POLISH JOURNAL OF ECOLOGY (Pol. J. Ecol.)	50	2	201–221	2002

Regular research paper

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UPPER VISTULA RIVER: RESPONSE OF AQUATIC COMMUNITIES TO POLLUTION AND IMPOUNDMENT. VIII. ZOOSESTON

ABSTRACT: Zooseston of the Vistula River section almost 340 km long was investigated in the years 1997/98. In 99 samples collected 90 species of rotifers, 16 cladocerans, 9 copepods and other animals belonging to: Harpacticoidea, Oligochaeta, Nematoda, Chironomidae, Odonata, Simulidae, Tardigrada and Coelenterata were found. Multiple regression analysis showed that the number of rotifers is significantly correlated with basic chemical indicators of water trophic state – phosphate, nitrate and nitrite as well as with the number of copepods which are usually predators. The numbers of copepods depends on the availability of possible prey, i.e. rotifers and cladocerans. Multiple regression confirmed known dependence of cladocerans from trophic conditions. Clustering of similarity matrices showed complex structure of sestonic assemblages on rhitral-potamal gradient additionally modified by hydrotechnical constructions. These constructions broke old river continuum. Ordination of sites gave complex pattern not only representing a simple gradient rithral – potamal but also all transient stages caused by hydrotechnical construction (large dam reservoir) or by inflows of polluted waters from the tributaries. Ecological meaning of principal component ordination (PC) for river zooseston assemblages is not simple and might be susceptible of various interpretations.

KEY WORDS: zooseston, communities structure, species richness, chemical parameters, PCA analysis.

1. INTRODUCTION

The Upper Vistula has two large dam reservoirs and 6 smaller weirs built in cascade system which caused that it become a wide waterway starting from the mouth of the left side tributary the Przemsza on the 95.1 km down the river. Presently, next two dams are under construction. All reservoirs are able to modify the structure of potamoplankton assemblages. Żurek and Dumnicka (1989) showed that zooplankton discharged from a big reservoir is efficiently exploited by bottom animals. Ten kilometres below the dam the outflowing zooplankton vanishes. Its range depends on flow size. Beyond the exploitation zone zooplankton is usually typical of a drift. Previous studies (Bednarz and Żurek 1988) showed that small river weirs are able to increase the abundance of zooplankton in the river. Physical transport of organisms may move populations away from areas suitable for growth. Similar observations were done by Butorin and Mordukhai-Boltovskoi (1978) on the Volga River, Shiel (1986) on Murray – Darling system, Pace *et al.* (1992) on Hudson River, Kiss (1994) on Danube.

Therefore, it seems to be interesting to follow the density and structure of the zooplankton communities along one third of the Vistula River (biggest Polish river) length, which is divided by river bars on first one hundred kilometres, and retains nearly natural character on the next 300– 400 km. Investigated river sector exhibited full gradient of environmental conditions: from turbulent, poor in nutrients stream, through more or less stagnant water until more or less polluted middle part of the river. Therefore, it was of great interest to evaluate the influence of different levels of environmental factors on main sestonic animals groups. Relationships with chemical indicators of trophy and pollution level in an anthropogenically changed river were the next reason for undertaking that study.

2. STUDY SITES

At the 550 m above sea level, on the 10 kilometre of the Vistula there is a first dam reservoir Wisła-Czarne. This reservoir gives an equalised outflow Q_{eq}= 0.26 $m^3 s^{-1}$, whereas a mean inflow is $Q_{mean,\ year}$ = 0.9 $m^3 s^{-1}$. The difference is used as drinking water by a small village Wisła. Retention time in the reservoir is 29 days (Olszanowski 1995) and at the highest damming ordinate 77.5 days. One kilometre below there is a small river bar (H = 9 m.) completely filled with mud. During the sampling period, the Wisła Czarne reservoir was periodically filled and emptied, (Fig. 1). On the 62 km there is a large Goczałkowice dam reservoir. Its volume is ca. 150 000 000 m^3. Retention time varies between 205 and 330 days, usually from 260 to 270 days. Going down the river, from the Przemsza inflow on the 95.1 km towards Cracow on the 166 km there are four 3–6 m high weirs with sluices. The last dam is on the 180.2 km at Przewóz. The next dam is located as far as Włocławek 500 km downstream so up there the Vistula is almost in a natural state. Scheme of sampling stations and main hydrotechmical objects on the river is presented on Fig. 2. In July 1997 after 10 days of heavy rainfalls in the catchement area there was a large flood wave. Moving time of the flood wave calculated from observed culminations on two water-gauges according to Pauli-Wilga and Wojciechowski (1998) was 13 hours and current velocity 3.5 km h^{-1}. More details are given by Żurek and Kasza (2002) in this volume. Other parameters are given in Table 1.

3. METHODS

Zooplankton samples were collected each month since March 1997 to March 1998. 50 to 600 dm^3 of water were filtered through a planktonic net of # 50 µm meshes. Samples were preserved in formalin. In the laboratory, the sample was usually condensed according to Standard Methods (Greenberg *et al.* 1992) and then, 5 to 100 percent of original sample in 1 ml of subsample was counted under microscope. All zooplankton densities are expressed in individuals per one litre of water.

2D plots were made in SURFER® programme – grid was computed by Kriging method. Deviation of these grids from observed points is better than 5%. Similarities were calculated in INDEX programme and then clustered in SYSTAT®. This last programme was also used for other statistical calculations.

Two similarity indices were used: Index *B1* of Pinkham and Pearson 1976 and *SIMI* of Stander 1970.

$$B_1 = \frac{1}{k} \sum \frac{Min(M_{ia}\ M_{ib})}{Max(M_{ia}\ M_{ib})} \tag{1}$$

where M is any desirable variable, e.g. numbers of individuals M in i-th taxa for site a and b.

$$SIMI = \frac{\sum P_{ia} P_{ib}}{\sqrt{P_{ia}^2}\sqrt{P_{ib}^2}} \tag{2}$$

where P_{ia} and P_{ib} are average relative abundances expressed as proportion for the collection dates of i-th species in a-th community. S is the number of species. The same formula is given by Pianka (1973, 1974) and MacArthur and Levins (1967). They interpreted this formula as an overlap index.

For stands classification PCA technique was used. Using similarity matrix which needs many species as the criteria an agglomerative approach was applied at each stage.

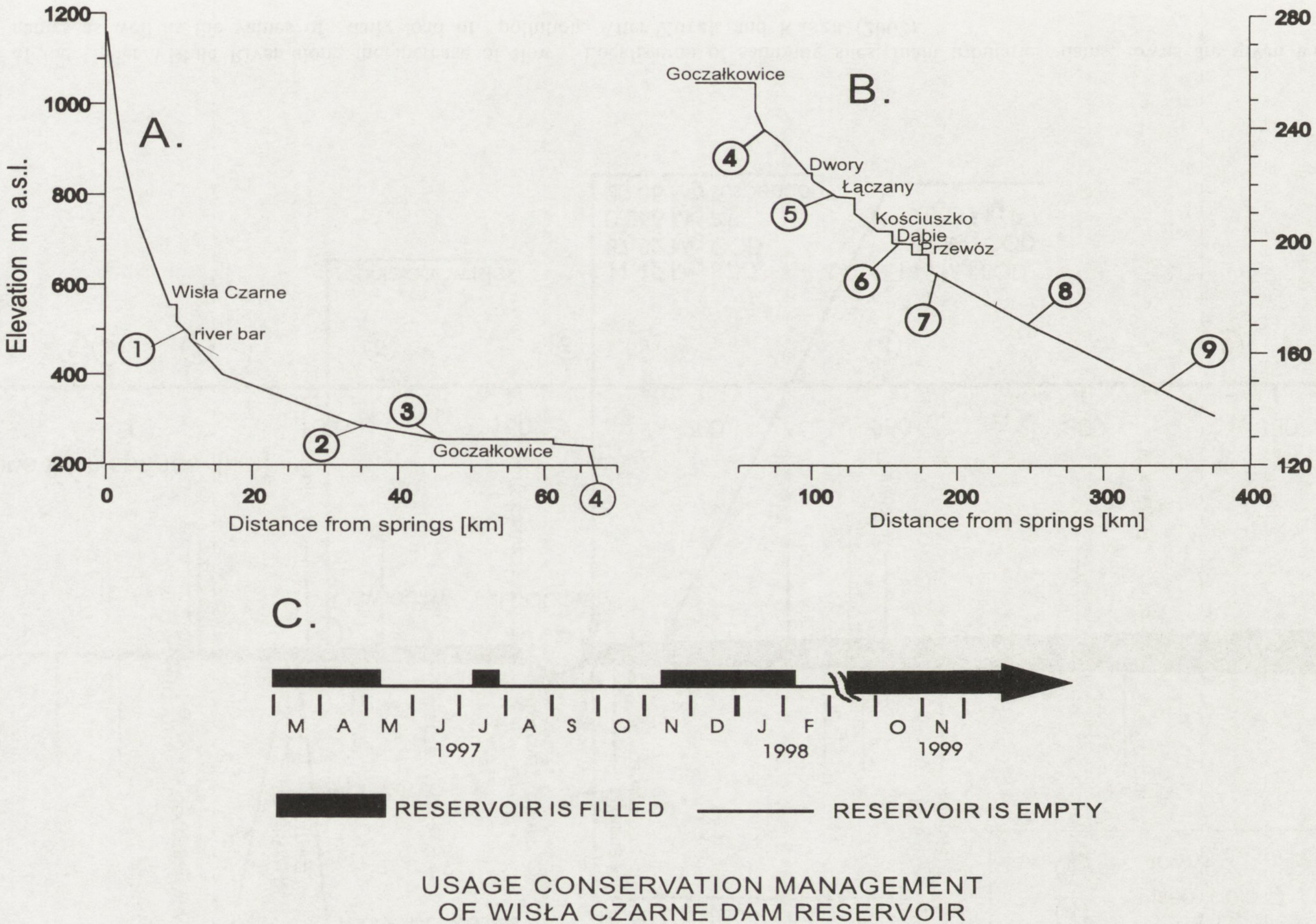

Fig. 1. Longitudinal profiles of the Vistula on water-level (measured on 9th of May 1998). A – the upper part from springs to the Goczałkowice dam, B – the lower part from the Goczałkowice dam reservoir to the end of Upper Vistula section (393.8 km of river course). The weirs are marked with their local names. 1 – 9 – sampling stations for this study. The scheme of water management in the Wisła Czarne dam reservoir in 1997/99 is given below (C). An arrow indicate that after repairing in November 1999 the reservoir is filled until these days. After Żurek and Kasza (2002).

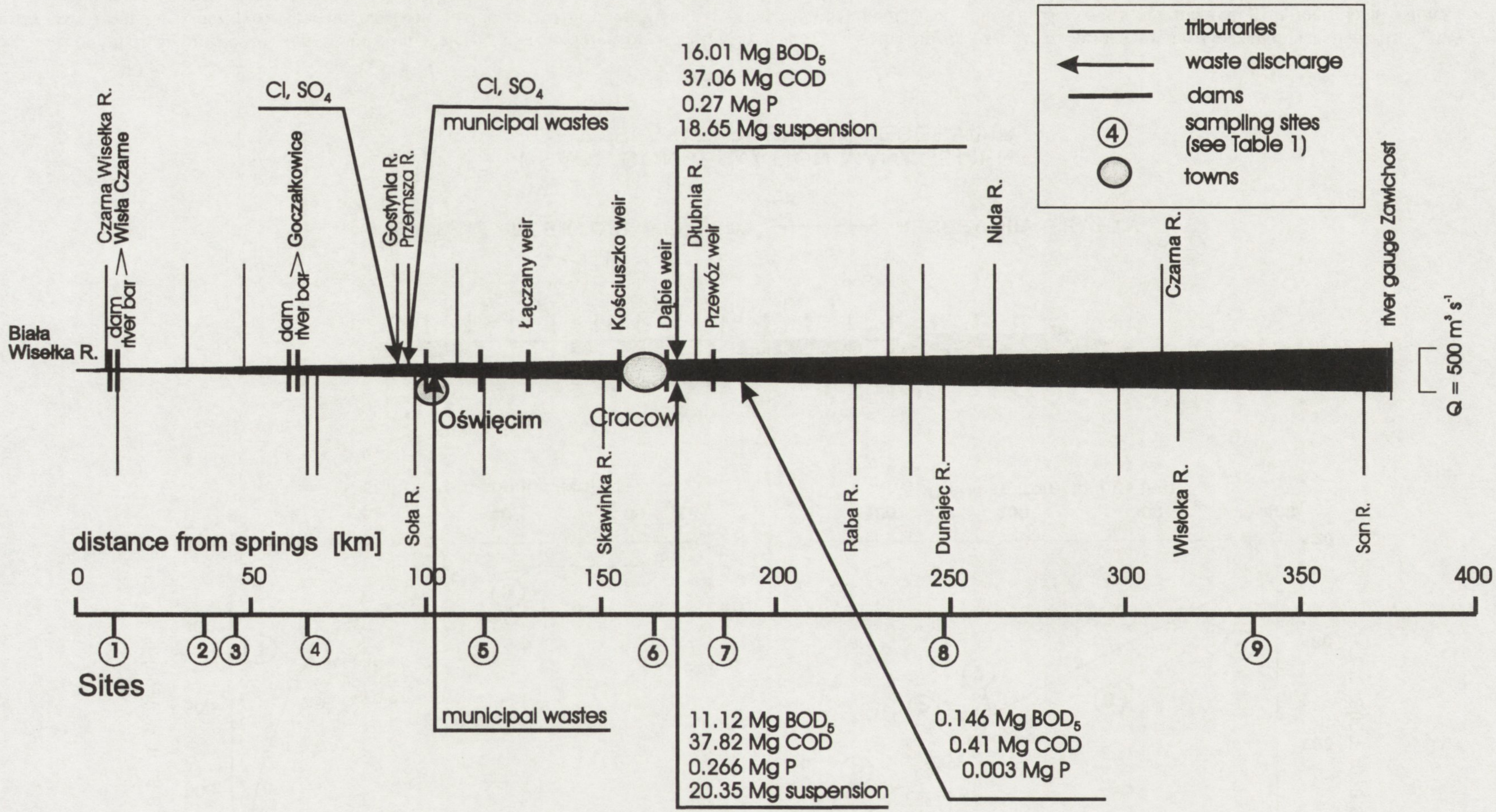

Fig. 2. Scheme of the Upper Vistula River along the increase of flow. Localisation of sampling sites, main tributaries, dams, towns are given with their respective local names as well as the values of daily load of pollution. After Żurek and Kasza (2002).

Table 1. Most important points and sampling sites (1–9) on the Vistula River. *for dams values concern the ordinate of spillway (overflow). Length in kilometers of the river includes corrections of the Vistula's banks which were done to the end of 1997. Distance from springs. After Żurek and Kasza (2002)

	Distance [km]	m a.s.l.*	Catchment [km^2]	Flow [m^3s^{-1}]			Beds and deposits	Remarks
				The highest	Mean	The lowest		
Wisła Czarne dam reservoir	9.6	554.2					clay	clear water, sometimes acid, damming 36.5 m, retention time 29 to 77 days
Site 1 (Wisła Czarne)	10.9	491.0	12.3	8.0	0.7	0.17	stones	clear water, gradient 11.1‰, current velocity 0.655 m s^{-1}
Wisła Czarne weir	11.4	489.0						retention time 20 minutes, damming 1.75 m
Site 2 (Skoczów town)	36.6	287.13	297.0	433	6.19	0.12	gravel, pebble, cobble and coarse sand	effluents from sewage treatment plant
Site 3 (Drogomyśl village)	45.7		312.3				gravel , pebble, coarse sand	effluents from ponds and purification plant at Skoczów town
Goczałkowice dam	61.2	256	523.1					3 km long earth dam, damming 12.60 m
(Goczałkowice dam reservoir)							mud	retention time ca. 150 days
Goczałkowice weir	62.2	243.75	523.6					damming 1.5 m
Site 4	66.2	239.78	738	288	9.52	0.47	coarse sand and sandy clay	outflow from dam reservoir, 5 km below the dam
Site 5 (Jankowice village)	117.6	217.0	5635.1				sand	mining waters providing by the Gostynia and the Przemsza trib. rich in Cl^{1-}, SO_4^{2-} suspension, NO_3^{1-}, PO_4^{3-} as well as municipal wastes from Silesia. Not purificated wastes from Oświęcim town
Łączany overflow dam	129.3	209.78	6941.6				mud	damming 6.5 m
Kościuszko overflow dam	155.3	199.38	7523.6					warmed water from electric power station discharged by the Skawinka River, damming 4.5 m
Site 6 (Cracow)	167.8	195.2	7999.9	2260	95.5	23.4	sand in the channel, mud at the banks	Cl^-, SO_4^{2-}, suspension, load of organic matter 74.88 Mg COD $year^{-1}$
Dąbie overflow dam	168.8	195.20	8101				mud at banks, sand in channel	damming 3.7 m.
Przewóz overflow dam	180.2	189.65	8333				mud at banks, sand in channel	damming 3.7 m.
Site 7 (Przylasek Rusiecki village)	185.20	189.0	8732				sand	site 2 km below the outflows of municipal wastes from Cracow
Site 8 (Opatowiec)	248.20		12 997	3130	210	62	mud, clay	slightly before connection with the Dunajec River. 25 km below inflow of clear water of large Raba River.
Site 9 (Machów village)	336.70	144.5	31 846	5260	309	71.2	sand in channel, mud at the banks, sandy islands	90 km below inflow of clear water from Dunajec River.

4. RESULTS

4.1. TEMPORAL SPATIAL DISTRIBUTION OF ZOOPLANKTON

In 99 samples 90 species of rotifers, 16 cladocerans, 9 copepods and other animals belonging to Harpacticoidea, Oligochaeta, Nematoda, Chironomidae, Odonata, Simulidae, Tardigrada and Coelenterata were found. Densities of each taxonomic group along the river and at a time are presented on Figs 3 and 4.

Potamoplankton of the Vistula River has typical composition, encountered also in other streams or rivers. The reservoir, barrages and large river weirs in the neighbourhood of Cracow have particular influence on species composition of zooplankton stated in the current of the river. The most numerous group of animals in the Vistula zooseston are rotifers. The season favourable for them to occur in the river is April to October. In winter their number is considerably lower. After vanishing zone, on 40–100 km, rotifers' populations increased. In practice, the great flood in July 1997 had no effect on rotifer populations. Quite different pattern is characteristic for numbers of cladocerans and copepods. Cladocerans, typical of stagnant waters, practically did not exist in the river waters. Instead of them species related to vegetation or deposits were found. These species belong to genus *Chydorus, Alona, Iliocryptus*. For all the main taxa, the Goczałkowice reservoir (on 62 km) plays the role as an *inoculum* for the river. Site located 3 km below the dam had usually high density of animals, in summer often more than 100 indiv. per liter. Plankton discharged from the reservoir quickly vanished along 40 km distance to 0–5 individuals. From first weirs of the cascade the numbers of zooplankton increased. The evidence of such function of the reservoir is the "island" of higher density visible on Figs 3 and 4, at site 4. Maxima of the increased densities of cladocerans are shifted for a month as compared with rotifers or copepods (Figs 3, 4). Weirs near Cracow (site 6, 165.2 km) only imperceptibly increase their populations, whereas below Cracow (site 7) trophic conditions seem to be favourable for rotifers as their numbers increase in spring to 200–400 individuals in a litre. Copepods' populations had a tendency to decrease on the 200 km long distance. Dams below Cracow only slightly increase their numbers.

Group of animals specified as drifted organisms consists mostly of little, juvenile individuals of Oligochaeta. In the upper parts of the river, having the character of a stream, the "other" group consists chiefly of juvenile Chironomidae and Plecoptera, Ephemeroptera or Odonata 0.3 to 0.7 mm long. Upper parts of the Vistula being of stream character – from springs to the Goczałkowice Reservoir (site 4) are very poor in zooseston independently from season of the year. Stream became slightly enriched in planktonic animals (chiefly rotifers), existing in stagnant waters of the Wisła Czarne reservoir, when it temporarily accumulated water and after that was quickly emptied for repair. Higher densities of group "other" in August at site 1 resulted from hydrotechnical works on the reservoir's bottom. This is visible in June 1997, Fig. 1.

The numbers of whole zooplankton showed two maxima of growth – "spring" in April – May and "autumn" in November. After decreased densities in the exploitation zone, its populations are rebuilt, especially in spring, (Fig. 4).

4.2. RELATIONSHIPS BETWEEN MAIN ZOOPLANKTONIC GROUPS AND ENVIRONMENTAL PARAMETERS

For this analysis stepwise regression method was used. Model was manually fitted by including or excluding 29 chemical variables, and with 3 other main planktonic taxa competing as independent variables. This method allowed to eliminate non significant parameters. In result the numbers of rotifers were a function of two biotic and four abiotic parameters:

Numbers of rotifers = f(Copepods, "Other", SiO_2, $N\text{-}NO_2$, PO_4, $N\text{-}NO_3$) (3)

The result is given in Table 2. Condition indices (square roots of the ratios of the larger eigenvalue to each successive eigenvalue) greater than 15 indicate the possibility of problems with collinearity (Belsley *et al.* 1980, Belsley 1991). Therefore, only variables with condition index lesser than 15 are important for regression. Values from Table 2 indicate that only first five values can be taken into account. Last three eigenvalues of

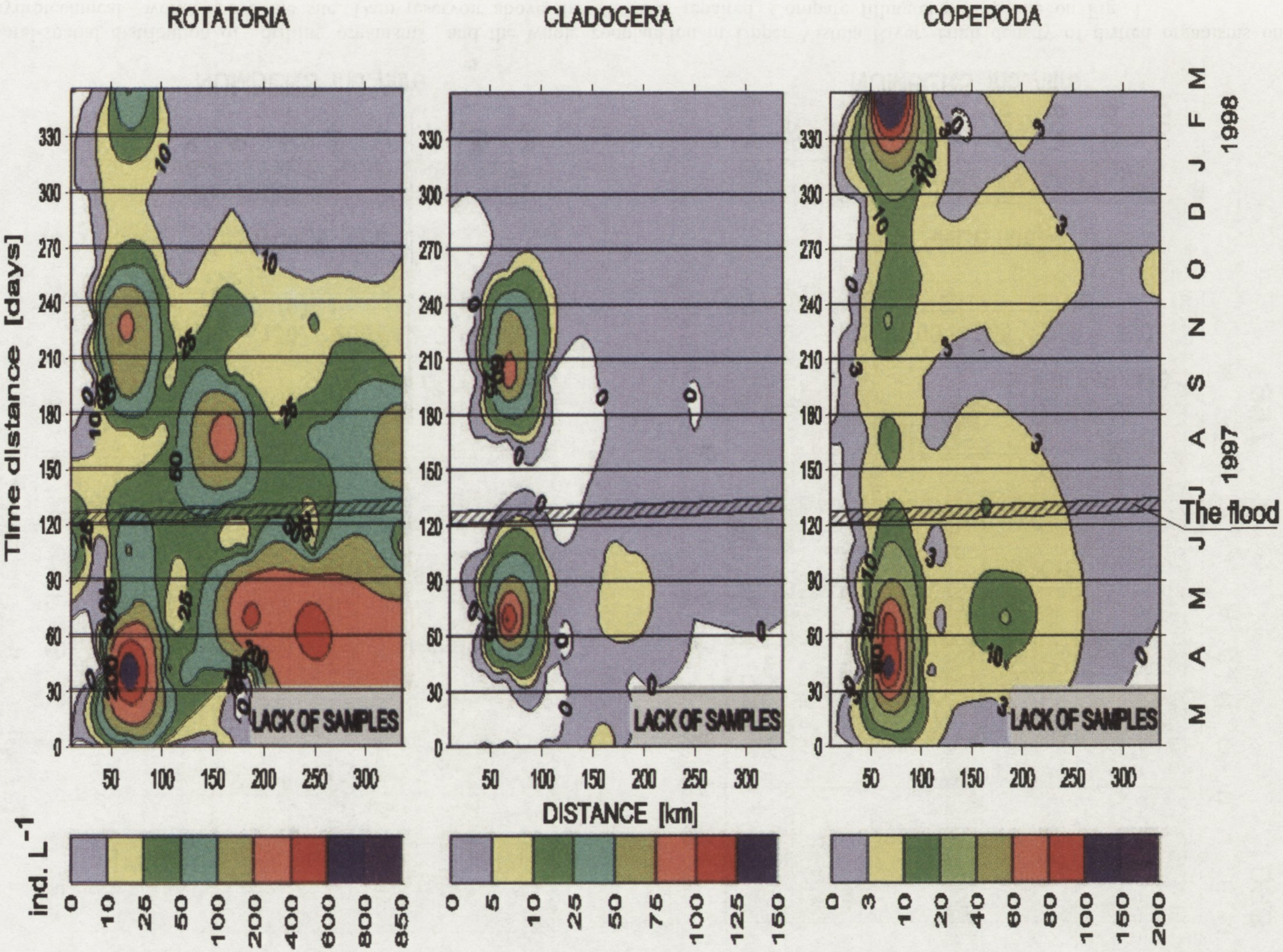

Fig. 3. Spatial and temporal distribution of rotifers, cladocerans and copepods. *Inoculum* function of large reservoir on 60 km is visible. Below the dam, zooplankton vanished until the cascade of weirs near Cracow (about 170 km). In downstream rotifers density increased whereas cladocerans diminished. Spring and autumn peaks of zooplankton density are also visible.

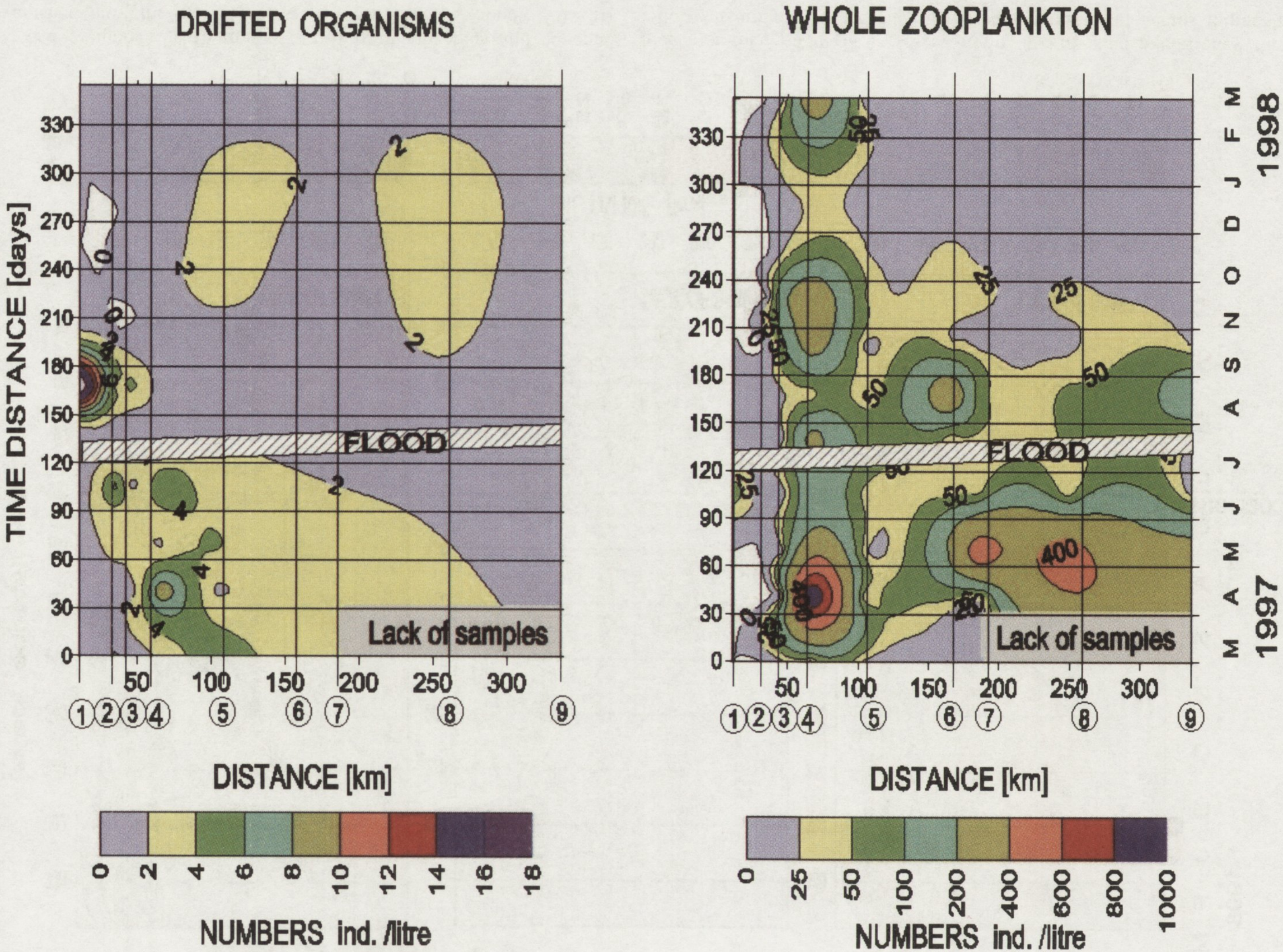

Fig. 4. Temporal-spatial distribution of drifting organisms and the whole zooplankton in Upper Vistula River. High density of drifted organisms on site 1 was caused by hydrotechnical works above the site. Dam reservoir above this site was repaired. Compare filling/empty regime on Fig. 1.

Table 2. Results of stepwise regression analysis for numbers of main components of Vistula plankton. For rotifers $N\text{-}NO_3$ proved to be not important for these animals. Comments in the text. Condition indices (square roots of the ratios of the larger eigenvalue to each successive eigenvalue) greater than 15 indicate the possibility of problems with collinearity. These indices are bolded

		Factors											
		constant	"other"	SiO_2	$N\text{-}NO_2$	PO_4	copepods	$N\text{-}NO_3$	COD	Oxygen	Rotifers	Cladocera	chlorophyll a
Numbers of rotifers	Eigenvalues of unit scaled X'X	4.430	0.988	0.659	0.630	0.148	0.127	0.019					
	condition indices	1.000	2.118	2.594	2.653	5.466	5.913	**15.190**					
Numbers of cladocerans	Eigenvalues of unit scaled X'X	4.219		0.580				0.138	0.051	0.012			
	Condition indices	1.000		2.696				5.537	9.084	**19.03**			
Numbers of copepods	Eigenvalues of unit scaled X'X	2.517						0.429			1.034	0.898	0.122
	Condition indices	1.000						2.424			1.560	1.674	4.543

Table 3. Correlation between density of main taxons of vistulian zooplankton and environmental factors. Increase in multiple correlation coefficient with included new variables into the model

Rotatoria			Cladocera			Copepoda			Drifted organisms		
Dep. Var.	$\lvert R \rvert$	r^2	Dep. Var.	$\lvert R \rvert$	r^2	Dep. var.	$\lvert R \rvert$	r^2	Dep. var.	$\lvert R \rvert$	r^2
SiO_2	0.467	0.218	SiO_2	0.354	0.126	Sum of rotifers	0.448	0.200	Sum of rotifers	0.326	0.106
Other	0.557	0.310	$N\text{-}NO_3$	0.426	0.181	$N\text{-}NO_3$	0.540	0.290	Turbidity	0.426	0.181
Sum of Cop	0.619	0.389	COD	0.462	0.214	Sum of Cladocera	0.603	0.363	Fe	0.470	0.221
$N\text{-}NO_3$	0.664	0.441	Oxygen	0.524	0.275	chlorophyll a	0,641	0.411	PO_4	0.492	0.242
PO_4	0.720	0.518							Oxydability	0.499	0.249
$N\text{-}NO_2$	0.805	0.648							Mg	0.510	0.26
									$N\text{-}NO_2$	0.521	0.271

X'X are nearly zero, showing that predictor variables comprise a relatively redundant set. This regression model is significant with $P < 0.001$, F ratio 14.882 for 6 and 83 degree of freedom.

For Cladocera regression analysis gave a simpler model:

Numbers of Cladocera = f(SiO_2, $N\text{-}NO_3$, COD_{Cr}, Oxygen) (4)

Detailed verification showed that variables SiO_2, COD and oxygen are significant with $P<0.01$, whereas $N\text{-}NO_3$ with $P<0.011$. All calculations were done for n=90. Regression is significant with $P<0.000$, F-ratio 8.057, for 4 and 85 df., multiple R= 0.524.

For copepods the same analysis resulted in a model:

Numbers of Copepods = f(Rotifers, Cladocerans, $N\text{-}NO_3$, chlorophyll *a*) (5)

All variables are significant with $P<0.02$. Dependence of copepods numbers on chlorophyll *a* is negative whereas the remaining dependences are positive. Regression calculated for n = 90 observations is significant with $P<0.000$, for 4 df. for regression and 85 df for residual, F ratio 13.43, $P<0.000$. Multiple correlation coefficient is only R=0.641. Especially important parameters for copepods seem to be the number of rotifers, cladocerans or algae. Only nitrogen as NO_3 is significant.

Each step in fitted process gave improved result of dependence. Results are collected in Table 3 for all four regressions. The best values of correlation coefficient $|r|$ were obtained for rotifers. Most of the significant variables are responsible for trophic state of water together with SiO_2 important for diatoms. Variable defined as "other" and Copepoda contain usually consumers of rotifers (predators and filtrators). Similarly, copepods depend on numbers of rotifers and also on cladocerans, less on algae expressed as chlorophyll *a*. This group depends on only one nutrient variable – i.e. nitrates. Significant dependence on nutrient variables: nitrates and SiO_2 is attributed to rare in river cladocerans. It is obvious that these elements are responsible for growth of diatoms in river. Lack of significant dependence on chlorophyll may indicate that these animals use also alternative food sources such as bacteria, picoplankton or amorphous organic matter. All these classes of food are included into the aggregate index COD.

Group of drift animals was correlated mainly with parameters connected with turbulent flow in river – turbidity and derived elements in suspension i.e. Fe and PO_4. Also variable "oxidability" is indirectly connected with suspension and amorphous part of organic matter.

4.3. SIMILARITIES OF SITES IN THE TIME AND SPACE

The cluster obtained as a result of formalised rules described in mathematical formulas of similarity indices and methods of linkage contains some sub-clusters which might be named to approximate its ecological meaning. Naming of clusters encircling some sites, links with answer the question – which and when the sites were aggregated.

Taking into account all samples collected at all sites during the whole year and clustering Pinkham's *B1* index (Pinkham and Pearson 1976) *the sites were grouped into a few classes. The largest class might be named "summer* ± spring/fall sites of the middle course of the river". At that times structure of planktonic populations was characteristic for this time and place. Sometimes, a sub-group of spring-summer sites included mountainous sites. It means that in summer plankton's structure in mountainous reaches became characteristic for lower reaches. Seasonally higher sites were similar to these ones of the middle course. Second group consists of two subclusters: "spring under reservoirs" sites and "summer of lower parts and winter ± autumn/spring mountainous sites". These groups are usually specified at 0.5 to 0.6 level of *B1*, (Fig 5).

This same procedure of clustering was done on matrix of *SIMI* indices. This index gave better specified groups, usually on the similarity level at 0.6–0.7. Zooplankton structure was classified into a group of winter-spring sites of the mountainous and middle course of the river which consists of two subgroups: winter of mountainous/middle course and winter-spring of middle and lower course. This group is very similar to that of summer sites as concerns of mountainous and lower parts of the river. These two large groups are similar to spring sites of mountainous and lower parts of the river. Untypical single sites, e.g. after flood or strong pollution, are collected at the end of

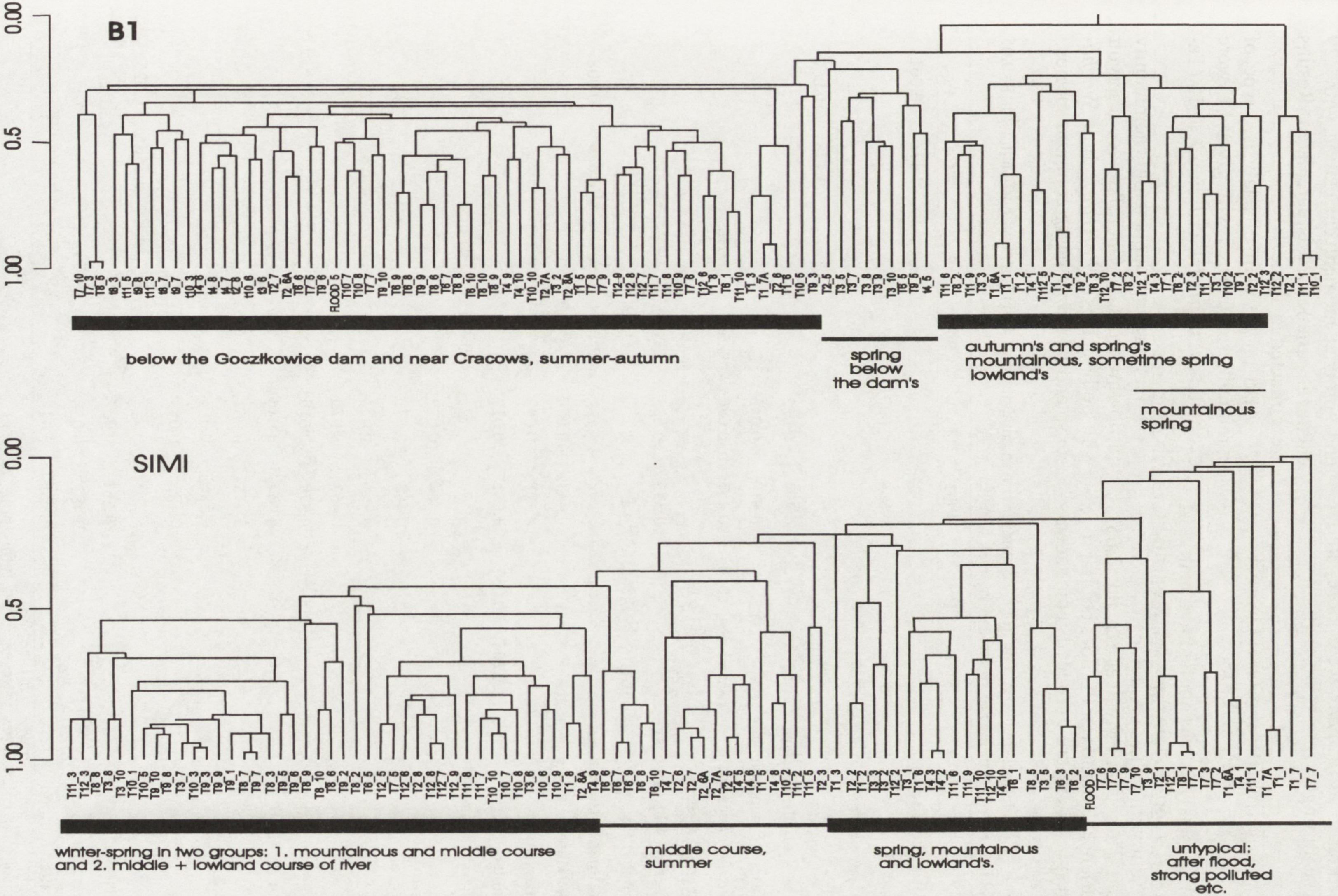

Fig. 5. Vistula zooplankton clusters of sites according to index B1 and SIMI. First number means the subsequent sampling terms, the next is the site's number. Dates of sampling are as follow: in 1997: **1** – 03–12; **2** – 04–21; **3** – 05–21, **4** – 06–22, **5** – 07–18, **6** – 07–29, **7** – 08–25, **8** – 09–29, **9** – 10–27, **10** – 11–24; in 1998: **11** – 01–06, **12** – 03–02. Most of sites in SIMI index is clustered at level 0.7 to 1 whereas in B1 index at 0.5 level. According to SIMI index, few sites below dam Wisła Czarne reservoir (on 10 km) and in Cracow (167.8 km), also below the weir are quite dissimilar to others.

cluster (Fig. 5). Using of two different criteria gave similar but not identical results. Sites according to *SIMI* index were more similar than according to *B1*.

4.4. PRINCIPAL COMPONENT ANALYSIS

PCA analysis was applied to a matrix of arranged zooplanktonic species. From all PC first four with values greater than 4 were extracted. These four PC values explain 52.65% of variance. Rotation of PC does not improve the result, therefore unrotated components were used. First four components were implemented into the initial abundance matrix and product moment correlation with 29 chemical parameter was calculated. Results are collected in Table 4.

Also in this step of analysis, type of communities connected with given PC were extracted assuming the criterion λ |0.1|, (Table 5).

PC1 represent euplanktonic community outflowing from the Goczałkowice reservoir with both species of *Polyrthra* , both *Synchaeta* sp and *Bosmina* being common species.

Table 4. Correlations between first four PC and environmental factors. Coefficients significant with P<0.05 are bolded, the remaining are printed in normal font

	PC1	P_{PC1}	PC2	P_{PC2}	PC3	P_{PC3}	PC4	P_{PC4}
Distance from springs							0.478	0.061
Age of water	**0.582**	0.018	**0.834**	0.000				
Flow per second	0.428	0.098						
Season*							0.478	0.061
Numbers of cladocerans			0.494	0.052				
Numbers of copepods			**0.510**	0.043				
Number of Diatoms	**0.591**	0.016	0.451	0.080	**0.527**	0.036		
Number of Greens	0.463	0.071						
Number of Blue-greens			**0.535**	0.033				
Chlorophyll *a*	0.470	0.066						
Heterotrophic bacteriae							**0.638**	0.008
Temperature			0.443	0.086				
Hardness total			**0.521**	0.039				
Alkalinity	**0.526**	0.037	**0.552**	0.027				
Hardness carbonate					0.461	0.072		
Ca			**0.564**	0.023				
Mg			0.462	0.072				
Cl			0.461	0.072				
SO_4			0.457	0.075				
$N\text{-}NO_2$			**0.579**	0.019				
Saturation CO_2			**0.509**	0.044				
CO_2			0.478	0.061				
BOD_5			**0.586**	0.017				
COD_{Cr}			0.482	0.059				
COD_{Mn}							**0.556**	0.025
Oxygen			**0.551**	0.027				
Dry residue			0.483	0.058				
Lost after ignition			**0.504**	0.046				

* – seasons for calculations were coded as 1 for spring to 4 for winter.

Table 5. Zooplankton grouped according to their loadings on 4 principal components denoted F1...F4. Some species are common for different communities. In world's rivers dominate assemblage *Brachionus- Keratella*, here denoted as F4 (compare Table 6). Bolded names indicates species characteristic for planktonic communities.

F1		F2	
Polyarthra vulgaris	**0.566**	***Keratella cochlearis***	**0.427**
Synchaeta kitina	0.170	*Brachionus quadridentatus*	0.293
Synchaeta oblonga	0.164	*Bosmina longirostris*	0.158
Bosmina longirostris	0.158	*Brachionus leydigi leydigi*	0.140
Brachionus leydigi leydigi	0.137	nauplii cyclopoida	0.138
Polyarthra minor	0.132		
Notholca squamula	0.130		
Brachnionus quadridentatus	0.126		
Keratella tecta	0.112		
F3		F4	
Keratella quadrata	0.800	***Brachionus calyciflorus***	0.911
Bosmina longirostris	0.749	***Brachionus leydigi tridentatus***	0.827
Brachionus leydigi leydigi	0.691	***Brachionus leydigi leydigi***	0.737
Brachionus calyciflorus.	0.576	***Keratella cochlearis***	0.632
Brachionus quadridententatus	0.469	***Brachionus angularis***	0.576
Brachionus leydigi tridentatus	0.428	***Bosmina longirostris***	0.432
Keratella tecta	0.391	copepodits	0.274
Synchaeta kitina	0.362	*Brachionus leydigi rotundus*	0.255
Brachionus angularis	0.317	*Keratella tecta*	0.231
copepodits	0.247	*Polyarthra dolichoptera*	0.192
Keratella cochlearis	0.210	*Brachionus nilsoni*	0.158
Bosmina coregoni	0.209	*Keratella quadrata*	0.159
Conochilus unicornis	0.181	*Brachionus urceolaris*	0.127
Brachionus leydigi rotundus	0.179	*Bosmina coregoni*	0.127
Asplanchna priodonta	0.141	*Brachionus plicatilis*	0.121
Polyarthra dolichoptera	0.131	nauplii cyclopoida	0.112
naupli cyclopoida	0.118		
Brachionus urceolaris	0.117		
Polyarthra vulgaris	0.110		

PC2 is weakly defined, however, the leading species *Keratella cochlearis* Gosse is typical eurytopic species found in oligotrophic as well in eutrophic waters. Species occurring together with *Brachionus quadridentatus* Hermann prefer environment rich in anions (Ruttner-Kolisko 1972).

PC3 seems to be connected with mesotrophic environment with abundant representation of species tolerant to trophic state fluctuations. PC picked out here summer species as *Polyarthra vulgaris* Carlin as well as winter species (cold stenotherm) like *P. dolichoptera* Idels.

PC4 consist of eutraphents and eurythermic species – it can be named "riverine *Brachionus* assemblage". This assemblage was noted below Cracow as far as to our last station on 336.7 km. It is known from the middle course of the river in Warsaw and lower course in Włocławek on 670 km. All these species are bacteriophagous – PC4 is also significantly correlated with the amount of bacteria (Table 4).

PCA technique was also applied to matrix having *B1* index and *SIMI* similarity indices. Results for *B1* matrix index are presented here. First two PC explain 46.7% of the vari-

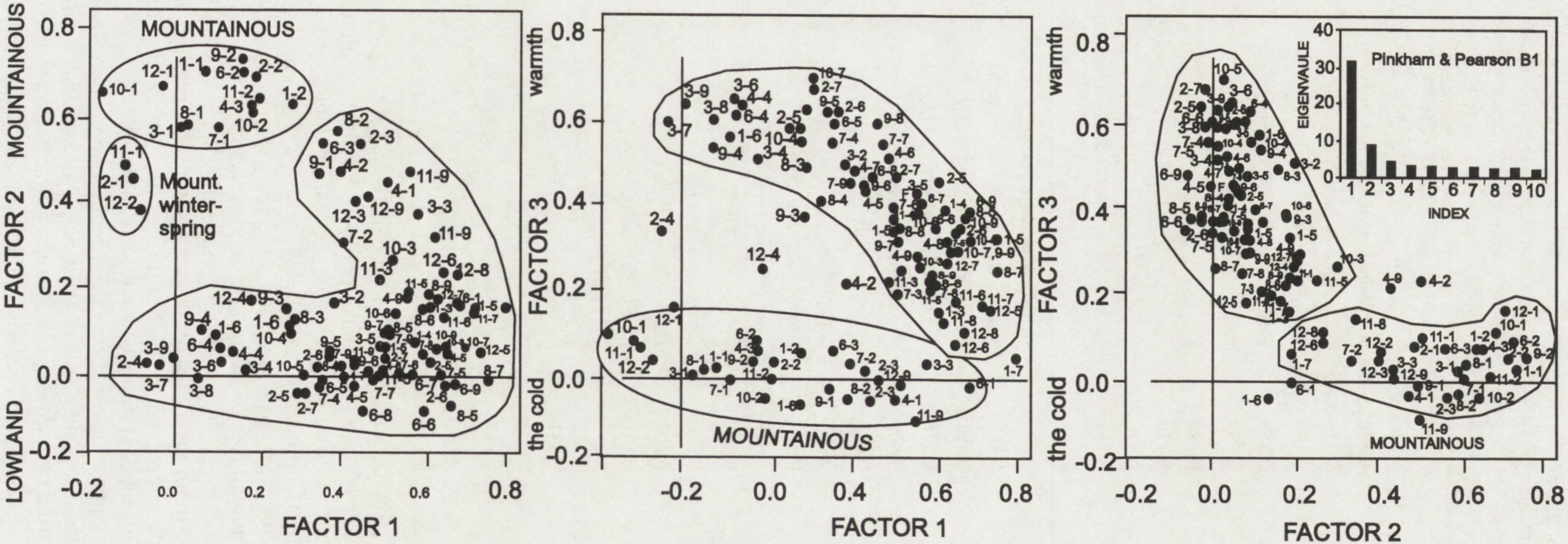

Fig. 6. Sites ordination of B1 matrix. In upper right corner first ten eigenvalues. Points are coded as follows: first number codes the date of sampling (see Fig. 5), second number concerns site. Mountainous sites independently on season make separate group.

ance. These values concern PC after varimax rotation. Obtained ordination of sites is presented on Fig 6. Intuitive analysis of sites distribution on PC1–PC2 plane in connection with results of PC correlation with physical and chemical parameters of the river allows to qualify PC1 as axis of "river size". In fact, it is significantly correlated with the distance of sites from sources as well as with the magnitude of flow. Simultaneously with increasing river size grows the concentration of chlorophyll *a* – also correlated with PC1. Factor 2 seems to differentiate "sites" according to temperature and pollution. PC3 can be named "trophic factor 1" – correlated with numbers of diatoms similarly as PC4 which is significantly correlated with heterotrophic bacteria, dissolved organic matter (COD_{Mn}) and season. All combinations of first three factors distinguish two large groups of sites: mountainous and lowlands, Fig. 6.

5. DISCUSSION

Zooplankton of the middle part of the Vistula River near Warsaw consists in 94 to 100% of rotifers (Papińska 1990). The author reported that their numbers in spring and early summer attained 200–300 individuals in one litre, whereas in autumn usually up to 2000–3000. This is similar tendency to that observed in the investigated section below Cracow at sites 7 to 10. Papińska (1990) observed an increase in zooplankton populations in the Vistula below the Narew mouth. This rapid increase seems to have typical origin from the outflow of large Zegrzyński reservoir situated on this river. Similar discharge of zooplankton took place below the Goczałkowice reservoir at site 4 on 62 km.

Water residence time was of substantial importance for development of zooplankton. Stagnancy of the Vistula's waters in Goczałkowice reservoir creates favourable conditions for development of rotifers, cladocerans and copepods (Figs 3 and 4). Similar opinion was presented by Pace *et al.* (1992) who stated that water residence time was an important property distinguishing differences in abundance of phytoplankton among river, reservoirs and lakes. Planktonic animals outflowing from the Goczałkowice reservoir are eliminated between 60 and 100 km downstream. This elimination concerns mainly cladocerans and copepods. These animals seem to be sensitive to turbulence. Cushing (1964) observed that zooplankton numbers generally decreased in stream sections of Saskatchewan lake-stream system. Exceptions to this trend were in lake-like portions of the lower stream where current was slow. Small rotifers and protozoans are more resistant to turbulence. Rotifers after decrease in their numbers to about 2–20 individuals per litre, keep this abundance on a distance about 250 km long with a tendency to increase from 100 to 337 km. According to Papińska 1990, Słoń and Kowalczewski 1991, also on the 100 km long section in the region of Warsaw, structure of zooplankton community is similar and simple. Also there dominate rotifers with genus *Brachionus* and *Keratella*. According to Żytkowicz *et al.* (1990), on 670 km of the Vistula course, biodiversity of zooplankton populations was higher than in the Upper Vistula sector. They found 146 species of rotifers, cladocerans and copepods. Only 16 species (13 of Rotatoria, 3 of Cladocera) were a constant component of zooplankton. Range of densities was similar to that found in our investigations, 126–2070 individuals of Rotatoria and 6 to 252 of Crustacea.

Interesting is the zoogeographical status of the Vistula against a background of main world's river. Main planktonic taxa are selected from source works and listed in the Table 6. It seems that number of reported species is a function of the time of investigation, lengths of investigated river sector and number of investigators. Many authors indicate on importance of size of a river, residence water time, proportion between lotic and lenitic reaches. Lists of main species noted in the rivers on five continents (Table 6) showed similarity to some degree. Structure of zooplanktonic communities changes from one river to another. The same species are in South and North America, Africa, Europe or Australia. Few common species have equatorial river and beyond the polar circle (Kruglova 1991). Other investigated rivers have similar structure of zooplanktonic populations as it was mentioned by Hynes (1972), Wu (1987) for Yangtze River, Pirozhnikov and Shulga (1957) for Yenisey, Lena and Ob, Partchuk (1995) for Tisa, May and Bass (1998) for Thames.

Generally in large rivers:

- Rotifera are more abundant than Crustacea both in numbers and sometimes in biomass.

Table 6.Main species of zooplankton in more important rivers of the world. Dominants marked with bold

Volga (Butorin and Mordukhai-Boltovskoi 1978)	**Blue Nile** (Taling and Rzóska 1967, Dumont 1986)	**Murray – Darling system** (Shiel 1986, Shiel 1990)	**Danube** (Tseyeb 1961, Balogh *et al.* 1994)	**Niger** (Dumont 1986)
Rotifera: ***Brachionus*** *bennini** *calyciflorus, urceolaris, angularis* *Conochilus spp* *Euchlanis dilatata* *Keratella quadrata* ***Synchaeta oblonga***	Rotifera: *Brachionus calyciflorus* *caudatus f. vulgaris* *Filinia longiseta* *Keratella tropica* *K.. cochlearis cochlearis* *Pedalia intermedia*	Rotifera: *Asplanchna brightwelli, sieboldi* ***Brachionus*** *angularis, calyciflorus, budapestinensis, diversicornis, urceolaris, falcatus* ***Filinia*** *australis, pejleri, opoliensis, longiseta, terminalis* ***Keratella*** *australis, tropica, cochlearis* ***Synchaeta*** *longipes, stylata, oblonga*	Rotifera: *Asplanchna priodonta* *Brachionus calyciflorus, budapestinensis, angularis,* *Keratella quadrata* *cochlearis* *Notholca striata* *Polyarthra vulgaris*	No data
Cladocera: *Bosminopsis deitersi** *Bosmina coregoni* *Daphnia longispina* *Diaphanosoma brachyurum* *Moina micrura*	Cladocera: *Bosmina longirostris* *Ceriodaphnia cornuta, dubia* *Diaphanosoma excisum* *Daphnia barbata* *D. lumholtzi* *Moina dubia*	Cladocera: *Bosmina meridionalis* *Chydorus sphaericus Diaphanosoma unguiculatum* *Daphnia lumholtzi* *Ceriodaphnia cornuta* *Moina micrura*	Cladocera: *Bosmina longirostris* *Chydorus sphaericus* *Daphnia hyalina*	Cladocera: *Diaphanosoma excisum* *D. sarsi* *Bosminopsos deitersi* *Bosmina longirostris* *Moina micrura* *Ceriodaphnia cornuta* *C. dubia* *Daphnia barbata, longispina* *Moinodaphnia macleayi*
Copepoda: *Eudiaptomus gracilis, graciloides* *Cyclops vicinus, strenuus, kolensis* *Mesocyclops leuckarti*	Copepoda: *Thermodiaptomus syngenes* *Tropodiaptomus processifer kraepelini* *Thermocyclops leuckarti* *Thermodiaptomus galebi*	Copepoda: *Boeckella triarticulata* *Calamoecia ampulla* *Australoyclops sp.* *Eucyclops sp* *Mesocyclops sp.* *Thermocyclopoides notius*	Copepoda: *Acanthocyclops vernalis* (?!) *A. robustus* *Cyclops vicinus, strenuus* *Eurytemora velox* *Diaptomus gracilis*	Copepoda: *Thermocyclops spp, Tropocyclops* (mainly endemic), *Diacyclops, Mesocyclops,* *Tropodiaptomus processifer* *Thermodiaptomus yabensis*

continued

Parana (Paggi and José de Paggi 1974, José de Paggi 1980, 1981)	**Orinoko** (Saunders and Lewis 1989, Rey and Vásquez 1989)	**Hudson** (Pace *et al.* 1992)	**Vistula** (Żurek 2000, and this paper)	**Rhine** (Admiraal *et.al.* 1994, de Ruyter van Steveninck *et al.* 1992, Van den Brink *et al.* 1994, Tubbing *et al.* 1994)
Rotifera: *Keratella americana, cochlearis, tropica* *Brachionus* (14 species) *calyciflorus, caudatus, quadridentatus, mirus, budapestinensis, falcatus, angularis, plicatilis* *Euchlanis dilatata* *Polyarthra trigla vulgaris* *Lecane proiecta* *Trichocerca rattus* *Synchaeta pectinata* *Conochilus, Filinia, Asplanchna*	Rotifera: *Brachionus spp.* *Filinia spp.* *Keratella spp* *Lecane spp.* *Trichocerca spp.*	Rotifera: *Keratella spp* *Polyarthra spp.* *Trichocerca spp.*	Rotifera: *Asplanchna priodonta* *Brachionus* (21 species *without forms) angularis, calyciflorus, leydigi, quadridentatus, urceolaris* *Filinia longiseta,* *Habrotrocha sp.* *Keratella quadrata & cochlearis* *Lecane closterocerca* *Polyarthra vulgaris* *Pompholyx sulcata* *Synchaeta oblonga & tremula*	Rotifera: ***Keratella cochlearis, quadrata*** ***Brachionus calyciorus****, angularis, quadridentatus, urceolaris, leydigi f.tridentata* *Filinia longiseta* *Notholca acuminata* *Polyarthra spp.* *Asplanchna spp.*
Cladocera: *Bosmina longirostris* *Bosminopsis deitersi* *Eubosmina tubicen* *Ceriodaphnia cornuta* *Diaphanosoma brachyurum* *Moina minuta*	Cladocera: *Bosmina spp.* *Bosminopsis spp.* *Ceriodaphnia spp.* *Diaphanosoma spp.* *Moina spp.*	Cladocera: *Bosmina longirostris*	Cladocera: *Bosmina longirostris* *Chydorus sphaericus* *Daphnia longispina, pulex* *Moina micrura*	Cladocera: *Bosmina sp.* *Daphnia sp.* *Alona sp.*
Copepoda: *Notodiaptomus coniferoides* + 8 other species of Calanoida : *Acanthocyclops robustus* *Mesocyclops sp.* *Macrocyclops sp.*	Copepoda: No data	Copepoda: *Diacyclops bicuspidatus thomasi*	Copepoda: *Acanthocyclops robustus* *Cyclops vicinus* *Mesocyclops leuckarti* *Thermocyclos crassus* *Eudiaptomus gracilis*	Copepoda: *Cyclops sp.* *Eurytemora sp.*

*Characteristic for Volga before making cascade.

• In all world's rivers are numerous: two genera of Rotatoria: *Brachionus* and *Keratella*; three genera of Cladocera: *Bosmina*, *Ceriodaphnia* and *Diaphanosoma* and two genera of Copepoda: *Mesocyclops, Thermocyclops* and *Acanthocyclops*.

• Species diversity is higher in temperate zone, lower in tropical and lowest in subpolar zones. In subpolar river is noted about 70 species (Rotatoria + Crustacea), acc. to Kruglova (1991), in temperate more than 200 like in Volga (Butorin and Mordukhai- Boltovskoi 1978, Mordukhai-Boltovskoi 1978), whereas in tropical about 100 Crustacea species (Dumont 1986).

• Species diversity depends on the natural or regulated character of a river.

• Each continent added own, sometimes endemic planktonic species. The most "endemic continent" seems to be Africa (Dumont 1986) and Australia (Shiel 1986).

Multivariate methods are useful for exploring relationships between environmental parameters and species communities. These methods generate hypotheses for future experimental verification. These problems are discussed by Greig-Smith (1980) or by Dolédec and Chessel (1994). Ordination of stands clearly revealed, independently on combination of the first three factors, groups of mountainous sites and the remaining. Large group of sites below the Goczałkowice reservoir represent all intermediate ordination on the positive side of factors 1, 2 and 3. First component seems to be strongly connected with food for plankters such as diatoms and possibilities of their growth, i.e. residence time of water. Factor 2 named "lowland-mountainous" (Fig. 6) is significantly correlated with residence time of water, anions and cations concentration, i.e. with hardness. It is interesting that the role of calcium and hydrogen carbonate is also significant for water macrophytes. This statement was obtained with PCA analysis and correlation (Wiegleb 1980). Lately Chessmann *et al.* (1999) showed in their model constructed to predict the probability of coccurence of each genus at a given site, the significant correlation of sessile diatoms with usually Ca-dependent parameters like alkalinity, hardness or electrical conductivity. Horse shoe type of sites pattern on the graph shows that environmental conditions in the Vistula do not represent a simple ecological gradient rithral – potamal. Situation is more complex – answer of zooplanktonic communities in different seasons of a year and in different places of hydrotechnically built-up river gave such a complex pattern.

The number of rotifers is correlated with basic chemical indicators of trophy: phosphate, nitrate and nitrite, dissolved silicate as well as with the number of copepods (usually predators). Similar dependence between nutrients and phytoplankton was observed in Rhine by de Ruyter van Stevenink *et al.* (1990). Decrease in silicate concentrations indicates that growth of diatoms does occurs. The authors quoted above stated also decline in algal biomass which was attributed to growing populations of Copepoda and Cladocera. Here, statistical analysis showed directly this relationship. The number of copepods depends on the availability of possible prey, i.e. rotifers and cladocerans. Multiple regression confirms known dependence of cladocerans on trophic conditions. It is known that Cladocera are able to eat not only the algae but also bacteria and small particles of detritus. The concentration of all these organic components is synthesized in COD factor. Measurements of grazing the microzooplankton appears to constitute and important process altering the phytoplankton community structure. As showed Kobayashi *et al.* (1996) in Hawkesbury-Nepean River, measured grazing rates would reduce the growth rates of phytoplankton of the river by 27–67 % on average.

Complex net of biotic and abiotic parameters cause sometimes fuzzy results. It is visible both in ordinated sites and in clusters. Statistical tools joined sometimes sites seemingly distant. Ecological interpretations of ordinated stands seem to be easier when they are supported by old, however still useful method of multiple regression or one of the numerous similarity indices.

6. SUMMARY

Investigations were carried out in 1997/1998 years on 340 km Vistula's reach from 10 do 340 km First site was located on 491 m. a.s.l , the last at 149 m (Fig. 1). This reach has very different features. Some parts have hydrotechnical constructions, tributaries Gostynka stream and Przemsza River discharged salt waters and serious load of municipal wastes, (Fig. 2). Detailed characteristics of sites are given in the Table 1. In 99 samples 90 species of ro-

tifers, 16 cladocerans, 9 copepods and other animals belonging to Harpacticoidea, Oligochaeta, Nematoda, Chironomidae, Odonata, Simulidae, Tardigrada and Coelenterata were found. Densities of each taxonomic group along the river and at a time are presented on Figs 3 and 4. Copepods had two maxima of density different from those for rotifers and cladocerans. All these planktonic taxons were discharged from big dam reservoir at Goczałkowice (on 61.2 km) and vanished until the cascade of few weirs near Cracow (ca. 170 km). Rotifers were abundant in the downstream reach whereas cladocerans and copepods diminished their numbers to 5–10 indiv. l^{-1}.

Two indices of similarity (*SIMI* and Pinkham's *B1*) were used. Matrices of these indices were clustered (Fig. 5). Most of sites in *SIMI* index was joined at level 0.7 to 1, whereas in *B1* index at 0.5 level.

Numbers of rotifers, cladocerans, copepods and drifting animals named "others" were correlated with 29 chemical variables, and with 3 other main planktonic taxa competing as independent variables. Using the stepwise regression, non significant parameters were eliminated. Significant parameters are showed in the Table 2. Usually nutritional features were significant. Nutrients important for algae were often important for animals. Increase in multiple correlation coefficient after including new variables are shown in the Table 3.

Principal component analysis was applied to a matrix of arranged zooplanktonic species. From all PC first four with values greater than 4 were extracted. These four PC values explain 52.65% of variance. First four components were implemented into the initial abundance matrix and product moment correlation with 29 chemical parameter was calculated. Results are collected in Table 4. For some assemblages nutritional conditions were important, whereas other prefer water rich in Ca or stagnant. In n this step of analysis, type of communities connected with given PC were extracted (Table 5). Some species are common for assemblages connected with different PC. Looking on pattern of sites ordination, (Fig. 6), and interlacing sites and sampling terms moving of planktonic assemblages in the gradient rhitral – potamal in the year cycle is visible. Downstream sites in winter are close to mountainous in summer and summer assemblages of middle course are similar to upstream.

Comparison of planktonic assemblages from the Vistula River with European and more important worlds rivers, showed common core of these similarity, These are the genus *Brachionus* and *Keratella* for Rotatoria and *Bosmina* with *Ceriodaphnia* for Cladocera. Basic taxonomic list is given in the Table 6.

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(*Received after revision July 2001*)