

Effect of suspended materials on zooplankton

2. Laboratory investigations of *Daphnia hyalina* Leydig*

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Manuscript submitted November 30, 1981

Abstract — Development of *Daphnia hyalina* populations cultivated in three kinds of turbid medium (suspension of bottom sediments, bentonite and red loam with a high content of clay minerals) combined with two concentrations of green alga *Selenastrum capricornutum* was investigated. The LC_{50} values were calculated. Ingested mineral suspension caused the increase in specific gravity and, as a result, in the velocity of sinking. The frequency of antenna beats increased by 13%. In concentrations greater than and equal to 100 mg dm^{-3} of suspensoids the respiration of *D. hyalina* was 10.6 to 32.4% higher, in dependence on *Daphnia* length. The influence of suspension depended both on the kind of suspension and the time of exposure.

Key words: zooplankton, *Daphnia hyalina*, population dynamics, swimming behaviour, metabolism.

1. Introduction

Mineral suspensions which affect the development of populations of zooplankton species are environmental factors relatively seldom taken into account. Suggestions and observations by other authors on this subject gave countenance to statistical calculations carried out by Paggi and Paggi (1974) who indicated that turbidity showed a distinct correlation with quantitative fluctuations of zooplankton in Parana River, Żurek (1980) found statistically significant (at $P < 0.05$) negative

* Study carried out under the MR. II/15 project.

relationships between the amount of mineral suspensions in ponds and numbers of *Keratella cochlearis* (Gosse), *K. quadrata* O.F.M., *Trichocerca cylindrica* Imhof, *Ceriodaphnia pulchella* Sars., *Daphnia pulex* Leydig. These results provided the basis to experiments carried out with the purpose of elucidating some aspects of relations between planktonic animals and suspensions. The *D. hyalina* Leydig used in experiment was the common species for the ponds and dam reservoirs investigated previously by Żurek (1980).

2. Material and methods

All experiments were performed with *Daphnia hyalina* from Rożnów reservoir (49° 44'N lat., 20° 41'E long.). This species was cultivated in laboratory conditions in Frank's et al. (1957) medium. The animals were fed by green alga *Selenastrum capricornutum* Printz. reared on Chu-10 medium. Algae were counted electronically by Coulter Counter.

Concentrations of suspensoids were measured by weight method.

The mineral composition of materials used for preparing the suspensions was analysed by Tokarski's method (1954).

Four main experiments were done. The object of the first was to estimate the growth of *D. hyalina* populations at constant food concentrations. The experiments were carried out during 24 and 32 days. Five individuals one day old were introduced into 50 cm³ medium containing in this volume: 0.5×10^5 , 25×10^5 , 5×10^6 cells of *Selenastrum capricornutum* above the filtration threshold. These concentrations were taken from another additional experiment which had dissolved that *D. hyalina* population in stationary phase after 24 hours is able to filter *S. capricornutum* to a concentration of 4600 ± 2200 cells cm⁻³. Hence the food concentrations were, respectively greater by 10^4 , 5×10^4 , and 10^5 cells cm⁻³ than threshold value. These numbers multiplied by volume of medium gave the values of the food relations of population in steady state phase. Every 24 hours animals were transferred into a new medium with the above mentioned food.

The experiment was performed in thermoluminostat under fluorescent lights 4000 lx and $20 \pm 0.5^\circ\text{C}$. The equation given by Czernaś (1977) allows to compute dry weight of *Selenastrum* cells:

$$y = 0.44 N - 0.04 \quad (1)$$

where: y is a dry weight $\times 100$ mg dm⁻³,

N = millions of cells in cm³.

The second experiment was carried out as a "continuous" culture. Its object was to compare the growth curves of *D. hyalina* cultured in conditions of permanently dosed food (or as in the next step the food with suspension) with analogous results obtained in the first experiment

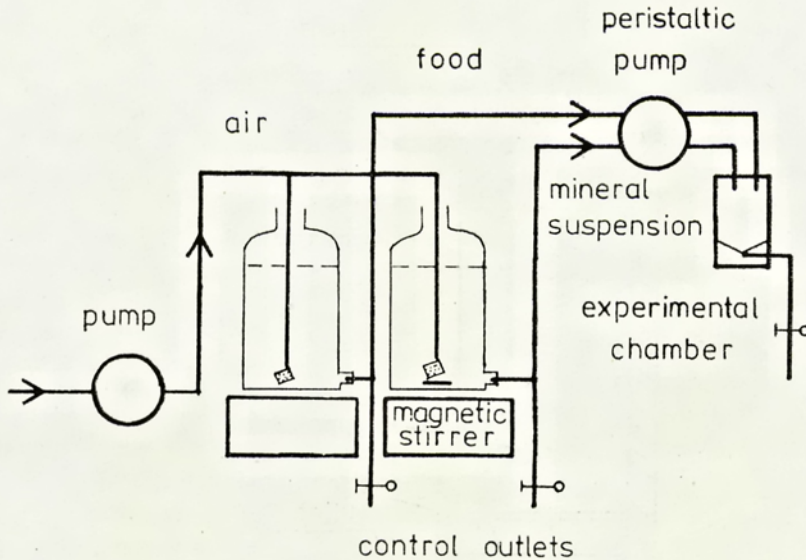


Fig. 1. Experimental unit for culture of *D. hyalina* in continuous exposure on suspension

with one per day exchanged medium and food and then to estimate the medium lethal concentrations (LC_{50}) of different suspensions permanently influencing the animals (without tapering off the suspensions concentration). Only two quantities of food (daily food ration: 25×10^5 and 5×10^6 cells day^{-1}) and three kinds of suspensions were investigated. Their mineralogical composition is given in Table I. Mineral suspension in concentrations: 100, 300, 500, 1500, and sometimes 2000 $mg\ dm^{-3}$ was used.

Table I. Mineral composition (in %) of materials used for preparing the suspensions

Compound	Bottom sediment	Bentonite	Red loam
Montmorillonite	4.67	42.93	25.27
Organic matter	6.56	0.97	2.00
Kaolinite	16.42	6.43	16.90
Calcite	10.01	3.78	0.35
Rest thermally inert	62.34	45.88	55.47

A. Bottom sediment from the Rożnów reservoir. According to Pasternak (1973) the sediment contains 90 per cent of particles lesser than 0.02 mm. In practice only 9.6 per cent of sediment it is being kept in suspension. The natural sediment tended to aggregate itself. The sediment contained 19.53 per cent of clay minerals (Table I).

B. Bentonite. Its main compounds are clay minerals — 42.9 per cent (Table I). The colloidal suspension of bentonite of light-grey colour, specific gravity $2.2\ g\ cm^{-3}$.

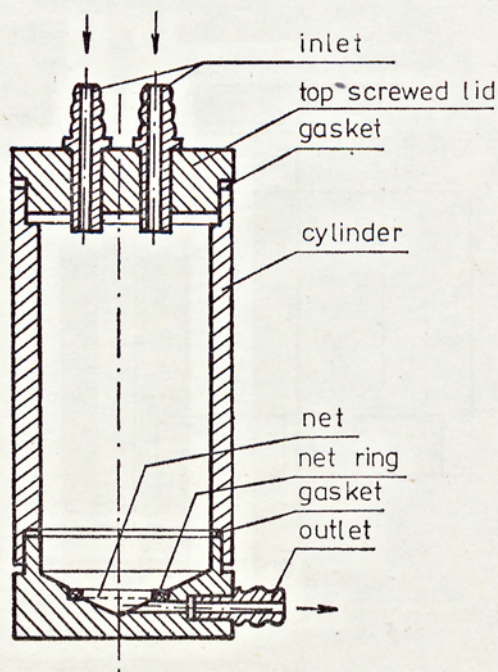


Fig. 2. Diagram of experimental chamber to the culture of animals

C. Red loam. Mean content of SiO_2 ca 64 per cent, Al_2O_3 —12, CaO —2. Loam consisted of clinoptilolite—mineral with a high sorption capacity—and other clay minerals. Specific gravity 2.14 g cm^{-3} . The suspension was of reddish-brown colour.

Basic experimental unit (figs 1, 2) had two 5 liter jars connected by peristaltic pump with an experimental chamber of 125 cm^3 volume. Both jars (one for food, the other for suspension) were aerated. The jar containing the mineral suspension was additionally mixed by magnetic stirrer. Concentrations of food and suspension were measured every day. A peristaltic pump was continuously dosing the suspension and food by two separate channels into the experimental chamber. This chamber was made of plexiglass, and could be easily taken down, and the animals counted. All units were calibrated, pH of water 7.0.

Third experiment. The velocity of sinking of *D. hyalina* in transparent chamber immersed in thermostated aquarium ($20.0 \pm 0.05^\circ\text{C}$) was observed. The front wall had a millimetric scale. The animals measured under a binocular microscope, previously exposed or not in a bentonite suspension, killed by means of 0.1 m KCN or left alive, were introduced into the chamber. The time of sinking in a given way and the amount of antenna beats were observed and noted; later, the velocity of sinking and the frequency of antennae beats (movements) required for continuous hovering at a constant depth were calculated.

The fourth experiment concerned the oxygen consumption by *D. hyalina* in suspensions. 50 to 150 individuals in three sorted-out size groups were exposed for 4 hours in calibrated bottles of ca 55 cm³ volume. Suspensions of bottom sediment, bentonite and red loam were used in concentrations 0, 100, 500 and 1000 mg dm⁻³. The temperature was 20.0°C. Oxygen was measured by Winkler method according to Carpenter (1965). For titration the 0.002 n sodium thiosulphate was applied.

3. Results

3.1. Noncontinuous culture. Medium without mineral suspensoids

The parameters of life cycle were estimated in unlimited food conditions. Maximal life duration time noted in such conditions amounted to 121 days, mean longevity 68 days, i.e. 9.7 weeks. At the end of life *D. hyalina* had a mean length of 2.5 ± 0.122 mm and width of head 1.12 ± 0.071 mm. The width was measured from the end of rostrum to attachment of the antenna muscle.

Dry weight of *D. hyalina* (range in length 0.63—2.47 and in width of head 0.25—1.13 mm) is given as:

$$W = 0.0035 L^{2.807 \pm 0.088}, \quad n = 75, r = 0.965 \quad (2)$$

or

$$W = 0.0328 w^{2.515 \pm 0.088}, \quad n = 75, r = 0.957 \quad (3)$$

where: *W* is a dry weight of individual in mg,

L and *w* — are length and width expressed in mm respectively.

With linear sizes, the volume of intestine changes according to equation:

$$V = 0.00194 L^{3.094 \pm 0.13}, \quad n = 43, r = 0.96 \quad (4)$$

where: *V* is a volume of digestive tract in mm³,

L — length in mm.

Turnover time of egg batch in unlimited food regime was equal to 3.05 ± 0.24 days (*n* = 90).

Simultaneously with abandonment of brood pouch by young daphnias the moulting follows. According to sign test, the probability of this event is greater than 99 per cent, *n* = 148. Less often the animals exuviated with one-day delay. The delay took place when a medium contained only 10 000 cells cm⁻³ above the filtration threshold (fig. 3).

In a medium with unlimited food, daphnias had 27.37 ± 4.55 clutch and a mean number of eggs in clutch 21.7 ± 5.3 .

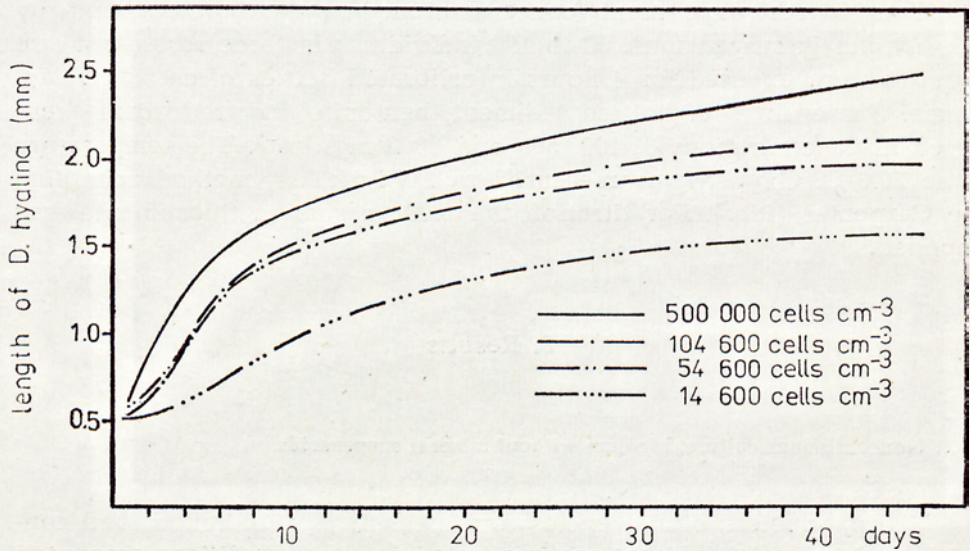


Fig. 3. Growth curves of *D. hyalina* fed on different amount of food

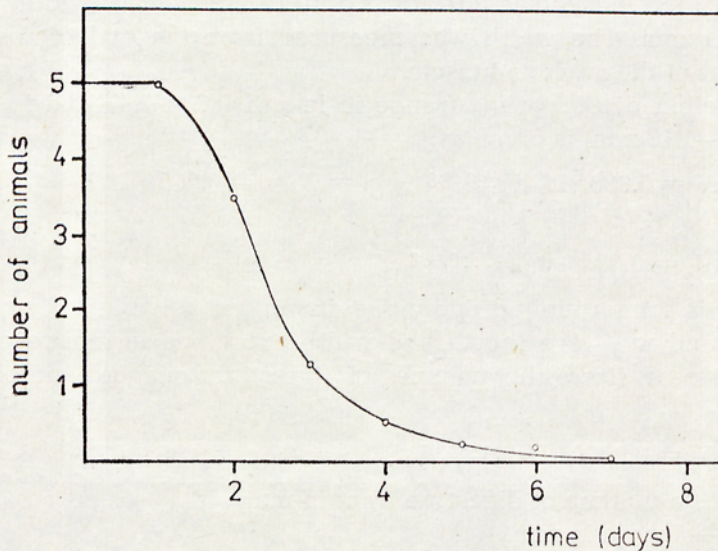


Fig. 4. Dying of the starved population of *D. hyalina*

Reduction of food quantity caused inhibition of growth (fig. 3). The sizes of the body were then lesser than with an unlimited access of food. After 46 days of cultivation in concentrations 10^5 , 5×10^4 and 10^4 cells cm^{-3} , length of daphnias amounted only to 86.8, 81.8, 64.5 per cent.

For lack of food, the first individuals died on the third day of starvation. Then after seven days of starvation the whole population died away (fig. 4).

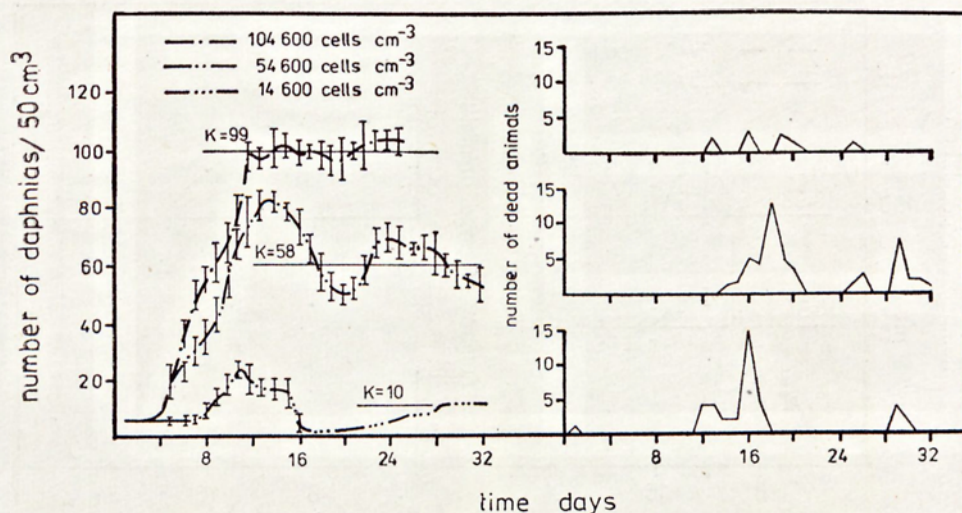


Fig. 5. Numbers of *D. hyalina* populations and number of dead daphniae in these populations cultured in three food concentrations. K — carrying capacity

In the lowest effective concentration of *Selenastrum* (10^4 cells cm^{-3}) daphnias population reached its maximal numbers — 24 animals after 13 days, and afterwards the overdensed population decreased to one individual in one half of the number of repeats and died in the other. Since then the population approximately stayed on the same level of carrying capacity (K) which was equal to 10 animals (fig. 5).

In the next concentration (5×10^4 cells cm^{-3}) the population attained a critical point after four days and on the ninth day, when a progeny of initial daphnias reached maturity, it rapidly increased in numbers. Mortality increased as the carrying capacity was exceeded (c. 38 per cent), then oscillated around the carrying capacity $K = 58$.

In the highest food concentration the critical point of population development after four days was attained. Since this moment the population grew to 99 and then oscillated about it.

3.2. Continuous culture

3.2.1. Medium without mineral suspensions

The dynamics of the population cultivated in a constant dosage of food is similar to the first experiment. Because of threshold concentration of food equiponderant to effective concentration 10^4 cells cm^{-3} was not carried out. With a potential food ration 2.5×10^6 cells day^{-1} (equivalence of concentration 5×10^4 cells cm^{-3}) the maximal numbers were

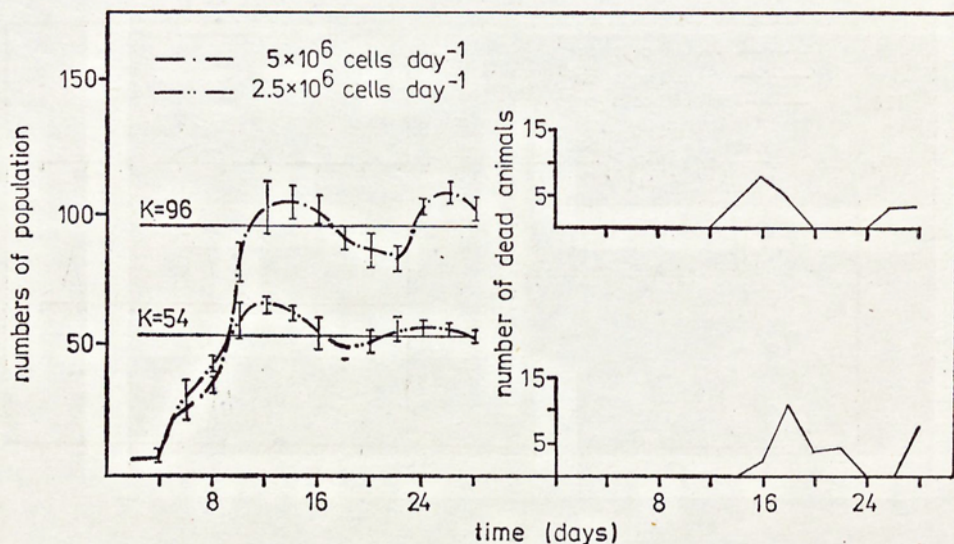


Fig. 6. Numbers of populations of *D. hyalina* and numbers of dead daphnias in these populations. Culture with continuous flow of food equivalent to two food rations. K — carrying capacity

attained after 12 days (fig. 6). Then, the number of animals fell down to 54 individuals, i.e. the carrying capacity. This result is slightly lesser than the same one in the former experiment.

The dynamics of population growth at food ration 5×10^6 cells day^{-1} was similar (see fig. 4). After the first exceeding of the carrying capacity, the mortality of animals increased (fig. 6). The carrying capacity amounted there to 96, which was a result by 3 individuals lesser as compared to culture of periodically dosed food.

3.2.2. Medium with mineral suspensions

Bottom sediment. Populations of *D. hyalina* living in concentrations 100 and 500 mg dm^{-3} with 2.5×10^6 cells of *Selenastrum* per day died away. The mortality was lower in such conditions than in a starved population; a population deprived of food, died after 7 to 8 days while there, after 16 days or more. In concentrations higher than 500 mg animals died more rapidly than in the starved population (fig. 4). This acceleration of the dying was caused by other factors than a lack of food. Twice higher food rations and 100 mg of suspension caused increase in numbers of population. In concentration 500 mg dm^{-3} the population nevertheless died away. After 16 days about 20 per cent of animals were alive. Higher concentrations of suspensions exerted

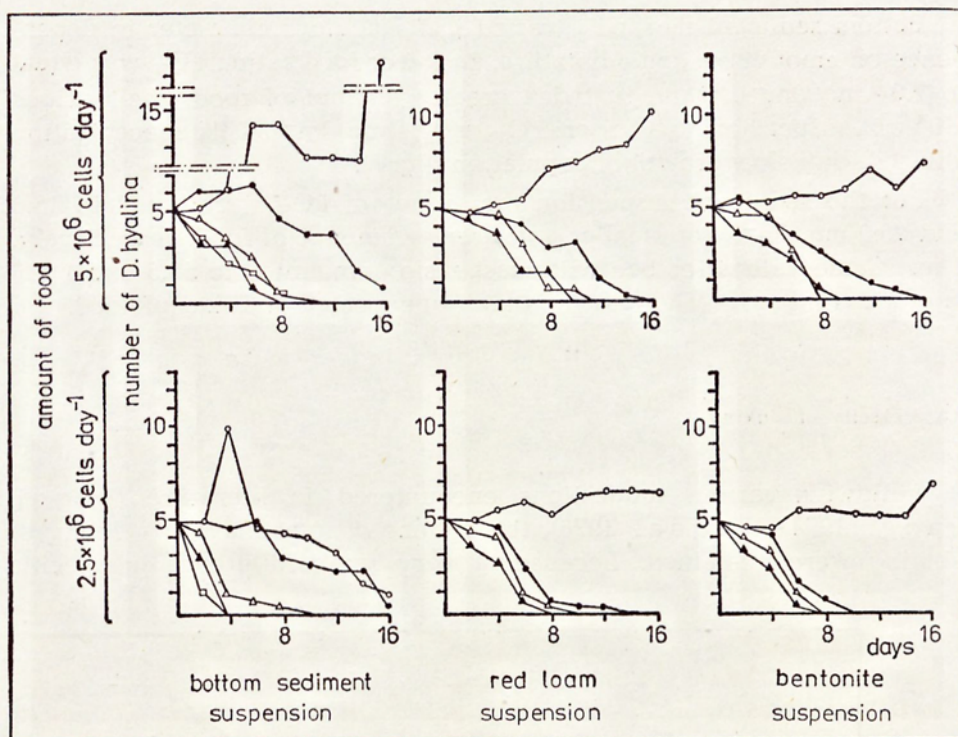


Fig. 7. Growth response of *D. hyalina* in the presence of mineral suspensions, o—o — 100 mg dm⁻³, ●—● — 500 mg dm⁻³, △—△ — 1000 mg dm⁻³, ▲—▲ — 1500 mg dm⁻³, □—□ — 2000 mg dm⁻³

a slightly less noxious influence on the animals, the population dying away after 8 to 10 days (fig. 7).

The above results (fig. 7) have served as basis for calculation the medium lethal concentration of suspensions. Computations were carried out for data obtained after eight days exposure in suspension. According to the control curve of growth (fig. 6), on the eighth day the population attained the mean number 41.5 (food ration 2.5×10^6 cells day⁻¹) and with 5×10^6 cells day⁻¹ — 32 individuals.

Table II. Medium lethal concentrations (LC_{50}) for *Daphnia hyalina* computed after an eight-day exposure. LC_{50} in mg/dm⁻³

Kind of suspension	Food ration	
	2.5×10^6 cells day ⁻¹	5×10^6 cells day ⁻¹
Bottom sediment	7.82	94.40
Red loam	15.33	25.02
Bentonite	18.52	11.35

Bottom sediment markedly varied in its noxious character in dependence on amount of food admixture. In lower food ration LC_{50} was equal to 7.84 mg dm^{-3} , while in twice greater amount of food, the noxious effect of suspension was lesser: $LC_{50} = 94.4 \text{ mg dm}^{-3}$. This concentration allowed for a slow growth of population (fig. 7).

For the red loam suspension the values of LC_{50} were equal to 15.3 and 25.0 mg dm^{-3} , for smaller and greater amount of food, respectively. These same values for bentonite suspension amounted to 18.5 and 11.35 mg dm^{-3} (Table II). The results is both unexpected and unexplained.

3.3. Velocity of sinking

Following various suggestions encountered in literature (Paggi, Paggi 1974, Wróbel 1976), the volume of intestine and velocity of sinking were examined. Because of very small difference in specific

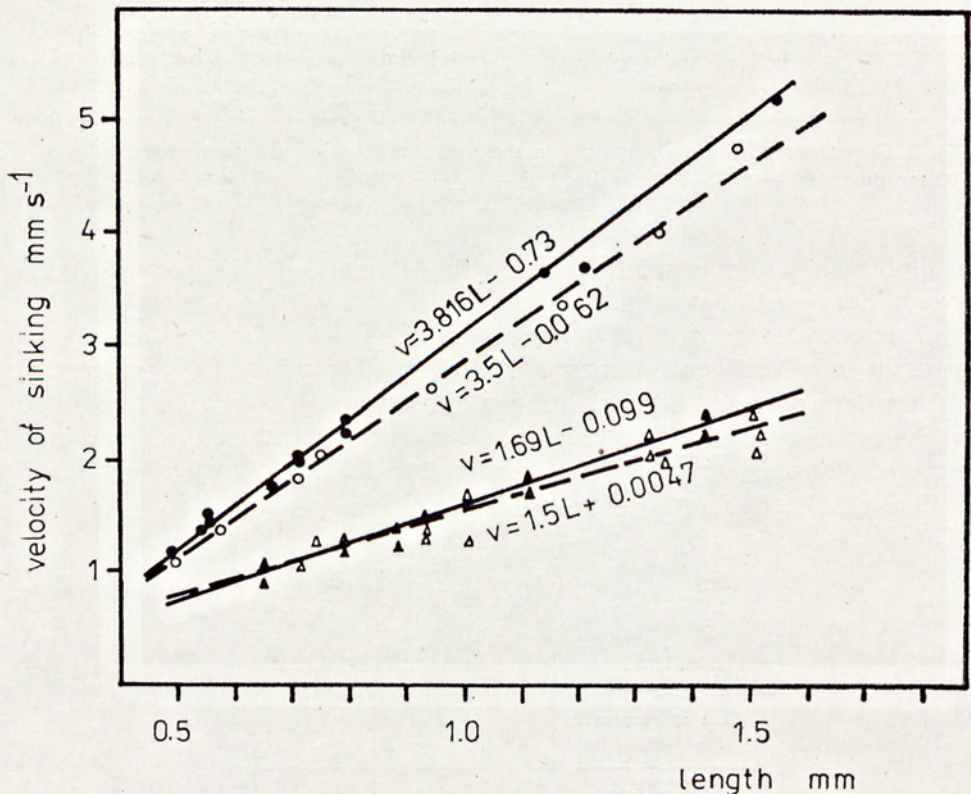


Fig. 8. Velocity and sinking of living or dead *D. hyalina* in relation to the body length (L)

weight of red loam and bentonite the experiments were carried out in suspension bentonite only.

The killed animals sank markedly faster than the live ones. This difference was caused by a lesser drag of moving in killed animals. The living daphnias sank with stretched antennas while those killed with KCN sank with antennas folded along the carapax. They sank headover heels. The velocity of sinking was proportional to linear size of animal (fig. 8). In constant conditions it could be presented with some simplification, as a linear equation of the $y = a \pm bX$ type. The killed animals exposed previously in suspension sank faster than the unexposed ones. This difference is highly significant. The value of t-test with $n_1 + n_2 - 4 = 14$ degrees of freedom for the hypothesis: $H_0: b_1 = b_2$ is 22.21. Thus, an alternative hypothesis may be accepted. High t value also had coefficient a, 14.34 and 19.01, respectively.

Living daphnias with intestine filled up by bentonite particles fall significantly faster than those with empty intestine or filled up with algae. The t value for hypothesis $H_0: b_1 = b_2$ with 19 degrees of freedom was 20.35. Coefficient a in equation for animals exposed in suspension had t value 4.207. The respective probability was $P < 0.001$. This same coefficient in equation for animals unexposed in suspension was non-significant, its t value being 1.312.

The increase in velocity sinking, calculated from the two last equations for 2 mm daphnia, amounted to about 9 per cent.

For motion of velocity v in a viscous medium of density ρ , the drag of a body is expressed by:

$$D = 1/2 \rho AC_d v^2 \quad (5)$$

where: A — was the frontal area of body,

C_d — its drag coefficient based on A.

Now, using equations given on fig. 8 (*D. hyalina* living and killed after exposure in bentonite suspension) proportion of area of sinking *Daphnia* with extended antennae to *Daphnia* sinking with antennae folded along the body for streamling may be calculated.

With the subscripts k and l used to denote sinking of the dead and living *Daphnia*, Eq. 5 was then transformed:

$$v = \sqrt{\frac{D}{1/2 AC_D \rho}} \quad (6)$$

taking: $v_k > v_l$ (7)

we have: $K = \frac{v_k}{v_l}$ (8)

and: $v_k = K v_l$ (9)

Substituting the value of v_k and v_l from Eq. 6 to 9 we get:

$$\sqrt{\frac{D_k}{\frac{1}{2} \rho A_k C_{Dk}}} = K \sqrt{\frac{D_1}{\frac{1}{2} \rho A_1 C_{D1}}} \quad (10)$$

After transformation it becomes:

$$\frac{D_k C_{D1}}{D_1 C_{Dk}} = K^2 \frac{A_k}{A_1} \quad (11)$$

In this case K^2 varied from 2.5 to 4.2, with length of *Daphnia* ranging from 0.5 to 1.5 mm. The area of *D. hyalina* passive tail-first sinking (A_1) is K^2 -fold greater than head-first sinking one.

In order to attain zero velocity of sinking, daphnia must do a certain number of antenna beats. The frequency of beats as a function of body length is constant. This relationship may be expressed as follows:

$$F_1 = 1.473 + 0.23 L \quad (12)$$

$$F_2 = 1.504 + 0.0084 L \quad (13)$$

where: F_1 and F_2 are frequencies of antenna beats of animals exposed in bentonite suspension and without exposure per second respectively,

L — length of daphnia in mm.

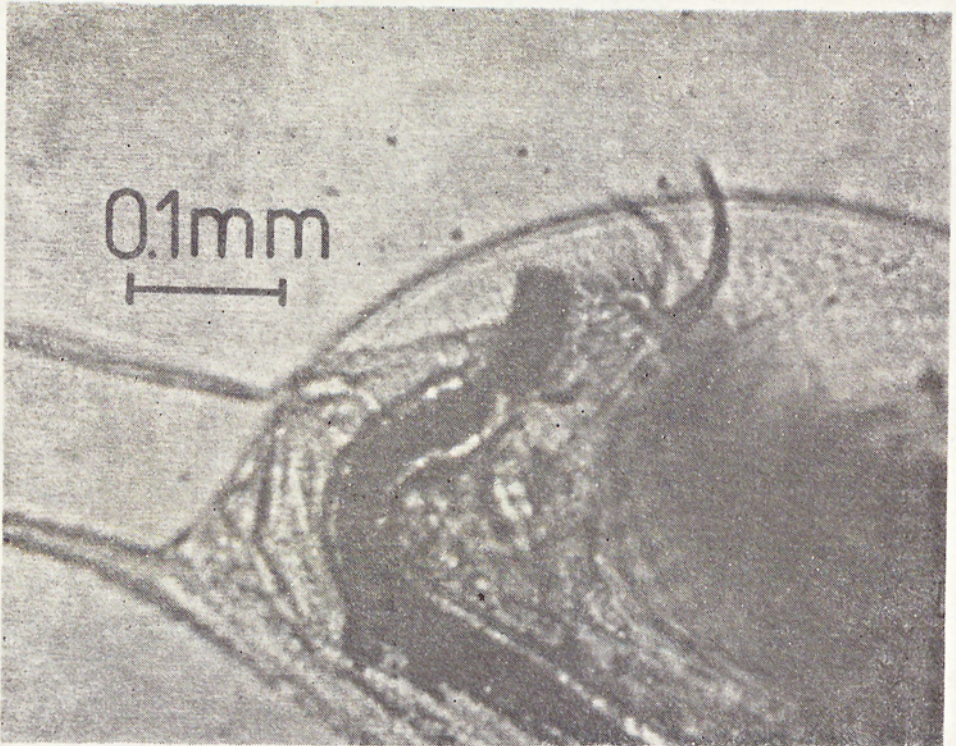


Fig. 9. *D. hyalina* at the time of defecation of mineral content of intestine (bentonite).

Both regression lines are parallel as the hypothesis $H_0: b_1=b_2$ must be accepted with $P < 0.05$. A very significant difference is between coefficients a , $p < 0.001$. Thus, the animals with intestine filled by mineral particles, beat with antennas about 13 per cent more frequently than the ones with intestines empty or filled with algae.

At the time of the experiments the absorption of mineral particles on carapaxes was observed. All kind of suspensoids in course of time clogged filtering bristles and setae. Grazed mineral particles are excrete as concise fecal pellets (figs 9, 10). Sediment suspension probably injured the epithelium of intestine because as it was observed, it very frequently glued up with mucus fecies. These were sometimes longer than the animal itself.

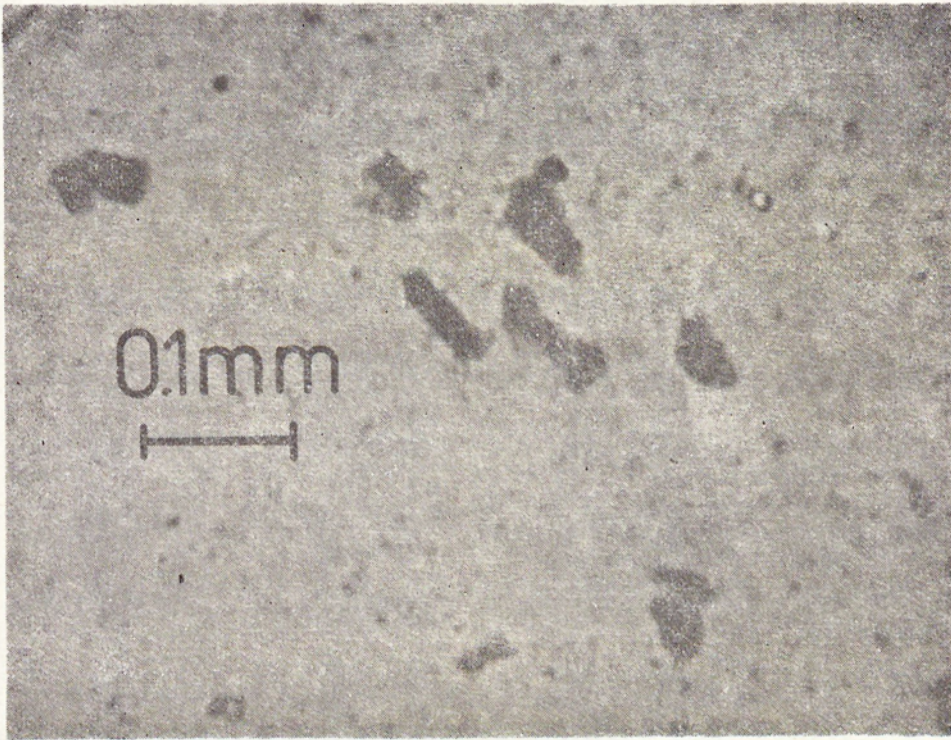


Fig. 10. Fecal pellets of *D. hyalina* consisting of aggregated fine particles of bentonite suspension. In the background fine dispersed particles of bentonite

3.4. Respiration of *D. hyalina* in sliming medium

The results of measurement of oxygen consumption are presented in Table III as a function of body length. The equations had an exponential form: $q = aL^b$. In all kind of suspensions, coefficient b was

Table III. Oxygen consumption ($\mu\text{l h}^{-1}$) by *Daphnia hyalina* in suspensions as a function of its length (mm). Equation in form $Q=aL^b$; σ_b - standard deviation of coefficient b; n - degrees of freedom

Kind of suspension	Concentration mg dm^{-3}	Coefficient		σ_b	n
Sediment	100	0.0306	2.767	0.024	15
	500	0.0304	2.748	0.019	15
	1000	0.0300	2.736	0.036	15
Red loam	100	0.0293	2.727	0.018	15
	500	0.0299	2.709	0.028	15
	1000	0.0290	2.290	0.031	15
Bentonite	100	0.0297	2.602	0.031	15
	500	0.0289	2.273	0.018	15
	1000	0.0286	2.676	0.040	15
Control	0	0.0237	2.823	0.048	45

somewhat lesser than in control. Differences were imperceptible there. Much more notable differences were shown by coefficient a. In all experiments with suspension, this coefficient was greater than in control; however, there was no important difference in different concentration of suspensoids. Therefore oxygen consumption for the examples below were calculated for mean values of coefficient a and b. In the bottom sediment suspension, the respiration of 0.5 mm *Daphnia* was by 32.4 per cent greater than in normal conditions, whereas in a red loam and bentonite suspensions the oxygen consumption amounted to 28.7 and 31.7 per cent above normal level. *Daphnia* of 2 mm length consumed more in suspension of the bottom sediment, red loam, and bentonite 22.8, 17.9, 10.6 per cent of oxygen.

4. Discussion

The results obtained in non continuous culture were somewhat different from the data given by other authors. Thus, dry weight of 2 mm *D. hyalina* from the Queen Mary Reservoir calculated according to Andrews's regression (cited after Bottrell et al. 1976) was 170.2 per cent higher than that calculated from the equation 1, which presents the result 15.4 per cent lower than Bottrell's et al. (1976).

With increase in body length, the volume of intestine increased more than body weight. The coefficient of regression line slope was there 3.094, i.e. 0.287 more than for the body — weight relation. This might be the result of evolutive adaptation of adult cladocerans which have reduced their ability to food digestion. Assimilability of algae diminishes through the life-time duration. Kryuchkova (1967) noted that assimilability of *Chlorella vulgaris* Beijerinck and other algae by young *Moina*

rectirostris Leydig amounted to 97.2 per cent whereas only 27.8 per cent at the end of life.

Turnover time of egg batch varied in the range reported by Vijverberg (1976) for *D. hyalina* living in the unfiltered lake water or in lake water filtered through 3—4 μm filter with addition of 40 000 *Scenedesmus* cells per cm^3 .

Longevity as stated above is similar to Vijverberg's data, it is enclosed in 3 σ for animals living in lake water filtered through 3—4 μm filter and in water enriched with 40 000 *Scenedesmus* cells per cm^3 . Mean longevity expressed as the mean duration time of life is equal to 68 days, i.e. 9.7 weeks. This is convergent with Vijverberg's and Arnold's (1971) results cited above for *D. pulex* fed with *Synechococcus cedrorum* Sauvageau (mean longevity 58 days, max. above 73 days in high and low food concentration).

The mean number of eggs in a clutch was high there. Taking into account the turnover time of egg batch, the mean number of young produced per female per week, amounted to 50 individuals. This was about 56 per cent greater than Vijverberg's data for the best kind of food (lake water filtered through 3—4 μm filter and 400 000 *Scenedesmus* cells per cm^3 added). Hence *Selenastrum capricornutum* seems to be better food.

Growth of *Daphnia hyalina* expressed as linear growth as calculated from mean length against time resulted in the shape of curves similar to that found by other authors for *Daphnia*: McArthur and Baillie (1929), Richman (1958), Buikema (1973), Vijverberg (1976, 1980), Kozłowski (1978) and others.

In the medium deprived of food, Arnold (1971) noted that the mean age of death for *D. pulex* was 21.3 days (4—23 range). This result was about threefold greater than that obtained by the author. The shape of curves of population growth as a function of time were similar to that found by other authors for different species of *Cladocera*. Also in continuous culture curves obtained and values of carrying capacity were similar. For this reason the curves of population growth obtained for two food regimes in these experiments were considered as control for next results.

Data shown on fig. 7 and in Table II display a strong effect of the digestible part of suspension on survival. The coefficient of population growth r' calculated for animals living in control continuous culture amounted to 0.165 (2.5×10^6 cells day^{-1}) and 0.289 (at 5×10^6 cells day^{-1}). The r' was calculated for an 8-day old population in limits ± 2 days.

Concentration 100 mg dm^{-3} of bottom sediment plus 5×10^6 cells day^{-1} allows for a relative quick growth of population although the curve of population growth has a local minimum between the tenth and

fourteenth day. Therefore r' was calculated there for 12 days interval has the value of 0.098. Twice lower amount of food caused the dying of population. The value of r' was 0.043. Also red loam and bentonite in 100 mg dm^{-3} had a similar effect, in a higher concentration of food the growth was better, in opposition to lower one where it was worse. 500 mg dm^{-3} concentration was lethal after 16 days nearly in every case. It is estimated that the change of sign of r' value occurred for concentrations between 150 and 300 mg dm^{-3} , dependent on food concentration. This range of negative influence was about fivefold lower than Robinson's data (1957) for *Daphnia magna* Straus. She did not confirm the harmful influence of pond bottom sediment (containing kaolinite, illite, vermiculite, quartz) on reproductive rate at levels up to 1458 ppm. Stephan (1953) noted that *Daphnia longispina* O.F.M. and *D. magna* after a six-day exposure in soil clay suspensions (500 mg dm^{-3}) diminished their numbers by 25 to 45 per cent. In concentration 300 mg dm^{-3} the mortality was very low there. This value range is similar to estimated values inhibiting development of populations in bottom sediment suspension. If we take into account LC_{50} value (Table II), the respective numbers will be lesser and in strong dependence on food level in suspension. Probably it is mainly due to the continuous character of experiment as opposed to that of Stephan's.

More toxic effect was produced by red loam and bentonite in de-

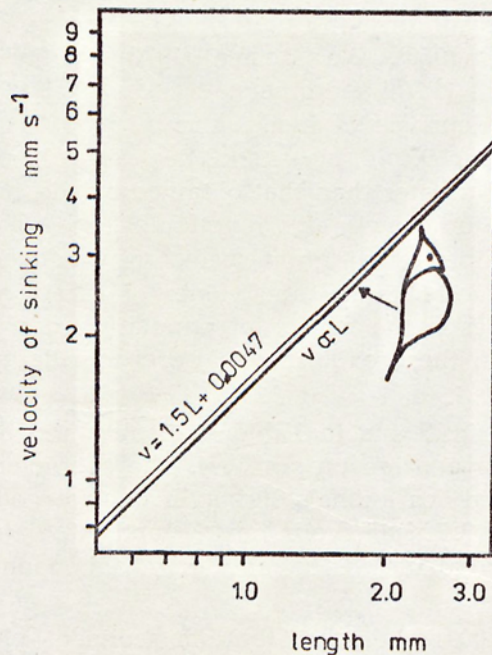


Fig. 11. The passive sinking of *D. hyalina* as compared to Brooks and Hutchinson's (1950) data for *Daphnia* sp.

pendence on food admixture to suspension. LC_{50} was less than 25 mg dm^{-3} . Another important factor was the proportion between clay minerals. Robinson (1957) wrote that montmorillonite was toxic for *D. magna* at levels greater than 102 ppm and daphnids had a peak reproduction at 13 ppm whereas kaolinite was shown to be non-toxic at levels as high as 392 ppm, and daphnia had a peak reproductive rate at 39 ppm. Higher contents of montmorillonite in bentonite could account for its higher toxicity. It is difficult to explain why bentonite suspension showed inversion of toxicity in relation to food admixture. Probably it was caused by a low initial number of animals and peculiar changes in mortality in the experiment which had given this low LC value.

The evidence from measurements of sinking velocity are highly convergent with Brooks and Hutchinson's (1950) data (fig. 11). The passive sinking of *D. hyalina* in its relation to the linear dimension (d) of the animal was proportional to d.

The right side of equation 11 could be interpreted as a standardized ratio of animal area with appendages which remained folded for streamlining while swimming, to area increased by extension of appendages. The area ratio varied there in K^2 range, i.e. about 2.5 to 4.2. According to Haury and Weihs (1976) this ratio could be 10 or greater for animals with highly developed spines and plumose appendages.

As is shown in 3.4 the costs of maintenance of the *D. hyalina* living in slimming medium are greater than in normal one. Klyashtorin and Yarzhombek (1973) noted that if metabolic and propulsion efficiencies are accounted for active swimming can then amount to 20–40 per cent of basal metabolism (BMR). The measure of oxygen consumption, as recorded in chapter 2, produces results notionally to approaching the ADMR proposed by Pearson (1947) and used by Grodziński (1966), but it is not a strictly average daily metabolism. The increase in oxygen consumption by 10 to 30 per cent may be the consequence — apart from a greater specific gravity — of a damage of intestine epithelium as has been suggested by Stephan (1953).

Acknowledgment

I would like to thank to dr. Ł. Krzeczowska-Wołoszyn for quantitative and qualitative analysis of collected samples of phytoplankton used in the first part of this paper. Among other acknowledgments I omitted her name for which I express my apologies.

5. Polish summary

Wpływ zawiesin na zooplankton

2. Badania laboratoryjne nad *Daphnia hyalina* Leydig

Badano rozwój populacji *Daphnia hyalina* hodowanych w trzech rodzajach zawiesin mineralnych (zawiesiny z osadu dennego, bentonitu i czerwonego iłu o wysokiej zawartości minerałów ilastych) i dwóch koncentracjach zielenicy *Selenastrum capricornutum* jako pokarmu. W celu wyeliminowania zmian stężenia zawiesin w czasie doświadczenia, przeprowadzono eksperymenty z ciągłym dozowaniem zawiesin i pokarmu (ryc. 1, 2). Stosowano zawiesiny w stężeniach: 100, 300, 500, 1500, 2000 mg dm⁻³. Skład mineralny zawiesin podano w tabeli I. Dwa warianty stężeń pokarmu obliczone z uwzględnieniem progu filtracji po 24 godzinach wynosiły $2,5 \times 10^6$ i 5×10^6 komórek dzień⁻¹ przy ciągłym dozowaniu, co jest równoważne stężeniu 5×10^4 i 10^5 komórek cm⁻³ w kulturze *D. hyalina* karmionej raz dziennie (ryc. 5, 6). We wszystkich wariantach doświadczenia stwierdzono zahamowanie wzrostu populacji (ryc. 7). Wartość LC₅₀ osadu dennego po ośmiiodniowej ekspozycji, przy niższej ilości pokarmu ($2,5 \times 10^6$ komórek dzień⁻¹) wynosi 7,8 mg dm⁻³, a przy dwukrotnie wyższej ilości 94,4 mg dm⁻³. Wartości LC₅₀ dla zawiesiny bentonitowej w mniejszej i większej ilości pokarmu wynoszą odpowiednio 18,52 i 11,35 mg dm⁻³. W zawiesinie z czerwonego iłu LC₅₀ wynosi 15,33 mg dm⁻³ w mniejszej i 25,02 mg dm⁻³ w większej ilości pokarmu (tabela II).

Stwierdzono, że populacja *D. hyalina* w środowisku pozbawionym pokarmu wymiera po siedmiu dniach głodowania (ryc. 4).

Zjedzony materiał mineralny powoduje wzrost ciężaru rozwielitki i w konsekwencji wzrost szybkości opadania (ryc. 8, 11). Aby utrzymać się na stałym poziomie, *D. hyalina* mająca wypełniony zawiesiną przewód pokarmowy musi wykonywać ruchy II antenami z częstotliwością o 13% wyższą. W stężeniach zawiesiny większych i równych 100 mg dm⁻³ wzrasta, w zależności od wielkości rozwielitki, jej respiracja w granicach od około 10 do 30% (tabela III). W niewielkich stężeniach zawiesin nie można wykluczyć również wpływu rozwielitek na ilość zawiesin. Na rycinach 9 i 10 wykazano, że drobnocząsteczkowa zawiesina mineralna po przejściu przez przewody pokarmowe rozwielitek zostaje sklejona w większe grudki, które mogą szybciej sedymentować.

Ustalono również zależność suchej masy *D. hyalina* od jej długości — równanie (2) i szerokości głowy (3), objętość przewodu pokarmowego w funkcji długości ciała (4), średnią długowieczność wynoszącą 68 dni, maksymalny czas życia — 121 dni oraz wyznaczono krzywe wzrostu *D. hyalina* hodowanej w różnych stężeniach pokarmu (ryc. 3).

6. References

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