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The effect of suspended materials on the zooplankton

I. Natural environments*

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Abstract — The influence of suspension upon zooplankton population in ponds, upland and lowland reservoirs was investigated. Suspension of pond containing a great deal of phytoplankton (max. turbidity 1200 mg SiO_2 dm^{-3} or 123 mg of mineral fixed residue) was significantly noxious for *Kereratella cochlearis, K. quadrata, Trichocerca cylindrica, Ceriodaphnia pulchella, Daphnia pulex, Chaoborus crystallinus.* Seston from lowland reservoir (max. turbidity 119.5 mg SiO_2 dm^{-3}) significantly and negatively influenced *Daphnia cuculata,* cladocerans as a whole and copepods. It stimulated development of rotifers. In upland reservoir at turbidity over 300 mg SiO_2 dm^{-3} (max. turbidity 898 mg SiO_2 dm^{-3}) zooplankton was practically absent. For all species occurring there, negative dependence with turbidity was found.

1. Introduction

The factors responsible for differences in zooplankton populations from one aquatic habitat to another are not always obvious. Marked variations in temperature, pH, oxygen concentration, and the amount of organic matter are known to limit distribution of planktonic animals. In natural and artificial aquatic environments there exist much more important subtle factors. One of them is the turbidity, rather felt than confirmed by hydrobiologists. Thienemann (1911) noted that in artificial lakes in Westphalia the autumn development of plankton occurred simultaneously with the highest transparency. The dependence between water turbidity and plankton development in river was mentioned by Behning (1929) and Rylov (1940). According to Berner (1951) turbidity was the cause of small numbers or a lack of many species in

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Missouri river. There was a low proportion of phyto- and zooplankton — 2 : 1. Sabaneeff (1956) indicated that the presence of mineral particles in Wezera river as well as a strong current and extremely high concentration of salt negatively influenced the feeding of zooplankton. Williams (1966) connects the extremely low rotifers population in Colorado, Arkansas and Snake rivers with the sliming of water. The hydrological regime and especially turbidity are the environmental parameters showing a distinct correlation with quantitative fluctuations of zooplankton (Paggi and Paggi, 1974).

Many descriptive observations concern the impoundments. For example, Siemińska (1952) found in Rożnów reservoir (on Dunajec river) a twice smaller number of plankton after heavy rainfalls. Krzanowski (1965) observed the diminution in zooplankton quantity in the reservoir after abundant rains. Also Smagowicz (1963) reported decrease of all zooplankters in reservoirs at postinundation period. Starzykowa (1972) carried out her investigation on zooplankton in the cascade of two reservoirs. In the lower smaller reservoir she found zooplankters in smaller numbers. This was caused by cold and muddy water flowing through the bottom flood-gates of the upper dam. The same author (Starzykowa 1973) connected a quantitatively and qualitatively very poor zooplankton in this lower reservoir with the influence of low temperature of water discharged from the upper one.

Tilzer et al. (1976) has discussed the effect of spring discharge of mudded water to the oligotrophic Tahoe lake. They found an increase in nutrients and, on the other hand a decrease in transparency. The final effect depends on the relation of loading suspensions to the amount of introduced biogenic substances.

In spite of large and conspicuous variations, turbidity as a factor affecting organism is a little understood. In laboratory conditions different problems connected with relation of zooplankton to mineral suspension were tried to be solved by Gaevskaja (1949), Stephan (1953), Robinson (1957). The results are often controversial. In many other cases suspensions of different kind of particles were used as a tracer in observations of feeding behavior, filtering selectivity (Gliwicz 1969), filtering rate (Ivanova 1966) etc.

By reason of descriptive and often controversial previous data, an attempt has been made to estimate the significance of natural conditions found in turbid planktonic environments.

2. Investigated area

Field investigations presented below were carried out in two reservoirs far removed from each other. One of them is situated in a mountainous region at Rożnów on Dunajec river (49° 44′ N lat., 20° 41′ W long.) and the second one at Goczałkowice, in upper lowland part of the River Vistula (49° 56′ N lat., 18° 54′ W long.). The third place of investigation were three ponds in the Experimental Station of the Polish Academy of Sciences at Gołysz (49° 52′ N lat., 18° 48′ W long.).

In south Poland there are many carp ponds. In this region their soils contain a comparatively considerable percentage of floating particles. Intensified carp culture management (mowing of submerged and inshore macrophytes) and fish feeding make an appreciable amount of bottom mineral suspension enter the water. By this reason, three ponds marked 7,9 and 8 with increased carp stocking and turbidity were examined.

South Polish rivers have a very unequal water-flow. Punzet (1975) comparing the right-sided tributaries of the River Vistula noted that the most affluent in water in the River Dunajec. It leads with its drainage area 1000 km^2 19.6 dm^3 s^{-1} km^{-1} of water. Next come the Rivers Soła and San, then Upper Vistula, Skawa, Raba. These tributaries have a very high absolute water-flow ratio (Q_{max}/Q_{min}) exceeding 1000, 2000 and more. In consequence of the large changes of water-flow, these rivers periodically bear considerable amounts of draw materials and drifts. This drift has much more floating particles (under 0.02 mm) than land soils. Chemical composition of water of the river is modified by the use of the catchment basin for farming purposes and influence of neighbouring towns and villages.

2.1. Ponds

The experimental pond complex in which the investigation was carried out was built on dust soils of aqueous origin (Pasternak 1965). Wróbel (1971) has done fishing description of these ponds. Granular composition of bottom soils was a follows: fraction of 1—0.05 mm make 23%, 0.05—0.02 mm — 30%, particles lesser than 0.02 mm constitued 38 per cent. Fraction smaller in size than 0.002 mm consisted in the first place of quartz — 88%, zircon — 1.5%, rutile 1% and others 0.5%. Thermoanalysis of bottom sediments showed 4% organic substances, 3% montmorillonite, 4.8% kaolinite, 0.8% carbonates, and the rest thermically inert 87.4%. Montmorillonite and kaolinite as main clay minerals give together 7.8%. Pond soils in the fish farm at Gołysz contain a small or average amount of calcium and magnesium. Sediments contain 43%

of floating particles. The pH of these soils is acid (Pasternak 1958, 1965).

Surface of each pond is 1500 sq. m. Fish stockings were as follows: pond No. 7—300 ind./hm^2 with mean weight 255 g; pond No. 8 — fish stocking — 3868 ind./hm^2, mean weight 248 g; pond No. 9 — fish stocking 900 ind./hm^2, mean weight 2489. At the end of sample collecting period ponds 8 and 9 gave ca 400 kg ammonium salpetre in 6 doses. Fish in pond 8 were fed additionally by common granulate.

2.2. Rożnów reservoir

The Dunajec drains Tatra region, Nowy Targ dale, Gorce, Pieniny, Beskid Sądecki and Pogórze Mountains. The highest Tatra parts of drainage basin are formed of crystalline rocks. In the somewhat lower parts of the Tatra Mts, limestones, marls, dolomites, slates and sandstones occur. The reservoir lies on the area covered in the upper part by sandstones and Magura schist fairly rich in calcium carbonate (Pasternak 1971).

The soils formed of these mother-rocks are acid. They are mostly skeleton soils, loams, river sands and in the river valleys alluvial soils (light, medium, heavy).

The river carries into the reservoir 43 mg dm^{-3} Ca, 10.6 Mg, 2.62 P, 11.92 Na, 0.07 Fe, 39 mg dm^{-3} SO_4. Furthermore, the River Dunajec transports a large load of biogens. Apart from the reservoir a daily load of PO_4 is 1500 kg, N-NO_3 — 5100 kg, N-NH_4 — 300 kg (Bombówna 1975).

The bottom sediments have a small amount of organic matter ranging from 1.53 to 3.49 per cent. pH in water extract is alkaline and in the upper part has an average 7.4 in the middle 7.3, and in the lower part 7.2. Sediments from the upper part of the reservoir had 25—77 per cent (mean 60.2 per cent) of floating particles (Pasternak, Cyberski 1975).

Water turbidity in the Dunajec fluctuated from 1 mg dm^{-3} in autumn-winter period up to the value of over 2000 mg dm^{-3} in high water period.

According to Starmach's (1958) classification of this reservoir is of the rheolimnic type.

2.3. Goczałkowice reservoir

Flysh formations in alternating layers form the substratum of the mountainous and submontane parts of the upper Vistula basin. They are composed of sandstone and schist, with inserted conglomerates in the mountainous part, and of schist and limestone in the submontane one.

Flysh formations of the submontane area are partially covered by Quarternary formations. The Goczałkowice reservoir (area 32 km^2, mean depth about 5 m) lies on these formations. All water is exchanged after 190 days (Wróbel 1969).

Bottom sediments have a greater amount of organic matter than reservoirs built on the mountain rivers e.g. Rożnów, Porąbka, Czchów (Wróbel 1958, 1969). South-west winds can generate waves 2.1 m high.

Tracz noted (1958) that in the first years of existence of the reservoir, its turbidity ranged from 2 to 37 mg SiO_2 dm^{-3}. In weight units this amounts to 4—15 mg dm^{-3}. Domańska (1958) reported for the same period that after rainfall, the River Vistula carried in reservoir 76.8 mg dm^{-3} mineral suspension.

3. Methods

All zooplankton samples were taken by 5 liter Patalas's bathometer. In ponds, 5 liter of water were collected at each of 4 stations. Investigations were carried out from June to August 1973. 30 samples were collected from ponds. In Rożnów reservoir samples were collected from surface level, 1.5 m depth, and further down to the bottom every 2 m. Volume of samples taken from both reservoirs was filtered by planktonic net No. 25 (with a side of square mesh 50 μm). Samples were preserved in 40 per cent formaline. From Rożnów reservoir 40 samples were collected in summer 1974. Throughout the 1974 year, 60 samples were collected from Goczałkowice reservoir. Simultaneously in the same way, qualitative samples were collected. Counting was carried out in a 0.5 or 1 cm^3 chamber under small magnification. Usually 10 to 15 per cent of sample was counted. For reservoirs, the number of species was plotted as a function of depth, than graphically integrated. Thus, the mean number of the species in the water column was calculated.

Water for phytoplankton analysis was taken (in ponds) from two levels 0—0.5 m and 0.5—1.0 m with Patalas's bathometer and mixed in bucket. 700 cm^3 of water was taken into a jar from the sample averaged in above way, then treated with several drops of Lugol's solution and left to settle for one day. Afterwards the sample was decanted and transferred as a whole into a small jar, and then preserved with Transeau solution. Quantitative and qualitative analyses was carried out under a cover slide in the drop of sample of a known volume. For statistical calculations, the quantity of particular classes or size groups was used. The criterion for including the alga into the given size group was the sum of its width and length. Small algae under 100 μm, medium between 100 and 250 μm, and large ones over 250 μm were distinguished.

The amount of bacteria in the bottom sediments from impoundments was determined by the direct counting method under the microscope with use of acridine orange as fluorescent dye and observation of fluorescence effect. The quantity of heterotrophic bacteria in water of ponds was determined indirectly by counting the colonies grown on bouillon agar after seven days of culture in 25°C.

Suspension was measured nephelometrically according to H e r m a n o w i c z et al. (1976) and as a mineral fixed residue after decrepitation at 550°C.

Oxygen was measured by Winkler's method (H e r m a n o w i c z et al. 1976).

Chlorophyll *a* was determined from sediment remain on membrane filter (dissoluble in acetone, 0.45 μm porosity) after filtration water of a known volume. The measurements were made at waves length of 750 and 663 mm. Chlorophyll content was calculated from standard curve.

Organic matter in water was determined using titrimetric method by wet combustion in potassium bichromate (H e r m a n o w i c z et al. 1976).

The mineral composition of sediments was performed by the thermoanalysis method (T o k a r s k i 1954).

Humic acids were fractionated according to the B o r a t y ń s k i and W i l k (1963) method.

Statistical analyses were carried out by calculation of multiple regression equations with the use of the method of least squares. The solving of equations system was performed directly from observed data by Cracovian root method. Estimations of standard errors of unknown quantities and s-test were calculated (W ł o d e k 1961, S t r z a ł k o w s k i and Ś l i ż y ń s k i 1978). The equations obtained are linear in form. In view of zero values of some characteristics and the impossibility of coding data for logarythmic transformations of equations, the latter have not been calculated for all species. For ponds data five characteristics were examined: temperature, concentration of oxygen dissolved in water, quantities of heterotrophic bacteria, turbidity, and coefficient of food basis (CFB). Equations for two sorts of expression of turbidity were calculated: as mg SiO_2 dm^{-3} and as concentration of mineral fixed residue (MFR) — mg dm^{-3}. The number of quantity CFB were: concentration of chlorophyll *a*, quantity of *Euglenophyta, Cyanophyta, Cryptophyta, Chrysophyta, Bacillariophyta, Chlorophyta*, of small, middle and large algae. Two characteristics — turbidity and temperature in regression analysis for data from impoundments were taken into account.

4. Results

4.1. Ponds

In the period from June to August water in the ponds had fairly high temperature. Its fluctuations were within the range of 16.8—23.9°C. Oxygen conditions considered as a mean in a vertical profile may be accepted as good. The smallest oxygen concentration amounted to 4.52, and the highest one to 13.23 mg dm^{-3}. The water of pond No. 7 had an average 16.8 mg O_2 COD as concerns dissolved organic matter while total COD was 20.22. COD of dissolved organic matter in pond No. 9 amounted to 18.6 and total 35.03. Pond 8 had the highest COD values 20 and 60 mg O_2 respectively.

The amount of heterotrophic bacteria found in the water of the unfertilized pond (No. 7) and fertilized with superphosphate (No. 9) was similar and amounted from ten to twenty thousand in 1 cm^3. In pond No. 8 where fishes were fed, the amount of bacteria attained several dozen thousands in cm^3.

The amount of suspension in water expressed as MFR varied with in the range of 12.7—123.0 mg^{-3}. Suspension expressed as turbidity in relation to the silica standard had values from 64 to 1200 mg SiO_2 dm^{-3}.

In phytoplankton composition green algae were the most numerous group. Their maximum quantity was 13×10^6 cells dm^{-3}. The next numerous group were blue-green algae. The diatom number did not undergo any major fluctuations and amounted to a few score per cm^3. The quantities of *Cryptophyta* formed likewise. *Euglenophyta* showed a dis-

Table I. Range of some parameters in ponds. The size of algae is a sum of width and length. Amounts of algae as cells cm^{-3}

Parameters	Pond		
	7	8	9
Temperature (°C)	19.00 - 23.73	17.00 - 23.91	16.80 - 23.87
Oxygen (mg dm^{-3})	7.25 - 9.23	4.75 - 8.16	5.87 - 13.23
Mineral fixed residue (mg dm^{-3})	12.70 - 22.70	41.20 - 123.00	27.60 - 120.00
Turbidity (mg SiO_2 dm^{-3})	53.0 - 250.0	217.0 - 1200.0	132.0 - 900.0
Bacteria (cells cm^{-3})	6860.0 - 31560.0	11610.0 - 24900.0	6630.0 - 61000.0
Chlorophyll a (µg dm^{-3})	12.0 - 80.0	240.0 - 440.0	65.0 - 260.0
Euglenophyta	0.00 - 7.85	0.00 - 308.45	0.00 - 66.53
Cyanophyta	7.14 - 1170.96	0.00 - 668.30	0.00 - 21.42
Cryptophyta	0.00 - 203.20	0.00 - 308.46	0.00 - 192.78
Chrysophyta	0.00 - 10.28	0.00 - 0.00	0.00 - 0.00
Bacillariophyta	11.42 - 137.08	0.00 - 62.83	5.46 - 74.25
Chlorophyta	164.22 - 4889.47	2727.00 - 12920.0	612.75 - 4355.40
algae < 100 µm	239.90 - 12703.5	2120.6 - 13171.15	649.76 - 4433.9
100 < algae < 250 µm	0.00 - 182.8	14.3 - 891.1	8.22 - 95.1
algae > 250 µm	0.00 - 15.71	0.00 - 102.8	0.00 - 55738.0

tinct preference of the pond with large turbidity and high concentration of organic matter. *Chrysophyta* was the class least frequently found.

The calculations were carried out for 16 species of rotifers, 7 species of cladocerans, 1 species of *Calanoida*, 2 sp. *Cyclopoida*, 1 sp. of *Diptera*, *Chaoborinae* and the group called "others" i.e.: *Brachionus urceolaris*, *B. quadridentatus*, *Lecane* sp., *Chydorus globosus*, *Kurtzia latissima*, *Alona rectangula*, *Alonella* sp., *Pleuroxus* sp., *Acanthocyclops* sp. which were the components of this group.

4.1.1. Rotifers

Conochiloides coenobasis practically was not resistant to ponds suspensions. When the suspension was expressed by MFR, all variants of CFB were nonsignificant. When it was expressed by SiO_2 all variants of CFB with two exception (chlorophyll and *Chlorophyta*) for which the relation was positive and low significant, no relation was noted.

Conochilus unicornis. No significant dependence was confirmed but in 18 variants the relation was inversely proportional to suspension.

Pompholyx sulcata. In the variant with suspension expressed by MFR

Table II. Sign of regression coefficient and it level of significancy as a per cent in ten variants changes of food kind. Suspension as mg of SiO_2 dm^{-3}. (A) and as mg of MFR dm^{-3}; (B) size of algae in μm.
Explanations: chl - chlorophylla; Eug - Euglenophyta; Cya - Cyanophyta; Cry - Cryptophyta; Chr - Chrysophyta; Bac - Bacillariophyta; Cho - Chlorophyta

Species	chl		Eug		Cya		Cry		Chr		Bac		Cho		<100		100<>250		>250	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Conochiloides coenobasis	5	+	+	+	+	−	+	−	+	−	+	−	10	−	+	−	+	−	+	−
Conochilus unicornis	+	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
Pompholyx sulcata	−	+	10	5	5	1	5	1	5	1	5	1	10	5	5	1	1	1	5	1
Keratella cochlearis	−	−	−5	−1	−5	−1	−1	−1	−1	−1	−5	−1	−5	−1	−5	−1	−1	−1	−1	−1
K. cochlearis f. tecta	−	+	−	+	+	1	+	1	+	1	+	5	−	−	+	5	+	1	+	5
K. quadrata	−	−10	−5	−1	−5	−1	−1	−1	−1	−1	−5	−1	−5	−1	−1	−1	−1	−1	−1	−1
Polyarthra dolichoptera	+	+	5	5	5	5	5	1	5	1	5	5	10	5	5	5	5	1	5	1
P. vulgaris	+	+	+	+	−	+	+	+	+	+	+	+	+	−	+	+	+	+	+	+
Brachionus diversicornis	−	−	−	−	−	+	−	+	−	−	−	−	−	−	−	−	−	−	−	+
B. cylyciflorus	+	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B. rubens	−	−	+	+	−	−	+	+	+	+	−	+	+	+	+	+	+	+	+	+
B. angularis	−10	−	−	+	−	−5	−	+	−	+	−	−	−	−	−	+	−	−	−	+
Trichocerca cylindrica	−	−	−	−10	−5	5	−5	−5	−10	−10	−10	−5	−	−	−10	−10	−5	−5	−5	−5
Filinia longiseta	+	+	+	10	10	+	10	1	10	5	10	5	+	+	+	10	10	1	10	5
Asplanchna girodi	10	+	10	+	10	−1	5	5	10	+	5	10	5	10	5	10	5	10	10	+
Synchaeta sp.	−	+	−10	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+
Others	−	+	−	−	+	10	−	+	−	−	+	+	−	−	−	−	−	+	−	−
Bosmina longirostris	−	−	+	+	+	1	+	1	+	1	+	5	−	+	+	5	10	1	+	1
Ceriodaphnia pulchella	−1	−5	−1	−1	−1	−5	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1
Diaphanosoma brachyurum	+	−	−	+	−	+	+	−	+	+	+	+	−	+	−	+	−	+	−	+
Daphnia longispina	−	5	−	+	−	−	−	+	−	+	−	−	−	−	+	+	−	−	−	+
D. pulex	−1	−	−1	−10	−5	−	−1	−5	−10	−5	−5	−10	−1	−5	−1	−5	−1	−5	−1	−
D. hyalina	−	−	−	−	−	−	−	−10	−	−	−	−	+	−	−	−	−	−	−	−
Moina micrura	+	+	5	1	1	1	1	1	1	1	1	1	5	5	1	1	1	1	1	1
Naupli	+	+	10	1	10	10	5	1	5	1	10	1	5	5	5	1	5	1	5	1
Copepodits	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
Thermocyclops crassus	−	+	+	+	+	+	+	10	+	5	+	+	+	+	+	10	+	10	+	+
Cyclops vicinus	−	−	10	5	−	10	10	5	10	10	−	+	−	+	10	5	10	5	5	1
Diaptomus gracilis	+	−	+	−	−	−	+	−	−	−	−	−	+	−	+	−	+	−	+	−
Chaoborus crystallinus	−	−	−10	−1	−1	+	−5	−1	−5	−1	−5	−1	−	−1	−5	−1	−5	−1	−5	−1
Sedimented volume of zooplankt.	−	−	−	−	−	+	−	+	−	+	−	+	−	−	−	+	−	−	−	−

and chlorophyll by CFB, no effect of the suspension was observed. If *Euglenophyta* or *Chlorophyta* were used as CFB the dependence was positive and significant at $P < 0.05$ level. In other variants the dependence was highly significant ($P < 0.01$ and less). In the case of variants with SiO_2, the significance of the relation was lasser as a rule, Table II. In the variant with chlorophyll *a* change of sign from positive to negative took place, and in the variants with *Chlorophyta* and *Euglenophyta* a displacement to $P < 0.1$ level. When the CFB were algae of medium size, the level of significance of regression coefficient did not change. In other variants the stimulation of increase in number of *P. sulcata* reached a moderately significant level, $P < 0.05$. In most variants the equations of regression indicated a significant increase in quantity of this species along with an increase in the amount of suspension.

Keratella cochlearis. In the variant with suspension expressed by MFR, in one case — chlorophyll, no dependence of suspension on the quantity of *K. cochlearis* was confirmed. The other nine variants showed a negative and highly significant dependence, $P < 0.01$ and sometimes $P < 0.001$. The change of manner of the expression of suspension amount did not cause major displacements in the significance of regression coefficient. In the variant with chlorophyll the effect of suspension remained negative and nonsignificant. In other four variants of CFB — *Cryptophyta, Chrysophyta,* small algae, large algae — the influence of suspension was negative and highly significant. In the remaining variants the order of dependence was invariable, only the level of significance diminished to $P < 0.05$.

Keratella cochlearis f. tecta reacted to suspension contrary to *K. cochlearis*. When the suspension was expressed by MFR, nearly all variants of CFB gave positive moderately or highly significant dependence. If the suspension was expressed by SiO_2 the coefficient of regression here discussed became nonsignificant, Table II.

Keratella quadrata reacted to suspension as *K. cochlearis*. In all variants of CFB and the forms of suspension expression the number of this species decreased along with turbidity augmentation, Table II. Nine variants of CFB (suspension as MFR) showed highly significant dependence, the tenth variant was of low significance — $P < 0.1$. With a change of suspension expression, in some variants (*Euglenophyta, Cyanophyta, Bacillariophyta, Chlorophyta*) the regression coefficient was significant at 0.05 level. In the other variants it continued to be highly significant.

Polyarthra dolichoptera appeared to prefer environment with a higher turbidity. When the suspension was expressed by MFR, the four variants of regression equation demonstrated highly significant stimulation as concerned the number of *P. dolichoptera;* in the remaining variants this dependence was significant at 0.05 level. With suspension expressed by

SiO_2 the variant with chlorophyll was nonsignificant, in *Chlorophyta* variant, the stimulation was of low significance, Table II.

In *Polyarthra vulgaris* independently from the form of expression of suspension and variant CFB, no significant dependency was noted.

Brachionus diversicornis similarly to the above species was not sensitive to suspension influence, Table II.

Brachionus calyciflorus, as it results from the table II, grows well in turbid water. In eighteen variants of MFR and CFB the dependence was positive and highly significant, Table II. No dependence in equations with chlorophyll as CFB was stated.

Brachionus rubens did not show distinct dependence on suspension

Brachionus angularis, similarly as the above species, was not dependent on suspension. Only one variant with *Cyanophyta* gave a significant dependence at 0.05 level. In other variants there was no dependence, Table II.

Trichocerca cylindrica. The quantity of population of this species diminished along with the increase in suspension. It was independent of the form of expression of suspension. When the suspension was expressed by MFR, a negative significant influence at 0.05 level in five variants of CFB was stated. Three variants of CFB (*Euglenophyta, Chrysophyta*, small algae) had a low significant relationship. Other variants were nonsignificant. With a changed form of expression of suspension there were some minor modifications. In four variants of CFB (*Cyanophyta, Cryptophyta*, medium and large algae), the influence of suspension was negative — $P < 0.05$ (Table II).

Filinia longiseta preferred an environment with augmented turbidity. In eight variants of CFB (suspension by MFR) the stimulation of quantity was confirmed. As concerns the variants with *Cryptophyta* and middle algae, the stimulation was highly significant. In variants with *Chrysophyta, Bacillariophyta* and large algae, the dependence was significant at 0.05 level. The variant with small algae and *Euglenophyta* was low significant (Table II). In the case of change of the form of suspension expression the significant level of coefficient treated diminished to $P < 0.1$ for the following CFB: *Cyanophyta, Cryptophyta, Chrysophyta, Bacillariophyta*, small and large algae. Other variants were nonsignificant.

Asplanchna girodi. If the suspension was expressed by MFR, the stimulation of population development was significant ($P < 0.1$) in the variants with *Bacillariophyta, Chlorophyta*, small and medium algae, Table II. When SiO_2 was used as a measure of suspension, all variants of CFB were positive and significant, Table II.

Synchaeta sp. did not show dependence on suspension. In 19 variants of CFB change and expression of suspension, nonsignificant coefficients were noted.

The other rotifers treated as one group did not reveal significant dependence on suspension. Aproximately one half variants were positive and the other half negative (Table II).

4.1.2. Cladocerans

Bosmina longirostris. When suspension was expressed by MFR and chlorophyll content used as CFB, the regression coefficient of this variable had a negative sign. When in the equation *Euglenophyta* and *Bacillariophyta* as CFB were used the equation-predicted effect was positive but nonsignificant. The other variants CFB usually had a positive sign and highly significant, Table II. The variant with turbidity expressed by SiO_2 from CFB had not significant relations.

Ceriodaphnia pulchella is a species showing highly significant reduction in numbers ($P < 0.01$ even $P < 0.001$) with increase in suspensoids, Table II. It was independent of CFB variant or the form of suspension expression.

Diaphanosoma brachyurum. The amount of suspension recorded in the ponds did not influence significantly the number of this species. Merely in different variants of CFB, the character of action changed into positive or negative. Negative dependence was more often observed when suspension was expressed as SiO_2, Table II.

Daphnia longispina. When the suspension was expressed by MFR and chlorophyll content by CFB according to regression equation, the increase in suspension caused an increase in number of *D. longispina* ($P < 0.05$). In othe other variants the respective regression coefficient is negative but statistically nonsignificant.

Daphnia hyalina. The respective regression coefficient except one variant (CFB — *Chlorophyta*) is invariably negative, once significantly (suspension as MFR, CFB — *Cryptophyta*), Table II.

Daphnia pulex diminished its number with increase in suspension amount irrespectively of the manner of expressing the suspension. In the case when suspension was expressed by MFR, the diminution of quantity prognosed by regression equation was statistically significant in seven variants ($P < 0.1$ or $P < 0.05$), but when expressed by SiO_2 (Table II) this diminution due to increase in suspension amount was low significant only in variant with *Chrysophyta* used as CFB. In variants with *Bacillariophyta* and *Cyanophyta,* the relation was moderately significant, in the other highly significant, $P < 0.01$.

Moina micrura found favourable developmental conditions at suspension ca 120 mg (as MFR), Table II. Only the chlorophyll variant is nonsignificant. If *Chlorophyta* are CFB, the influence of suspension was moderately significant, other variants were highly significant, $P < 0.01$.

The varians with suspension as SiO_2 and *Euglenophyta* as well *Chlorophyta* as CFB stimulation of development *M. micrura* was observed. This stimulation was higher in the remaining variants ($P < 0.01$ or $P < 0.001$).

4.1.3. Copepods

Naupli. This stage responded significantly positively to the increase in the amount of suspensions and irrespectively of the manner of its expression. When chlorophyll was used as a CFB the relation in this variant became nonsignificant irrespectively of the manner of suspension amount expression. When suspension was expressed by MFR the dependence in variants with *Cyanophyta* and *Chlorophyta* was respectively little and moderately significant, in other variants highly significant at 0.01 level.

Copepodits respond by a decrease in quantity when the suspension concentration is increased. For all CFB and the manner of suspension expression this dependence was statistically nonsignificant, Table II.

Thermocyclops crassus. When the suspension was expressed by SiO_2, the number of this species did not depend on its amount in all ten variants of CFB, Table II. When the suspension was expressed by MFR then in the variant with *Chrysophyta* the increase in quantity of this species along with the analogical one in the amount of suspensions ($P < 0.05$) was observed. In variants with *Cryptophyta* including small and medium algae this increase was significant with $P < 0.1$, Table II.

Cyclops vicinus. The number of this species significantly and positively depends on the amount of suspension ($P < 0.05$ and $P < 0.01$), independently of CFB assumed in calculations. Only in three variants of CFB changes (chlorophyll, *Cyanophyta, Bacillariophyta*) no relation between the quantity of *C. vicinus* and suspension was noted, Table II. When suspension was expressed as MFR, and the number of large algae was used as CFB then the dependence on suspension was highly significant.

Diaptomus gracilis. No dependence of the quantity of this species on suspension was stated, both forms of its expression having been used.

4.1.4. Other animals

Chaoborus crystallinus almost in all variants of MFR and CFB demonstrated a highly significant decrease in the amount with suspension increase, Table II. The change of form expression of suspension slightly diminished the level of significance to $P < 0.05$.

The sedimented volume of zooplankton in all variants was independent of suspension, Table II.

4.2. Rożnów reservoir

The interdependence between the quantity of seven species of rotifers, four cladocerans, naupli, as well as between the sum of rotifers cladocerans and copepods, were analysed. Regression equations were calculated for two variables: temperature (range 13.0—21.6°C) and turbidity (varied in the range 3—898 mg SiO_2 dm^{-3}).

4.2.1. Rotifers

Polyarthra major diminished its numbers with suspension increase, $P < 0.001$. Logarythmic transformation of equation gave a slightly lower significance, $P < 0.01$, Table III.

Table III. Relationships between amount of species and their groups (y) on temperature (T) and turbidity (S) in Rożnów reservoir. Coefficients of linear multiple regression: $y = a + bT + cS$; DF - degree of freedom

Species	Coefficients			Error of coefficients			Calculated t- test			DF
y [individ. dm^{-3}]	a	b	c	a	b	c	a	b	c	
Polyarthra major	357.645	-14.638	-0.163	94.959	5.156	0.040	3.766	-2.839	-4.065	37
Keratella cochlearis	-10.924	0.868	-0.000	10.879	0.591	0.005	-1.004	1.469	-0.081	37
K. cochlearis f. tecta	31.806	-1.305	-0.007	23.627	1.283	0.010	1.346	-1.017	-0.698	37
K. quadrata	0.509	0.012	-0.001	1.888	0.103	0.001	0.270	0.118	-0.733	37
Synchaeta longipes	57.018	-1.249	-0.019	121.742	6.611	0.052	0.468	-0.189	-0.369	37
Filinia longiseta	28.998	-1.423	-0.010	15.142	0.822	0.006	1.915	-1.730	-1.498	37
Asplanchna priodonta	0.144	0.076	0.001	4.570	0.248	0.002	0.032	0.307	0.271	37
Rotifera, sum	453.782	-16.031	-0.231	213.564	11.596	0.090	2.125	-1.382	-2.556	37
Bosmina coregoni and long.	17.529	-0.279	-0.015	29.554	1.605	0.013	0.593	-0.174	-1.231	37
Daphnia longispina	-2.421	1.020	-0.017	25.753	1.398	0.011	-0.094	0.729	-1.536	37
Daphnia cucullata	-199.034	14.912	-0.017	100.579	5.461	0.043	-1.979	2.730	-0.408	37
Cladocera, sum	-218.547	18.096	-0.043	142.464	7.736	0.060	-1.534	2.339	-0.711	37
naupli	283.269	-11.835	-0.111	74.955	4.070	0.032	3.779	-2.908	-3.488	37
Copepoda, sum	395.678	-15.942	-0.150	116.410	6.321	0.049	3.399	-2.522	-3.054	37

Keratella cochlearis reacted negatively on suspension, however the respective regression coefficient was nonsignificant, Table III.

Keratella cochlearis f. tecta responded negatively but nonsignificantly, Table III.

Keratella quadrata. Its number was independent of temperature. Turbidity negatively affected its numbers, Table III. The logarythmic transformation gave a better aproximation than the one linear one.

Synchaeta longipes. The respective coefficient was negative and nonsignificant, Table III.

Filina longiseta responded to the increase in suspension with the decrease in population number. It was, however not a significant relation, Table III.

Asplanchna priodonta as one of the not numerous species reacted positively on suspension increase, Table III.

Rotifers total. Quantity throw-back influenced significantly on suspension at 0.02 level, Table III.

4.2.2. Cladocerans

Daphnia cucullata showed highly significant dependence on temperature ($P < 0.01$ in linear equation, $P < 0.005$ in logarythmic transformation), Table III. At higher concentration than c. 200 mg SiO_2, *D. cucullata* practically was absent.

Daphnia longispina reacts to suspension much strongly than *D. cucullata*. Dependence was negative. It was positive as concerns temperature and much strongly expressed in logarythmic transformation of equation, Table III.

Bosmina coregoni and *longirostris* responded with a decrease in population number, Table III.

Cladocerans, sum. This group reacted negatively to suspension. At concentrations higher than about 300 mg SiO_2 practically they were absent. Along with an increase in temperature, the cladocerans significantly increased their number, Table III.

4.2.3. Copepods

Naupli. Their reaction to suspension was negative, highly significant, Table III. Those stages reacted also negatively on temperature increase.

Copepods, sum. This group was composed of *Acanthocyclops robustus, Cyclops vicinus, C. tatricus, Diacyclops* sp. and their copepodit stages. It reacted negatively and highly significantly to suspension, Table III.

4.3. Goczałkowice reservoir

The dependence of the number of particular zooplanktonic species or their group on temperature and turbidity was investigated. Temperature in the investigated period (the year 1974) varied from 2.3—21.4°C and turbidity from 8 to 119.5 mg SiO_2 dm^{-3}. The rather infrequent sampling periods (every two, three weeks) missed the time of very high turbidity hence certainly the dependence appears less marked.

4.3.1. Rotifers

Polyarthra vulgaris. The number of this species was independent of suspension, Table IV, while it was significantly dependent on temperature.

Synchaeta pectinata. It seems that this species preferred the kind of suspension existing in the reservoir ($P < 0.1$). The quantity of the species correlated more distinctly with temperature, Table IV.

Table IV. Relationships between amount of species and their groups (y) on temperature (T) and turbidity (S) in Goczałkowice reservoir. Coefficients of linear multiple regression:
$y = a + bT + cS$; DF – degree of freedom

	Coefficients			Error of coefficients			Calculated t-test			DF
y [individ. dm^{-3}]	a	b	c	a	b	c	a	b	c	
Protozoa, sum	315.533	-12.126	-0.084	64.058	4.298	0.205	4.926	-2.821	-0.410	57
Polyarthra vulgaris	-5.604	5.651	0.070	46.015	3.087	0.147	-0.122	1.831	0.474	57
Synchaeta pectinata	-123.599	12.409	0.452	74.085	4.971	0.237	-1.668	2.497	1.903	57
Rotifera, sum	-152.993	25.316	0.883	130.590	8.762	0.419	-1.172	2.889	2.109	57
Daphnia cucullata	2.240	2.338	-0.076	6.412	0.430	0.021	0.349	5.434	-3.719	57
Cladocera, sum	-1.644	3.953	-0.104	9.009	0.604	0.029	-0.182	6.539	-3.612	57
Copepoda, sum	70.281	-0.081	-0.102	11.617	0.779	0.037	6.050	-0.104	-2.742	57
Whole zooplankton	226.030	17.879	0.561	149.170	10.008	0.478	1.515	1.786	1.174	57

Rotifers, sum. The effect of the influence of suspension on this group was distinctly positive, $P < 0.05$. Also highly positive and significant was temperature influence on rotifers — $P < 0.01$ for linear approximation (Table IV), and $P < 0.0005$ for logarythmic transformation of equation.

4.3.2. Cladocerans, copepods

Daphnia cucullata reacted stronger to suspension than all cladocerans together. Value t test with 57 degrees of freedom was equal to -3.719 for linear form and -3.504 for logarythmic transformation. A still stronger dependence was on temperature, Table IV.

Cladocerans, sum. Both forms of equation regression gave negative and highly significant dependence, $P < 0.001$, Table IV. Relationship on temperature was also positive and significant, $P < 0.0001$.

Copepods, sum. This group like cladocerans reduced its quantity with an increase of suspension. Respective probabilities of error amount to 0.01 for linear equation and 0.001 for logarythmic form.

4.3.3. Other groups

Protozoa, sum. These rather avoided turbid waters yet the dependence was not significant. The dependence on temperature was stronger. Logarythmic approximation was better, $P < 0.001$.

Zooplankton, total. The number of all species together was independent of suspension regardless of equation form. The dependence on temperature was significant in both regression forms, Table IV.

5. Discussion

A number of publications cited in chapter 1 have suggested the existence of a factor rarely taken into account but influenced on the aquatic life. There is a suspension. The relationship between the quantity of zooplankton and water transparency was expressed in numbers by Paggi and Paggi (1974) for the first time. According to them the coefficient of correlation between the number of zooplankton and the logarythm of water transparency is r: 0.68. In this case turbidity was caused by a typical mineral suspension and transparency (in the River Parana) measured by Secchi disc varied in the range 9—67 cm. In view of a strong dependence of visibility of Secchi disc on water colour (Åberg, Rodhe, 1942) and in lakes on the number of algae, the estimation of relation between turbidity and the occurrence of organisms require additional information about suspension character.

In the statistical analysis which defines the dependence of occurrence of large systematic units on suspension, not always the revealed lack of significant dependence testifies to its lack in relation to separate species. In the case when the effect of the given factor is confirmed, probably all or almost all species composing the examined taxon of higher order, react in the same manner. One of them may react very significantly and there occurs the phenomenon of covering less significant relations. Besides, the linear equation not always presents the best image.

Maximal concentration of suspension expressed by MFR in ponds water amounted to about 120 mg, Table I. Maximal concentration of chlorophyll *a* was about 400 µg. After its conversion into biomass of phytoplankton, it yields 16 mg dm^{-3}.

Assuming that ash constitutes one per cent of biomass, the calculated share of MFR of phytoplankton origin gives 0.16 mg dm^{-3}. This is hardly 0.13 per cent of total MFR. Mineral parts of animal origin give a per cent but slightly over this value.

Hence the share of mineral substances of organic origin is overestimated about 1 per cent. The suspension was of small-particle character.

The above data suggest that the proportion of biomass to MFR amounts to 1 : 7.5 which may be tolerated by some species. From the different life spectra of individual species results a full range of transitions from a high significant stimulation of the growth of population, through the lack of dependence to high significant noxious influence of suspensions.

The ponds seston unselectively filtered by some species causes a decrease in the feeding value of the filtrate. It depends on the proportion of nonassimilated particles to food. The differences in those proportions may vary in the range of the size of filtration ability in some species.

An other factor strongly differentiating animal sensivity to suspension is the morphological structure and behaviour of animals. A lack of influence noted in ponds or even a stimulation of copepod development by suspension is probably caused by a rapid vibrating of the mouthparts and jerky spurts, the outcome of powerfull thrusts of the thoracic legs alternating with antenna movements. In given conditions it may by sufficient to keep the filtration apparatus in efficiency. Its morphological structure in *Cladocera* points to much greater possibility for clogging by the filtered suspension. Although, the *Cladocera* can clean their filtration apparatus, yet above certain concentrations and time of exposure this mechanism may be deceptive. The concentration of ponds suspension of the order of 120 mg MFR (a respective turbidity 1200 mg SiO_2), for most animals seems to be profitable or neutral. According to Stephan (1953) the suspension concentrations prepared with soil, clay and sand are noxious to *Daphnia magna* and *Bosmina coregoni* in the range of 500 mg concentration. Pejler (1965, fig. 34) found in Swedish lakes that such *Cladocera* as *D. cucullata, Ceriodaphnia quadrangula, Bosmina longirostris* most frequently live in lakes with low transparency, 1 m below. In the investigated ponds *Bosmina longirostris, Diaphanosoma brachyurum, Daphnia longispina, D. hyalina, Moina micrura* prefer an augmented turbidity or were neutral. On the other hand *Ceriodaphnia pulchella* and *D. pulex* avoid a higher turbidity. Nevertheless the literature of the subject does not mention noxious amounts of suspensions for those species. Among rotifers one can distinguish a group of species stimulated by suspension. These are: *Pompholyx sulcata, Keratella cochlearis f. tecta, Polyarthra dolichoptera, Brachionus calyciflorus, Filinia longiseta, Asplanchna girodi*. Pejler (1965) noted the same relation for *P. sulcata* and *F. longiseta*.

The corona in majority of these species belongs according to B e a u c h a m p's classification (1907) to *Euchlanis* type. R e m a n e (1932) has called it a filtration type. The structure of corona, mastax and its activity reveal a conspicuous possibility of identification of "unsavoury" food by sensory bristles receiving food in mouth. Not eaten particles are thrown out with backward water current.

Maximal size of particles which may be eaten by rotifers amounts to about 10 μm. The species of *Brachionus* genera can eat bigger particles — up to 20 μm. Nevertheless, a series deviations was observed. D u m o n t (1977) noted that *B. calyciflorus* may "gnaw" algae even as large as *Aphanizomenon*, and *Polyarthra dolichoptera* can eat *Cryptomonas* sp. whose dimensions are 16×48 μm (P o u r r i o t, 1965). P e j l e r noted the consumption of *Ceratium* and *Peridinium* genera by *P. euryptera*. The possibility of taking advantage of much larger food particles than it is usually considered and the merits of corona structure give them the opportunity of good development, and success in competition with other species in an environment rich in mineral suspensions. Probably such species as *Conochilus unicornis, Conochiloides coenobasis, Polyarthra vulgaris, Brachionus rubens, B. diversicornis, B. angularis, Synchaeta* sp. and the rotifers group named „others" do not show dependence on suspension.

To the rotifers group avoiding suspension have been included: *Keratella cochlearis, K. quadrata, Trichocerca cylindrica.*

The next factor modifying the reaction of some species to suspension from one aquatic habitat to another is the quality of suspension. This is distinctly seen when comparing the results from Rożnów and Goczałkowice reservoirs.

Practically in the shallow Goczałkowice reservoir, the photosynthesis may occur down to the bottom. It is known from numerous papers that a part of the products of photosynthesis is released by algae into the medium (F o g g et al. 1965, N a l e w a j k o 1966, H a l l e b u s t 1974, S a u n d e r s et al. 1975). Extracellular products are also released by bacteria (W i l k i n s o n 1958, T o m l i s o n et C a m p b e l 1963, D u n s t a l l 1975). These products as well as dead organisms are a good medium for developing bacteria (N a l e w a j k o et L e a n 1972, N a l e w a j k o et al. 1976). Extracellular secretions by complex fixation may grow to the size of colloids and particles (J o n e s et S t e w a r t 1969, W e t z e l 1969, H a r r i s et M i t c h e l 1973). Simple organic compounds give less or more complex humic compounds as a result of polymerization. These compounds together with particles of clay minerals create organic-mineral complexes containing a great deal of biologically valuable compound (glycine, leucine, proline, valine, glutamic acid, aspartic acid — Ł a k o m i e c 1975). They are inhabited by numerous bacteria. Therefore the quality of mineral suspensions entered into a reservoir may be distinctly changed. A long time of water exchange in the Goczałkowice reservoir favours such processes. The next factor is a higher share of clay minerals in bottom sediments of Goczałkowice reservoir than at Rożnów (data in parentheses). The Goczałkowice sediment had 9.57 ± 1.15 (4.67 ± 1.45) per cent of montmorillonite, 23.52 ± 3.22 (16.42 ± 7.12) of kaolinite and 2.43 ± 0.81 (10.01 ± 1.58) of Ca. According to Chan (1951) a low content of Ca leads to increase the ability of clay minerals forming the connection with humic acids.

For the above reasons the number of bacteria in sediments of this reservoir amounts to $1.927 \times 10^9 \pm 0.436 \times 10^9$ g^{-1} of dry sediment and $0.89 \times 10^9 \pm 0.146 \times 10^9$ g^{-1} in Rożnów reservoir.

Likewise a higher concentration of bitumens was noted in the Goczałkowice sediments: 2.64 ± 1.075 mg C g^{-1} (Rożnów sediments had 1.00 ± 0.336 of that), humic acids 4.656 ± 1.158 mg C g^{-1} in 0.1 n NaOH extract (respectively in Rożnów reservoir 2.469 ± 0.615) and fulvic acids 4.306 ± 0.851 and 3.827 ± 0.874 mg Cg^{-1}.

It is not unlikely that sediments in the Goczałkowice reservoir resuspended by waves and Langmuir circulation in a state of suspension cause the success of rotifers while *Cladocera* and *Copepoda* indicate negative dependence. In the Rożnów reservoir the resuspension of sediments by wind practically cannot take place contrary to the action of simple suspension transported with water river. Then, because the suspension is rapidly deposited, the time of exposure is shorter and limited to the upper part of the reservoir. Therefore, in spite of a few times greater sliming in the Rożnów reservoir, a notable part of the results, though negative, is statistically nonsignificant. Significantly the rotifers and copepods decrease their numbers. *Cladocera* do not show significant dependence, but this may be caused by a different reaction of species in this group, e.g. the number of *Bosmina coregoni* and *longirostris* is independent of suspension. It is mentioned by Pejler (1965) that *B. coregoni* is numerous in very transparent waters whereas *B. longirostris* prefers a low transparency of water.

In the samples from Goczałkowice reservoir of a turbidity higher than 60 mg SiO_2 plankton animals occurred hardly in 10 per cent. Respectively for Rożnów reservoir this same treshold of turbidity amounts slightly to over 300 mg SiO_2.

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STRESZCZENIE

Metodą regresji wielokrotnej analizowano związek między liczebnością gatunków zooplanktonowych, ich grup i stadiów rozwojowych. Badania prowadzono w stawach, płytkim zbiorniku zaporowym (zbiornik goczałkowicki) i w głębokim zbiorniku zaporowym (zbiornik rożnowski). Maksymalna mętność stwierdzona w okresie badawczym wynosi: w stawach 1200 mg SiO_2 dm^{-3} (= 123 mg reszty mineralnej po prażeniu dm^{-3}), w zbiorniku rożnowskim 898 mg SiO_2, a w goczałkowickim 119.5 mg SiO_2 dm^{-3}.

Stwierdzono, że wyrażanie ilości zawiesiny jako mg SiO_2 powoduje obniżenie poziomu istotności zależności w porównaniu z ilością zawiesin wyrażonych jako mineralna reszta po prażeniu. Skutek działania zawiesin w danym środowisku jest niejednakowy dla poszczególnych gatunków. W stawach *Keratella quadrata, K. cochlearis, Trichocerca cylindrica* redukują swoją liczebność ze wzrostem ilości zawiesin. *Conochiloides coenobasis, Conochilus unicornis, Polyarthra vulgaris, Brachionus rubens, B. diversicornis, B. angularis, Synchaeta* sp. nie wykazują zależności od zawiesiny, a rozwój *Pompholyx sulcata, Keratella cochlearis f. tecta, Polyarthra dolichoptera, Brachionus calyciflorus, Filinia longiseta, Asplanchna girodi* jest nawet stymulowany. Z pozostałych zwierząt z tego samego środowiska na zawiesinę reagują negatywnie *Ceriodaphnia pulchella, Daphnia pulex, Chaoborus crystallinus.* Seston zbiornika goczałkowickiego działa negatywnie na gatunki duże: *Daphnia cucullata*, wioślarki ogółem, widłonogi. Nie wpływa lub nawet stymuluje rozwój gatunków małych: *Snychaeta pectinata*, wrotki ogółem, pierwotniaki.

Krótki czas narażenia na działanie zawiesin w zbiorniku rożnowskim jest przyczyną zmniejszenia stopnia istotności statystycznej działania zawiesin na zooplankton. Niemniej, jest to dla *Polyarthra major*, wrotków ogółem, *Daphnia longispina*, wioślarek ogółem, stadiów naupliusowych widłonogów i widłonogów ogółem zależność wysoce negatywna. Przy zmętnieniach powyżej 300 mg SiO_2 nie stwierdzano z reguły występowania zooplanktonu.

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