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Polskie Archiwum Hydrobiologii existing as such since 1953, is a continuation of *Archiwum Hydrobiologii i Rybactwa* founded in 1926 under the editorship of A. Lityński; during the period 1926 to 1939 and in 1947, thirteen volumes of *Archiwum Hydrobiologii i Rybactwa* have appeared, volume XII, 3, 4, published in September 1939, being almost entirely destroyed due to war action.

The journal publishes original works reporting experimental results, descriptive works and theoretical investigations in every sphere of hydrobiology. The article must contain original research not already published and which is not being considered for publications elsewhere. Papers will be published in the official Congress languages of Societas Internationalis Limnologiae (at present: English, French, Italian and German).

The Editorial Board request the manuscripts conform to the requirements set out in No. 1 of vol. XVIII; those manuscripts not conforming to these be returned to the author for alteration.

The present issue of the *Polish Archives of Hydrobiology* is wholly devoted to the problems of biological production in carp ponds ecosystems. The papers here published were presented to the symposium held on February 20 and 21, 1969 in the Fish Culture Research Station of Institute of Inland Fisheries in Żabieniec near Warsaw. The symposium was a part of the Polish contribution to the PF section of the International Biological Programme. 70 research workers from various Polish centers took part in it. The team of the Fish Culture Research Station of Institute of Inland Fisheries in Żabieniec near Warsaw presented their investigations on fry ponds (nursery ponds); the team of the Laboratory of Water Biology of the Polish Academy of Sciences, Cracow, submitted reports on fingerling ponds (second transfer ponds). The main topic discussed was the influence of various types of fertilization on production processes at various trophic levels; besides, results of investigations on other methods of intensification of fish production (stock density, moulty species stock) and on abiotic conditions in ponds were presented.

Editors

POLSKIE ARCHIWUM HYDROBIOLOGII (Pol. Arch. Hydrobiol.)	18	2	119–128	1971

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THE INFLUENCE OF FERTILIZATION UPON THE QUANTITATIVE OCCURRENCE OF HETEROTROPHIC BACTERIA IN FRY PONDS

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ABSTRACT

The changes of the number of heterotrophic bacteria in experimental fry ponds fed with various mineral and organic manures, and with varying numbers per ha of *Cyprinus carpio* L. and of phytophagous fish *Ctenopharyngodon idella* Val. and *Hypophthalmichthys molitrix* Val. have been investigated.

CONTENTS

1. INTRODUCTION

Only a small part of the numerous papers on water microbiology concerns the ponds. Quantitative and qualitative changes in bacteria in fertilized ponds were studied by Beliazkaya (1958b), Gulaja (1956), Matusiak (1954), Ristich (1965), Rodina (1952, 1958, 1959), and Żołnierkiewicz-Łysakowska (1965). They all found a stimulating influence of mineral and organic fertilization upon the development of bacteria. They proved, too, that the growth of microorganisms depended also on the density of a population and on the species distribution of phytoplankton and zooplankton. The problem of influence of phytoplankton on bacteria was discussed by many authors, who explained it by such factors as bacteriostatic effect of phytoplankton (Drabkova 1965, Novożilova 1955), by secretion of substances toxical for bacteria (Braginskij 1955, Krzywicka 1966, Matusiak et al. 1965, Razumov 1948), or by competition for food between the two groups of organisms (Guseva 1951, Rigler 1956).

The aim of the present paper is to define the influence of mineral and organic fertilizing of fry ponds on the changes of the amount of heterotrophic bacteria, defined by the method of inoculations.

2. METHODS

The materials were collected during 1966, 1967 and 1968 from the experimental fry ponds of the Institute of Inland Fisheries, Fish Culture Research Station at Żabieniec near Warsaw. The ponds are rectangles 40×50 m, 0.2 ha of surface, 0.8 m of depth; each of them is individually supplied with water from the River Jeziorka. All the ponds can be drained off; their bases are mineral.

In the Table I the types of fertilizers and of fish stock are shown. One week old fry was put into the ponds and reared for 40 days. During this time, from the end of May to the half of July, microbiological investigations of water of these ponds were carried out. A detailed description of the fertilizing experiments is reported in Wolny (1970).

Samples of water for microbiological analysis were drawn at one week intervals during 1966 and 1968. In 1967 the sampling was more frequent, water was drawn for analysis 3 hr before and 24 hr after supplying each dose of a fertilizer. The aim was to learn whether a single dose of a fertilizer can be directly reflected by

Table I. Research scheme of fry ponds in 1966–1968

Year	Pond No.	Fertilizer (kg/ha)	Stocking (ind./ha)	Average No. of bacteria (ind./ml of water)
1966	4 12	—	125,000 (common carp)	9330 10,230
	5 13	acid ammonium carbonate (N — 210) + superphosphate (P_2O_5 — 50)		11,830 8510
	6 14	ammonium sulphate (N — 210) + superphosphate (P_2O_5 — 50)		10,130 9700
1967	4 12	—	125,000 (common carp)	7860 6900
	5 13	ammonium saltpetre (N — 210) + superphosphate (P_2O_5 — 50)		39,820 10,720
	3 10	ammonium saltpetre (N — 105) + superphosphate (P_2O_5 — 25) + cow dung (N — 105)		5980 9690
	2 11	cow dung (N — 210)		6010 6190
1968	4 12	—	125,000 (common carp)	1670 2790
	5 13	urea (N — 210) + superphosphate (P_2O_5 — 50)	250,000 (common carp)	2390 2750
	6 14		125,000 (common carp)	3000 3370
	10		125,000 (common carp) 125,000 (silver carp)	3610
	11		125,000 (common carp) 125,000 (grass carp)	4310

the number of bacteria. The sampling in 1967 and 1968 had started before the first dose of manure was applied, and before the fry was let in; in 1966 investigations started after an introductory double dose of fertilizer had been applied. In total, there were 7 series of tests made in 1966, 12 series in 1967, and 8 series in 1968.

Samples were taken in 5 sites: in the centre and in 4 corners, about 2 meters from a bank. At each site a sample was drawn at 25 cm from the surface of water and at 10 cm from the bottom. Water was drawn to 200 ml bottles by means of a sampler designed after Isačenko's (1951) apparatus. It enabled sampling from a definite depth, without mixing the material with water from other layers.

The samples of water were shattered mechanically for 15 min to disrupt clusters of microorganisms. Then samples from one layer of the same pond were poured into a single flask, to serve for further tests. 1 ml of such an initial sample was dissolved in 9 ml of 0.85% solution of NaCl. A number of dissolutions was made subsequently, of which the 1 : 100 up to 1 : 10,000 solutions were inoculated most frequently. The inoculations were made in three parallel repetitions on agar nutrient medium, by a method of deep-seated inoculations on Petri dishes. Here are the ingredients of the agar medium with pH 7.2: agar-agar 20 g, glucose anhydrate 5 g, pancreatic digest of casein "Difco" 2 g, bacto-yeast extract "Difco" 0.5 g, water from the examined reservoir 1000 ml.

The inoculations have been incubated at 25°C for 7 days. From the moment of sampling to the beginning of incubation 4 hr passed. Only these dissolutions were considered in which from 30 to 300 colonies developed on the dishes (Matuszewski 1947). Results were related to 1 ml of water.

Data about temperature, O_2 content and pH were taken from regular routine measurements carried out by Chemical Section of Institute of Inland Fisheries at Żabieniec.

3. RESULTS

VERTICAL DISTRIBUTION OF BACTERIA IN THE WATER

During the whole vegetation season the amount of heterotrophic bacteria in the next-to-bottom water layer was in average 1.3 to 3.8 times greater than in surface layer. During the periods when maximal amounts of the heterotrophs were found in the whole column of water, the difference was made larger because of a more intensive growth of bacteria near the bottom. This phenomenon was observed in most ponds, irrespective of the type of fertilization (Fig. 2 and 3).

THE INFLUENCE OF VARIOUS KINDS OF FERTILIZATION UPON THE DYNAMICS OF THE AMOUNT OF BACTERIA

Mean amounts of the heterotrophs for the whole vegetation period of 1966 (Fig. 1) did not reveal significant differences between the several kinds of fertilizers. In 1967, however, in the ponds fed with mineral fertilizers only, the number of bacteria was three times greater than in the control ponds, while in those fertilized with cow dung their number was by 18% smaller than in the controls (Table I). The experiment made in that year (cf. Methods, above) did not reveal significant immediate changes in the amount of the heterotrophs after introduction of single doses of fertilizers into the ponds.

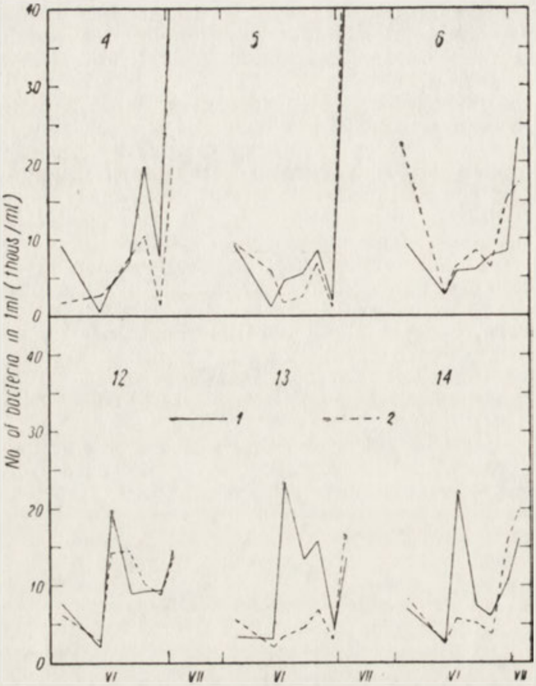

Fig. 1. Dynamics of the amount of bacteria in fry ponds in 1966. 1 — No. of bacteria in surface layer; 2 — No. of bacteria in the next-to-bottom layer

THE INFLUENCE OF MINERAL FERTILIZATION AND OF VARIOUS FISH STOCK UPON THE AMOUNT OF BACTERIA

In 1968, with the ponds stocked with carp and phytophagous fish fry, the highest amounts of bacteria were found in the fertilized ponds with mixed stock of carp and of *Ctenopharyngodon idella,* and next in those with mixed carp and *Hypophthalmichthys molitrix* fry. In average, during the whole vegetation season there were about twice as many bacteria in these ponds than in the controls. Ponds stocked with 125,000 and 250,000 of fry per ha yielded similar amounts of bacteria. The smallest amount of heterotrophs was found in the control ponds (Table I).

Two remarkable moments could be observed in the seasonal dynamics of the heterotrophic bacteria growth in the investigated ponds (Fig. 2 and 3). The first occurred during the initial 10 to 14 days, or sometimes even 3 to 5 days, when the amount of bacteria reached its peak immediately, both near the surface and near the bottom of a pond. At temperatures of 14.5 to 21°C, the number of bacteria increased fourfold or even tenfold, as e.g. in ponds No. 5 and 13 (Fig. 2). Another peculiar moment was marked by a decrease and, in its final phase, by a fresh growth of the amount of bacteria. In many cases this growth reached more than a half of the initial maximum. Another finding of

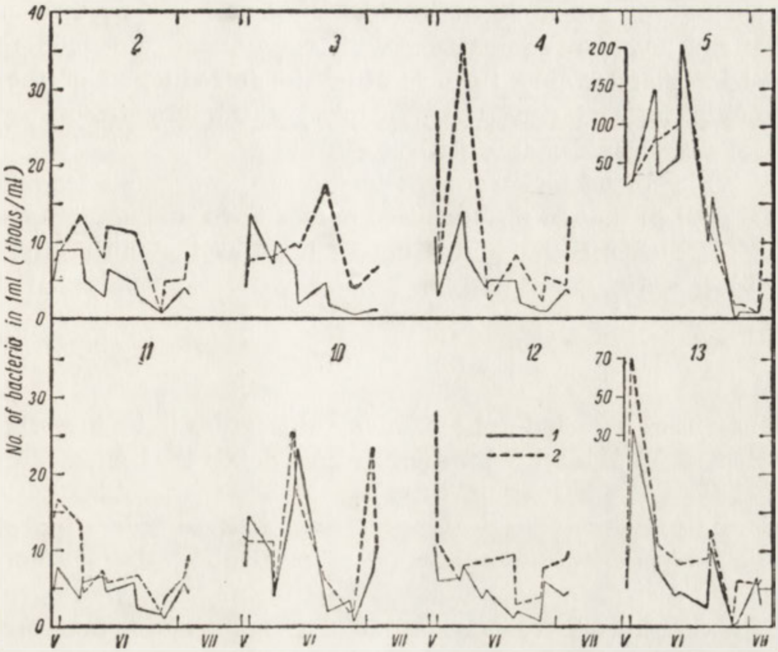

Fig. 2. Dynamics of the amount of bacteria in fry ponds in 1966. 1 — No. of bacteria in surface layer; 2 — No. of bacteria in the next-to-bottom layer

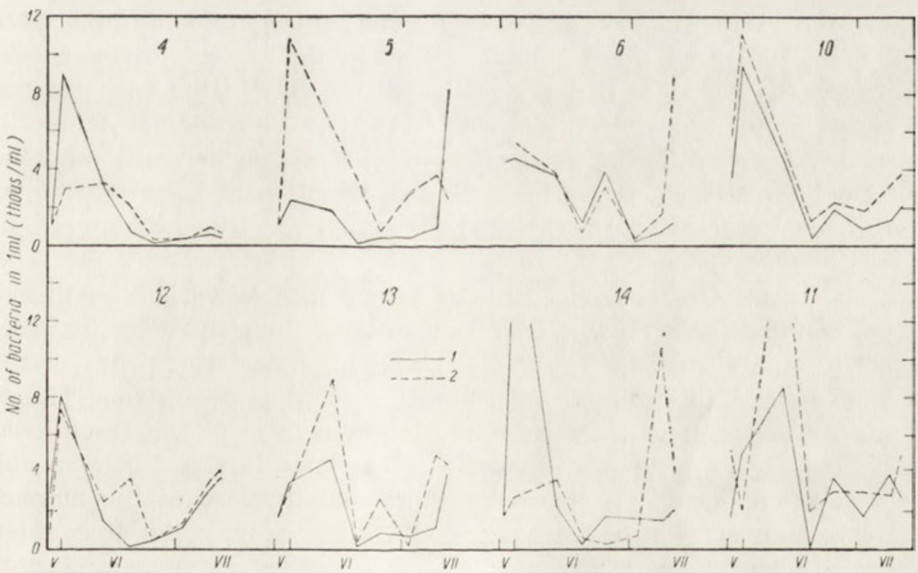

Fig. 3. Dynamics of the amount of bacteria in fry ponds in 1968. 1 — No. of bacteria in surface layer; 2 — No. of bacteria in the next-to-bottom layer

the final period was a twofold increase of the number of bacteria in the next-to-bottom layer in comparison with the surface. In 1966 microbiological tests started only 10 days after the introduction of the first dose of fertilizers, and thus the dynamics of the growth of bacteria during that season could not be analysed in full.

The dynamics of bacterial growth in the fertilized ponds and in the controls differed in that in the fertilized ones a third maximum appeared in the half of each season, though not as huge as the initial and final peaks.

4. DISCUSSION

Environment of fry pond presents many difficulties in its investigation, as the period of filling and vegetation in such ponds is short, while physical and chemical conditions in them are highly changeable. As literature concerning fry ponds is in general lacking, a consideration of our results in a context of quantitative data found by other authors for commercial or rearing ponds would be difficult and not always proper.

A small vertical differentiation of the number of heterotrophic bacteria in the water column of the ponds can be accounted for morphometrical conditions predominating in those reservoirs: small depth (average 1 m), full circulation of water, transparency, and small temperature differences between surface and bottom. Data in literature are ambiguous. Rodina (1958) found that in ponds the bottom bacterial flora was 10 to 100 times more abundant than in the water column above; however, it is not clear if she investigated bacteria in the bottom layer of water, or in the bottom sediments. Beliazkaya (1958a) investigated three lakes differing by degree of trophism and by depth, and she found only small differences in vertical distribution of bacteria. Similar results were obtained by Niewolak (1966) for lakes, and by Gulaja (1956) for ponds.

The dynamics of bacterial growth in presence of various fertilizers partly confirms the results of other authors. Investigations by Beliazkaya (1958b) and Rodina (1959) in commercial ponds of the Latvian and Tadjik SSR during summer seasons proved strong effects of mineral and organic manures — the latter in form of the green mass of harvested grass — upon the number of bacteria in water column and at the bottom. Rodina observed a threefold increase of the number of bacteria after fertilization, but she made a reservation that these phenomena had been rather unstable and depended upon many factors such as the kind of a fertilizer, its amount and accessibility, water temperature, and the character of a pond. Numbers of microorganisms reported by the two authors reach hundreds of thousands or even millions of bacterial cells in 1 ml of water. A comparison with our results (only tens of thousands of bacteria in 1 ml of water) seems to point to an important role played by the factors mentioned by Rodina, in particular of water temperature and the general character of a reservoir. This is also witnessed by a study of fingerling ponds at Żabieniec carried out by Żołnierkiewicz-Łysakowska (1965) who appreciated the amount of heterotrophic bacteria in fertilized ponds as about 12,000 cells in 1 ml of water.

Cow dung applied in 1967 resulted in smaller amounts of bacteria than in the control, and in low fishering efficiency. The increase of individual weight of carp fry in these ponds was 1.1 g, while it was 1.3 g in the unfertilized ponds (Wolny 1968). Januszko (1970a) who studied the phytoplankton of these ponds, found the smallest amount and biomass of algae in the ponds fed with cow dung. Perhaps the way of introducing of manure to the ponds was not proper; it was put there before the filling and ploughed-in. Another factor inhibiting the growth of bacteria, important with this type of fertilizing, was water temperature, lower in 1967 than in the other two research seasons.

In 1968 the highest amount of heterotrophic bacteria, as well as the best effects of fish production, were obtained in ponds with mixed stock of carp and phytophagous fish (Wolny 1968, 1970). It may be added that water in these ponds was the least transparent, and the best oxygen conditions prevailed during the whole period of the ponds exploitation. An extra stock of phytophagous fish causes an acceleration of the circulation of organic substances. An investigation by Opuszyński (1965) of phytophagous fish revealed that *Ctenopharyngodon idella* fertilizes the ponds by excreting partly digested mass of plants, which decays readily and thereby increases the amount of mineral substances. On this basis phytoplankton develops, which is main food of *Hypophthalmichthys molitrix*. Carps explore the bottom seeking for food and accelerated the decay of dead organic substances.

The observed maximal amount of heterotrophs during the first two days after the filling of the ponds can be accounted for by allochtonic origin of the bulk of bacteria inhabiting the ponds. This is confirmed by the presence of only 5% of sporing forms.

The decrease of the amount of bacteria after 10 days, and its subsequent increase, are effects of changes occurring in the whole environment. During this period other groups of water organisms begin to develop, i.e. phyto- and zooplankton. Thus the factor inhibiting the growth of bacteria during that time might be the bacteriostatic action of phytoplankton secretions (Krzywicka 1966, Matusiak et al. 1965, Razumov

1948). Competition for food between bacteria and phytoplankton (Guseva 1951, Rigler 1956) is little probable, as the amount of heterotrophs is in general small, and fertilizing restores the supply of nutritious substances. In 1966 greater amounts of bacteria were observed than 1967 and 1968, while little phytoplankton was found in that year (Januszko 1970 b). Zooplankton, which eats up bacteria, as well as phytoplankton, play important roles in the whole of pond biocenosis.

The final increase of the amount of bacteria is connected with necrosis of water organisms, increase of the layer of mud and of water temperature, and a shift of the food of zooplankton.

Amounts of bacteria appearing in experimental ponds certainly depend on physical and chemical factors, too. Indeed, a comparison of mean water temperatures in individual ponds with the respective amount of bacteria, did not reveal any clear influence of this factor, but still, it was in 1966, when the number of days with temperatures above 20°C was highest within a few years, that the amounts of bacteria were the greatest.

Water pH maintained at the level of 7.0 and more, positively influenced the general development of microflora, as a supplementary research proved that 92% of pond microorganisms could develop at pH>6. Another favourable factor was oxygen saturation of water exceeding 100%.

5. CONCLUSIONS

1. Mineral fertilizing stimulates the amount of heterotrophic bacteria in fry ponds.
2. Types of applied fertilizers do not bring about essential differences in the amounts of bacteria.
3. An introduction of mixed stock of carp and of phytophagous fish in fertilized ponds brings about a stronger increase of the amount of heterotrophic bacteria than fertilizing alone.
4. Differences in vertical distribution of bacteria between surface and next-to-bottom layer are not great.

6. SUMMARY

During 1966 to 1968 seasonal dynamics of the amount of heterotrophic bacteria in waters of fry ponds fertilized with mineral substances (acid ammonium carbonate, ammonium sulphate, ammonium saltpetre, urea, superphosphate), and with organic ones (cow dung) was studied. Bacteria were cultivated on Petri dishes with a nutrient agar. Dishes were incubated at 25°C during 7 days.

A positive influence of mineral fertilizers on the amount of heterotrophic microorganisms was found. An introduction of mixed stock to the ponds, composed of carp fry (*Cyprinus carpio* L.) and of phytophagous fish (*Ctenopharyngodon idella* Val. and *Hypophthalmichthys molitrix* Val.) caused a double increase of the amount of bacteria in comparison with ponds stocked with carp fry only.

The relation of the amounts of bacteria near the bottom and near the surface fluctuated from 1.3 to 3.8.

7. STRESZCZENIE

W latach 1966–1968 badano dynamikę sezonową liczebności bakterii heterotroficznych w toni wodnej stawów typu przesadki I, nawożonych mineralnie (kwaśny węglan amonu, siarczan amonu, saletra amonowa, mocznik, superfosfat) i organicznie (obornik). Hodowlę bakterii prowadzono na płytkach Petriego z agarem odżywczym. Płytki inkubowano w temp. 25°C przez 7 dni.

Badania wykazały dodatni wpływ nawozów mineralnych na liczebność mikroorganizmów heterotroficznych. Wprowadzenie do stawów obsad mieszanych, złożonych z wylęgu karpia (*Cyprinus carpio* L.) i ryb roślinożernych (*Ctenopharyngodon idella* Val. i *Hypophthalmichthys molitrix* Val.) spowodowało dwukrotny wzrost ilości bakterii, w porównaniu ze stawami obsadzonymi tylko wylęgiem karpia.

Stosunek ilości bakterii w warstwie przydennej do ilości stwierdzonej w warstwie powierzchniowej wahał się od 1,3 do 3,8.

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M. JANUSZKO

THE EFFECT OF FERTILIZERS ON PHYTOPLANKTON DEVELOPMENT IN FRY PONDS

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ABSTRACT

The effects of mineral and organic fertilizers on the biomass, amount and species composition of algae was studied during June and July of 1966 and 1967 in fry ponds of Institute of Inland Fisheries at Żabieniec. Algae development in the ponds and in the inlet was compared. The following rank order of effectiveness of fertilizers was obtained, measured by the index of increase of the biomass and of the amount of algae: 1. Norway saltpetre + superphosphate, 2. Norway saltpetre + superphosphate + cow dung (the amount of mineral fertilizers being half smaller than above), 3. ammonium carbonate + superphosphate, 4. ammonium sulphate + superphosphate. The use of cow dung brought no effect. Mineral fertilizing caused a significant increase of the amount of Chlorophyta. The general growth dynamics was strongly influenced by zooplankton and water temperature. The algae developed several times more amply in the non-fertilized ponds than in the inlet.

CONTENTS

1. INTRODUCTION

Ponds are fertilized in order to increase the amount of bacteria and algae, which supply food for the fish, usually through the intermediate trophic level, i.e., the invertebrate fauna.

The problem has been tackled repeatedly, and there are some interesting findings, but it is still far from being solved (Wróbel 1964, Winberg and Ljahnovič 1965, Wolny (1967). In particular, it has not been established, what kinds of mineral and organic manures are most effective in stimulating the growth of the desired algae species, or what are the optimum doses and frequencies of their application.

In this paper researches in fry ponds are reported. The aim was to establish the influence of fertilizers on species composition, amount and biomass of algae, and to assess the dynamics of algae development in the ponds and in the inlet.

2. METHODS AND MATERIALS

Experiments were made in 14 fry ponds during the same periods of the years 1966 and 1967. The surface of each pond is 0.2 ha, and the depth is about 1 m. The ponds are fed with water from the River Jeziorka. The ponds were manured with organic and mineral fertilizers, and they were stocked with equal amounts of carp fry. An exact description of fishing experiments and of the fertilizing schedules is given in Wolny (1970).

Table I presents a simplified pattern of fertilizing of the investigated ponds.

Table I. The scheme of fertilizing (acc. to Wolny 1970)

Year	Pond No.	Fertilizers	kg/ha
1966	4, 12	— (control)	—
	5, 13	acid ammonium carbonate (N) superphosphate (P_2O_5)	210 50
	6, 14	ammonium sulphate (N) superphosphate (P_2O_5)	210 50
1967	4, 12	— (control)	—
	5, 13	Norway saltpetre (N) superphosphate (P_2O_5)	210 25
	3, 10	Norway saltpetre (N) superphosphate (P_2O_5) cow dung	105 25 20,000
	2, 11	cow dung	40,000

Samples were drawn along each pond's diagonal with a 1 l Patalas apparatus (Patalas 1954). 10 l of water was drawn into a bucket, 5 l thereof from the surface, and another 5 from near the bottom. After mixing, 100 ml of water was separated for a scrutiny by the drop method. Water was not filtered through a plankton net. Phytoplankton was counted when alive, and for exact qualitative determinations, it was fixed with Lugol's lotion. Single algae cells, living individually or in colonies, and cenobia were regarded as individuals. The amount of algae has been expressed by number of individuals per cm^3. The biomass was computed from the cells' volume, and the results reported in g/m^3, assuming their specific weight to be equal to one.

3. RESULTS

Mean amount of phytoplankton

It was found that the mean amount of algae increased significantly under the influence of mineral fertilizers (Table II). In 1966, the amount in comparison with the control ponds, was four times greater in the ponds fertilized with ammonium carbonate and superphosphate, and 1.5 times greater in the ponds fertilized with ammonium sulphate and superphosphate. In 1967 both mineral and organic manures were applied. The

Table II. Mean amounts and biomass of phytoplankton

Year	Pond No.	Fertilizers	No. of ind. x 1000/cm²	Average No. of ind. x 1000/cm²	Increase indicator	Biomass (g/cm²)	Average biomass (g/cm²)	Increase indicator
1966	4 12	— (control)	45 34	39	1	16.2 27.0	21.6	1
	5 13	carbonate + superphosphate	263 52	158	4.0	34.8 38.4	36.6	1.7
	6 14	sulphate + superphosphate	65.5 56	61	1.5	35.5 22.3	28.9	1.3
1967	4 12	— (control)	24 25.5	24.7	1	39.2 32.9	36.0	1
	5 13	Norway saltpetre + superphosphate (full dose)	193.5 195.5	194.5	7.9	67.3 316.0	191.6	5.3
	3 10	Norway saltpetre + superphosphate (half dose) + cow dung	133.5 69.5	101.5	4.1	93.2 186.3	139.6	3.8
	2 11	cow dung	20 33	26.5	1	28.6 18.9	23.7	0.6
	inlet	—	3	3	0.1	0.7	0.7	0.02

results were different for each kind of manure. The increase of algae amount in comparison with the control ponds was greater in the ponds more amply fertilized with saltpetre and superphosphate (No. 5 and 13) than in those where the dose was twice smaller (No. 3 and 10). Cow dung (No. 2 and 11) caused no significant increase in the amount of algae as compared with the controls. The algae amount in the inlet was 10 times smaller than in the control ponds.

Predominating types of algae

The phytoplankton of the studied ponds was similar during the two years. The algae belonged to five types: Chlorophyta, Chrysophyta, Euglenophyta, Pyrrophyta and Cyanophyta. The two types mentioned first were the most numerous, and made up 97.5 up to 99.5% of the total amount (Table III).

Mineral fertilizing caused mainly an increase of the amount of Chlorophyta. Thus in 1966 their amount increased 6.5 times in carbonate manured ponds, and 1.5 times in sulphate manured ones. In that year, an influence of mineral fertilizing upon the amount of Chrysophyta was also observed. In comparison with the control ponds, its amount increased 1.3 times in ponds with carbonate, and 1.5 times in those with sulphate. However, in 1967 the amount of Chrysophyta either decreased a little (ponds No. 5 and 13) or it increased insignificantly after fertilizing (all the other ponds). The amount of Chlorophyta in 1967 increased in proportion to the applied dose of saltpetre. Its amount was ten times greater in ponds No. 5 and 13, and five times greater in No. 3 and 10 in comparison with the controls.

Cow dung did not influence the amount of Chlorophyta and Chrysophyta, but it caused a decrease of their biomass.

Dynamics of amount changes of Chlorophyta and Chrysophyta

Results of observations of the dynamics of amount changes are presented in Fig. 1. In 1966, at the beginning of the research period, Chrysophyta predominated in all the ponds, and then their amount has been steadily decreasing. The amount of Chlorophyta has been gradually increasing, and by the end of June it was this type that was by far predominating. In both curves two maxima can be seen, occurring at the same moments for all the ponds. In 1967 there was only one maximum in both curves. Besides, at the first days of investigation, Chrysophyta predominated only in three ponds, while in all the others Chlorophyta were most numerous from the outset. In June and at the beginning of July, Chlorophyta dominated in most ponds, and only exceptionally

Table III. Predominating types of algae, average amounts of organisms × 1000/cm³ (1), percentage of the total amount (2) and indicator of the increase of amount in comparison with the control ponds (3)

Year	Pond No.	Fertilizers	Chlorophyta			Chrysophyta			Total (%)
			1	2	3	1	2	3	
1966	4 12	— (control)	20	49.7	1	19	49.7	1	99.4
	5 13	carbonate + superphosphate	131	77.5	6.5	25	21.5	1.3	99.0
	6 14	sulphate + superphosphate	31	50.0	1.5	29	47.5	1.5	97.5
1967	4 12	— (control)	17	69.0	1.0	7	30.3	1.0	99.3
	5 13	Norway saltpetre + superphosphate (full dose)	186	95.8	10.9	5	2.9	0.7	98.7
	3 10	Norway saltpetre + superphosphate (half dose) + cow dung	89	88.2	5.2	11	10.7	1.4	98.9
	2 11	cow dung	18	67.6	1.0	8	31.9	1.1	99.5
	inlet	—	1	79.8	—	0.27	18.6	—	98.4

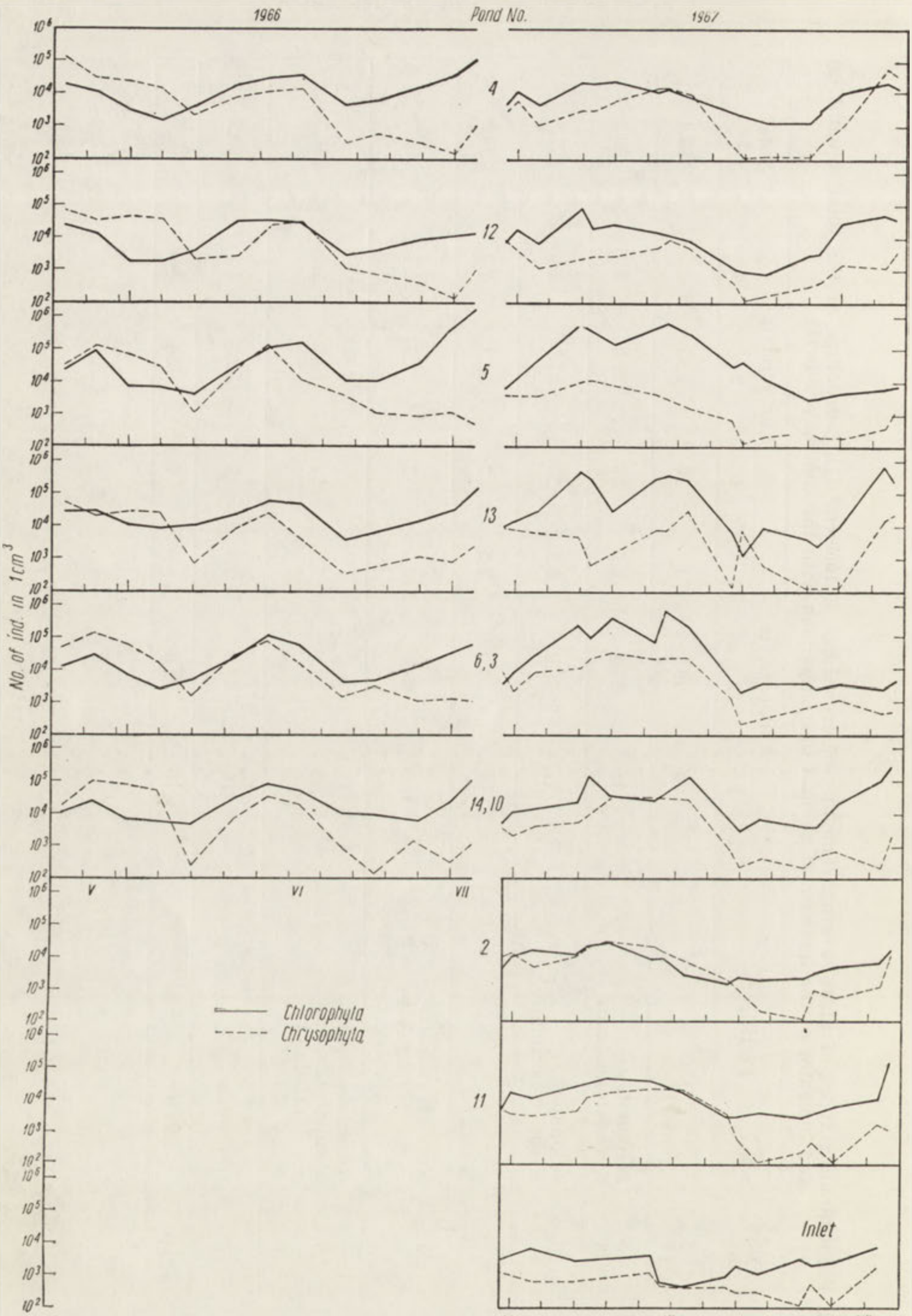

Fig. 1. Dynamics of total amount of Chlorophyta and Chrysophyta in 1966–1967

Chrysophyta were in majority. Their predominance was usually small and short-timed, and thus a comparison of seasonal means showed a predominance of Chlorophyta in all the ponds.

Species composition

In 1966, 45 algae species were found, from 26 to 31 species in a single pond. The respective numbers for 1967 are 58 species, 36 to 46 in a single pond. A detailed list of the species and their percentages have been reported in earlier works (J a n u s z k o 1970 a, b).

In 1966 the predominating species were *Chlorella minutissima* Fott, *Stephanodiscus Hantzschii* Grun. and Chlamydomonadoceae (Table IV).

It can be seen from the data that fertilizing influenced an increase of the amount of Chlorophyta more than of Chrysophyta. However, the biomass of Chrysophyta was greater because of the size of the Stephanodiscus. As the Chlorella and Chlamydomonadoceae species are smaller, the Chlorophyta biomass was lesser. A similar pattern had been observed earlier in the control ponds.

The majority of the Chlorophyta biomass was constituted by large forms, *Eudorina elegans* Ehrbg. and *Pandorina morum* Bory, even though their amounts and percentages in the total amount was negligible. However, the biomass of the numerous small algae was small; these were: *Coelastrum microsporum* Naeg., *Pediastrum duplex* Meyen., *Oocystis elliptica* W. West, *Staurastrum sp.* (Chlorophyta), and *Trachelomonas sp.*, *Cryptomonas reflexa* (Marsson) Skuja, *Phacus sp.*, (Euglenophyta), *Cymbella lanceolata* (Ehrbg.) Heurek, *Synedra ulna* (Nitzsch) Ehrbg., *Melosira varians* Ag. (Bacillariophyta).

In 1967 similar species predominated as in 1966, but *Ankistrodesmus angustus* Bern (Korsch) was added to the small predominating algae, and *Volvox aureus* Ehrbg. to the largest ones (Table V). The increase of the amount of Chlorella and Ankistrodesmus was large in ponds with saltpetre and superphosphate. The increase of Chlamydomonadoceae was small, and it occurred only in ponds with full doses of saltpetre without cow dung. The amount of Stephanodiscus under the influence of fertilizers was negligible, and in ponds No. 5 and 13 even some decrease was observed. Despite, the share of Stephanodiscus in the total biomass was rather significant, and greater than that of the small though numerous Chlorophyta. However, the Chlorophyta biomass was in the end greater because of the development of large forms, such as Eudorina and Pandorina. Small algae species, numerous but contributing little to the biomass, were similar as in 1966.

In the ponds fertilized with cow dung, the amount of the predominating algae was maintained at a level similar to that in the controls,

Table IV. Algae predominating in amount or biomass in 1966

Algae	Indicators: % of the total algae No. of ind./cm³ biomass (g/m³)	Ponds No. 4,12 (control)	Ponds No. 5, 13 (ammonium carbonate + superphosphate)	Ponds No. 6, 14 (ammonium sulphate + superphosphate)
Chlorella	%	19.5	57.5	27.5
	number	8300	113,800	16,800
	biomass	0.12	1.60	0.24
Stephanodiscus	%	46	19	45
	number	18,000	21,800	27,600
	biomass	12.76	15.45	19.59
Chlamydomonadaceae	%	26	15.0	18.5
	number	10,100	13,300	11,100
	biomass	0.34	0.44	0.37
Eudorina	%		0.01	
	number	—	6	—
	biomass		10.59	
Pandorina	%	0.02		0.01
	number	6	—	6
	biomass	3.14		3.14
Biomass of predominating algae		16.4	28.0	23.3
Biomass of total algae		21.6	36.6	28.9

Table V. Algae predominating in amount or biomass in 1967

Algae	Indicators: % of the total algae No. of ind./cm^3 biomass (g/m^3)	Ponds No. 4, 12 (control)	Ponds No. 5, 13 (Norway saltpetre + superphosphate full dose+cow dung)	Ponds No. 3, 10 (Norway saltpetre + superphosphate (half dose)	Ponds No. 2, 11 (cow dung)
Chlorella	%	38	83	50	35
	number	9400	156,700	46,800	9700
	biomass	0.50	2.21	0.66	0.14
Ankistrodesmus	%	5.5	9	30	15
	number	1400	17,800	36,100	4400
	biomass	0.03	0.39	0.79	0.10
Stephanodiscus	%	27	2	10.5	32
	number	6500	3800	9250	7550
	biomass	4.62	2.70	6.60	2.10
Chlamydomonadaceae	%	15	3,5	4	11
	number	3700	6850	3700	2700
	biomass	0.12	0.23	0.12	0.09
Eudorina	%	0,01	0.01	0.06	
	number	3.5	28	46	—
	biomass	6.18	49.42	81.19	
Pandorina	%	0.1	0.1	0.07	0.1
	number	38	211	77	28
	biomass	20.13	110.61	40.53	14.64
Volvox	%		0.001		
	number	—	3.5	0.5	0.5
	biomass		6.18	0.88	0.88
Biomass of predominating algae		31.6	171.7	130.8	17.9
Biomass of total algae		36.0	191.6	139.6	23.7

except for Ankistrodesmus, which grew significantly. However, the total algae biomass in these ponds was smaller in comparison with the controls, both for the predominating species and for the total algae contents.

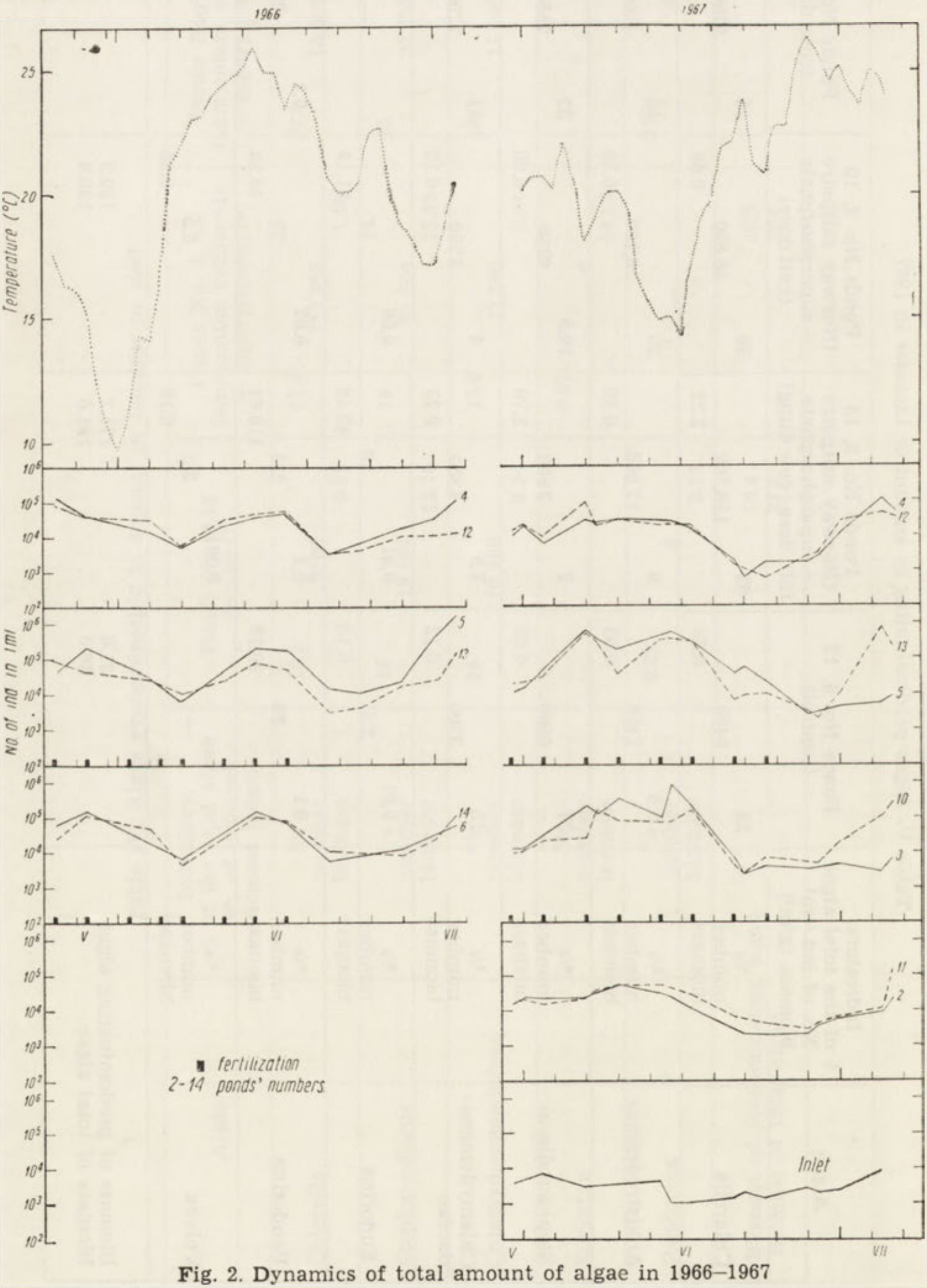

Fig. 2. Dynamics of total amount of algae in 1966–1967

It can be seen from Tables III, IV and V that nitrogen fertilizing stimulated the development of algae in both years, in particular of Chlorophyta. In 1966 a favourable influence of nitrogen fertilizers on the growth of Stephanodiscus was also observed. However, in 1967 fertilizing had but a small and ambiguous influence on Stephanodiscus development.

Stephanodiscus had a decisive share in the total biomass in 1966, while in 1967 the biomass of Chlorophyta developed more strongly because of a more intensive growth of larger forms.

Dynamics of the total amount of phytoplankton

In all the ponds, significant and similarly timed changes of the amount of algae were observed (Fig. 2). Analysing the factors which might influence this phenomenon, the possibility of phytoplankton and zooplankton interaction, water temperature, and the timing of fertilizing were considered. The changes of the dynamics of algae amounts were compared with the amounts of zooplankton, based on unpublished (1967) materials by G r y g i e r e k. It was observed (cf. Fig. 3) that after

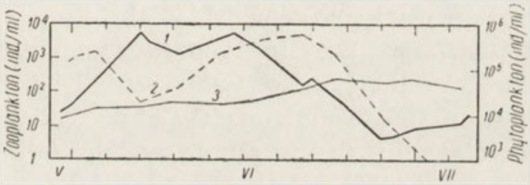

Fig. 3. Dynamics of total amount of individuals in pond No. 5. 1 — algae, 2 — Rotatoria, 3 — Crustacea

a gradual increase of the amount of Crustacea and Rotatoria, a remarkable decrease of phytoplankton amount followed, beginning from the half of June. After a few days the amount of Rotatoria dropped, too, apparently as a result of an exhaustion of algae by zooplankton. As soon as the number of Rotatoria was small enough, a growth of the amount of phytoplankton recommenced. These data allow to assess the influence of zooplankton upon the amount of algae. A more detailed discussion of this subject, with quantitative data from all the studied ponds, can be found in J a n u s z k o (1970 b).

It seems that water temperature has been another factor influencing the amount of algae (Fig. 2). During both research years, high water temperatures favored the development of algae, while decreases of temperature were followed by a drop of their number within a few days.

No direct influence of single doses of mineral fertilizers upon the amount of algae was observed.

4. DISCUSSION

Effective influence of various mineral fertilizers upon the development of algae was found by many authors: Wunder et al. (1935), Utermöhl (1936), Musatova and Kuznecov (1951), Fott (1952), Weimann (1944), Fesenko and Posumjanskaja (1965), Francuzova (1967), and others. In Kanoda (1961) and Bahtina (1967) the influence of the saltpetre is discussed. Studies on cow dung efficiency are less numerous (Bombówna et al. 1962, Havlena 1956), but nonetheless a positive effect of manure was described. Thus it is difficult to interpret the fact that in the present paper no positive effect of cow dung on algae development has been found. Possibly it was caused by a different method of applying of the manure, as well as by a too short period of inundation (about five weeks), as the study was made in fry ponds.

The effectiveness of fertilizing was defined by the biomass of algae. A comparison of biomass and amount proved that the indicator of amount alone was not reliable. We usually expect larger biomass to be related with greater amount. However, this is by no means always the case. The amount indicator can thus sometimes bias the proper interpretation of the effects of fertilization. E.g., in 1966 the amount of algae in pond No. 13 was much lower than in No. 5, but still the fish production efficiency was highest in the former one (Wolny 1970). However, when the biomass was weighed, it turned out to be the highest in No. 13, thus allowing for a consistent interpretation.

The efficiency of fertilization assessed by means of the biomass indicator rendered lower increase rates in comparison with the control ponds than the amount indicator, but still the two rank orders of efficiency increase were similar for all the ponds. The highest biomass increase in comparison with the controls was found in the ponds manured with full doses of saltpetre and superphosphate (Table II). The sequence of decreasing efficiency was as follows: saltpetre with superphosphate and cow dung, with mineral fertilizers applied in a twice smaller dose; carbonate with superphosphate; sulphate with superphosphate. An application of cow dung alone gave a negative results.

The present findings concerning the biomass was compared with results of other authors writing on ponds. Phytoplankton biomass can be expressed by various units. E.g., Winberg and Ljahnovič (1965) assumed dry weight content in wet weight of phytoplankton to be about 10%. In rough estimations they made use of dry and ash-free weight indiscriminately, as the amount of ash is negligible in all algae except the Diatoma.

As early as 1939, Smith and Swingle arrived at the conclusion that phytoplankton should best be kept at the level of 15 to 30 mg of ash-free substance per one litre, since higher biomasses are apt to produce negative effects of phytoplankton overgrowth. They quote an example of death of fishes at the biomass of 76.1 mg/l.

Nowak (1961) found in Czechoslovak ponds that dry weight of blossoming Aphanisomenon was almost 50 mg/l.

Černjakova (1961) investigated 69 ponds in Byelorussia. She classified them into 4 categories depending on the biomass contents: 1. wet weight biomass below 1 mg/l — 28%; 2. wet weight biomass from 1 to 10 mg/l — 48%; 3. wet weight biomass from 10 to 100 mg/l — 20%; 4. wet weight biomass above 100 mg/l — 2 ponds. Winberg and Ljahnovič (1965) appreciated these ponds as poor with respect to phytoplankton development.

Ljahnovič and Prosjanik (1962) have made systematic observations of 40 ponds in Byelorussian fishing farms between 1950 and 1960. The mean wet weight biomasses were as follows: 9.5 g/m^3 of water in 16 ponds, 39 g/m^3 in 8 ponds, 118 g/m^3 in 9 ponds, 207 g/m^3 in 7 ponds. The authors found that eutrophication of ponds increased as the years passed under the influence of fertilizing. While in the early fifties phytoplankton biomass had not exceeded 8 to 10 g/m^3, then it reached 40 to 50 g/m^3, and finally it approached 250 to 300 g/m^3 or more. At the same time the fishing efficiency of the ponds increased from 150 to 600 or even 800 kg/ha.

Winberg and Ljahnovič (1965) express an opinion that the ponds fertilization ought to aim at a high, but not too high, phytoplankton biomass. They classify phytoplankton development into four degrees (in wet weight biomass): small, 0.4 to 4 mg/l; mean, 4 to 40 mg/l; high, 40 to 400 mg/l; very high, 400 mg/l or more.

In terms of this classification, phytoplankton in the investigated ponds at Żabieniec has been kept within the mean values range. Only in the saltpetre fertilized ponds its degree of development was high. Such a pattern is rather safe for the fish, and it even suggests a possibility of an increase of fertilizing.

Before fertilization, two types of algae had been most numerous, Chlorophyta and Chrysophyta. Mineral fertilizing stimulated an increase of the amount of Chlorophyta, while the level of Chrysophyta, if its mean value for the whole research period be concerned, remained almost unchanged.

The predominating algae such as Chlorella, Ankistrodesmus, Chlamydomonadoceae and Stephanodiscus constitute a readily accessible food for the zooplankton because of their small size (from 3 to 12 μ), and thus they are disirable in ponds' biocenosis. It may seem doubtful, whether Pandorina and Eudorina can be eaten by the zooplankton, as these algae are few but rather large, often exceeding 150 μ, and thus they constitute a material proportion of the biomass. However, during the division period they are split into numerous smaller offspring organisms which can be eaten up. Anyway, Rylov (1948), Richman (1958), Edmondson (1961), Sushchenya (1961) and others report that Crustacea can devour particles up to 150 μ large. Small algae are also food of Rotatoria (Ito 1955, Galkovskaja 1961, Sivko 1961, Erman 1962).

The dynamics of the amount of algae is difficult to interpret. This problem has been analysed by many investigators and it is not fully clear still, as various biotic and abiotic factors seem to be involved (Hutchinson 1967). It seems, however, that in the investigated ponds it was the zooplankton and water temperature which exerted the major influence upon the phytoplankton amount dynamics.

5. SUMMARY

The investigation was made in 1966 and 1967 in ponds of the Institute of Inland Fisheries, Fish Culture Research Station at Żabieniec near Warsaw. The ponds were fertilized with mineral and organic manures, and stocked with similar amounts of carp fry.

The aim of the study was to find out, in what ways the applied fertilizers influenced the amount, biomass, and species composition of algae, to try to interpret the dynamics of algae amount, and to compare algae development in the ponds and in the inlet.

It was found (Table II) that fertilizing with saltpetre and superphosphate was the most effective, saltpetre with superphosphate in half dose and cow dung held the second rank, carbonate with superphosphate ranked as third, and sulphate with superphosphate ranked as fourth. Cow dung yielded no effect. The sequence was similar when either algae amount or biomass was used as an efficiency indicator.

The biomass in fertilized ponds ranged from 19 do 316 g/m^3. This remains in general within the mean range according with Winberg and Ljahnovič (1965) rough classification of phytoplankton development. Only in the saltpetre fertilized ponds the phytoplankton biomass approached to high. Such a pattern did not threat with an excessive growth of phytoplankton, and even some increase in fertilization seemed safe.

The Chlorophyta and Chrysophyta algae were the predominating types (Table III). Mineral fertilizing resulted mainly in an increase of the amount of Chlorophyta (Fig. 1). It is suggested that all the algae that are found in the ponds, can be eaten by zooplankton.

In all ponds significant and consistently timed changes in the amount of algae were observed (Fig. 2). They might be caused, among other things, by changes of water temperature (Fig. 2) and by zooplankton development (Fig. 3).

In the river inlet the algae amount was ten times smaller than in the non-fertilized ponds.

6. STRESZCZENIE

Badania przeprowadzono w latach 1966–1967 w stawach Zakładu Gospodarki Stawowej Instytutu Rybactwa Śródlądowego w Żabieńcu koło Warszawy. Stawy nawożone były mineralnie i organicznie, a zarybione jednakową obsadą wylęgu karpia.

Celem pracy było: stwierdzenie w jaki sposób zastosowane nawozy wpływają na liczebność, biomasę i skład gatunkowy glonów; próba interpretacji dynamiki liczebności glonów, oraz porównanie rozwoju glonów w stawach i doprowadzalniku.

Wykazano (Tab. II), że na wzrost biomasy glonów najwydatniej wpłynęło nawożenie saletrą z superfosfatem, saletra z superfosfatem (połowa dawki) i obornikiem zajęła drugie miejsce, trzecie — węglan z superfosfatem, czwarte — siarczan z superfosfatem. Nawożenie obornikiem nie dało efektu. Rozpatrując wzrost liczebności glonów, uzyskano taką samą kolejność jak przy biomasie.

W stawach nawożonych uzyskano biomasę w granicach 19–316 g/m³. Zestawiając te dane z podanymi przez Winberga i Ljahnoviča (1965) orientacyjnymi wskaźnikami stopnia rozwoju fitoplanktonu, można dojść do wniosku, że biomasa fitoplanktonu utrzymywała się w granicach biomasy średniej. Biomasa duża występowała tylko w stawach z saletrą. Taki układ nie stwarzał niebezpieczeństwa nadmiernego wzrostu fitoplanktonu, a nawet sugerował możliwość zwiększenia nawożenia.

Dominowały glony należące do typów Chlorophyta i Chrysophyta (Tab. III). Nawożenie mineralne wpłynęło przede wszystkim na wzrost liczebności Chlorophyta (Fig. 1). Wysunięto przypuszczenie, że wszystkie występujące w stawach glony mogły stanowić pokarm dostępny dla zooplanktonu.

We wszystkich stawach obserwowano znaczne, zgodne czasowo, zmiany liczebności glonów (Fig. 2). Przyczyną tych zmian mogły być m.in. temperatura wody (Fig. 2) i rozwój zooplanktonu (Fig. 3).

W doprowadzalniku wody z rzeki, poziom liczebności glonów był dziesięciokrotnie niższy niż w stawach nie nawożonych.

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ZOOPLANKTON PRODUCTION IN VARIOUSLY FERTILIZED FRY PONDS

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ABSTRACT

Zooplankton production in 6 variously fertilized fry ponds filled from the end of May until the beginning of July was assessed by the method of Winberg et al. (1965) for Crustacea, and Galkovskaja (1965) for Rotatoria. Large differences in zooplankton production in the several ponds were found, but the influence of fertilization was not proved.

CONTENTS

1. INTRODUCTION

Investigations of productivity of ponds as ecosystems are a part of the International Biological Programme. The present paper belongs to the group elaborated in the Fish Culture Research Station at Żabieniec. Its aim is a comparison of zooplankton production in variously fertilized ponds.

2. TERRAIN AND METHODS

Six ponds were investigated, two of them (No. 4 and 12) were unfertilized, two other (No. 6 and 14) were fertilized with superphosphate and with ammonium sulphate (50 kg of P_2O_5 and 210 kg of N per ha), the remaining two (No. 5 and 13) were fertilized with superphosphate and ammonium bicarbonate (50 kg of P_2O_5 and 210 kg of N per ha). All the ponds were similar as to their surface, construction and method of filling. However, they differed in bottoms permeability. According to this factor they were classified into two groups: less permeable, in which water was exchanged during 11 to 20 days (No. 12, 13 and 14), and more permeable, with 5–10 days period of water exchange (No. 4, 5 and 6). A detailed description of the field of research can be found in Wolny (1970).

Zooplankton samples have been taken every day since the filling of ponds on May 23rd until the sluicing down on July 4th, 1966. A series of contents of 20 one-litre Patalas' (1954) samplers was considered as a single sample. Water was drawn along the ponds' diagonals, from two levels: at 20 cm from the surface, and at 20 cm from the bottom, and it was then sipped through a 49×49 μ plankton net.

For computation of the Copepoda and Cladocera production, Winberg's et al. (1965) plotting method was used, accounting for fecundity, increases of individual weights, and duration of life of organisms. Species composition, number of individuals, their lengths, and number of eggs was defined in the collected samples. Fifty individuals of each of the 3 dominating species were measured in each sample. Exact data on age structure of the *Eudiaptomus zachariasi* Poppe population are given in Grygierek (1971) and data on the influence of fertilization upon length of *Daphnia longispina* O.F. Müller are stated in Grygierek (1970). For computation of biomasses of individuals on the basis of their sizes, standard weight tables were used (Starmach 1955).

Duration of development of the most numerous species occurring in the investigated ponds, *Eudiaptomus zachariasi* Poppe, was assessed by considering the terms of appearance of the several stages, and the changes of age structure of the population (Grygierek 1971). This method was used by a number of authors: Carter (1965), Eichhorn (1967), Węgleńska (1968). It was concluded from these observations that the development of an egg and a nauplius has been going on for at least 4 days. In production computations it was assumed that an egg developed for 1 day (the assumption based on Shushkina 1964), and a nauplius for 3 days. The development of copepodite (till maturity) has been taking at least 10 days. Differences in development period of the same generation of one species in different ponds, and of different generations in one pond, could reach a few days. The shortest time of development of one generation was 14 days, and the longest — 23 days.

Efforts to establish a time of development of Cladocera have failed. Their dominating species were *Daphnia longispina* O.F. Müller and *Moina rectirostris* Leydig. Because of a great diversity of thermal and feeding conditions, it was assumed that postembrional development of both species has been lasting for 5 days in average in all ponds, and egg development 2 days (data from Manujlova 1958 and Pechen 1965). The three species just mentioned made up 72% of the mean number, and 96% of the mean biomass of all Crustacea.

In computation of the total zooplankton production it was assumed that production of the other Crustacea remained in such relation to the total production, as their biomass to the total one.

Rotatoria production was computed by the method of Galkovskaja (1965), assuming for all the species the same period of development "from an egg to an egg", i.e. 3 days, and the same standard live weight of an individual, i.e. 0.0005 mg. The most numerous among the Rotatoria were the genera Brachionus, Pomphylox and Synchaeta.

3. RESULTS

Zooplankton production values during the whole season, and relationships between production and biomass of zooplankton in the several ponds, are stated in Table I. It has been calculated that during 35 days of exploitation of the reservoirs no less than 22.0 mg/l of zooplankton was produced in the unfertilized ponds, and no more than 42.9 mg/l in the fertilized ones; i.e. between 0.63 and 1.23 mg/l per day in average. Even though zooplankton production in the unfertilized ponds, less or more permeable, has been somewhat lesser than in the fertilized ones with similar permeabilities, the data do not allow to speak about an apparent influence of fertilization upon zooplankton output. The differences between the unfertilized ponds and the fertilized ones were of the same order as those within the fertilized group. It was only in the ammonium carbonate supplied pond No. 13 that zooplankton production was markedly higher.

Table I. Production P and biomass B of zooplankton stated in mg/l in variously fertilized ponds during 35 days, i.e. from the filling to the sluicing down of the ponds

Content	Unfertilized				Fertilized with ammonium sulphate + superphosphate				Fertilized with ammonium carbonate + superphosphate			
	No. 4		No. 12		No. 6		No. 14		No. 5		No. 13	
	P	B	P	B	P	B	P	B	P	B	P	B
Eudiaptomus zachariasi	12.19	92.12	11.04	79.19	5.76	40.10	10.33	73.75	11.07	78.18	7.75	50.96
Moina rectirostris	0.18	2.02	0.57	6.90	0.08	0.52	0.65	38.72	0.06	0.16	1.61	22.49
Daphnia longispina	8.19	38.34	15.50	71.69	16.49	126.93	15.83	90.46	8.80	66.84	29.28	194.32
Other Crustacea	0.20	0.40	0.76	1.87	0.12	0.50	0.91	1.10	0.33	0.32	3.49	4.07
Rotatoria	1.22	3.65	1.17	3.54	4.45	12.58	1.85	5.71	4.69	14.09	0.82	2.83
Total a*	21.98	136.53			26.90	180.63			24.95	159.59		
Total b**			29.04	163.19			29.57	209.74			42.95	274.67
Average daily production (P/35)	0.63		0.83		0.77		0.84		0.71		1.23	
Mean P/B coefficient	0.161		0.177		0.149		0.141		0.156		0.156	
Turnover T_B (days)	6.2		5.6		6.7		7.1		6.4		6.4	

*a — more permeable ponds.

**b — less permeable ponds.

However, irrespective of the differences in absolute production and biomass values, differences were observed between mean values of the *P/B* coefficient and the turnover rates *T/B*. Both indices reveal dissimilar production processes in the fertilized and unfertilized ponds. The highest mean intensity of zooplankton production (highest *P/B*), and the slowest turnover rate was observed in the unfertilized ponds. The lowest *P/B* values were found in the ponds fertilized with ammonium sulphate. It was in those ponds that the period required for biomass exchange (mean biomass turnover period) was the longest one.

There were differences in the share of the several species in the total zooplankton production. In the less permeable ponds (No. 12, 13, 14), in which *D. longispina* mass appearance occurred earlier than in the more permeable ones (No. 4, 5, 6; Grygierek 1970), production of this species was about 50% of zooplankton production. The second predominating species in these ponds was *Eudiaptomus zachariasi*. In two of the more permeable ponds its production was even greater than that of *D. longispina*. Production of Rotatoria was relatively small. Their share in the total zooplankton production was highest in the fertilized and more permeable ponds, in which the Cladocera, as it has been mentioned, developed only at the end of the experiment period.

Intensity of production of the several species, expressed by the *P/B* coefficient, has been changing during the whole season, but in different ways in various ponds. In general, 24 hr *P/B* coefficients for Cladocera have been changing rather irregularly, though higher values were more often observed during the first two weeks of exploitation of the ponds. It was during this period that the values close to 1.0 were recorded. Production intensity of *Eudiaptomus zachariasi* at the beginning of the population's development, when the rapidly growing juvenile forms prevailed, was almost twice as high as it was later, when adult forms were more numerous. The 24 hr *P/B* coefficient dropped from its early peak value of 0.22 down to 0.13. The relation between age structure of a population, and the seasonal average production intensity of the species, was quite remarkable in *Daphnia longispina* (Table II). Adult individuals were most numerous in ponds with lowest production intensities, and most scanty in those with highest production intensities. Of course, the less and more permeable ponds were considered separately. The said relationship was much less marked in *Eudiaptomus zachariasi* (Table III). In the less permeable ponds, production intensities of *E. zachariasi* was a little higher in environments with lesser numbers of adult individuals, but in the more permeable ponds there was no correlation at all between production intensity and either the absolute amount of adult forms, or their proportion in the population. It should be noted that production

Table II. Average production values of *Dapnia longispina* in variously fertilized ponds during the whole research season

Group of ponds	Fertilizers	Pond No.	No. of ind. in 1 l		% of adult individuals	No. of eggs laid by 1 female	Production (mg/l/24 hr)	24 hr P/B coefficient	Biomass turnover T_B (days)
			total	adult					
a*	Unfertilized	4	12.5	7.8	63	6.0	0.24	0.25	4.8
	Superphosphate + ammonium carbonate	5	11.6	7.3	64	9.4	0.27	0.14	7.6
	Superphosphate + ammonium sulphate	6	25.5	18.4	72	9.4	0.51	0.12	7.7
b**	Unfertilized	12	27.3	15.8	58	6.6	0.46	0.31	4.7
	Superphosphate + ammonium carbonate	14	26.3	15.1	65	5.0	0.51	0.17	5.7
	Superphosphate + ammonium sulphate	13	48.8	34.6	71	7.1	0.88	0.15	6.7

*a — more permeable ponds.

**b — less permeable ponds.

Table III. Average production values of *Eudiaptomus zachariasi* in variously fertilized ponds during the whole research period

Group of ponds	Fertilizers	Pond No.	No. of ind. in 1 l		% of adult individuals	No. of eggs laid by 1 female	Production (mg/l/24 hr)	24 hr P/B coefficient	Biomass turnover T_B (days)
			total	adult					
a*	Unfertilized	4	90	9.9	11.0	36	0.36	0.16	7.7
	Superphosphate + ammonium carbonate	5	85	9.3	11.0	49	0.32	0.16	7.0
	Superphosphate + ammonium sulphate	6	60	6.8	11.2	57	0.18	0.18	6.9
b**	Unfertilized	12	68	10.2	15.0	35	0.31	0.16	7.7
	Superphosphate + ammonium carbonate	14	67	18.1	27.0	31	0.29	0.16	7.1
	Superphosphate + ammonium sulphate	13	52	11.0	21.2	34	0.27	0.16	6.3

*a — more permeable ponds.

**b — less permeable ponds.

intensity of *Daphnia longispina*, as well as of *Eudiaptomus zachariasi*, was in a reversed proportion to the production in a pond.

Production intensity of the third common species of Crustacea, *Moina rectirostris*, varied within a rather wide range, both in time, and when various ponds were considered. In opposition to the species discussed above, its average production intensity was proportional to its production in a given pond. It must be added that production of *M. rectirostris* was at least a dozen times lower than that of *D. longispina* and *E. zachariasi*.

Production intensity did not depend on individual fecundity in a species. *D. longispina* females have been laying more eggs in ponds with higher production but lesser intensity of production, while females of *E. zachariasi* behaved in an opposite manner, i.e., they have been laying more eggs in ponds with lower production (Tables II and III).

4. DISCUSSION

There were large differences up to 100%, between daily zooplankton production values in the several ponds (Table I). Still, no influence of fertilization can be said to have been established, as the fertilized ponds differed between each other as much as they did with the unfertilized ones. Perhaps, it was caused by some other differences between the ponds. Grygierek (1970) proved that amounts and durations of development of several groups of organisms depended largely on permeability of ponds. Rotatoria were more numerous, and Cladocera developed later, in the more permeable ponds that in the more tight ones. In similarly fertilized reservoirs, different aggregates of animals have developed.

There are data in literature (Ostapenya et al. 1968) printing that even quite similar species, like *Daphnia magna*, *D. pulex*, or *Moina rectirostris*, are able to use and assimilate the same food differently. In identical environments, production of zooplanton aggregates with different species compositions may be fairly dissimilar. That is why it seems impossible to bring out the influence of fertilization upon zooplankton by the method of comparing its production in ponds with various timing of species development and species compositions; still, it is not meant at all that fertilization does not influence zooplankton. This would be incompatible with data on zooplankton biomass, and above all on its production intensity (Table I).

Zooplankton production intensity in the fertilized ponds was lower than in the unfertilized ones. As it has been proved by Niewiadomska-Krüger (1971) and Januszko (1971), there was more bacteria and small algae, which are zooplankton food, in the fertilized ponds.

Considering this, it may be supposed that the development of Cladocera in the fertilized ponds has taken less time than in the unfertilized ones. However, it was assumed in the present study that all individuals in all ponds have been developing at the same rate. It is thus possible, that if the actual time of Cladocera development had been taken care of, the differences between the ponds with respect to production intensity could have vanished, at least in part, too. The fact that production intensity did fall down indeed, was witnessed by data on age structure of *D. longispina* populations, the species constituting the bulk of production of the discussed aggregate of animals. Its adult individuals were most numerous in ponds with the greatest production, and the lowest intensity of production (Table II).

It can be supposed that the percentage of adult individuals depends on fecundity. Such interpretation can be accepted as accounting for the changes in the *Eudiaptomus zachariasi* population. Females have been laying less eggs in ponds with lesser production intensities (Table III). A decrease of the amount of eggs resulted in a similar decrease of the amount of rapidly growing juvenile forms. This problem has been discussed in a work on *E. zachariasi* development in various environmental conditions (Grygierek 1971). However, a reversed relationship between fecundity and production intensity was observed for *Daphnia longispina*. It was in ponds with higher production, and with lower production intensities, that more eggs were laid by females. Thus fecundity of individuals was not the only factor determining an age structure and production intensity of the population.

The data of Trzoch-Szalkiewicz (1970) allow to suppose that an important role in increasing production intensity might have been played by fish. The author proved that even a few days old carp fry has been eating up large Crustaceans more intensively than small ones. As large, adult individuals have been eaten up, the population of food animals was becoming younger, and its production intensity was thereby increased. All the investigated ponds were stocked with the same amounts of fish. Thus the pressure of fish on food animals was probably all the more strong, as the latter were less ample in the environment. Zooplankton was most scanty in the unfertilized ponds, and it was there that zooplankton production intensity was highest, according with the hypothesis.

The facts here presented confirm the conclusion, suggested in earlier works (Grygierek 1962, 1965), that fish, as predators, directly influence the general productivity of a reservoir.

5. SUMMARY

Zooplankton production in six variously fertilized carp fry ponds was determined by the Winberg et al. (1965) plotting method for Copepoda and Cladocera, and by the Galkovskaja (1965) method for Rotatoria.

Large differences in zooplankton production in the several ponds were observed, but no fertilization influence was proved. Average seasonal zooplankton production ranged from 0.63 to 1.23 mg/l/24 hr (Table I).

The highest production intensities were observed in unfertilized ponds. Average production intensities of the most numerous species, *Daphnia longispina* and *Eudiaptomus zachariasi*, tended to decrease as absolute production values have been increasing (Table II and III). Production intensity was highest when young animals have been predominant.

6. STRESZCZENIE

Stosując metodę wyliczeniową Winberga et al. (1965) dla Copepoda i Cladocera oraz Galkovskiej (1965) dla Rotatoria obliczono produkcję zooplanktonu w sześciu różnie nawożonych stawach typu pierwszych przesadek.

Stwierdzono duże różnice w produkcji zooplanktonu w poszczególnych stawach, ale nie wykazano wpływu nawożenia. Produkcja zooplanktonu wyniosła średnio w ciągu sezonu od 0,63 do 1,23 mg/l/dobę (Tab. I).

Największą intensywność produkcji stwierdzono w stawach nie nawożonych. Średnia intensywność produkcji gatunków najliczniejszych, *Daphnia longispina* i *Eudiaptomus zachariasi* malała wraz ze wzrostem bezwzględnych wartości ich produkcji (Tab. II i III). Intensywność produkcji była największa w okresie przewagi form młodych.

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POLSKIE ARCHIWUM HYDROBIOLOGII (Pol. Arch. Hydrobiol.)	18	2	157–165	1971

G. TRZOCH - SZALKIEWICZ

FOOD CONSUMED BY CARP FRY AS AN ELEMENT OF UTILIZATION OF POND PRODUCTION

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ABSTRACT

Food of carp fry in ponds fertilized with mineral and organic manures was studied. During the second week of their life the fish fed mainly on zooplankton, and then also on Chironomidae, which became their main food. The mean weight of nutrients eaten by the fish was highest in the ponds fed with mineral fertilizers, and lowest in unfertilized ponds.

CONTENTS

1. INTRODUCTION

The beginning of feeding is one of the critical periods for a fish. Intensive growth creates high demand for food, which must be abundant enough and appriopriate. Fish cannot starve at this early age, and thus adequate food supply is more essential than ever.

The aim of this paper was to define the composition of natural food of carps during the first 4 weeks of their life, and a comparison of fry foods in variously fertilized ponds.

2. MATERIAL AND METHODS

Material was collected during 1966 and 1967. The scrutinized fish were hauled from variously fertilized fry ponds, 0.2 ha of surface, 1 m of depth, stocked with 125,000 individuals per hectare. Draughts were made between 10 and 12 a.m. The scheme of fertilizing is presented in Table I (for more details see Wolny 1970).

In 1966 the fish hatched on May 27th, and they were stocked into fry ponds on June 2nd; 5 fish were hauled from each pond on June 10, 17 and 24, and on July 4.

In 1967 the fish hatched on May 31st, and they were stocked into fry ponds on June 5th; 10 fish were hauled from each pond on June 13, 15, 17, 20, 23, 27 and on July 4.

Table I. Scheme of fertilization

1966			1967		
Pond No.	Fertilizer	Dose (kg/ha)	Pond No.	Fertilizer	Dose (kg/ha)
4, 12	—	—	4, 12	—	—
6, 14	ammonium sulphate	1050	5, 13	Norway saltpetre	650
	+ superphosphate	305		+ superphosphate	305
5, 13	ammonium carbonate	1235	3, 10	cow dung	21,000
	+ superphosphate	305		+ Norway saltpetre	325
				+ superphosphate	152.5
			2, 11	cow dung	42,000

The fish were put in 5% formaline solution, and then their alimentary canals were prepared and scrutinized with a miscroscope. The found remnants of organisms were identified, counted and measured (e.g., for Chironomidae, length was ganged). The wet weight of the eaten organisms was then computed from tables found in literature (Morduhaj-Boltovskoj 1954, Starmach 1955). Average values plotted on data from 2 similarly fertilized ponds were stated.

The food was classified into three basic groups of nutrients:

1. Chironomidae — larvae and pupae,
2. Zooplankton — Cladocera, Copepoda, Ostracoda, Rotatoria,
3. "Others" — Ephemeroptera, Corixidae, Coleoptera, Chaoborus, Hymenoptera, Trichoptera, Brachycera, Culicidae, Heleidae.

Ivlev's coefficient of food selection (Ivlev 1955) was computed for 1966. Data on percentage share of each food species in relation to environment were taken from Grygierek (1970) and Wójcik-Migała (in prep.). Environment tests were made in the ponds and on the days where and when carp fry was draughted. Ivlev's coefficient was computed for wet weight, and for each fish individually, and then average values were calculated. In 1967 Ivlev's coefficient was not computed, as complete data on the environment were lacking.

3. RESULTS

CARP FRY FOOD RELATED WITH AGE

The first components of carp fry food were immature forms of Copepoda and Rotatoria. During the first week of carp life in fry ponds zooplankton was its main food (the first 1966 sample, on June 10, and the first two 1967 samples, on June 13 and 15). Nauplia of Copepoda made up 27–88%, and Rotatoria 0.2–44% of food weight (Fig. 1 and 2). The following species of Rotatoria were eaten up: *Keratella quadrata, Keratella cochlearis* and *Brachionus sp.* Chironomidae were scantily consumed during this week.

During the second week (one sample in 1966, on June 17, and 3 samples in 1967, on June 17, 20, 23) the share of zooplankton in carp food dropped (Fig. 1 and 2). The consumed zooplankton consisted of larger species, such as *Daphnia longispina, Ceriodaphnia sp., Sida sp.,* and in great amounts *Moina rectirostris*. Besides, adult forms of Cyclopidae and Diaptomidae appeared, whose immature forms had been eaten up already during the first week of living of carp in fry ponds. As the share of zooplankton in carp food has been dropping, larvae and pupae of Chironomidae have become its main component, in particular *Cricotopus silvestris*, Microtendipes, Cryptochironomus. Mainly small larvae, lesser than 2 mm were eaten up. Pupae made up 7–40% of the whole biomass of Chironomidae during that period.

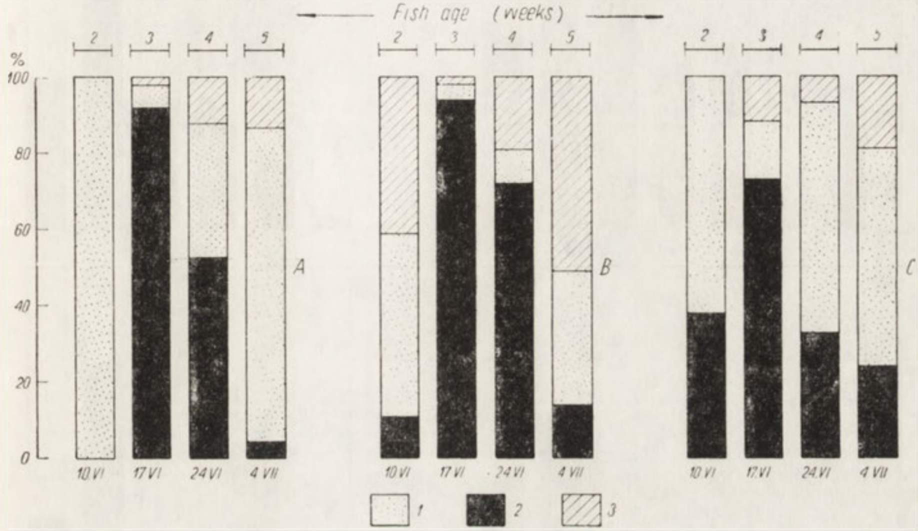

Fig. 1. Percentage of the several groups of invertebrates in the wet weight of carp fry food in 1966. A — unfertilized ponds, B — fertilized with ammonium sulphate + superphosphate, C — fertilized with ammonium carbonate. 1 — zooplankton, 2 — Chironomidae, 3 — Others

During the third week of fish living in fry ponds (and the fourth week of their life) one sample was taken in 1966 (on June 24) and one in 1967 (on June 27). Chironomidae constituted the main food of fish, which is particularly clear in 1967 (Fig. 2). The same species of Chironomidae were consumed, but larger, from 2 to 5 mm and more. The composition of the eaten zooplankton changed; *Moina rectirostris* became less frequent. Other species were substituted for it, like *Daphnia sp., Bosmina sp.* and *Chydorus sp.*

During the fourth week of carp fry life in ponds (samples on July 4 in both years) the share of Chironomidae in the food weight dropped (Fig. 1 and 2). The fish recommenced to swallow small larvae, lesser than 2 mm of length, mostly from the families Orthocladine, Tanytarsini and Corynoneurinae. The most frequently consumed species of Chironomidae was *Cricotopus silvestris,* which was eaten up until the end of the research period, and made up 70–87% of the consumed Chironomidae. Among the

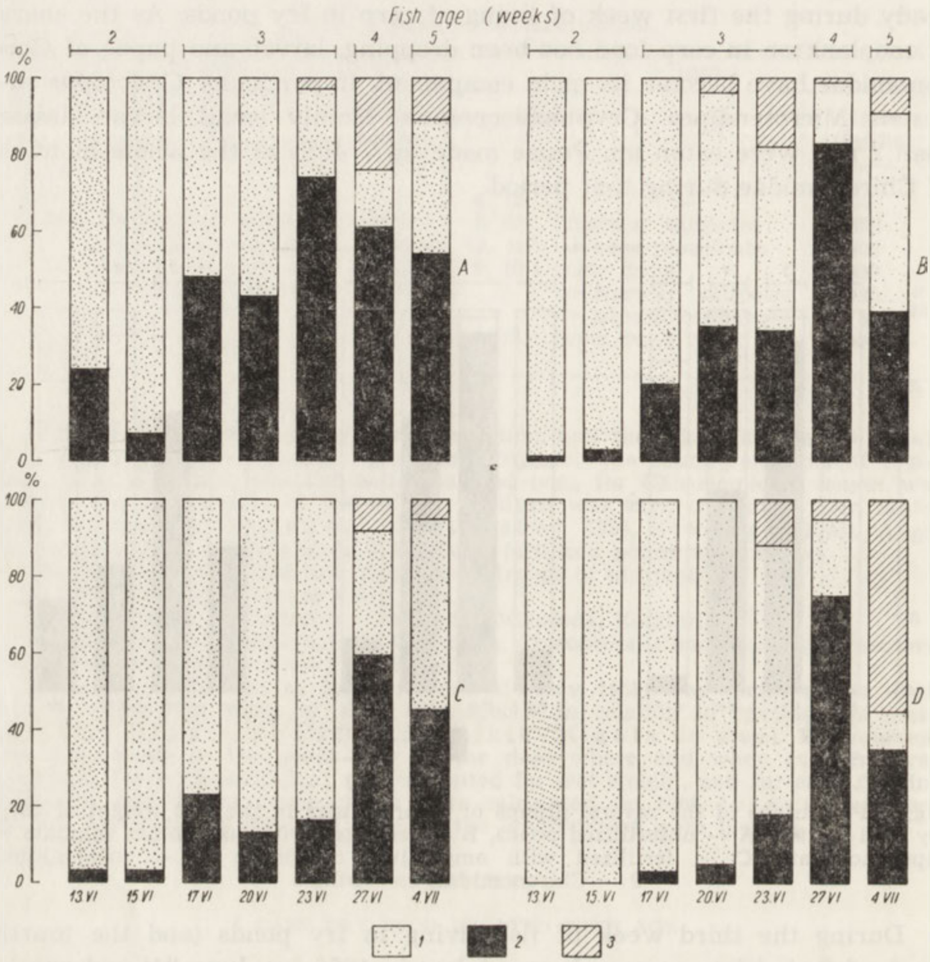

Fig. 2. Percentage of the several groups of invertebrates in the wet weight of carp fry food in 1967. A — unfertilized ponds, B — fertilized with Norway saltpetre + superphosphate, C — fertilized with cow dung + Norway salpetre + superphosphate, D — fertilized with cow dung. 1 — zooplankton, 2 — Chironomidae, 3 — Others

eaten zooplankton *Daphnia longispina* and various forms of Diaptomidae prevailed. Smaller species, like *Bosmina sp.*, *Chydorus sp.*, *Alona sp.*, and *Ascroperus sp.* were found in alimentary canals of fish from unfertilized and manured with cow dung ponds.

Animals classified to the group "Others", were eaten from the second week of fish life in ponds, but they were not consumed by all the fish. It seems, however, that the fish liked to eat Corixidae, Ephemeroptera, and Chaoborus. The following species were found only accidentally: Hydrocarinae, Coleoptera, Brachycera, Hymenoptera, and free-floating

Nematoda. The share of the group "Others" in carp food was not large; it was in average 16.2% during the whole 1966 research period, and 17% in 1967.

No phytoplankton organisms were found in alimentary canals of fish. Chironomidae were observed to be the main food of fish in almost all ponds, and during both years.

Ivlev's coefficient of food selection, computed for 1966 (Table II)

Table II. Ivlev's coefficient of food selection for 1966

Date of sampling	Type of fertilizers								
	Unfertilized			Ammonium sulphate + superphosphate			Ammonium carbonate + superphoshate		
	Zooplankton	Chironomidae	Others	Zooplankton	Chironomidae	Others	Zooplankton	Chironomidae	Others
10.VI	0.9	—*	—	0.89	—0.76	0.45	0.94	—0.57	—
17.VI	—0.53	0.05	—	—0.54	0.12	— 0.26	—0.4	0.07	0.65
24.VI	—0.03	0.49	0.68	—0.73	0.26	0.34	—0.42	—0.05	0.89
4.VII	0.12	—0.76	0.70	0.01	—0.82	+0.60	0	—0.23	0.9

* The coefficient was not computed because of a lack of data about the environment.

changed with fish age, and it confirmed the described regularities. During the first week of fish life in fry ponds, Ivlev's index for zooplankton was positive. As the fish grew, Ivlev's index for zooplankton decreased and it increased for the Chironomidae.

CARP FRY FOOD RELATED WITH THE TYPE OF FERTILIZATION

Fertilization of the ponds influenced the composition of food, and the dimensions of the eaten organisms. Thus, e.g., fish from the cow dung manured ponds ate Chironomidae beginning from their third week of life, while in alimentary canals of fish from the minerally fertilized ponds this type of food was found earlier (Fig. 2 C). In food of fish from the ponds manured with cow dung, either alone, or with Norway saltpetre, the percentage of Chironomidae was smaller than in food of fish from ponds fertilized with Norway saltpetre alone, or unfertilized (Fig. 2).

Average wet weights of all zooplankton individuals found in all samples collected in similarly fertilized ponds were computed. The same was done for Chironomidae. This allowed for a ranking of ponds from highest to lowest average weights of single individuals eaten by fish. Here are the lists for the two research years.

Fertilization	Average weight of 1 ind. (mg) Zooplankton	Chironomidae
	1966	
Ammonium carbonate	0.0658	0.743
Ammonium sulphate	0.0496	0.591
Unfertilized	0.0384	0.502
	1967	
Norway saltpetre	0.0226	0.277
Norway saltpetre + cow dung	0.0210	0.235
Cow dung	0.0132	0.170
Unfertilized	0.0139	0.151

In 1966 the weights of zooplankton organisms and of Chironomidae were highest in the ponds fertilized with ammonium carbonate, and lowest in the unfertilized ones. In 1967 the two rank orders were similar, too, except for the cow dung, which caused a small decrease of weight of the eaten individuals in comparison with the unfertilized ponds, instead of increasing it.

4. DISCUSSION

During the first week of fish life in fry ponds, zooplankton was their most important food, in particular immature forms of Copepoda and Rotatoria. Skaziński (1966) and Korinek (1966) reported similar composition of carp food. Karzinkin (1955) found that Copepoda are better digested than Cladocera by fry in the same age. This fact may account for more frequent intake of Copepoda by carp fry.

During the second week *Moina rectirostris* predominated in the zooplankton. During the third week other species were eaten up, like *Daphnia sp., Bosmina sp., Chydorus sp.*

Grygierek (1970) reports a similar composition of these species in ponds. During the period of mass intake of *Moina rectirostris* by fish, Grygierek observed a mass appearance of this species in ponds. Boruckij (1960) reports that fish are apt to eat the kind of food which is most ample and most easily accessible at a given moment.

Chironomidae were in general the most important food. Many authors point out the importance of Chironomidae larvae and pupae in carp fry food, as well as the particular preference of carp for these organisms (Vaas and Vaas van Oven 1959, Gurzęda 1965). During their fourth week in ponds, fish have been eating up smaller larvae of Chironomidae, below 2 mm. According to Gurzęda (1960) a shift to smaller larvae is connected with a former mass flight of imagines, after which the share of smaller larvae increases. Lubyanov (1956), who studied the dynamics of Chironomidae biomass, in ponds during a whole year cycle, pointed out that a decrease of larvae biomass may be caused by their transformation and flights out of water.

The group "Others", composing Ephemeroptera, Corixidae, Chaoborus, Culicidae, Coleoptera, Hymenoptera, Brachycera, Heleidae, Trichoptera, contributed little to the carp fry food. This kind of food is considered as not typical for carp fry. Gurzęda (1965) found out that it was not eaten at all during the domination of Daphnia and Chironomidae. Skaziński (1966) pointed to the fact of frequent consumption of Corixidae by 14 days old carp fry, this finding was confirmed here.

No phytoplankton was observed in the fish's alimentary canals. Januszko (1970) proved that phytoplankton was so small in size that it could hardly be observed even if it had been there.

The high selectivity index for the group "Others" is perhaps overestimated, as environment studies have been focused mainly on zooplankton and Chironomidae, and it seems that the presence of other organisms in water might have been neglected. E.g., Corixidae, Hydracarinae, Chaoborus, and other organisms found in alimentary canals, have not been found in the environment at all.

Włodek (1965), studying chemical composition of *Daphnia magna*, found an increase of protein and fat contents similar to increase of weight of these organisms under the influence of higher fertility of water. In our study an increase of weight of the eaten organisms under the influence of fertilization (mineral in particular) was found.

5. SUMMARY

The paper aimed to disclose the utilization of food by carp fry in fry ponds, minerally and organically fertilized. 120 fish were scrutinized in 1966 and 560 fish in 1967. Each fish was investigated individually.

During the first week in fry ponds, Copepoda and Rotatoria were the basic food of carp. During later weeks the fish fed on larvae and pupae of Chironomidae.

Average weight of a single devoured organism has been changing as the fish grew and it depended on fertilization. The weight of zooplankton and of Chironomidae changed similarly under the influence of fertilization. Their weight in 1966 was highest in the ponds fertilized with ammonium carbonate, next in those fed with ammonium sulphate, and lowest in the controls. In 1967 the weight was highest in the ponds fertilized with Norway saltpetre, next with ammonium saltpetre + cow dung, and it was lowest for zooplankton in the ponds fed with cow dung alone, and for Chironomidae in the controls. The group "Others" did not offer basic food in fry ponds. Relatively greatest number of these organisms was found in alimentary canals of fish from ponds supplied with cow dung.

6. STRESZCZENIE

Celem pracy było prześledzenie wykorzystania pokarmu przez wylęg karpia w stawach przesadkowych I nawożonych mineralnie i organicznie. Przebadano 120 ryb w 1966 r. oraz 560 ryb w 1967 r. Każda ryba była badana indywidualnie.

W pierwszym tygodniu pobytu karpia w stawach zasadniczym pokarmem były Copepoda i Rotatoria. W następnych tygodniach ryby odżywiały się larwami i poczwarkami Chironomidae.

Średni ciężar jednego zjadanego osobnika pokarmowego zmieniał się w miarę wzrostu ryb i zależał od nawożenia. Nawożenie wpływało prawie jednakowo na ciężar zooplanktonu i Chironomidae. Ciężar wyżeranych organizmów w 1966 r. był największy w stawach nawożonych węglanem amonu, średni — siarczanem amonu i najniższy w stawach kontrolnych. W 1967 r. największy był w stawach nawożonych saletrą amonową, średni — saletrą amonową z obornikiem, a najniższy dla zooplanktonu w stawach nawożonych obornikiem, a dla Chironomidae — w stawach kontrolnych. Grupa „Inne" nie stanowiła podstawowego pokarmu ryb w stawach przesadkowych I. Stosunkowo największą ilość spotykano w przewodach pokarmowych ryb ze stawów nawożonych obornikiem.

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S. WRÓBEL

PRODUCTION OF BASIC COMMUNITIES IN PONDS WITH MINERAL FERTILIZATION PONDS — FERTILIZATION AND DESCRIPTION

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ABSTRACT

This is an introduction to a collection of studies carried out in Experimental Farm of Laboratory of Water Biology of the Polish Academy od Sciences. Conclusions from earlier investigations on fertilization are presented, as well as a description of ponds in which the production of all the trophic levels was studied.

Ponds, small and shallow water reservoirs, are built mainly for producing fish. In Poland, as in many other European countries, the main species cultivated in ponds is the carp (*Cyprinus carpio*). It feeds on zooplankton and bottom fauna, and on fodder, mostly plant, produced outside of a pond. Within the actually prevailing system of fish production in ponds, secondary production of zooplankton and of the bottom fauna is essentially decisive for the efficiency. Secondary production is limited by the amount of organic matter, either produced in a pond (primary production, mostly of phytoplankton), or supplied from outside in form of organic manure or fish fodder. The latter contributes directly (by leaching) or indirectly (fish excrements) to an increase of organic matter content in pond water. Thus the secondary production of the trophic levels which constitute the basic food for fish can be influenced either by increasing primary production by mineral fertilization, or by providing ready organic substances by organic manuring.

Though the chain from mineral salts supplied in form of fertilizers to the last, economically useful level, which are fish, is rather long, still this way of influencing the production of organic matter, and thereby the fish production, increases the amount of oxygen dissolved in water, which is another factor of efficiency increase.

Fertilization of ponds in Europe has been for many years a subject of researches and debates. A part of the advocates of fertilization have held an opinion that phosphorus alone should be used, while others believed that the use of nitrogen together with phosphorus would bring better effects. Numerous studies carried out after World War II have settled these debates in favour of applying both types of fertilizers together (Winberg and Ljahnovič 1965). However, this is true only for ponds in the temperate climate. The favourable action of this type of fertilization is witnessed by the research project carried out in the Experimental Fishery Farms of the Laboratory of Water Biology at Gołysz (Cieszyn district). These farms are situated at the opening of the Moravian Gate, separating the Carpathian mountain chain from the Sudetes, in the wide valley of the Upper Vistula, under 49°52′ N of latitude and 18°48′ E of longitude, 260 to 270 m above the sea level.

The ponds are supplied with water from the Vistula, poor in mineral salts, like the other Carpathian rivers. Average cations contents in water is: Ca — 22.5 mg/l, Mg — 3.0, K — 2.0, Na — 6.8. Phosphates content rarely exceeds 0.020 mg/l, only nitrates content reaches sometimes 1.5 mg/l (Wróbel 1965 b).

The researches on ponds fertilization concerned the influence of fertilizers on chemical contents of water, on quality and quantity of plant and animal communities, and on fish production. The results can be stated as follows:

1. The most favourable kind of fertilization of ponds was the joint application of phosphorus and nitrogen fertilizers.

2. With this type of fertilization, a more uniform development of phytoplankton was observed, consisting mainly of small Chlorophyta (Protococcales), while in the ponds fertilized with phosphates alone, periodic water-blooms of Cyanophyta appeared (Bucka 1960, 1966).

3. Primary production of phytoplankton in the P+N fertilized ponds was 3 to 4 times greater than in the unfertilized ones, it amounted in average to 1950 kcal/m^2 during a season.

4. Fish production in the P+N fertilized ponds was also 3 to 4 times greater than in the unfertilized ones, and twice greater than those fertilized with phosphates alone (while the amounts of the elements supplied did not exceed 120 kg of N and 22 kg of P per hectare).

5. Carp production was in average 2.75% of primary production of phytoplankton (the correlation coefficient was 0.89 — Wróbel 1970).

The above regularities seem to be valid for the temperate climate ponds, or perhaps even for a narrow strip of this climatic zone.

As the results of studies on ponds fertilization in various climatic zones are compared, a growing effectiveness of nitrogen supplied together with phosphorus can be observed with the increasing geographical latitude. Nitrogen fertilization was proved to be unnecessary in the tropics (Prowse 1966), while in the subtropical climate it was found that P+N fertilization had a positive influence on fish production in spring and autumn, while in summer its effects were not better than those of phosphorus alone (Hepher 1962). The increase of nitrogen demand under higher latitudes can be explained by poorer assimilation of atmospheric nitrogen by bacteria and Cyanophyceae, and by slower turnover rate (Fig. 1) and subsequent accumulation of nitrogen in the organic matter on bottoms of ponds. Even in temperate climate it can happen during sunny and warm summers that nitrogen fertilization will have little or no effect.

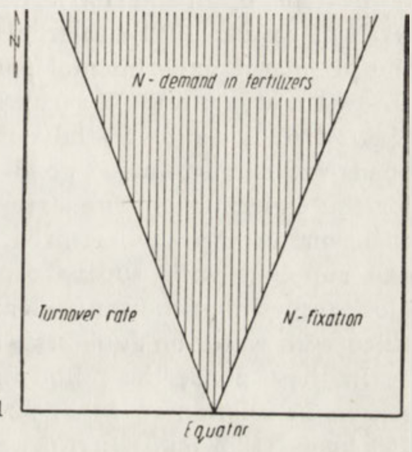

Fig. 1. A hypothetical increase of nitrogen demand in ponds depending on geographical latitude

Studies on fertilization described above have been most often carried out in ponds stocked with 2 or 3 years old commercial carps. In our climatic conditions these ponds are filled with water in April and sluiced down in October; they remain dry during winter. The period of fish growth is in average 165 days. Less studies have been made in ponds for cultivation of carps during their first year of life. They are under water for a period of only 100 to 120 days. The system of fry culture consists in resettling the fish to larger ponds twice in their life. This system was introduced by Dubisz in eighteen-seventies on the farm Landek, now belonging to the chain of Experimental Farm of Laboratory of Water Biology. The principles of this system must be presented by way of an explanation. The spawning of carps takes place in spawning pools of 100 to 300 m^2 of surface, in May or June. Fish larvae are caught and transported to fry ponds of 1 to 2 ha of surface and 50–70 cm of depth. They remain there during 4 to 6 weeks. It may be added that the whole morphogenesis of carp in our climate takes about 40 days (Matlak 1966). At the break of June and July fish weighing from 1 to 3 g are transferred to fingerling ponds which are normal carp ponds.

On the Gołysz farm 24 experimental ponds have been built up to 1965. The surface of each pond is 1500 m^2 (50 by 30 m), and their average depth is 90 cm. Each pond has got an individual inlet and outlet. They were filled for the first time in July 1965. In 1966 they were under water during the whole vegetation season (from April to October). They were stocked with equal amounts of yearling carp, 670 individuals per ha. Fish production was in average 200 kg/ha. During the first year of exploitation of the ponds only lime was applied (150 kg per one pond, or 1000 kg per hectare).

Bottoms of all the Gołysz ponds consist of dusty soils, of water origin (Pasternak 1959); their pH value fluctuates from 5.0 to 6.0, while the pH of the experimental ponds before the first filling was 6.4 to 6.7 (Lewkowicz and Wróbel 1971).

In 1967 a complex study of the effects of fertilization of fingerling ponds was carried out. 12 ponds making up the strip A (Fig. 2) were used for the experiments. The strip A was devided into 4 blocks, 3 ponds in each, one of them unfertilized, one fed with superphosphate alone, and one supplied with superphosphate and ammonium saltpetre. In each block (repetition) the three elements were chosen by lot. The ponds were filled with water on June 21st, 1967.

In these ponds the following fertilizers were used during the whole season in relation to 1 ha: 32 kg P (3.5 mg/l) in superphosphate, and 163 kg N (18.2 mg/l) in Norway saltpetre. The ponds fertilized with nitrogen received also phosphorus in the same amount as stated above, and the N : P ratio was 5.2. Fertilizers were supplied from June 23 at weekly intervals (6 doses), and at the end of August and at the beginning of September (8 doses in total).

Each pond was stocked with 2600 carps (17,300 per ha), hauled on October 23.

To avoid additional supply of organic matter, and to facilitate comparison of fish and the other trophic levels production, no feeding of fish was applied. Another reason to avoid feeding of fish was the need to observe the development of phytoplankton in ponds under the influence of the supplied mineral nutrients. Investigations of ponds, in which various factors can be controlled at will, provide important data for an explanation of the causes of eutrophication of surface waters, and for an elaborating of methods to prevent it.

In the studies carried out by the Laboratory of Water Biology in earlier years, mainly the qualitative and quantitative features of plant

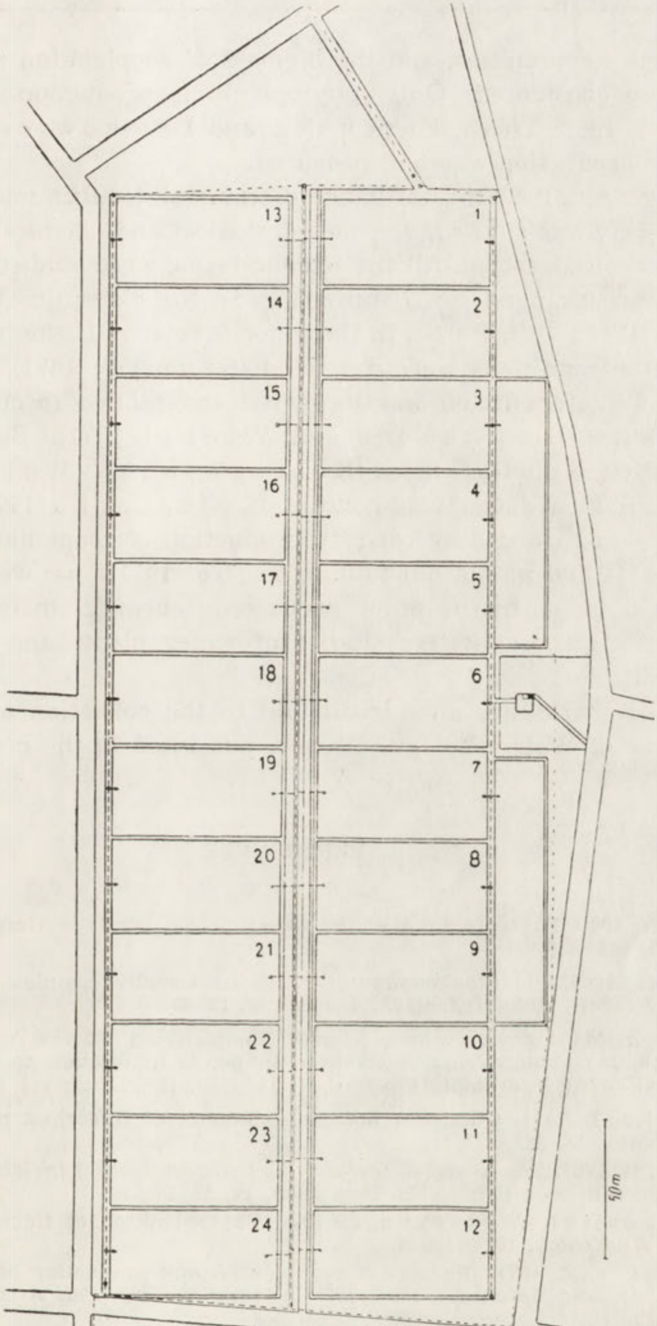

Fig. 2. The pattern of experimental ponds at Gołysz. 1, 5, 7, 11 -- controls; 3, 6, 8, 12 — ponds fertilized with P; 2, 4, 9, 10 — ponds fertilized with N + P

and animal communities, and the biomass of zooplankton and of bottom fauna were considered. Only phytoplankton production was assessed (Wróbel 1962, 1965 a, Ferenska and Lewkowicz 1966), while secondary production was not measured.

However, in 1967 the influence of mineral fertilization upon all the trophic levels was studied, and meteorological and chemical factors were taken into consideration. All the trophic levels were studied in one series only, comprising pond No. 7 (unfertilized), No. 8 (fertilized with P), and No. 9 (fertilized with P+N). In those ponds solar radiation was measured, and thermic conditions were described (Szumiec 1971), primary production of phytoplankton was measured and related to chemical conditions in water (Lewkowicz and Wróbel 1971). Besides, quality and quantity of phytoplankton (Krzeczkowska-Wołoszyn 1971) and bottom microfauna was considered (Grabacka 1971). Particular attention was turned on secondary production of zooplankton (Lewkowicz 1971) and of bottom fauna (Zięba 1971), as well as of fish (Włodek 1971). In the other ponds only chemical investigations, and quantitative and qualitative studies of water plants and animals were carried out.

These remarks are an introduction to the collection of papers from Laboratory of Water Biology, Cracow, published in the present issue.

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M. SZUMIEC

SOLAR RADIATION, WATER TEMPERATURE AND PRIMARY PRODUCTION IN CARP PONDS

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ABSTRACT

An attempt has been made to define the interrelations between the total solar radiation intensity, water temperature, total primary production in carp ponds. A linear relation between changes in solar energy with time and water temperature has been found. Vertical gradients of water temperature were proportional to vertical gradients of radiation in all the investigated ponds. An approximately linear relation between primary production and solar energy was observed only in deeper layers of the fertilized ponds.

CONTENTS

1. INTRODUCTION

Fertilization of fish ponds causes an intensive growth of phytoplankton which may cut off solar energy from deeper layers of water. Thus what was intended to make for an increase of production, may actually impede it by hindering photosynthesis in deep water. This brings the significance of solar energy into attention and calls for its exact measurements.

Besides direct influence of solar radiation upon photosynthesis as its source of energy, there is an indirect relationship as well, due to an influence of temperature upon an intensity of primary production (Gessner 1955, Hepher 1962). The bulk of solar energy absorbed in water is converted into heat and then transmitted to the environment by evaporation, radiation, and exchange with the air and the bottom. In effect, only a few per cent of the absorbed energy can remain accumulated in ponds (Szumiec 1969).

2. METHOD

An attempt at establishing the influence of radiation intensity upon water temperature and primary production has been made within a complex survey of ponds' productivity, carried out in the Experimental Farm of Laboratory of Water Biology of Polish Academy of Sciences at Gołysz, during the vegetation season (from May to September) in 1967. Measurements were taken in three ponds: No. 7 — control, No. 8 — fertilized with superphosphate, No. 9 — fertilized with superphosphate and Norway saltpetre. All the ponds have equal surface of 1500 m², and similar mean depths of 1 m. The total radiation intensity (from 0.3 to 1.5 μ) was measured with a limnoactinometer (Stenz 1938, 1953) adapted to pond conditions. To describe water transparency in the three ponds during the whole season, measurements results were reduced to the vertical direction of solar rays (Birge and Juday 1929, Eckel 1935, Stenz 1938, 1953).

To measure water temperatures, mercur thermometers in vinidure coats were used, adapted to sampling of water at desired depths. Water temperature and radiation intensity was measured at 1, 5, 10, 20, 30, 50 and 80–100 cm of depth. Values of total primary production were taken from investigations by Lewkowicz and Wróbel (1971) who employed the light and dark bottles method, distributed at 10, 50 and 100 cm of depth. The bottles were exposed during 24 hr beginning from 9 a.m. Production measurements started in the third decade of June and ended in the first half of October.

Radiation and thermal conditions during the 1967 vegetation season at Gołysz were characterized in terms of mean monthly water temperatures, monthly sums of sunshine duration, monthly sums of radiation energy, and their deviations from many years mean values. Decade and daily values of radiation and of pond water temperatures are reported. Sunshine duration was measured with a Campbell-Stokes sunshine recorder, radiation intensity with a Moll-Gorczyński pyranometer and with a limnoactinometer. The results of the series of measurements of radiation intensity were interpolated by the method of harmonic analysis, and the sums of energy during the particular time spans were calculated on the base of the continuous distribution (Szumiec 1968). Many years average values were computed from data of the nearest meteo station (Cieszyn), according with the accepted climatological procedures (Alisov et al. 1956).

3. RESULTS AND DISCUSSION

Heat intake resulting from solar energy absorption was greater during the 1967 season than in other years. This is indicated by positive deviations of sunshine duration and solar radiation (Table I). Mean monthly

Table I. Monthly average values of water temperature ϑ and monthly sums of sunshine duration U and solar radiation R. Δ — deviations from the many years values

Meteorological factors	V	VI	VII	VIII	IX	V–IX
ϑ (°C)	16.1	20.2	23.6	21.6	18.2	18.6
$\Delta\vartheta$	0.4	0.3	2.8	1.5	1.9	1.4
U (hr)	212	256	271	210	139	952
ΔU	36	39	57	16	—13	136
ΣR (cal · cm⁻²)	8504	12,067	13,582	9461	5091	41,902
$\Delta\Sigma R$	1178	2476	2088	1159	—98	5625

temperatures of water also assumed value higher from those recorded as many years means. A positive deviation of water temperature was also recorded in September, even though the deviation for solar energy records was negative during that month. This might have been due to a large accumulation of heat in the soil during the summer, and its subsequent emission in autumn and influx to the ponds by turbulent exchange with the air and consecutive exchange with the ponds' bottoms (Szumiec 1969). Similarly, the large positive deviation of water temperature in July might have been a result of intensive insolation in June. The sums R of radiation energy for ten days' periods, and the mean water temperatures ϑ for similar periods, which are presented only for the time span of primary production measurements (Fig. 1 A) clearly indicate favourable insolation conditions during the third decade of July. In effect, the mean water temperature for this decade was the highest recorded in 1967. From that moment water temperature has been gradually dropping down until the end of the research period. It has been found that there is a simple relation between a decade's water temperature and the amount of solar energy:

$$\frac{\vartheta}{R} = n_1$$

The values assumed by the coefficient n_1, indicating the contribution of solar energy R in thermal changes occurring in the ponds, have been fluctuating within a narrow range during the research period (Table II).

Table II. Mean monthly values of the n_1 coefficient

	V	VI	VII	VIII	IX	Averages V–IX
1967	0.059	0.050	0.054	0.071	0.107	0.068
Many years values	0.066	0.062	0.056	0.075	0.094	0.071

The lowest values of n_1, observed during the half of the summer, resulted from extensive losses of heat by evaporation from the ponds' surfaces; its greatest intensity occurred in July (Szumiec 1969). The increase of n_1 in autumn indicates that mean water temperatures drop down at a slower rate than the influx of energy R, while at the beginning of the vegetation season ϑ increases a little faster than R.

Diurnal means of water temperature and of radiation fluctuated most during the first three weeks of July (Fig. 1 B). During that period, the highest difference between two consecutive days in amounts of thermal energy at the ponds' surfaces exceeded 500 cal $\cdot$ cm^{-2}. The longest period

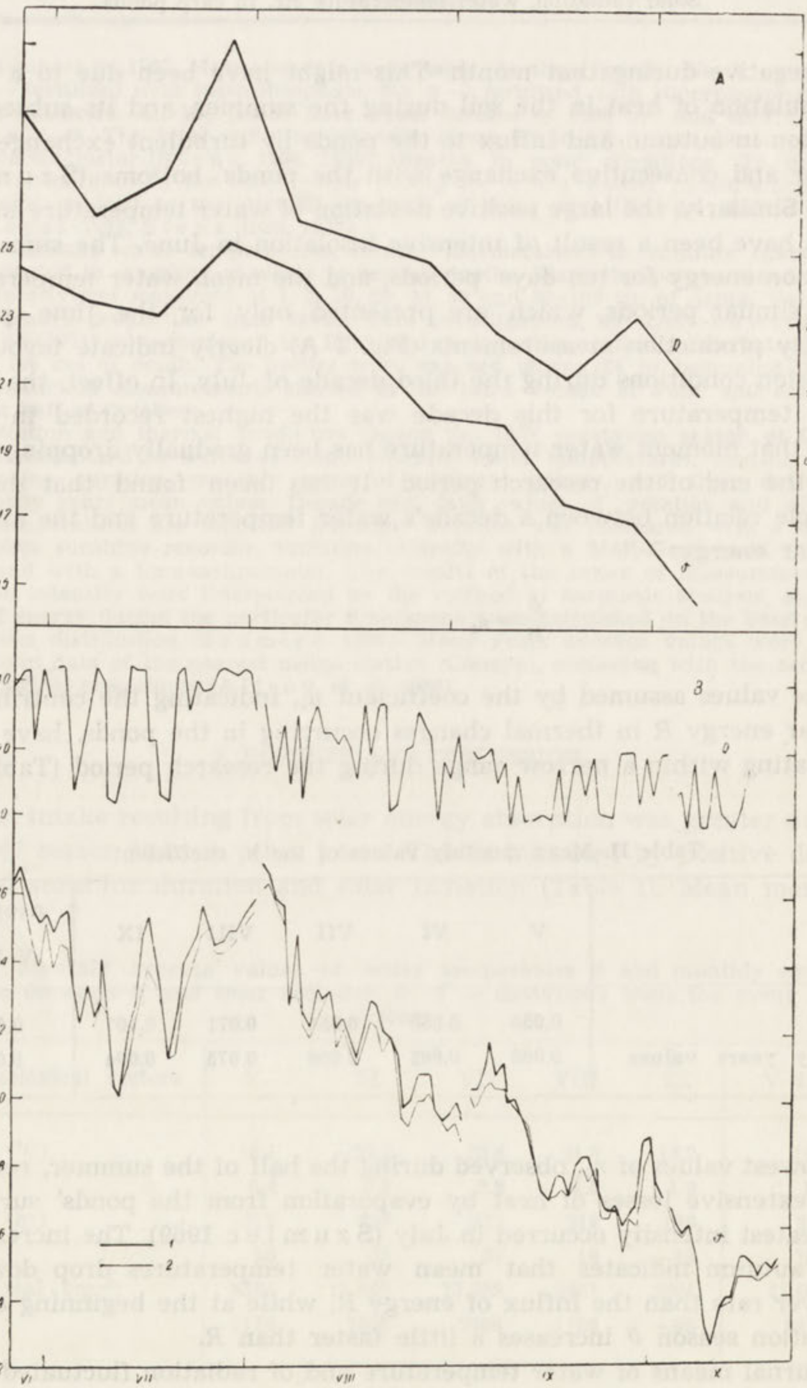

Fig. 1. Changes during the season of (A) decade sums of radiation *R* and of mean decade water temperature *ϑ*, and (B) diurnal values of *R* and *ϑ*. 1 — surface; 2 — bottom

of high and steady influx of heat during the third decade of July caused an increase of mean daily water temperatures in the whole capacity of water; the maximum was observed on August 1. The decreasing amplitude of oscillations of R has been reflected by decreasing fluctuations of water temperatures.

An analysis of diurnal primary production P and of energy R plotted for the period of exposition of bottles proved that it was only at the depth of 10 cm that no obvious relation between the two values existed (Fig. 2). Thus the point of saturation is situated below 10 cm (i.e., the

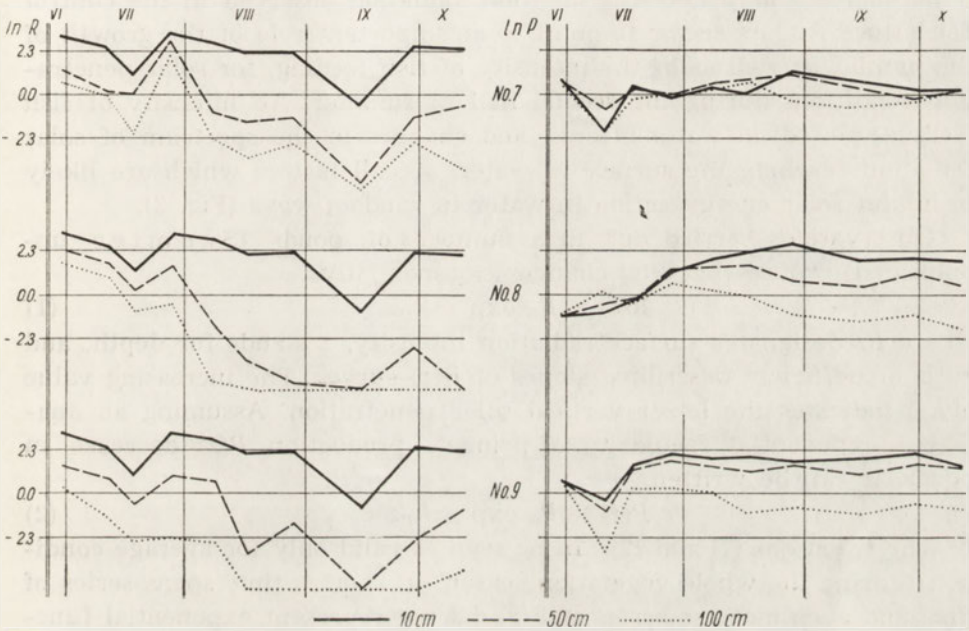

Fig. 2. Changes during the season of radiation intensity R (cal · cm^{-2} · hr^{-1} and of primary production P (mg O_2 l^{-1} · 24 hr^{-1}) in the ponds No. 7, 8, 9at several depths, on a logarithmic scale

point with such light intensity, at which photosynthesis attains its maximum — cf. S t a r z e c k i 1969). There were other factors which determined the extent of production at this depth; in this case the fertilizers were decisive. In pond No. 8 slower action of phosphorus fertilizing caused a shift of the maximum of production to the second half of August, while in No. 9, fed with phosphorus and nitrogen, the highest value of production was observed at the end of July. The increase of primary production near the surface caused a decrease of radiation intensity in deeper layers. As a result, the distribution of R in time was different in each pond (Fig. 2). It was found that at the production value of 10 mg O_2/l/24 hr recorded at the depth of 10 cm, the energy R dropped rapidly with depth. A fall of R below 0.1 cal · cm² · hr⁻¹ evidently inhibited photosynthesis. Such relationship has been observed since the half of the vegetation season at the depth of 50 cm and below in pond No. 8, and in the next-to-bottom layers of pond No. 9 (Fig. 3). The value of R here reported as inhibiting photosynthesis is lower than those usually quoted by various authors as observed in large water reservoirs (Gessner 1955, Steele 1962). Probably this is an effect of adaptation of pond plants to small amounts of light.

A decrease of penetration of solar radiation observed in the control pond since August seems to point to an important role of the growth of the humus, as well as of the intensity of fish feeding, for solar penetration conditions during the second half of summer. An intensity of fish feeding, periodical water-blooms, and changes in the spectrum of solar radiation reaching the surface of water, are all factors which are likely to inhibit solar energy action in water in random ways (Fig. 3).

Observations carried out in a number of ponds (Szumiec unpublished) proved that $R(z)$ changes exponentially:

$$R(z) = R_0 \exp -k_R z \quad (1)$$

where R_0 designates surface radiation intensity, z stands for depth, and k_R is a coefficient describing slopes of $R(z)$ curves. The increasing value of $|k_R|$ indicates the lesser vertical solar penetration. Assuming an analogous exponential regularity of primary production $P(z)$ decrease in ponds, it can be written:

$$P(z) = P_0 \exp -k_P z \quad (2)$$

The equations (1) and (2) can be seen as valid only for average conditions during the whole vegetation season. In shorter time spans series of $R(z)$, and even more so series of $P(z)$ did not represent exponential functions (Fig. 3). For P_0 values smaller than 1 $cal \cdot cm^{-2} \cdot 24\ hr^{-1}$, $P(z)$ assumed uniform values from surface to bottom, or even production increased with depth. Assuming the equations (1) and (2) to be valid, coefficients k_R and k_P were computed (Table III). It can be seen that radiation intensity drops down with growing depth at a much faster rate than production. This was caused by a great loss of radiation energy in the upper 10 cm layer of water. Values of k_R related to the 10 cm depth approached the values of k_P for ponds No. 8 and 9. From the viewpoint of production efficiency, the highest and still advantageous value of k_R should not exceed 0.06 for R_0 from 10 $cal \cdot cm^{-2} \cdot hr^{-1}$.

Representing the changes of water temperature in relation to depth as an exponential function:

$$\vartheta(z) = \vartheta_0 \exp -k_\vartheta z \quad (3)$$

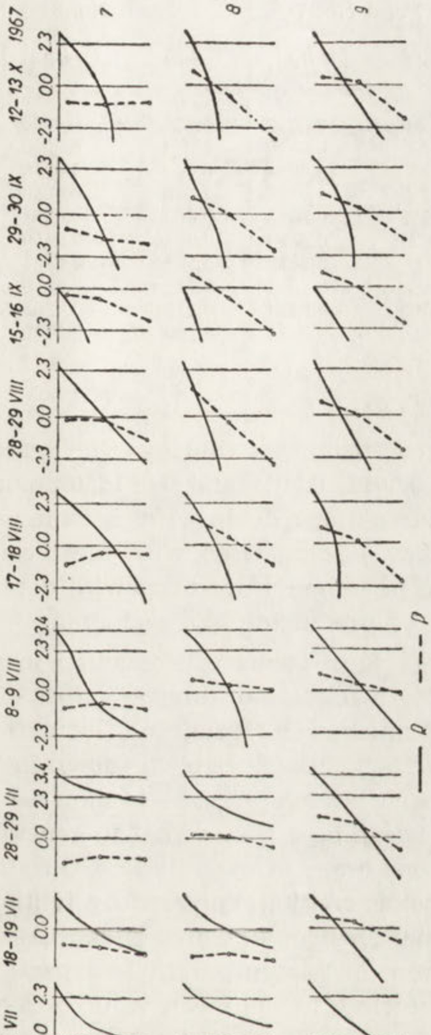

Fig. 3. Changes during the season of vertical distributions of radiation R (cal · cm-2 · hr-1) and of primary production P (cal · cm-2 · 24 hr-1) on a logarithmic scale

Table III. Values of the k_R and k_P coefficients

Date	Pond No. 7		Pond No. 8		Pond No. 9	
	k_R	k_P	k_R	k_P	k_R	k_P
29–30 VI	—0.030	—0.0012	—0.030	0.0000	—0.020	0.0000
11–12 VII	—0.054	0.0110	—0.043	0.0096	—0.053	—0.0120
18–19 VII	—0.055	0.0024	—0.049	0.0016	—0.072	—0.0081
28–29 VII	—0.032	0.0036	—0.058	—0.0086	—0.079	—0.0125
8–9 VIII	—0.052	0.0025	—0.063	—0.0091	—0.080	—0.0110
17–18 VIII	—0.063	0.0094	—0.081	—0.0156	—0.103	—0.0190
28–29 VIII	—0.066	—0.0062	—0.102	—0.0391	—0.082	—0.0180
15–16 IX	—0.069	—0.0084	—0.113	—0.0310	—0.082	—0.0226
29–30 IX	—0.070	—0.0504	—0.110	—0.0283	—0.081	—0.0200
12–13 X	—0.055	—0.0014	—0.100	—0.0328	—0.080	—0.0130

mean values of the coefficient k_ϑ during the research period were computed; they were 0.0012, 0.0019 and 0.0016 for ponds No. 7, 8 and 9 respectively. Their fluctuations during the season were much smaller than that of k_R and k_P. A comparison with mean values of k_R and k_P indicates that the rate of temperature drop with depth is much smaller than similar decrease of production and radiation.

Utilization of energy R in primary production in ponds is presented as a coefficient n_2, being a relation of diurnal values of P to R: $P/R = n_2$. This coefficient has a much wider range of fluctuations than n_1 (Table IV). It results from the fact the values of n_2 shown in Table IV represent single measurements, and not averages, as is the case with the values of n_1 (Tables II and IV). It can be assumed that in general the coefficient n_2 is smaller than n_1 by one order of magnitude. Utilization of solar energy in photosynthesis in ponds can be expressed by tenth of per cent, while its utilization in thermal changes in water is expressed in full per cents. The measurement taken on September 15 is a particular case; on that day n_2 assumed a value close to the mean value of n_1. It was a result of a very small influx of energy R on that day, as the skies were covered with thick stratus clouds. This indicates special situations of high utilization of solar energy, observed when R drops suddenly after a period of intensive insolation.

Medium vertical cross-sections of the values of R, ϑ and P were compared (Fig. 4), and an attempt was made to establish their interrelations. The highest intensity of radiation was recorded in the control pond, where it was by 0.01 $\text{cal} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ greater than in the fertilized ponds in the whole water capacity. Differences in the amounts of R between the fertilized and control ponds increased in proportion to depth

Table IV. Diurnal values of the n_2 and n_1 coefficients

n_2

Pond No.	VI	VII			VIII			IX		X
	29–30	11–12	18–19	28–29	8–9	17–18	28–29	15–16	29–30	12–13
7	0.0011	0.0003	0.0038	0.0005	0.0010	0.0018	0.0027	0.0292	0.0009	0.0014
8	0.0002	0.0007	0.0025	0.0018	0.0036	0:0059	0.0068	0.0651	0.0035	0.0032
9	0.0011	0.0004	0.0123	0.0037	0.0037	0.0045	0.0038	0.0768	0.0048	0.0033

n_1

Month	VI	VII			VIII			IX			X
Decade	III	I	II	III	I	II	III	I	II	III	I
Average values	0.048	0.068	0.058	0.045	0.071	0.068	0.082	0.111	0.146	0.083	0.156

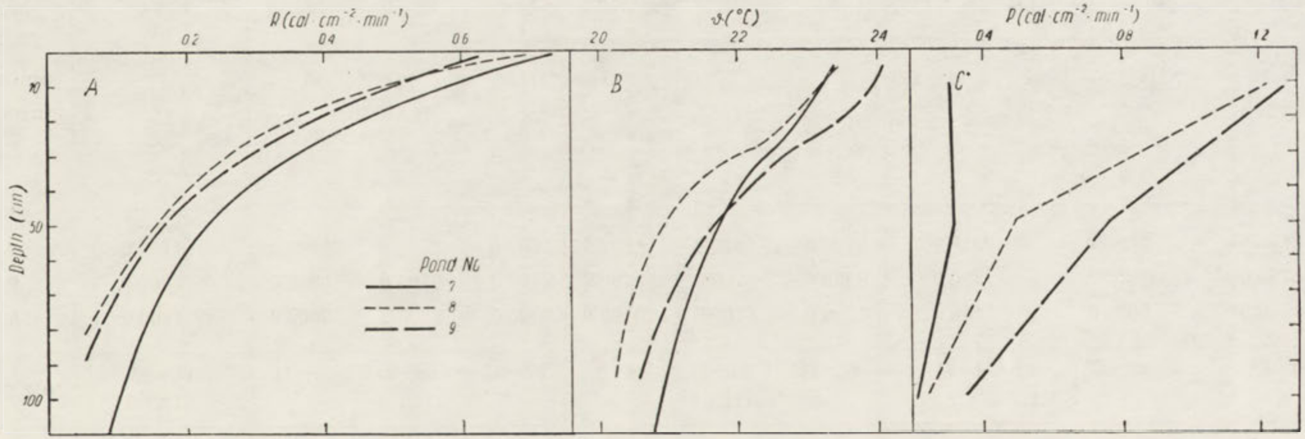

Fig. 4. Vertical distribution of mean values for the whole season of (A) radiation intensity R, (B) water temperature ϑ, (C) primary production P

(Fig. 4 A). The drop of radiation from the surface to the bottom is typical for carp ponds, in which solar energy is absorbed at 20 to 40 cm to 50% of its surface value (Szumiec 1961).

The vertical distributions of ϑ and P obviously depended on $R(z)$. The greatest vertical gradients of water temperature corresponded with the greatest vertical gradients of R in the pond fertilized with superphosphate. In effect of a more intensive absorption of heat, its surface temperature was higher than in the control, while near the bottom it was lower (Fig. 4 B).

The vertical decrease of primary production in each pond (Fig. 4 C) reflected the interrelation between $R(z)$ and $P(z)$. The highest penetration of radiation in the control pond was a result of low production in it. On the other hand, the vertical gradients of R and P in the fertilized ponds revealed a proportionality; e.g., it was in the superphosphate fed pond No. 8 that the penetration of solar radiation was lowest, and there, too, production has been dropping down with depth at a quickest rate. The total primary production during the whole season was highest in pond No. 9, fertilized with superphosphate with Norway saltpetre. The mean radiation intensity in this pond was higher than in No. 8, and thus it can be supposed that in the latter it was solar energy that was limiting production in the span of the whole season.

The interrelation between water temperature and primary production in the fertilized ponds found its reflection in the highest production occurring in the pond with the highest mean temperature of water.

5. SUMMARY

The paper discusses the interrelations between time and depth changes, of the total radiation intensity, water temperature, and total primary production in ponds fertilized with various mineral elements, and in a control pond at the Experimental Farm at Gołysz, from June to October 1967.

A linear relation was found between the changes of water temperature and radiation intensity. The coefficient of this relation assuming the lowest values during the period of maximal evaporation — in the middle of summer, and the highest values in autumn, when the considerable influx of heat from the air was observed. A proportionate relation was found between the vertical gradients of temperature and radiation in the fertilized and control ponds.

It was only in the fertilized ponds that a correlation between primary production and solar radiation intensity was observed. An increase of primary production up to about 10 mg $O_2 \cdot l^{-1}$ in the surface layer during the first half of the season caused a remarkable decrease of penetration of radiation to the deeper layers of the ponds. As a result, in the fertilized ponds production has been changing since that time in an approximately linear manner with the amount of solar energy. It can be assumed that the mean values of radiation intensity during the whole season are a factor controlling primary production in fertilized ponds.

It has been found that in fertilized ponds the vertical change of radiation intensity, water temperature and primary production can be represented roughly as exponential functions.

Computations have revealed that the utilization of solar energy in the process of primary production in the ponds has been limited to a few tenths of a per cent, while the share of this energy in thermal changes amounted to a few per cent.

6. STRESZCZENIE

Rozpatrywano zależności między czasowymi i pionowymi zmianami natężenia całkowitego promieniowania słonecznego, temperaturą wody i całkowitą produkcją pierwotną w stawach nawożonych różnymi składnikami mineralnymi oraz w stawie kontrolnym, położonych w Gospodarstwie Doświadczalnym Gołysz, w okresie od czerwca do października 1967 r.

Między czasowymi zmianami natężenia promieniowania i temperaturą wody stwierdzono liniową zależność. Zmniejszanie współczynnika określającego tę zależność obserwowano w okresach maksymalnego parowania, natomiast zwiększenie — w okresie największego dopływu ciepła do stawów z otoczenia. Stwierdzono proporcjonalną zależność między pionowymi gradientami temperatury i promieniowania w stawach nawożonych i kontrolnym.

Korelację między produkcją pierwotną i natężeniem promieniowania słonecznego zaobserwowano jedynie w stawach nawożonych. Wzrost produkcji pierwotnej do wysokości około 10 mg $O_2 \cdot l^{-1}$ w powierzchniowej warstwie wody w połowie sezonu, powodował wyraźny spadek przenikania promieni do głębszych partii stawów. W wyniku tego, poniżej 10 cm produkcja zmieniała się w stawach nawożonych w przybliżeniu liniowo wraz z ilością energii słonecznej. Można przyjąć, że w czasie całego sezonu średnie wartości natężenia promieniowania słonecznego są czynnikiem kontrolującym produkcję pierwotną w stawach nawożonych.

Stwierdzono, że w stawach nawożonych pionowe zmiany natężenia promieniowania, temperatury wody i produkcji pierwotnej można z pewnym przybliżeniem przedstawić w postaci funkcji wykładniczej.

Obliczenia wykazały, że wykorzystanie energii słonecznej w procesie produkcji pierwotnej w stawach ograniczało się do kilku dziesiętnych procent, natomiast udział tej energii w zmianach cieplnych wynosił kilka procent.

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SOME CHEMICAL FACTORS AND PRIMARY PRODUCTION OF PHYTOPLANKTON IN FINGERLING PONDS

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ABSTRACT

An influence of fertilization upon chemical conditions and primary production of phytoplankton was studied. Remarkable effects of phosphorus fertilization upon phytoplankton production were found, while an addition of phosphorus + nitrogen fertilizers caused only a small increase of primary production as compared with phosphorus alone. Phytoplankton made use of only 8% of the supplied phosphates.

CONTENTS

1. INTRODUCTION

Chemical investigations of pond waters, and a less extensive analyses of pond soils, were carried out during 1967 as a part of a survey of the effects of fertilization of fingerling ponds. Measurements of primary production of phytoplankton were the main focus, as it is a subtle indicator of effects of various procedures, and of fertilization in particular.

Fertilization stimulates phytoplankton development, while various types and mixtures of fertilizers often bring about an emergence of peculiar algae communities, thereby influencing the extent of production, and even more so its utilization by the subsequent trophic levels. Photosynthesis of water plants in its turn influences the pH value and other chemical factors in pond water and soil.

The aim of the study was to investigate the influence of phosphorus and of phosphorus + nitrogen fertilizers upon primary production of phytoplankton, and upon chemical conditions prevailing in the ponds.

A description of the studied ponds, of the inlet water, and of the fertilization procedures, is given in W r ó b e l (1971) in the present issue.

2. METHODS

Investigations on the primary production were carried out in three experimental ponds with mean surface 1500 m^2 and mean depth 0.9 m; pond No. 7 remained unfertilized, No. 8 was fertilized with superphosphate (3.5 mg P/l in 8 doses), and No. 9 was fertilized with superphosphate and Norway saltpetre (18.2 mg N/l in 8 doses).

The first soil samples were collected in 1965, before the initial filling of the newly constructed ponds, from the level 0–10 cm. The second sampling occurred in 1967, after a fish haul. Samples were then taken from two levels, i.e., 0–1 cm and 0–10 cm. All the soil indications were made according with methods accepted in soil science (Lityński et al. 1965). The total iron content was indicated in the 0.1 N HCl extract.

In water the following characteristics were indicated: alkalinity, total hardness, phosphates and mineral compounds of nitrogen (NO_3^-, NO_2^-, NH_4^+, pH value, dissolved oxygen content, oxydability and chemical oxygen demand (the organic carbon content was computed from the C.O.D.), and organic phosphorus. Indications were made according with Just and Hermanowicz (1964), except for organic phosphorus, which was indicated according with Czensny (1960).

The chlorophyll "a" contents was also indicated by filtering plankton through membrane filters. Chlorophyll was extracted by 90% acetone and indicated in a spectrocolorimeter; the Sandoz Co. Ltd. chlorophyll standard for the drawing of the calibration curve was applied.

The phytoplankton primary production was indicated at three depth levels: at the surface, at 50 cm and at 100 cm, using the oxygen method of light and dark bottles (Winberg 1960). The period of exposition was always 24 hr, starting between 9 and 10 a.m.

3. RESULTS

DESCRIPTION OF POND SOILS

Before the filling with water, the pond soils had been marked by low organic matter content, while the C : N ratio had ranged from 8.3 to 10.3 (Table I). The pH had been slightly acid. In 1967, after three years of exploitation, extensive changes of the physical and chemical properties of the bottom soils were found. The organic matter contents increased, in particular in the 0–1 cm layer. As a result of liming, the total of exchangeable bases in the fertilized ponds increased. The amount of iron increased notably. The high pH value of water, recorded several times during the vegetation season, was bringing about a precipitation of iron compounds and their accumulation at the ponds' bottoms.

CHEMICAL CHARACTERISTICS OF WATER

The experimental ponds, as well as the other fish ponds at Gołysz, are supplied with Vistula water. Total hardness of the inlet only at rare moments exceeds 80.0 mg $CaCO_3$/l, mean Ca content being 22 mg/l, and mean Mg content 3 mg/l (Wróbel 1965 b). As a result of liming before the initial filling (90 g of CaO/m^2), total hardness of water increased most in the unfertilized pond (Table II). Lesser increases of hardness were found in fertilized ponds, with the minimum in the pond fed with superphosphate alone (Table III). Alkaline reaction has been maintained

Table I. Some physico-chemical properties of pond soils

	Pond No. 7			Pond No. 8			Pond No. 9		
	1965	1967		1965	1967		1965	1967	
Depth (cm)	0–10	0–10	0–1	0–10	0–10	0–1	0–10	0–10	0–1
pH of H_2O	6.7	6.5	7.5	6.4	6.4	7.2	6.6	6.8	7.2
pH of KCl	5.8	5.7	6.9	5.3	5.8	6.7	5.5	6.5	6.9
Hydrolytic acidity (meq/100 g)	1.94	2.44	1.22	1.94	2.08	1.36	1.94	1.94	1.44
Total exchangeable bases (meq/100 g)	11.56	10.33	12.74	10.70	11.15	12.86	10.13	11.94	12.02
Sorption capacity (meq/100 g)	13.50	12.77	13.96	12.64	13.23	14.22	12.07	13.88	13.46
Degree of base saturation (%)	85.6	80.9	91.3	84.6	84.3	90.4	83.9	86.0	89.3
Organic carbon (%)	1.197	1.573	1.606	1.082	1.232	1.411	1.157	1.545	1.691
Total nitrogen (%)	0.130	0.153	0.176	0.112	0.132	0.165	0.120	0.162	0.203
C : N	9.21	10.28	9.13	9.66	9.33	8.55	9.64	9.54	8.33
Iron (mg/100 g)	24.0	66.5	84.0	28.5	66.5	90.5	27.0	86.0	102.0

Table II. Chemical composition of water in control pond No. 7 in 1967

Date	28 VI	10.VII	19.VII	28.VII	8.VIII	17.VIII	28.VIII	15.IX	28.IX	11.X
Temperature (°C)	26.0	19.9	23.7	25.2	21.7	23.0	19.2	17.6	18.0	15.2
pH	8.0	7.2	7.4	7.5	7.6	7.8	7.5	7.5	7.8	8.0
Phenolphthalein alkalinity (meq/l)	0	0	0	0	0	0	0	0	0	0
Total alkalinity (meq/l)	1.32	2.0	2.22	2.43	2.58	2.70	2.80	2.68	2.60	2.75
Total hardness ($CaCO_3$ mg/l)	85.6	115.1	123.1	130.2	134.7	142.7	142.7	140.0	144.5	145.4
Ammonia nitrogen (mg/l)	—	—	0.22	0.22	0.28	0.35	0.28	0.20	0.22	0.24
Nitrite nitrogen (mg/l)	0.018	0.003	0.003	0.004	0.001	0.001	0.004	0.004	0.002	0.002
Nitrate nitrogen (mg/l)	0.612	0.200	0.137	0.080	0.050	0.075	0.080	0.075	0.100	0.080
Phosphate phosphorus (mg/l)	0.016	0.042	0.032	0.013	0.016	—	0.016	0.016	—	0.010
Organic phosphorus (mg/l)	0.15	0.12	0.13	0.13	0.09	—	0.13	0.09	—	0.07
Permanganate C.O.D. (O_2 mg/l)	4.77	8.62	8.47	8.32	8.82	8.51	8.37	7.58	6.51	7.44
Bichromate C.O.D. (O_2 mg/l)	—	22.9	23.7	25.7	24.4	26.4	29.0	25.9	22.1	26.0
Turbidity (SiO_2 mg/l)	16	13	23	21	35	35	94	48	23	20

Table III. Chemical composition of water in P pond No. 8 in 1967

Date	28.VI	10.VII	19.VII	28.VII	8.VIII	17.VIII	28.VIII	15.IX	28.IX	11.X
Temperature (°C)	26.1	19.7	23.7	25.0	20.7	22.7	19.0	17.4	17.9	15.4
pH	9.3	7.5	7.7	8.7	8.6	9.0	8.4	7.3	8.6	7.8
Phenolphthalein alkalinity (meq/l)	0.26	0	0	0.09	0.04	0.21	0.02	0	0.04	0
Total alkalinity (meq/l)	1.24	1.78	1.88	2.04	1.84	1.81	1.56	1.62	1.64	1.80
Total hardness ($CaCO_3$ mg/l)	87.4	112.4	117.7	124.9	105.2	107.0	93.6	89.2	94.6	104.4
Ammonia nitrogen (mg/l)	—	—	0.12	0.17	0.22	0.20	0.20	0.80	0.28	0.38
Nitrite nitrogen (mg/l)	0.003	0.013	0.003	0.005	0.001	0.001	0.004	0.014	0.064	0.074
Nitrate nitrogen (mg/l)	0.150	0.251	0.112	0.062	0.062	0.055	0.094	0.062	0.070	0.128
Phosphate phosphorus (mg/l)	0.205	0.235	0.170	0.134	0.023	—	0.020	0.098	—	0.039
Organic phosphorus (mg/l)	0.21	0.15	0.21	0.22	0.27	—	0.34	0.26	—	0.19
Permanganate C.O.D. (O_2 mg/l)	8.16	6.93	7.39	8.32	9.42	9.42	13.33	11.38	12.40	10.23
Bichromate C.O.D. (O_2 mg/l)	—	16.8	23.7	28.7	38.2	40.4	47.4	38.9	44.1	36.7
Turbidity (SiO_2 mg/l)	16	10	16	25	108	69	160	113	200	118

Table IV. Chemical composition of water in N + P pond No. 9 in 1967

Date	28.VI	10.VII	19.VII	28.VII	8.VIII	17.VIII	28.VIII	15.IX	28.IX	11.X
Temperature (°C)	25.3	19.9	23.2	24.5	21.3	22.4	18.9	17.6	17.9	15.1
pH	9.9	7.1	7.4	8.1	7.6	8.6	7.4	7.5	8.0	7.8
Phenolphthalein alkalinity (meq/l)	0.52	0	0	0	0	0.06	0	0	0	0
Total alkalinity (meq/l)	1.16	2.02	2.30	2.38	2.56	2.66	2.40	2.32	2.32	2.45
Total hardness ($CaCO_3$ mg/l)	83.8	121.3	129.3	132.0	133.8	139.2	132.0	130.2	134.7	132.9
Ammonia nitrogen (mg/l)	—	—	0.80	0.21	0.35	0.27	0.35	0.32	0.41	0.38
Nitrite nitrogen (mg/l)	0.029	0.036	0.020	0.098	0.001	0.003	0.033	0.150	0.002	0.006
Nitrate nitrogen (mg/l)	0.525	0.310	0.362	0.238	0.065	0.078	0.430	0.205	0.082	0.080
Phosphate phosphorus (mg/l)	0.033	0.241	0.121	0.039	0.016	—	0.020	0.048	—	0.029
Organic phosphorus (mg/l)	0.26	0.24	0.38	0.32	0.37	—	0.35	0.27	—	0.24
Permanganate C.O.D. (O_2 mg/l)	8.93	9.70	13.55	21.87	12.16	12.46	10.29	10.74	14.26	9.92
Bichromate C.O.D. (O_2 mg/l)	—	26.0	54.8	40.0	39.7	49.7	39.7	36.0	56.7	41.3
Turbidity (SiO_2 mg/l)	39	16	27	55	104	118	200	113	104	124

in it for the longest period, and thus it was there that most carbonates precipitated. Before the sluicing down of waters, in pond No. 7 the hardness was 145.4 mg $CaCO_3$/l, and in pond No. 8 it was 104.4 mg/l.

The total hardness of water allowed to assess the amount of lime which had floated off with drainage before the fish haul. The loss was 33% of the CaO amount supplied by the liming in the unfertilized pond, 9% in the pond fed with superphosphate alone, and 27% in the phosphorus + nitrogen fertilized pond. It is remarkable that the loss of lime was highest in the pond with law eutrophication level.

The mean phosphates content in the unfertilized pond water was 0.020 mg P/l, and in the fertilized ones it was 0.116 mg/l (No. 8) and 0.068 mg/l (No. 9; see Table IV). During the warmest months of July and August, when the highest primary production was observed, the phosphates content in the fertilized ponds fell down to the level recorded in the unfertilized one. A comparison of the amount of phosphorus supplied in a single dose (0.44 mg P/l) with the PO_4 amount actually found in water, reveals a rapid elimination of the phosphates. During the vast primary production periods, the phosphates content used to drop to the pre-fertilization level after 5 to 7 days. The phosphates content decrease was in average 0.064 mg P/l/24 hr in pond No. 8, and 0.069 mg P/l/24 hr in No. 9.

The mean organic phosphorus contents in pond waters were as follows: No. 7 — 0.114 mg P/l; No. 8 — 0.231 mg P/l; No. 9 — 0.304 mg P/l. Thus it was largest in the pond fertilized with nitrogen in addition of phosphorus.

Mineral and organic phosphorus found in water constituted only a small percentage of the amount supplied in the fertilizers; it amounted to 6.1% in the pond fertilized with P alone, and 6.8% in the P + N fed pond. Also the drainage loss was not large; for both fertilized ponds it was 7.0% of the amount supplied.

In pond No. 9, fertilized with ammonium nitrate, at some periods the nitrates content was found to be larger than in the other two, though even in No. 9 it dropped in August to a level recorded in the ponds not supplied with nitrogen. The drop of mineral nitrates during one day was five times larger than of phosphorus. It was 0.320 mg N/l. It should be mentioned that the N : P ratio in the fertilizers was equal to 5.2.

One of the indicators of the effectiveness of fertilization is the organic matter content in pond waters. Organic carbon and phosphorus were measured in 12 ponds, 4 of which remained unfertilized, 4 were fed with superphosphate, and 4 with superphosphate and Norway saltpetre (Wróbel 1971). The lowest amounts of organic carbon were found in the control ponds, and the highest in those fertilized with P + N (see Fig. 1).

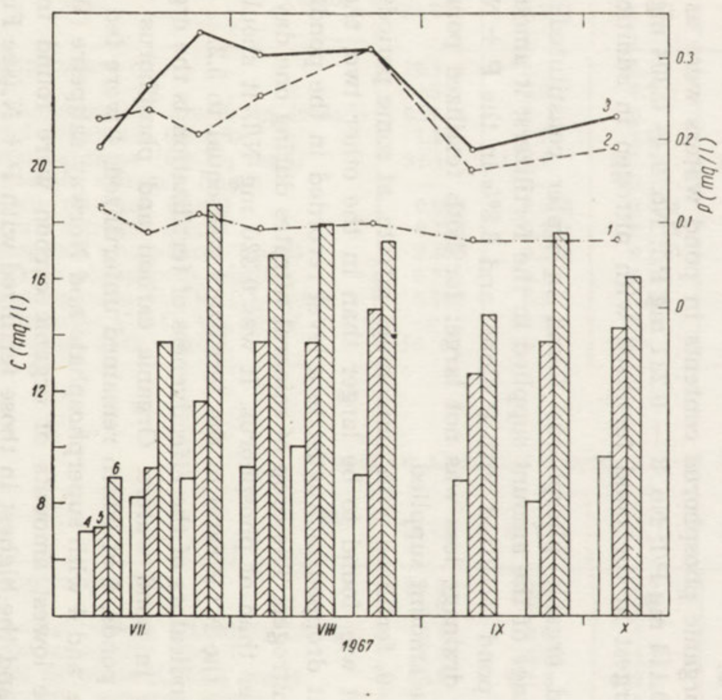

Fig. 1. Organic phosphorus and carbon content in pond water (average values from 4 tests). 1 — P org. in control ponds; 2 — P org. in P-fertilized ponds; 3 — P org. in N + P fertilized ponds; 4 — C org. in control ponds; 5 — C org. in P-fertilized ponds; 6 — C org. in P + N fertilized ponds

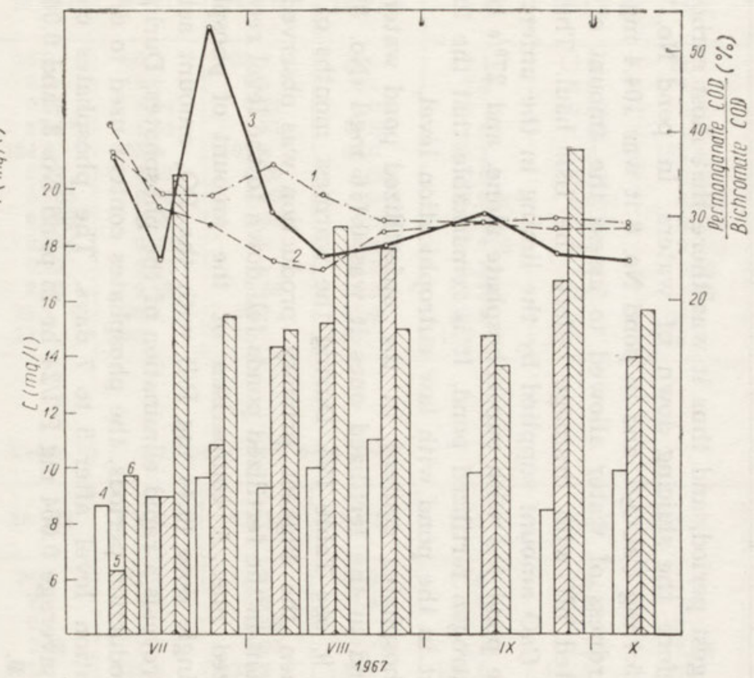

Fig. 2. Per cent ratio of permanganate COD. to bichromate COD. in ponds (1 — No. 7, 2 — No. 8, 3 — No. 9), and organic carbon content in waters of ponds (4 — No. 7, 5 — No. 8, 6 — No. 9)

This regularity was observed independent of the moment of sampling. In Figure 2 the amount of carbon in ponds No. 7, 8 and 9 is presented, which were fertilized in the three ways designated above. The lowest C values are here observed in the control pond, and the highest in the P + N fed pond. The mean C amounts were: 9.4 mg C/l in No. 7; 13.1 mg C/l in No. 8; 16.0 mg C/l in No. 9. Figure 2 presents also the oxidation degree of organic matter by $KMnO_4$ (oxydability) in relation to the C.O.D. The most extensive fluctuations of the ratio of oxydability to the C.O.D. were observed in pond No. 9; they ranged from 23 to 52%, and some regularity could be observed. During rapid increases of the organic matter content, the percentage of $KMnO_4$ oxidation decreased, and it increased when the organic matter content dropped.

The level of oxygen dissolved in water depended upon the intensity of photosynthesis and the destruction of organic matter. In the unfertilized pond No. 7 it happened only at the beginning of the season that 100% of oxygen saturation was observed (Fig. 3). During the whole season it was kept lower. The largest fluctuations of oxygen content were recorded in the P + N fed pond No. 9 (from 10 to 170%); they were somewhat lesser in pond No. 8 (from 40 to 130%). It must be added that the oxygen contents presented in Tables II, III and IV constitute average values from O_2 indications at three depth levels in each pond. In spite of intensive fertilization, attempts to avoid large fluctuations of oxygen content in pond waters failed.

PRIMARY PRODUCTION OF PHYTOPLANKTON

In the differently fertilized ponds, similar algae communities could be found, with Cyanophyta prevailing in August. In pond No. 9 Chlorophyta were present all the time in large amount (Krzeczkowska-Wołoszyn 1971). During the maximal production period, in August, in pond No. 8, Cyanophyta of the genera Anabaena and *Aphanizomenon flos aquae* predominated, while in pond No. 9, Chlorophyta (Volvocales) and Euglenophyta were responsible for maximum productivity (in July). In the unfertilized pond, both Cyanophyta and Chlorophyta could be found, but their amounts were small in comparison with the fertilized ponds.

Mean chlorophyll content in water of the superphosphate fed pond (No. 8) was four times larger than in the unfertilized pond, while in the P + N fed pond No. 9 it was only 4.5 times larger than in the control.

The total primary phytoplankton production in No. 8 was 2.3 times larger than in the control, while in No. 9 it was 2.8 times larger. Remarkable is the phenomenon of total production increase in the P + N

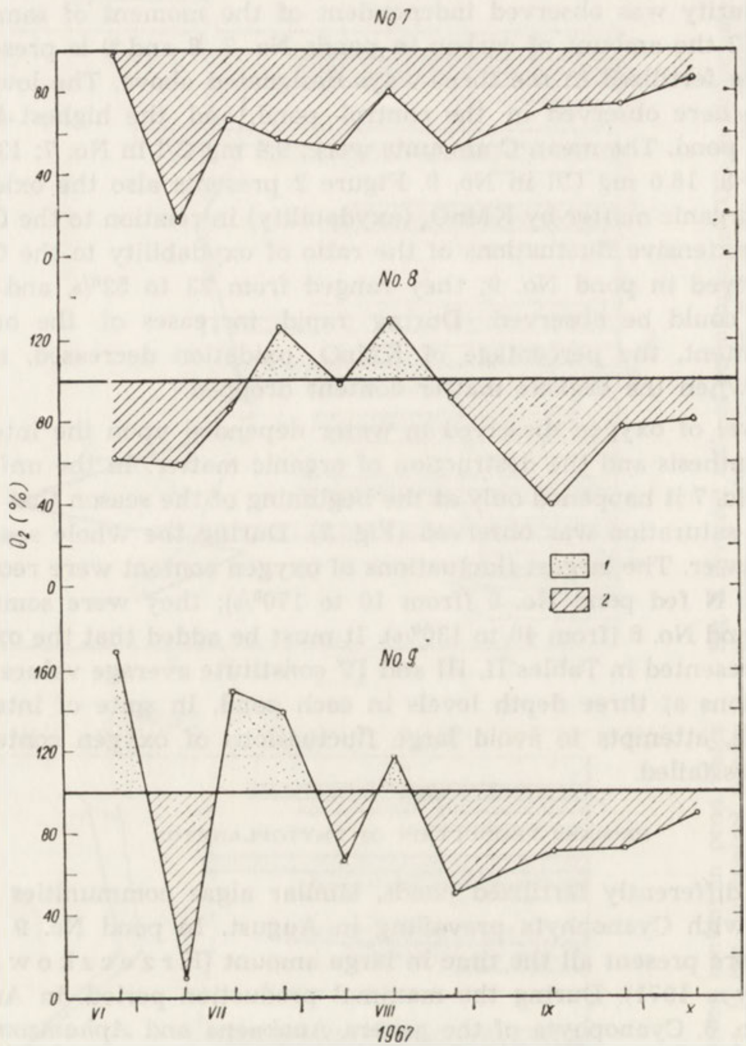

Fig. 3. Per cent of oxygen content in ponds' waters. 1 — O_2 deficit; 2 — oversaturation

fed pond in comparison with the pond fertilized with phosphorus alone, in spite of a somewhat lesser net production in No. 9. Thus, in the mixed fertilized pond the B.O.D. increased by 33%.

The timing of maximum productivity was different for the control and phosphorus-fertilized pond on one hand, and the phosphorus + nitrogen fed one on the other (Fig. 4). In No. 7 and 8, maximum productivity was recorded at the same moments, while in No. 9 it had been observed a month earlier. In the fertilized ponds, the beginning of the research period was marked by a notable predomination of decay processes over organic synthesis. Probably two or three days earlier a moment of high production had occurred, which was missed, as observations started two days too late. During the first half of July bad weather caused a notable drop of phytoplankton production in all ponds. Solar radiation during this period was two to six times less intensive than on sunny days (S z u m i e c 1971).

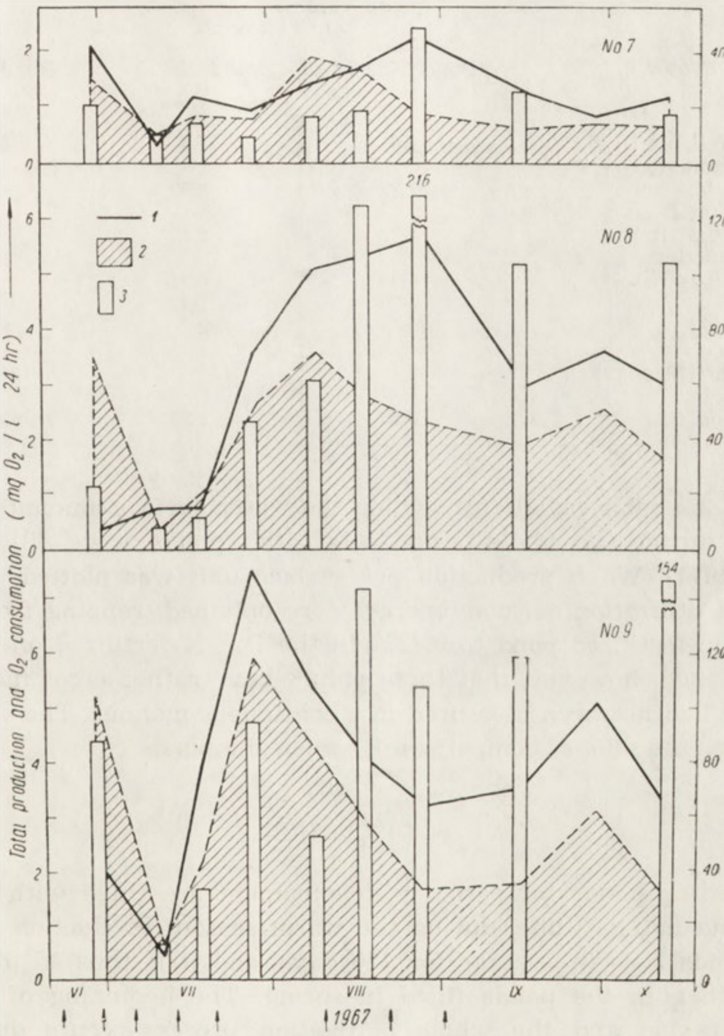

Fig. 4. Primary production and chlorophyll content in ponds. 1 — total production; 2 — B.O.D.; 3 — chlorophyll content. Arrows denote fertilization

In Table V the ratio of the total production during the whole period of research to the average phytoplankton biomass is shown; biomass was computed from chlorophyll contents, assuming that it constitutes 2.5% of dry weight of phytoplankton. From a comparison of the Production/ Biomass ratio it can be seen that photosynthesis has been occurring most intensively in the unfertilized pond, in which water has been the least turbid (Table II).

Table V. Comparison of primary production and other factors in ponds (mean values)

Factor	Pond No. 7	Pond No. 8	Pond No. 9
Chlorophyll (μg/l)	19.6	77.3	88.8
Total production — P (mg O_2/l/24 hr)	1.33	3.09	3.77
Destruction D (mg O_2/l/24 hr)	1.02	2.17	2.88
Net production (mg O_2/l/24 hr)	0.31	0.92	0.89
P : D	1.30	1.42	1.31
P : B	140	82	88
Production (kcal/m²/120 days)	502	1135	1366
Use of solar radiation (%)	0.15	0.35	0.42

The total solar radiation reaching the water surface amounted to 32.5 kcal/cm² during the whole period when the ponds were filled (Szumiec 1971). When production per surface unit was plotted, very low values of utilization of solar energy were obtained, ranging from 0.15% in the non-fertilized pond to 0.42% in the P + N fertilized one. It must be mentioned, however, that these values have rather error margins, as radiation had not been measured in a continuous manner. The values are quoted for the sake of comparison between the ponds.

4. DISCUSSION

Fingerling ponds for carp fry development are filled with water in the second half of June, during the warm season. Production period in these ponds lasts in average for 120 days, and it is thus 45 to 50 days shorter than in the ponds filled in spring. The beginning of the production period and the whole cultivation process occurs during the warmest months. This fact is important for the shaping of chemical conditions in pond waters, and for the effects of the nitrogen and phosphorus compounds supplied in fertilizers. It should be added that the 1967 summer was rather favourable, as both the solar radiation and temperature were higher than average (S z u m i e c 1971). Meteorological factors influenced the rate of nitrogen and phosphorus compounds elimination. The decrease of nitrogen contents was 0.32 mg/l/24 hr in pond No. 9, and of phosphorus 0.064 to 0.069 mg/l/24 hr (average values for No. 8 and 9 respectively), while the ratio of N + P decrease reflected the ratio of these elements as supplied in the fertilizers.

The decrease of P + N mineral compounds contents was not due to biological sorption alone. Assuming the net production (i.e., its value after deducting the production yielded by the unfertilized pond) as the basis for the assessment of biological phosphorus sorption, very low values were obtained, not exceeding 8%, which means that only 8% of the eliminated phosphorus had been utilized in primary phytoplankton production (it was assumed that one weight unit of P is absorbed per 40 units of carbon).

As primary production values during a season are considered (Fig. 4), it can be seen that the provision of phosphorus alone did not change the timing of maximum and minimum production of organic matter, but it had an important influence upon the extent of such production. The use of nitrogen together with phosphorus shifted the maximum productivity moment from the end of August to the end of July, while production increase was not large in comparison with the difference between the unfertilized and phosphorus fed ponds.

Thus the hypothesis (W r ó b e l 1971) is confirmed that nitrogen demand, or the influence of nitrogen upon productivity, depends on physical factors, and most of all upon temperature. The influence of nitrogen fertilizing alongside with phosphorus fertilizing is greater under higher geographical latitudes, and under a given latitude it is greater when average temperatures during a growth season are lower. Thus mixed fertilizing is more effective in ponds which are filled with water from a spring, and are fertilized from the beginning of May (W r ó b e l 1962).

Primary production of phytoplankton in the studied ponds, and in the fertilized ponds in particular, must be judged as rather low, as it was 1135 kcal/m² in pond No. 8, and 1366 kcal/m² in No. 9. It must be stressed that such results were obtained in ponds which were intensively fertilized, as 32 kg of P and 163 kg of N were supplied per one hectare. In other ponds of the same farm as many as 2000 to 2800 kcal/m² during a season were obtained, while less P + N was provided (W r ó b e l 1962, 1965 a, b, 1970, F e r e ń s k a and L e w k o w i c z 1966).

Chemical analyses of waters and soils were carried out in new ponds, utilized for only three years. This fact offered an opportunity to assess the influence of the presence of water upon the soil. In under-water soils occurred an increase of organic matter content and of general nitrogen, and most of all of general iron. Similar changes had been found earlier by Stangenberg (1943) who compared chemical contents of pond soils and of neighbouring dry soils. Another phenomenon was an accumulation of phosphorus on the ponds' bottoms, as the losses during the sluicing before a fish haul were only 7% as compared with the amount supplied in superphosphate.

5. SUMMARY

In 1967 experiments were carried out to study the influence of fertilizing on production of all the trophic levels in fingerling ponds. The study was made in experimental ponds at Gołysz.

Very rapid decrease of nutrition elements content supplied in fertilizers was found. The decrease of mineral nitrogen compounds was 0.32 mg/l during 24 hr in average, which amounted to 14% of nitrogen supplied in a single dose of ammonium nitrate.

The decrease of phosphates content was five times lesser (0.066 mg P/l/24 hr), but this, too, constituted 15% of phosphorus supplied in a single dose of superphosphate.

An attempt was made to assess the share of phytoplankton in elimination of phosphates, considering the net production of phytoplankton. This share was small and amounted to only 8%.

The primary production of phytoplankton in the studied ponds was rather low. During the season (i.e., 120 days) it was 501 kcal/m^2 in the unfertilized pond, 1135 kcal/m^2 in the superphosphate fertilized pond, and 1366 kcal/m^2 in the pond fed with superphosphate and ammonium nitrate. In the latter, destruction increased notably, which was perhaps responsible for the large oxygen deficit occurring in some periods.

During the warm and sunny 1967 summer a very slight effect of nitrogen fertilizing (added to P) could be observed in comparison with the pond to which phosphorus only was supplied.

6. STRESZCZENIE

W 1967 r. przeprowadzono badania nad wpływem nawożenia mineralnego na produkcję wszystkich poziomów troficznych w stawach przesadkowych. Doświadczenia wykonano w stawach eksperymentalnych w Gołyszu.

Stwierdzono bardzo szybki spadek zawartości składników odżywczych dostarczanych w nawozach. Spadek mineralnych form azotu wynosił średnio 0,32 mg/l w ciągu doby, co stanowiło ok. 14% dodanego azotu w jednej dawce saletry amonowej.

Mimo że spadek zawartości fosforanów był pięciokrotnie mniejszy (średnio dla stawów 0,066 mg P/l/dobę), wynosił również ok. 15% fosforu dodanego w 1 dawce.

Ponadto próbowano ocenić udział fitoplanktonu w eliminacji fosforanów, uwzględniając produkcję netto fitoplanktonu. Udział ten był niewielki i wynosił zaledwie 8%.

Produkcja pierwotna fitoplanktonu w badanych stawach była raczej niska. W ciągu sezonu (120 dni) wynosiła ona: w stawie bez nawożenia — 501 kcal/m^2, w stawie nawożonym samym superfosfatem — 1135 kcal/m^2 i w stawie nawożonym superfosfatem i saletrą amonową — 1366 kcal/m^2. W tym ostatnim zwiększyła się znacznie destrukcja, co prawdopodobnie spowodowało w pewnych okresach duży deficyt tlenu.

W ciepłym i pogodnym sezonie w 1967 r. zaznaczył się niski efekt nawożenia azotowego (łącznie z P) w porównaniu ze stawem, do którego dodawano sam fosfor.

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PHYTOPLANKTON OF FINGERLING PONDS

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ABSTRACT

Phytoplankton of variously fertilized fingerling ponds of the Experimental Farm of the Laboratory of Water Biology at Gołysz was investigated. Species composition, and amount of algae were estimated, and their surfaces were computed. A relationship between these factors and the type of fertilization was confirmed. Primary production in the control pond was lower than in the fertilized ponds.

CONTENTS

1. INTRODUCTION

The present report is a part of a team project performed in 1967 on fingerling carp ponds of the Experimental Farm of the Laboratory of Water Biology of the Polish Academy of Sciences at Gołysz (Cieszyn district). Samples were collected at the same or similar terms as for the other analyses, both biological (Grabacka 1971, Lewkowicz 1971, Zięba 1971) and chemical ones (Lewkowicz and Wróbel 1971) reported in the present issue.

The main aim of this work was to investigate the qualitative and quantitative composition and also the surface of algae in relation to the type of fertilization.

2. TERRAIN AND METHODS

Researches were carried out in 3 fingerling ponds (No. 7 — control, No. 8 — fertilized with superphosphate, No. 9 — fertilized with ammonium nitrate and superphosphate). Two ponds were filled for the first time in 1965 for about two months (July and August). In 1966 they have been filled from April to October. In 1967 they were filled on June 20th, and sluiced down on October 17th. During this period they were fertilized 8 times (June 23 and 30, July 6, 14 and 21, August 10 and 22, September 1, 1967), each time 3.5 mg P/l were put into No. 8, and 18.2 mg N/l + 3.5 mg P/l into No. 9.

Samples were drawn with a 5 litres, 50 cm high, Patalas (1954) sampler, in four sites of each pond. As the depth of water at these sites was usually 60 to 70 cm, almost the whole of the water column could be sampled. Water was then strained through a plankton net No. 25 (77.5 threads per 10 mm); besides, 100 ml of the unstrained water was sampled from the center of each pond.

Parallely with qualitative analyses, amont (number of specimens in 1 l of water) and surfaces of projections of algal cells (in mm^2/l of water) were calculated according to the method elaborated and described in details by Starmach (1969 a, b). Two preparations, each of 0.05 ml capacity, were made from every sample of water. Always 10 fields in each preparation were counted by means of a net micrometer fixed in eyepiece 12.5× and objective 40×. In that context, a net micrometer has 400 square fields; one of them covers a surface of 100 μ^2.

3. RESULTS

QUALITATIVE COMPOSITION

118 species and 6 varieties belonging to 69 genera have been distinguished in phytoplankton of the investigated ponds. Here is a full list of the found forms (the figures 7, 8 or 9 refer to the pond number in which a respective form was found).

Anabaena circinalis Rbh 7, 8, *A. ellipsoides* Boloch. em. Woron. 8, *A. flos aquae* (Lyngb.) Breb. 7, *A. solitaria* Kleb. 7, 8, *A. spiroides* Kleb. 7, 8, *A. Sp. div.* 8, *Aphanizomenon flos aquae* (L.) Ralfs 8, 9, *Aphanocapsa sp.* 7, 8, *Gomphosphaeria sp.* 7, 8, 9, *Merismopedia tenuissima* Lemm. 8, 9, *Microcystis aeruginosa* Kütz. 7, 8, 9, *Oscillatoria sp.* 7, 9, *Romeria elegans* (Koczw.) Wołoszyńska 8, *Colacium vesiculosum* Ehr. 7, 8, 9, *Euglena acus* Ehr. 7, 8, 9, *E. proxima* Dangeard 7, 8, *E. tripteris* (Duj.) Klebs 7, 8, 9, *E. sp.* 7, 8, 9, *Lepocinclis ovum* Lemm. 7, 8, *Phacus helicoides* Pochm. 9, *P. longicauda* (Ehr.) Duj. 8, 9, *P. orbicularis* Hübner 9, *P. pleuronectes* (Müll.) Duj. 7, 8, 9, *P. tortus* (Lemm.) Skv. 8, *B. triqueter* (Ehr.) Duj. 7, 8, 9, *P. sp.* 8, *Strombomonas fluviatilis* (Lemm.) Defl. 7, 8, 9, *S. sp.* 8, *Trachelomonas Dybowskii* Dreż. 7, 8, *T. hispida* (Perty) Stein em. Defl. 7, 8, 9, *T. hispida var. coronata* Lemm. 8, *T. hispida var. duplex* Defl. 9, *T. oblonga* Lemm. 8, *T. planctonica* Swir. 7, 8, *T. planctonica var. oblonga* Dreż. 8, *T. punctata* Kuff. et Conr. 8, *T. rotunda* Swir. em. Defl. 8, *T. similis* Stokes 8, *T. superba* (Swir.) Defl. 8, *T. verrucosa* Stokes 7, *T. volvocina* Ehr. 7, 8, 9, *T. sp. div.* 7, 8, 9, *Ceratium hirundinella* Duj. 7, 8, 9, *Peridinium sp.* 7, 9, *Dichotomococcus curvatus* Korschik. 7, 8, *Ophiocytium capitatum* Wolle 8, *Oph. sp.* 9, *Dinobryon divergens* Imhof 8, 9, *D. sociale* Ehr. 7, *Mallomonas sp.* 7, *Ochromonas sp.* 8, *Synura uvella* Ehr. 7, 8, 9, *Cryptomonas erosa* Ehr. 7, *C. sp. div.* 7, 8, 9, *Achnanthes sp. div.* 7, 9, *Cyclotella sp. div.* 7, *Cymbella sp. div.* 7, 8, *Cymatopleura solea* (Breb.) W. Sm. 7, 8, *Diatoma vulgare* Bory 7, *Eunotia sp. div.* 8, 9, *Gomphonema olivaceum* (Lyngb.) Kütz. 7, *G. sp. div.* 7, 8, 9, *Melosira granulata var. angustissima* (Ehr.) Ralfs 7, 8, 9, *M. varians* Ag. 7, 8, 9, *Navicula cryptocephala* Kütz. 7, 8, *N. sp. div.* 7, 8, 9, *Nitzschia acicularis* W. Sm. 7, 8, *N. sp. div.* 7, 8, 9, *Synedra acus* Kütz. 7, 8, 9, *S. ulna* (Nitzsch.) Ehr. 7, 8, 9, *Bacillariophyceae n. det.* 7, 8, 9, *Actinastrum Hantzschii* Lagerh. 7, *A. Hantzschii var. fluviatile* Schroed. 9, *A. pseudomirabilis* Korschik. 7, 8, 9, *Asterococcus superbus* (Cienk.) Sch. 7, 8, 9, *Botryococcus Braunii* (Snow) Printz 7, 8, 9, *Characium gracilipes* Lamb. 7, 8, 9, *Ch. limneticum* Lemm. 7, *Coelastrum cambricum* Archer 8, 9, *C. microsporum* Näg. 9, *C. proboscideum* Bohl. 7, 8, 9, *Crucigenia quadrata* Morren 7, 8, 9, *C. apiculata* (Lemm.) Schmidle 7, 8, 9, *C. rectangularis* (A. Braun) Gay 7, 8, 9, *C. tetrapedia* (Kirchn.) West et West 9, *C. sp. div.* 7, 8, 9, *Didymocystis sp.* 9, *Dictyosphaerium Ehrenbergianum* Näg. 7, *D. pulchellum* Wood 7, 8, 9, *Elakatothrix sp.* 7, 8, *Golenkinia radiata* Chod. 7, 8, *Kirchneriella sp. div.* 7, 8, 9, *Lagerheimia ciliata* (Lagerh.) Chod. 7, 8, *L. Chodatii* Bern. 7, 8, 9, *Micractinium pusillum* Fr. 9, *Nephrochlamys subsolitaria* (West.) Korschik. 7, 8, 9, *N. sp.* 8, 9, *Oocystis elliptica* W. West 8, 9, *O. gigas* Archer 9, *O. lacustris Chodat* 8, 9, *O. parva* West et West 9, *O. sp.* 7, 8, *Pediastrum biradiatum* Meyen 9, *P. Boryanum* (Turp.) Menegh. 7, 8, 9, *P. duplex* Meyen 9, *P. obtusum* Lucles 9, *P. tetras* Ehr. Ralfs 7, 9, *Scenedesmus acuminatus* (Lagerh.) Chod. 7, 8, 9, *S. acutus* Meyen 7, 8, 9, *S. acutus f. alternans* Hortob. 7, 8, 9, *S. acutiformis* Schroed. 9, *S. alternans* Reinsch. 7, *S. arcuatus* Lemm. 9, *S. armatus* (Chod.) G. M. Smith 7, *S. brasiliensis* Bohl. 8, *S. denticulatus* Lagerh. 7, 9, *S. ecornis* (Ralfs) Chod. 7, 8, 9, *S. granulatus* W. S. West 9, *S.*

opoliensis (Richt.) 7, 8, 9, *S. ovalternus* Chod. 7, *S. quadricauda* Chod. 7, 8, 9, *S. quadricauda var. maximus* W. et West 9, *S. spinosus* Chod. 7, 8, 9, *S. sp. div.* 7, 8, 9, *Schroederia setigera* (Schroed.) Lemm. 7, *Sphaerocystis Schroeteri* Chod. 8, 9, *Tetraëdron caudatum* (C.) Hansg. 9, *T. minimum* (A. Braun) Hansg. 7, 8, 9, *T. regulare* Kütz. 7, 9, *T. trigonum* (Näg.) Hansg. 8, *Westella botryoides* W. West 7, 8, 9, *Chlamydomonas sp. div.* 7, 8, 9, *Eudorina elegans* (L.) Ehr. 7, 8, 9, *Gonium pectorale* Müll. 7, 8, 9, *Pandorina morum* Bory 7, 8, 9, *Phacotus lenticularis* Ehr. 8, 9, *Uva elongata* (Korschik.) Fott 7, 9, *Volvox aureus* Ehr. 9, *V. globator* Ehr. 7, 8, 9, *Closterium acerosum* (Schrank.) Ehr. 7, *C. Ehrenbergii* Menegh. 7, *C. sp. div.* 7, 8, 9, *Cosmarium Botrytis* Menegh. 7, 9, *C. subcrenatum* Hantzsch. 7, *C. sp. div.* 7, 8, 9. *Desmidium Swartzii* Ag. 8, *Staurastrum alternans* Breb. 7, 8, 9, *Spirogyra sp.* 8, 9, *Zygnema sp.* 8, 9.

The greatest number of species was found among the Chlorophyta, of the order Chlorococcales. Some of them, notably those belonging to the genera Scenedesmus, Crucigenia, Tetraëdron, Ankistrodesmus, Botryococcus and Pediastrum, occurred in the particular ponds during the whole research period. Mass appearance or water-blooms of some species of the order Volvacales (*Phacotus lenticularis, Volvox aureus, V. globator, Chlamydomonas sp.*) could be most often observed in the fertilized ponds. Some of the Euglenophyta, mainly from the genus Trachelomonas, tended to be a constant element of plankton of the investigated ponds. Bacillariophyceae *Melosira granulata var. angustissima, M. varians, Synedra acus, S. ulna,* Navicula, Gomphonema and Nitzschia were also frequently found, particularly in the control pond. In August and September Cyanophyta have been prevailing: *Aphanizomenon flos aquae, Microcrystis aeruginosa,* and species belonging to the genus Anabaena.

AMOUNT AND SURFACES OF ALGAE

Numbers of individuals belonging to the several systematic groups have been changing in various ponds and periods (Fig. 1).

In pond No. 7, Chlorophyta and Cyanophyta have been most numerous. Their amounts tended to be similar, but changes in their quantities in relation to time were observed. Volvocales have been appearing abundantly, but for short periods only. So e.g. it was at the end of June only that *Uva alongata* (Korshikov) Fott *comb. nova, Pyrobotrys elongata* Korshikov appeared on mass scale (Bucka et al. 1968), and *Gonium pectorale* and *Eudorina elegans* were numerous. *Volvox aureus* and *V. globator* appeared in the small amounts and in single samples. On the other hand, Chlorococcales, as opposed to Volvocales, tended to be less numerous but their presence has been more continuous. They could be observed in greatest numbers at the end of June and in August.

The general amount of Cyanophyta was largely determined by the amount of *Aphanizomenon flos aquae*. It was found as early as the first sampling, then in August, and its quantity increased in September.

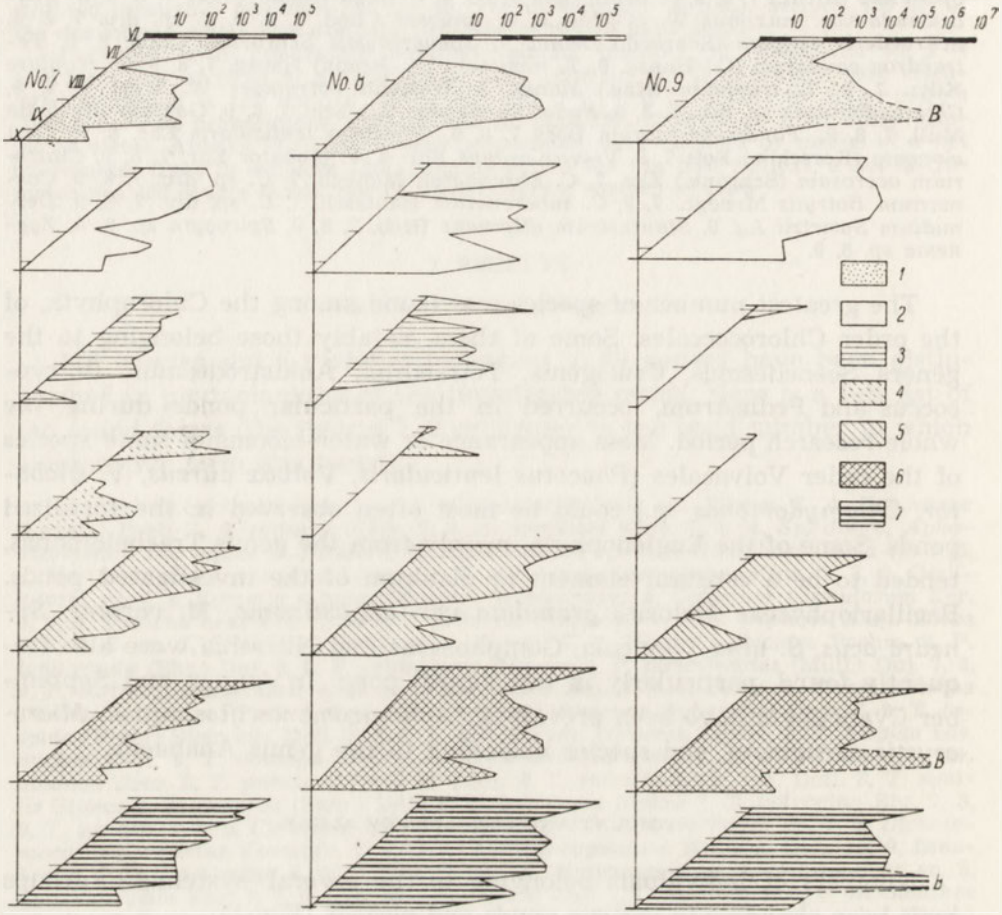

Fig. 1. Amounts of algae in 1 l of water in ponds No. 7, 8 and 9. 1 — Cyanophyta, 2 — Euglenophyta, 3 — Dinophyceae, 4 — Chrysophyceae, 5 — Bacillariophyceae, 6 — Chlorophyta, 7 — total. B — water-bloom of *Aphanizomenon flos aquae, Volvox globator* and *V. aureus*

Bacillariophyceae were also a frequent component of plankton. The maximum of their occurrence was noted at the end of June. During the first half of the filling period of the ponds, species belonging to the genera of Nitzschia, Navicula or Gomphonema had been prevailing, and later *Melosira granulata var. angustissima* was predominant.

Other algae fairly frequently recorded were *Ceriatum hirundinella* of the Dinophyceae, and *Dinobryon divergens* of the Chrysophyceae.

Surfaces of algae are presented in Table I. The greatest surfaces were computed for Volvocales hauled in June. Chlorococcales, roughly half as numerous as Volvocales, yielded almost 6 times smaller surfaces.

Table I. Total surfaces of algae expressed in mm^2/1 l of water

Algae	Pond No. 7										
	27.VI	11.VII	17.VII	27.VII	11.VIII	18.VIII	28.VIII	14.IX	23.IX	28.IX	12.X
Cyanophyta	2.55	1.00	0.09	0.01	3.98	1.34	5.69	9.30	58.16	—	2.38
Euglenophyta	0.06	1.25	1.32	0.20	0.66	0.12	0.01	1.33	0.50	0.12	0.38
Dinophyceae	0.04	0.15	0.08	0.18	0.22	0.65	0.35	2.15	—	—	0.35
Chrysophyceae	2.22	1.28	52.40	—	—	0.06	0.06	7.70	8.00	0.48	6.30
Bacillariophyceae	2.30	0.10	1.06	0.25	5.40	0.30	0.02	3.23	0.37	0.02	0.80
Chlorophyta	127.50	0.60	1.22	0.33	4.50	2.10	0.22	4.02	6.31	1.24	0.78
Total	134.67	4.38	56.17	0.97	14.76	4.57	6.35	27.73	73.34	1.86	10.99
Algae	Pond No. 8										
	27.VI	11.VII	17.VII	27.VII	7.VIII	18.VIII	28.VIII	5.IX	14.IX	28.IX	12.X
Cyanophyta	—	—	1.26	28.80	24.32	384.25	1403.60	955.35	25.00	22.50	0.05
Euglenophyta	5.85	1.60	2.05	—	14.30	7.14	61.15	0.35	6.70	538.70	2.40
Dinophyceae	—	33.50	—	2.50	0.60	11.50	4.82	161.15	20.52	—	—
Chrysophyceae	0.03	—	0.10	8.80	—	—	—	—	—	—	—
Bacillariophyceae	49.99	6.50	1.57	58.45	93.61	2.40	—	10.64	0.45	22.00	0.25
Chlorophyta	377.40	8.67	10.31	21.39	433.11	433.11	228.30	1108.31	3.50	561.22	1.02
Total	433.27	50.27	15.19	119.94	565.94	838.40	1697.87	2235.80	56.17	1144.42	3.72
Algae	Pond No. 9										
	27.VI	11.VII	17.VII	27.VII	11.VIII		28.VIII			23.IX	12.X
Cyanophyta	2.95	0.72	10.80	20.90	2462.40		8090.15			443.52	0.90
Euglenophyta	1.22	2.05	5.21	29.60	155.40		243.26			2.45	17.13
Dinophyceae	0.30	—	—	—	—		—			—	—
Bacillariophyceae	4.30	0.80	4.50	2.20	32.65		—			0.80	0.03
Chlorophyta	226.75	34.75	1638.25	26.22	357.70		261.57			8.50	21.87
Total	235.52	38.32	1658.76	78.92	3008.15		8594.98			455.27	39.93

Large surfaces were also found for Cyanophyta, particularly in June, August and September. This was mainly accounted for by trychome of *Aphanizomen flos aquae* and *Anabaena sp. div.*, and at some terms by large colonies of *Microcystis aeruginosa*.

Chrysophyceae, in spite of their number which was a few times smaller, have had rather large surfaces because of extensive colonies of *Dinobryon divergens*. However, Bacillariophyceae which were almost three times more numerous, yielded almost six times smaller surfaces. During the second half of the filling period, Bacillariophyceae surfaces could be sometimes larger than during the first one because of large amounts of threads of *Melosira granulata var. angustissima*.

In pond No. 8 Cyanophyta, Euglenophyta and Chlorophyta have been prevailing, and their amounts have been similar.

The genera Anabaena and Aphanizomenon have been predominant among the Cyanophyta, particularly during August and the first half of September.

Among Euglenophyta, the following species have been recorded most abundantly and steadily: *Trachelomonas volvocina, T. hispida, T. hispida var. coronata*, and *T. armata*. Their number grew at the end of August, and at the end of September their mass appearance was observed.

Volvocales have been developing only sporadically and in small amounts, with the exception of *Chlamydomonas sp.*, which caused a water-bloom at the end of August, and of *Phacotus lenticularis* at the beginning of September. Chlorococcales showed the greatest constancy of occurrence. They were mainly represented by the genera Scenedesmus, Crucigenia and Tetraëdron, most numerous at the end of June and at the end of September. *Actinastrum Hantzschii* and *Ankistrodesmus falcatus* appeared most numerously at the end of June.

Bacillariophyceae were observed in large numbers only at some terms.

The share of Dinophyceae, Conjugales, Cryptophyceae and Chrysophyceae was negligible.

The greatest surfaces were recorded for Cyanophyta, which were also the most numerous.

The surfaces of Volvocales and Chlorococcales were fairly similar, even though the former were almost twice as numerous. Among Volvocales, the water-blooms of *Chlamydomonas sp.* and of *Phacotus lenticularis*, both small in size, were observed. On the other hand, among Chlorococcales larger algae were as common as the prevailing smaller forms, as e.g. Pediastrum, Botryoccocus, Ankistrodesmus.

Euglenophyta, recorded in amounts similar to those of Cyanophyta and Chlorococcales, yielded several times smaller total surfaces, which was caused by the small size of their almost sole element, the genus of Trachelomonas.

Similar surfaces were computed for the more than four times lesser amount of Dinophyceae in comparison with Bacillariphyceae, as their only representant, *Ceratium hirundinella* is large in size.

Amounts and surfaces of Cryptophyceae, Chrysophyceae and Conjugales were negligible in comparison with other algae.

In pond No. 9 the most numerous were Cyanophyta, appearing in mass during September. *Aphanizomenon flos aquae* was predominant, and *Microcystis aeroginosa* and *Anabaena sp.* were less numerous. Euglenophyta appeared in all the samples, but they were most abundant in August. Trachelomonas was their predominant or sometimes the only genus.

Of the Volvocales, only *Uva elongata* appeared amply at the end of June. A very intensive water-bloom of *Volvox aureus* and *V. globator* was remarkable in the half of September. Chlorococcales, in particular the genera Scenedesmus, Pediastrum and Coelastrum, have been constantly present. Their total amount was close to that of Euglenophyta; a mass development occurred in June for the genus Characium, and in August for Scenedesmus. Other algae were observed rather sporadically and in small quantities.

The greatest surfaces were computed for the otherwise most numerous Cyanophyta. The most numerous trichomes of *Aphanizomenon flos aquae* often yielded total surfaces similar or much smaller than the not numerous but very large colonies of *Microcystis aeruginosa*.

Euglenophyta and Chlorococcales which occurred in similar amounts, have had similar surfaces as well. Among Chlorococcales the less numerous but large forms (Pediastrum, Coelastrum, Ankistrodesmus) reached the most extensive surfaces, while the most numerous small species, such as e.g. Characium and Scenedesmus, rendered the lesser surface values.

Surfaces and amounts of the other algae were negligible.

4. DISCUSSION

The most numerous phytoplankton groups in the investigated ponds have been Chlorophyta, Cyanophyta and Euglenophyta. However, their amounts differed depending on the type of fertilization. The control pond was marked in general by a small amount of algae. Fertilization has remarkably influenced the amount of phytoplankton, in particular of the three groups mentioned above, causing the fertilized ponds to acquire a polytrophic character (S t a r m a c h 1969 c).

In pond No. 9, fertilized with superphosphate and ammonium nitrate, the amount of Euglenophyta was significantly greater during the whole period of filling than in No. 8, fertilized with superphosphate only, in which their mass appearance was recorded only once, on September 28th. It was probably related with an earlier mass development of Cyanophyta and Chlorophyta, which could contribute by their disappearing to an increase of the supply of assimilable nitrogen in water. Starmach (1969 c) reports that nitrogen in form of ammonium nitrate is most favourable for the development of Euglenophyta. In the present study it was thus in pond No. 9, supplied with superphosphate and ammonium nitrate, that they were most numerous (mainly the genus Trachelomonas). Nygaard (1949) considers them to be an important indicator of strongly trophic waters. According to the many authors (Langhans 1936, Winberg 1952, Schäperclaus 1957, Müller 1958, Bucka 1960, Krzeczkowska 1963, Kyselowa 1966, Starmach 1969 c) Cyanophyta require the large amounts of phosphorus. These algae appeared in much greater amounts in the superphosphate enriched ponds No. 8 and 9 than in the unfertilized one. Thus it can be seen that the presence of some algae depends on types of fertilization. Another factor which was perhaps decisive was the fact that the ponds were young. It is remarkable (cf. Sent-Iler 1935, Širokova 1936, Radzimovskij 1955, Krzeczkowska-Wołoszyn 1966) that in young ponds Euglenales, Volvocales and Chlorococcales are predominant. It was these groups which were typical for the investigated ponds at Gołysz. According to Svirenko (1922), a decrease of the quantity of Euglenales and Volvocales, and their substitution by Protococcales, Chrysophyceae and Dinophyceae indicates a process of settling of a new pond, usually lasting for 5 or 6 years.

Algae appeared in the investigated ponds in large amounts immediately after their filling, mainly Volvocales and some of the Chlorococcales (e.g. *Actinastrum Hantzschii*, Ankistrodesmus). Bucka and Kyselowa (1967) remarked that these algae were typical mainly for the spring and summer period (May, June, July) in the ponds investigated by them. It is nitrogen compounds supplied by inlet waters which are mainly responsible for a strong development of phytoplankton, often observed during the initial phase after the filling (Nygaard 1938, Schäperclaus 1957).

The algae were most numerous in August, but in September their mass appearances were also recorded. Their surfaces have also been the greatest during these months.

With respect to the results of the investigations of the primary production expressed in mg O_2/l/24 hr (Lewkowicz and Wróbel

1971) a convergence of its course with oscillations in qualitative and quantitative composition of algae and their surfaces has been observed. It was found that primary production in the unfertilized pond was lesser than in the fertilized ones. The quantities and summary surfaces of algae computed in the present work have been smaller in the unfertilized pond, too. The highest consistency between production and quantity in pond No. 8 fertilized with superphosphate was observed. A high production at the beginning of the vegetation period in the ponds, related with the development of Chlorophyta, dropped significantly about the half of July, as the amount and surface of these algae showed a similar decrease. The next increase of production, with the maximum at the end of August, was paralleled by an increase of the amount and surface of algae (Chlorophyta and Cyanophyta).

It seems that what can be reasonably expected from an application of the different methods of research, is a general consistency of results, rather than a strict correlation between them. Results of investigations by various authors testify that, e.g., biological analyses by no means always strictly correspond with chemical ones. Sometimes it leads even to the different classifications of water reservoirs. E.g., a lake defined by Ruttner (1931) as oligotrophic, was estimated by means of biological criteria as eutrophic (Thienemann 1931). Bucka (1966), who investigated plankton communities, defined the studied fertilized ponds at Gołysz as moderately eutrophic, whereas parallel chemical data (Wróbel 1962) indicated strong eutrophy. Similar results were obtained by Czeczuga (1959) who investigated the Rajgrod lakes.

The extent of production depends not only on amount of algae, but also on their qualitative composition. It is known that small algae, in particular those classified as nannoplankton ones, are important producers of carbohydrates. Owing to their small sizes, rapid growth, and division, they have the largest active surface and thus they are the most important producers of organic matter (Starmach 1969 c). According to Findenegg (1965), nannoplankton organisms usually assimilate much more of CO_2 than Bacillariophyceae or Cyanophyta. This has been also pointed out by Czeczuga et al. (1968) who estimated the share of nannoplankton in the primary production of phytoplankton from 57 up to 99%.

According to Findenegg (1965), production of algae is marked by rapid changes. It is vulnerable to both an increase and a decrease of light intensity. Thus assimilation rates depend on hour and weather. A lack of correspondence between primary production and amount of algae may also result from the difficulty in distinguishing between living and dying or dead cells. Extent of production may depend, too, on the stage of development of algae. Thus e.g. Chlorophyta in the phase of division appeared intensively in pond No. 8 by the end of July and at the beginning of August. At the same time a remarkable increase of primary production was observed (Lewkowicz and Wróbel 1971). Bacteria and zooplankton are other factors influencing primary production. Sushchenija (1958) maintains that zooplankton can positively influence assimilation in algae; if it was so, organic matter production would depend not only on phytoplankton, but on plankton in general.

Probably mass presence of *Colacium vesiculosum* also influenced the extent of primary production in the investigated ponds. In many samples, animals (Cyclops, Diaptomus, nauplii, *Scapholeberis mucronata, Keratella cochlearis, K. quadrata)* were abundantly covered with it. However, it was impossible to count the number of Colacium on animals, and thus the separate individuals, being a very small fraction of their total amount, were left out of consideration, too.

5. SUMMARY

In 1967 a qualitative and quantitative composition as well as the surfaces of algae in the differently fertilized fingerling ponds were investigated in Experimental Farms of the Laboratory of Water Biology at Gołysz.

As a rule, Chlorophyta, Cyanophyta, and Euglenophyta were the most numerous constituents of phytoplankton. A relationship between fertilization and appearance of phytoplankton was observed. In the control pond, small amounts of algae were recorded, in opposition to the ponds in which fertilization positively influenced the amounts and surfaces of phytoplankton, indicating a polytrophic character of these ponds. Probably the age of the ponds was the factor underlying the plankton composition; the type of succession observed was characteristic for the first years of the filling of ponds. A relationship between primary production expressed in mg O_2/l/24 hr, and qualitative and quantitative composition as well as surfaces of algae was confirmed.

6. STRESZCZENIE

Zbadano skład jakościowy, ilościowy i powierzchnie glonów w różnie nawożonych stawach przesadkowych w Gospodarstwie Doświadczalnym w Gołyszu w 1967 r.

Chlorophyta, Cyanophyta i Euglenophyta były z reguły najliczniejszym składnikiem fitoplanktonu. Obserwowano zależność w występowaniu fitoplanktonu od nawożenia. W stawie kontrolnym notowano małą ilość glonów, w przeciwieństwie do stawów z nawożeniem, które wpłynęło korzystnie na liczebność i powierzchnie fitoplanktonu, wskazując na politroficzny charakter tych stawów. Na skład planktonu miał prawdopodobnie wpływ wiek stawów: zachodząca w badanym planktonie sukcesja jest zwykle obserwowana w pierwszych latach zalania stawów. Stwierdzono zależność między produkcją pierwotną wyrażoną w mg O_2/l/24 godz. a składem jakościowym i ilościowym glonów oraz ich powierzchniami.

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BIOMASS OF ZOOPLANKTON AND PRODUCTION OF SOME SPECIES OF ROTATORIA AND *DAPHNIA LONGISPINA* IN CARP PONDS

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ABSTRACT

This is a report on zooplankton biomass and production of its dominating species during the filling period of three differently fertilized fingerling carp ponds. In the fertilized ponds the biomass was greater than in the unfertilized one. Fertilizing caused an increase of production of Rotatoria. Production during the whole research period, and mean daily coefficient *P*/*B* in *Daphnia longispina* were lowest in the unfertilized pond, and highest in that fertilized with nitrogen + phosphorus.

CONTENTS

1. INTRODUCTION

The existing literature on zooplankton production are mainly reports on works in lakes or in dam reservoirs (Winberg et al. 1965, Pechen 1965, Petrovič 1968, Hillbricht-Ilkowska 1967, Hillbricht-Ilkowska et al. 1966, Ždanova 1969). It was studied in ponds by Galkovskaja and Ljahnovič (1966).

In 1967 and 1968, experiments were made on the influence of nitrogen + phosphorus fertilizing upon primary production of phytoplankton (Lewkowicz and Wróbel 1971), zooplankton production (the present paper), benthos production (Zięba 1971), and carp fry production (Włodek 1971). The studies were made in fingerling ponds of the Experimental Farm of the Laboratory of Water Biology of the Polish Academy of Sciences at Gołysz. The aim of the present work consisted in assessing the biomass and production of zooplankton in three differently fertilized ponds, investigated during 1967. Pond No. 7 was not fertilized (control), No. 8 was fed with phosphorus, and No. 9 was supplied with phosphorus + nitrogen. Data on amounts of the elements introduced and on fish growth are stated in Table I.

The surface of each pond was 0.15 ha; the ponds were filled on June 22nd, and sluiced down to haul fish on October 25th. They were stocked with 2600 of carp fry per pond. Mean water temperature in June, July and August was higher than 20°C, in September it oscillated from 16 to 20°C, and in October from 13 to 19°C. The maximum temperature of 26.6°C was recorded at the beginning of August. Thermal description of the ponds is given by Szumiec (1971).

Table I. Fertilization and fish increments in investigated ponds

Pond No.	Fertilization			Total increment (kg/ha)
	No. of doses	P (kg/ha)	N (kg/ha)	
7	—	—	—	286.0
8	8	32	—	412.0
9	8	32	163	508.0

2. METHODS

Zooplankton was sampled at five days intervals with a Patalas (1954) plankton sampler, of capacity of 5 l, four spots in each pond. The first samples were drawn on June 28th, the last on October 9th. Water (20 l) from each pond was sipped through a No. 25 net. The samples were conserved with 4% formaline solution, and counting was done for 3 Kolkwitz chambers of 0.5 ml capacity from each sample. Age structure and fecundity of *D. longispina* were defined by measuring 50 individuals from each conserved sample.

Data on eggs development and youthful phases durations of Daphnia were defined with due consideration to the influence of water temperature; the relevant curves are given in Pechen (1965) and Hillbricht-Ilkowska and Patalas (1967). Mean water temperatures for the five days intervals did not exceed 25.8°C during the whole research season.

The mean life time of adults Daphnia was assumed to be 30 days for temperatures around 25°C (Hall 1964). As no Daphnia eggs below 800 μ were found, all individuals not exceeding this length were considered as juvenile.

To compute the biomass of Rotatoria, Kosova's (1961) tables were employed, for Cladocera, Pechen's (1965) formulas were used, and for Copepoda, the Ščerbakov's (1952) formula; the tables and formulas allow to compute an individual's weight if its linear dimensions are known.

Net production of a few plankton species of Rotatoria was computed by Galkovskaja's (1965) method. From the same paper data were taken on a relative daily increase of their number, for water temperatures not exceeding 20°C. No Krogh's curve amendments were taken into account, as they are insignificant for the higher temperatures. Production of *Daphnia longispina* was established with the computation method of Winberg et al. (1965).

3. RESULTS

An obvious influence of fertilization of the ponds on zooplankton biomass was observed (Fig. 1). The highest medium zooplankton biomass during the whole season was found in pond No. 9; it was 9.38 mg/l; in No. 8 it was 8.08 mg/l, and in the unfertilized No. 7 it was only 3.95 mg/l. Mean Rotatoria biomasses in No. 8, and 9 were similar (2.86 mg/l and 2.66 mg/l respectively), while in No. 7 it was 0.32 mg/l. 98% of Rotatoria biomass in No. 8 and 9, and 93% in No. 7 were made up of the following species: *Polyartha trigla vulgaris*, Conochiloidae, *Asplanchna priodonta, Asplanchna brightwelli, Brachionus calyciflorus, Trichocerca cylindrica, Pompholyx sulcata, Keratella cochlearis, Filinia longiseta, Keratella quadrata.*

The biomass of Cladocera and Copepoda was very changeable. In pond No. 7, mass appearance of Daphnia was observed immediately after the

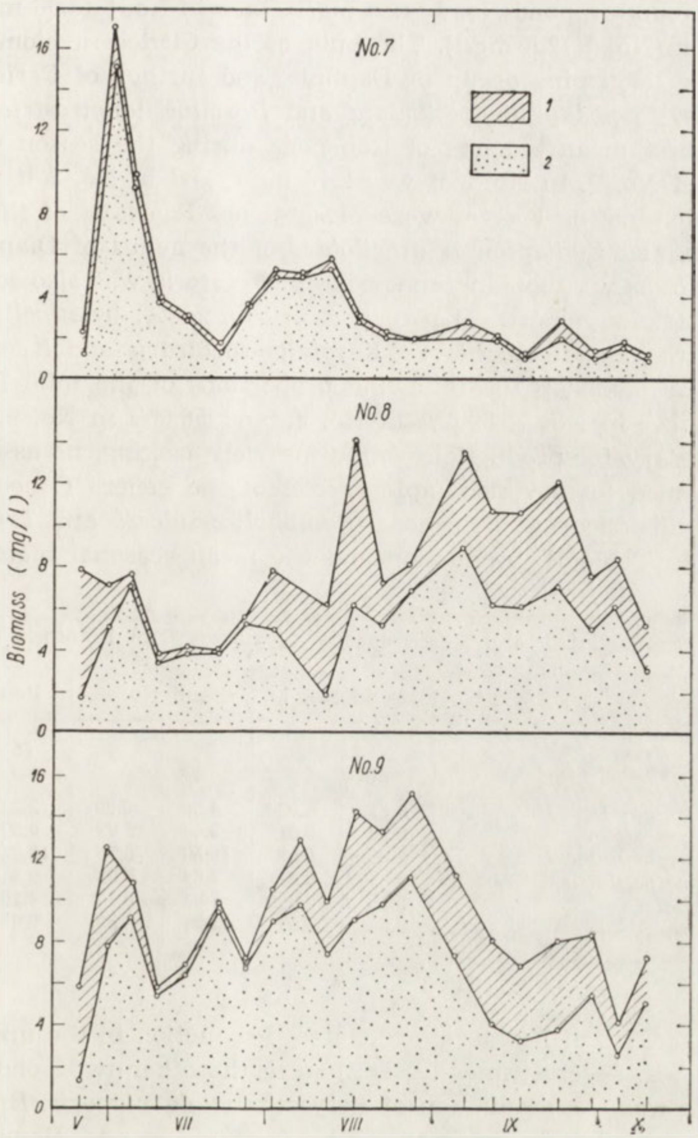

Fig. 1. Zooplankton biomass in mg/l. 1 — Rotatoria, 2 — Cladocera and Copepoda

filling, and then it fell down, never to exceed 5 mg/l. In No. 8 and 9 the biomass of Cladocera and Copepoda was parallel with the organic carbon contents in pond water (Lewkowicz and Wróbel 1971). In No. 9 the highest Cladocera biomass was observed in July and August, and in No. 8 in September. The highest medium Cladocera biomass during the season was found in pond No. 9 (4.39 mg/l), then in No. 8 (3.08 mg/l), and the lowest in No. 7 (2.8 mg/l). The bulk of the Cladocera biomass consisted of the longispina group of Daphnia, and further of *Ceriodaphnia quadrangula, Ceriodaphnia reticulata* and *Bosmina longirostris.*

The highest mean biomass of Copepoda during the season was 2.32 mg/l in pond No. 9. In No. 8 it was 2.13 mg/l, and in No. 7 it was 0.82 mg/l. The dominating species were *Mesocyclops leuckarti* of the Cyclopidae genus, and *Eudiaptomus graciloides* of the genus of Diaptomidae

Production of six zooplankton species of Rotatoria was also computed: *Polyarthra trigla vulgaris, Asplanchna priodonta, A. brigtwelli, Filinia longiseta, Brachionus calyciflorus, Keratella cochlearis* and *K. quadrata*. These species made up the following proportions of the total Rotatoria biomass: 46.7% in No. 7, 59.8% in No. 8, and 56.6% in No. 9. As the values necessary for production computing were lacking, no assessments were performed for several ample species of the genera Conochiloidae, *Brachionus diversicornis, B. rubens, Pompholyx sulcata* and *Trichocerca cylindrica*. In Table II, production and the mean seasonal biomasses of

Table II. Production *P* and mean seasonal biomasses *B* of Rotatoria (mg/l)

Species	Pond No. 7		Pond No. 8		Pond No. 9	
	P	*B*	*P*	*B*	*P*	*B*
Keratella cochlearis	0.82	0.034	4.69	0.20	2.23	0.10
Keratella quadrata	0.33	0.01	0.54	0.02	0.57	0.02
Polyarthra trigla vulgaris	2.85	0.08	19.53	0.56	16.61	0.60
Brachionus calyciflorus	0.27	0.01	4.64	0.22	9.31	0.37
Filinia longiseta	0.25	0.02	7.01	0.17	4.16	0.13
Asplanchna sp. div.	0.50	0.02	13.71	0.59	9.65	0.43

the several species of Rotatoria are stated. Production in the unfertilized pond No. 7 was several times lesser than in the other two ponds. Particularly high was the production of *Polyartha trigla vulgaris, Brachionus calyciflorus,* and *Filinia lingiseta* in the fertilized ponds. However, the *Keratella quadrata* production in pond No. 7 was only a little lower than in the fertilized ponds. In the phosphorus fertilized pond No. 8 the production of *Keratella cochlearis* and of *Filinia longiseta* was higher than in the nitrogen + phosphorus fertilized pond No. 9, while the *Brachionus calyciflorus* production was highest in No. 9. In Figure 2, production of *Polyarthra vulgaris* in the investigated ponds is plotted. It was obviously lower in No. 7 than in the other two ponds; only at the beginning of the season, just after the filling, it was somewhat higher than in the pond

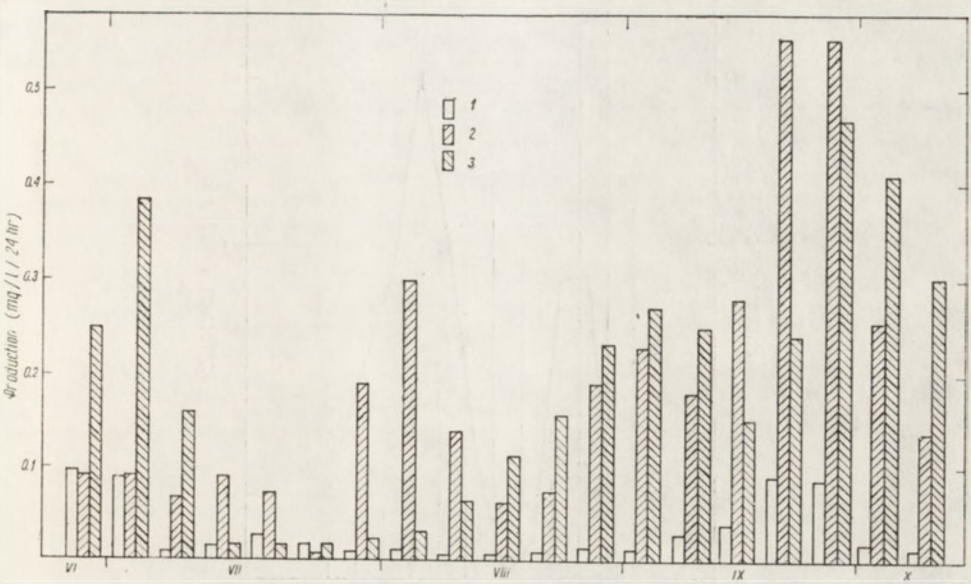

Fig. 2. Daily production of *Polyarthra trigla vulgaris*. 1 — pond No. 7, 2 — pond No. 8, 3 — pond No. 9

fertilized with phosphorus. The mean seasonal production of *Polyarthra trigla vulgaris* in the two fertilized ponds was almost equal; only some differences in timing were observed. In all the investigated ponds, production of this species was highest in September, as of most Rotatoria. Production of *Brachionus calyciflorus* was highest just after the filling of the ponds, while later this species has occurred only occasionally.

It is possible that Rotatoria of the genus Asplanchna influenced production of the another Rotatoria species. The Asplanchna are predators, though they also feed on algae. In the investigated ponds the species *Asplanchna priodonta* was numerous, and there were also lesser amounts of *Asplanchna brightwelli*; the two species were considered together in production assessments. In pond No. 8 the highest production of *Asplanchna sp. div.* was observed during a period of a drop of the biomass of the other Rotatoria, after a former maximum (Fig. 3). It may be supposed that production of the predatory Asplanchna depends on the biomass of the other species of Rotatoria which are its food, while on the other hand Asplanchna influences the total Rotatoria biomass. In pond No. 9, *Asplanchna sp. div.* was observed in great number at the beginning of July, during mass appearance of *Branchionus calyciflorus*. In the unfertilized pond No. 7 very few *Asplanchna sp. div.* were found.

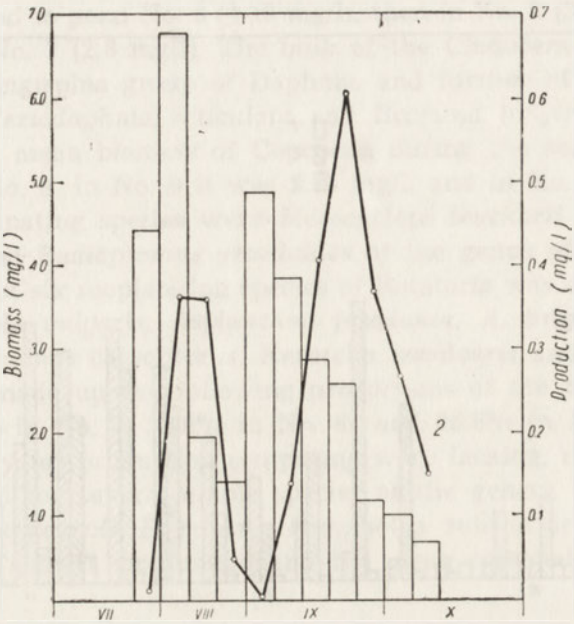

Fig. 3. Daily production of *Asplanchna sp. div.* in pond No. 8 against the biomass of the other Rotatoria. 1 — the Rotatoria biomass, 2 — production of *Asplanchna sp. div.*

Production of *Daphnia longispina* during the whole season (109 days) was 39.6 mg/l in pond No. 7, 54.2 mg/l in No. 8, and 58.2 mg/l in No. 9. Production was 16 times higher than biomass in pond No. 7; 21.8 times in No. 8, and 23.3 times in No. 9. The lowest production in mg/l/24 hr was found in No. 7 (unfertilized), then in No. 8, and the highest in No. 9,

Table III. Production and biomass of *Daphnia longispina*

	Pond No. 7	Pond No. 8	Pond No. 9
Production (mg/l/24 hr)	0.36	0.48	0.53
Mean biomass (mg/l)	2.39	2.48	2.45
Mean daily P/B coefficient	0.15	0.19	0.21

while the medium seasonal biomasses were almost equal in all the ponds. It was the mass appearance of *Daphnia longispina* in pond No. 7 just after the filling which was responsible for the fact the medium biomass in this pond was similar to those in No. 8 and 9. Mean daily coefficient of P to B was lowest in No. 7, and highest in No. 9 (Table III). Production of *Daphnia longispina* has been changing during the research season (Fig. 4). In the unfertilized pond No. 7 high production of *Daphnia longispina* was observed in the first half of July, and later during the

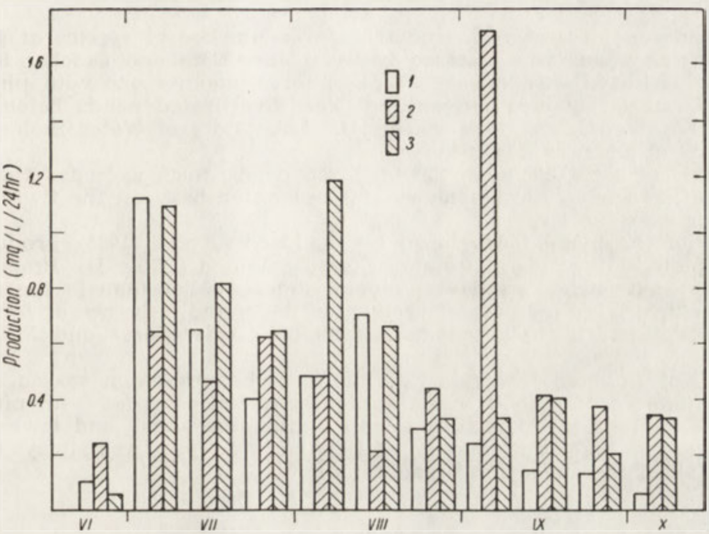

Fig. 4. Daily production of *Daphnia longispina*. 1 — pond No. 7, 2 — pond No. 8, 3 — pond No. 9

season it has been lower than in the other two. In No. 9, high production was observed at the beginning of August, and in No. 8 a month later. High production of *Daphnia longispina* was always associated with intensive processes of destruction of organic matter solved in pond waters (Lewkowicz and Wróbel 1971).

4. CONCLUSIONS

1. Fertilization of the investigated ponds brought about an increase of the zooplankton biomass. In the pond fertilized with nitrogen + phosphorus, zooplankton developed more rapidly than in the pond fertilized with phosphorus only.

2. Production of *Daphnia longispina* in the fertilized ponds was much higher than in the unfertilized one; no large differences between seasonal productions in the pond fertilized with nitrogen + phosphorus and in that fed with phosphorus alone were found. It is remarkable that in the unfertilized pond, *Daphnia longispina* appeared on mass scale immediately after the filling; this might have been associated with intensive processes of destruction occurring on the bottom after the filling.

3. Production of Rotatoria in the fertilized ponds was several times greater than in the unfertilized one. Production of *Brachionus calyciflorus* was found to be the highest in the pond fertilized with nitrogen + phosphorus.

Acknowledgement

I wish to thank Dr. G. A. Galkovskaja from the Minsk Institute of Fish Economy for her valuable suggestions, indispensable for this work.

5. SUMMARY

The zooplankton biomass and production of a number of species of Rotatoria in three fingerling ponds was assessed between June 28th and October 9th, 1967. One pond was fertilized with nitrogen + phosphorus, another one with phosphorus alone, and the third remained unfertilized. The investigated ponds belong to the Experimental Farm at Gołysz, managed by the Laboratory of Water Biology of the Polish Academy of Sciences in Cracow.

The biomass of zooplankton in the fertilized ponds much exceeded that in the control. The differences of the biomasses of zooplankton between the two variously fertilized ponds were not large.

By means of the method developed by Galkovskaja (1965), production of a number of plankton species of Rotatoria was computed (Table II). Production of Rotatoria in the unfertilized pond was several times smaller than in the fertilized ones. A particularly large increase of production under the influence of fertilization was found in *Polyarthra trigla vulgaris*, *Brachionus calyciflorus* and *Filinia longiseta*.

Production of *Daphnia longispina* during the whole research season, and the medium daily relation of *P* to *B*, was the highest in the pond fed with nitrogen + phosphorus, next in the pond fertilized with phosphorus alone, and lowest in the unfertilized one. The highest production of *Daphnia longispina* was always observed after a rapid fall of the amount of organic matter.

6. STRESZCZENIE

Określono biomasę zooplanktonu i produkcję kilku gatunków Rotatoria i *Daphnia longispina* w trzech stawach typu przesadki II w okresie od 28. VI do 9. X 1967 r. Jeden z badanych stawów nawożony był azotem i fosforem, drugi samym fosforem, a trzeci nie był nawożony. Badane stawy leżą w obrębie Gospodarstwa Doświadczalnego Gołysz należącego do Zakładu Biologii Wód Polskiej Akademii Nauk w Krakowie.

Biomasa zooplanktonu w stawach nawożonych znacznie przewyższała biomasę w stawie kontrolnym. Różnice w wielkości biomasy zooplanktonu pomiędzy stawami różnie nawożonymi były niewielkie.

Stosując metodę Galkovskiej (1965) obliczono produkcję kilku planktonowych gatunków Rotatoria (Tab. II). Produkcja Rotatoria w stawie nie nawożonym była kilkakrotnie niższa niż w nawożonych stawach. Szczególnie duży wzrost produkcji pod wpływem nawożenia zaobserwowano u *Polyarthra trigla vulgaris, Brachionus calyciflorus i Filinia longiseta.*

Produkcja *Daphnia longispina* za cały okres badań, podobnie jak średni dobowy *P/B*, była najwyższa w stawie nawożonym azotem i fosforem, średnia w stawie nawożonym fosforem, a najniższa w stawie nie nawożonym. Najwyższą produkcję *Daphnia longispina* stwierdzano zawsze po gwałtownym spadku ilości materii organicznej.

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CILIATA IN BOTTOM SEDIMENTS OF FINGERLING PONDS

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ABSTRACT

Species composition and amounts of Ciliata during exploitation of three differently fertilized fingerling ponds were studied in 1967. 62 species of Ciliata were found. The greatest amount of organisms was found in the nitrogen + phosphorus fertilized pond. Maximal amounts of Ciliata were observed soon after periods of high production of *Daphnia sp.*

CONTENTS

1. INTRODUCTION

Various forms of microbenthos, above all Protozoa and Rotatoria, are an important element of the bottom fauna of water reservoirs. However, their role in the metabolism of such reservoirs is far from being explained. They seem to be an important link in the chain of changes occurring in bottom mud.

Protozoa supply food for small Metazoa, and they are thus an important element in the food chain. Numerous Protozoa, and among them the Ciliata, are detritus feeders, and thus they contribute a lot to the reduction of organic matter likely to pile up on the bottom. Besides, the bacteriophagous Ciliata are a natural selective factor for the bottom bacteria populations.

The aim of the present paper was to investigate the development of Ciliata populations in bottom mud of fingerling ponds. It was a part of a complex survey made by the Laboratory of Water Biology, Polish Academy of Sciences in Cracow, in fingerling ponds built in 1965 on the Experimental Farm at Gołysz.

2. METHODS

The materials of microfauna from three fingerling ponds were analysed: No. 7 (unfertilized — control), No. 8 (fertilized with phosphorus supplied in superphosphate), and No. 9 (fertilized with phosphorus and nitrogen, supplied in Norway saltpetre and superphosphate). Samples were taken during the third year of exploitation of the ponds (1967), on two sites in each. One sampling site was near the pond's outlet, and the other in a corner of the shallower part. Samples from both sites were rather similar, and the amounts of mud were small. 50 samples of bottom sediment were taken in all, at about 10 days intervals (Fig. 1), from July until the beginning of October from the fertilized ponds, and from July until the half of September from the control. Material was collected by means of a Starmach's (unpublished) mud sampler, sucking about 75 ml of bottom sediment mixed with bottom water. The samples were kept in a cool place in 150 ml glass bottles. The material was elaborated when still alive, and analyses of quantity and quality were performed as early as possible. Usually 5 preparations were prepared from one sample, and investigated under a microscope. The number of individuals in a sample was determined, and a mean value for all the five slides was computed. The next step consisted in evaluating the number of the Ciliata in a sample on the Grospietsch scale (1958). The scale is quoted with Table I. The number of individual Ciliata in 1 cm^3 of bottom sediment could be assessed from the data, as the sediment capacity was identical in each preparation (0.02 ml).

To grasp the frequency of occurrence of the several species, the percentage of occurrence in all the samples was computed for each species. They could be classified into 4 groups of species:

1. very frequent — found in 51–100% of samples,
2. frequent — found in 21–50% of samples,
3. rare — found in 11–20% of samples,
4. very rare — found in $<$ 10% of samples.

3. RESULTS

62 forms of Ciliata were found. 43 were identified as to their species, and for the other only the genus was stated. Here is a full list of the found Ciliata forms. The figures 7, 8 or 9 refer to the pond number in which a respective form was found.

Aspidisca costata Clap. et L. — 7, 8, 9, *Aspidisca herbicola* Kahl — 9, *Aspidisca lynceus* Ehrb. — 7, 8, 9, *Aspidisca turrita* Ehrb. — 9, *Aspidisca sp.* — 7, *Atopodinium sp.* — 7, 8, 9, *Chilodonella cucullulus* O. F. Müller — 8, 9, *Chilodonella sp.* — 7, 8, 9, *Cinetochilum margaritaceum* Perty — 7, 8, 9, *Codonella cratera* Leidy — 8, 9, *Coleps amphacanthus* Ehrb. — 7, 8, 9, *Coleps hirtus* Nitzch — 7, 8, 9, *Cyclidium citrullus* Cohn — 7, 8, 9, — *Cyclidium sp.* — 7, 8, 9, *Dichilum sp.* — 8, *Frontonia acuminata* Ehrb. — 9, *Frontonia leucas* Ehrb. — 7, 8, 9, *Frontonia vernalis* Ehrb. — 7, 9, *Halteria grandinella* O. F. Müller — 7, 8, 9, *Lancrymaria olor* O. F. Müller — 8, 9, *Lembadion bullinum* Perty — 7, 8, 9, *Lembadion lucens* Maskell — 8, 9, *Lionotus lamella* Schewiakoff — 7, 8, 9, *Lionotus sp.* — 7, 8, 9, *Loxocephalus sp.* — 9, *Loxodes rostrum* O. F. Müller — 7, 8, *Loxodes striatus* Engelmann — 7, 8, 9, *Loxophyllum helus* Stokes — 7, 8, 9, *Mesodinium acarus* Stein — 7, 8, *Mesodinium cinctum* Calkins — 7, 9, *Metacystis sp.*, — 7, *Metopus es* O. F. Müller — 7, 8, 9, *Metopus undulans* Stokes — 7, 9, *Metopus sp.* — 7, 9, *Oxytricha sp.* — 7, 8, 9, *Paramecium caudatum* Ehrb. — 7, 8, 9, *Paruroleptus lacteus* Kahl — 8, 9, *Paruroleptus musculus var. simplex* Kahl — 7, 8, 9, *Prorodon ovum* Ehrb.-Kahl — 7, 8, 9, *Prorodon teres* Ehrb. — 7, *Prorodon sp.* — 7, 8, 9, *Pseudoprorodon sp.* — 7, *Spathidium barbatula* Penard — 7, *Spathidium faurei* Kahl — 9, *Spathidium lieberkühni* Bütschli — 8, *Spathidium lucidum* Kahl — 8, *Spathidium porculus* Penard — 7, 9, *Spathidium sp.* — 7, 8, 9, *Spirostomum filum* (Ehrb.) Penard — 7, 8, 9, *Spirostomum minus* Roux — 7, 8, 9, *Stentor roeseli* Ehrb. — 7, 8, 9, *Stentor coeruleus* Ehrb. — 8, 9, *Stichotricha secunda* Perty — 7, 8, 9, *Strobilidium gyrans* Stokes — 8, *Trachelophyllum sp.* — 7, 8, 9, *Trichopelma euglenivora* Kahl — 7, 8, 9, *Urocentrum turbo* O. F. Müller — 7, 8, 9, *Uroleptus limnetis* Stokes — 7, 8, 9, *Uroleptus sp.* — 7, 8, 9, *Urosoma sp.* — 7, *Urostyla sp.* — 7, 8, 9, *Vorticella sp.* — 8, 9.

The numbers of species were similar for each pond: 46 forms of Ciliata were found in pond No. 7, 45 forms in No. 8, and 50 forms in No. 9.

Species differentiation between the ponds was as follows: 33 forms (or 53.2%) were species encountered in all the three ponds, 14 species were found in 2 ponds (22.6%), and 15 species were found in one pond only (24.2%). The forms belonging to the first group were mostly common and numerous species, while in the other two groups more rare and scanty forms tended to prevail.

Species differentiation between the sampling sites within the same ponds was even less marked than between the ponds. Amounts and visual appearance of mud collected from two sites in the same pond were quite similar. The chosen sampling sites differed as to their depth, but they were all free from vascular plants.

During the research period large changes in the Ciliata composition was found. There were species appearing during almost the whole time, and there were others which appeared irregularly, or even quite occasionally. When frequency of occurrence of the particular species were assessed in terms of percentages of their respective shares in the total number of samples, it turned out that only 5 species appeared very frequently: *Aspidisca costata, Cinetochilum margaritaceum, Coleps hirtus, Prorodon ovum* and *Uroleptus limnetis*. Their quantities were by no means constant during the research period. Except *Aspidisca costata*, all the other species appeared in large amounts during the whole time (or almost so), and most often it was they that determined the growth of number of the Ciliata population. Among the group of frequently appearing species there were 13 forms, and another 13 were assigned to the third group (rare forms). These appeared most often in small numbers, and they hardly influenced the quantitative proportions of the respective samples. The most numerous was the fourth group of very rare species, which comprised 31 forms, i.e. 50% of their total number. Those species appeared very rarely and in very small amounts. In Table I are presented the changes of species composition, and frequencies of the Ciliata in pond No. 9.

Amounts of Ciliata in the bottom sediments were highly changeable during time, and in the three ponds. The greatest amounts of Ciliata developed in the nitrogen + phosphorus fertilized pond No. 9. In the other two ponds they were markedly less numerous. In Figure 1 a comparison of the amounts of Ciliata found near the outlets of the ponds can be seen. In pond No. 9 the number of Ciliata increased rapidly during a few days after the filling, and it reached its first peak on July 27th, 1967. A second peak was observed on August 29th. Both times, the most numerous were Ciliata of the species *Coleps hirtus, Loxocephalus sp.* and *Uroleptus limnetis* (cf. Table I). The number of species was also greater on those days. The lowest amounts of Ciliata were observed in Septem-

Table I. Changes in species composition and freguencies of occurrence of Ciliata in fingerling pond No. 9 in 1967

	Spieces	VII						VIII						IX			X
		9		18	17	27		8	7	17	19	29	28	5		14	12
		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Very frequent	*Aspidisca costata*			2	2	2	2	0	0	2	0	1	2	0	0		0
	Cinetochilum margaritaceum			2	2	0	1	0	2	2	2		2	2	2	2	
	Coleps hirtus	3	2	5	3	4	3	4	4	3	3	3	4	2	2	1	1
	Oxytricha sp.	1	0	1	0	0	1							0	0		1
	Paramecium caudatum		0		2	2	2	0	1	1	2		2		1		
	Prorodon ovum			0	1		3	1	1	0	1	1		1	1	1	
	Uroleptus limnetis	1	1	0	0	3	3	2	2	1	0	1	2	1	2		
Frequent	*Chilodonella sp.*						2			1			0			1	
	Cyclidium citrullus	0			0	1		0	1								
	Halteria grandinella		0			0	1		0	0	0						
	Lionotus sp.	0	0		0						0				3	0	0
	Loxocephalus sp.					5						5	5	1			
	Loxophyllum helus									1	0		0				
	Metopus sp.	1		0	0				0					0			
	Paruroleptus lacteus									2	0						
	Paruroleptus muscuclus			1	1		0			1			1				
	Prorodon sp.	1	1	1		2							1				
	Spirostomum minus		1		0		1								2		
	Stentor coeruleus						0			1	2	3	2		2	1	
	Trachelophyllum sp.					1	0			1		1	1	0	0		
	Uroleptus sp.		0			2	3	1	1			1					
	Urostyla sp.	0				1	0						2	1			

Date of sampling

Rare	*Aspidisca lynceus*						0		0								
	Codonella cratera									1					1		
	Coleps amphacanthus	2										2		2			
	Cyclidium sp.			0							0						
	Lembadion lucens					1											
	Lionotus lamella						1			1			1				
	Loxodes striatus												2		1		
	Spirostomum filum										0	0	1				
	Stentor roeseli						1		0				1				
	Stichotricha secunda						0										1
	Trichopelma euglenivora					0	1										
Very rare	*Aspidisca herbicola*											0					
	Aspidisca turrita					1											
	Atopodinium sp.								0								
	Chilodonella cucullulus								1								
	Frontonia acuminata						1										
	Frontonia leucas				0												
	Frontonia vernalis		0														
	Lacrymaria olor																0
	Lembadion bullinum					0											
	Mesodinium cinctum																3
	Metopus es														0		
	Metopus undulans														0		
	Spathidium faurei									0							
	Spathidium porculus							0									
	Spathidium sp.						0										
	Urocentrum turbo					1											
	Vorticella sp.														2		

A — the deeper sampling site.
B — the shallow sampling site.

The evaluation scale (Grospietsch 1958):
0 — found once,
1 — rare (1 or 2 specimen under the cover glass),
2 — not numerous (3–10 specimens),
3 — numerous (11–20 specimens),
4 — very numerous (21–30 specimens),
5 — mass occurrence (30 or more specimens).

ber and October. The dynamics of Ciliata quantity in the shallow sampling site in pond No. 9 was very similar to that observed in the deeper site, while the actual numbers of Ciliata in both sites differed only a little.

In the other two ponds, No. 7 and 8, a much poorer, fauna of Ciliata has developed similar for both ponds. No regularity in Ciliata incidence has been observed during the research period. In comparison with No. 9,

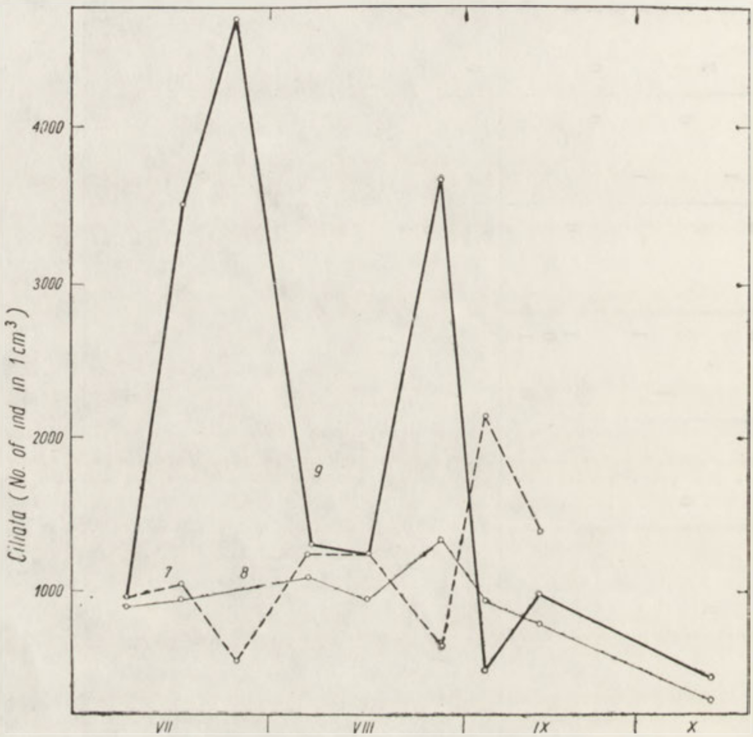

Fig. 1. Amounts of Ciliata in bottom sediments, 7–9 — numbers of ponds

much less change was observed. From August until the half of September some more Ciliata developed in these ponds. The following species were rather numerous: *Cinetochilum margaritaceum, Coleps hirtus, Lembadion bullinum, Loxodes striatus, Prorodon ovum* and *Uroleptus limnetis*. The curves of amounts of Ciliata in the shallow and deep sites in pond No. 8 were quite similar, while in the control pond No. 7 significant differences were observed, e.g., on July 27th there was a large decrease of Ciliata number in the deeper site, while in the shallower one their number increased extensively. Such a reversed pattern was also recorded on August 29th, when a second decrease of amount during the season was recorded in the deeper site, while in the shallower one the second maximum ocurred.

4. DISCUSSION

A large changeability of the amount of Ciliata was observed in the investigated ponds during the whole research period, and the peaks occurred in each pond at different dates. A parallelism in the changes of Ciliata amounts, and in productivity of plankton crustaceans of the *Daphnia sp.* genus was observed (Fig. 2). Amounts of Ciliata in bottom sediments have been increasing materially soon after maximum productivity of *Daphnia sp.* in plankton, perhaps as a result of sinking down of large amounts of organic remnants. It should be noted that at the

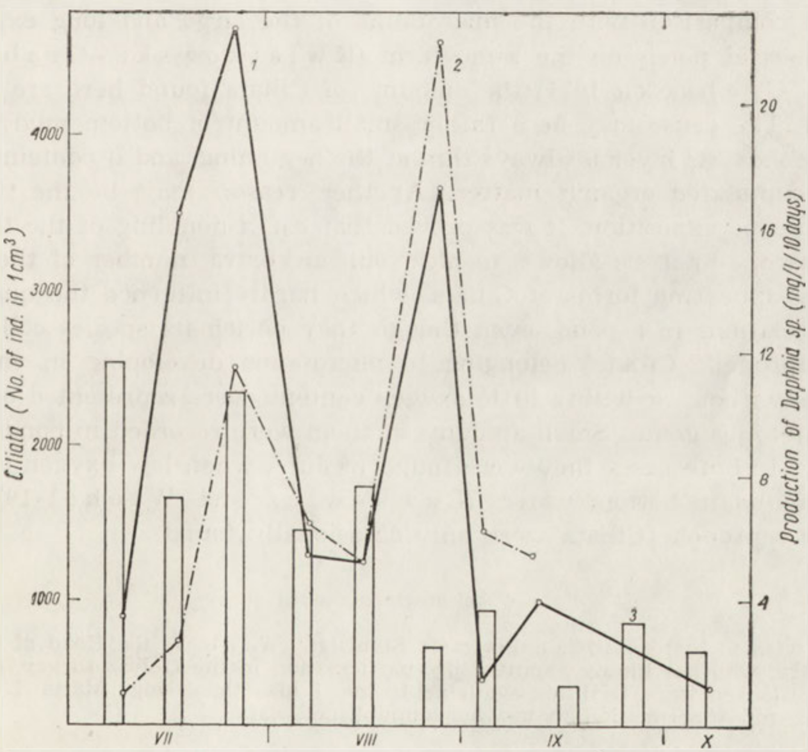

Fig. 2. A comparison of amounts of Ciliata in bottom sediment with 10 days production of *Daphnia sp.* in plankton of pond No. 9. 1 — amount of Ciliata in the deeper sampling site, 2 — amount of Ciliata in the shallower sampling site, 3 — production of *Daphnia sp.* according with Lewkowicz (1971)

dates of appearance of maximum quantities of Ciliata, it was *Loxocephalus sp.* and *Coleps hirtus* which appeared in great numbers. Species belonging to the genus of Loxocephalus feed on bacteria (Kahl 1935), while *Coleps hirtus* eats mixed food, but it is apt to be essentially histophagous (Fauré-Fremiet 1950, Stout 1956), as it feeds most often on fresh tissues. It must be emphasized that Ciliata feeding basically on bacteria prevailed in the whole collected material. During the period of ample development of *Daphnia sp.* in plankton, numerous dead organisms sink down, and perhaps a strong bacterial growth results. This previous favourable conditions for *Loxocephalus sp.* development, and the crustacean remnants accumulating on the bottom offer food for the *Coleps hirtus* species, often found by the author in the investigated material, feeding in *Daphnia sp.* shells. It is remarkable that the Ciliata feeding on algae were in obvious minority, and they were never really ample. In ponds No. 7 and 8, where there was less of *Daphnia sp.*, similar relations were observed. There the amounts of Ciliata were much lesser.

In comparison with the microfauna of the large and long exploited commercial ponds on the same farm (Kwiatkowska-Grabacka 1965, Grabacka 1971) the amounts of Ciliata found here are rather small. The cause may be a rather small amount of bottom mud in the new ponds; its layer is always thin at the beginning, and it contains little of accumulated organic matter. Another reason may be the time of microscope exposition. It was proved that e.g. a doubling of the time of microscope analysis allows to pick out an extra number of the more rarely appearing forms of Ciliata, which hardly influence the quantitative relations in a pond, even though they enrich its species collection.

Sapropelic Ciliata, belonging to microfauna developing in environments without or with a little oxygen content, were represented only by the Metopus genus. Small amounts of them were recorded in ponds No. 7 and 8. In both cases they were found in July, when low oxygen content was found in bottom waters (Lewkowicz and Wróbel 1971). In No. 9 sapropelic Ciliata were only occasionally found.

Acknowledgements

I wish to thank Assistant Professor Stanisław Wróbel, the Head of the Laboratory, who has kindly admitted my participation in the Gołysz survey, and has made the necessary facilities available to me. I also thank mgr Maria Lewkowicz, for a permission to use her unpublished data.

5. SUMMARY

In 1967 Ciliata in bottom sediments in three differently fertilized fingerling ponds were investigated in the Experimental Farm at Gołysz (Cieszyn district) belonging to the Laboratory of Water Biology of the Polish Academy of Sciences.

Species composition and quantity of Ciliata was studied. The number of Ciliata species was rather small (62).

Quantitative dynamics of Ciliata in the studied ponds varied. The most rich microfauna developed in the pond fertilized with nitrogen and phosphorus, in opposition to the pond fertilized with phosphorus only, and the control one, where the amounts of Ciliata were markedly smaller.

In the investigated ponds, mainly bacteriophagous Ciliata developed.

A marked increase of the number of Ciliata, in particular of the genera *Coleps hirtus* and *Loxocephalus sp.*, was observed soon after the maximum of production of *Daphnia sp.* in plankton, i.e. during increased sinking of these crustaceans to the bottom. This regularity was most remarkable in the pond fertilized with nitrogen and phosphorus.

6. STRESZCZENIE

W 1967 r. badano Ciliata w osadach dennych trzech stawów przesadkowych II w Gospodarstwie Doświadczalnym Gołysz pow. Cieszyn, należącym do Zakładu Biologii Wód Polskiej Akademii Nauk.

Badano skład gatunkowy i ilościowe występowanie Ciliata. Liczba gatunków Ciliata w badanych stawach była niewielka (62).

Dynamika liczebności orzęsków kształtowała się w poszczególnych stawach odmiennie. Najbogatsza mikrofauna rozwinęła się w stawie nawożonym azotem i fosforem, w przeciwieństwie do stawu nawożonego wyłącznie fosforem oraz kontrolnego, w których ilości mikrofauny były wyraźnie mniejsze.

W badanych stawach rozwijały się głównie orzęski odżywiające się bakteriami.

Stwierdzono, że wyraźny wzrost liczebności orzęsków, a zwłaszcza gatunków *Coleps hirtus* i *Loxocephalus sp.* następował w krótkim czasie po wystąpieniu maksimum w produkcji *Daphnia sp.* w planktonie, tj. w okresie zwiększonego opadania tych skorupiaków na dno. Powyższa prawidłowość była najwyraźniejsza w stawie nawożonym azotem i fosforem.

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Stout, J. D. 1956. Reaction of ciliates to environmental factors. *Ecology*, 37, 178–191.

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W pracy badano Ciliata w osadach dennych trzech stawów przesadkowych II w Gospodarstwie Doświadczalnym Gołysz pow. Cieszyn, należącym do Zakładu Biologii Wód Polskiej Akademii Nauk.

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Dynamika ilościowa orzęsków kształtowała się w poszczególnych stawach różnie. Najbardziej mikrofauna rozwinęła się w stawie nawożonym azotem i fosforem w przeciwieństwie do stawu nawożonego wyłącznie fosforem oraz kontrolnego, w których ilości orzęsków były znacznie mniejsze.

W badanych stawach rozwijały się głównie orzęski odżywiające się bakteriami.

Stwierdzono, że wyraźny wzrost liczebności orzęsków, a zwłaszcza gatunków Colpidium i Cinetochilum, zaobserwowano w krótkim czasie po wystąpieniu maksimum w produkcji Daphnia sp. w planktonie, tj. w okresie zwiększonego opadania tych skorupiaków na dno. Powyższa prawidłowość była najwyraźniejsza w stawie nawożonym azotem i fosforem.

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PRODUCTION OF MACROBENTHOS IN FINGERLING PONDS

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ABSTRACT

Three fingerling ponds were investigated between June 29 and October 17, 1967. Production was estimated by G r e z e's method. The production of *Chironomus f. l. thummi* and *Chironomus f. l. plumosus* was considerably greater than of other *Chironomidae* species and of other groups of fauna. At the beginning of research *Chironomus f. l. thummi* predominated in the ponds, and later on *Chironomus f. l. plumosus*. The greatest production of macrobenthos was found in the pond fertilized with superphosphate and ammonium nitrate.

CONTENTS

1. INTRODUCTION

The aim of the work was to estimate the production of benthos biomass in three fairly small and equal fingerling ponds during the 1967 season. The ponds are a part of a large fish cultivation complex in which mineral fertilization has been applied (P or P + N), but some ponds have been left unfertilized. Differences in the settling of the ponds' bottoms by fauna could thus be expected, resulting from unequal degrees of eutrophication of environments. To ascertain reasonable comparability of data, each pond was stocked with an equal amount of fish.

The present work is a part of a team survey on productivity of the new ponds, built in 1965 in the Experimental Farm at Gołysz (Cieszyn district) and managed by the Laboratory of Water Biology of the Polish Academy of Sciences.

2. TERRAIN, MATERIALS AND METHOD

Three fingerling ponds were investigated, each of 1500 m² of surface and 0.8 to 1.2 m of depth. They form a part of a large complex of ponds, comprising 24 identical rectangular reservoirs grouped in one area. The ponds were filled with water for the first time in 1965, and then in 1966. In 1967, liming was applied in all the ponds before the filling, while mineral fertilization started immediately after the filling (on June 20) and it was repeated eight times, until September 1. The dosage was each time 7.5 kg of superphosphate for ponds No. 8 and 9, and 9.0 kg of ammonium nitrate for No. 9. Pond No. 7 remained unfertilized. Each pond was stocked with 2600 of carp fry weighing initially 2 g a piece. No fodder was added, so that the fish have been feeding on natural nutrients only.

More detailed data on environmental conditions are stated in other papers published in this issue: Wróbel (1971), Lewkowicz and Wróbel (1971) and Szumiec (1971).

Materials were sampled 12 times at about 10 days intervals, starting on June 29 (the ninth day after the filling), up to October 17, 1967, i.e. immediately before the fish haul and the sluicing down of water. The period for which benthos production has been estimated was 120 days since the filling.

Six samples were taken from each pond, 100 cm² each, by means of an Ekman-Birge dredge. Two samples were taken near the inlet, two in the center, and two near the outlet. There were slight differences between the selected sites as to their depths, and overgrowing by vascular flora composed of *Glyceria aquatica* L., *Heleocharis acicularis* L. and mosses, and sometimes also as to the type of bottom surface which might contain smaller or greater addition of sand or clay. There were also differences as to soil density. Surfaces of bottoms were in general lacking in organic sediments, as they have been washed off by water waving, and destroyed by the grazing carps, particularly so during the initial phase of exploitation of the ponds. Land plant remnants, ploughed-in before the filling, also contributed to the bottoms' contents.

The found animals were determined and measured with an exactitude to 1 mm. The measurements were referred to relevant biomass values as stated in Morduhaj-Boltovskoj (1954), and to weighings by the present author.

The Greze's (1965) method was applied to compute biomass production. In this method, the basic parameters are: quantity, average biomass of an individual, values of biomass increases during 24 hr in each of the classes of length, stipulated at the intervals of 3 or 4 mm. This procedure enables the estimation of production in communities comprising animals of various ages, including larvae of insects belonging to the bottom fauna.

The diurnal increase of the biomass of larvae of each of the dominants considered in this paper was computed in two ways. In the first method, being the author's own one, the differences in the average individual weights of larvae between two neighbouring size classes in two consecutive terms t_1 and t_2 were accepted as the starting point.

The increase of the youngest larvae with a length up to 3 mm (1st age class) was computed from the biomass of the egg. For larvae of the 2nd age class, the increase was determined by subtracting from the mean mass of larvae in t_2 a half of the mean individual mass of the 1st class in the preceding term — t_1. For older larvae (in classes 3, 4 etc.) the value of the mean arithmetic number of the sum of two preceding classes in t_1 was subtracted from the value of the mean mass of those larvae in t_2. Particular results calculated for periods of time of about 10 days were then referred to a period of 24 hours and this yielded the diurnal increase.

Average value of diurnal increase computed in this manner turned out to be very close to the values obtained by means of the second method described in Konstantinov (1958), at least for larvae up to 18 mm of length. The time of survival of a generation, which must be known in any method of interpolation, was estimated by age analysis of the particular forms of larvae and of seasonal changes of the dynamics of their quantity.

Production of those Chironomidae species was calculated, as their amount, and in particular their biomass usually exceeded 90% of the total macrobenthos, sometimes even attaining nearly 100%.

3. RESULTS

FAUNA COMPOSITION

Almost the whole bottom fauna of the investigated fingerling ponds, besides the microbenthos, was composed of *Chironomidae* larvae, among which 25 forms were distinquished in total.

The form *Chironomus f. l. thummi* Kieff, which was not defined exactly, could be considered as a single species, as its larvae have appeared during a short period of time, particularly those of the first generation. During this initial period the number of larvae have reached their peak, amounting to 3815 individuals in 1 m^2 in control pond No. 7, up to 2143 ind./m^2 in superphosphate fertilized No. 8, and to 5683 ind./m^2 in the N + P fertilized No. 9. Mass development of *Chironomus f. l. thummi* larvae did not occur simultaneously in these neighbouring ponds. and since August to the end of the vegetative season this form was almost completely absent from the fertilized ponds.

The large larvae of *Chironomus f. l. plumosus* (mainly *Ch. plumosus* L.) and the smaller ones *Glyptotendipes ex gr. gripekoveni* Kieff. (*G. paripes* Edw.) were the most common. They have started to appear in fairly large numbers only since the amount of *Chironomus f. l. thummi* begun to decrease. Later on, they have been settling on the bottoms more or less numerously until the ponds were drained off. However, neither of these species have ever appeared in such mass quantities as *Chironomus f. l. thummi*. An increase of the number of individuals of *Chironomus f. l. plumosus* was mainly recorded in September; most of these larvae were found in the superphosphate fertilized pond (933, 617 and 1984 ind./m^2 in the three September samples), and in the pond fertilized with superphosphate and ammonium nitrate (317, 533 and 550 ind./m^2 respectively). In the control pond their quantity has usually been small and fairly changeable, reaching from 100 up to 333 individuals in 1 m^2 of the bottom. In the same pond *Glyptotendipes ex gr. gripekoveni* has been rather numerous; its maximum quantities were observed in September and October (up to 500 ind./m^2).

Medium size larvae of *Microtendipes ex gr. chloris (M. pedellus* De Gerr) and *Endochironomus ex gr. tendens* Fabr. (*E. tendens* Fabr.) were more numerous in the control pond than in the fertilized ones; the periods of their appearance have been rather short in both fertilized ponds (mainly in July and in autumn). Larvae of *Endochironomus ex gr. tendens* in the collected material measure up to 12 mm. Their most numerous appearances were recorded in the unfertilized pond (583 ind./m^2) and in the P + N fertilized (200 ind./m^2) on July 7. In pond No. 7 there were recorded up to 900 ind./m^2 of *Microtendipes ex gr. chloris* larvae, while in both the fertilized ponds there were up to 281 ind./m^2 (No. 8, July 27), and 316 ind./m^2 (No. 9, October 7).

The small larvae of *Polypedilum ex gr. nubeculosum* Meig. (*P. nubeculosum* Meig.) were a relatively common component of the benthos. They have been particularly abundant in the bottom of the control pond (up to 584 ind./m^2 during summer, and 1300 ind./m^2 on October 17), as well as of the superphosphate fertilized pond (400 to 784 ind./m^2). In pond No. 9 they were much less numerous (up to 400 ind./m^2). Polypedilum larvae, though fairly numerous, contributed only in a slight degree to the general production of biomass.

Since July 7, the predator Procladius Skuse has been a constant and during some periods numerous (100–200 ind./m^2) representative of the Chironomidae. These larvae could have influenced the quantities of some benthos organisms. The other predator species more or less common were: *Cryptochironomus ex gr. defectus, C. ex gr. pararostratus* Harn., *C. ex gr. vulneratus* (Zett.), *Pelopia punctipennis* (Meig.), *Ablabesmyia monilis* L., *A. lentiginosa* Fries., and besides *Culicoides sp.* of the Ceratopogonidae, *Tabanus sp.* of the Tabanidae and *Sialis sp.* of the Megaloptera.

Besides the forms already mentioned, the bottoms of the investigated ponds were settled by other Chironomidae, either rare or scanty, such as: *Endochironomus ex gr. dispar* Meig (more frequent only in No. 9, fertilized with N + P), *Glyptotendipes ex gr. polytomus* Kieff., *Chironomus sp., Polypedilum ex gr. scalaenum* Schrank (more frequent in No. 8 with P only), *P. ex gr. convictum* Walk., *Polypedilum sp., Einfeldia ex gr. carbonaria* Meig., *Tanytarsus ex gr. gregarius* Kieff., *T. ex gr. mancus* Walk., *Psectrocladius ex gr. psilopterus* Kieff. (pond No. 8), and a few forms not classified more exactly. Larvae of *Cricotopus ex gr. silvestris* F. were rather numerous in pond No. 8 since the beginning of the season until the end of July (up to 117 ind./m^2).

Larvae of *Chaoborus sp.* have not been taken into consideration in the results of the study, as they are apt to be found, besides the next-to-bottom layer, in higher water, strate, where they find a part of their food.

Larvae of other insects were represented only sporadically and in minimal quantities in bottom communities. Among them Ephemeroptera (*Caenis horaria* L.), Coleoptera (*Berosus spinosus* Stev.) and Trichoptera (*Polycentropus sp.*) can be mentioned.

Individual specimens of Oligochaeta (*Limnodrilus hoffmeisteri* Clap.) were found only a few times and at the very beginning of the vegetation period a single individual of the amphibiotic species *Eiseniella tetraedra* Savigny was recorded in pond No. 8.

Single living specimens of the small species *Gyraulus albus* Müll. were occasionally found in pond No. 9. Besides, small empty shells of other Gastropoda were found in the benthos of the investigated ponds.

By means of an analysis of the dynamics of periodical quantitative changes in the age structure, the time of development of the larvae *Chironomus f. l. thummi* was estimated as about 19 days.

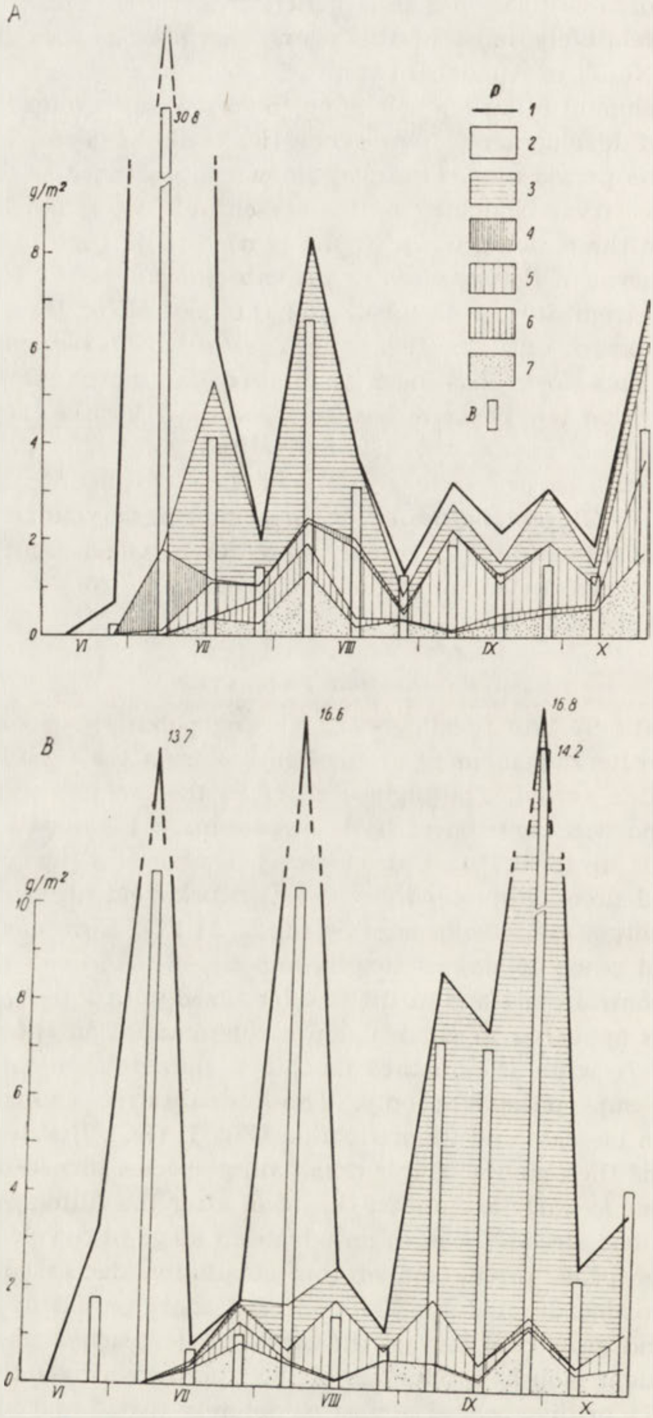
The life cycles of *Chironomus f. l. plumosus* were not uniform. During the period of investigation 3 or 4 generations of this species have been observed. Relatively most of the young larvae were usually collected from pond No. 8, in August. In spite of a not clear pattern of periodical changes of amount of larvae belonging to various age groups, an approximate time of development of one generation could be established as about 22 days. This period was certainly somewhat prolonged in autumn, and a part of the larvae belonging to this season failed to attain full development before the sluicing down of the ponds at the time of a fish haul.

Young larvae of *Polypedilum ex gr. nubeculosum* have been appearing numerously from July to October, and thus not all of them terminated their development until the fish haul. The time of development of a generation of this form has been estimated as approximately 16 days. A similar period (16–17 days) has been assumed for the larval stage of *Microtendipes ex gr. chloris, Glyptotendipes ex gr. gripekoveni,* and *Endochironomus ex gr. tendens.* It was difficult to distinguish particular generations in *Glyptotendipes ex gr. gripekoveni,* as younger larve have been present alongside with older ones for a longer time than other forms. The larval development of the predatory Procladius Skuse has been taking about 14 days.

BIOMASS AND PRODUCTION

The relatively late flooding of fingerling ponds has been favourable for an intensive development of the benthos from the very beginning of the production period. The highest share in the biomass and production of this fauna was contributed by: *Chironomus f. l. thummi* (during the filling period up to 91.7%), *Chironomus f. l. plumosus* (up to 91.0%) and in a lesser degree, *Glyptotendipes ex gr. gripekoveni* (up to 68.9%) besides *Polypedilum ex gr. nubeculosum* (up to 31.1%). *Chironomus f. l. plumosus* could reach 25 mm of length, and *Ch. f. l. thummi* only 17 mm.

In the control pond and in the one fertilized with P + N, *Chironomus f. l. thummi* appeared in particularly great numbers in the second sampling (July 7), while it remained much less numerous in the pond fertilized with superphosphate only. Those qualitative changes appeared distinctly in biomass and its production (Fig. 1 ABC). Besides, in the fertilized ponds the amount of this dominating species turned out to be relatively large as early as June 29, i.e. soon after the filling. A part of the individuals has already been in an advanced stage of development. After the summer peak, production of this population decreased remarkably in the third decade of July. Thus, after a short period of an intensive hatching and growth of larvae, the larval stage reached its end. During the subsequent months production of this species was usually very small (pond No. 7), or dissapeared almost completely (No. 8 and 9).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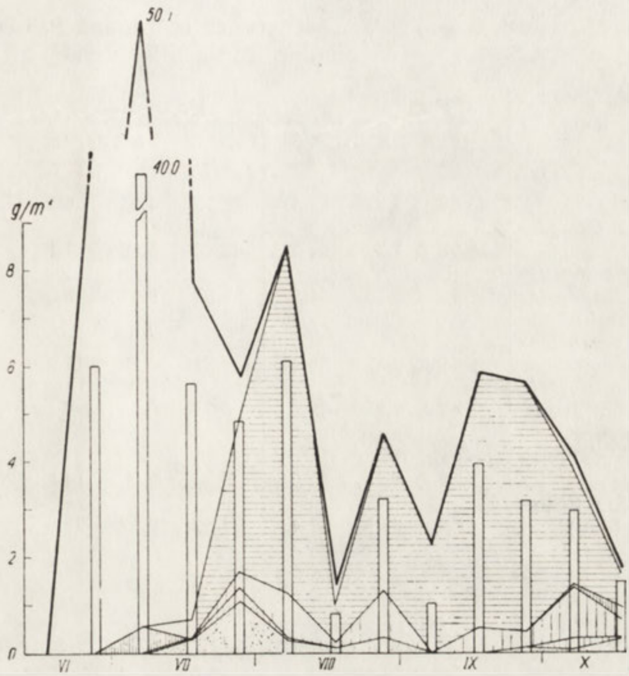

Fig. 1. Seasonal changes of production (*P*) and biomass (*B*) of more important benthos components. A — pond No. 7 (control), B — No. 8 (superphosphate), C — No. 9 (superphosphate + ammonium nitrate). 1 — total production of larvae, 2 — *Chironomus f. l. thummi*, 3 — *Ch. f. l. plumosus*, 4 — *Endochironomus ex gr. tendens*, 5 — *Glyptotendipes ex gr. gripekoveni*, 6 — *Microtendipes ex gr. chloris*, 7 — *Polypedilum ex gr. nubeculosum*

Table I presents production (*P*), average biomass (*B*) and *P*/*B* coefficient for the several non predatory predominating species and for the rapacious form Procladius Skuse. The quoted data point to the great contribution of the two predominating species, *Chironomus f. l. thummi* and *Chironomus f. l. plumosus* to benthos production in comparison with the other, less numerous and small species. It also appeared that in both of the fertilized ponds the amount of biomass produced by *Ch. f. l. plumosus* was almost twice as large as the production of these larvae in the control pond. The total net production of Chironomidae larvae in each of the three ponds, however, was similar, as in No. 7 the larvae of *Ch. f. l. thummi* and of 4 other forms of Chironomidae were relatively numerous. In the control pond the period of appearance of the *Ch. f. l. thummi* larvae has been longer than in the fertilized ponds. Besides, on some terms of sampling the biomass of these larvae was small enough to lower significantly the value of the average seasonal biomass. Thus the *P*/*B* coefficient (with *P* relatively large) turned out to be correspondingly high. The

Table I. Production P, average biomass B* (g/m²) and P/B coefficient of the predominating Chiromidae larvae

Species	Pond No. 7			Pond No. 8			Pond No. 9		
	P	B	P/B	P	B	P/B	P	B	P/B
Chironomus f.l. thummi	48.39	3.92	12.3	32.18	4.95	6.5	58.96	7.57	7.8
Chironomus f.l. plumosus	15.99	1.24	12.9	40.80	3.66	11.1	30.69	2.06	14.9
Endochironomus ex gr. tendens	2.35	0.16	14.7	0.27	0.03	9.0	0.87	0.14	6.2
Glyptotendipes ex gr. gripekoveni	9.72	0.32	30.4	4.82	0.28	17.2	4.62	0.30	15.4
Microtendipes ex gr. chloris	3.67	0.21	17.5	0.73	0.08	9.1	0.68	0.07	9.7
Polypedilum ex gr. nubeculosum	5.80	0.97	15.7	5.53	0.38	14.5	2.48	0.18	13.8
Procladius Skuse (predatory)	1.07	0.05	21.4	2.52	0.12	21.0	1.93	0.10	19.3

* For periods of appearance of a given form only.

pattern in pond No. 7 was also similar for larvae of *Endochironomus ex gr. tendens*, *Glyptotendipes ex gr. gripekoveni* and *Microtendipes ex gr. chloris*.

In Table II production and the average seasonal biomass of the larvae of *Chironomidae* are stated jointly. The general value of B was computed

Table II. Total production P, average biomass B (g/m²) and P/B coefficient of predominating non-predatory Chironomidae larvae

Parameters	Pond No. 7	Pond No. 8	Pond No. 9
P	85.92	84.33	98.30
B	4.59	5.03	6.61
P/B	18.7	16.6	14.9

for 6 forms, out of 12 series of samples (terms). It can be seen from those data that pond No. 8, with its slightly higher average biomass than the control, yielded a slightly lower production; however, these small differences of production value are within the limits of a methodical error. The P/B coefficient was the highest in the control pond, and the lowest in the N + P fertilized one.

Not very large production of larvae *Chironomus f. l. thummi* in the P fertilized pond, had two peaks during the first half of the investigation period, and not one, as in the control pond, or where two types of fertilizers had been applied. One of the causes might be different trophic relations, e. g. connected with an uneven distribution of flooded plants.

A particularly high *P/B* coefficient (at small values of *B*) in the three ponds was typical for the larvae of Procladius Skuse. They belong to the rapacious, small species, marked by remarkable constancy of appearance in many pond environments.

4. DISCUSSION

The peculiarity of the bottom environment was mainly caused by the fact that the ponds were young and sediments were not fully formed. A pond bottom looked like wet soil, with fresh organic sediment on its surface. After the filling with water, an intensive decay of ploughed-in plants has been probably occurring. In favourable thermal and oxygen conditions a strong development of bacteria, protozoans, and other microbenthos organisms must have taken place. Trophic changes, brought about by decay of plant matter, and partly by the action of fertilizers, have been in turn favourable for production of some large species of Chironomidae. In advantageous chemical conditions algae also developed abundantly (Krzeczkowska-Wołoszyn 1971), which rendered high primary production (Lewkowicz and Wróbel 1971). Its utilization by larvae of Chironomidae has been confirmed by analyses of their food (Kyselowa and Zięba in prep.). Periodical changes in bottom macrofauna production also pointed to its dependence on the quantitative development of microbenthos (Grabacka 1971), but mainly on phytoplankton (Krzeczkowska-Wołoszyn 1971) and on primary production (Lewkowicz and Wróbel 1971). For instance, intensification of the development of the two main predominating species (*Chironomus f. l. thummi* and *Ch. f. l. plumosus*) often occurred during periods of mass appearance of certain groups of algae and Ciliata, and even of zooplankton (cf. Lewkowicz 1971). Perhaps the thermal conditions, characterized by Szumiec (1971), have also favoured a rapid growth of *Chironomus f. l. thummi.*

Oligochaeta occurred in the investigated fingerling ponds very scantily in comparison with commercial carp ponds of the Experimental Farm at Gołysz (Zięba 1963, 1967), as well as with ponds in other areas, where they were reported to be one of the important benthos groups (Patriarche and Ball 1949, Merla 1966). This was undoubtedly important for the trophic conditions and for development of other bottom invertebrates, and mainly for larvae of Chironomidae, which settled the bottom immediately after the filling of fingerling ponds.

Results of studies on macrobenthos have been partly related to changes caused by different eutrophication of the ponds; these changes have been partly expressed by the general level of production of this fauna (and by its ratio to the average seasonal biomass, i.e., the *P/B* coefficient), as well as by quantities of occurrence of the few predominating forms. As already mentioned, production in two ponds was influenced by fertilizers. However, this factor has acquired real significance only after the decay of the mass of plant matter and the exhaustion of food supply for one of the greatest and most numerous benthos species.

Exceptionally abundant appearances, and thereby the large production of *Chironomus f. l. thummi* larvae at the beginning of July (and in pond No. 8 even as late as the beginning of August) can be considered as indicating that the influence of flooding of the scarified soil with ploughed--in plants was stronger than that of fertilization. This is also confirmed by the large production of this benthos form in the unfertilized pond No. 7 during that early period. Larvae of *Chironomus f. l. thummi* are generally considered as indicative for putretaction processes occurring in polluted waters; they have also appeared abundantly in carp ponds at Żabieniec (Wójcik-Migała 1965).

High degree of eutrophication after an application of fertilizers could be seen, among other things, in the production of another important dominating species, *Chironomus f. l. plumosus*. Production of these larvae has been higher than that of *Ch. f. l. thummi* only when superphosphate was applied; in control conditions they were much less abundant than in environments with fertilizers. Anyway, the highest production of larvae of *Chironomidae* (with an exceptionally high contribution of *Ch. f. l. thummi*) was recorded in the pond supplied with mixed N + P fertilizers.

Ten days intervals of sampling terms proved to be sufficient to define the intensity of production and to obtain a clear pattern of the seasonal variability in the summer fingerling ponds. The employed method of estimating production allowed to compute its value even in cases of a large differentiation of age of the several important components of the benthos fauna. The author of the method (Greze 1965) used it for defining fish production, and Kajak (1967) employed it in investigating lake benthos.

As a 0.5 mm net was used for rinsing the benthos, some losses of larvae belonging to the first age class (below 3 to 4 mm of length) could be expected. However, according to Kajak (1967) the share of those smallest individuals in the total benthos production is negligible. It seems, too, that losses in fauna caused by the rapacious larvae (Procladius Skuse) were not large.

However, the rapidly growing carp fry, feeding, besides plankton, on macrobenthos, could have caused more significant decrease in the production. This has been stated earlier in another group of fingerling ponds in the same farm (Skaziński 1966). An increase of fish production as a result of fertilization has been proved in the ponds now investigated by Włodek (1971). It can thus be expected that fish have been feeding largely on natural food. However, losses in benthos are compensated in a short time by new generations of invertebrates, mainly by larvae of insects.

Acknowledgements

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5. SUMMARY

Investigation was carried out in three fingerling ponds, of 1500 m² each, in the Experimental Farm at Gołysz (Cieszyn district). Material was sampled at 10 days intervals, from June 29 to October 17, 1967. Each time 6 samples were collected from every pond by means of an Ekman-Birge dredge, with a surface of 100 cm². Two ponds were fertilized (No. 8 with superphosphate, and No. 9 with superphosphate and ammonium nitrate, and the third one remained unfertilized.

Larvae of Chironomidae (25 forms) were large by prevailing in the macrobenthos. Among them the most abundant were *Chironomus f. l. thummi* and *Ch. f. l. plumosus* while *Glyptotendipes ex gr. gripekoveni* were less numerous; the biomass of these species was large. Larvae of this group formed more than 90%, or even close to 100% of the total community biomass.

Soon after the filling of the ponds *Chironomus f. l. thummi* appeared in a large amount. After a few weeks, however, the large form *Chironomus f. l. plumosus* prevailed in fertilized ponds for a longer period than in the control (Fig. 1 ABC). Other species of the bottom fauna were usually scanty and relatively small.

Biomass production was computed for 6 non-predatory and 1 rapacious form of Chironomidae, by means of Greze's method (1965). The highest production of *Chironomus f. l. thummi* was recorded in the N + P fertilized pond, and then in the control one (Table 1). It shows that the development of those larvae depended mainly on the food coming from decomposed water plants at the bottom (Table I). The eutrophizing influence of fertilizers was expressed in the occurrence of the second predominant species, *Ch. f. l. plumosus*, mainly in August and September.

Pond No. 9, fertilized with N + P, yielded the highest benthos production, 98.30 g/m². In No. 8 (P) and No. 7 (control) values of biomass production were similar. The *P/B* coefficient was the lowest in the P + N fertilized pond, and the highest in the control one (Table II).

6. STRESZCZENIE

Badania wykonano w trzech stawach przesadkowych o powierzchni 1500 m² każdy, w Gospodarstwie Doświadczalnym Gołysz (pow. Cieszyn). Materiał zbierano za pomocą czerpacza Ekman-Birge o powierzchni 100 cm² co około 10 dni, w okresie od 29. VI do 17. X 1967 r., uzyskując każdorazowo po 6 prób ze stawu. Dwa stawy były nawożone, staw Nr 8 — superfosfatem, Nr 9 — superfosfat + saletra amonowa, a trzeci (Nr 7) nie był nawożony.

W składzie makrobentosu przeważały zdecydowanie larwy Chironomidae — 25 form. Wśród nich największy udział miały *Chironomus f. l. thummi, Ch. f. l. plumosus*, a mniejszy *Glyptotendipes ex gr. gripekoveni*; biomasa tych gatunków była duża. Larwy tej grupy stanowiły przeważnie ponad 90 — do blisko 100% biomasy całego zgrupowania.

Wkrótce po napełnieniu stawów wystąpił bardzo licznie *Chironomus f. l. thummi*. Po kilku tygodniach dominacja należała głównie do dużej formy *Chironomus f. l. plumosus*, utrzymywała się ona dłużej w stawach nawożonych niż w kontrolnym (Fig. 1). Inne gatunki fauny dennej były zwykle nieliczne i stosunkowo małe.

Produkcję biomasy wyliczono dla 6 niedrapieżnych i 1 drapieżnej formy Chironomidae metodą Greze (1965). Największą produkcję *Chironomus f. l. thummi*

stwierdzono w stawie z nawozami N + P, a najniższą w stawie z nawozem P (Tab. I). Eutrofizujący wpływ nawozów wyraził się w występowaniu drugiego dominanta, *Chironomus f. l. plumosus*, przede wszystkim w sierpniu i wrześniu.

Staw Nr 9 nawożony N + P wykazał najwyższą produkcję bentosu, 98,30 g/1 m². W stawach Nr 8 (P) i nienawożonym Nr 7, wielkość produkcji biomasy była nieco niższa i podobna w obu stawach. Współczynnik *P/B* był najniższy w stawie z nawozami P + N, a najwyższy w stawie kontrolnym (Tab. II).

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BIOMASS AND PRODUCTION OF CARP FRY IN DIFFERENTLY FERTILIZED FINGERLING PONDS

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ABSTRACT

Carp fry was investigated in 12 differently fertilized ponds. The growth of fish was assessed by measuring weight, total and body length, height and breadth of fish in samples taken about every 10 days. Knowing the density of fish at the stocking and when fishing out the pond, 7 elementary mathematical functions were applied alternatively for estimating the mortality (survival) of fish in intermediary time intervals. The individual growth, biomass and production were highest in the ponds fertilized with N + P. The variability of the fish weight and its correlation with production were also studied.

CONTENTS

1. INTRODUCTION

The aim of this work was to estimate an influence of the mineral fertilization of ponds on the biomass and production of the carp fry as well as to choose a mathematical model for survival of fish. The dependence between the variability in the weight of fish and the fish production was also examined.

2. TERRAIN, MATERIAL AND METHODS

Research was carried out in 12 ponds of the Experimental Farm of the Laboratory of Water Biology at Gołysz (Cieszyn district) in 1967. Four ponds (No. 1, 5, 7, 11) were unfertilized (control), four ponds (No. 3, 6, 8, 12) were fertilized with phosphorus, and four ponds (No. 2, 4, 9, 10) were fertilized with nitrogen + phosphorus. Phosphorus was added to the ponds in 8 equal doses as well as nitrogen in the form of superphosphate and Norway saltpetre, respectively. During the vegetation season 32 kg of P/ha and 163 kg of N/ha were supplied to the ponds, the ratio N : P being 5.2. This corresponded to 3.5 mg of P/l of water and 18.2 mg N/l of water according to Wróbel (1971).

The growth of carp fry was observed under two different types of mineral fertilization. Unfertilized ponds were used for comparison.

In terms of genetics, the population of stocked carp fry formed a mixed population of different strains of carp bred at the Experimental Farm at Gołysz. The strains resembled the population of carp used in commercial ponds. Generally, they belonged to a race known at present as "the Polish carp", and formerly (in 19th century) — as the race of "Galician carp". For reference see e.g. Włodek (1967).

Each experimental pond was stocked on 3rd July 1967 with 2600 fish. The mean weight of an individual was 2 g. Samples of fish were taken from the ponds about every 10 days at random by means of a small drag net during the vegetation season, i.e. from the stocking to the fishing out the ponds.

The growth in weight was examined, and 4 morphological features were also measured.

The features for the biometrical measurements were chosen according to the commonly used method (e.g. Włodek 1961). The following biometrical measurements were taken for each specimen caught in a sample:

x_1 — weight (g),
x_2 — total length (cm),
x_3 — body length (cm),
x_4 — maximal height (cm),
x_5 — maximal breadth (cm).

The features are given here in the sequence (permutation) used usually in measurements of fish.

The representativeness of sampling the fry was tested on 23rd October. Twelve samples were taken and estimated according to usual procedure. After this the ponds were emptied and the whole population was counted and weighed. It was found that 10 samples out of 12 were considered as representative statistically.

During the vegetation season 108 samples were drawn so it was possible to compare the results obtained by the usual procedure of the sampling with the real mean weight. The means of samples in 10 cases out of 12 possible ones were laying in the confidence intervals of the total population (Snedecor 1959), thus the representativeness and probability of the sampling method of a small drag net was 83%. There was one evident exception, that of pond No. 11 on 24th of August.

The formulae used for the determination of fish biomass and production were taken after Chapman (1968):

$$\text{Biomass } (B) = N \cdot \bar{x}$$

where: N — the number of the individuals in a pond at time t, $\bar{x}$ — the arithmetic mean of the weight of an individual at time t.

$$\text{Production } (P) = G \cdot \bar{B}$$

where:

$B = (B_1 + B_2) : 2$ — the average biomass at two time intervals,
$G = (\ln \bar{x}_1 - \ln \bar{x}_2) : \Delta t$ — the instantaneous coefficient of growth,
$\ln \bar{x}_1$, $\ln \bar{x}_2$ — natural logarithms of the mean weights at two time intervals,
Δt — the increment of time.

In Chapman's (1968) calculations, the increment of time, Δt, was constant, e.g. 1 month interval between the successive samples ($\Delta t = 1$). In the present paper the time interval was about 10 days. However, the period between the last two samples was 40 days, so an allowance had to be taken in the calculations.

In the experiment, 3048 individuals of fry were measured, 12,624 results were obtained for 5 above mentioned features.

3. RESULTS

INDIVIDUAL GROWTH

In order to calculate the biomass of fry the mean individual weight must be known as well as the number of individuals in the population at the sampling time. As the sampling method was representative, the means were calculated from the samples. The average individual growth of carp fry depending on the type of fertilization is given in Fig. 1. In

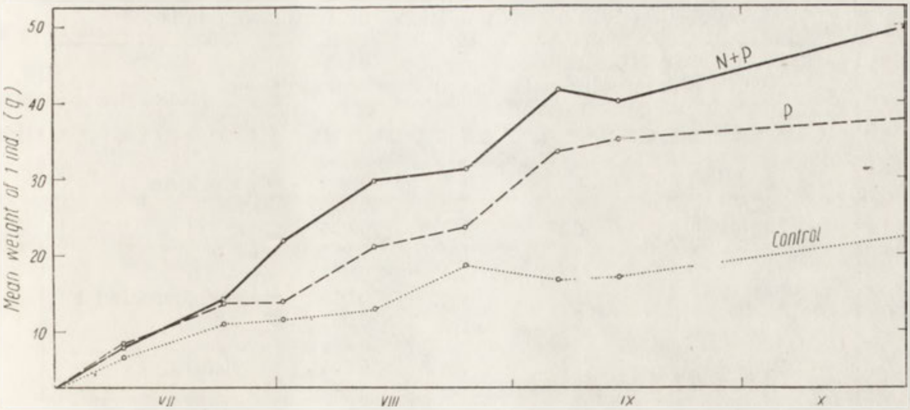

Fig. 1. The mean individual growth of carp fry depending on the type of fertilization in fingerling ponds

the first period of growth, the growth curves for the fertilized ponds run parallelly but from the beginning they run considerably higher than those for the control ponds. The average of the individual growth was greatest during the whole season in the N + P fertilized ponds, in the ponds fed with P it was intermediary, and in the unfertilized ponds it was lowest. The best growth was observed in pond No. 10 fertilized with N + P, the lowest — in pond No. 1, which was a control one. A peak of growth in the N + P fed ponds was observed at the beginning of September and in the control ponds at the end of August.

Examining an individual growth in each particular pond during the whole season one can observe a variety of the growth curves (not presented here). The growth curves of the N + P fertilized ponds present a more compact picture than those of the other ponds. Discrepancies between the values obtained at the fishing out were greatest among the P fertilized ponds, nearly twice as high as those for the N + P fertilized ponds. Therefore, one can infer that the effect of N + P fertilization was more stable in respect to the ultimate result than that of other types of fertilization. In almost all the ponds already mentioned, peaks and depressions of the growth rate can be observed.

When fishing out, it was found that the mean weight of fry of four P fertilized ponds was 171% of that of the unfertilized ponds, the mean individual weight of fry of the N + P ponds was 215% of that of the unfertilized ponds. This only fact shows the significant influence of the type of fertilization on the mean individual weight growth of the carp fry. The significance of the effect of fertilization on the individual weight growth was evaluated using F test (Snedecor 1959). The results are presented in Table I. The significant influence of the fertilization was

Table I. The probability P of a greater value for the variance ratio coefficient F. Control ponds versus fertilized ponds

Sample No.	Duration of growth in fingerling ponds (days)	Probability (P)	Remarks
1	0	0.000	stocking
2	9	<0.050	
3	22	<0.025	
4	30	<0.025	
5	42	<0.005	
6	54	<0.025	for corrected F
7	66	<0.005	
8	74	<0.005	
9	114	<0.005	fishing

already found during the initial growth of fry in fingerling ponds; and this growth significantly increased after 25th July.

At the end of August the variance ratio test showed no significance. It was caused by an unusually high rise in the value of the average weight in control pond No. 11. The sample from this pond was probably not representative as the further sample was similar to the others. It caused a distortion of the average and in the consequence a lack of significance. When this distortion was corrected by an average of the remaining three control ponds, a significance of the fertilization effect was restored.

SURVIVAL

The calculation of the number of fish at the time of sampling is difficult because of the impossibility of emptying a pond every 10 days. The number of fry can be determined precisely only when stocking and fishing out the pond. A considerable mortality of fry occurring in fingerling ponds during the vegetation season should be taken into account.

In order to estimate the number of the individuals living in the population at any time t, i.e. at the time of sampling, a regularity of the decrease of the number of fry in the population should be assumed arbitrarily. Such assumptions of mortality (or of survival) were accepted in this paper to be elementary mathematical functions.

The decrease in the population numbers could be observed experimentally at the fishing out the ponds, the numbers of individuals fished out were different in every pond.

The average mortality in the fertilized ponds was practically the same: 31.6 and 31.7% (Table II). The type of the fertilization did not affect it. The mortality in the control ponds was greater — 43.7%, i.e. 12% more than in the fertilized ponds.

Seven different types of mortality in the population were assumed as described by 7 elementary mathematical functions: 1. linear function, 2. exponential function, 3. logarithmic function, 4. parabolic 2nd degree function, 5. parabolic 3rd degree function, 6. power function, 7. hyperbolic function.

Thus the second factor needed for the calculation of the biomass is to be obtained, but in 7 different alternative magnitudes depending on the hypotheses of the function taken.

Table II. Average mortality of fry depending on fertilization of ponds

Ponds	Stocking number of individuals per pond	Number of fished out individuals (average per pond)	% of the mortality in 1 pond
control	2600	1464	43.7
N + P fertilized	2600	1779	31.6
P fertilized	2600	1775	31.7

An example of using of the exponential function for the calculation of survival is given below:

The hypothetical number of individuals at sampling (y) was found from the formula $y = c + a^x$, where c — number of individuals fished on 23 October (1779), x — number of days between sampling and fishing out the pond, a^x — number of fish living at sampling (a — a positive number different from 1).

Since y_1 is known as being the stocking number on 3rd July, i.e. 2600 individuals, and $x_1 = 114$, it is possible to find the log a value for sample No. 1:

$$a^{x_1} = 2600 - 1779 = 821$$
$$x_1 = 114$$
$$114 \log a = \log 821 = 2.91430$$
$$\log a = 0.025564$$

and to calculate the subsequent y_2, ..., y_9 values which are given in Table III.

CHANGES OF BIOMASS

Basing on 7 different types of survival, 7 different values of the biomass could be calculated. The average biomass expressed by 7 values for all ponds irrespectively of the type of fertilization was calculated. Figure 2 presents 7 curves of average biomass for total 12 ponds, drafted according to the different functions. The following conclusions can be drawn from Fig. 2:

1. The greatest increase of the fry biomass occurred from the stocking to the beginning of September. After that period the biomass amount diminished and was recovering slowly during the rest of the period. For the lower laying biomass curves the recovery was up to the highest point which was reached earlier, and for the higher laying curves there was no recovery to such a point.

2. The general pattern of the changes in biomass increment was practically similar irrespective to the 7 different hypotheses accepted, the curves of the biomass took approximately similar trend. Two extremely running curves were: one based on the logarithmic hypothesis of the survival and the other on the exponential hypothesis. The logarithmic survival gave the highest evaluation of the biomass, the exponential one — the lowest. The linear hypothesis is situated in central position for all types of the survival. The remaining curves resulting from the other hypotheses run approximately between the two extremal curves with some unimportant exceptions.

3. From the above it results that the linear hypothesis gives an estimation of the average biomass, and that such linear hypothesis is very useful especially when no other information concerning the possible mortality is available.

4. It follows that the real value of the biomass must intervene somewhere between the two extremal functions and therefore there is no need to calculate always all 7 estimates; it is sufficient to calculate the limits and the average curve only (linear hypothesis). Those two extremes of the biomass delimit a surface on a graph called "an alternative surface of the biomass". The real value of biomass is falls within tho-

Table III. An example of the calculation of the hypothetical number of surviving carp in pond No. 9 during the experiment, according to the exponential hypothesis of mortality. Explanations are given in the text

Sample No.	Days between flishing out and sampling x	$x \cdot \log a$	a^x	Hypothetical number of specimens at sampling $y = 1779 + a^x$
1	114	2.91430	821	2600
2	105	2.68422	483.3	2262
3	92	2.35139	224.8	2004
4	84	2.14738	140.3	1919
5	72	1.84061	69.3	1848
6	60	1.53334	34.2	1813
7	48	1.22707	16.9	1796
8	40	1.02256	10.5	1790
9	0	0.00000	1.0	1780

se limits. The best way to present the hypothetical values of the biomass in a pond is to plot them on a graph giving the upper limit (logarithmic hypothesis), the lower limit (exponential hypothesis) and the average (linear hypothesis). The biomass of fry during the whole experiment was presented in this way in Fig. 3. The biomass of fry was dependent on the type of fertilization. According to three types of fertilization three different surfaces gave the possible area where the real value of the biomass should be. Practically, those three alternative surfaces do not coincide. This proves that the fertilization significantly influenced the biomass

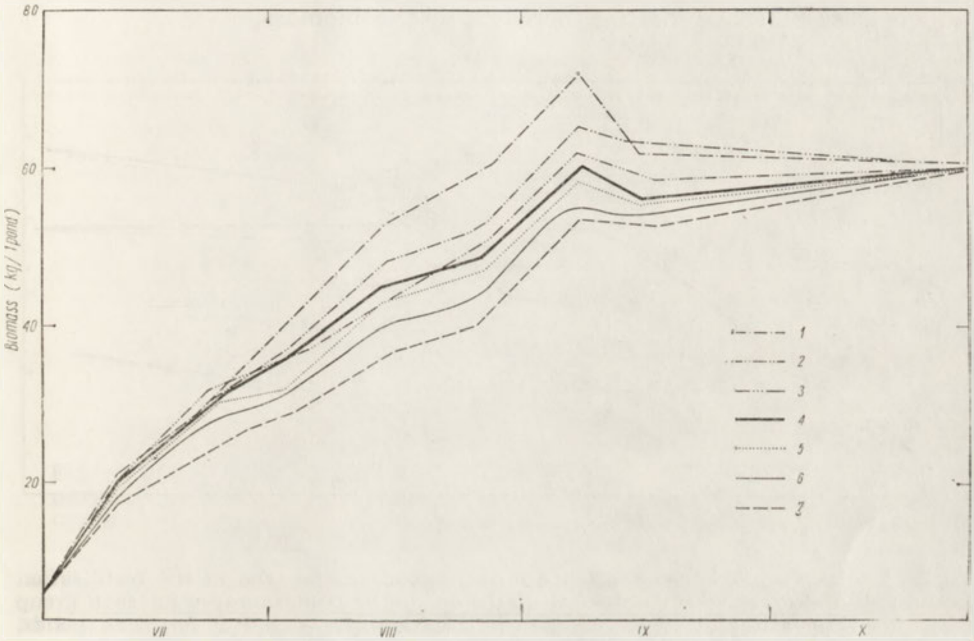

Fig. 2. The average biomass in 12 experimental ponds (kg/1 pond) according to different hypotheses of survival: 1 — logarithmic, 2 — hyperbolic, 3 — power function, 4 — linear, 5 — parabolic x^2, 6 — parabolic x^3, 7 — exponential

amount in the fingerling ponds. The highest amount of the biomass in the N + P fertilized ponds can be observed. Lower to this surface and neighbouring closely but practically not coinciding is the alternative surface of the biomass from the P fertilized ponds. The surface of biomass of the control ponds takes the lowest position. The increase of the biomass of the fertilized ponds runs parallelly up to the end of July (3rd sample) and then differentiates, the average biomass of the N + P fertilized ponds shows a steeper increase than that of the P fertilized ponds. The biomass of the control ponds is smaller from the beginning. The peak of the biomass was observed in the fertilized ponds at the beginning of September, but in the control ponds, at the end of August, that is earlier than in the fertilized ponds. After the peak there is a break down in all three groups. The recovery of growth can be observed only in the N + P fertilized ponds and in the control ponds.

From the above it may be presumed that the amount of the fry biomass in a pond is more dependent on the individual weight of specimens than on the type of function that describes their survival. Thus it is not the mortality but the growth of the specimen in the population which is responsible for the increases of the biomass.

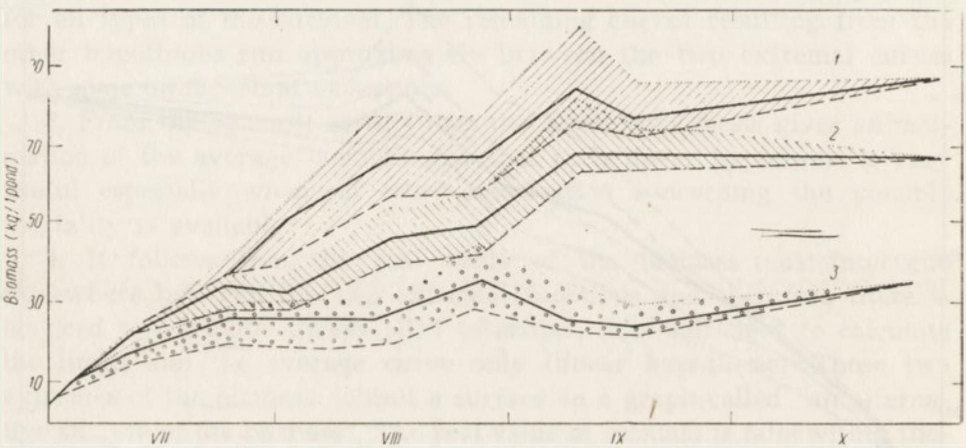

Fig. 3. The average biomass (kg/1 pond), depending on the type of the fertilization presented in alternative surfaces (Calculated on the basis of averages for each group of ponds from different types of the fertilization). 1 — N + P fertilized ponds, 2 — P fertilized ponds, 3 — control ponds

The interdependence between the exponential survival (the lowest estimate of the biomass), the individual growth curve, and the biomass curve in this experiment, taken as an average for one pond, is shown in Fig. 4. Different units were used for those features, therefore, in order to compare them, they had to be presented in the form of indices. The respective indices were calculated on the basis of the arithmetic means for each feature: number of individuals — 1896.4, biomass — 36.0028 kg, individual growth in weight — 20.5010 g. One can see from Fig. 4 that a high and positive correlation existed in the ponds between the individual growth of fry and the biomass in the pond with a negative correlation found between those two features and the exponential function of surviving numbers, i.e. the mortality and the biomass were not interdependent. After calculating the correlation coefficient for the individual growth and the amount of the biomass, the coefficient r proved to be very high, nearly 1.

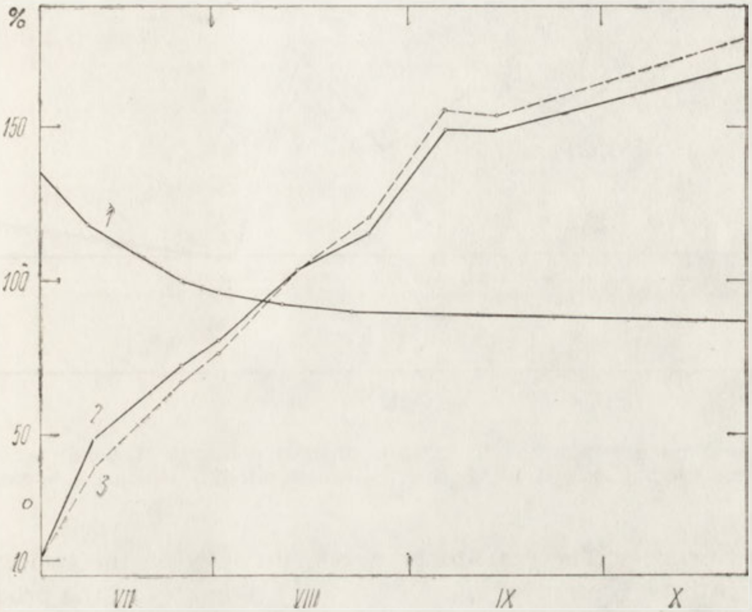

Fig. 4. The interdependence between the survival (1), the biomass in the pond (2), and the individual growth of weight (3) during the experiment. The curves were calculated as indices on the basis of respective arithmetic means

On the basis of Fig. 2–4 it is possible to draw a general conclusion as to the method of calculating the biomass. For fry older than one month one can assume the linear hypothesis of the development. The biomass calculated in other ways showed always the same regularity. The different functions did not alter the general pattern of the biomass increment. Therefore the easiest curve to calculate is of the practical importance and this is the curve of the linear survival.

PRODUCTION

The assumption of different elementary mathematical functions as survival hypotheses did not influence also the general regularity of the time changes of production (Fig. 5). Similarly as for the biomass, the logarithmic and exponential survival functions gave extreme production values. The linear hypothesis gives the curve running in between the

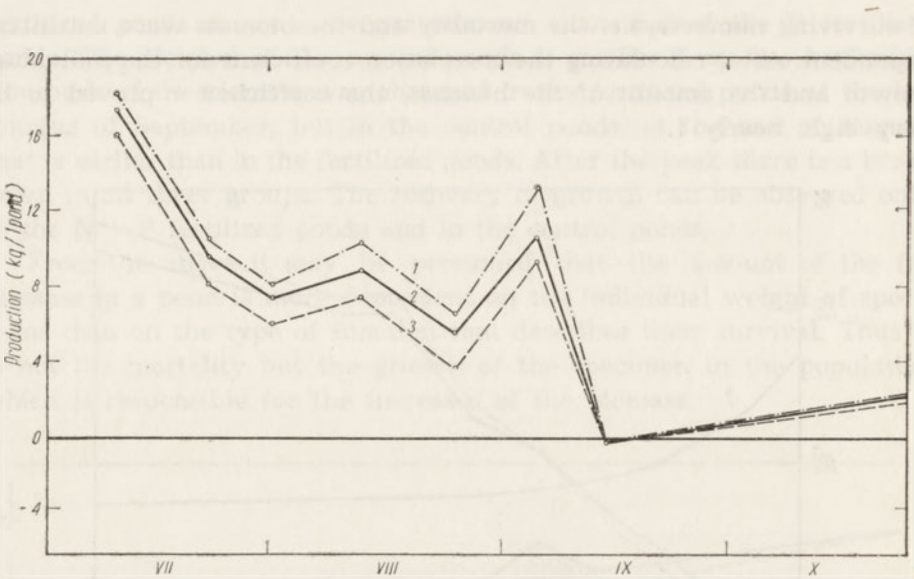

Fig. 5. The average production in 12 experimental ponds (kg/1 pond) according to three different hypotheses of survival: 1 — logarithmic, 2 — linear, 3 — exponential

two former curves. The remaining curves run between the two extremal curves and there is no need to calculate all 7 estimates of the production; it is sufficient, similarly as it was in the case of the biomass calculations, to calculate only three (from the logarithmic, exponential and linear functions). Therefore, only these estimative curves together with the linear estimate, are given in Fig. 5.

The high value of production was observed at the outset of the experiment. In the first decade the greatest value of production in ponds was reached irrespective of the assumed hypothesis of survival. Then a decrease of production appeared with a small peak approximately at the middle of August, a second great peak occurred at the beginning of September, then a sharp decrease followed down to the negative level and a slow recovery during the rest of the period of September and in October to the time of fishing out the ponds. The negative production means that the fish were loosing the weight, i.e. they partly covered their cost of maintenance from the substances stored in the body.

This was a general pattern of the production changes in all ponds. This pattern was illustrated by each of the assumed hypotheses of survival.

The peak of production found in early September coincides in the first decade with the peak of biomass in the fertilized ponds and coincides with the greatest growth rate of the individual weight. On the basis of the above, Figure 6 was compiled. The pattern of changes is here quite irregular for all three types of fertilization. The N + P ponds curve shows the greatest variation, it has three distinctive peaks, in early July,

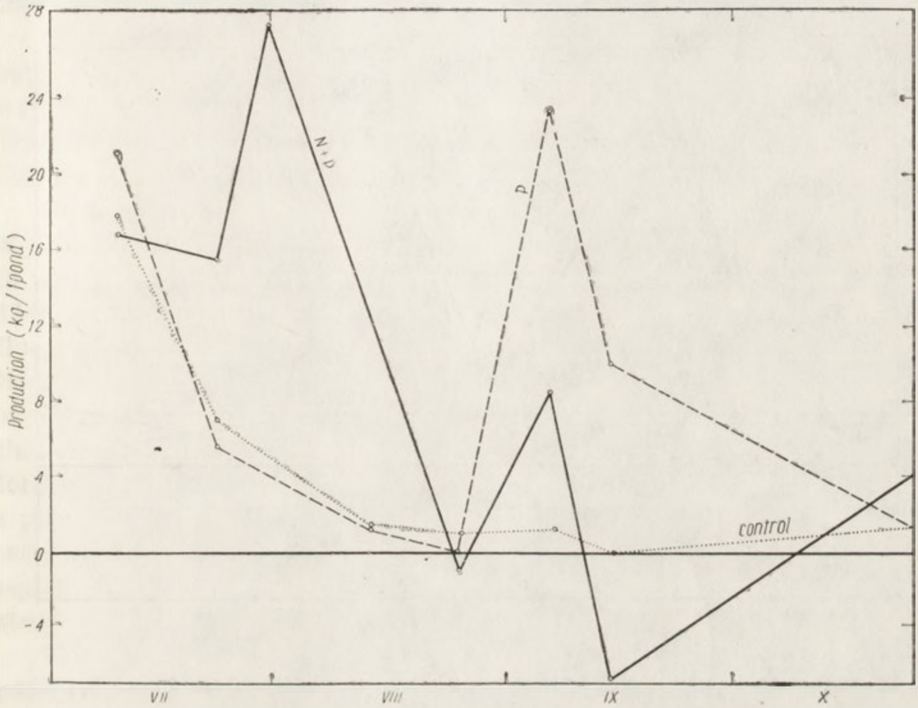

Fig. 6. Production in differently fertilized ponds on the basis of linear hypothesis of survival. 1 — N + P fertilized ponds, 2 — P fertilized ponds, 3 — control ponds

early August, and in early September, i.e. the peak occurs every 30 days. The P ponds curve has also three peaks. It coincides in early July and early September with those of N + P curve. The control ponds show only two peaks in early July and at the end of August. The negative production was observed in the N + P ponds and the control ponds. In the control ponds this was early September after the end of the peak in August when such production was noted and in the N + P ponds the fish showed the negative production in the middle of September, after the peak in the first days of this month. There was a slow subsequent recovery. The P fertilized ponds did not show negative production. The greatest downfall in the production was observed for the N + P ponds (Fig. 6).

In order to compare production with the results of other authors in this issue who worked with three ponds (No. 7, 8, 9), Fig. 7 was plotted. The control pond No. 7 shows a steady decrease in the production from the early July peak to the fishing. The greatest divergences are seen in the N + P pond (No. 9), practically the negative production is seen in

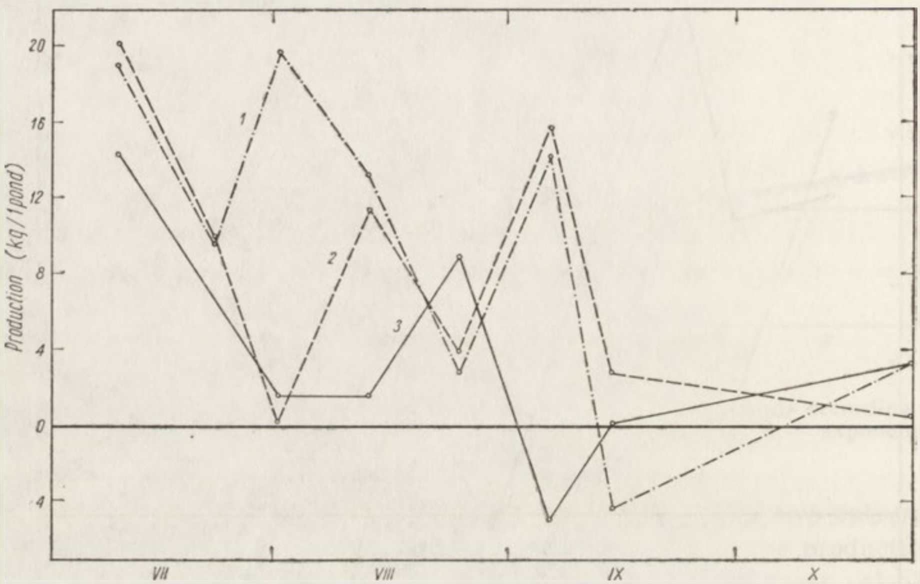

Fig. 7. Production in ponds No. 7 (1), 8 (2), 9 (3) on the basis of the linear hypothesis of survival

this pond in the middle of September, on the other hand, the greatest peak of production is seen at the end of July. Pond No. 8 (P fertilized) shows two distinct peaks and it is characteristic that the second peak which occurred in early September was even greater than the peak in early August.

VARIABILITY OF STUDIED FEATURES

An interesting regularity was observed in the features measured. In every pond throughout the experiment, with variability expressed in the terms of the coefficients of variation ($v^0/_0$), one could see that 5 examined variables which were considered in the given permutation, showed the magnitude of the relative variability arranged always in the same sequence. The following variability sequence was obtained: x_2 (total length) < x_3 (body length) < x_4 (maximal height) < x_5 (maximal breadth) < x_1 (weight). Had the variables been arranged in another order (sequence, permutation) the same regularity of variability values would have occurred but in another sequence. It is interesting that the v% coefficients between the x_2 and x_3 variables did not differ greatly, despite this fact the v% in the x_2 for the same pond was always smaller than v% in x_3.

The relative variability of the weight in the investigated ponds was between 30–40%, on the average. The greatest observed v% for a pond was found in an unfertilized pond (No. 5, beginning of August) — 62%. The smallest v% was also in an unfertilized pond (No. 11, middle of July).

On the average during the whole experiment the relative variability of the weight was greater in the unfertilized ponds (v% = 38.9%) than in the P fertilized ponds (v% = 34.5%) and in the N + P ponds (v% = 32.0%). It seems, therefore, probable that the fertilization had an influence on the process of the equalization of the growth in the population. Nevertheless this is not quite certain because the differences in v% of the averages for the groups of the ponds are not great and, besides this, only 50% of all samples show such an order of magnitude. Therefore it is not possible to take this fact as a regularity in the growth of a population in particular conditions. It is probable that the fertilization causing the abundance of food for fish influences the process of the equalization through the quicker individual growth (Fig. 1) in this early stage of the development.

The relative variability of the growth was smallest in all groups of ponds for the first net sample (indicated as sample 2 in Table III) but it is noteworthy that at that time the greatest discrepancies between ponds were observed in the control ponds (about 16%). The smallest discrepancies were observed in the P fertilized ponds — about 4% and in the N + P fertilized ponds — about 7%. This is very characteristic and proves that the differentiation in the growth began later in the fertilized ponds than in the unfertilized ones.

PRODUCTION AND WEIGHT VARIABILITY

Variability of weight rises from the first net sample attaining its maximum in early September for the control ponds (45.6%). It is noteworthy that the highest population variability coincides for those ponds with their negative production, in this respect the causes of the variability are in the opinion of the present author understandable: the fish searching for food in the pond differentiated more in the period of negative production than in the period of a great abundance of food. The fish showed individual capabilities of finding food and this was the principal cause for the greatest differentiation between them. At the end of the growth the variability drops somewhat in those ponds. In the N + P fertilized ponds the greatest variability of the population was observed at the end of August (42%) which also coincides (Fig. 6) with a heavy downfall of productivity. It is interesting that when the production has risen in those ponds the variability dropped afterwards by about 4% and has risen to a 41% level which coincides with the drop of production to the minus level (Fig. 6). Towards the end of the growth there is a considerable drop in variability by about 12%. The P fertilized ponds do not show great fluctuations in the v%, one can observe there the greatest rise in the second half of July (of 10%), the maximum was reached on the first days of August (37%) and in late September (39.3%). From the peak in September there is a 8% drop towards the end of growth. The rise observed in July coincides characteristically with the drop of production in that time (Fig. 6). The peak of production in August is linked with a 4% fall in weight variability in those ponds. In September such regularity was not observed: there was a peak and a drop in the production but there was no response in the variability.

Unfortunately no net samples were taken at the stocking and the initial variability of the stock is left unknown. From other sources it is known that such variability in weight can be high for the one month fry population — about 50% or even more. The growth in the first decade was relatively so rapid that this might have caused a quick equalization of the population in comparison with the initial variability. The problem of interdependence of the amount of production and the relative variability is very interesting and may lead to important conclusions for the selection of reproducers of carp in particular and for fish in general.

To clear the problem of the apparent negative correlation one has calculated the correlation coefficients for the experiment on the basis of the hypothesis of linear survival. The r coefficients are presented in Table IV. The coefficients could be calculated only after the first decade of growth. Although the initial variability was unknown, the values in Table IV present an interesting picture. The coefficients are high (above 0.5) and all but one are negative. Only the control ponds show a significant negative coefficient of correlation, all other groups show no significance. In three particular ponds (7, 8 and 9) the control pond and the N + P fertilized pond show significance. Both the ponds show high significance of this correlation.

The results outlined in this paper pertain only to the experiment during the vegetation season of 1967. It would be worth-while to know whether the same regularities would hold in other years.

Table IV. Coefficients of correlation (r) between the production in ponds or group of ponds and the relative variability

	Ponds	Coefficient of correlation r	Statistical significance
Group of ponds	control	— 0.85	<0.01
	P fertilized	— 0.52	NS
	N + P fertilized	— 0.50	NS
	Total 12 ponds	— 0.61	NS
Particular ponds	No. 7 (control)	— 0.82	<0.01
	No. 8 (P fertilized)	+ 0.13	NS
	No. 9 (N + P fertilized)	— 0.83	<0.01

* NS — Non significance.

4. DISCUSSION

The N + P fertilization gave more stable yields than the P fertilization. This aspect of fertilization of water in fingerling ponds of the carp is especially important from the economic point of view.

There exists, of course, a possibility that the mathematical functions taken to describe the mortality do not represent the real mortality occurring in a given pond, but there must be an assumption made as to the way in which the decrease in numbers occurs in the population; without this assumption the biomass would not be calculated. Chapman (1968) is of the opinion that the real mortality in young populations of fish follows the exponential type of function, Backiel and Zamojska (1969) assumed that the mortality in carp fry changes with the same speed during the growth season. He stated that in the case of 12–20% mortality at the time of fishing out the ponds the error resulting from this assumption would not be great.

When the greatest mortality occurs in a pond just after the stocking, which might be the case in special circumstances, e.g. when the fish were tired by prolonged keeping in floating boxes during warm weather or because of some infectious disease, the exponential survival hypothesis would be valid for the population. Also one cannot exclude the possibility that the greatest losses might occur at the end of the season. Unless data are known about the true mortality in a pond the best and the practical way is to choose the linear type of survival.

In this experiment during the whole time the fry were examined by a pathologist dr. Markiewicz, alongside with the taking of samples. According to his statement the losses of fish in the ponds were distributed evenly over the period of this experiment.

In respect to the comparison of the experimental mortality between the fertilized and unfertilized ponds it is interesting to note that Wolny (1962) found in his experiment a 10% greater mortality in the ponds where fish were not fed as compared with that of the fed ones. There is striking similarity in those two figures (12% for the unfertilized and 10% for the not fed).

The same sequence of the relative variability was described by Yablokov (1966), on the basis of a work on mice by Adamczewska (1959). Yablokov called this type of regularity: keeping of a "position in a row", which is equivalent to the keeping of a position in a column, too. The order of magnitude of the coefficients of variation appears in the same sequence provided the variables appear in the same order (permutation). In our experiment this regularity was observed in 78% of the investigated ponds.

The statistically correlated coincidence between production and relative variability in the case of the unfertilized ponds indicates that when a fry population is hungry (that is when it shows negative production) it differentiates more than a population living in the abundance of food caused, for instance, by the mineral fertilization of water. The cause of their greater differentiation may be that in the case of hunger (negative production) or rapidly diminishing production, as it was e.g. in pond No. 9, an augmented capacity shows in some specimens or in a group of specimens to grasp for the food even at the expense of other fish. In other words, they show greater agressiveness than other specimens. When the food is abundant this type of the agressiveness does not appear in the population. Evoking such agressiveness among the population is not a positive effect for the population, especially if it is caused by hunger. Kirpichnikov (1966) draws the attention to this problem in connection with the breeding of carp. The well growing fry, coming from a population that underwent hunger in its life, may be specimens of the positive limit of the variation, i.e., the agressive specimen, in case of hunger. When they are let to grow old and ripen for selection they may be chosen as the best ones by the process of selection because they show a good record of growth. The modern pond management strives at maximum production from the water surface by means of intensive methods of cultivation which include the applying of best growing varieties of carp. The future reproducers should grow up in conditions of plenty of food in the pond. From such a population the fish may be taken for breeding. The carp breeder should avoid therefore the rearing of carp fry for future selection in conditions of rapidly diminishing production or of direct hunger which may be provoked in the pond by overcrowding it with fry. Table IV leads to the conclusion known to old practitioners that the fry for future selection should grow up in the best nutritive conditions. Only such specimens that grow best in the conditions of plenty of food in the pond and therefore are not "Cazy" in searching for food, should be egligible for future reproducers through the process of selection. Such specimens are the predestinated future reproducers. This is a very interesting problem closely linked with the problem of the breeding of "carp jumpers". The problem needs further study.

Acknowledgements

I wish to thank those who gathered materials for this work under the guidance of Dr. J. Szumiec, and to Doc. Dr. Stanisław Wróbel, the Head of Laboratory of Water Biology, for permission to use them.

5. SUMMARY

The changes in the biomass and in production of the Polish carp fry cultivated at the Experimental Farms of Laboratory of Water Biology at Gołysz (Cieszyn District) were investigated during the vegetation season of 1967.

The biomass was calculated on the basis of measurements of fish from random samples and on the basis of the hypothetical densities of the sampled populations. The density was calculated for the time of sampling taking alternatively 7 elementary mathematical functions as a regularity in mortality. Therefore the changes in the biomass with time were represented by clusters of curves. The greatest biomass was observed in the nitrogen + phosphorus fertilized ponds.

Production was calculated on the basis of 7 alternative biomass curves, it showed greater variability than the biomass. There were two distinct peaks for the production taken as the overall average: the first peak after the stocking which occurred in mid-July and the second at the beginning of September. The greatest production was observed in the N + P fertilized ponds.

The individual growth in weight was investigated and the significance of the fertilization influence was tested. It was shown that there was a statistically significant influence of the fertilization on the individual growth in weight.

The time variability of 5 biometrical features was also examined by means of the coefficients of variation. In the unfertilized ponds there was found a high and statistically significant negative correlation between production and relative variability.

6. STRESZCZENIE

W 1967 r. badano rozwój biomasy i produkcji narybku polskich karpi w Gospodarstwie Doświadczalnym Zakładu Biologii Wód Polskiej Akademii Nauk w Gołyszu (powiat Cieszyn).

Biomasę obliczano na podstawie pomiarów prób losowych oraz na podstawie hipotetycznych liczebności populacji, z których pobierano próby. Liczebność populacji w czasie pobierania próby szacowano przyjmując alternatywnie 7 elementarnych funkcji matematycznych jako prawidłowość śmiertelności. Zmiany w biomasie były więc reprezentowane przez wiązki krzywych. Największą biomasę obserwowano w stawach nawożonych azotem i fosforem.

Produkcję obliczano na podstawie 7 alternatywnych krzywych biomasy; wykazywała ona większą zmienność niż biomasa. Obserwowano dwa wyraźne szczyty

produkcji (dane przeciętne z wszystkich stawów): pierwszy szczyt po obsadzeniu stawów narybkiem w połowie lipca oraz drugi na początku września. Największą produkcję obserwowano w stawach nawożonych azotem i fosforem.

Badano indywidualny wzrost wagi oraz wpływ nawożenia stawów na wzrost. Wykazano, że istnieje statystycznie istotny wpływ nawożenia na wzrost indywidualny.

Badano także zmienność w czasie 5 cech biometrycznych, za pomocą współczynników zmienności. W stawach nienawożonych zaobserwowano dużą, istotną statystycznie, ujemną korelację pomiędzy produkcją a względną zmiennością.

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