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**The effect of fish on resuspension of bottom sediments  
and relationships between zooplankton  
and suspended materials**

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Abstract — The percentage of organic carbon in sedimenting suspension was considerably higher before stocking the pond with fish and decreased in proportion to the increase in the amount of suspension after stocking the pond with carp. For some zooplankton species equations of multiple regression containing the amount of suspension, expressed as ash were calculated. For *Chaobcrus cyrstallinus* a negative and significant dependence was obtained with  $P < 0.1$ , and for the remaining species a negative and significant one with  $P < 0.05$ . Various ways of the action of mineral suspensions on the zooplankton of ponds and dam reservoirs are discussed.

Key words: ponds, bioturbation, fish, zooplankton.

### **1. Introduction**

Investigations on processes occurring between bottom sediments and water rarely take into consideration the effect of the fish and macro-organisms living in the sediments on nutrient cycling, oxygen conditions, and transport of sediments in aquatic ecosystems. The role of bioturbation is often neglected in models because of its low significance in some types of water bodies, as was shown by K a m p - N i e l s e n et al. (1982) for phosphorus in Lake Esrom. On the other hand, resuspended sediments render an important effect on the dynamics of release of phosphorus for algae (G o l t e r m a n 1973, 1984, G u

n a t i l a k a 1982), while that of suspended materials is often of consequence for the rate of primary production (T i l z e r et al. 1976) and the amount of zooplankton in ponds (EIFAC 1964, Ż u r e k 1980) and rivers (B e h n i n g 1929, S m a g o w i c z 1963, K r z a n o w s k i 1965, P a g g i J. C., S. J. P a g g i 1974, H a r t 1986a, b). The experimental studies of S t e p h a n (unpubl. data), R o b i n s o n (1957), Ż u r e k (1982), T ó t h (1982), B ł ę d z k i (1990), and A r r u d a et al. (1983) confirm the importance of this factor and indicate the necessity of further detailed investigations on the subject.

A high concentration of suspension in rivers and dam reservoirs is observed after heavy rain. Other reasons for a great quantity of suspensions may be wave action and bioresuspension with intensive aquaculture in shallow lakes and ponds. In Poland and in other countries, benthophagous fish are bred, such as the carp or tench (B a r t h e l m s 1983, G a l o 1984), whose food spectrum changes with age. During the first three weeks the larvae of fish feed mainly on cladocerans (63), rotifers (10.4), and the small larvae of Chironomidae, Protozoa, Bacillariophyceae (M a t l a k & M a t l a k 1976). Thus they exploit the environments of the deep water, while older and heavier fish pass to the exploitation of bottom communities.

Because of the lack of studies on the influence of fish on the resuspension of sediments and the primary production of phytoplankton and zooplankton, the aim of the present paper was to study the interaction between fish and bottom sediments, as well as between suspension and the production of phytoplankton and the development of zooplankton.

## 2. Study area

The investigations were carried out in the natural environment and in laboratory conditions, the former being carried out in ponds at Gołysz (49°52' N, 18°48' W). The resuspension of bottom sediments by fish was investigated in two 8 ha ponds. The fish biomass changed during the season and was checked by the method of tentative fishing. The ponds were filled with water in winter. The first pond (A) was stocked in June with carp fingerling (total biomass 190 kg ha<sup>-1</sup>, mean individual weight 60 g). The second pond (B) was stocked in July with 20 kg ha<sup>-1</sup> (mean individual weight 0.5 kg). In neither pond were the fish additionally fed. The dependence between the density of stock and thickness of the trophogenic water layer was measured in other ponds stocked with carp fingerling. The investigated ponds were stocked with 6 000, 24 000, and 60 000 indiv. ha<sup>-1</sup>.

In three other experimental ponds, Nos 7, 8, and 9 observations were made on the effect of pond depth upon the concentrations of suspension and upon the dependence of the amount of suspension on the composition of zooplankton species. Detailed limnological data on 11137 P a s t e r n a k (1965), W r ó b e l (1971).

### 3. Material and methods

The field investigations were performed in various years from 1972 to 1985. Oxygen was measured by W i n k l e r ' s method (H e r m a n o w i c z et al 1976). Organic carbon in the water and sediments was determined by the titrimetric method after wet combustion in potassium bichromate (H e r m a n o w i c z et al. 1976). Chlorophyll a was determined in acetone extract, according to G o l t e r m a n (1970). The amount of phosphates was measured by the molybdenum method (H e r m a n o w i c z et al. 1976). For determining the amount of resuspended bottom sediment, sediment traps were used according to Ł a w a c z (1959) Primary production was determined by estimation of the O<sub>2</sub> concentration in dark and light bottles according to V i n b e r g (1960)- it was measured every 20 cm counting from the surface.

The suspension was measured nephelometrically according to H e r m a n o w i c z et al. (1976) and as a total fixed residue at 550°C The number of heterotrophic bacteria in the water of ponds was determined directly by counting colonies growing on agar bouillon after 7 days of culture at 25°C

Ali zooplankton samples were taken by a 5 l P a t a l a s bathometer - thirty samples of zooplankton were taken from ponds. Counting was carried out in a 1 cm<sup>3</sup> chamber under small magnification The water for analysis of phytoplankton in ponds 7, 8, 9 was taken only from two levels: 0.0-0.5 and 0.5-1.0 m with a Patalas bathometer and mixed in a bucket. 700 cm<sup>3</sup> water averaged in such a way was transferred to a jar than treated with Lugol's solution and allowed to stand for one day. The sample was then decanted and the whole transferred to a small jar. Quantitative and qualitative analyses were carried out. Statistical analysis was performed by calculating the multiple regression.

### 4. Results

The numbers of stock and the fish biomass were the main factors affecting the magnitude of processes of suspension sedimentation before stocking the ponds with fish the quantity of sediment in the traps

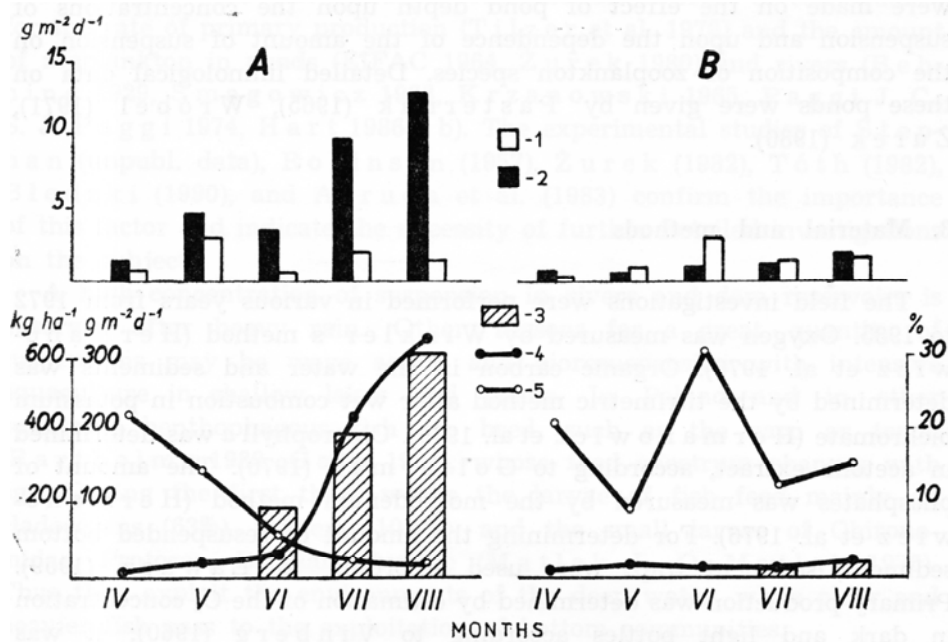


Fig. 1. Effect of fish stock on amount of sedimenting solids in Ponds A (fish stock 190 kg ha<sup>-1</sup>) and B (fish stock 20 kg ha<sup>-1</sup>). 1 - primary production of phytoplankton (g m<sup>-2</sup> d<sup>-1</sup>); 2 — content of organic C in sediment in traps (g m<sup>-2</sup> d<sup>-1</sup>); 3 — fish biomass (kg ha<sup>-1</sup>); 4 — amount of sediment in traps (g m<sup>-2</sup> d<sup>-1</sup>); 5 — % of organic C in sediment in traps.

was small, showing no great differences between the investigated ponds (fig. 1). After stocking with carp the amount of sedimenting suspension increased rapidly in Pond A, reaching over 300 g m<sup>-2</sup> d<sup>-1</sup> in August while in Pond B, in which the much smaller fishes constituted a considerably smaller total biomass, it increased minimally. The relatively small amount of sedimenting suspension in Pond A in June was caused by late stocking, which took place in the second half of June and by the short, only 10 days, feeding by fishes on the bottom of the pond.

After stocking the pond with fish, the amount of sedimenting organic carbon, in terms of the areas of both ponds, increased proportionally to the increase in fish biomass during the season (fig. 1). In Pond A the percentage of organic carbon in sedimenting suspension was considerably higher before stocking and decreased proportionally to the increase in suspension. In July and August it fell below 5 i.e. to the level of its content in the bottom sediments. In Pond B the amount of organic matter in the sedimenting suspension was greater for the whole season. The amount of organic carbon in

this pond depended mainly on the primary production of phytoplankton and resuspension of bottom sediment caused by abiotic factors.

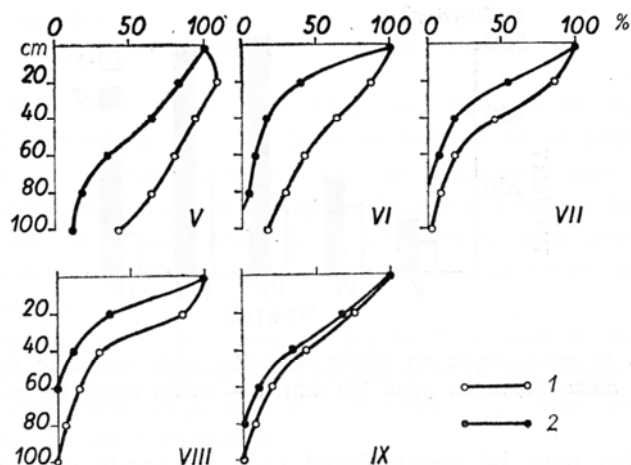


Fig 2 Mean monthly primary production of phytoplankton as a function of fish stock. Production in surface layer = 100-%, 1 – 6000 one year-carp per ha; 2 – 24 000 one year-carp per ha

The highest percentage value of organic carbon contained in the resuspended organic matter was found in June, i.e. when the primary production of phytoplankton was also highest. During the whole period of investigation, in Pond B the content of organic matter produced by the phytoplankton was higher or similar to that in the trapped sedimenting suspension after conversion into the unit of pond area. It may be supposed that in this pond a considerable part of the organic matter which was not consumed by zooplankton or decomposed by bacteria was the main source of organic carbon found in the sedimenting suspension.

Only during the first two months of the investigation in Pond A could the organic carbon contained in the phytoplankton have a decisive effect on the content of organic carbon in the traps for suspension. The differences between the amount of organic carbon in the sedimenting suspension and the magnitude of primary productions were small. After the introduction of the fish, the amount of C determined in the sediments from traps was much higher than that obtained from primary production.

The amount of resuspended sediment as depending on fish biomass may be calculated on the basis of data presented in fig. 1. In this experiment the amount of daily resuspended sediments was 5–6 times greater than the fish biomass, with 40–200 g individual of the carp.

The observations carried out in ponds showed that pond water with mineral suspensions does not accumulate phosphates, which quickly decay after each mineral fertilization. On the other hand, in spite of the absence or small amount of phosphorus dissolved on the water, a strong development of phytoplankton was observed, for which phosphates absorbed by mineral suspension may be a main source of phosphorus.

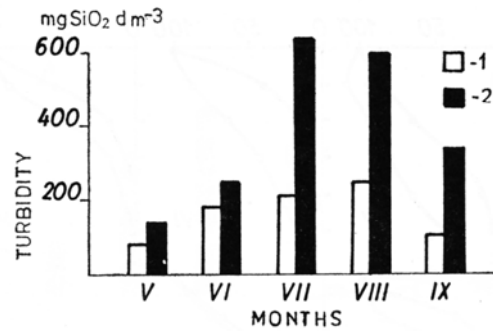


Fig. 3. Effect of pond depth on water turbidity with the same fish stock. 1 — mean depth on pond 160 cm; 2 — mean depth 80 cm

Phosphates may be accumulated only in ponds with a small fish biomass or when the fish stop feeding owing to disease or low temperature, i.e. when the amount of suspensions decreases. The effects of adsorption — desorption were not measured in these ponds. The laboratory experiments showed that the amount of phosphates absorbed by the suspension reached  $0.5 \text{ mg P g}^{-1}$  suspension dry weight.

As the content of resuspended suspension in the pond water increases with the higher density of fish stock, the trophogenic layer of the water becomes thinner. In the experiment carried out in ponds with various stocks of fish a close relation was found between the stock density and the thickness of the trophogenic water layer (fig. 2). In the period from June to August, in ponds with a dense fish stock, the photosynthesis of phytoplankton decreased twofold at a depth of 20 cm in relation to the surface layer.

The effect of fish on the concentration of suspension depends also on the depth of the water body. In the experiment carried out in two ponds 80 and 160 deep with a similar stock of fish, the amount of suspension per volume unit in the shallower pond was much larger than in the deeper one (fig. 3). In the shallower pond it was also observed that the primary production of phytoplankton was lower per unit area, the trophogenic layer was thinner, and the production of fish lower. At the highest concentrations of suspension in this pond, photosynthesis of algae occurred only in the layer down to 40 cm.

The investigations on the relationship between the zooplankton species and the suspension were carried out in Ponds 7, 8, and 9, which had the

following environment parameters:

Temperature (°C)	16.8—23.8
Oxygen (mg dm <sup>-3</sup> )	4.75—13.23
Suspension as ash (mg dm <sup>-3</sup> )	12.70—123.00
Chlorophyll a (µg dm <sup>-3</sup> )	12.0—440.0
Heterotrophic bacteria (cells cm <sup>-3</sup> )	6630—61 000

Assuming that chlorophyll a is 2.5%, and ash 1% of the biomass, the calculated percentage of total mineral suspension of phytoplankton origin is 0.2. If we take into account an additional part of ash of zooplankton origin, the total percentage of biogenic ash may be estimated as about 1% and with somewhat different factors as a few per cent. Therefore, hardly any of the total suspension expressed as ash was of biogenic origin.

For zooplankton animals living in ponds 7, 8, and 9, equations of multiple regressions were calculated. The numbers of the rotifers *Keratella cochlearis* f. *cochlearis* (Y<sub>1</sub>), and *K. quadrata* (Y<sub>2</sub>) may be modelled by the function of some variables:

$$Y_1 = 402.79 - 34.96 X_2 - 198 X_3 + 1.39 X_9 - 32.79 X_{10} \quad P_{X_3} < 0.04$$

$$Y_2 = 26.68 - 1.17 X_2 - 0.17 X_3 + 0.001 X_7 + 1.94 X_{10} \quad P_{X_3} < 0.004$$

where:

X1— temperature (°C)	9 — Bacillariophyceae
X2— oxygen (mg Oz dm <sup>-3</sup> )	X10 —Chrysophyceae
X3 — ash (mg dm <sup>-3</sup> )	X11 —Chlorophyceae
X4 — Chlorophyll a (ug dm <sup>-3</sup> )	X12 — small algae
X7— Cyanophyceae	X13 — medium algae
X8— Cryptophyceae	

The numbers of algae are expressed in thousands of cells dm<sup>-3</sup> (= cells cm<sup>-3</sup>). A negative dependence on suspension was shown by *Trichocerca* sp. (Y3), *Ceriodaphnia pulchella* (Y4), *Diaphanosoma brachyurum* (Y5), *Chaoborus crystallinus* (Y6):

$$Y_3 = -3.1 + 11.03 X_1 + 16.19 X_2 - 1.07 X_3 \quad P_{X_3} < 0.012$$

$$Y_4 = -42.113 + 2.972 X_1 - 0.164 X_3 + 0.001 X_7 + 0.101 X_{13} \quad P_{X_3} < 0.004$$

$$Y_5 = -9.62 + 4.11 X_1 - 4.87 X_2 - 0.4 X_3 - 0.09 X_4 - 0.003 X_7 - 0.07 X_8 + 0.21 X_9 + 0.003 X_{11} \quad P_{X_3} < 0.006$$

$$Y_6 = 15.79 - 0.92 X_2 - 0.05 X_3 - 0.0188 X_4 + 0.27 X_{10} + 0.0006 X_{11} + 0.0005 X_{12} \quad P_{X_3} < 0.10.$$

## 5. Discussion

In considering the presented results, it may be stated that the amount of suspension obtained by resuspension depends not only upon abiotic but also biotic factors. The effect of fish on the amount of resuspension of sediments depends on the mechanical composition of the soil of the pond bottom and on the level of production intensification of the carp, i.e. on the biomass of fish per unit area.

The amount of sediment resuspended by fish was 5—6 times greater than their biomass. It may be supposed that these calculation results may be lower than the reality. The error may be attributed to the fact that traps were placed 15 cm above the bottom, i.e. 15 of the pond depth. Only fine, sedimenting particles could be caught, while the larger ones could not reach the traps. The large amount of resuspended sediment may seriously affect the biological and chemical properties of the pond environment. The greater mineralization of sediments resulting from a more intensive contact with dissolved oxygen would lead one to expect an acceleration in the time of nutrient rotation. Here also the process of sorption and desorption of nutrients occurs (in particular of phosphorus) by the mineral particles of the suspension. Many authors indicate a barely perceptible or harmful mechanism of dependence of mineral suspension on living animals. The results of these dependences have been found in direct observations of animals as well as in regression models. For example, the relationship between zooplankton and turbidity in Goczałkowice Reservoir, in which turbidity ranged from 8 to 119.5 mg SiO<sub>2</sub>, dm<sup>-3</sup>, was significant and negative for cladocerans and positive for rotifers. With a turbidity exceeding 100 mg SiO<sub>2</sub>, no cladocerans were found in the reservoir. In Rożnów Reservoir the multiple regression showed a very significant and negative dependence of rotifers on turbidity. The turbidity here varied from 3 to 898 mg SiO<sub>2</sub>, dm<sup>-3</sup> and when it was above 700 mg SiO<sub>2</sub>, no zooplankton occurred (Żurk 1980). The trophogenic water layer, lowered as an effect of suspension, causes a reduction in photosynthetic intensity and has a negative effect on the oxygen conditions and stratification as well as on the value of primary production. The reduction of primary production in deeper layers was connected with the reduced penetration of solar radiation to the pond with a high stock density (Szumiec 1975 Tilzer et al. 1976).

Except for researches carried out in rivers, ponds, or other water bodies, which showed different kinds of effect of the mineral particles of suspension on living organisms, several mechanisms of their action were investigated, which were confirmed in laboratory experiments. Robinson (1957) showed an favourable effect on survival and reproduction of *Daphnia magna* of low concentrations of kaolinite, montmorillonite, illite, pond sediments, glass, Indian ink and chlorite. In higher concentrations, the effect was harmful or toxic.

The estimation of  $LC_{50}$  value for *Daphnia hyalina* exposed to various kinds of mineral suspension and two concentrations of algae, showed a significant effect of food density on decreasing of harmful effect of the mineral suspension. In the suspension of the bottom sediment and in a low concentration of food  $LC_{50}$  was  $7.8 \text{ mg dm}^{-3}$  while at a twice higher concentration of food it was 94.4. The toxicity of red loam to a smaller degree depended on the food addition —  $LC_{50}$  values were 15.3 and  $25.0 \text{ mg dm}^{-3}$ . Bentonite suspension in a low concentration of food gave the results  $18.5 \text{ mg dm}^{-3}$  (Żurk 1982).

Rylov (1940) suggested that mineral seston may cause an increase in the animal weight and in consequence an increase in energy consumption. Observations of drowning speed showed that *D. hyalina* with its alimentary canal filled with bentonite suspension drowned at a speed expressed in  $\text{mm s}^{-1}$  corresponding with the equation

$v = 1.69 L - 0.099$ , where  $L$  is the length of the *Daphnia* in mm. When the alimentary canal was filled with algae, drowning was slower:  $v = 1.5 L + 0.047$ . The equations differ significantly with  $P < 0.001$ .

The increase in specific gravity results in an oxygen consumption by *D. hyalina* (Żurk 1982). It should be noted that abundant populations of plankton animals may be responsible for accelerated sedimentation of suspended mineral particles. The process of aggregation of fine suspension in faecal pellets was photographically documented by Tóth (1982) and Żurk (1982).

## 6. Polish summary

Wpływ ryb na resuspensji osadów dennych i zależności  
pomiędzy zawiesinami a zooplanktonem

Biomasa i wielkość obsad ryb w stawach miała istotny wpływ na ilość resuspendowanej z osadów zawiesiny. Ilość resuspendowanej zawiesiny przez ryby w ciągu doby przewyższała 5—6 razy biomasę ryb w stawie. Zawartość węgla organicznego w zawieszynie była odwrotnie proporcjonalna do ilości zawiesin w wodzie (ryc. 1).

W stawach z wysoką obsadą ryb, węgiel organiczny w wodzie, w głównej mierze pochodził z resuspendowanych osadów dennych a w stawach z małą biomasą ryb z produkcji pierwotnej fitoplanktonu. Resuspendowane przez ryby zawiesiny powodowały zmniejszenie warstwy trofogenicznej dla fitoplanktonu (ryc. 2) oraz pogorszenie warunków tlenowych. Resuspensja osadów była silniejsza w stawie płytkim (>80 cm) niż w stawie głębokim (>160 cm) (ryc. 3).

Liczebność wrotków *Keratella cochlearis f. cochlearis* (Y1) i *K. quadrata* (Y2), *Trichocerca* sp. (Y3), *Ceriodaphnia pulchella* (Y4), *Diaphanosoma brachyurum* (Y5), *Chaoborus crystallinus* (Y6) może być prognozowana równaniem regresji wielo-krotnej. Dla wspomnianych wyżej gatunków

równania takie z koncentracji popiołów jako jedna ze zmiennych, wykazują wysoce istotną (niekiedy z  $P < 0,004$ ) i ujemną zależność od tego czynnika.

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