfs.	BMs	1200	—	75	100	210	520	600	620
10	<i>Melosira italica</i> (Ehr.) Kütz.	BMs	1600	—	100	265	300	550	550	800
11	<i>Tabellaria fenestrata</i> Kütz.	BMs	200	—	—	—	—	100	220	200
12	<i>Tabellaria flocculosa</i> (Roth.) Kütz.	Os	240	—	10	—	—	—	10	10
13	<i>Meridion circulare</i> Agardh.	Os	2400	—	10	50	170	300	400	1000
14	<i>Diatoma vulgare</i> Bory	BMs	15	—	—	—	—	5	10	—
15	<i>Fragilaria crotonensis</i> Kitt.	BMs	600	—	50	85	170	320	450	400
16	<i>Synedra ulna</i> (Nitzsch.) Ehr.	BMs	3000	10	30	50	100	125	115	100
17	<i>Synedra acus</i> v. <i>angustissima</i> Grun.	Os	150	—	—	—	—	—	—	—
18	<i>Rhoicosphaenia curvata</i> (Kütz.) Grun.	BMs	20	—	—	5	25	20	20	25
19	<i>Stauroneis phoenicenteron</i> Ehr.	BMs	30	5	—	30	50	90	80	90
20	<i>Navicula cryptocephala</i> Kütz.	AMs	5	—	3	85	180	200	230	65
21	<i>Navicula rhynchocephala</i> Kütz.	BMs	80	—	5	10	25	80	75	80
22	<i>Navicula viridula</i> Kütz.	AMs	5	—	10	20	25	30	45	10
23	<i>Pinnularia maior</i> (Kütz.) Cl.	BMs	20	—	5	20	70	70	100	80
24	<i>Pinnularia viridis</i> (Nitzsch.) Bory	BMs	40	—	30	25	40	25	30	40
25	<i>Hantzschia amphioxys</i> (Ehr.) Grun.	AMs	5	—	5	85	180	200	230	65
26	<i>Nitzschia palea</i> (Kütz.) Smith.	AMs	—	5	5	100	90	120	100	60
27	<i>Cymatopleura solea</i> Smith.	BMs	—	—	—	—	25	10	20	20
28	<i>Cymatopleura elliptica</i> Smith.	BMs	—	—	—	—	15	20	10	15
29	<i>Pediastrum boryanum</i> Menegh.	BMs	5	—	—	—	—	—	—	25

1	2	3	4	5	6	7	8	9	10	11
30	<i>Scenedesmus quadricauda</i> Bréb.	BMs	—	—	—	5	10	30	20	5
31	<i>Microspora amoena</i> (Kütz.) Rabh.	Os	120	—	10	5	—	—	—	—
32	<i>Ulothrix zonata</i> Kütz.	Os	600	—	20	5	—	—	—	10
33	<i>Closterium acerosum</i> Ehr.	AMs	—	—	5	15	15	25	—	5
34	<i>Closterium moniliferum</i> Kütz.	BMs	10	—	—	—	—	—	—	—
35	<i>Closterium Ehrenbergii</i> Menegh.	BMs	10	—	—	5	10	—	—	—
36	<i>Closterium Leibleinii</i> Kütz.	AMs	—	—	—	—	—	—	—	5
37	<i>Pelomyxa palustris</i> Greef	Ps	—	395	600	158	10	—	—	10
38	<i>Paramaecium caudatum</i> Ehr.	AMs	—	350	170	50	10	10	—	—
39	<i>Paramaecium putrinum</i> Clap. et Lachm.	Ps	—	20	125	50	—	—	—	—
40	<i>Paramaecium bursaria</i> Focke	BMs	480	—	45	50	20	20	20	10
41	<i>Lionotus fascicola</i> Ehr.	AMs	—	10	15	—	—	—	—	—
42	<i>Nassula gracilis</i> Kahl	Os	440	—	—	—	—	—	10	—
43	<i>Metopus es</i> Clap. et Lachm.	Ps	—	5	5	—	—	—	—	—
44	<i>Chilodonella cucullulus</i> OFM	AMs	—	—	5	5	—	—	—	—
45	<i>Amphileptus Claparedei</i> Stein.	AMs	—	5	50	30	10	10	—	—
46	<i>Aspidisca costata</i> (Duj.) Clap. et Lachm.	BMs	—	—	—	—	—	10	5	10
47	<i>Euplotes charon</i> (OFM) Stein.	BMs	—	—	—	—	—	5	10	5
48	<i>Vorticella microstoma</i> Ehr.	Ps	—	5	—	—	—	—	—	—
49	<i>Vorticella convallaria</i> Noland	AMs	—	—	—	5	—	—	—	5
50	<i>Opercularia coarctata</i> Clap. et Lachm.	AMs	—	30	20	30	20	20	10	10
51	<i>Glaucoma scintillans</i> Ehr.	Ps	—	20	30	10	—	—	—	—
52	<i>Monostyla lunaris</i> Ehr.	BMs	40	—	—	10	5	—	5	10
53	<i>Chironomus thumi</i> (larvae)	Ps	—	10	10	10	5	—	—	5
54	<i>Tubifex tubifex</i> Lamarck	Ps	—	—	5	—	—	—	—	—

Abkürzungen: Ps — polisaprobiont, AMs — α -mezosaprobiont, BMs — β -mezosaprobiont, Os — oligosaprobiont.

Das System, welches auf der Zeichnung 1 vorgestellt wurde, weist für die einzelnen Achsen folgende Neigungen der Winkel auf: die Achse I — der Oligosaprobionte = $157^{\circ}30'$; die Achse II — der β -Mezosaprobionte = $112^{\circ}30'$; die Achse III — der α -Mezosaprobionte = $67^{\circ}30'$; die Achse IV — der Polisaprobionte = $22^{\circ}30'$. Die zusätzlichen Linien 1, 2, 3, 4, 5 bezeichnen die Grenzen der Zonen. Die oligosaprobe Zone befindet sich zwischen den Linien 1 und 2 (180° und 135°), die β -mezosaprobe Zone zwischen den Linien 2 und 3 (135°

und 90°), die α -mezosaprobe Zone zwischen den Linien 3 und 4 (90° und 45°) und die polisaprobe Zone zwischen den Linien 4 und 5 (45° und 0°).

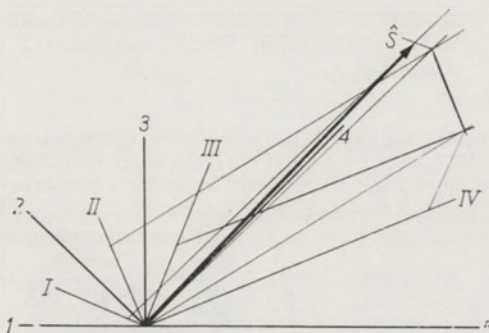


Abb. 2. Schema der Bezeichnung des Vektors der Saprobität \hat{S}
 \hat{S} — Vektor der Saprobität; die übrigen Bezeichnungen wie auf der Abb. 1

Die Abbildung 2 zeigt die Ergebnisse des Summierens der Vektoren für die Stelle 3, bei der Anwendung der Skala 1 mm = 20 Einzelwesen. Der Tabelle II nach beträgt die Zahl der Einzelwesen der oligosaprogen Zone für die Stelle 3—901. Demgemäss wird auf der Achse I, von der Mitte des Systems ausgehend, ein 4,5 mm langer Abschnitt bezeichnet. Die Zahl der Einzelwesen für die β -mezosaprobe Zone beträgt 470/1; bei Anwendung derselben Skala bezeichnen wir auf der Achse II — der α -mezosaprogen — 23,5 mm. Analogisch werden die Indexe für die übrigen Zonen angebracht: auf der Achse III — der β -mezosaprogen — 22,7 mm, auf der Achse IV — der Polisaprogen — 83,0 mm. Jetzt werden die Achsen, deren Länge auf diese Weise bestimmt wurden, bei Anwendung des Vektorenprinzips summiert. Der Winkel des Resultante-Vektors \hat{S} , der die Summe aller Komponente-Vektoren bildet, bezeichnet den saproben Wert der Ansammlung der lebenden Organismen in der geforschten Probe.

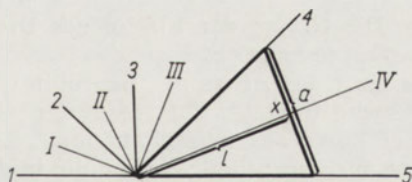


Abb. 3. Schema der Bezeichnung des saprobionten Spektrum. Die Erläuterung der Bezeichnungen im Text

Im Falle, der auf der Abbildung 2 vorgestellt wurde, liegt der Resultante-Vektor der Saprobität \hat{S} für die Stelle 3 zwischen der Linie 3 und 4 und weist auf α -mezosaprogen Charakter der Ansammlung der Lebewesen dieser Stelle, wobei die Lage des Vektors in der Nähe der Grenze mit der polisaprogen Zone, auf eine sehr starke Beziehung zu dieser Zone deutet.

Die Werte der Winkel der Saprobität \hat{S} für die Proben, die an 8 Stellen der Krasowska Struga entnommen wurden, befinden sich auf der Tabelle II.

Das System welches auf der Abbildung 1 vorgestellt wurde, kann mit Erfolg für die Zeichnung eines deutlichen und klaren Spektrum der Saprobität der Probe aus der betreffenden Stelle ausgenutzt werden. In diesem

Tabelle II

Zusammenstellung des zahlenmässigen Vorkommens der Leitorganismen verschiedener Zonen und des Indexes der Saprobität nach Pantle und Buck sowie der Winkelwert des Vektors des Saprobität für den geforschten Abschnitt der Krasowska Struga

Leitorganismen	Zahl der Einzelwesen in 1 l Wasser Stelle							
	1	2	3	4	5	6	7	8
Oligosaprobionte	4070	—	90	70	170	301	435	1110
β -Mezosaprobionte	11810	15	470	795	1255	2620	3070	3485
α -Mezosaprobionte	20	545	453	530	460	525	555	215
Polisaprobionte	—	1340	1660	443	35	10	—	31
Index der Saprobität nach Pantle und Buck	1,73	3,45	2,66	2,56	2,63	2,29	2,06	2,32
Winkelwert des Vektors der Saprobität \hat{S}	125°	36°	53°	79°	105°	110°	113°	121°

Ziele wird die Zahl der Leitorganismen aus jeder Zone, die in der betreffenden Probe festgestellt wurde, als dementsprechende Fläche in den erwähnten System vorgestellt. Die Abbildung 3 zeigt das Schema für die Verfertigung des Saprobien-Spektrum für die polisaprobe Zone. Die Fläche zwischen zwei Linien, die die Grenzen jeder Zone bezeichnen (auf dem Schema: für die polisaprobe Zone die Linien 4 und 5) können durch einen Vertikalriss „a“ geschlossen werden, der die Achse der Saprobität dieser Zone (auf dem Schema die Achse IV) senkrecht durchreißt. Auf diese Weise erhalten wir einen gleichschenkligen Dreieck, der auf der Abbildung 3 mit einer dicken Linie ausgesprochen wurde. Die Grösse der Fläche des Dreiecks (der Zone) kann beliebig zugespart werden, je nach der Lage des Durchschnittspunktes „x“ der senkrechten Linie „a“ mit der Achse der Saprobität, also zugleich abhängig von der Länge des Abschnittes „l“. Mit Hilfe der Grösse der Fläche des Dreiecks der gegebenen Zone, ausgedrückt in mm², kann die Zahl der Leitorganismen dieser Zone ausgesprochen werden, die in der Probe der betreffenden Zone festgestellt wurden, wobei angenommen wird, dass 1 mm² der Fläche einer bestimmten Zahl der Organismen entspricht, zum Beispiel 1 Einzelwesen oder, bei Anwendung der Skala 1 : 10 — 10 Einzelwesen.

Die Tabelle III zeigt die Flächengrösse der Zonen berechnet für die Länge „l“ im Bereiche von 0,1—9,9 cm. Die Flächengrösse der Zonen im diesen Bereiche der Länge „l“ betragen 0,4—4059 mm² und erlauben eine Bezeichnung des Vortretens derselben Zahl der Leitorganismen jeder Zone in der geprüften Probe, oder, bei Anwendung einer zutreffenden Skala — einer beliebig grösserer deren Zahl (Multiplum).

Tabelle III

Zusammenstellung der Flächengröße der Zonen bei verschiedenen Längen der Achse „l“

Länge der Achse „l“	Flächen- grösse der Zone in mm ²	Länge der Achse „l“	Flächen- grösse der Zone in mm ²	Länge der Achse „l“	Flächen- grösse der Zone in mm ²	Länge der Achse „l“	Flächen- grösse der Zone in mm ²	Länge der Achse „l“	Flächen- grösse der Zone in mm ²
0	—	0	41,42	0	165,68	0	372,78	0	662,72
1	0,4142	1	50,1182	1	182,6622	1	398,0462	1	696,2702
2	1,6568	2	59,6448	2	200,5728	2	424,1408	2	730,6488
3	3,7278	3	69,9998	3	219,1118	3	451,0638	3	765,8558
4	6,6272	4	81,1832	4	238,5792	4	478,8152	4	801,8912
0 5	10,3550	1 5	93,1950	2 5	258,8750	3 5	507,3950	4 5	838,7550
6	14,9112	6	106,1352	6	279,9992	6	536,8032	6	876,4472
7	20,2958	7	119,7038	7	301,9518	7	567,0398	7	914,9678
8	26,5088	8	134,2008	8	324,7328	8	598,1048	8	954,3168
9	33,5452	9	149,5262	9	348,3422	9	629,9982	9	994,4942
0	1035,50	0	1491,12	0	2029,58	0	2650,88	0	3354,52
1	1077,3342	1	1541,2382	1	2087,9822	1	2717,5662	1	3429,9902
2	1119,9968	2	1592,1848	2	2147,2128	2	2785,0808	2	3505,7888
3	1163,4878	3	1643,9598	3	2207,2718	3	2853,4238	3	3582,4158
4	1207,8072	4	1696,5632	4	2268,1592	4	2922,5952	4	3659,8712
5 5	1252,9550	6 5	1749,9950	7 5	2329,8750	8 5	2992,5950	9 5	3738,1550
6	1298,9312	6	1804,2552	6	2392,4192	6	3063,4232	6	3817,2672
7	1345,7358	7	1859,3438	7	2455,7918	7	3135,0798	7	3897,2078
8	1393,3688	8	1915,2608	8	2519,9928	8	3207,5648	8	3977,9768
9	1441,8302	9	1972,0062	9	2585,0222	9	3280,8782	9	4059,5742

Die Abbildung 4 zeigt die Saprobität Spektren der Krasowska Struga für die Proben 1—8 mit der Bezeichnung der Vektore der Saprobität S für diese Proben. Auf Grund dieser Zeichnung kann festgestellt werden, dass in der Stelle 1, die oberhalb der Stelle des Zuflusses der Verunreinigungen gelegen ist, die Ansammlung der Lebeorganismen den β -mezosaprobien Charakter aufweist, mit einer gewissen Anknüpfung zur Oligosaprobität. Den dominierenden Anteil an dieser Probe hatten die β -mezosaprobien Organismen bei einem beträchtlichen Anteil der Oligosaprobien und verschwindenden Anteil der α -Mezosaprobien und völligen Fehlen der Polisaprobien (Abbildung 4, Fig. a). Der Vektor der Saprobität S liegt in der linken Hälfte der β -mezosaprobien Zone die mit der oligosaprobien grenzt. Die Verunreinigungen die zu den geforschten Wasserlauf zugeführt wurden (die Stelle 2) bildeten ein polisaprobies Milieu und waren vorwiegend durch Organismen besiedelt die für die polisaprobe und α -mezosaprobe Zone charakteristisch sind (Abbildung 4, Fig. b). Der Einfluss dieser Verunreinigungen auf die Ansammlung der Lebewesen der 3 Stelle war deutlich, da diese Stelle unterhalb des Zuflusses der Verunreinigungen gelegen ist. Die Ansammlung der Einzelwesen dieser Stelle nahm den α -mezosaprobien Charakter an, mit einer starken Anknüpfung zur Polisaprobität.

Die Polisaprobien dominierten hier deutlich, bei einem viel minderen zahlenmässigen Vorkommen der α - und β -Mezosaprobien und sehr niedrigen Vorkommen der Oligosaprobien. Der Vektor der Saprobität S liegt im

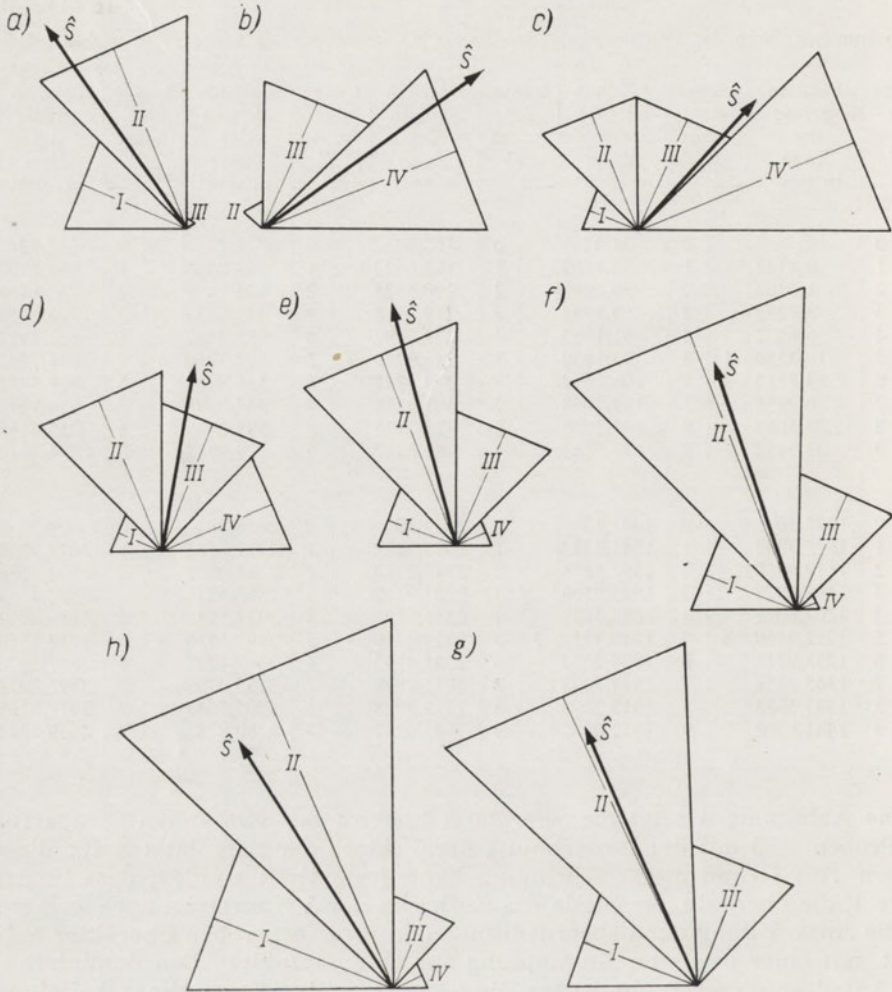


Abb. 4. Die saprobionten Spektren der Proben entnommen aus Krasowska Struga
 I — Oligosaprobionte, II — β -Mezosaprobionte, III — α -Mezosaprobionte, IV — Polisaprobionte;
 S — Vektor der Saprobität. Fig. a-h = Spektren für die Stellen 1 bis 8.

Bereiche der α -mezosaprobionten Zone, jedoch in der Nähe der polisaprobionten Zone. Zwischen den Stellen 3 und 4 tritt eine sehr deutliche Reduktion der Zahl der polisaprobionten Organismen hervor, der Anteil der β -Mezosaprobionten vergrößert sich. Der Vektor der Saprobität der Stelle 4 bleibt weiterhin in der α -mezosaprobionten Zone, verschiebt sich jedoch zur Hälfte, die mit der β -mezosaprobionten Zone grenzt. Ab der Stelle 5 vermindert sich weiterhin stufenweise die Zahl der Polisaprobionten und die Zahl der β -Mezosaprobionten wie auch der Oligosaprobionten wächst hervorragend. Dies findet seinen Ausdruck in den stufenweisen Übergang des Saprobionten-Vektors \hat{S} zu der β -mezosaprobionten Zone.

Die Ergebnisse die auf dem Wege der Bezeichnung des Vektors der Saprobität \bar{S} erhalten wurden, können leicht in der Gestalt einer linearen Reihe vorgestellt werden (Abbildung 5). Dies erlaubt auch festzustellen, dass die vorteilhaften Änderungen des Charakters der Ansammlung der Lebewesen — die mit der Entfernung von der Verunreinigungsstelle vorkommen und die auf die Verminderung des Grades der Verunreinigung hinweisen — am schnellsten in den Abschnitt zwischen der Stelle 3/4 und 4/5 vorsichgehen.

Die lineare Reihe geführt für den geforschten Abschnitt der Krasowska Struga auf Grund der Saprobität-Indexes, berechnet nach der Methode von Pantle und Buck zeigt einen anderen Verlauf (Abbildung 5). Die Unterschiede zwischen den Ergebnissen die auf Grund der Methode des Vektors der Saprobität \bar{S} bestimmt wurden und der Ergebnisse die nach der Methode von Pantle und Buck erhalten wurden, sind für die Stelle 2, 3, 5 und 8 besonders deutlich.

Der Vektor der Saprobität \bar{S} bestimmt für die Stelle 2 (der Zufluss der Verunreinigungen zur Krasowska Struga) liegt deutlich in der polisaprogenen Zone (Abbildung 4 Fig. b und Abbildung 5). Der Index der Saprobität berechnet nach der Methode von Pantle und Buck besitzt dagegen, für dieselbe Stelle noch immer Werte, die in der α -mezosaprogenen Zone enthalten sind (Abbildung 5). Die Ansammlung der Leitorganismen die in der Probe aus der Stelle 2 festgestellt wurden, bestanden aus Indikatoren der Polisaprobität, die in einer deutlich dominierenden Zahl vortraten (1340/1); das Vortreten von α -Mezosaprobionten wurde in viel geringerer Zahl festgestellt (545/1) — und der β -Mezosaprobionten nur in schwindender Zahl (Tabelle II). Diese Tatsache beweist, dass die Ergebnisse, die bei Anwendung der Methode des Vektors der Saprobität \bar{S} erhalten wurden, als richtig zu betrachten sind.

In der Probe die aus der Stelle 3 (unterhalb des Zuflusses der Verunreinigungen) entnommen wurde, herrschte auch eine ausgesprochene Dominanz der Polisaprobionten, die in einer Zahl von 1660/1 festgestellt wurden. Die übrigen Gruppen der Leitorganismen waren viel schwächer vertreten: α -Mezosaprobionten = 453/1, β -Mezosaprobionten = 479/1 und Oligosaprobionten = 90/1. Der Index der Saprobität, berechnet nach der Methode von Pantle und Buck liegt, für die Stelle 3, im Bereiche der α -mezosaprogenen Zone. Im Anbetracht der mikroskopisch festgestellten Zusammensetzung der Ansammlung der Leitorganismen (Abb. 4 Fig. c.), ist dies Ergebnis als regelrecht zu betrachten, welches bei Anwendung der Methode des Bezeichnes des Vektors der Saprobität erhalten wurde; obzwar diese Ansammlung auch als α -mezosaprogen charakterisiert wurde, jedoch ist ihre Anknüpfung an die Polisaprobität deutlich erkennbar: der Vektor der Saprobität \bar{S} liegt an der Grenze mit der polisaprogenen Zone. (Abb. 4, Fig. c. und Abb. 5).

Der Methode von Pantle und Buck nach unterliegt die Saprobität der Ansammlung der Lebewesen an den Stellen 3, 4 und 5 fast keinen Änderungen (Abbildung 5). Bei der Überprüfung des saprobiontischen Spektrums für diese Stellen (Abbildung 4 Fig. c, d, e.) kommt die Unregelrechtigkeit dieser Interpretation deutlich zum Vorschein, die Ergebnisse dagegen die nach der Methode der Bezeichnung des Vektors der Saprobität erhalten wurden, sind als regelrecht zu betrachten.

Die Unregelrechtigkeit der Methode von Pantle und Buck kommt auch deutlich zum Vorschein in dem Wert der Saprobität-Indexes der für die Stelle 8 berechnet wurde. Die Polisaprobionten, die hier nur zufällig und in

schwindender Zahl festgestellt wurden, erhöhen mit Unrecht den Wert, was auf eine Erhöhung des Grades der Verunreinigung deuten würde. In der Wirklichkeit ist der Grad der Verunreinigung niedriger; dies findet seinen Ausdruck in der Starken Erhöhung der Zahl der Oligosaprobionten und der β -Mezosaprobionten wie auch in der Verminderung der Zahl der α -Mezosaprobionten (Abbildung 4 Fig. g. und h.).

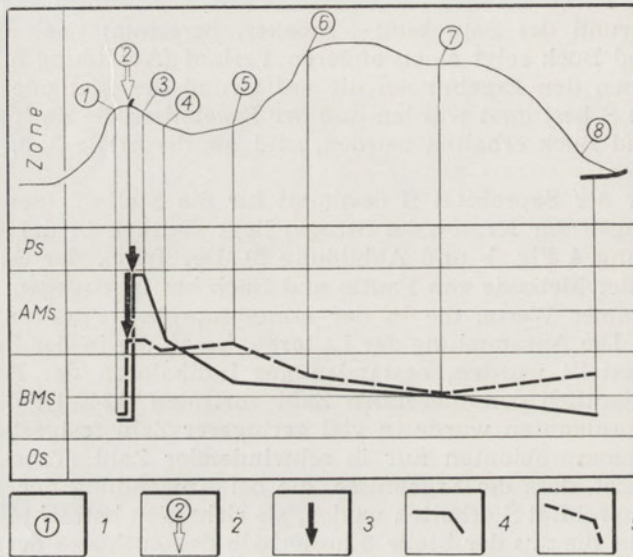


Abb. 5. Die lineare Reihe der Saprobität der Ansammlungen der Lebewesen aus den Proben des Biosestons der Krasowska Struga

1 — Probenentnahmestellen, 2 — Zufluss der Verunreinigung, 3 — Saprobität der zufließenden Verunreinigungen, 4 — Saprobität des Biosestons bestimmt nach der Methode des Vektors der Saprobität S, 5 — Saprobität des Biosestons bestimmt nach der Methode von Pantle und Buck. Ps — polisaprobe Zone, AMs — α -mezosaprobe Zone, BMs — β -mezosaprobe Zone, Os — oligosaprobe Zone

Den unveröffentlichten chemischen Forschungen nach, die für Krasowska Struga in der Anstalt für Wasserschutz des Institutes für Wasserwirtschaft in Wrocław durchgeführt wurden, vermindert sich die Verunreinigung, die bei der Stelle 3 ihren Beginn hat, an den weiteren Stellen und erreicht die niedrigsten Werte bei der Mündung des geprüften Wasserlaufes in den Widawa — Fluss. Die Oxibitität die ihr Maximum an der Stelle 3 erreicht hatte, fällt an den zwei weiteren Stellen rasch ab, um weiter — bis zur Stelle 8 — schon mild abzufallen. Einen ähnlichen Verlauf weist auch die BSB_5 Kurve auf: die Sauerstoff — Linie dagegen wächst von ihren Minimum bei der Stelle 3 bis zur Stelle 5 ziemlich rasch auf; der Sauerstoffgehalt wächst auch weiterhin, schon stufenweise, bis zu der Mündung des Flusses.

Die chemischen Forschungen also bestätigen die Regelrechtigkeit der Methode der Interpretation der biologischen Prüfungen die mit Hilfe des Vektors der Saprobität S durchgeführt wurden und beweisen dass die auf diesem Wege erhaltenen Ergebnisse als massgebend betrachtet sein können.

3. ZUSAMMENFASSUNG

Eine neue Methode der Interpretation der Ergebnisse der hydrobiologischen Forschungen bei der Schätzung des Verunreinigungsgrades der Gewässer wird vorgeschlagen. Die Methode beruht auf dem Prinzip des Summierens der Vektore. Die Anwendung dieser Methode wurde am Beispiel der Ergebnisse der hydrobiologischen Forschungen vorgestellt, die bei der Prüfung des sommerlichen Bioestons der Krasowska Struga, eines linken Zuflusses des Flusses Widawa durchgeführt wurden. Auf Grund der mikroskopischen Analyse der entnommenen Proben (Tab. I.) wurden die Zahlen der Leitorganismen zusammengestellt die für 1 l Wasser zu fallen (Tabelle 2). Die absoluten Zahlen der Leitorganismen für die einzelnen Verunreinigungs — Zonen oder den prozentsatzigen Anteil der einzelnen Leitgruppen bezeichnet man auf dem System, wie es auf der Zeichnung 1 vorgestellt wurde, indem man an den Achsen die betreffende Zahl oder den prozentsatzigen Anteil der Gruppen vorstellt.

In den System der auf der Abbildung 1. vorgestellt wurde besitzt die Achse I — der Oligosaprobionten Winkelneigung von $157^{\circ}30'$, die Achse II — der Betamezosaprobionten — $112^{\circ}30'$, die Achse III — der Alfamezosaprobionten — $67^{\circ}30'$ und die Achse IV — der Polisaprobionten — $22^{\circ}30'$. Die zusätzlichen Linien bezeichnen die Grenzen der Zonen: die oligosaprobe Zone ist von den Linien 1 und 2 umfasst (180° und 135°), die β -mezosaprobe Zone zwischen den Linien 2 und 3 (135° und 90°), die α -mezosaprobe Zone zwischen den Linien 3 und 4 (90° und 45°), die polisaprobe Zone zwischen den Linien 4 und 5 (45° und 0°). Die Achsen, deren Länge nach der Zahl der Leitorganismen der einzelnen Zonen — oder des prozentsatzigen Anteiles dieser Organismen in der allgemeinen Zahl der Leitorganismen, die als 100% angenommen werden — berechnet wurde, werden auf Grund des Summierens der Vektore zusammengezählt. Der Winkel des Resultante — Vektors S, der die Summe aller Komponente — Vektoren der Achsen bildet, bezeichnet den saprobiontischen Wert der Ansammlung der Lebeorganismen der geprüften Probe. Auf der Abbildung 2 werden beispielsweise die Resultate des Summierens der Vektore vorgestellt, welche auf Grund der absoluten Zahl der Leitorganismen der einzelnen Zonen der Stelle 3 berechnet wurden. Der Winkelwert der Vektore der Saprobität S der durchforschten Stellen der Krasowska Struga wurde auf der Tabelle II zusammengestellt.

Die Ordnung die auf der Abbildung 1 vorgestellt wurde, kann auch zu einer graphischen Vorstellung des saprobiontischen Spektrum dienen. In diesem Ziele wird die Zahl der Leitorganismen jeder Zone, festgestellt in der gegebener Probe, als eine entsprechende Flächengrosse in der erwähnten Ordnung vorgestellt. Die Abbildung 3 gibt ein Schema der Bezeichnung des Spektrum der Saprobität für die polisaprobe Zone. Auf der Abbildung 4 werden die Spektra der Saprobität, mit der Bezeichnung der Vektore der Saprobität S für die geforschten Proben vorgestellt. Auf der Abbildung 5 werden, in der Gestalt einer linearen Reihe, die Ergebnisse vorgestellt, welche auf dem Wege der Bezeichnung des Vektors der Saprobität und nach der Methode von Pantle und Buck erhalten wurden. Der Vergleich der Resultate der biologischen Forschung die nach der Vektor-Methode und nach der Methode von Pantle und Buck erhalten wurden mit den Resultaten der physikalisch-chemischen Analysen deuten auf die Regelrechtigkeit der Ergebnisse die nach der Methode der Bezeichnung des Vektors der Saprobität erreicht sind.

4. STRESZCZENIE

Celem pracy jest zaproponowanie nowej metody interpretacji wyników badań hydrobiologicznych przy ocenie stopnia zanieczyszczenia wód, opartej na zasadzie sumowania wektorów. Zastosowanie nowej metody przedstawiono na przykładzie wyników hydrobiologicznych badań letniego bioestonu Krasowskiej Strugi, lewobrzeżnego dopływu rzeki Widawy. Na podstawie wyników mikroskopowej analizy pobranych próbek (tablica I) zestawiono ilości organizmów wskaźnikowych przypadające na 1 l wody (tablica II). Bez względu na ilości organizmów wskaźnikowych poszczególnych stref zanieczyszczenia lub procentowy udział poszczególnych

grup wskaźnikowych, wykreśla się na układzie przedstawionym na rysunku 1, odcinając na właściwych osiach odpowiednie ilości lub procentowy udział poszczególnych grup.

W układzie przedstawionym na rys. 1 oś I — eligosaprobiontów posiada kąt nachylenia $157^{\circ}30'$; oś II — betamezosaprobiontów $112^{\circ}30'$; oś III — alfamezosaprobiontów $67^{\circ}30'$; oś IV — polisaprobiontów $22^{\circ}30'$. Granice stref wyznaczają linie dodatkowe: strefa oligosaprobowa mieści się pomiędzy liniami 1 i 2 (180° i 135°), strefa β -mezosaprobowa pomiędzy liniami 2 i 3 (135° i 90°), strefa α -mezosaprobowa pomiędzy liniami 3 i 4 (90° i 45°), strefa polisaprobowa pomiędzy liniami 4 i 5 (45° i 0°). Osie o długościach wyznaczonych według ilości organizmów wskaźnikowych poszczególnych stref lub według procentowego ich udziału w ogólnej ilości organizmów wskaźnikowych przyjętej za 100%, dodaje się na zasadzie sumowania wektorów. Kąt wektora wypadkowego \bar{S} jako suma wszystkich składowych wektorów-osi, wyznacza saprobiontyczną wartość zbiorowiska organizmów żywych danej próbki. Rysunek 2 przedstawia wynik przykładowego sumowania wektorów wyznaczonych według bezwzględnej ilości organizmów wskaźnikowych poszczególnych stref dla stanowiska 3. Wartość kątów wektora saprobowości \bar{S} przebadanych stanowisk Krasowskiej Strugi zestawiono w tabeli II.

Układ przedstawiony na rys. 1 można też wykorzystać do graficznego przedstawienia spektrum saprobiontycznego. W tym celu ilości osobników wskaźnikowych każdej strefy, stwierdzone w danej próbce przedstawia się przy pomocy odpowiedniej wielkości powierzchni każdej strefy na wspomnianym układzie. Rysunek 3 przedstawia schemat wykreślenia spektrum saprobowości dla strefy polisaprobowej. Rysunek przedstawia spektra saprobowości z wykreślonymi wektorami saprobowości \bar{S} dla przebadanych próbek.

Na rys. 5 przedstawiono w postaci ciągu liniowego wyniki otrzymane drogą wykreślenia wektora saprobowości \bar{S} oraz metodą Pantle i Buck'a. Porównanie wyników badań biologicznych uzyskanych przy pomocy metody wektorowej i metody Pantle i Buck'a z wynikami analiz fizyko-chemicznych przemawia na korzyść metody wektorowej, wskazując na prawidłowość wyników otrzymanych przez wyznaczenie wektora saprobowości \bar{S} .

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A. SZCZEPAŃSKI

SCATTERING OF LIGHT AND VISIBILITY IN WATER OF DIFFERENT TYPES OF LAKES

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ABSTRACT

Seasonal variations in turbidity of water masses in lakes have been analysed and a connection of these variations with the stagnation periods has been stressed. It is also demonstrated that some relations exist between limnological type of lake and turbidity scheme. Visibility is determined by the quantity of suspended matter: It has also been ascertained that the Secchi disk disappears, if the quantity of suspended matter above it attains a determined and fairly constant value.

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1. Introduction
2. Methods and materials
3. Results
 - A. Scattering of light
 - a. Day variations
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 - B. Scattering of light and types of lakes
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 - b. Mesotrophic lakes
 - c. Eutrophic lakes
4. Visibility and ability to scatter light.
Discussion and conclusions
5. Summary
6. Streszczenie
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1. INTRODUCTION

The elements of the environment of light in lakes have been long a subject of limnological research, and literature on these problems is fairly abundant.

As concerns numerous factors conditioning the environment of light, turbidity of water has so far been relatively less examined. This term is used to determine several, mutually connected phenomena that, depending upon the method of measurement, stress various aspects of the problem.

On the one hand, this term defines the quantity of suspended matter, particularly as concerns sanitary examinations. On the other hand, the term "turbidity" is used as that signifying the reversibility of the transmission of light.

The magnitude of the transmission of light depends upon the absorption of light by water, by dissolved chemical components, and by seston. However, in waters of dystrophic lakes, due to their intense colour, the value of the absorption of light is high, in spite of the fact that they can contain a small amount of suspended particles. Thus, an opinion that seston is exclusively or mainly responsible for a decrease in the intensity of light in water, seems not to be always justified.

The term "turbidity" is also applied to define the Tyndall effect. The term "ability to scatter light" would probably be more univocal here.

The ability to scatter light in natural waters illustrates the physical side of the phenomenon, and not the quantity of the suspended matter. Although both quantity and character of the suspended matter generally decide upon the value of Tyndall effect, this dependence is linear only in the case of homogeneous suspended matter, characterized by equigranular scattering particles. Since water masses are distinguished by the ability to scatter light, this method can be of use in studying the dynamics of water masses and of their circulation (KREY 1952).

The turbidity of water is connected with visibility. This term is used to determine the boundary of identification of objects immersed in water. Theoretical bases of interpretation of this measurement underwent, in the course of the development of limnology, considerable changes. For example, ICHIMURA (1956) cit. according to VOLLENWEIDER (1960), stresses a fact that the visibility is inversely proportional to seston in water, and defines the coefficients of this dependence.

The purpose of the present work was to explain the range of variation in ability to scatter light in lakes of various limnological types, to explain both variations and (to explain) seasonal ability to scatter light, and to determine whether of this parameter may be useful in studies on accumulation of suspended autochthonous and allochthonous substance in lake water. Thus, the purpose was also to control the so far accepted theorem on the accumulation of suspended matter in metalimnion.

Moreover, an attempt was made to explain the connection existing between the ability to scatter light with visibility.

2. METHODS AND MATERIALS

The present examinations are based on laboratory measurements of intensity of Tyndall effect. Water samples taken at certain depths were brought to the laboratory in bottles with a glass plug. The samples were not preserved. To explain whether the water samples do not change their optical properties at the time from the sampling moment to the period of analysis, turbidity measurements of the same samples were made every two hours. After a temporary increase in turbidity the optical properties of a sample do not change during 24 hours considerably. This temporary increase in turbidity can be explained by air bubbling that takes place when sample temperature is lower than room temperature.

In the case of water taken from hypolimnion of eutrophic lakes characterized by the presence of iron in polytype (STANGENBERG 1936), a possibility exists of iron hydroxide precipitation after oxidation of the sample during transportation and laboratory manipulations. In certain cases, CaCO_3 precipitation from solution can be expected as well. This concerns bottom water in the lake of "lakelet" type (STANGENBERG 1936), and water in which an intense biological decalcification takes place. Such conditions do not restrict the scope of application of the method, and point to a necessity of connecting the measurements of ability to scatter light in water with hydrochemical examinations.

The Tyndall effect of lake water samples was determined by means of Pulfrich's nephelometer, and the results were converted into units of "absolute turbidity". This term is used by the firm C. Zeiss-Jena to define the quantity of light that is scattered by a sample at an angle of 45° from the direction of an entering light beam, as compared with the quantity of the entering light.

The values of "absolute turbidity" obtained in that way were considerably low, since in lacustrine water characterized by minimum amount of suspend-

ed matter, the percentage of light scattered at an angle of 45° is scarce. To avoid operations with a large number of zeros in decimal fractions, the results were multiplied by 10^{-6} . This can be exemplified as follows: a sample has scattered 0.002% of the quantum of entering light, at an angle of 45° from a direction of a light beam i.e. the absolute turbidity of water sample amounted — according to the definition of constructors of nephelometer — to 0.00002 Units of Absolute Turbidity (UAT). Thus: $0.002\% = 0.00002 \text{ UAT} = 20 \times 10^{-6} \text{ UAT}$. *

The application of the unit of "absolute turbidity" enables us to compare the results of the examinations made by various scientists who use nephelometers of other types. So, for example, the results of the measurements of distilled water turbidity by SCHMIDT-RIES (1956) coincide with those of our investigations.

The data obtained by OHLE (1952) were compared in Table 1 with those from certain Mazury lakes. It has also been ascertained that the ability to scatter light in waters of Holstein Lake District did not differ greatly from that of the Mazury Lake District.

Table 1

Comparison of the ability to scatter light in water of several lakes from the vicinity of Plön (according to Ohle, 1952), and in water of the Mazury Lakes (own measurements)

Holstein Lake District			Mazury Lake District		
Name of lake		UAT $\times 10^6$	Name of lake		UAT $\times 10^6$
Diecksee	XI.39	1414	Hańcza	IV.57	700
Kellersee	XI.39	1475	Białe Wig.	VII.57	1600
Grosskleissee	XI.39	2543	Mikołajskie	VIII.58	2700
Heidensee	II.38	4680	Jeziork	VIII.57	5200
Lebrader Teich	II.39	10820	Głębokie near Głębock		
				VIII.57	10900
Heidensee	VII.38	36400	Elckie	VII.57	11200
Lebrader Teich	VIII.38	49100	Miałkie	VIII.58	14000

The measurements of Tyndall effect were made instead of troublesome computations in the case of experimental cultures. For one-species population, as it frequently takes place in the cultures of planktonic organisms, the value of Tyndall effect is directly proportional to population density. This method enables us to determine quickly the quantity of planktonic or bacterial organisms in cultures (DILLER V. M., KERSTEN H. 1954).

The measurements of visibility conducted from the beginning of limnology, depending on immersion of a white disk in water, and in determination of depth at which this disk is no more visible, were not an object of detailed methodological investigations. Discussions by SAUBERER and RUTTNER (1941) are rather of theoretical character and are not supported by experimental studies, as stressed by ABERG and RCDHE (1948). They give a review of various opinions as to the factors that affect visibility, point to a close

* The units used further in the text should be always understood as millionth parts of the numbers written.

dependence between the visibility and the amount of suspended matter in water, and stress a lack of studies that could clarify this problem.

When lowering the disk, at the boundary of visibility we deal with a sum of all effects connected with the water layer above the disk.

Intense research works that made basis of this elaboration were carried out in the Mikołajki Lake. They lasted from 1954 to 1958. The material for comparative studies was collected from 35 lakes of the Mazury Lake District, and in the years 1955—1958. The list of lakes studied is presented in Table 2. The data of visibility measurements, found in the literature, are used as well.

The names of the lakes presented in Table 2 are given according to the dictionary by RCSPOND S. (1951), and in the case of a name lacking in this dictionary — according to the Polish Map 1:100.000 or, after all, according

Table 2

List of lakes investigated

No.	Name of lake	Area ha	Depth in metres	
			According to catalogue	Own measure- ments
1	Babięty Wielkie	251	25	63
2	Białe Wigierskie	108,3	34	
3	Beldany	1246	31	41,4
4	Elckie Lake	409	57	
5	Flosek			6
6	Głębokie Lake near Głębock			8,9
7	Głębokie near Żelwąg	46	29	
8	Guzianka Wielka	72	29,5	
9	Hańcza	305,8	108,5	
10	Inulec	178,5		5,5
11	Jeziorak	3230	12	
12	Juno	304	32,5	
13	Jorzec			10,6
14	Kuchenka			2,7
15	Lisunie			6,6
16	Majcz Wielki	154		10,8
17	Majcz Mały	22,7		2,4
18	Mamry Przysań			38
19	Miałkie	18,7		2,5
20	Mikołajskie Lake	470	27,8	
21	Nidzkie Lake	1784	25	
22	Niegocin	2669	40	
23	Płociczne near Żelwąg	10,8		2,8
24	Skonał			5,5
25	Smolaczek			5,5
26	Śniardwy	10660	25	
27	Tałtowisko	313	35	38,7
28	Talły	762	51	
29	Tejstmy	222	34	
30	Ublick Wielki	279	25	
31	Warnoły			
32	Wądołek	1	16	
33	Wejsunek			
34	Wuksniki	121	64	
35	Żelwążek	12,1		4,4

to the information obtained in the areas of study. The areas and depths were given according to the Catalogue of Polish Lakes (1954). However, if the measurements show greater depths, these latter are given in the last column of the table.

The whole of the material consists of 4,538 measurements of ability to scatter light in waters of the lakes investigated.

Typological considerations are based on the analyses of chemical composition of water at the bottom layer and are made mainly by suggestion of STANGENEERG M., (1936).

The writer is grateful to all the colleagues for their assistance in collecting materials necessary for this elaboration.

3. RESULTS

A. SCATTERING OF LIGHT

a. Day variations

The day variations in the Mikołajki Lake, which is the main object of this study, are shown in Fig. 1. During the course of a day, the values of ability to scatter light are considerably high. In the night they fall to increase again in the next day. The highest amplitude of these oscillations

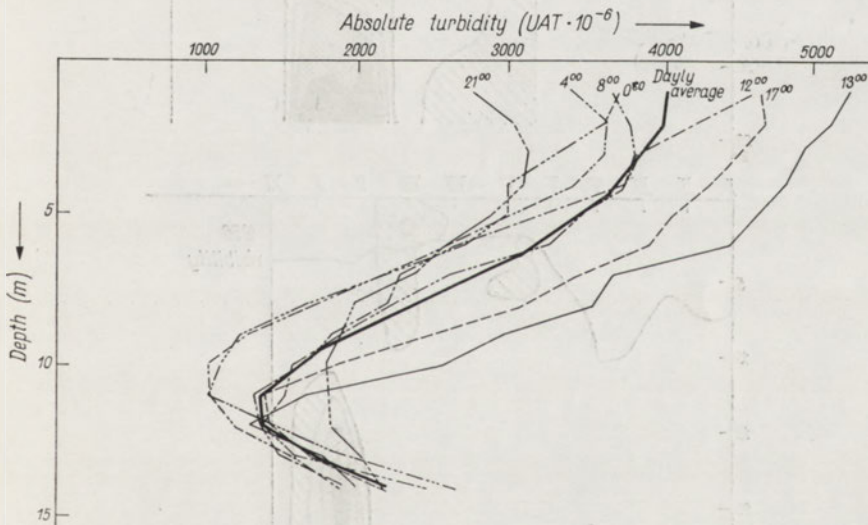


Fig. 1. Day variation of ability to scatter light in water and daily mean value in the Lake Mikołajki

which occur on the surface decreases with the depth. At a depth of 12 m no changes can practically be observed. The amplitude of these changes at the surface layer ranges from 2,530 UAT (25.8 at 13⁰⁰) to 2,270 UAT (25.8 at 21⁰⁰).

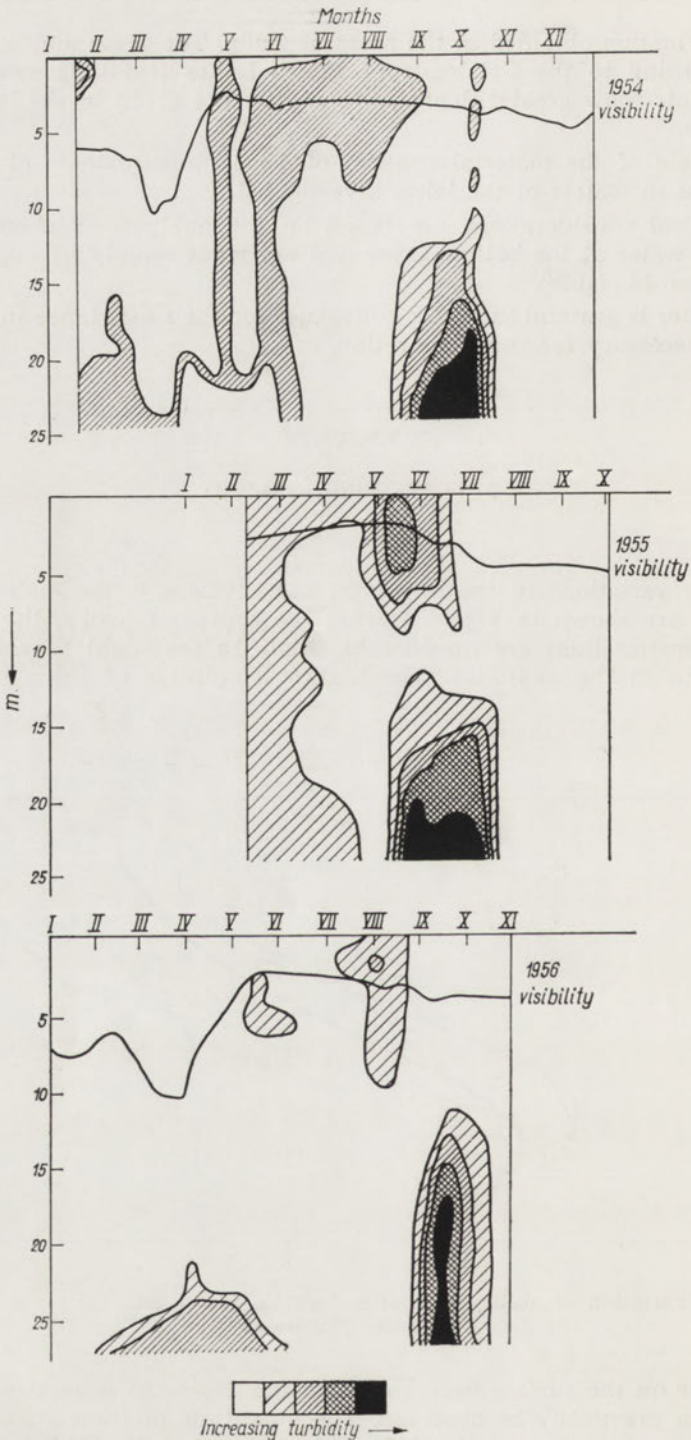


Fig. 2. Seasonal changes of ability to scatter light in the Lake Mikołajki

b. Seasonal variations

To explain the seasonal variations an analysis of ability to scatter light in water of the Lake Mikołajki was being made during three successive years, from 1955 to 1957. Samples were taken once a week or a decade at the deepest site of the lake, from the surface down to the bottom, 1 metre apart. Figure 2 shows changes in ability to scatter light in a water column at the deepest site of the lake during the successive years.

It proved that waters of an eutrophic lake as, for example, those of the Mikołajki Lake, are optically stratified and show changes during annual cycles. The autumnal circulation (November, December), at the time of which the water masses are optically uniform and include slight amounts of suspended particles scattering light, is followed by winter stagnation. In winter, the suspended matter is displaced beneath the ice cover; middle layers, about 6 m below water surface, are cleared up, as compared with both surface and bottom layers. This phenomenon does not appear on a considerably large scale, and can easily be explained by physical processes that take place beneath the ice cover. These are: (a) settlement of suspended matter heavier than water, and (b) rising of the suspended matter, lighter than water, to the surface. Due to these two opposed processes, the resultant can be observed in the form of decreasing amount of suspended matter in the middle layers of lake water. This phenomenon may be observed at the

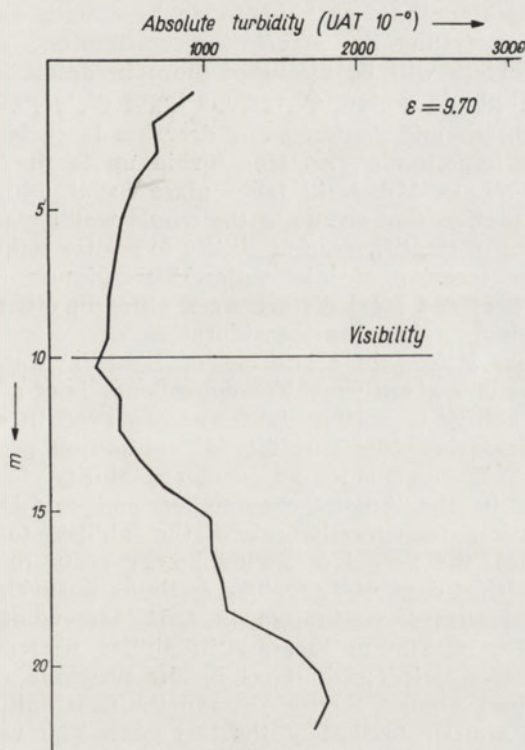


Fig. 3. Curve of ability to scatter light on 15.3.1954 in the Lake Mikołajki

close of winter stagnation. Figure 3 presents curves of ability to scatter light, observed in March, 1954.

After ice thawing, during the spring circulation, first an increase in ability to scatter light may be observed to occur in water masses. A differentiation connected with the depth is, however, lacking. This is the result of mixing of water masses during circulation.

This spring increase in turbidity of water is related to the spring blooms of phytoplankton (SZCZEPAŃSKI, 1966).

At the beginning of the summer stagnation of lake water, the differentiation in ability to scatter light rapidly increases. In the first period, up to midsummer, the increase can be observed in the epilimnion, whereas in the metalimnion and hypolimnion, the ability to scatter light decreases. The turbidity of epilimnion show the highest values of scattering at a depth of about 1—2 m below water level. This is connected here with the distribution of maximum amounts of phytoplankton.

In the second half of August, an increase in ability to scatter light has been ascertained to occur in the deeper layer. The intensity of scattering of light in this zone is considerably greater than in the epilimnion. Of particular importance is the fact that between the turbid water layer of epilimnion and hypolimnion, fairly clear water of thermocline occurs. Water of epilimnion is about tenfold more turbid than that of metalimnion. On the other hand, water of hypolimnion is 20 or 25 times more turbid than that of metalimnion. Thus, an opinion that we have to do here with an accumulation of suspended particles falling down off the epilimnion, seems not to be justified. This problem will be discussed more in detail in the Chapter on ability to scatter light in waters of various types of lakes.

Beginning with the mid-September, a decrease in turbidity of epilimnion is noted, whereas hypolimnion remains turbid up to the autumnal circulation which in the Lake Mikołajki takes place usually in the mid-October.

Autumnal circulation that occurs in the whole water masses is responsible for a disappearance of stratification of ability to scatter light. Such a situation persists up to the freezing of lake water. This picture can be subject to various, mainly short and local disturbances, since in other case no stability of the system could be taken into consideration.

The seasonal variations in scattering of light in water are related to climatic conditions of a given year. The dependence is of a general character. In 1954, a mean ability to scatter light was observed in spring circulation, the month May inclusive. The turbidity of epilimnion persisted throughout the whole August. The period of an increased ability to scatter light in hypolimnion was in the August, September and mid-October time. The autumnal circulation temporarily raised the ability to scatter light in epilimnion. In 1955, the period of spring homogeneity in ability to scatter light ended in the first days of June. The epilimnetic turbidities lasted, however, as compared with the situation in 1954, somewhat longer, reaching mid-September. The maximum increase in ability to scatter light fell on mid-August, and was twice as high as in the previous year. Hypolimnion turbidities comprised August, September and the first half of October. Thus, the situation was similar to that of the last year. The values of ability to scatter light in the period of the summer stagnation in hypolimnion were in both years also similar.

In 1956, the spring increase in ability to scatter light occurred in May and was characterized by considerably lower intensity. Summer epilimnetic turbidities began in July and ended in the second half of August. The intensity of ability to scatter light was also lower than in the previous year. The increased values of ability to scatter light in hypolimnion comprised, during the summer stagnation, the second half of August, September and the first half of October. Thus, they appeared about 2 weeks later, as compared with the previous years, but were similar in their intensities.

As concerns climatic conditions, the years 1954—1956 were different. The year 1954 may be thought to represent an average one. On the other hand, the year 1955 was extremely dry. The sum of precipitations from 1.5.1955 to 1.10.1955 amounted to 201.5 mm. Most days were windless, and intensity of stagnation processes was notably high. This resulted in a great ability to scatter light in epilimnion.

The year 1956 was very rainy, with precipitations amounting to 318.4 mm. Most days were windy. Due to a considerable cloudiness and windiness, the epilimnion differentiated during the summer stagnation from that of the last years in having lower values of ability to scatter light in water.

The changes in ability to scatter light in epilimnion may be explained by the dynamics of the planktonic communities that live in these layers. On the other hand, the summer increase in ability to scatter light in hypolimnion cannot be explained by the presence of suspended matter of epilimnetic origin accumulated in it. In this case, an increase in quantity of suspended matter could be observed already in metalimnion, a fact not evidenced by the material under examination.

The reason for the increase in ability to scatter light in deep waters should be expected either in the processes that take place in hypolimnion or in the processes occurring between the bottom and water. Cold water flowing out of sources, or water charged with bottom solutions coming from sublittoral and upper profundal can also be taken into account. Precipitation of iron hydroxides should be excluded here, since the Fe amounts are not high and do not exceed 0.5 mg/l (1 m above the bottom).

Similarly, an influence of CaCO_3 should also be rejected, because the ability to scatter light increases in hypolimnion uninterruptedly from July to October, and is not accompanied by any increase in carbonate and Ca contents. An increase in organic seston in hypolimnion water during stagnation is here more probable. OHLE (1958) has described the phenomenon of carrying away mud particles from the bottom, connected with an intense liberation of methane from the sediment during the stagnation period.

B. SCATTERING OF LIGHT AND TYPES OF LAKES

The classification of lakes and subdivision into limnological types were based on the fact that in eutrophic lakes a large amount of nutrient salts is found, favourable to the development of phytoplankton responsible for blooms. Oligotrophic lakes are poor in nutrient salts that restrict the development of phytoplankton (NEUMANN 1931). An increased amount of phytoplankton in eutrophic lakes causes an increase in scattering of light. Thus, we may expect that an analysis of the ability to scatter light can replace

the troublesome investigations of phytoplankton, on a scale adequate for typological purposes. The investigations conducted to explain this problem covered 35 lakes that belong to the following types:

I. Holomict lakes (24) including:	
lowland oligotrophy	3
mesotrophy	4
eutrophy	15
dystrophy	2
II. Bradymict lakes	2
III. Polymict lakes	9

a. Oligotrophic lakes

On the basis of the data from literature and on own materials (STANGENBERG 1936; OLSZEWSKI 1953; SZCZEPAŃSKI 1961) the Lakes Białe Węgierskie, Hańcza and Wukniki were classified to the group of lowland oligotrophy. Table 3 presents the results of own analyses of bottom water (1 m above the bottom) of the lakes under consideration.

Table 3

Some environmental data of lakes investigated

Name of lake	Date	Visibility in m	Values (1 m above bottom)				
			t°C	Oxy- gen %	pH	Ca mg/l	P
Oligotrophy							
Białe Węgierskie	12.8.57	—	5,2	52,0	7,5	—	n.d.
Hańcza	16.8.57	8,0	4,6	71,0	7,8	47,0	n.d.
Wukniki	20.8.57	6,2	4,7	67,9	7,5	97,4	n.d.
Mesotrophy							
Mamry Przyszań	14.8.58	3,3	8,2	33,0	7,1	70,0	0,049
Tałtowisko	9.8.58	2,9	6,4	24,2	7,5	82,9	traces
Tejstymy	19.8.57	2,8	6,2	16,7	7,4	79,5	traces
Babięty Wielkie	12.8.58	2,0	4,6	42,3	7,4	96,6	0,050
Eutrophy							
Głębokie near Zelwąg	25.8.57	3,4	6,0	5,2	7,1	71,4	traces
Niegocin	9.8.57	3,0	8,9	3,3	7,3	77,3	n.d.
Jagodne	17.7.61	2,8	5,8	2,0	7,4	50,0	0,02
Elckie	16.8.57	1,0	4,7	8,8	7,5	77,3	0,16
Juno	19.8.57	1,5	6,5	0,5	7,5	66,1	0,05
Beldany	7.8.57	2,25	7,4	0,13	7,2	69,4	traces
Mikołajskie	23.8.57	3,0	10,0	traces	7,3	77,6	
Nidzkie	2.8.57	2,7	8,2	0,0	7,2	76,2	n.d.
Jorzec	20.8.58	1,6	10,5	0,0	7,0	92,4	0,52
Bradymixy							
Guzianka Wielka	2.8.57	5,2	7,3	0,0	7,3	76,2	
	18.8.58	—	4,5	0,0	7,0		
Wądołek	5.8.34	2,5	4,5	0,0	6,3		0,052
	Stangen- berg						
	17.7.59	2,5	4,9	0,0	6,0		0,043
	Szczepań- ski						

No differentiation in stratification of ability to scatter light in water has been ascertained in the lakes studied (Fig. 4). The values of the ability to scatter light are low, and do not exceed 1,500 UAT, and in the Lake Wuksniki and in hypolimnion of the Lake Hańcza are even lower than 1,000 UAT. To illustrate this problem we would like stress that the values of ability to scatter light in distilled water amount to 150–300 UAT.

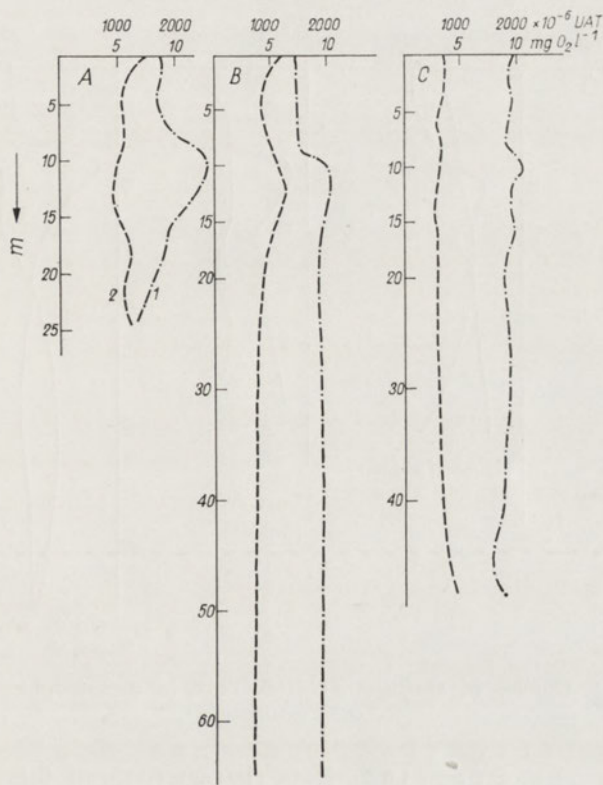


Fig. 4. Curves of ability to scatter light in oligotrophic lakes

A — Białe Wig, lake 12 VIII 57; B — Hańcza lake 16 VIII 57; C — Wuksniki lake 28 VIII 57;
1-0; 2-turbidity

b. Mesotrophic lakes

The group of the mesotrophic lakes that take an intermediate position between the oligotrophy and eutrophy is highly irregular. Thus, each of these lakes should be considered separately. Here belong: such lakes as Mamry-Przystań, Tałtowisko, Babięty Wielkie and Tejstymy.

The minimum value of the ability to scatter light, slightly marked and occurring in metalimnion or somewhat lower, does not decrease below 1,000 UAT. The Lake Mamry-Przystań is here an exception disclosing a value strongly approximate to the boundaries characteristics of the oligotrophic lakes. The surface maxima of ability to scatter light amount to 3,000 UAT,

and in the case of Babięta Wielkie they even exceed 3,000 UAT. The bottom maxima of this ability are, as a rule, approximate to the surface ones.

Fig. 5 presents curves of ability to scatter light and oxygen curves of the group of lakes in study. Some limnological data concerning bottom water of these lakes are shown in Table 3. Owing to differentiated character of the lakes under consideration, they will be discussed separately.

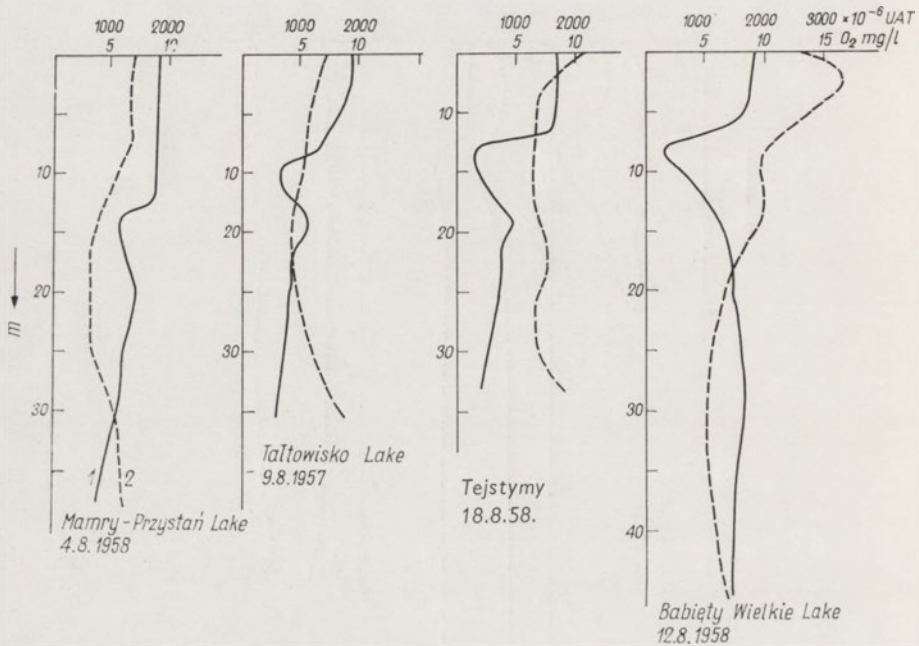


Fig. 5. Curves of ability to scatter light in mesotrophic lakes
1 — O₂; 2 — turbidity

Lake Mamry-Przystań. Data characteristic of this lake are scarce. Some data concerning chemical properties of this lake are given by GIEYSZTOR and ODECHOWSKA (1958). According to their measurements, the oxygen content on 8.8.1950 was 33% of the whole saturation, and carbonate content amounted to 2.64 m val., the phosphate content being 0.3 mg/l PO₄. During own measurements the author observed that thermocline was at a depth of 12—16 m. Oxygen saturation in hypolimnion at a depth of 20 m was 59.9% of the whole saturation, and at the bottom only about 33%. The curve of ability to scatter light was similar to that of oligotrophic character. The lake seems to be distinctly in the early stage of mesotrophy.

Lake Tałtowisko. Still scarcer data are found in respect to the Lake Tałtowisko. Comparing all previous data, OLSZEWSKI (1953) mentions only a work by WILLER (1923), in which carbonate contents measured at the lake surface on 14.10.1919, amounted to 133 mg/l CaCO₃. OLSZEWSKI and PASCHALSKI (1954) give a series of chemical determinations of sub-surface waters and between waters of this lake measured on 9.9.1950, and classify them as those representing mesotrophic lake. On the basis of oxygen occur-

ring at the bottom layers (9.8.1957 — 27.5%, 9.8.1959 — 23.9% and 8.8.1960 — 26.0%). The Lake Tałtowisko should be related to mesotrophy; but somewhat later the oxygen contents drop at the bottom considerably so that at the time preceding autumnal circulation, its quantity amounts to 1—3% of saturation.

In the Lake Tałtowisko *Mysis relicta* (Loven) has been found. Due to a fact that this form is cold-loving and oxygen-loving we may assume that the periods of oxygen decrease are short and do not comprise the whole hypolimnion. The curve of ability to scatter light is slightly bent, and corresponds to oligotrophy. At the bottom, this ability increases to 1,700 UAT.

Lake Babięty Wielkie. There are somewhat more data characterizing the lake considered. BRANDT (1944) considers the Lake Babięty Wielkie as an oligotrophic lake. OLSZEWSKI (1953) however, when analysing Brandt's materials, draws a conclusion that this lake should be referred to a-mesotrophic lakes. This conclusion is corroborated by the data obtained by OLSZEWSKI and PASCHALSKI (1959). The materials gathered by Brandt point to a fact that the quantity of oxygen in metalimnion does not drop below 4.8 mg/l (22.8.1938). It results, however, from our materials that the quantity of oxygen is considerably lower and decreases below 2 mg/l (30 mg/l on 12.8.1958 and 1.73 mg/l on 31.7.1959).

It is possible that the process of eutrophization of the lake considered caused changes in oxygen saturation in metalimnion during the period of summer stagnation. It is also possible that Brandt, having samples taken at greater distances than our samples, omitted the oxygen minimum of metalimnion.

The oxygen saturation in hypolimnion is considerably high. On 12.8.1959 the quantity of oxygen in hypolimnion exceeded 50% of saturation, and only in the lowest layers of hypolimnion it decreased to 42% of saturation. On 31.7.1959, the amount of oxygen was more than 60% of saturation, and at the bottom reached 54.4%. Thermocline occurs fairly high (6—8 m), as compared with the lakes of these dimensions.

The curves of ability to scatter light in hypolimnion are similar to those of oligotrophic type. In epilimnion, however, there are observed conditions approaching eutrophy (3,300 UAT). It seems that the highly productive epilimnion, characterized by a great amount of phytoplankton, cannot affect the great masses of water in hypolimnion which are of an oligotrophic nature.

Lake Tejstymy. According to OLSZEWSKI (1953), the Lake Tejstymy is greatly depending upon the activity of wind. Our observations of 19.8.1957 point to a fairly distinct stability of the lake. The stability of water masses of the lake in study is proved by a relatively cold hypolimnion (6.2°C), thermal gradient amounting in metalimnion to 2.9°/m at a depth of 6—8 metres, a sharp decrease of oxygen at the same depth (3.40 mg O₂/l/m), and minimum of oxygen in metalimnion amounting to 1.54 mg/l O₂ with 4.7 mg/l in upper hypolimnion.

The curve of ability to scatter light, with the minimum amounting to 1,300 UAT at a depth of 6—12 m, is characterized by an arcuate shape. At the surface, the values of the ability to scatter light exceed 3,000 UAT. To this boundary approach also the values measured at the bottom. On the basis of oxygen found at the bottom (16.7% of saturation), the Lake Tejstymy should be related to the b-mesotrophic lakes.

The mesotrophic lakes discussed above have been arranged according to the degree of trophity.

The Lake Mamry-Przystań occurs at the boundary of oligotrophy and mesotrophy, and under these conditions the quantity of phosphates (0.3 mg/l), ascertained by GIEYSZTOR and ODECHOWSKA (1958), seems to be alarming.

The Lake Tałtowisko (is situated falls in the middle) in between a-mesotrophy and b-mesotrophy. The presence of *Mysis relicta* (Loven) that needs for its development at least 50% of oxygen saturation of hypolimnion water, points, according to THIENEMANN (1925), that decreased amounts of oxygen in hypolimnion are of short duration allowing this species to survive.

The Lake Tejstymy undoubtedly belongs to the group of b-mesotrophic lakes (16.7% O₂ at a depth of 1 m above the bottom).

The Lake Babięta Wielkie should especially be discussed mainly due to the intensely producing epilimnion over the oxygen-rich hypolimnion (visibility: 2.45 m on 8.6.1959, 1.85 m on 6.7.1959, 1.75 m on 31.7.1959, 2.65 m on 15.9.1959).

The curves of the ability to scatter light in water occur as almost straight line (Mamry) to arcuate line (Tejstymy). In the Lake Babięta Wielkie the course of the curve is disturbed by the seston of epilimnion.

c. Eutrophic lakes

Limnologically, these lakes are different. They were examined in various stages of summer stagnation, thus their curves of the ability to scatter light are variously formed.

Limnological data, as concerns bottom waters in certain eutrophic lakes discussed in this paper, are shown in Table 3.

Lake Tałty. According to OLSZEWSKI and PASCHALSKI (1959) hypolimnion bears traces of oxygen (0.1—0.4 mh/l) on 14.9.1950. The measurements* from 24.8.1956 show the presence of oxygen amounting to 4.0—3.25 mg/l. The author's measurements from 19.7.1961 in hypolimnion illustrate 2.21—1.38 mg O₂/l (above 10% of saturation).

A high oxygen saturation in hypolimnion in 1956 points to a lower primary production, as compared with other years. This situation is reflected in a curve of the ability to scatter light, resembling the curves of mesotrophic type, and appearing between 1,000—2,000 UAT (Fig. 6). This points to an early eutrophy of the lake considered.

Lake Juno seems to be still in the first stage of stagnation, when water of epilimnion shows a fairly great intensity of the ability to scatter light, whereas hypolimnion is not turbid as yet. The Lake Elckie passes from the first stage into the second stage, i.e. areas strongly scattering light began to develop in the lower hypolimnion. Most probably, the source of these turbidities should be expected in the contact zone between water and bottom. Epilimnion is continuously characterized by the ability to scatter light on a large scale. Both layers are separated by relatively transparent water of metalimnion and upper hypolimnion. The lakes Beldany, Jerzec, Niegocin and Jagodne (not discussed in detail in this paper) are in the same stage of development.

* Measurements made by the Hydrochemistry Department of the Agricultural University in Olsztyn

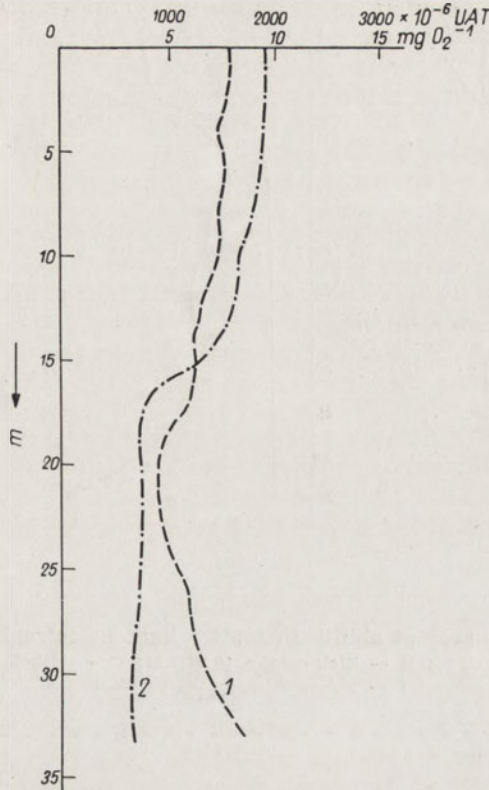


Fig. 6. Oxygen curve and curve of ability to scatter light in the Lake Tały
1 — turbidity; 2 — O_2

Both Lake Mikołajki and Lake Nidzkie reached already the second stage of summer stagnation, in which epilimnion water underwent clarification, whereas in hypolimnion the turbidity continuously increased.

The curves of the ability to scatter light are characterized by distinct minimum in metalimnion. Epilimnetic maximum in the lakes characterized by strong eutrophy, as, for example in the Lake Jerzec, reaches up to 10,400 UAT, or in the Lake Elckie, with increased eutrophy due to municipal sewage waters, to 11,200 UAT. The bottom maximum of the ability to scatter light reaches, in the lakes with sulphuretted hydrogen, up to 6,600 UAT in hypolimnion (Lake Nidzkie), or even 40,200 UAT (Lake Jerzec). In this connection, the curve of the ability to scatter light in the eutrophic Lake Niegoćin, deviating from the typical form, is here characteristic. It points to a relatively small amount of suspended particles that scatter light. The curves of the ability to scatter light in eutrophic lakes are given in Fig. 7.

Fertility of the eutrophic lakes and mass development of phytoplankton are responsible for a fact that the curves of the ability to scatter light show maximum values in epilimnion, the visibility in these lakes being lower.

Lake Ublík Wielki was characterized at the time of examination by a deviation from the most typical systems of ability to scatter light in

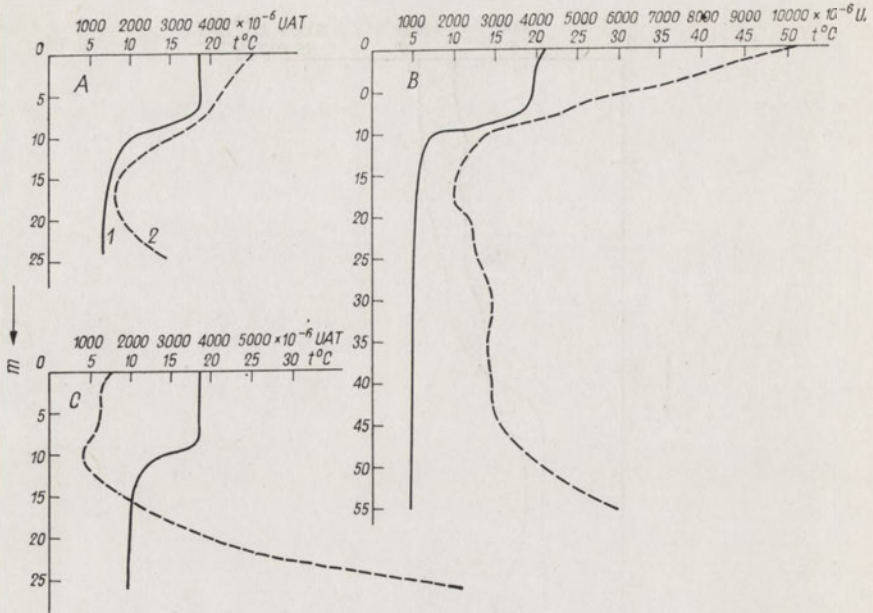


Fig. 7. Curves of ability to scatter light in eutrophic lakes
 A — Juno lake 19 VIII 57; B — Elckie lake 16 VIII 57; C — Mikołajskie lake 23 VIII 57;
 1 — temperature; 2 — turbidity

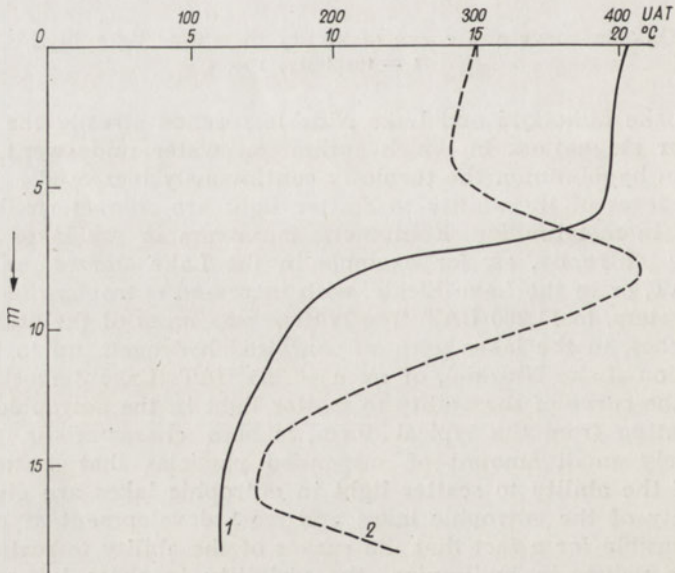


Fig. 8. Curve of ability to scatter light in the Lake Ublik Wielki
 1 — temperature; 2 — turbidity

eutrophic lakes, presented in Fig. 7 and arranged according to the degree of stagnation. Its curve of the ability to scatter light is presented in Fig. 8. The Lake Guzianka Wielka is characterized by a distinct tendency to meromixy, i.e. to be of bradymict character (PASSOWICZ 1938). A considerable stability of waters of this lake is illustrated in Fig. 9.

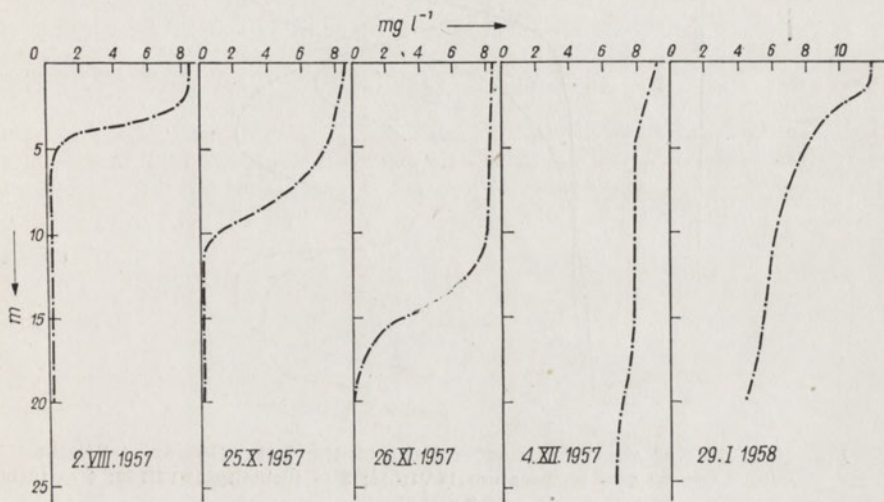


Fig. 9. Oxygen curve of the Lake Guzianka Wielka

As it may be seen in the above figure, the autumnal circulation lasted in 1957 notably short (from 26.11 to 4.12.1957) and did not lead to a complete oxygen saturation of hypolimnion, since in the day of freezing of this lake (4.12.1957) the oxygen content of the bottom layers reached barely 50% of the whole saturation.

Table 3 presents data concerning bottom water of the lake under consideration for a period of two successive years. Figure 10 demonstrates the curves of the ability to scatter light in water of the Lake Guzianka Wielka, in corresponding years.

The Lake Wądołek is the next bradymict lake in the Suwałki Region. This basin was especially elaborated by PASSOWICZ (1938), who referred it to meromict lakes.

A comparison of the data obtained by STANGENBERG (1936) and those collected during our examinations is presented in Table 3.

As an example of the transition between holimixy and polymixy, i.e. between the lakes characterized by the presence of epilimnion and metalimnion only, may serve here the lakes Lisunie and Skonał.

Figure 11 illustrates a series of thermo-oxygen profiles of the Lake Skonał. They show that epilimnion reaches almost the bottom of the lake. A similar picture represents the thermal-oxygen curve of the Lake Lisunie. The curves of the ability to scatter light in waters of the lakes under consideration are approximate to those of eutrophic lakes (Fig. 7).

Distinct polymict lakes, independently of their sizes, e.g. small lakes as Miałkie, Werpuny or Kuchenka, and Sniardwy the largest lake in Poland,

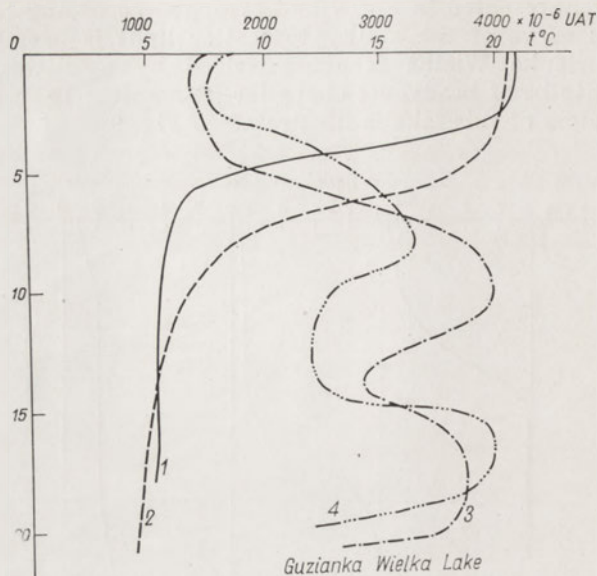


Fig. 10. Curve of ability to scatter light in the Lake Guzianka Wielka
 1 — temperature 2 VIII 57; 2 — temperature 18 VIII 58; 3 — turbidity 18 VIII 58; 4 — turbidity 2 VIII 57

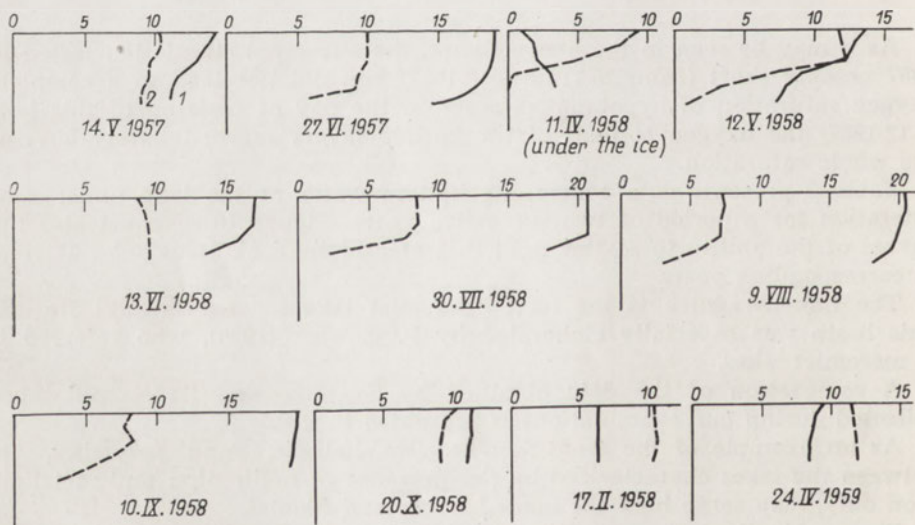


Fig. 11. Thermal, oxygen curves of the Lake Skonał
 1 — temperature; 2 — O_2

are characterized by a common lack of differentiation in the degree of the ability to scatter light, although close to the bottom these values considerably increase.

In winter, when the ice cover protects the water masses from wind activity and from atmospheric influences, stronger stratification may appear in such lakes, or sharp deficiency in oxygen may occur.

Such a situation is illustrated by a thermal-oxygen diagram characteristic of the deepest site Markwardek within the Lake Śniardwy, from 21.2.1958 (Fig. 12). The decrease in oxygen content was at that time so strong that it led to an accumulation of sulphuretted hydrogen at the bottom. A strong production of this lake is responsible for the formation of typically eutrophic sediment that consumes large amounts of oxygen.

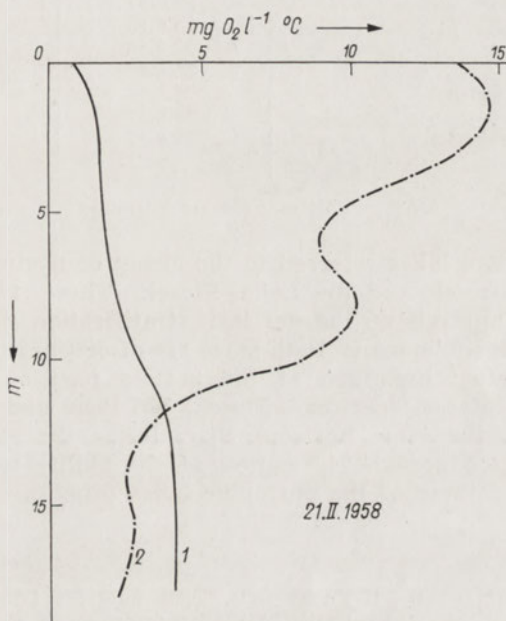


Fig. 12. Thermal, oxygen curve of the Lake Śniardwy, 21.2.1958
1 — temperature; 2 — O_2

In the case of a sunny and windless summer, as it was in 1959, in the Śniardwy area there may appear oxyclines and thermoclines which in the year mentioned above, were of short duration. A similar short-lasting thermocline was also observed at the beginning of June 1958.

After the formation of thermocline, the bottom turbidity distinctly increases. In shallower lakes, but of considerable areas, as for example the Lake Jeziorak, the degree of scattering of light does not differ greatly in the individual layers, but the absolute values are considerably greater than in the Lake Śniardwy.

The value of the ability to scatter light, various in the individual lakes, points to a certain dependence upon their area. Large lakes are characterized by lower values of the ability to scatter light. This dependence is not distinctly expressed since the value of the ability to scatter light is connected with the development of plankton, thus with the trophicity of a lake, and

not with its size. It ranges from 1,200 UAT in the Lake Śniardwy to 13,500 UAT in the Lake Miałkie. The mean value of the ability to scatter light in water of polymict lakes is shown in Table 4.

Table 4
Mean values of the ability to scatter light in polymict lakes

Name of lake	Date	Mean UAT
Śniardwy	23.8.57	1200
Zelwążek	25.8.58	1800
Kuchenka	22.8.58	2000
Jeziorak	26.8.58	5600
Płociczno near Zelwąg	25.8.58	5600
Inulec	27.8.57	7000
Głębokie near Głębock	21.8.57	10500

UAT = Unit of Absolute Turbidity

There are still two lakes referred to the group of dystrophic lakes. These are the Lake Smolaczek and the Lake Flosek. These two bog-lakes are shallow, thus an analysis of the vertical stratification in the ability to scatter light can hardly be made. Both lakes are of distinct stagnant character, revealing sulphuretted hydrogen at the bottom part of the water mass. Strong thermal gradients (6.4°C/m—Flosek, 30.7.1958) and oxygen gradients (6.4 mg O₂/l/m at the same horizon) characterize the stability of waters during the stagnation period. The curves of the ability to scatter light are of the same type as those of the eutrophic lakes (Fig. 7).

4. VISIBILITY AND ABILITY TO SCATTER LIGHT. DISCUSSION AND CONCLUSIONS

If the definition that light coming from a disk placed at the boundary of visibility to the observer's eye is so weak that the eye does not perceive it, were reasonable, then an increase in the intensity of light would exceed this extreme value, and the disk would become visible, i.e. it might be lowered to obtain new boundary of visibility. In consequence of this, the visibility would depend upon the intensity of light, and this has not been observed.

The seston that occurs in water is responsible for the scattering of light. Part of the light is directed towards the water surface and leaves the water basin.

The intensity of light in the water masses is connected with the visibility. Sauberer and Ruttner (1941) relate the visibility with the light of the water mass. According to these authors, the Secchi disk is not visible in the moment in which the light of the water mass corresponds in its intensity to that of the light reflected from the disk.

It should be added here that the interpretation of visibility greatly differs from the theory of visibility accepted in meteorology. Visibility in the air

is reversely proportional to the logarithm of the coefficient of air transparency, and this depends upon the quantity of water vapour and dust in the atmosphere (KOSTIN 1952, SHARONOV 1947).

Changes in visibility of the Lake Mikołajki during the year 1954 are shown in Fig. 13. Considerable visibility can be observed in this lake in January and February (over 6 m). In mid-March the visibility was characterized by the greatest value and exceeded 10 m to decrease at the close of March to 6.80 m. Subsequently, shortly after thawing period, it decreased to 3 m. During the summer, the visibility is constant and corresponds to 3 m to increase in the autumn up to 4 m. The changes under consideration were observed in 1954. In 1955, due to somewhat greater blooms, the visibility was in all the lakes lower, the differences in the Lake Mikołajki being about 1 m, as compared with the previous year.

The seasonal change in the visibility of various lakes may be distinguished by various course according to their limnological types. It results from the observation of the visibility in the Lake Wigry that the maximum visibility occurs in November-December (11.5 m, LITYŃSKI 1926), to decrease during the winter period by 2–3 m, and to fall after thawing to about 4–5 m. Beginning with the mid-summer period, the visibility systematically increases to obtain its maximum in December.

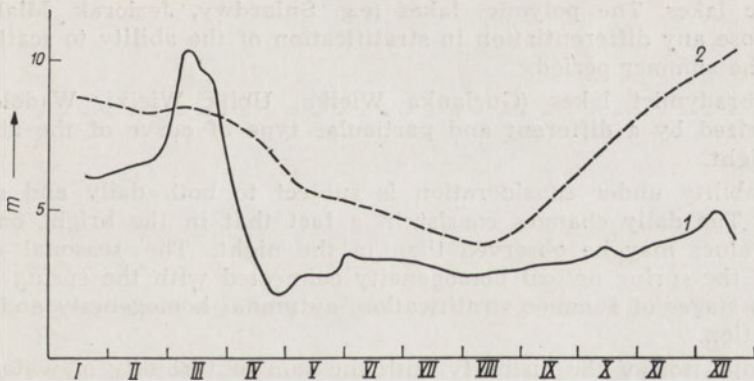


Fig. 13. Visibility (Secchi) in the Lakes Mikołajki and Wigry
1 — Mikołajskie lake; 2 — Wigry lake

The greatest mean monthly visibilities in the Lake Mikołajki are observed under the ice cover in the period from January to March. At that time they exceed 6 metres. In April, this value diminishes to 4.3 m to attain in the summer period a value below 3 m. In October, the value raises to 3.75 m and increases to 4.5 m in December. After freezing, the value of the visibility approximately increases to the winter values (above 6 metres). The differences, which can be observed, should be related to the typological differences in the lakes studied.

The mean values of visibility of the individual lake types (according to measurements in 88 lakes) calculated on the basis of STANGENBERG'S materials (1936), concerning the summer stagnation, are as follows:

Ologotrophic lakes	7.4 m
a — mesotrophic	5.6 m
b — mesotrophic	3.8 m
Eutrophic lakes	2.7 m
Bog-lakes	2.4 m.

Typological classification is based on a presumption that in oligotrophic lakes a small amount of plankton occurs, and that this plankton is very abundant in eutrophic lakes (NAUMANN 1931). This allowed the author to assume that instead of troublesome examinations of phytoplankton, a quick method of investigations of the ability to scatter light should be applied in the typological research works. This property is characteristically connected with the type of a lake. The oligotrophic lakes (Hańcza, Wuksniki, Białe Wig.) do not reveal any differentiation in the ability to scatter light in vertical profile. The mesotrophic lakes (Mamry-Przystań, Tałtowisko, Tejstymy and Babięta Wielki) show a differentiation in the ability to scatter light in vertical profile. The absolute values of turbidity are somewhat higher than in the group of oligotrophic lakes. The eutrophic lakes (for example Beldany, Elckie, Mikołajki, Nidzkie) are characterized, during the summer stagnation, by a distinct differentiation in turbidity in vertical profile. In the dystrophic lakes (Fłosek, Smolaczek) the character of the differentiation in the ability to scatter light is approximate to that of the eutrophic lakes. The polymict lakes (e.g. Śniardwy, Jeziorak, Miałkie) do not disclose any differentiation in stratification of the ability to scatter light during the summer period.

The bradymict lakes (Guzianka Wielka, Ublik Wielki, Wądołek) are characterized by a different and particular type of curve of the ability to scatter light.

The ability under consideration is subject to both daily and seasonal changes. The daily changes consist in a fact that in the bright day some higher values may be observed than in the night. The seasonal changes comprise the spring optical homogeneity connected with the spring circulation, two stages of summer stratification, autumnal homogeneity and winter stratification.

A comparison of the visibility with the sum of turbidity of water above the disk (computed as $\int T/z/dz$ for 66 pairs of measurements — SZCZEPAŃSKI 1958) gives, in Pearson correlation, the value of $r = 0.20$. For 147 pairs of measurements the value r amounts to only 0.029. Thus, we see that with the increase in materials, the coefficient r strongly decreases, tending to be of 0 value. The changes in visibility do not correspond to that of sum of suspended matter, i.e. the amount of the suspended particles above the disk is constant (C). This means that the changes in visibility are not connected with those in quantity of suspended matter that occurs in a water column above the disk. This should be understood that the disappearance of disk is not conditioned by a defined weakening of visible radiation, but certain constant and determined sum of turbidity is here necessary. This value is for the Lake Mikołajki as follows:

1954 — 64.8	of scattering units
1955 — 64.3	„ „ „
1956 — 65.5	„ „ „

The mean value for all the measurements in all the lakes investigated was 60.7 of scattering units. Fig. 14 presents a relation between the visibility and ability to scatter light. It results from the data presented that the disk disappears when is completely concealed by the suspended matter.

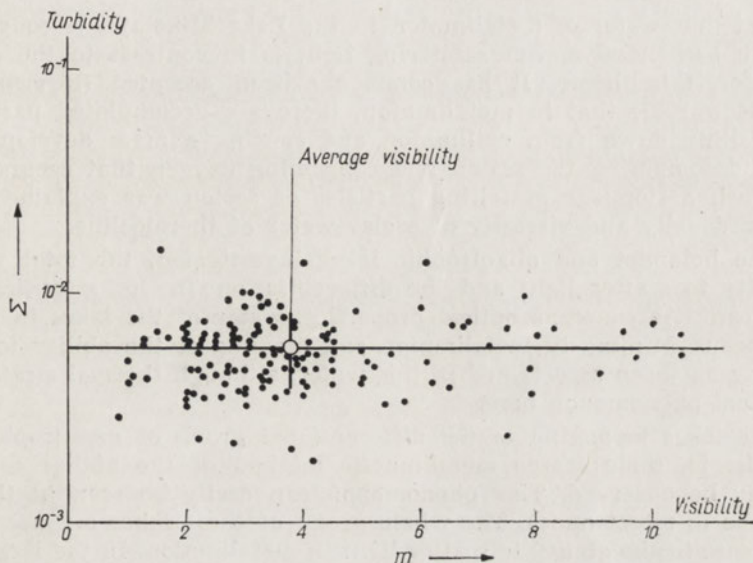


Fig. 14. Dependence between visibility and ability to scatter light in lake water

In the years characterized by more considerable blooms, the same value of turbidity sum is due to a thinner water layer only and, therefore, the visibility in these years is lower.

In most European lakes and almost in all European lowland lakes, seston forming suspended matter and determining the visibility of water, consists mainly of phytoplankton. Due to this fact, the production of a lake can be estimated on the measurements of visibility. The conclusion is the more reasonable, the greater is the visibility observed in the lakes examined. The lakes characterized by great visibility are no doubt oligotrophic. On the other hand, the lakes disclosing a slight visibility are probably eutrophic; probably, since the supply of allochthonous mineral materials is possible in the lakes fed by glacier water, which decreases its visibility, but does not rise its trophic properties. Dystrophic lakes, characterized by coloured waters due to humus substances, also deviate from this scheme. These causes are, however, easy to be proved, and, consequently, can easily be taken into account.

The visibilities in the lakes of the Suwałki region (STANGENBERG 1936) point to this relation univocally. The average visibilities of the lakes examined by the Station at Mikołajki were as follows: oligotrophy—7.1 m, mesotrophy—2.75 m, eutrophy—2.3 m. These values are lower than those obtained by Stangenberg. Most probably, the differences between the average values of these types should be related to the soil-landscape differences.

The visibilities of the lakes in the Tatra Mts. amount to 19 m (Wielki Staw Hińczowa), and the average visibility of the lakes situated at a height amounting to more than 1,500 m above sea level are 11 m (SEDLMEYER 1929). A comparison of lowland oligotrophy with mountaneous oligotrophy points to fairly considerable differences.

A fact that water of metalimnion in the Lake Mikołajki is considerably poorer in suspended matter scattering light is in contrast to the previous opinion on this theme. It has commonly been accepted (RUTTNER 1940, HUTCHINSON 1957) that in metalimnion, there are accumulated particles of seston falling down from epilimnion and causing a mass development of bacteria decomposing the seston and consuming oxygen that occurs in this layer. Such a stoppage of falling particles of seston was explained by an increased density and viscosity of cooler water of thermocline.

In the holomict and oligotrophic lakes investigated, the total value of the ability to scatter light and the differentiation in its stratification is insignificant. As concerns optical properties, water of the lakes in study is homogeneous. Minima in metalimnion and maxima of the ability to scatter light have not been ascertained in this water, although thermal stratification is a normal phenomenon here.

In the lakes belonging to the differentiated group of mesotrophic lakes (conf. Fig. 5), some scarce metalimnetic minima of the ability to scatter light may be observed. This phenomenon can easily be seen in the Lake Tałtowisko (b-mesotrophy). The whole group of these lakes did not disclose any increase in the ability to scatter light in metalimnion. In the large group of holomict and eutrophic lakes the metalimnetic minima of the ability to scatter light are distinctly visible (Fig. 7). In some cases they are slightly displaced downward so that the minimum of the ability to scatter light falls not in the middle of metalimnion, but appears in the boundary zone between metalimnion and hypolimnion. The occurrence of maxima of the ability to scatter light in the metalimnion of the eutrophic lakes has not been ascertained at all. A different picture of differentiation in the ability to scatter light has been observed only in the bradymict lakes.

It results from the data presented above that all holomict lakes, independently of the degree of their trophy, either do not show any differentiations, or are characterized by the minimum of the ability to scatter light in the metalimnion. A maximum ability to scatter light has never been ascertained.

This is in contrast to the previous opinion as concerns the metalimnetic layer. It has generally been accepted that metalimnion is a zone of accumulation of seston. In consequence of this we should expect that the ability to scatter light in this layer will increase. STANGENBERG (1959) stressed this problem during his examination of BOD of lake waters, and pointed out that no increased values of BOD could be observed in metalimnion that could evidence the presence of a larger amount of organic substances decomposed by bacteria in this layer. When analysing the distribution of bacteria in the water masses of the Italian lakes, STANGENBERG (1966) observed the maxima of their occurrence in the lower epilimnion or in the metalimnion. However, the quantities of the bacteria examined were so insignificant that they could not affect the picture of distribution of suspended matter in water. Our observations allow us to enlarge the conclusion drawn by

STANGENBERG (1959) and to state that in metalimnion of the holomict lakes no greater accumulation of seston can be encountered.

In consequence of this we should explain the appearance of oxygen deficits in the metalimnion, which in extreme cases can cause a complete loss of oxygen and the appearance of H_2S . This, however, requires a special researches that can explain the hydrodynamics of the metalimnion and biological and chemical processes in this layer.

5. SUMMARY

Results are presented of the researches on natural turbidity of lake waters. The studies covered 35 lakes of the Mazury Lake District. Measurements of turbidity were made by examination of Tyndall effect using Pulfrich's nephelometer.

Daily and seasonal variations of the ability to scatter light in lake water are discussed. It has been ascertained that the daily variations of the ability to scatter light occur in water of epilimnion.

Seasonal variations involve the entire water masses and are connected with the general dynamics of the changes in a lake. Spring circulation is connected with the spring optical homogeneity of water. As concerns summer stagnation, two stages of summer stratification have been ascertained. It has been stressed that the epilimnetic turbidity and hypolimnetic turbidity are distinct phenomena. Autumnal circulation leads to the autumnal optical homogeneity which is followed by winter stratification after freezing of the lake. Supposed causes of turbidity in hypolimnion are given, and factors affecting the dynamics of the changes in seasonal ability to scatter light are presented.

Continuous occurrence of minima of ability to scatter light in metalimnion is discussed, and a coincidence of this phenomenon with the shape of the BOD curves in metalimnion is stressed. A conclusion by STANGENBERG (1959) has been corroborated that no accumulation of organic compounds can be observed in metalimnion, although so far this problem was so interpreted.

Biological consequences resulting from these conclusions are stressed. According to these observations the "rain of corpses" does not accumulate in metalimnion, or is exceptionally small. It has been ascertained that oligotrophic lakes do not show any distinct differentiations in the quantity of suspended matter in vertical profile. Mesotrophic lakes, in turn, show a slight differentiation in turbidity. Eutrophic holomict lakes and dystrophic lakes are characterized by differentiated ability to scatter light.

Bradymict lakes are characterized by a different shape of the curve of ability to scatter light, which is distinguished by the occurrence of maximum of turbidity in the upper hypolimnion. Polymict lakes disclose an equalized turbidity in vertical profile.

It has been ascertained that the coefficient of correlation between the visibility and the sum of suspended matter computed as $\int T/z/dz$ tends to zero, a fact proving that no correlation exists between these features.

Moreover, a dependency is stressed between visibility and mean turbidity of water layers above the disk. This is a consequence of the theorem that the sum of suspended matter above the disk is constant.

A dependence between visibility and limnological type of lake has also been taken into consideration.

STRESZCZENIE

Przedstawione zostały wyniki badań nad mętnością naturalną wód jeziornych. Badaniami objęto 35 jezior Pojezierza Mazurskiego. Pomiarów mętności dokonowano przez pomiar efektu Tyndalla przy użyciu nefelometru Pulfricha. Omówiono zmienność dobową i sezonową zdolności rozpraszania światła przez wody jeziorne. Stwierdzono, że zmienność dobową zdolności rozpraszania światła obejmuje wody epilimnionu.

Zmienność sezonowa obejmuje całą toń wodną i związana jest z ogólną dynamiką zmian w jeziorze. Cyrkulacja wiosenna związana jest z wiosenną jednorodnością optyczną wody. W czasie letniej stagnacji wyróżniono dwa stadia letniego uwarstwienia. Wskazano na to, że zmętnienie epilimnetyczne i hypolimnetyczne nie są ze sobą związane. Jesienna cyrkulacja prowadzi do jesiennej jednorodności optycznej, która przechodzi po zamarznięciu jeziora w uwarstwienie zimowe. Podano prawdopodobne przyczyny zmętnień hypolimnionu. Wskazano na przyczyny kształtujące dynamikę zmian sezonowych zdolności rozpraszania.

Podkreślono stałe występowanie minimów zdolności rozpraszania światła w metalimnionie. Stwierdzono zbieżność tego zjawiska z ukształtowaniem krzywych BZT w metalimnionie. Potwierdzono wniosek STANGENBERGA (1959), że w metalimnionie nie obserwuje się nagromadzenia związków organicznych, co było dotychczas powszechnie przyjmowane.

Podkreślono biologiczne konsekwencje wynikające z tych wniosków. Zgodnie z tymi obserwacjami „deszcz trupów” nie nagromadza się w metalimnionie, względnie jest znikomo mały. Stwierdzono, że jeziora oligotroficzne nie wykazują wyraźnych różnicowań ilości zawiesiny w profilu pionowym. Jeziora mezotroficzne wykazują nieznaczne różnicowanie mętności. Jeziora eutroficzne holomiktyczne i jeziora dystroficzne posiadają różnicowania zdolności rozpraszania.

Jeziora bradymiktyczne posiadają odmienny kształt krzywej zdolności rozpraszania charakteryzujący się występowaniem maksimum mętności w górnym hypolimnionie. Jeziora polimiktyczne mają mętność wyrównawczą w profilu pionowym.

Stwierdzono, że współczynnik korelacji między widzialnością a sumą zawiesiny liczonej jako $J M/z/dz$ zbliża się do zera co świadczy, że między tymi cechami nie zachodzi korelacja.

Wskazano na zależność między widzialnością a średnią mętnością warstw wody leżących nad krążkiem. Jest to konsekwencją stwierdzenia, że suma zawiesiny nad krążkiem jest wielkością stałą.

Wskazano na zależność między widzialnością a typem limnologicznym jeziora.

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