BOGATOVA I.B. (1951)
Quantitative data on the feeding of Cyclops strenuus Fischer and Cyclops viridis Jurine.
Trudy saratov. Otd. vses. nauchno-issled. Inst. ozer. rech. ryb. Khoz. 1, 163-76.

Cyclopids, exactly in the same way as daphnids, appear as a significant component in the nutrition of plankton-feeding fishes and the young of the majority of fishes.

The utilization of planktonic food in the artificial rearing of young of migratory fishes necessitates more thorough study of the biology and development of methods of culture of various planktonic organisms.

In the greater part of the works devoted to the study of the biology and methods of culture of Cladocera (Gaevskaya, 1941, 1945; Zarinskaya, 1939; Kastal'skaya-Karzinkina, 1942; Rodina, 1940, 1946, 1948a, 1948b and others), the biology of cyclopids was studied relatively slightly, and methods of their culture have scarcely been developed. The feeding of cyclopids is illuminated only on the qualitative side in the special investigations of Naumann (1923), Dzyuban (1937, 1939) and partially in the works of Amelina (1927), Zelikman (1944) and other authors.

It is established that the food spectrum of cyclopids is extremely broad: daphnids, planarians, copepodite stages of copepods (cannibalism), rotifers, protists, bacteria, phytoplankton and so on.

The majority of authors agree on this, that cyclopids possess selectivity and actively seize their food. Animal food, evidently, appears proferable to them.

It is clear that the problem of studying these or other components of feeding in the general food spectrum can be definitely resolved only after obtaining exact quantitative data on the feeding of cyclopids. This information likewise is necessary for the development scientifically of sound methods of culturing cyclopids.

Dzyuban appears the only author who gives some idea of the quantitative consumption by cyclopids of animal food (daphnids, planarians, copepodite stages of cyclopids). In the work of Dzyuban it is shown that one cyclopid eats in 24 hours 10-14 small daphnids (length 0.5 - 0.6 mm) or 2 cyclopids in the copepodite stages, or large daphnids, etc. Unfortunately the author does not cite weight characteristics, that in a significant degree deprives this information of comparative value.

The propounded work appears an attempt to fill the gap in the study of the quantitative side of the feeding of cyclopids; in it is investigated the size of the 24-hour ration of cyclopids feeding on protists, the dependence of the ration on some factors of the external medium, and the difference of 24-hour consumption per unit weight of body with two species of cyclopids (Cyclops strenuus and Cyclops viridis).

Material & Methods

Material for the experiments - C. strenuus and C. viridis - was obtained from ponds, situated within the boundaries of Moscow (Kalitnikovski and Sokol'nicheski ponds). When brought into the laboratory the cyclopids were placed in clean tap water, in which they felt quite well.

For observations on the qualitative character of the feeding of cyclopids were employed cultures of Scenedesmus and infusoria. All experiments on quantitative evaluation of feeding were conducted on cultures of infusoria.

From the point of view of purity in the set-up of the experiments it was very tempting to employ the technique of a culture of infusoria on a synthetic medium (Ostergaut's medium, Beneke's solution), since in this case variations arising from the nutrient medium easily yield to control. However, as our purpose was to obtain data under conditions near to nature we therefore employed the usual technique of culture on a hay infusion. The hay (timothy), after drenching with boiling water, (calculated at 5-10g timothy to 1 l. of water), was steeped for 2 hours, then the infusion was filtered, and after 1-2 days the medium was prepared for inoculation with infusoria. The culture thus obtained was maintained at an average temperature of 16-22°C. At the first sign of dying-out of the culture (reduction in quantity of infusoria, putrid odour), it was renewed, decanting half or two-thirds of the old fluid and adding fresh hay infusion.

In order to have the chance of producing at any moment a sufficient quantity of infusoria some trials were made to concentrate them by mechanical means with the help of a centrifuge or a water-jet pump. It seemed that the infusoria insufficiently well endured this operation, and besides this, with them were filtered out too many unwanted particles. Therefore we changed over to the method of biological concentration, based on the tendency of infusoria to collect on the upper layer of the nutrient medium, i.e. where the bacterial film is formed and the oxygen regime is more favourable. The increase in the concentration of infusoria by this means was produced in a Vinogradsky flask. Infusoria in large quantities was collected in flint flasks from which it was carefully drawn off by pipette and placed in a vessel from which food was dealt for the experiment.

The basic methodic difficulty of the organization of the experiments consisted in the great variability of the protozoan cultures.

Not finding a method to eliminate fluctuations in the quantity of infusoria even in the course of short-term experiments, and taking into account that this fluctuation must have been a source of significant errors, we, in the final calculations and results took into consideration only these experiments in which the concentration of infusoria in the control did not change more than 25% from its original value.

Analysis of the influence of the duration of the experiment on the size of the 24-hour ration showed that with an increase in the length of the experiment, consumption of food by C. viridis and C. strenuus decreased, but % consumed increased. (fig. 1). Evidently, the animals in the late hours already had not food in sufficient quantity, and consequently could not completely satisfy their food requirements. All these considerations compelled us to decide on the formulation of experiments of unprolonged duration (3-4 hours), thus more easily allowing for the possibility of changes in the control, and food all the time sufficient for the animals. The experiments were carried out in Erlenmeyer flasks with the volume of liquid in the flask equal to 30 cm^3.

Such a comparatively small volume of food medium was taken because in this case it was easier to maintain equal distribution of infusoria in the body of the liquid. The concentration of cyclopids in the experiments was 1-2 per 1cm^3. With such a density of "planting" the animals do not interfere with one another and at the same time the decrease of infusoria is well observed. The quantity of food eaten up by all the cyclopids was determined in the usual way, as the difference between the initial and final concentrations of infusoria.

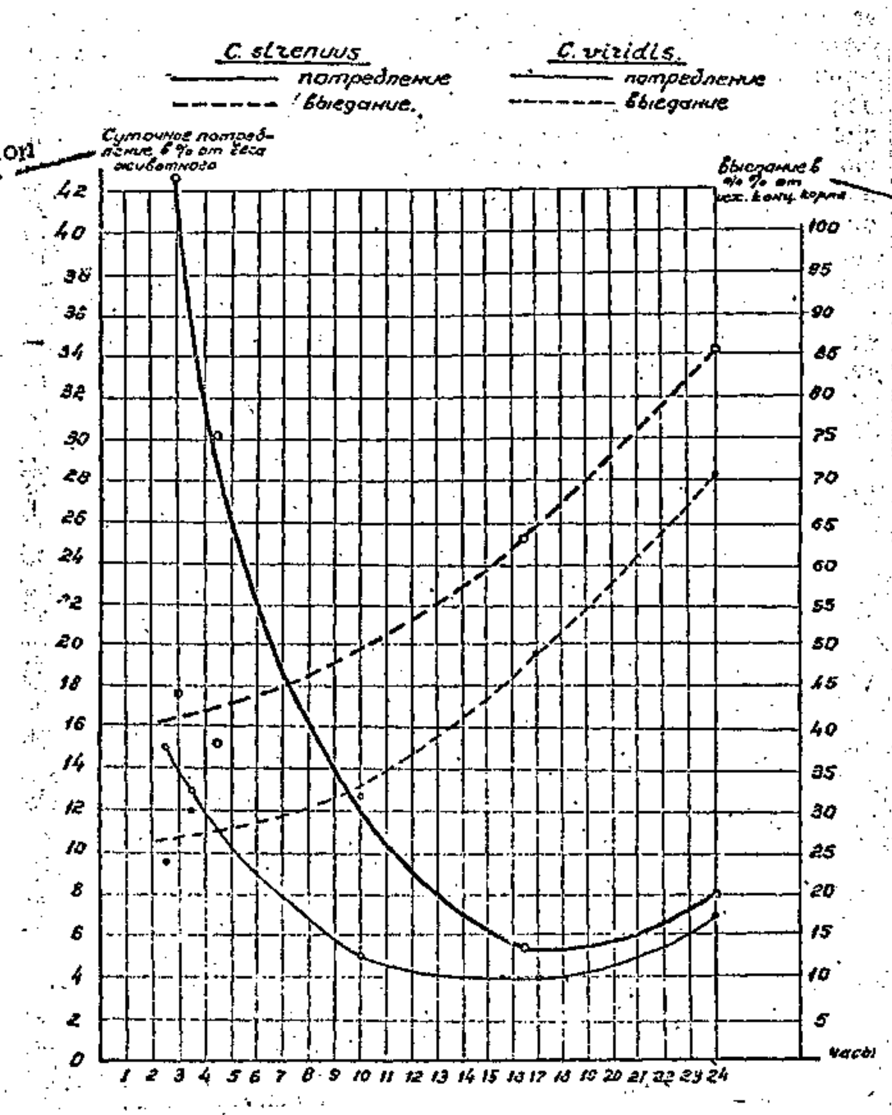
Calculation of the quantity of infusoria was effected in the following manner: from each vessel a stempl pipette (0.1 cm^3) drew 10 samples for checking. After this, as the samples were deposited on a graduated glass, they were fixed in Shaudin's fluid and counted under a binocular (microscope). Observations showed that infusoria with this sort of fixation did not break down for a long time.

After this, as data were obtained on the quantity of infusoria consumed in a day by a single cyclopid, a calculation was made of the consumption of food per 1 gm wet weight of cyclopid. The wet weight of infusoria was determined according to the volume of the animal. The volume of Paramaecium was calculated from the ellipsoid formula -
$\frac{3}{4}\pi$. a.b.c., where a, b, and c are [semi-axes of rotation].
~~[2 radial axes]~~. In our case $a = \frac{L}{2}$ (L - length of infusoria),

Fig. 1. 24-hour consumption of infusoria by cyclopids with various duration of experiments.

C. strenuus	C. viridis
——— consumption	——— consumption
- - - - - eaten	- - - - - eaten

24-hour consumption in % of weight of animal



eaten in o/o % of initial concentration of food

24 hours

Fig. 2. 24-hour consumption of infusoria by cyclopid C. viridis at different temperatures.

Concentration of food 900-1100

- - - - - - eaten

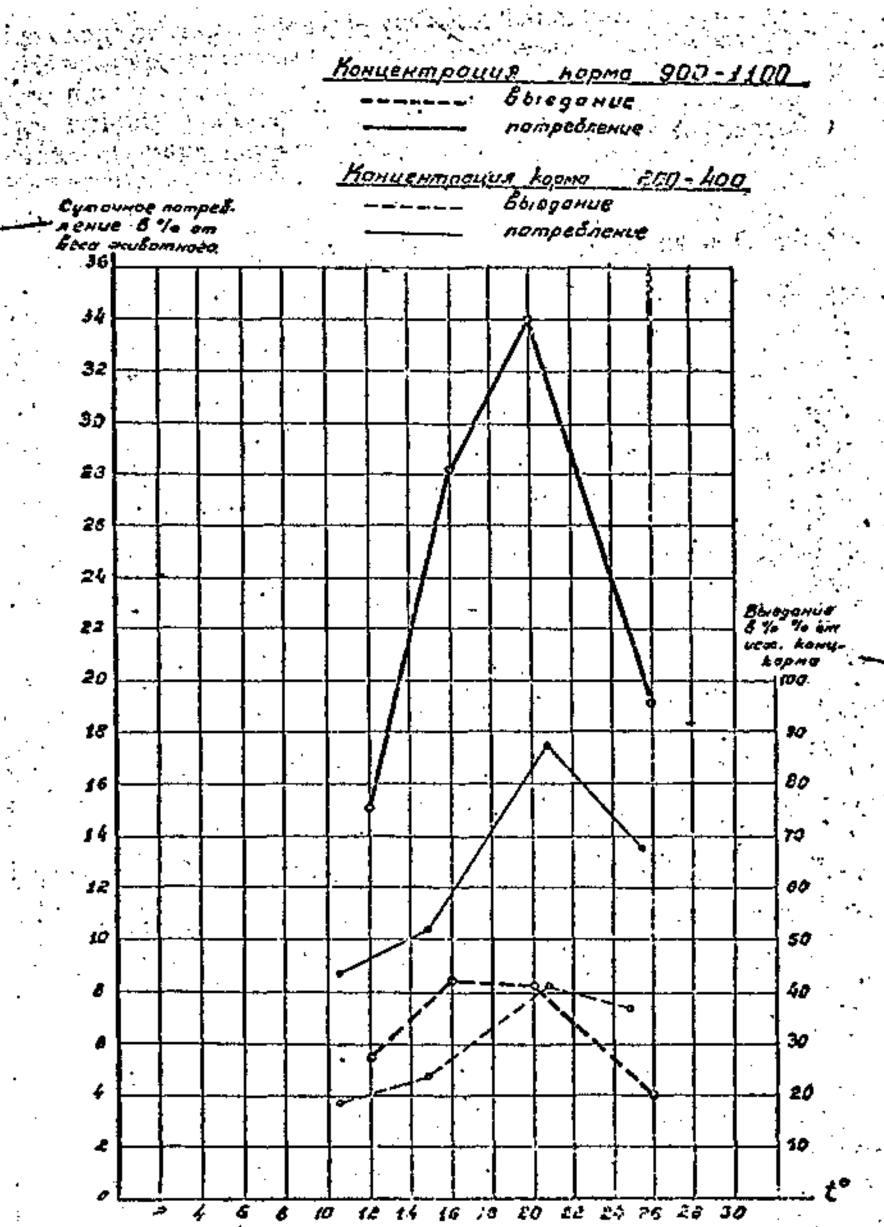
———— consumption

Concentration of food 200-400

— — — — — eaten

———— consumption

24-hour consumption in % of wet weight of animal



eaten in % % of initial concentration of food

$b = c = \frac{C}{2}$ (C – width of infusoria). In conversion of the volume data to weight the specific weight of protoplasm is allowed for. The cyclopids were weighed on an analytical balance in a watch glass, after the water had been carefully drawn off from the glass with filter paper.

It is necessary to note that after the weighed cyclopids had been washed from the glass back into the water, all the animals, with few exceptions, remained alive.

Observations on the qualitative side of the feeding of cyclopids

Prior to commencing determination of the 24-hour food rations of C. strenuus and C. viridis, certain observations were made on the qualitative side of their feeding. These observations played a subordinate role in our work; the aim of them was to find food, convenient for quantitative calculation and wholly satisfactory for the food requirements of the cyclopids.

At our disposal were 2 food cultures which answered well to the first of these requirements – a culture of the planktonic alga Scenedesmus and a culture of infusoria. These cultures were convenient for carrying out quantitative research by the so-called counting method.

With the aim of comparison of the food value of Scenedesmus and infusoria observations were made which were needed to establish whether cyclopids ingested offered food, and to what extent it satisfied their vital requirements. The arrangement of such observations was dictated by circumstances, as in the literature there were extremely contradictory indications on the role of plant food in the feeding of cyclopids. The majority of authors reckon that cyclopids consume phytoplankton; among them Dzyuban (1937, 1939), on the basis of dissection of the guts of cyclopids maintained in cultures of planktonic algae, arrived at the conclusion that cyclopids did not completely consume plant food.

The relative stability of phytoplankton cultures, and the tempting prospect of obtaining, with the feeding of cyclopids on Scenedesmus, quantitative data having higher comparative value, forced us to approach in more detail clarification of the significance of Scenedesmus in the feeding of cyclopids. There was made a series of dissections of stomachs and a study of their contents in C. viridis, maintained in different food media (one part in a culture of protista and a second part in a culture of Paramaecium).

The contents of the stomachs of C. viridis, taken from the culture of protozoa, were an amosphous brown mass without any kind of discernible inclusions.

Studies under the microscope of the gut contents of cyclopids which had remained for several hours in a culture of Scenedesmus, revealed this alga in all parts of the gut. A large quantity of outwardly intact cells of this algae, tinted with green colour, were revealed in the fecal masses of the animals studied.

In this way was established without doubt the fact of the digestion by cyclopids of plant food.

The problem of to what extent both kinds of food satisfy the vital requirements of cyclopids was solved in a second series of observations in which the animals were maintained for a long time on monocultures of algae and protista. It appeared that with feeding on infusoria and bacteria cyclopids normally lived, multiplied and grew for several months and disappeared only with the onset of high summer temperatures. In the presence of cyclopids decay of the cultures of protists does not take place.

The maintenance of cyclopids on a culture of Scenedesmus gave negative results: adult animals lived for some time in this medium, but the young died and growth was retarded.

Thus, a comparison of the two food objects showed a preference for infusorian food rather than vegetable. If animal food is absent, cyclopids will eat vegetable, but evidently it is badly assimilated by them, and does not provide for their normal requirements. The principal significance of protista in the feeding of cyclopids has already been reported in the work of Zelikman (1944) and other authors. Zelikman reckons that "small animals (Protozoa and others) constitute the main source of nutrition of freshwater cyclopids of all ages, or at least, form an indispensable component of their food material...."

Therefore we decided on infusorial food for the set-up of quantitative investigations.

24-hour rations of C. strenuus. Influence of concentration of food on intensity of food consumption.

Experiments on the nutrition of C. strenuus were carried out in August and September 1946 and 1947, firstly on pure and mixed cultures of infusoria (experiments 1-9) and later on monocultures (experiments 10-47).

In the presence of mixed cultures, if they are offered in practicable concentrations, it can be observed that the cyclopids in the first instance eat up the large infusoria (average weight 6×10^{-8} g each) and the smaller (mean weight 0.4×10^{-8} g each) are eaten up in smaller quantity. For example, in Expt. 7, the percentage eaten of the large forms in relation to the original concentration of infusoria was equal to 42.8% and the smaller forms were eaten at the same time only to 14.4%.

Proceeding from these data as has also been reported in the literature, we in all experiments disregarded bacterial nutrition, reckoning that the cyclopids ate up the larger food (infusoria) in the first instance.

The weight of C. strenuus in the experiments ranged from 0.06 mg to 0.1 mg.

The mean 24-hour ration of food of C. strenuus, calculated from 47 experiments, was equal to 473 infusoria per cyclopid. The mean 24-hour food index (ration as % of weight of animal) was 26.8%.

All experiments were carried out at one and the same time of year, with near temperature conditions and with uniform experimental material. In spite of this, variations in the 24-hour rations from the mean value were very significant. For example, in 1947 with a mean 24-hour ration of 28.8% the minimum ration was equal to 4% and the maximum 66.6%. In 1946, the mean 24-hour ration was lower (22.4%) than in the experiments of 1947 (28.8%).

The basic reason determining the fluctuation of the 24-hour ration in our experiments was different concentrations of the food cultures.

Table 1 gives an idea of the relation which exists between the density of the food culture (infusoria) and the 24-hour ration for C. strenuus.

It may be noted that with increased concentration of infusoria the 24-hour consumption of food of C. strenuus increased regularly, but the % of eaten food fell. This same regularity was shown in experiments with C. viridis (Table 2).

Starving cyclopids, as was to be expected, consume, in the presence of equal concentrations of infusoria, significantly more food than animals in a state of comparative satiation. If we compare the consumption of food of starving C. strenuus in the presence of different concentrations of infusoria, then it appears that they eat up an approximately equal quantity of food. The concentration of food here does not appear such an important influence in virtue of the heightened searching capacity of the animal under conditions of starvation. The quantity of food which the hungry animal consumes we took at maximum ration. It gave for C. strenuus a value of 61.0%. A very close quantity was eaten up by fed animals with maximum food concentration for our experiments, i.e. with greatest availability. In this case the 24-hour ration of C. strenuus was equal to 66.6%.

24-hour rations of Cyclops viridis. Influence of temperature on intensity of consumption of food

Experiments on the feeding of C. viridis were carried out in 1947 in spring (March, April, May), summer (June, July, August) and autumn (October), initially on a culture of Paramaecium sp. (mean weight of 1 infusorium 22.0×10^{-8} g), and later on a culture of Paramaecium caudatum (weight of 1 infusorium 6×10^{-8} g). The mean weight of cyclopids in the experiments was equal to 0.29 mg, varying from 0.25 to 0.35 mg. The mean 24-hour ration of C. viridis was equal to 11.4%, varying from 0.4 to 37.8%. In all 68 experiments were carried out with C. viridis.

The problem of the influence of the concentration of the food culture on the 24-hour ration of C. viridis was investigated further.

For this, in order to find out whether seasonal fluctuation influenced the consumption of food of C. viridis, we carried out comparative similar experiments, set out at different seasons (spring, summer, autumn). A comparison of the results obtained in spring and summer under the same temperature and other conditions showed that the intensity of feeding changed very little from spring to summer and from summer to autumn. This agrees with the biology of C. viridis which, judging from our observations and data from the literature, does not have a definite maximum of reproduction, but reproduces continuously. Walter (1922) demonstrated for this species 8 maxima of reproduction, beginning in January and ending in the month of December. Therefore we reckon it possible to compare the clear role of the temperature factor in the feeding of C. viridis in experiments established under different temperatures in the months of June, August and October.

In order to eliminate the influence of the concentration of the food culture on the 24-hour ration, comparison was made of experiments with average concentrations of infusoria (200-400 individuals per 1 cm^3) and of experiments in which the concentrations of food were higher. The results are presented in Tables 3 and 4. From these tables, and also from the graph (fig.2) it is evident that the temperature optimum for the feeding of C. viridis is equal to 20-21°C.

The optimum temperature conditions for feeding, obtained in our experiments, tallied with that temperature which was reckoned best in the culture of other planktonic crustaceans in medium latitudes. For example, in the work of Zarinski (1939) it seems that the optimum temperature regime of a culture of Daphnia magna should be reckoned as 18-20°C.

According to the data of Kastal'skaya-Karzinkina (1942), the temperature optimum for Daphnia magna lies between 17-24°C.

Table 1. 24-hour consumption of infusoria by C. strenuus with different concentrations of food.

Temperature 18-20°C. Duration of experiment, 4 hours.

	Numbers of infusoria in 1 cm^3	100-200	200-400	400-600	600-800	1000-1200
(a)	Mean 24-hour consumption of infusoria per 1 cyclops	204.8	396.6	546.6	747.2	1111
(b)	Mean 24-hour consumption of infusoria in g per 1 cyclops	12.2×10^{-6}	23.8×10^{-6}	32.8×10^{-6}	44.8×10^{-6}	66.6×10^{-6}
(c)	Mean 24-hour consumption in % of wet weight of cyclops	12.2	27.4	36.0	44.8	66.6
(d)	(Amount) eaten in % of initial concentration of food	84.8	43.5	37.2	32.8	34.7

Table 2. 24-hour consumption of infusoria by C. viridis with different concentrations of food.

Temperature 18–21°C. Duration of experiment, 4 hours.

	Numbers of infusoria in 1 cm^3	100–200	200–300	300–400	400–500	500–600	600–700	800–900	1000–1100
(a)	Mean 24-hour consumption of infusoria per 1 cyclops	264.0	342.4	384.0	604.0	747.0	998.4	1368.0	1591
(b)	Mean 24-hour consumption of infusoria in g per 1 cyclops	15.8×10^{-6}	395×10^{-6}	230×10^{-6}	362×10^{-6}	448×10^{-6}	598×10^{-6}	820×10^{-6}	954×10^{-6}
(c)	Mean 24-hour consumption in % of wet weight of cyclops	4.8	11.0	8.0	12.8	15.6	21.2	28.2	34.0
(d)	(Amount) eaten in % of initial concentration of food	37.9	50.0	31.8	27.6	33.8	31.8	42.1	41.7

Table 3. 24-hour consumption of infusoria by C. viridis with different temperatures.

Concentration of food 200-400 individuals / cm^3

	Temperature	$9-12^o$	$12-18^o$	$18-24^o$	$24-27^o$
(a)	Mean consumption of 1 cyclops in individuals	335.0	484.1	784.2	618.4
(b)	Mean consumption of 1 cyclops in g	23.4×10^{-6}	29.0×10^{-6}	47.0×10^{-6}	37.0×10^{-6}
(c)	Mean consumption in % to weight of cyclops	8.4	10.2	16.8	12.8
(d)	(Amount) eaten in % of initial concentration of food	19.6	24.3	40.8	37.4

Table 4. 24-hour consumption of infusoria by <u>C. viridis</u> with different temperatures.

Concentration of food 800-1100 individuals / cm^3

Temperature	12^o	16^o	20^o	25-27^o
(a) Mean consumption of 1 cyclops in individuals	756	1368	1591	936
(b) Mean consumption of 1 cyclops in g	45.4×10^{-6}	82.0×10^{-6}	95.4×10^{-6}	56.0×10^{-6}
(c) Mean consumption in % to weight of cyclops	15.6	28.2	34.0	19.2
(d) (Amount) eaten in % of initial concentration of food	27.6	42.1	41.7	19.8

Reduction of intensity of feeding with reduced temperature is explained by the depression of general activity of the animals and the weakening of the action of the digestive juices. With transition to a temperature higher than optimal, consumption of food falls, and after 26°C in our experiments began massive death of cyclopids. It must be noted that the influence of the concentration of food on the ration in given conditions, exactly as also in the preceding experiments, predominates over the influence of other factors. For example, the 24-hour ration at low temperature (12°C), but with high concentration of food objects was almost equal to the 24-hour ration at optimal temperature but lower concentration of infusoria. In the first case it showed a value of 15.6%, in the second, 16.8%.

Comparison of 24-hour ration of C. strenuus and C. viridis.

The 24-hour consumption of infusoria in grams per individual of C. viridis with feeding on similar food, the same concentration of infusoria and other equal conditions, somewhat exceeds the consumption in grams by one individual of C. strenuus (fig.3).

However, on conversion to per unit of weight of the cyclopids the mean ration of C. strenuus exceeds more than twice the mean ration of C. viridis (fig.4) (in the first case, 26.8%, in the second, 12.4%). It is possible that feeding on small organisms living in the water has not for C. viridis such great importance as for C. strenuus, since the first form satisfied a considerable part of its food requirements by detritus. We reached this conclusion, observing the behaviour of the animals in an aquarium. C. viridis keeps mainly to the bottom layers of the water and as it were falls on the detritus covering the bottom of the vessel. C. strenuus, on the contrary, continuously moves in the depth of the water, feeding on organisms suspended in the water, and very rarely dropping to the bottom of the vessel. In low volumes of water with long-term maintenance C. strenuus feels worse than C. viridis. Such differences in behaviour become intelligible if one takes into account the difference of the form of life of the studied animals in natural conditions.

C. viridis appears the typical form of small ponds and the littoral zone of small water-bodies, C. strenuus has within the limits of the species a certain amount of biological variation; our experiments were carried out on that form which lives in the pelagic zone of water-bodies.

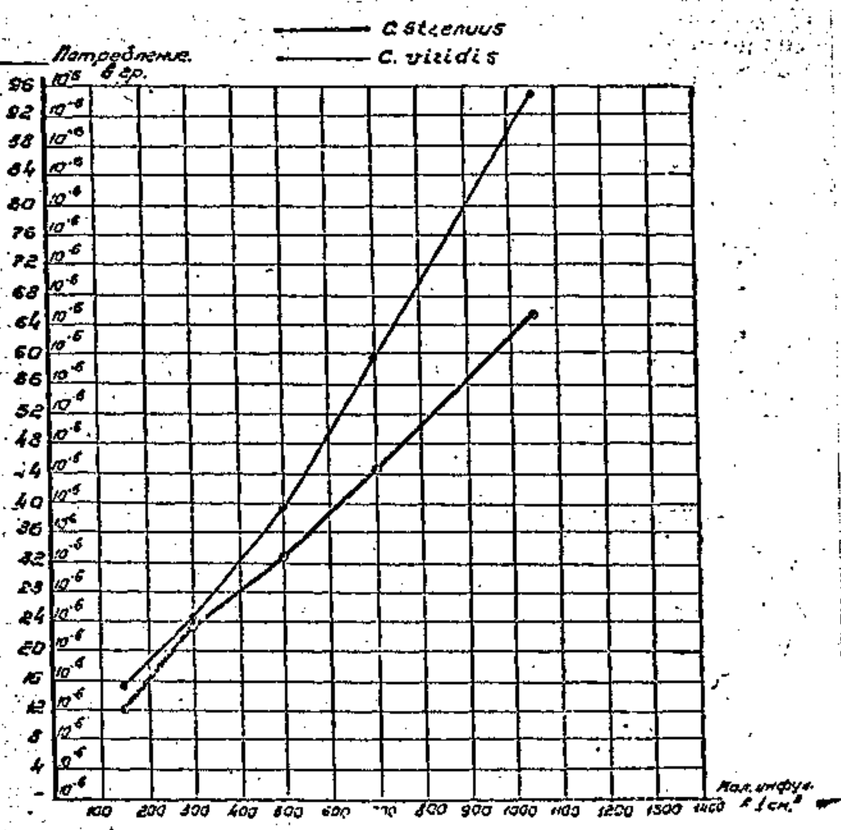
Thus a difference of ecological conditions finds its expression in all aspects of the activity of the animals, among them in the character of their feeding.

Fig. 3. 24-hour consumption of infusoria by both species of Cyclops, per individual in grams.

——— C. strenuus

——— C. viridis

Consumption in gr.



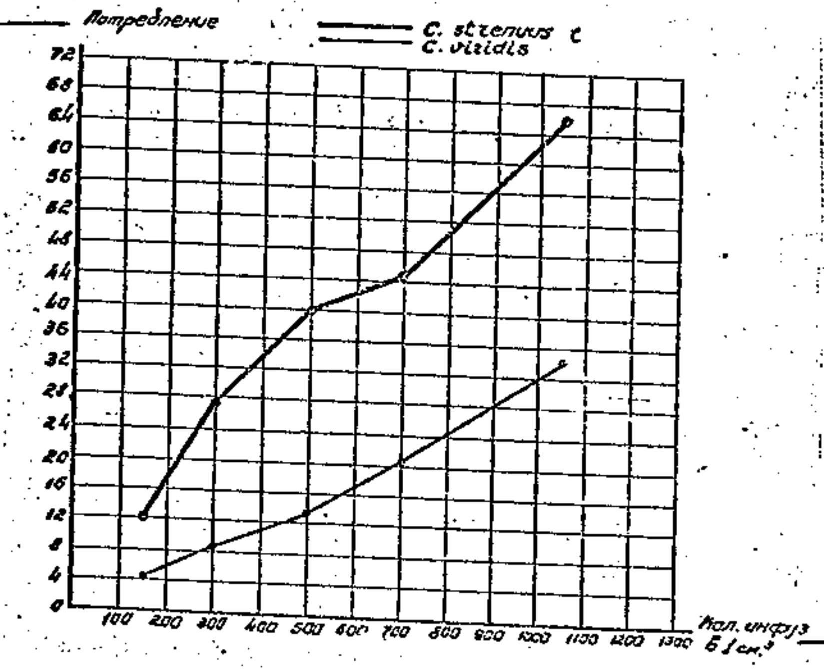
Number of infusoria in 1 cm^3

Fig. 4. 24-hour consumption of infusoria by both species of *Cyclops* as percentage of wet weight.

C. strenuus

C. viridis

Consumption



Number of infusoria in 1 cm^3

Conclusions

1. The mean 24-hour ration of C. strenuus comprises 26.8% of the wet weight of the cyclopids the maximum daily ration in the experiments was 61-66% of wet weight, and the minimum 4%.

2. The mean 24-hour ration of C. viridis (11.4%) is significantly less than the mean ration of C. strenuus. This is connected with the difference of biology of these species, and also with the concentration of infusoria in the experiments, as a rule, not completely satisfying the food requirements of C. viridis, by far larger than C. strenuus. The maximum 24-hour ration of C. viridis in our experiments was equal to 37.8%, and the minimum 0.8%.

3. The variation of the 24-hour ration depends on the changes in concentration of the food cultures. With an increase in the concentration of infusoria the ration increases; and with a lessening of the concentration, it lessens.

4. The intensity of feeding depends on temperature. The optimum for the feeding of the cyclopids in the experiments was a temperature of 20-21°C.

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Notice

Please note that these translations were produced to assist the scientific staff of the FBA (Freshwater Biological Association) in their research. These translations were done by scientific staff with relevant language skills and not by professional translators.