EKOLOGIA POLSKA (Ekol. pol.)	25	3	421–429	1977

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FACTORS INFLUENCING BENTHOS BIOMASS IN SHALLOW LAKE ENVIRONMENTS*

ABSTRACT: Very high increase of benthos biomass (total biomass – 18 times, biomass of *Chironomidae* – more than 70 times) occurred in enclosures where plankton was exploited using plankton nets. The assumed cause was the change in planktonic community and resulting better food conditions for benthos. In all other experimental variants (protection from fish, addition of food, artificial oxygen deficit, stirring of mud) changes in benthos were much smaller.

Contents

1. INTRODUCTION

The goal of the work was to look for the main factors deciding about the biomass of benthos, especially the ones which would essentially change the benthos biomass. The influence of the following factors was investigated: protection from fish, addition of food, killing all animals and thus destroying the structure of the community, imitation of the stirring of mud by fish while feeding, changes of the planktonic community.

The work was carried out in an eutrophic, pond type Lake Warniak, 38.0 ha of area, 3.7 m of maximal depth, densely covered with aquatic plants. The experiments were made in places with bare, soft mud bottom, about 1 m deep.

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*Praca wykonana w ramach problemu węzłowego nr 09.1.7 („Procesy decydujące o czystości powierzchniowych wód śródlądowych").

2. METHODS

2.1. General

Two series of experiments were carried out; first in 1968, consisting of all variants mentioned, except deliberate changes in the planktonic community, the second in 1975 consisting of the following variants: protection from fish, manuring (=addition of food), changes in planktonic community.

2.2. First series of experiments

a. 12 experimental tubes with the diameter of 0.7 m made of painted wire carcase covered with nylon netting with mesh size 2 x 2 mm were inserted into the bottom; their upper edge was about 20 cm above the water surface. Three of these tubes were control, to all others food was added: in the form of baker yeasts (25 or 50 g in suspension) – 4 tubes, condensed plankton killed by heating – 2 tubes, powdered milk – 1 tube, *Elodea canadensis* Rich. chopped into small pieces and killd by heating – 2 tubes. The food was added weekly. The netting after a few days became covered with very thin slime film, which made the tube plankton-tight, altough not benthos-tight. This resulted in the abundant plankton development in the tubes.

b. The 4 m^2 part of the bottom (at a distance of about 100 m from the experimental tubes) was tightly covered from the sides and the top with black foil for a month; this resulted in the complete oxygen deficit, which killed all the animals. After removal of the foil (4 days before sampling started), one half of this piece of the bottom was left accessible for fish, the second one was fenced with the netting 1 × 1 cm, to protect it against fish.

c. The other, analogical and neighbouring to the previous variant part of the bottom was throughly stirred with the rake, four days before the sampling started, to imitate the action of fish while feeding. One half of this piece of the environment was left unfenced, the other was fenced against fish, like above. The experiments lasted for 1 month. They began on June 26th, by setting the tubes and other enclosures, adding the food, taking off the foil from the place with oxygen deficit, raking the bottom.

Samples of macrobenthos were then taken on 1st, 8th, 14th, and 24th of July (at the same time food was added to the proper variant of the experiment) with the Kajak corer – 4 samples of 10 cm^2 in each of the experimental tubes (48 samples every time, 192 altogether), and 5 samples of 45 cm^2 each in every of the other variants (20 every time, 80 altogether). Two series of samples in the open lake were also taken – one close to the tubes, and the second one close to other variants (10 every time, 40 altogether). The samples were sieved through a 0.4 × 0.4 mm sieve and preserved in 4% formalin. The biomass of the particular groups of the benthos was estimated on the torsion balance.

2.3. Second series of experiments

The experiment was carried out in the same type of experimental tubes as above, but with the walls made of the plastic foil. There were 3 variants of this experiment: control, manuring with the cow manure, and exploitation of the plankton with plankton net; both these procedures were repeated 3 times in weekly intervals, during July 1975. Benthic samples were taken 2.5 months later, in October, 5 samples of 45 cm^2 in each of the variants and in the open lake; they were treated as in the 1st series of experiments.

3. RESULTS

The average share of *Chironomidae* in the total benthos biomass was 60%, the dominant forms being *Tanytarsus gregarius* Kieff., *Limnochironomus nervosus* (Staeg.), *Tanytarsus mancus* (Walk.), *Polypedilum nubeculosum* (Meig.), *Cryptochironomus viridulus* (Fabr.). *Procladius* sp., *Glyptotendipes gripekoveni* Kieff., *Chironomus plumosus* L., *Ch. anthracinus* Zett., *Endochironomus tendens* (Fabr.), *Microtendipes chloris* (Meig.). *Tubificidae*, *Heleidae*. *Trichoptera*, *Sialis lutaria* L., *Hirudinea; Hydracarina* were common, *Ephemeroptera* were abundant occasionally.

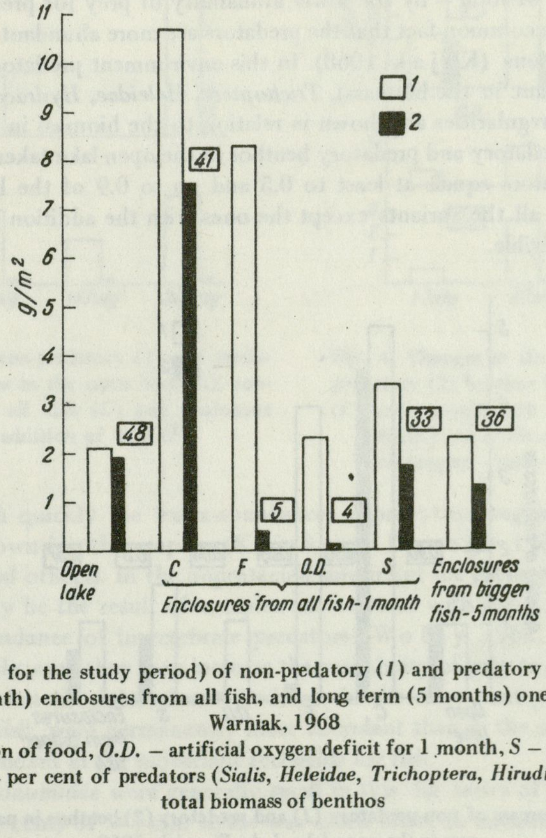

Fig. 1. Biomass (average for the study period) of non-predatory (*1*) and predatory (*2*) benthos in the open lake, short term (1 month) enclosures from all fish, and long term (5 months) ones from bigger fish. Lake Warniak, 1968

C – control, *F* – addition of food, *O.D.* – artificial oxygen deficit for 1 month, *S* – artificial stirring of mud. Numbers in rectangles – per cent of predators (*Sialis, Heleidae, Trichoptera, Hirudinea, Hydracarina*) in the total biomass of benthos

If the average biomass of the benthos in particular variants of the 1st series of experiments is taken for the whole study period, it appears that the significantly higher (about 4–6 times) biomass than the one in the open lake[1], is noted in the control and in the variant with the addition of food. Sometimes the biomass was 25% higher in the tubes to which dead plankton was added as compared to control ones and the others to which other kinds of food were added, but for this general consideration, all the tubes with the addition of food are treated

[1] Both series of samples from the open lake are here taken together, since their averages were similar.

together. In all other variants the biomass was similar, or slightly (not more than twice) higher than in the open lake. The biomass in larger (100 m^2) enclosures from fish in the same lake is given for comparison (after Kajak 1972) (Fig. 1). Data for the subvariants protected and unprotected against fish of the variants with the oxygen deficit and with the stirring of the mud have been taken together for this general comparison; later they will be treated separately. Beside the differences in the biomass of the non-predatory benthos, the ones in the biomass of invertebrate predators, and their share in the total biomass of the benthos, are striking. The share of these predators is very low, many times lower in the variants with the addition of food and with the oxygen deficit, than in the other ones. In the variant with the previous oxygen deficit this phenomenon can be explained by unfavourable environmental conditions, in the one with the addition of food – by the lower availability of prey for predators due to better food conditions. It is a common fact that the predators are more abundant in the environments with poor food conditions (Kajak 1968). In this environment predators consisted of *Sialis lutaria* (usually dominant in the biomass), *Trichoptera, Heleidae, Hydracarina, Hirudinea.* All the above mentioned regularities are shown in relation to the biomass in the open lake (both the biomass of non-predatory and predatory benthos in the open lake taken as 1.0) in Figure 2. The biomass of predators equals at least to 0.5 and up to 0.9 of the biomass of the non-predatory benthos in all the variants except the ones with the addition of food and oxygen deficit, where it is negligible.

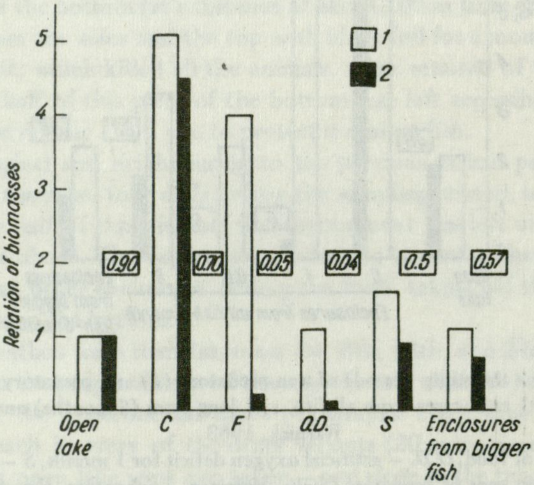

Fig. 2. Relation of the biomass of non-predatory (*1*) and predatory (*2*) benthos in particular variants, to the one in the open lake. Lake Warniak, 1968

C – control, *F* – addition of food, *O.D.* – artificial oxygen deficit for 1 month, *S* – artificial stirring of mud. Numbers in rectangles – relation of predatory to non-predatory benthos in the given variant

The biomass of predators is very stable in these two variants (food addition and oxygen deficit) whilst it varies significantly in all the others (Figs. 3, 4). Probably due to good food conditions in the variant with the addition of food, prey are persistently resistant to predators, whilst in the other variants the situation varies. Sometimes the predators are more abundant than their prey (Figs. 3, 4). As a rule, there is much more predators in the variant with the stirred mud and the protection from fish as compared to the open lake and the variant with the stirred mud accessible for fish; obviously either invertebrate predators or fish (to some extent

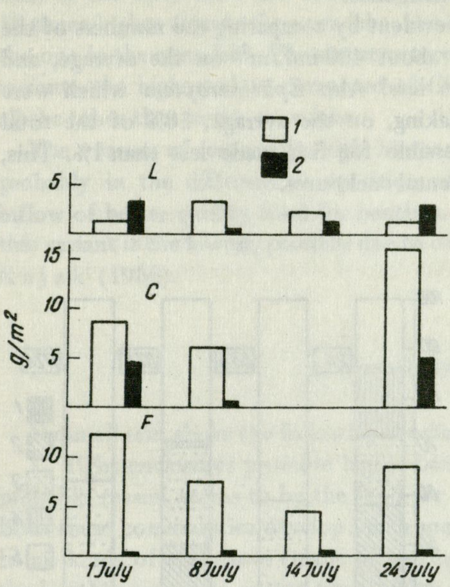

Fig. 3. Changes in the non-predatory (*1*) and predatory (*2*) benthos biomas in the open lake (*L*), control enclosures against all fish (*C*) and analogous enclosures with addition of food (*F*)

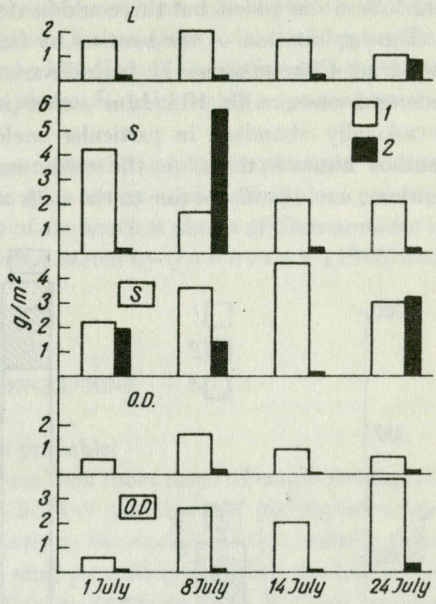

Fig. 4. Changes in the non-predatory (*1*) and predatory (*2*) benthos biomass in the open lake (*L*) and variants with artificial oxygen deficit (*O.D.*) and artificially stirred mud (*S*)
In rectangles – parts protected against fish

alternatively) diminish quickly the extra-abundance of prey; their regulation by invertebrate predators was also shown in other papers (Kajak and Dusoge 1970, Z. Kajak and A. Kajak 1975, and others). In the unprotected subvariant the predators are abundant only once (Fig. 4); this may be the result of complex connections with fish. On the one hand, the fish decrease the abundance of invertebrate predators (Wolny 1962, Kajak 1972), on the other, by stirring the mud they may increase the availability of prey to these predators. This might be the reason that the invertebrate predators in the subvariant previously stirred, but later inaccessible for fish, were permanently more abundant than in the open lake, whilst only occasionally more abundant in the subvariant accessible for fish.

The larvae of *Chironomidae* were generally small in this 1st series of experiments – up to 6 mm. The share (per cent) of ≥4 mm larvae was much lower in environments accessible for fish, and higher in inaccessible ones:

Variants		Per cent
accessible for fish	open lake	– 20
	stirred mud	– 13
	oxygen deficit	– 28
inaccessible for fish	stirred mud	– 50
	oxygen deficit	– 45

The share of two oldest classes was also low, about 20% in control and experimental tubes to which food was added, but this could be due to the emergence.

The exploitation of the benthos by fish is most evident by comparing the numbers of the pupae of *Chironomidae* in fenced variants, with about 400 ind./m^2 on the average, and unfenced ones, with 10 ind./m^2, that is 40 times less! Also *Ephemeroptera* which were occasionally abundant in particular enclosures, making, on the average, 18% of the total benthos biomass there, in the environments accessible for fish made less than 1%. This, however, could partly be due to the walls of experimental enclosures.

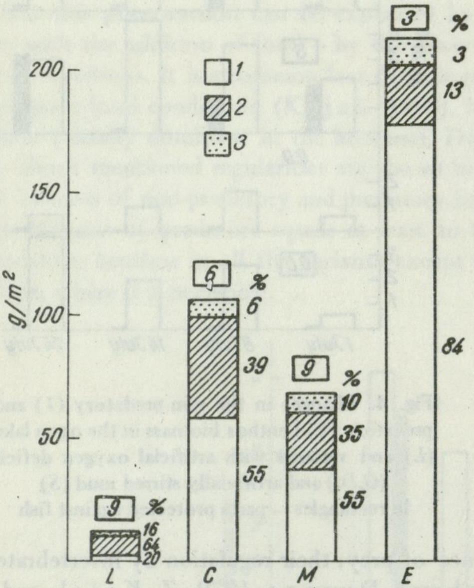

Fig. 5. Biomass of benthos in the open lake (*L*) and enclosures: control (*C*), manured (*M*) and with exploitation of plankton (*E*). Lake Warniak, 1975
1 – *Chironomidae*, *2* – *Oligochaeta*, *3* – others. In rectangles – per cent of predators in total benthos biomass

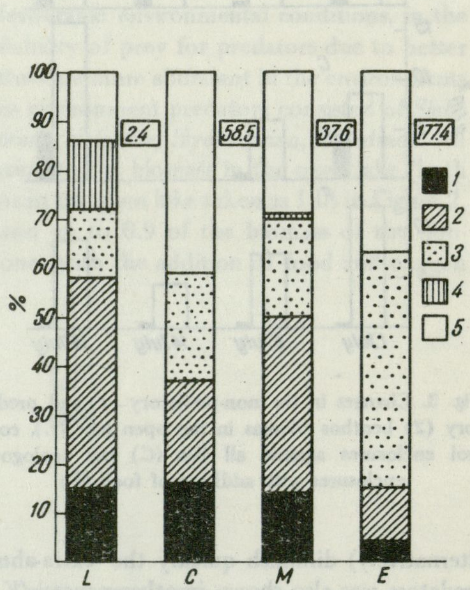

Fig. 6. Share of particular size classes of *Chironomidae* in their total numbers
1 – ≤ 4 mm, *2* – 5–7 mm, *3* – 8–12 mm, *4* – 13–18 mm, *5* – ≥ 19 mm. In rectangles – biomass of *Chironomidae* (g/m^2). For explanation of *L, C, M, E* see Figure 5

In the 2nd series of experiments (Fig. 5) the biomass of the benthos in the control variant was about 10 times higher than in the open lake, so the difference was greater than in the 1st series of experiments. The absolute values of the biomass in the 2nd series were higher than in the 1st one. The share of predators in the control variant was higher than in the open lake, probably due to some overcrowding of the prey and their increased availability to predators. The biomass in the manured variant was lower than in the control one, although several times higher than in the open lake. The share of predators in the manured variant, that is the one with better food conditions, was lower than in the control one, similarly as in the 1st series. The extraordinary high biomass of the benthos was found in the variant with the exploitation of plankton. This level of the biomass, more than 200 g/m^2, is not often encountered in nature. The share of predators was very low, possibly indicating very good feeding conditions of the non-predatory benthos, and its low availability for invertebrate predators. The share of

Chironomidae was especially high in this variant, although in all the tubes it was much higher than in the open lake. The total benthos biomass was in the variant with exploited plankton 18 times higher than in the open lake, but the biomass of *Chironomidae* – 74 times higher than the one in the open lake. The size structure of *Chironomidae* (Fig. 6) was different in particular variants, the highest class, composed of *Chironomus plumosus*, being much more numerous in all the tubes than in the open lake.

The reason of especially high biomass in the variant with exploited plankton consists probably in the different composition of plankton (due to its exploitation), and resulting inflow of better quality food for benthos. The share of the smallest classes of *Chironomidae* in this variant is the lowest, possibly due to overcrowding, as stated by J o n a s s o n (1965) and K a j a k (1968).

4. DISCUSSION AND CONCLUSIONS

From all said above the following conclusions seem probable:

1. Tight enclosures promote higher benthos biomass than those made of coarse netting; the probable reason seems to be the food for benthos – both of plankton and periphyton origin. Both these communities develop much more abundantly in the enclosures than outside them. In all kinds of enclosures (made of netting 12 × 12 mm) protecting from fish the biomass of the benthos was up to several times higher, whilst in tight enclosures – up to 20 times, reaching sometimes very high level. On the other hand, in the larger (6 m^2) tight enclosures where plankton was very poor due to feeding of silver carp, and the possible amount of food of periphytonic origin sinking to the bottom (per the unit of bottom area) was small due to larger size of enclosures, the biomass of the benthos was only slightly higher than in the open lake (K a j a k et al. 1975). This also proves that the high abundance of benthos was not caused by the increased transparency and possibly resulting higher abundance of benthic algae. The transparency in large tight enclosures with silver carp was higher than in small ones with exploited plankton, but the benthos biomass was only slightly increased in the first, whilst very significantly in the second ones.

2. The quality of food seems to have special importance; the addition of food in the 1st series of experiments resulted in the decrease of the abundance of predators, but did not increase the biomass of the benthos. Probably in this changed situation, with more food and few predators, the character of interrelationships within non-predatory benthos – competition, etc., changed in such a way, that it kept the biomass of the benthos relatively low.

Dead plankton gave slightly better results than the other kinds of food; this is in agreement with the selectivity of algae, and especially diatoms by *Chironomidae* (K a j a k and W a r d a 1968, K a j a k and R y b a k 1970).

Although the benthos reacts very vividly and quickly to every change in the environment as well as on its own abundance, composition and structure (K a j a k 1963, 1964a, 1964b, 1966, 1968, 1972, L e l l a k 1965, K a j a k and D u s o g e 1967, 1970 and others), many times higher biomass was obtained only in the essentially changed planktonic community and resulting different food conditions for the benthos. The structure and interrelationships of benthos seem to have a secondary importance, as the mechanisms regulating the community, on the background of food conditions.

3. The influence of fish on the benthos seems to be complex. Diminishing (directly, and by decreasing the abundance of prey) the abundance of invertebrate predators, and bigger non-

-predatory forms (the removal of the latter decreases competition and other adverse interrelationships), fishes should increase the rate of the production of the benthos; on the other hand they can, beside strong exploitation of the benthos (especially of pupae of *Chironomidae*) increase the availability of prey for invertebrate predators, by stirring the bottom.

5. SUMMARY

A series of experiments was carried out in shallow (about 1 m) environments, with bare bottom, of an eutrophic lake. The goal of the work was to find out factors deciding about the level of benthos abundance. Experimental tubes, 0.7 m^2, inserted into the bottom and emerged about 20 cm above the water surface, and experimental enclosures, 2 m^2, were applied; these devices were made of plastic foil or netting with mesh dimensions of several to about 10 mm.

Following experimental procedures were carried out (simulating natural phenomena in a lake): oxygen deficit, stirring of the mud (as while fish feeding), addition of various food, changes in planktonic community resulting from net plankton exploitation. Each of these treatments resulted in change (usually not exceeding several times) of benthos abundance and change of share (as well as dynamics) of benthic invertebrate predators. The share of predators was, as a rule, smaller at better food conditions (Figs. 1–4).

Only in one experimental variant – with the exploitation of plankton, the biomass of benthos increased essentially – one can say that the level of abundance changed; the biomass of benthos changed 18 times, and the biomass of the dominant component – *Chironomidae* – more than 70 times in relation to the state in the open lake in the neighbourhood (Fig. 5).

Food conditions, including quality of food, seem to be essential for the level of benthos abundance. On this background benthic predators and competition can probably cause fluctuations and differences in abundance up to several times.

The role of fish seems to be complex; decreasing directly (or by decreasing the abundance of prey) the abundance of invertebrate predators and bigger non-predatory forms (decrease of the latter diminishes, in turn, competition and other disadvantageous interrelationships) the fish act towards increasing biomass and production of benthos. On the other hand, they act in the opposite direction – not only exploiting benthos, but also stirring the bottom and thus increasing the availability of benthos for invertebrate predators, by destroying protective accomodations of benthic organisms.

6. POLISH SUMMARY (STRESZCZENIE)

W płytkich (ok. 1 m) niezarośniętych środowiskach jeziora eutroficznego przeprowadzono szereg eksperymentów celem wyjaśnienia jakie czynniki decydują o poziomie biomasy bentosu. Eksperymenty prowadzono w rurach eksperymentalnych o powierzchni 0.7 m^2, wbitych w dno i wystających około 20 cm nad powierzchnię wody oraz w zagrodach eksperymentalnych o powierzchni około 2 m^2; urządzenia te były wykonane z folii lub siatki o rozmiarach oczek od kilku do kilkunastu milimetrów.

Zastosowano następujące zabiegi eksperymentalne (naśladując zjawiska naturalne w jeziorze); deficyt tlenowy, mieszanie mułu (jak przy żerowaniu ryb), dodawanie różnych rodzajów pokarmu, zmiany w zespole planktonowym wywołane odłowem planktonu sieciowego. Każdy z zabiegów eksperymentalnych powodował zmianę biomasy bentosu – na ogół nie większą niż kilka razy – oraz zmiany udziału (i dynamiki) drapieżców bezkręgowych. Z reguły udział drapieżców był mniejszy w lepszych warunkach pokarmowych (fig. 1–4).

W jednym tylko wariancie eksperymentu – z wyłowem planktonu sieciowego – biomasa bentosu zwiększyła się zasadniczo, na tyle, że można mówić o zmianie poziomu obfitości. Biomasa bentosu wzrosła 18 razy, zaś dominującego składnika – *Chironomidae* – ponad 70 razy w stosunku do stanu w jeziorze w sąsiedztwie eksperymentu (fig. 5).

Warunki pokarmowe, w tym jakość pokarmu, wydają się zasadnicze dla poziomu występowania bentosu. Na tym tle drapieżce bezkręgowe i stosunki konkurencyjne prawdopodobnie mogą powodować wahania i różnice liczebności do kilku razy.

Rola ryb jest – jak się wydaje – złożona; zmniejszając bezpośrednio (lub przez obniżenie obfitości ofiar) biomasę drapieżców bezkręgowych i większych form niedrapieżnych (to ostatnie zmniejsza konkurencję i

inne niekorzystne oddziaływania wzajemne) ryby wpływają w kierunku zwiększenia produkcji i biomasy bentosu. Z drugiej strony oddziałują one jednak także w kierunku przeciwnym – nie tylko przez wyżeranie, ale również przez zwiększanie dostępności organizmów bentosowych dla drapieżców bezkręgowych przez mieszanie dna i niszczenie przystosowań ochronnych bentosu.

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