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MACROINVERTEBRATE DRIFT IN A LOWLAND RIVER DURING ITS RECOVERY TO THE NATURAL DISCHARGE* **

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A b s t r a c t. The aim of the study was to learn the composition and seasonal dynamics of the macroinvertebrate drift of the Drzewiczka River in a period of the river's recovering to its natural discharge (renaturisation), after almost seven decades of impoundment and two decades of canoeing track functioning there. In five dominant river habitats, morphometric and hydraulic river parameters were recorded beside the abundance of drifting macroinvertebrates to assess which of them determine the amount of the macroinvertebrate drift. Macroinvertebrates constituted from 0.5 to 2.3% of the total weight of the transported organic matter. Their relatively high density in the water column (the maximum was 4947 specimens per 100 m^{-3} in H_M in May) may be explained by colmatation. In the macroinvertebrate drift, dipterans of the Chironomidae family (mainly Orthocladiinae and Tanytarsini), mayflies (mainly *Baetis*), and black-flies (Simulidae) were dominant.

K e y w o r d s: macroinvertebrate drift, Chironomidae, Trichoptera, river, renaturisation

INTRODUCTION

Migration of benthic invertebrates in streams is caused primarily by drift; other mechanisms of aquatic organisms dispersion are of lesser importance [5,13,25,26, 29,38-40]. Entrance into drift is caused by a variety of mechanisms, including biotic and abiotic variables; among the latter, hydraulic characteristics play the key role in redistribution of benthic individuals. According to Statzner [33], macro-invertebrates

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emigrate if the near-bottom flow either decreases below the minimum or surpasses a maximum value; at the minimum value the drift entry of the animals is considered as an active process while at the maximum value as the erosion of animals similar to inorganic substrate.

Many streams worldwide are altered, mainly by changes in their discharge. However, some impounded rivers have recently returned to their natural discharge, for example owing to dam removal [10]. Nevertheless, this process may induce some additional effects, one of them being a step increase in sediment load to downstream reach. A similar effect may be achieved if a dam reservoir was emptied in order to perform its dredging. Such a mechanism was observed in the Drzewieckie Reservoir and in the lowland Drzewiczka River. Thus, the main objective of this study is to estimate the quality and quantity of macroinvertebrate drift in the lowland river which returned to its natural discharge after several decades of flow disturbance caused by damming and functioning of a wild-water slalom canoeing track (CT).

STUDY AREA

The lowland Drzewiczka River is a part of the Vistula River drainage basin. The Drzewiczka River arises at 248 m a.s.l., is 81.3 km long and empties into the Pilica River at 130 m a.s.l. Its catchments area is ca. 1,083 km^2 and the slope ranges from 2.7-2.5‰ in the upper reaches to 0.8-0.7‰ in the middle and lower course. The study area (20º29′14″ E and 51º27′08″ N) was established within a fourth order stream section, about 1.5 km downstream of the dam reservoir and directly downstream of canoeing track. This reservoir, called Lake Drzewieckie, has an area of 0.84 km^2, and was constructed between 1932 and 1936, mainly in order to supply water to a metallurgical factory and for recreation. In 1980 a wild-water slalom canoeing track (W-WSCT, about 2 km long) of a mountainous character was built just below the dam reservoir. Due to these constructions the hydrological regime of the river downstream of the dam became very variable and decisively different from the natural one. Every day, over a two hour period, a large volume of water was released, mainly in the afternoon, to enable the training of canoeists [11,35]. But in February, 2002, when the dam reservoir was gradually being emptied before its dredging, the Drzewiczka River returned to its natural discharge; our investigations concern the early period of its renaturisation.

Five dominant habitats of the Drzewiczka reach were distributed along a 160 m reach; the habitat selection was determined by variables that have a great impact on the microdistribution of lotic macroinvertebrates, such as: current velocity, water depth, substratum composition, presence of macrophytes and food resources (BPOM, TPOM, periphyton). The following habitats were marked:

- pool habitat (D_P)
- stagnant habitat covered with emergent macrophytes where *Glyceria maxima* (Hartm.) Holmb. were dominant (D_S),
- macrophyte–dominated habitat at the investigated reach (D_M); vegetation cover included large patches of *Potamogeton lucens* L., *Potamogeton crispus* L. and small patches of *Potamogeton pectinatus* L.
- bank habitat (D_B)
- riffle habitat (D_R).

It is worth noting that the Drzewiczka River flows across agricultural land overgrown by numerous grasses, the riparian trees being mainly *Alnus glutinosa* (L.) Gaertn. and *Populus* sp. Further details of these habitats are given by Szczerkowska *et al*. [23], Tszydel *et al*. [36], Dukowska *et al*. [11].

MATERIAL AND METHODS

Samples from each of the five habitats were collected in the Drzewiczka River monthly, in the morning, from November 2002 to October 2003, during the recovery of the river to the natural discharge. In order to estimate the amounts of both fine and coarse transported particulate organic matter (TFPOM and TCPOM) and number of drifting macroinvertebrates, three nets (mesh size 400 μm) 1.5 m in length were mounted on 0.5 × 0.7 m frames; they were put into each habitat for ten minutes – see details in Grzybkowska [16]. In the laboratory, macroinvertebrates captured in the nets were sorted, identified, counted and then calculated for 100 m^3. Detrital materials were selected into two fractions: coarse (TCPOM > 1 mm) and fine particulate organic matter (TFPOM < 1 mm). Organic matter was then dried at 60ºC for two days, weighed, ashed at 600ºC for two hours and reweighed; the same procedure was applied to the biomass of macroinvertebrate drift.

To measure the total amounts of transported organic matter (TPOM), triplicate water samples were collected in 10 l plastic bags. These samples were filtered through Whatman filters and the amount of TFPOM was added to the mass of organic matter caught in the frames.

At the same time as the drift samples, benthic samples from the five sampling habitats were also collected in the Drzewiczka River. Ten of the latter samples were collected with a 10 cm^2 (100 cm^2 of stream-bed area) tubular sampler at each habitat (H_L). The sampler was pushed into the bottom sediment to a depth of 15 cm (and also through vegetation if it was present). In each habitat (H_L) temperature, depth, current speed and area of the habitat were measured. Additional samples were taken to analyse the composition of particulate inorganic matter according to Cummins [8] and to calculate substrate inorganic index SI [31]. These samples were also used to determine the organic matter content in the bottom sediment [30]. Benthic organic matter was analysed as transported POM.

Benthic samples of 50 cm^2 each were also taken at each habitat in order to estimate chlorophyll *a* concentration [15].

Data were log transformed (x + 1), when necessary, to satisfy the requirement of normality and homogeneity of variance. Analysis of variance (two-way ANOVA) was used to examine spatial and temporal variance of benthic and transported organic matter, inorganic substratum, chlorophyll *a*, hydraulic parameters, as well as the density of drifting macroinvertebrates. Pearson correlation coefficients were calculated to examine relationships between the biomass of particular invertebrate groups and given biotic and abiotic parameters. The canonical correlation was used to examine the relationship between the biomass of all macrobenthic groups and all environmental variables.

All statistical analyses were carried out using CCS Statistica (StatSoft, 2000).

RESULTS

Riverine variables

Characteristics of the investigated habitats in the Drzewiczka River are shown in Table 1.

Statistical differences between particular habitats of the Drzewiczka River were recorded for current velocity, substrate inorganic index (SI) and benthic POM (Tab. 1, Fig. 1). A final detailed examination showed that the final effect was caused by the differences between H_S and the other habitats (ANOVA, post-hoc Tukey test $P < 0.0001$), and between H_R and H_M ($P < 0.006$) and H_B ($P < 0.014$).

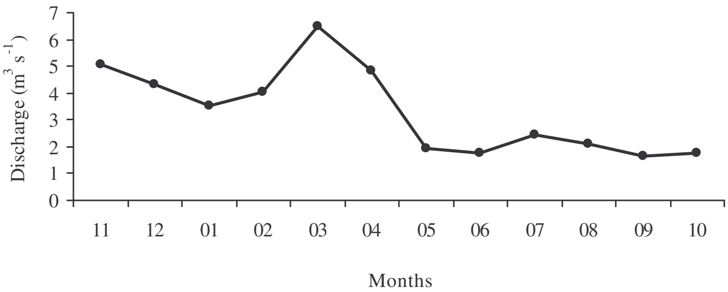

Fig. 1. Discharge of the Drzewiczka River over the investigated cycle

Inorganic substrate composition (expressed as SI, Tab. 1) varied significantly between habitats; differences between H_P and H_M (ANOVA, post-hoc Tukey test $P < 0.005$) and between H_S and H_B ($P < 0.05$) and H_R ($P < 0.0008$) and between

H_M and H_B ($P < 0.0007$) and H_R ($P < 0.0001$) were responsible for this. Over the annual cycle SI gradually decreased thanks to deposition of sand; as it was proved by our later investigations this phenomenon occurred all the time so SI in the spring of 2005 reached respectively 3.2 at H_P, 0.4 at H_S, 0.8 at H_M, 3.8 at H_B, and 7.2 at H_R, respectively (materials in prep.)

Table 1. Mean values ($\bar{x}$) and ranges (R) of selected characteristics of the investigated habitats (H_L) of the Drzewiczka River

Habitats (H_L) Variables		H_P	H_S	H_M	H_B	H_R
Depth	$\bar{x}$	0.42	0.40	0.46	0.36	0.44
(m)	R	0.32-0.54	0.27-0.55	0.30-0.68	0.25-0.55	0.33-0.67
Current velocity	$\bar{x}$	0.52	0.02	0.35	0.37	0.57
($m\ s^{-1}$)	R	0.22-0.87	0.00-0.10	0.16-0.61	0.30-0.74	0.35-0.86
SI	$\bar{x}$	8.0	4.3	2.4	8.7	12.4
(mm)	R	0.3-15.7	0.3-10.4	0.6-4.5	2.6-16.9	8.7-15.6
Oxygen	$\bar{x}$	2.03	1.94	2.08	1.97	2.22
($mg\ l^{-1}$)	R	0.78-2.69	0.67-2.65	1.14-2.67	0.49-2.65	1.01-3.33
Chlorophyll *a*	$\bar{x}$	177.7	332.8	150.0	137.8	261.7
($mg\ m^{-2}$)	R	15.4-725.7	37.0-927.2	35.0-322.7	12.3-278.5	59.0-1364.1
BFPOM	$\bar{x}$	4047	11932	3186	3943	2829
($g\ m^{-2}$)	R	1892-7091	6989-19515	1340-7294	1597-10114	1402-4409
BCPOM	$\bar{x}$	1064	1701	1433	423	211
($g\ m^{-2}$)	R	186-2324	898-2836	315-1709	129-1283	71-462
TFPOM	$\bar{x}$	11.23	27.15	12.94	12.65	16.95
($g\ m^{-3}$)	R	2.02-25.35	5.06-154.76	4.74-28.85	1.83-21.10	2.94-54.81
TCPOM	$\bar{x}$	0.325	0.166	0.354	0.353	0.118
($g\ m^{-3}$)	R	0.013-1.937	0.0005-0.488	0.006-0.828	0.012-1.567	0.209-0.769

Two benthic particulate organic matter (BPOM) fractions: coarse (BCPOM) and fine (BFPOM), and two transported particulate organic matter fractions (TPOM): coarse (TCPOM) and fine (TFPOM) are presented; SI – granularity of inorganic substrate index, chlorophyll *a* – concentration in periphyton.

Benthic POM (BPOM) was dominated by BFPOM; the highest values of this fraction were recorded at the stagnant habitat. Thus, the obtained ANOVA result is assumed to be the effect of the differences between H_S and the other habitats. The lowest amounts of benthic coarse POM were recorded at the bank and riffle habitats, while the statistically highest at the other habitats. The fine particulate organic matter dominated among the transported organic matter (Fig. 2), reaching the highest values at H_S.

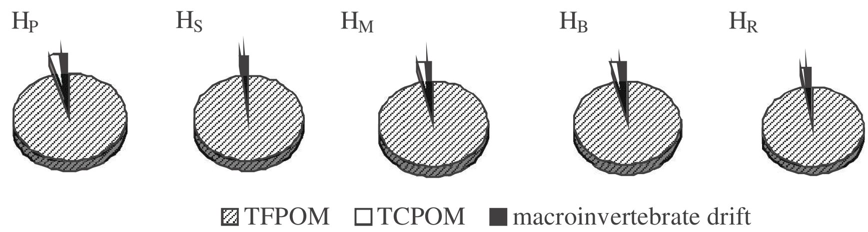

Fig. 2. Percentages of the main transported organic matter fractions at given habitats (H_L) of the Drzewiczka River

Table 2. Pearson „r" correlation coefficients between riverine parameters and drift of macroinvertebrate biomass in the investigated habitats; explanations as in Table 1

TAXA	
Oligochaeta	depth**
Ephemeroptera	TCPOM*
Heteroptera	
Hydropsyche pellucidula	TCPOM*
Halesus radiatus	TCPOM***
Psychomyia pusilla	- SI*, BCPOM*
Cheumatopsyche lepida	TCPOM**, - BFPOM*
Brachycentrus subnubilus	
Hydropsyhe contubernalis	TCPOM***
Simuliidae	- depth*
Tanypodinae	- cur. vel.*, BFPOM*, TFPOM*
Prodiamesinae	
Diamesinae	
Orthocladiinae	TCPOM***
Chironomini	- cur. vel.*, BFPOM**, TFPOM**
Tanytarsini	- cur. vel.*, BFPOM*, TCPOM*
Total	TCPOM***

Significance level of correlation coefficient: * $P < 0.05$, **$P < 0.01$, ***$P < 0.001$

Fauna in transported organic matter

Animals constituted only a small part of transported organic matter (Fig. 2). Over the annual cycle the highest percentages of drifting individuals, including both water and terrestrial fractions, in the total TPOM were determined at H_R (over 2.3%), while the lowest one at H_S (0.5%); at the other habitats this proportion was: 1.3% at H_M and H_B and 1.6% at $H_{P.}$

Among terrestrial individuals winged insects, such as Diptera (numerous chironomids although contributing rather little to the total biomass), Heteroptera, Coleoptera and Hymenoptera dominated, although Araneina and Oligochaeta, rinsed from ecotone zones, were also noted. Over the annual cycle the highest percentages of terrestrial drift were recorded at H_P, reaching 1.1% of the total biomass of macroinvertebrate drift, while the lowest ones were noted at H_B, where their contribution to the total biomass was lower than 0.1%; at other habitats these values were about 0.2% at H_M and H_R% and 0.1% at H_S. Seasonal dynamics of terrestrial insect biomass in the drift was also noted; their highest biomass was recorded in spring and autumn.

In summer larvae and young fish (cyprinids) were recorded at habitats H_P, H_S and H_B. However, those vertebrates were not taken into account in drift analysis.

Macroinvertebrate drift

The distribution of given macroinvertebrate taxa biomass and densities at particulate habitats is shown in Figure. 3. Besides Orthocladiinae (Chironomidae), Ephemeroptera (mainly *Baetis*) frequently migrated, especially from May to July at the stagnant habitat, as did Simuliidae. These dipterans were found at every habitat but they reached the highest density at the bank habitat with the peak number in May-June. Other numerous taxa in the drift were Trichoptera; caddies flies were mainly *represented* by *Hydropsyche pellucidula* (Curtis) and *Psychomyia pussilla* (Fabricius). These two species were recorded mainly at H_S in summer. The other trichopteran species, such as *Cheumatopsyche lepida* (Pictet)*, Brachycentrus subnubilus* Curtis and *Hydropsyhe contubernalis* McLachlan*,* were less conspicuous in the drift. Trichopteran contribution to total macroinvertebrate biomass was higher than to the total density because of its large size. An extraordinarily high biomass of drifting macroinvertebrates was recorded at H_M in March, when *Halesus radiatus* (Curtis) was found in the drift sampling net. Heteroptera were only numerous at the stagnant habitats; their peak abundance was recorded in July. Small individuals of Oligochaeta were rarely recorded in the drift.

At each habitat of the Drzewiczka River chironomid biomass reached a high percentage of the total macroinvertebrate density, but not of biomass (Fig. 3). Among them, orthoclad midges dominated in terms of biomass, in spite of the rather small-sized individuals constituting this subfamily. At each habitat a maximum of abundance was observed in March and May, with the highest peak at H_M (over 4000 inds. 100 m^{-3}).

Rather small individuals constitute Tanytarsini; these chironomids reached their highest density at two habitats, H_S and H_M, while the lowest one at H_R (Fig. 3).

Chironomini, typical sediment-dwelling organisms, were less numerous in drift than the mentioned above chironomid taxa (Fig. 3); the highest density of Chironomini larvae was recorded at H_S in June (over 25% of the total migrating fauna). At other habitats the larvae of this taxon also migrated mainly in June, while the peaks of pupal exuvia at each habitat were recorded in May; these data testify to the completion of the life cycle of the winter generation.

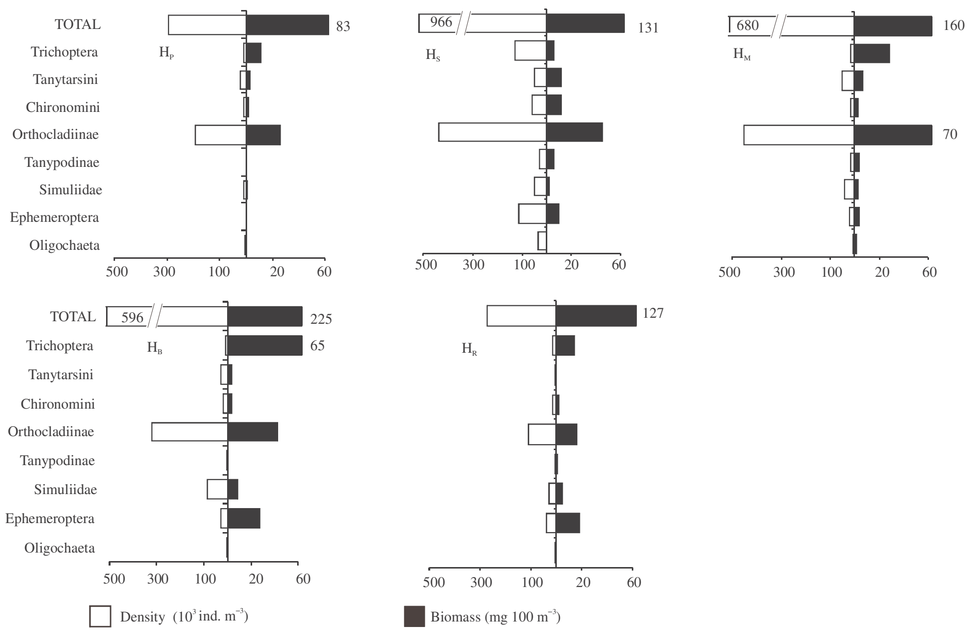

Fig. 3. Mean annual density and biomass of the main macroinvertebrate taxa in the drift at the investigated habitats (H_L) of the Drzewiczka River

Over the investigated cycle the highest frequency of occurrence of tanypod predators were recorded at the macrophyte habitat, but its highest average density and biomass were noted at the stagnant habitat (about 5% of total chironomid density and biomass). The maximum of tanypod abundance was noted at H_S in May (over 200 inds. 100 m^{-3}).

Larvae of Diamesinae and Prodiamesinae were sporadically observed; individuals of the former subfamily mainly at H_R and H_B , while of the latter one at H_M and H_B.

The Pearson "r" correlation was used to examine the relationship between abiotic parameters and the biomass of given macroinvertebrate taxa (Tab. 2). Chironomini, Tanytarsini and predatory Tanypodinae were correlated with the highest number of riverine parameters. Among environmental variables current velocity, depth and amount of benthic and transported organic matter were those that mostly determined the abundance of the dominant macroinvertebrate taxa.

A statistically significant correlation was recorded between all investigated environmental variables and total macrobenthic biomass (canonical R=0.814, test Chi^2 (128) = 161.54, P<0.024). TCPOM among riverine variables and Tanytarsini among animal variables showed the highest positive relationship with factor 1.

DISCUSSION

Macroinvertebrate drift, also called water-borne transport, is a very important mechanism in colonisation and dispersion of aquatic individuals in lotic ecosystems, thus in maintenance of lotic community structure [24]. Downstream transport of aquatic invertebrates by the current also plays a key role in energy transformation and elements cycling in the functioning of the river [2,21]. However, macroinvertebrate drift contributes little to the total mass of transported organic matter. Data from the fourth section of the Drzewiczka River are congruent with statements concerning other streams [3,20,28,37]. Nevertheless, sometimes in rivers the percentage of drift in TPOM is higher, reaching up to 6% (low order stream section in Canada [9]).

Some aquatic invertebrates are more common in the drift because of their exceptional drift abilities; they can easily enter and leave the water column [agile swimmers, 2,4,13,20,27,32]. Among insects there are Ephemeroptera, some Plecoptera and Trichoptera, and among Crustacea-Isopoda and Amphipoda. Their movement may be also interpreted in a behavioural context based upon foraging opportunities and predator avoidance. Invertebrate predators are very important in determining drift density, while fishes in determining the timing of drift [22]. In the Drzewiczka River *Baetis* and trichopterans belonged to such drift-prone macroinvertebrates. On the other hand, in the water column there were numerous invertebrates without legs, such as dipterans larvae, mainly Simuliidae and some taxa of Chironomidae. Among this last taxon Orthocladiinae constituted a significant percentage of the drift in the Drzewiczka River; mobile larvae of this subfamily were very numerous, especially in May, including both early instars (distributional drift) and old larvae, before pupation (life cycle stage). Orthoclads are known to develop behavioural drift (foraging behavioural) throughout their whole larval life [14,18,23,34,41]. In turn a low abundance of Chironomini in the drift, despite a high one in the benthos in the Drzewiczka River, may be explained by their mode of life; only small size individuals migrate to seek and colonize suitable stream bed (distributional drift), while older larvae of this taxon are already typical sediment-dwelling organisms.

The drift abundance of the Drzewiczka River occurred within the range determined in other north temperate streams [1,7]. However, the number of organisms in the water column in the Drzewiczka River during its renaturisation was higher than in the previous period of high flow fluctuations [Grzybkowska, material in prep.] and in this river of the same order but in the reach downstream where discharge was close to the natural level [17]. This phenomenon may be explained by a permanent process during the renaturisation which had a great impact on the river biota – a stepwise increase in sediment load to downstream reaches. These changes were confirmed by the values of the inorganic substrate index; as the final effect (three years after renaturisation had begun) strong decreases in SI were noted at each habitat [Szczerkowska, Tszydel, materials in prep.]. The deposition of fine sand downstream, as well as of particulate organic matter [colmatation, 10, 6], led to changes of the quality and quantity of submerged macrophytes in the Drzewiczka River [Kucharski, material in prep.], as well as to redistribution of sediment-dwelling fauna [36]. The stepwise decrease of typical riffle zoobenthos abundance concerned mainly caddies flies: both scrapers, (*Psychomyia pusilla*), and filtering collectors (Hydropsychidae) and chironomid scrapers (Orthocladiinae), while the tanypod (Chironomidae) predators sharply increased. Such an extraordinary presence of predators may testify to the macroinvertebrate assemblage in the river being in a permanent state of non-equilibrium [12].

CONCLUSION

Among the biotic factors, zoobenthos density and composition are known to influence drift rate and composition, while among environmental variables primarily sediment transport with the current velocity and channel stability were indicated by limnologists as main abiotic factors affecting the drift activity of macroinvertebrates [23]. Thus, in the Drzewiczka River permanent transport of sediment was one of the main causes of high mobility of macroinvertebrates.

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FAUNA UNOSZONA W RENATURYZOWANEJ NIZINNEJ RZECE

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S t r e s z c z e n i e. Celem badań było poznanie składu i dynamiki sezonowej dryfu w Drzewiczce w okresie jej powrotu do naturalnego przepływu, po prawie siedmiu dekadach piętrzenia i dwu dekadach funkcjonowania toru kajakowego. W pięciu dominujących siedliskach rzeki, obok obfitości dryfujących bezkręgowców szacowano parametry morfometryczne i hydrauliczne rzeki celem określenia, które z nich determinują wysokość dryfu. Makrobezkręgowce stanowiły od 0,5 do 2,3% całkowitej masy unoszonej materii organicznej. Ich stosunkowo wysokie zagęszczenie w toni wodnej (maksimum przypadało w maju 4947 osobników w 100 m^{-3} w H_M) można wyjaśnić kolmatacją. W faunie unoszonej dominowały muchówki z rodziny Chironomidae (głównie Orthocladiinae i Tanytarsini, jętki Ephemenoptera (głównie *Baetis*) oraz meszki (Simuliidae).

S ł o w a k l u c z o w e: makrobezkręgowce, dryf, Chironomidae, Trichoptera, rzeka, renaturyzacja