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ROMAN ŻUREK

Biomasa zooplanktonu i produkcja niektórych gatunków wrotków i wioślarek w trzech stawach o różnej obsadzie kroczkami karpia

The zooplankton biomass and production of some species of rotifers and cladocerans in three ponds with different second year carp fry stocking

Mémoire présenté le 4 juin 1973 dans la séance de la Commission Biologique de l'Académie Polonaise des Sciences, Cracovie

Abstract — In the present paper the biomass and production of three species of cladocerans and seven species of rotifers in three experimental ponds of the Experimental Station of the Polish Academy of Sciences, at Gołysz, were calculated. The surface of each pond was 1500 sq. m., the stocking amounting to 45, 135, and 540 specimens of the second year carp fry (K_2) per pond. The influence of *Chaoborus crystallinus* larvae and *Asplanchna brightwelli* on the amount of the zooplankton biomass was discussed and t he estimated counts of some parameters of the energy balance of *A. brightwelli*, *Moina micrura*, *Daphnia longispina*, and *Bosmina longirostris* in the investigated ponds were carried out.

The aim of the present work was the quantitative determination of differences in the biomass of crustaceans and plankton rotifers and the production of selected species in the ponds with different degrees of intensity of carp production. Studies of this type had previously been carried out but the majority of them dealt with the influence of carp fry on the zooplankton (Gurzęda 1960, Grygierek 1962, 1965, Trzoch-Szalkiewicz 1970), while those discussing the zooplankton in the ponds with older fish were less numerous.

Material and methods

The investigations were carried out in three ponds (Nos 3, 10, and 5) out of the group of 24 experimental ponds in the grounds of the Experimental Station of the Polish Academy of Sciences at Gołysz. The surface of each pond is 1500 sq. m. (50 x 30 m), the mean depth being 90 cm. Each pond has a separate inflow and outflow. A more detailed description of these ponds was given by Wróbel (1971). On 9th April the investigated ponds were filled with water and stocked with second year carp fry. All losses resulting from the mortality of fish were made up and the initial stocking did not change throughout the whole season.

The samples were taken every two or three days in the period from 10 th July to 4th August 1971. A 5-litre Patalas bathometer was used, a total amount of 20 litres being taken for 1 sample in 4 places in a pond, from two levels. The collected water was filtered through No 25 plankton net and preserved. The analysis of the quantitative composition was carried out in a 0·5 ml Kolkwitz chamber. Depending on the number of a given species three to some scores of chambers were counted. Owing to this the mean error of a given species in a sample (with the exception of *Eudiaptomus graciloides* for which this error amounts to about 15 per cent) is in general under 5 or even 1 per cent.

Fecundity and age structure were determined by the measurement of about 150 specimens in each sample. Since no eggs were found in the specimens of a body length less than 1030 μm for *Daphnia longispina*, 340 μm for *Bosmina longirostris*, and 930 μm for *Moina micrura*, larger specimens were regarded as adults. The data on the period of development of eggs and of juvenile forms, depending on the temperature, were taken from the work of Grass et al. (1969) and Pečen (1965 a).

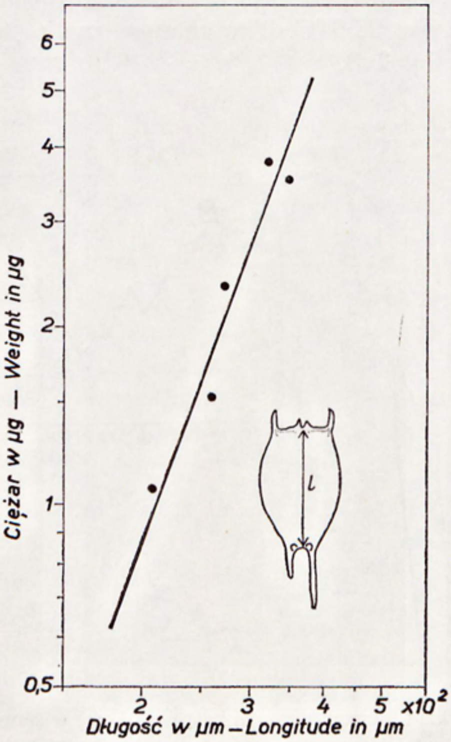
According to Hall (1964), it was accepted that the average period of life of an adult *Daphnia* was 30 days at 25°C, of *Moina micrura* 14·7 days at 20·1 °C (Krjučkova 1967), and of *Bosmina longirostris* 16·5 days at 17 °C (Ždanova 1969).

The *Cladocera* biomass was calculated using Pečen's (1965 b) and Ošmera's (1966) formulas. Ščerbakov's formula (1952) was used for *Cyclopidae* and the data of Morduchaj-Boltovskoj (1954) and Sinel'nikova (1963) for *E. graciloides*.

The biomass of rotifers was calculated from the data of Kosova (1961) and Kiselev (1956). The *Asplanchna brightwelli* biomass was calculated using the regression equation given by Bregman (1968) for the data of Kosova. Since the dimensions of preserved animals differ from those of living animals, the dependences given by Bregman (1968) for computing actual length of *Asplanchna* were used.

In order to calculate the *Brachionus diversicornis* biomass plasticine models of this rotifer were made in the scale 250:1 and their volume was measured. It was assumed that the specific weight of the body of a rotifer equalled 1 $g.cm^{-3}$. The weights obtained from these data, re-counted to actual dimensions, are presented in fig. 1. The biomass of rotifers of this species with dimensions differing from those of the models was obtained by interpolation.

The period of embryonal and post-embryonal development was calculated using Pourriot et Deluzarches's (1971) formulas and the data of Galkovskaja (1965) and the production of cladocerans by the method of Vinberg et al. (1965). If the data obtained from the literature, dependent on the temperature, were only concerned with a certain range of temperatures, then that value for the temperature prevailing in the environment was obtained using the correction from Krogh's curve.



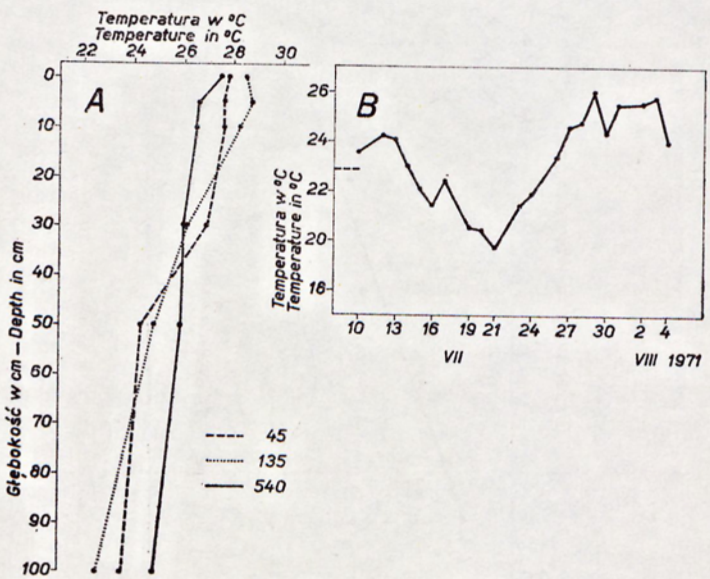
Ryc. 1. Zależność ciężaru od długości ciała wrotka *Brachionus diversicornis*
Fig. 1. Dependence of weight on the body length of the rotifer *Brachionus diversicornis*

For the calculation of the phytoplankton biomass the measurement of the chlorophyll content was carried out every five days. 25—50 ml of the pond water was filtered through a 0·45 µm membrane filter. Chlorophyll was extracted from the deposited algae and determined by a Spekol spectrophotometer at a wave-length of 663 µm, according to the rules given by SCOR — UNESCO (1966). The approximate phytoplankton biomass was obtained by multiplying the amount of chlorophyll by 40.

The oxygen content was measured using Winkler's method.

Description of the environment

In the period of investigations the temperature of the small ponds ranged from 19·7 to 26·0 °C. The least differences in the water temperature at various depths were observed in the pond stocked with 540 fishes (fig. 2 A). Greater differences in the temperatures were observed in the pond with 135 fishes, while in one stocked with 45 fishes a sudden fall in temperature occurred at a depth of 30 cm. This example concerns the distribution of temperatures between 10—11 a.m. In the period of the investigations the mean temperature of the three ponds was 22·9 °C. The changes in the temperatures of these ponds are given in fig. 2 B.



Ryc. 2. A — dzienny rozkład temperatur ze zmianą głębokości w stawach o różnej obsadzie ryb; B — zmiany średniej temperatury wody w okresie 10. VII—4. VIII. 1971 r.

Fig. 2. A — Daily distribution of temperatures with the change in depth in the ponds with different fish stocking; B — Changes in the mean temperature of water in the period from 10th July to 4th August 1971

During the day the oxygen conditions were good in all three ponds. The oxygen content exceeded the value of 5 mg. l^{-1}, which is regarded as the lower limit of good oxygen conditions for carp. At night the oxygen content considerably decreased, especially in the pond with 135 and 540 fishes, and amounted to 1·2—2·5 mg. l^{-1} near the bottom. In the pond with 45 fishes the oxygen content did not significantly decrease below 5 mg even near the bottom at night. During the night the depletion of oxygen from the surface layers and its equilization in the whole mass of the water occurred. The oxygen content was measured at midday and at 3·30 a.m.

The mean chlorophyll content and the estimated phytoplankton biomass, calculated on the basis of the assumption that the chlorophyll content amounts to 2·5 per cent of the alga biomass, are given in Table I.

In the first half of July the small ponds were overgrown with higher plants. The weakest development of vegetation was found in the pond with 135 fishes, the plants covering only about 10 per cent of its surface. The surfaces of the remaining ponds were overgrown about 50 per cent. The decidedly dominating species were: *Glyceria aquatica* and *Potamogeton natans*, lesser amounts of *Schoenoplectus lacustris*, *Potamogeton compressus*, *Typha angustifolia*, *Alisma plantago-aquatica*, *Sagittaria sagittifolia*, and *Heleocharis* sp. being also observed in smaller amounts. In the second half of July these plants were mown.

Tabela I. Niektóre dane o badanych stawach

Table I. Some data on the investigated ponds

Nr stawu No of pond	Ilość ryb w stawie Number of fish in the pond	Ilość ryb/ha Number of fish/ha	Karmienie i nawożenie Feeding and fertilization	Średnia zawartość chlorofilu w µg.l^{-1} Average amount of chlorophyll in µg.l^{-1}	Średnia biomasa fitoplanktonu w mg.l^{-1} Average phytoplankton biomass in mg.l^{-1}
3	540	3 600	Granulat zwykły superfosfat + NH_4NO_3 Common granulate superphosphate +	394	15.75
10	135	900	superfosfat + NH_4NO_3 superphosphate +	106	4.24
5	45	135	–	41	1.64

The dynamics of numbers and biomass

Rotifers. In the period of the investigations four species of rotifers dominated successively in the pond stocked with 45 fishes: *Conochilus unicornis*, *Keratella cochlearis*, *Trichocerca cylindrica*, and *Synchaeta pectinata*. Their greatest numbers were 1600, 310, 1230, and 1540 specimens/litre respectively. With these numbers the biomass of *C. unicornis* amounted to almost 91 per cent of the biomass of all rotifers in the period of its dominance; *T. cylindrica* to 77·6 per cent, and *K. cochlearis* and *S. pectinata* to 30 and 36 per cent respectively. *Asplanchna brightwelli*, occurring in small numbers, amounted with *S. pectinata* to 36·4 per cent of the biomass. The numbers of dominants exceeded those of subdominants by 27—10 times. The most abundant development of *K. cochlearis* was observed in the period of lowest temperatures and the most numerous occurrence of the predatory *Chaoroborus crystallinus* larvae. In this period the average biomass of rotifers was 1·445 mg l^{-1}.

In the second half of July *Brachionus calyciflorus* strongly developed in the pond stocked with 135 fishes: 860 specimens with a biomass of 5·14 mg l^{-1}, i.e. 73 per cent of the biomass of all rotifers in this period, being found then. *Brachionus angularis* occurred in the only slightly lower number of 760 specimens but its biomass amounted to only 4·3 per cent of the biomass of all rotifers in this period. The numbers of the remaining rotifers reached a level 12 to 20 times lower. On the turn of July and August the decided dominant was *Synchaeta pectinata*. At this time its number was 3500 specimens with a biomass of 1·40 mg. l^{-1}. *Polyarthra dolichoptera* and *Filina longiseta*, which accompanied the dominant, one after the other reached their maximum numbers of about 300 specimens per 1 litre and biomass of 0·25 and 0·085 mg. l^{-1} respectively. This period is favourable for the development of *Asplanchna brightwelli* whose greatest number occurs three days after the occurrence of the greatest number of *Synchaeta pectinata*, i.e. 150 specimens per 1 litre. The specimens are numerous but small and their biomass amounts to 2·97 mg. l^{-1}. The remaining species such as *Brachionus rubens*, *B. diversicornis*, *Keratella quadrata*, *K. cochlearis*, *Trichocerca cylindrica*, and *Conochilus unicornis* occur to the number of 1—60 specimens per litre and do not play any important role. The mean biomass of all rotifers amounts to 3·55 mg. l^{-1} in the period from 10th July to 4th August.

In the pond stocked with 540 fishes the situation is similar but other species appear as dominants. In the second decade of July *Polyarthra dolichoptera* and *Conochilus unicornis* dominate in succession. The first species occurred to the number of 1150 specimens per litre and amounted to a biomass of 0·92 mg, l^{-1}, i.e. about 23 per cent of the biomass of all rotifers in the period of its dominance. The second species occurred to the number of 1500 specimens per litre with a biomass of 2·94 mg. l^{-1}, this being almost 80·5 per cent of the rotifer biomass in this period. The remaining species were 12—20 times less numerous. At the end of July *Brachionus calyciflorus* was most numerous (450 specimens per 1 litre) and a biomass of 3·90 mg. l^{-1}, i.e. 71·5 per cent of the biomass of all rotifers in this period. The rotifers *Keratella cochlearis*, *K. quadrata*, *K. testudo*, *Polyarthra vulgaris*, *Pompholyx sulcata* and *Brachionus diversicornis* occur in a proportion to the dominant similar to that in the first half of July. In the investigation period the mean biomass of rotifers was 4·46 mg. l^{-1}.

Cladocerans. In all ponds the absence of large cladocerans was observed. *Daphnia magna* was not encountered, large adult specimens of *D. longispina* being also rare. The highest mean biomass (0·465 mg. l^{-1}) and production (0·092 mg. l^{-1}. 24 hrs $^{-1}$= 0·0414 cal. l^{-1}. 24 hrs^{-1}) of this species was found in the pond stocked with 45 fishes.

Besides the subdominant *D. longispina*. *Diaphanosoma brachyurum* and *Ceriodaphnia reticulata* occurred in the whole period. *Moina micrura* occurred only till 19th July. In this period the mean biomass of cladocerans was 2·76 mg. l^{-1}.

Tablica II. Przybliżony dobowy bilans energi dla kilku skorupiaków planktonowych z trzech stawów o różnym stopniu eutrofizacji i różnej obsadzie. + - wartości oczekiwane wyliczone ze wzoru Vinberga. Wyniki są podane w kaloriach na litr wody na dobę.
P - produkcja; C - racja pokarmowa; Q - metabolizm; Q/W - intensywność metabolizmu;
$K_1 = P/C$; $K_2 = K_1 . I = P : (P + Q)$; $Q/W = 1/I . (C - P)$; $1/I = (P + Q) : C$

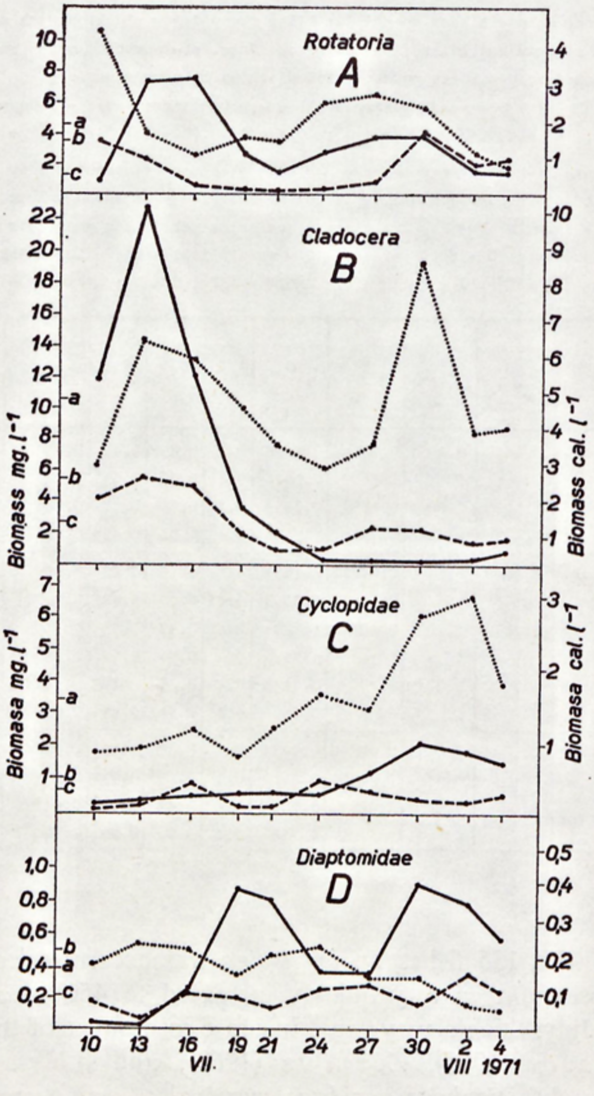
Table II. Approximate 24-hour energy balance for some plankton crustaceans from 3 ponds with different degrees of eutrophication and differend stocking. + - expected values calculated from Vinberg's formula. Results are given in calories per 1 lite water per 24 hours.
P - production; C - food ration; Q - metabolism; Q/W - intensity of metabolism;
$K_1 = P/C$; $K_2 = K_1 . I = P : (P + Q)$; $Q/W = 1/I . (C - P)$; $1/I = (P + Q) : C$

Obsada Stocking	Gatunki Species	B W in mg	B	P	C	1/I	K_1	K_2	Q	Q/W . $mg^{-1}.doba^{-1}$. $mg^{-1}.24\text{-hours}^{-1}$ cal	$\mu l\ O_2$
45	Daphnia longispina	0.4647	0.2091	0.04144	0.1673	0.4	0.25	0.45	0.0502	0.1081	22.24
					0.1614^{+}	0.4^{+}	0.26^{+}	0.64^{+}	0.02313^{+}	0.0498^{+}	10.24^{+}
	Moina micrura	1.9565	0.8806	0.4197	0.705	0.4	0.59	0.78	0.1141	0.0585	12.0
					1.237^{+}	0.4^{+}	0.34^{+}	0.85^{+}	0.0754^{+}	0.0386^{+}	7.93^{+}
135	Daphnia longispina	0.3019	0.1359	0.01109	0.1087	0.4	0.10	0.22	0.039	0.1290	26.55
					0.0653^{+}	0.4^{+}	0.17^{+}	0.42^{+}	0.0150^{+}	0.0497^{+}	10.24^{+}
	Moina micrura	3.6012	1.6205	0.4834	1.300	0.4	0.37	0.59	0.3266	0.0907	18.66
					1.555^{+}	0.4^{+}	0.31^{+}	0.77^{+}	0.1388^{+}	0.0386^{+}	7.93^{+}
	Bosmina longirostris	1.7152	0.7718	0.1569	0.6175	0.4	0.25	0.46	0.1844	0.1079	5.5
					0.639^{+}	0.4^{+}	0.24^{+}	0.61^{+}	0.0986^{+}	0.0552^{+}	11.81^{+}
540	Daphnia longispina	0.0264	0.0119	0.00348	0.0095	0.4	0.37	0.59	0.00242	0.0915	4.7
					0.0120^{+}	0.4^{+}	0.29^{+}	0.73^{+}	0.00131^{+}	0.0497^{+}	10.24^{+}
	Moina micrura	10.066	4.5297	1.5233	3.63	0.4	0.42	0.64	0.8427	0.084	17.23
					4.778^{+}	0.4^{+}	0.32^{+}	0.79^{+}	0.380^{+}	0.0386^{+}	7.93^{+}

In the pond with 135 fishes *D. longispina* was accompanied by *Bosmina longirostris* whose number very quickly increased to 450 specimens/litre in the first half of July. Such a very rapid increase in number of this species was observed by Saadi (1965), Ždanova (1969), and others. *Ceriodaphnia reticulata* and, rarely, *Diaphanosoma brachyurum* also occur there. The biomass and production of *D. longispina* is lower than in the former pond while the production of *Moina micrura* is slightly higher (Table II).

In the pond stocked with 540 fishes the occurrence of the genus *Bosmina* and *Diaphanosoma* was not observed while small numbers of *D. longispina* and *C. reticulata* were encountered. *Moina micrura* was most numerous in the two warmest seasons (cf. fig. 2 B) and reached the number of 113 and 130 specimens/litre, this corresponding to a biomass of 14·1 and 17·4 mg. 1^{-1} respectively.

Copepods. Only two species of this order occurred in greater numbers: *Thermocyclops crassus* and *Eudiaptomus graciloides*.



Ryc. 3. Zmiany biomasy *Rotatoria* (A), *Cladocera* (B), *Cyclopidae* (C) i *Diaptomidae* (D) w stawie z obsadą 540 ryb (linia kropkowana), 135 ryb (linia ciągła), 45 ryb (linia przerywana); a, b, c — odpowiednio średni poziom biomasy w tych stawach

Fig. 3. Changes in the biomass of *Rotatoria* (A), *Cladocera* (B), *Cyclopidae* (C), and *Diaptomidae* (D) in the pond with the stocking of 540 fishes (dotted line), 135 fishes (continuous line), and 45 fishes (broken line); a, b, c — respectively the mean level of biomass in these ponds

In the pond stocked with 45 fishes the *Th. crassus* biomass amounted to only 0·6 mg. 1^{-1}, while in the pond stocked with 135 fishes the biomass of this species was 2·4 mg. 1^{-1}. In the period of occurrence of the predatory larvae of *Chaoborus crystallinus* a decrease in the biomass of *Th. crassus* was observed above all owing to the elimination of nauplii.

In the pond stocked with 540 fishes, besides *Th. crassus* and *E. graciloides*, *Cyclops vicinus* occurs to the number of about 5 per cent. At the end of July the biomass of *Th. crassus* increased and amounted to 6·7 mg. l^{-1} with 1670 nauplii, 280 copepodites, and 50 adults per litre.

Eudiaptomus graciloides occurred in insignificant numbers and its mean biomass amounted to about 0·4 mg. l^{-1} in all three ponds (fig. 3 D).

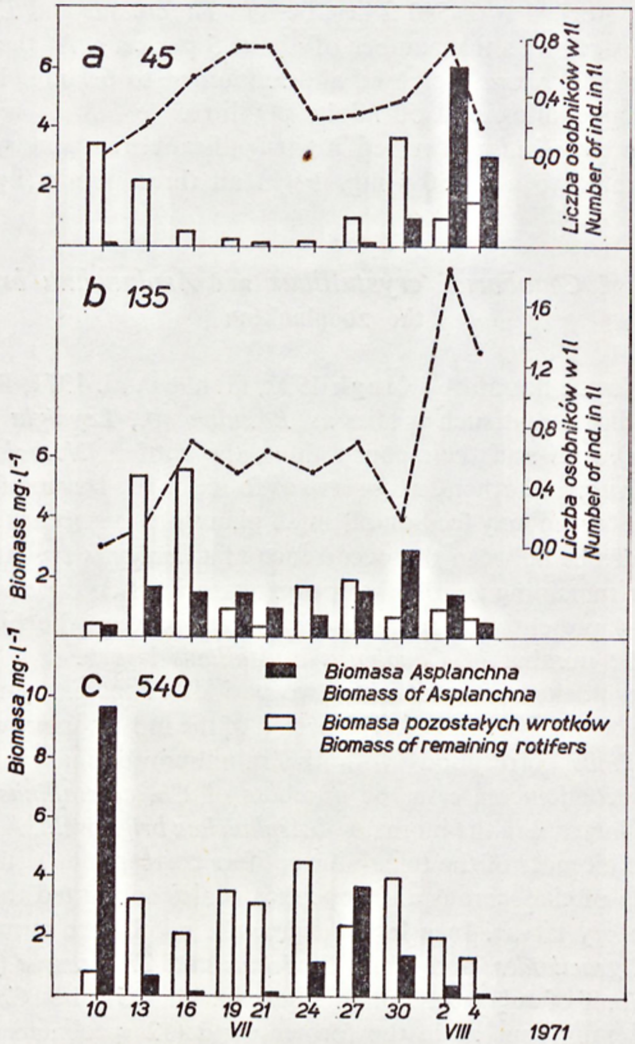
The influence of *Chaoborus crystallinus* and *Asplanchna brightwelli* on the zooplankton

Many data in the literature (Klugh 1927, Grass et al. 1971, Parma 1971, and others) indicate that such species as *Bosmina* sp., *Leydigia* sp., *Cyclops vicinus*, *C. fimbratius* and their copepodites, the rotifers *Notholca squamula*, *Keratella quadrata*, and others, may serve as food for the larvae of this species. Virtually, these larvae may feed on all small plankton crustaceans and rotifers, hence a dependence between the occurrence of *Chaoborus* sp. larvae and the number of the remaining zooplankton organisms is often observed (Comita 1972). Figure 4 presents the relations occurring between the biomass of all rotifers and the number of *Chaoborus crystallinus* larvae.

In the pond stocked with 45 fishes two periods of increase in the number of these larvae distinctly occurred. The period of the most numerous occurrence of *Ch. crystallinus* corresponds with the minimum biomass of the rotifer plankton. A second increase in the numbers of *Ch. crystallinus* agrees with a considerable increase in the biomass of *Asplanchna brightwelli*. A considerable decrease in the biomass of the remaining rotifers corresponds with this period. The population of cladocerans and copepods is also submitted to the pressure of these predatory larvae. In a lesser degree their influence is marked in the biomass of *E. graciloides*, and adult *C. vicinus* and *Th. crassus* (cf. fig. 3 D).

In the first half of July in the pond stocked with 135 fishes *Ch. crystallinus* was almost as numerous as in the former pond (12 specimens per 20 litres of water) but occurred for a longer period: 2 weeks. Double the number of *Ch. crystallinus* was observed on 2nd August. A negative dependence also occurs between the rotifer biomass and the increase in the number of larvae. The biomass of cladocerans and copepods is also lower in the periods of numerous occurrence of the larvae of this species.

In the pond stocked with 540 fishes no *Chaoborus* larvae were encountered in a 20-litre sample. The biomass of rotifers is here on the average 4·5 mg.l^{-1}. Here *Asplanchna* only has a visible influence on the biomass of the remaining species of rotifers. To each increase in the biomass of this species corresponds a simultaneous decrease in the biomass of the remaining rotifers. A similar dependence between the production of *Asplanchna* and the biomass of other rotifers was observed by Lewkowicz (1971) who found the maximum production of *Asplanchna* some days after the maximum biomass of other



Ryc. 4. Liczebność larw *Chaoborus crystallinus* (linia przerywana) oraz biomasa *Asplanchna* i pozostałych wrotków w stawach o różnej obsadzie

Fig. 4. Number of *Chaoborus crystallinus* larvae (broken line), and the biomass of *Asplanchna* and of the remaining rotifers in the ponds with different fish stocking

rotifers and a subsequent decrease in production parallel to the decrease in the biomass of the remaining rotifers.

The increase in the amount of food accessible for *A. brightwelli* and the change in other factors connected with eutrophication brought about a three days earlier occurrence of greater numbers of this rotifer in the pond stocked with 135 fishes and a six days earlier one in the pond stocked with 540 fishes, as compared with the pond with the least number of fish.

Some data on the energy balance of some species of *Cladocenra* and *Asplanchna brightwelli*

If for all three ponds we accept the mean phytoplankton biomass of 7·2 mg. 1^{-1} and the weight of a cell of $1 \cdot 10^{-7}$ mg (according to Verduin 1959 weights of this order were found for *Sphaerocystis schroeteri*, *Scenedesmus bijuga*, *Ankistrodesmus falcatus*), it is easy to calculate that the number of cells in 1 ml amounts to 72 000. With such an amount of food the usually accepted daily food ration is 80—90 per cent of the body weight. The daily food ration is a very changeable value and that of 80 per cent assumed later for all species in all ponds may only serve for estimation counts.

In further discussion the biomass of crustaceans and rotifers is expressed in calories. It was accepted that the caloricity of 1 mg of wet biomass amounts to 0·450 cal.

Cladocerans. For *Daphnia longispina* from the pond stocked with 45 fishes with a mean biomass of 0·465 mg. 1^{-1}, i.e. 0·209 cal. 1^{-1}, the food ration amounts to 0·167 cal. 1^{-1}. 24 hrs^{-1}. If the most probable value of assimilability amounts to $1/I = 0{\cdot}4$, the energy losses brought about by the metabolism in the production $P = 0{\cdot}041144$ cal. 1^{-1}. 24 hrs^{-1} should amount to $Q = 0{\cdot}4$ $(0{\cdot}1673—0{\cdot}04144) = 0{\cdot}05024$ cal. 1^{-1}. 24 hrs^{-1}. The intensity of metabolism with a biomass of 0·4647 mg is calculated as follows: $Q/B = 0{\cdot}05024 : 0{\cdot}4647 =$ 0·1081 cal. mg^{-1}. 1^{-1}. 24 hrs^{-1}. If this value is divided by the calorific equivalent of 1 μl 0_2 equalling 0·00486 cal. μl^{-1}, we obtain 22·24 μl 0_2. mg^{-1}. 1^{-1}. 24 hrs^{-1}. This result is almost 100 per cent higher than that calculated from Vinberg's formula. The coefficient K_1 amounts to $0{\cdot}04144 : 0{\cdot}1673 = 0{\cdot}25$, the coefficient K_2 calculated from the formula $K_1 = P\ (P + Q)$ amounts to 0·45.

The same result may be obtained with the use of the general formula for crustaceans which determines the dependence of metabolism on the body weight (Vinberg 1950).

$$Q = 0{\cdot}165\ W^{0{,}81} \quad \text{or} \quad Q/B = 0{\cdot}165\ W^{-0{,}19}$$

where Q is the oxygen consumption by one specimen at 20 °C in millilitres of 0_2 per hour, and W is the weight of the animal in grams. The coefficient 0·165 is multiplied by 24 and the oxygen consumption by one animal in ml in 24 hrs is obtained. If the oxygen consumption is expressed in μl and the weight in mg, the coefficient will not change. Since in the period of investigation the mean water temperature was 22·9 °C, the coefficient 3·96 was divided by 0·7866 and consequently a formula was obtained which determined the value of metabolism at the average temperature of the environment in convenient units: μl $0_2 \cdot 24$ hrs^{-1}. $specimen^{-1}$ — $Q = 5{\cdot}04\ W^{0{,}81}$.

Since the mean weight of *D. longispina* in the three investigated ponds was 0·024 mg, of *Bosmina longirostris* 0·013 mg, and of *Moina micrura* 0·092 mg, the expected value of the metabolism of these cladocerans was 10·24; 11·81; and 7·93 μl 0_2. mg^{-1}. 24 hrs^{-1} respectively. For *D. longispina* in the pond stocked with 45 fishes the expected value of energy losses brought about by the respiration of animals amounts to 10·24 μl 0_2. mg^{-1}. 24 hrs^{-1} x 0·00486 cal. $\mu l^{-1} 0_2$ x 0·4647 mg. 1^{-1} = 0·02313 cal. 1^{-1}. 24 hrs^{-1}. Hence with the production of P = 0·04144 cal. 1^{-1}. 24 hrs^{-1} the assimilation is P + Q/B = 0·06457 cal. 1^{-1}. 24 hrs^{-1}, this constituting 38·6 per cent of the daily food ration. If we assume that the assimilability 1/I = 0·4, the food ration will be 0·06457:0·4 = 0·1614 cal. 1^{-1}. 24 hrs^{-1}, i.e. 77·2 per cent of the biomass.

Similar calculations carried out for the remaining species and ponds are given in Table II.

Rotifers. For this group of animals very scarce data on their metabolism are found in the literature. The most comprehensive study was presented by Pourriot (1971). This author measured the oxygen consumption of 8 species and found that in pond water the oxygen consumption is proportional to the content of protein in their bodies. The author gave the obtained results in the form of an equation of the $Q = a W^b$ type, where Q is the oxygen consumption in nl. $specimens^{-1}$. hr^{-1} and W is the protein content in μg per 100 specimens. From the data given by the author it is easy to calculate the coefficient a. It amounts to 0·134. If we assume that the protein content in rotifers, as in *Brachionus calyciflorus*, amount to 41·2 per cent of the dry biomass (Lavrovskaja, quoted according to Erman 1962) and that the dry matter constitutes 10 per cent of the wet matter, we obtain the equation

$$Q = 0{\cdot}55\ W^1$$

where Q is the oxygen consumption in nl. hr^{-1}. $specimen^{-1}$ and W is the weight of this rotifer in μg. Then the coefficient "a" was multiplied by 24, 4·86. 10^{-6} and 1000 in order to obtain the oxygen consumption in calories per 24 hrs by one rotifer, its weight being given in mg. The coefficient "a" then amounts to 0·064. After its division by 0·7866 the formula adjusted to the mean temperature of the environment was obtained. Since the papers on the size of the daily food ration and on the assimilability of various food are extremely scarce, the lack of data limited the estimation counts to some parameters of the energy balance for *Asplanchna brightwelli*. Its average weight calculated from the measurement of 500 specimens amounted to 0·064 mg. Thus the oxygen consumption should amount to 0·081 x 0·064 mg = 0·0052 cal. 24 hrs^{-1}. $specimen^{-1}$ or 1·07 μl 0_2. 24 hrs^{-1}. $specimen^{-1}$. The intensity of metabolism is constant and amounts to 0·081 cal. mg^{-1}. 24 hrs^{-1} or 16·6 μl 0_2. mg^{-1}. 24 hrs^{-1}. The remaining elements of the energy balance were calculated similarly as those for *D. longispina*, assuming that the assimilability 1/I = 0·8 and that the daily food ration amounted to 80 per cent of the body weight. The results are presented in Table IV. The agreement between the expected and calculated values are much greater than in cladocerans. This may suggest highly homogeneous and easily assimilable food taken by *Asplanchna*. The possibility of taking larger algae (Gilbert 1967) seems to play a lesser role here.

Discussion

With reagard to the zooplankton biomass the pond stocked with 45 fishes differed in the greatest measure from the remaining ones. The threefold increase in the stocking of fish and the fertilization bring about a considerable increase in the zooplankton biomass. The increase in stocking to 540 fishes in the pond gives rise to a further increase in the zooplankton biomass.

A similar type of dependence of the increase in the zooplankton biomass on the increase in the number of carp fry was observed by Grygierek (1962). Undoubtedly the indirect reason for a considerable increase in the zooplankton biomass (10·60 and 18·3 mg. l^{-1} as compared with 4·94 mg. l^{-1} in the pond stocked with 45 fishes) were the fish which set in motion the biogenic substances of the bottom by mixing up the sludge with the bottom layer of the water. These substances and bacteria living on the bottom mixed up by thermic currents and waves, bring about stronger development of the nannoplankton and hence an increase in the food basis of the zooplankton. Such an increase in the number of heterotrophic bacteria after the introduction of fish into a pond was observed by Niewiadomska-Krüger (1971).

An additional factor leading to an increase in the biomass and in the production of phyto- and zooplankton was the fertilization of the ponds stocked with 135 and 540 fishes with superphosphate and ammonium nitrate. Nevertheless, Grygierek (1971) did not succeed in proving the influence of nitrogen-phosphorous fertilization on zooplankton production, while Lewkowicz (1971) found a considerably higher zooplankton biomass and production of some species of rotifers in ponds fertilized with P and N + P. However, no great differences in the zooplankton biomass in differently fertilized ponds were observed by this author. Lachnovič et al. (1972) reported a strong influence of fertilization on zooplankton biomass and production. Therefore the almost four times greater zooplankton biomass in the pond stocked with 135 fishes as compared with the one stocked with 45 fishes should not be regarded only as the result of increased stocking but also as an effect of fertilization. Favourable food conditions brought about a considerable increase in the production of some rotifers (Table III). A particularly strong increase in the production of *Brachionus calyciflorus*, *Polyarthra dolichoptera*, and *Asplanchna brightwelli* was observed.

In the pond stocked with 540 fishes an additional eutrophication factor of the environment was supplementary feeding of fish with 16·5 kg daily of

Tabela III. Średnia dobowa wartość biomasy i produkcji niektórych gatunków wrotków w stawach o różnej obsadzie ryb. Biomasa i produkcja wyrażone w kaloriach. + - średnie z 8 dni; P - produkcja; B - biomasa

Table III. Average 24-hour value of biomass and production of some species of rotifers in the ponds with different fish stocking. Biomass and production expressed in calories. + - means for 8 days; P - production; B - biomass

Gatunki Species	Obsada 45 ryb Stocking of 45 fishes		Obsada 135 ryb Stocking of 135 fishes		Obsada 540 ryb Stocking of 540 fishes	
	P	B	P	B	P	B
Polyarthra dolichoptera	0.00579	0.0108	0.01715	0.02655	0.0503	0.2248
Keratella quadrata	0.00218	0.00483	0.00425	0.00925	-	-
- cochlearis	0.00385	0.0143	0.00207	0.00708	-	-
Brachionus calyciflorus	0.0362+	0.03995+	0.5558	0.7395	0.7302	0.9152
Synchaeta pectinata	0.04833	0.04975	0.1792	0.214	-	-
Filinia longiseta	-	-	0.01087	0.00958	0.00774	0.00984
Asplanchna brightwelli	0.02097	0.04147	0.2564	0.6514	0.2813	0.6808

common granulate. The decomposition of organic substances leached out of this fodder and the excrement of fish daily amounting to at least some kilograms, led to a still stronger development of microorganisms and of the phyto- and zooplankton. Consequently at night severe oxygen losses occur here. At this period high temperature is also a factor activating the processes of production and destruction. Hence great numbers of *Brachionus calyciflorus* and *Moina micrura*, species characteristic for warm, rich in nutritive substances and self-purifying water bodies, occur in this pond. The mass occurrence of these species has a significant influence on the increase in the average level of biomass in this pond. The higher level of the biomass here is brought about by supplementary feeding and further increasing the fish stock.

From the fourth week in the life of the carp greater and greater bottom animals begin to dominate in its food (Trzoch-Szalkiewicz 1971) while plankton plays a lesser and lesser role, the pressure of fish on the fauna of planktonic crustaceans diminishing. Nevertheless, the lack of large cladocerans and of the larvae of *Chaoborus* in the pond with the largest fish stock seems to indicate the occurrence of such pressure. Even the small *Moina micrura* does not attain such biomass and production as in the ponds not stocked with fish under similar trophic conditions (Krjučkova 1972).

Previously a reverse dependence between the occurrence of *Asplanchna* and the biomass of other rotifers was observed. After the consideration (similar to that carried out for *Cyclops vicinus* by Dumont 1972) for the model *Asplanchna* of the weight of 0·064 mg, resembling a sphere 0·496 mm in diameter and swimming with the speed of 1·5 mm. sec^{-1} in the environment where *Keratella quadrata* occurs to the number of 2000 specimens per 1 litre and with a weight of 0·00066 mg (Sebestyen 1958), the former in 24 hrs encounters a biomass of 0·033 mg, which constitutes 51·5 per cent of its weight. With the most numerous occurrence of this rotifer (*Asplanchna*) it may be the factor limiting the numbers and biomass of the remaining rotifers. With regard to production, in the pond stocked with 45 fishes, the consumption of *A. brightwelli* contributes to about 31 per cent of the production of those rotifers for which it was calculated. In other ponds it amounts to about 70 per cent. In the period of most numerous occurrence the consumption of *A. brightwelli* may even reach 300 per cent of the production of these rotifers. In practice this percentage will be lower because the production of the remaining rotifers, protozoans, and algae, which may also serve as food for *A. brightwelli* (Gilbert 1967), is not considered.

A comparison of the value of the food ration of *D. longispina*, *B. longirostris* and *M. micrura* necessary for the production of the amount of biomass which is given in Table II with the phytoplankton biomass (for the pond with the greatest fish stocking *Ceriodaphnia reticulata* occurring in great numbers was taken into consideration) indicates that in all ponds a reserve of phytoplankton occurs to the amount of about 100—120 per cent of the daily food ration of these cladocerans.

Table II presents the approximate energy balance of some species of cladocerans. It suggests that the coefficient of the utilization of energy for the growth (K_2) considerably exceeds the values given by Ostapienia et al. (1968) for *D. magna*, *D. pulex*, and *M. micrura*, by Vasileva (1959) for *D. pulex*, and even the maximum value of $K_2 = 0{\cdot}6$ given by Vinberg (1964) for various aquatic crustaceans. According to the data of Krjučkova (1967), K_2 for *M. micrura* slightly changes in its lifetime and amounts to 0·397—0·449, the coefficient K_1 being maintained nearly at a normal level, though it is very high. Krjučkova reports that for young specimens of *M. micrura* this coefficient amounts to 0·947 (for the animals fed with *Chlorella vulgaris*), and at the end of their life it attains only 0·018. In all three ponds the coefficient K_1 for *Moina micrura* was found to be higher than was expected, this suggesting the young age of the population.

The deviations which occur between the expected and calculated results may have been brought about by the various degrees of assimilability of food, various intensity of metabolism, different age of the animals, and above all by various food rations.

The same coefficients and parameters calculated for *A. brightwelli* (Table IV) show a much smaller range of changes than those of cladocerans. This may indicate a highly homogeneous and fairly assimilable food of this rotifer.

All treatments applied for the intensification of fish production brought about a considerable increase in the biomass and production of the zooplankton. This is particularly manifested on the example of *M. micrura*, which has an almost four times higher production in the pond with 540 fishes than in that

Tablica IV. Przybliżony dobowy bilans energetyczny Asplanchna brightwelli. + - wartości oczekiwane. Wszystkie wyniki podane w kaloriach w 1 litrze wody na dobę. B - biomasa; P - produkcja; C - racja pokarmowa; Q - metabolizm; Q/W - intensywność metabolizmu; $K_1 = P/C$; $K_2 = K_1 \cdot I = P : (P + Q)$; $Q/W = 1/I \cdot (C - P)$; $1/I = (P + Q) : C$.

Table IV. Approximate 24-hour energy balance for Asplanchna brightwelli. + - expected values. All results are given in calories per 1 litre water per 24 hours. B - biomass; P - production; C - food ration; Q - metabolism; Q/W - intensity of metabolism; $K_1 = P/C$; $K_2 = K_1 \cdot I = P : (P + Q)$; $Q/W = 1/I \cdot (C - P)$; $1/I = (P + Q) : C$.

Obsada Stocking	B w in mg	B	P	C	1/I	K_1	K_2	Q	Q/W . mg^{-1}.doba^{-1} . mg^{-1}.24-hours^{-1} cal	µl O_2
45	0.9215	0.04147	0.02097	0.0332 0.0356+	0.8 0.8+	0.63 0.59+	0.68 0.74+	0.00976 0.00746+	0.1059 0.0813+	21.8 16.75+
135	1.4475	0.6514	0.2564	0.521 0.467+	0.8 0.8+	0.49 0.55+	0.55 0.69+	0.2117 0.1173+	0.1463 0.0813+	30.1 16.75+
540	1.5129	0.6808	0.2813	0.5446 0.5048+	0.8 0.8+	0.52 0.56+	0.57 0.70+	0.2107 0.1225+	0.1392 0.0813+	28.65 16.75+

stocked with 45 fishes. The production of *Brachionus calyciflorus* is over 20 time greater than in a control pond. However, for the greater biomass and production in the pond with the largest stock a lower number of species "works" as compared with the weaker eutrophicated ponds.

Conclusions

1. N + P fertilization and the stocking of 135 fishes per pond brought about an increase in the zooplankton biomass from 4·94 mg. l^{-1} to 10·6 mg. l^{-1}, while an increase in the stocking to 540 fishes and additional feeding of fish effected a further increase in the biomass to 18·3 mg. l^{-1}.

2. The treatments intensifying the fish production cause a very strong increase in the production of some species (*Moina micrura*, *Brachionus calyciflorus*, *Asplanchna brightwelli*) and a decrease in production or the absence of other species.

3. In the ponds stocked with 45 and 135 fishes predatory larvae of *Chaoborus crystallinus* and *Asplanchna brightwelli* strongly influence the dynamics of the numbers and biomass of the zooplankton.

4. It seems that the stocking of 540 fishes per pond exerts considerable pressure on the zooplankton. The occurrence of *Chaoborus* larvae is not observed here, the number of *D. longispina* is considerably decreased, and *M. micrura* does not attain such high numbers and biomass as it does under similar trophic conditions without fish.

5. Very rapid changes in the numbers and biomass of rotifers are observed. Every three — six days another species dominates while two species rarely dominate at the same time.

STRESZCZENIE

Badania prowadzone w lipcu 1971 r. w Zakładzie Doświadczalnym PAN w Gołyszu. Próby zooplanktonu pobierano przez okres 25 dni, co dwa, trzy dni z trzech stawów o obsadzie 45, 135 i 540 sztuk kroczka karpia (K_2). Powierzchnia każdego stawu wynosi 1500 m^2. Stosując metodę Galkovskiej (1965) obliczono produkcję 7 gatunków wrotków. Ich średniodobowa produkcja wykazuje kilkakrotny wzrost w stawie nawożonym N + P i z obsadą 135 ryb w porównaniu do stawu kontrolnego. Dalsze zwiększenie obsady ryb do 540 na staw, dokarmianie ich oraz nawożenie nie zwiększyło praktycznie produkcji tych wrotków. Średnia biomasa wszystkich wrotków w 1 litrze wynosiła 1,445, 3,547 i 4,46 mg.

Metodą Vinberga (1965) wyliczono produkcję *Moina micrura*, *Daphnia longispina* i *Bosmina longirostris*. Ich średnia dobowa produkcja w stawie kontrolnym wynosi 1,025 mg. 1^{-1}. W stawie z obsadą 135 ryb wzrasta o około 40 % (1,45 mg. 1^{-1}), a w stawie z obsadą 540 ryb o około 230 % (3, 39 mg. 1^{-1}). Średnia biomasa wszystkich wioślarek wynosiła 2,76, 5, 595, i 10, 56 mg. 1^{-1}. Biomasa całego zespołu wrotkowo-skorupiakowego wynosiła 4,96, 10,6 i 18,83 mg. 1^{-1}.

W stawach z obsadą 45 i 135 ryb stwierdzono występowanie larw *Chaoborus crystallinus*, którego drapieżnictwo znacznie wpływało na biomasę szczególnie wrotków.

Na podstawie danych o produkcji, biomasie i danych literaturowych wyliczono szacunkowy bilans energetyczny *Asplanchna brightwelli* i wymienionych wyżej trzech wioślarek. Oczekiwane parametry bilansu wykazują większą zgodność z wyliczonymi dla *Asplanchna* niż dla wioślarek.

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Adres autora — Author's address

mgr Roman Żurek

Zakład Biologii Wód, Polska Akademia Nauk, ul. Sławkowska 17, 31—016 Kraków

ERRATA

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