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Composition of ciliate fauna and its seasonal changes in fluvial drift

Biserka Primc-Habdija[1], Ivan Habdija, Milan Meštrov and Ines Radanović

Department of Zoology, Faculty of Science, University of Zagreb, Croatia

Key words: Ciliate composition, seston, discharge, fluvial drift.

ABSTRACT

Ciliate composition and its seasonal changes in seston depending on the discharge regime were analyzed in the lower rhithral area of the river Sava. Higher values for ciliate density, dry biomass, index of species diversity and concentration of particulate organic matter (POM) were associated with discharge peaks. Using the power model: $y = ax^b \pm c$ a significant positive correlation was found between POM and ciliate dry biomass (as dependent variables) and discharge (as independent variable). The ciliate drift constitutes 0.78% of the total annual POM transport. Depending on the discharge regime, the composition of ciliate drift reflects the temporal and structural changes in periphytic community.

Introduction

Seston, or living and non-living particulate organic matter (POM), is a major component in the energy transport along the river system. Recent studies have described the seasonal variations in the composition, concentration and transport of POM in relation to physical processes (Liaw and MacCrimmon, 1977; Sedell et al., 1978; Naiman and Sedell, 1979; Newbern et al., 1981; Webster and Golladay, 1984; Webster et al., 1987; Wallace et al., 1982; Angardi, 1991). These published data concentrate on the relations and interactions among fractions of different sizes in particulate organic matter (POM) and their origin with respect to hydrographic factors. From the point of view of trophic relationships, seston represents the major transportable energy base for benthic filter-feeder consumers in rivers. For example, Gislason (1985) and Morin and Peters (1988) found a strong positive correlation between the annual production of filter-feeding simulids and POM concentration. Maciolek (1966) reported that the populations of filter-feeding comsumers in Convict Creek are limited by a minimum seasonal seston concentration of about 0.5 mg dm^{-3}. Despite the numerous published data on annual fluxes of seston constituents, there is no clear picture of the concentration and composition of living seston components. From a trophic point of view, it is important to determine the amount contributed by each of the living seston constituents. However, there are no methods available to separate POM into living and non-living components for direct biomass determination. The determination of living seston material is possible only by analyzing plant and animal taxonomic groups separately by microscopic counts.

It is clear that in rhithral areas the living seston components originate from the benthic communities. For this reason the composition of seston fauna depends qualitatively and quantitatively upon the biocenotic spectrum of the microbenthic community as well as upon the discharge and its effect on particle drift through erosion. In the periphytic community, Bick et al. (1975) and Schönborn (1982) found that ciliate density decreases with an increase in current velocity.

In a detailed study Stössel (1987) analyzed the direct and indirect influence of discharge on the periphytic ciliate community. As well as describing the indirect effect (dilution of organic loading, sedimentation, bacterial density affected by discharge and time point of sampling after discharge peak), he emphasized that the vagile ciliates were much more susceptible to discharge fluctuation than were the sessile peritrichids.

The purpose of this study is to present the seasonal variations in the concentration and composition of ciliated protozoans in the seston at three sample sites located in the lower rhithral area of the river Sava. The faunistic structure, abundance, the Shannon-Weaver index, Sørensen's index and trophic structure parameters were used for the biocenotic characterization of seston ciliates. It has been hypothesized that seston structure and ciliate abundance in the lower rhithral area depend both upon discharge fluctuation and the qualitative and the quantitative structure of ciliates in the benthic community.

Methods

Seston samples were collected at monthly intervals during 1992 from each of three sites (S1, S2, S3) located in the lower rhithral area of the river Sava. Samples were taken from the main current with a 5-l Van Dorn bottle. Three replicate 200 ml samples from the water bottle were preserved with 8.6 ml of a saturated solution of $HgCl_2$, and stained with a drop of 0.04% bromophenol blue (Pace and Orcutt, 1981). The remnant portion of the water bottle sample was used for the analysis of suspended matter (SM) and particulate organic matter (POM).

Each of three preserved replicate 200-ml samples was concentrated by settling to 20 ml. After a period of storage, the supernatant was removed and five 2-ml samples were analyzed in a Sedgwick-Rafter chamber with an OPTON M 35 inverted microscope at 100 × magnification. For each month and for each of three sites, the actual ciliate population density (Ind. l^{-1}) was calculated as the mean of 15 2-ml subsamples (3 replicate 200-ml samples × 5–2 ml subsamples). Total counts generally exceeded 100 individuals for each sample; therefore, 95% confidence limits for single counts were ± 20 or less. For the reason that the differences in actual monthly population density among three sites were not significant, the interpretation of seasonal changes of ciliate density is based upon the mean of three sites.

Ciliate volumes were estimated by geometric approximation and their biomass was calculated by applying a conservative conversion factor of 0.279 pg dry biomass per 1 μm^3 cell volume (Gates et al., 1982). The dry mass values were converted to energy units using the conversion value of 21.15 J per 1 mg dry mass, which is an average of the values given by Finlay and Uhlig (1981) for *Tetrahymena pyriformis*.

Most ciliates were identified to species and in some cases to genus or family with the aid of standard identification keys: Kahl (1930–1935), Bick (1972), Corliss (1979), Curds (1982) and Curds et al. (1983). When necessary, the samples were prepared for microscopical examination with a silver-staining method (Foissner, 1982). Information concerning food habits was taken from literature reports (Kahl, 1930–1935; Bick, 1972; Corliss, 1979; Fenchel and Jørgensen, 1977; Taylor, 1979; Pratt and Cairns, 1985) or from our own observations.

Discharge was measured at a limnograph serviced by a nuclear power plant (Fig. 1). Suspended matter (SM) was measured (weekly) after drying at 80 °C for 24 hours. Particulate organic matter (POM), including coarse, fine and ultrafine particulate organic matter (CPOM, >1 mm; FPOM, 50 μm–1 mm; UPOM, 0.5–50 μm), was determined (once monthly) by filtering samples of river water through tared Whatman GF/C glass filter (porosity = 0.5 μm) and by dry combustion at 550 °C for 4 hrs. Each glass filter was corrected by a factor of 0.8 mg for each sample due to loss of filter mass during combustion (Golterman, 1969). Monthly values of POM were expressed as g dry mass per m^3. Dry mass POM values were converted to energy units using the conversion factor of 19.65 KJ per 1 g POM dry mass (Habdija, 1987). Analysis of variance showed that the differences among sites were not significant and for this reason the interpretation of seasonal changes of POM is based upon the actual monthly values calculated as a mean of the three sites in the investigated area.

The similarity coefficient according to Sørensen (1948) was used to determine the degree of correspondence between ciliate composition in the seston and periphytic communities. Diversity of ciliate seston was calculated by the Shannon diversity index (H') according to Shannon and Weaver (1949).

In regression estimates the power model $y = ax^b + c$ was used to evaluate the association between discharge regime (as independent variable) and concentration of particulate organic matter, suspended matter and ciliate dry biomass (as dependent variables). The index of correlation $R^2 = 1 - \Sigma (Y_i - Y_0)^2 / \Sigma (Y_i - Y)^2$, where Y_i is the dependent variable, Y_0 is predicted value and Y its mean, was used to evaluate the fit of the regression model and ANOVA to evaluate the level of significance.

Description of sites studied

The study was undertaken at three sites (S1, S2 and S3) on the river Sava in the zone situated in Slovenia near the boundary between Croatia and Slovenia. The river Sava has its source in the Julian Alps and flows into the Danube (Fig. 1). The investigated section, located in the lower rhithral area, comprises a length of 15 km

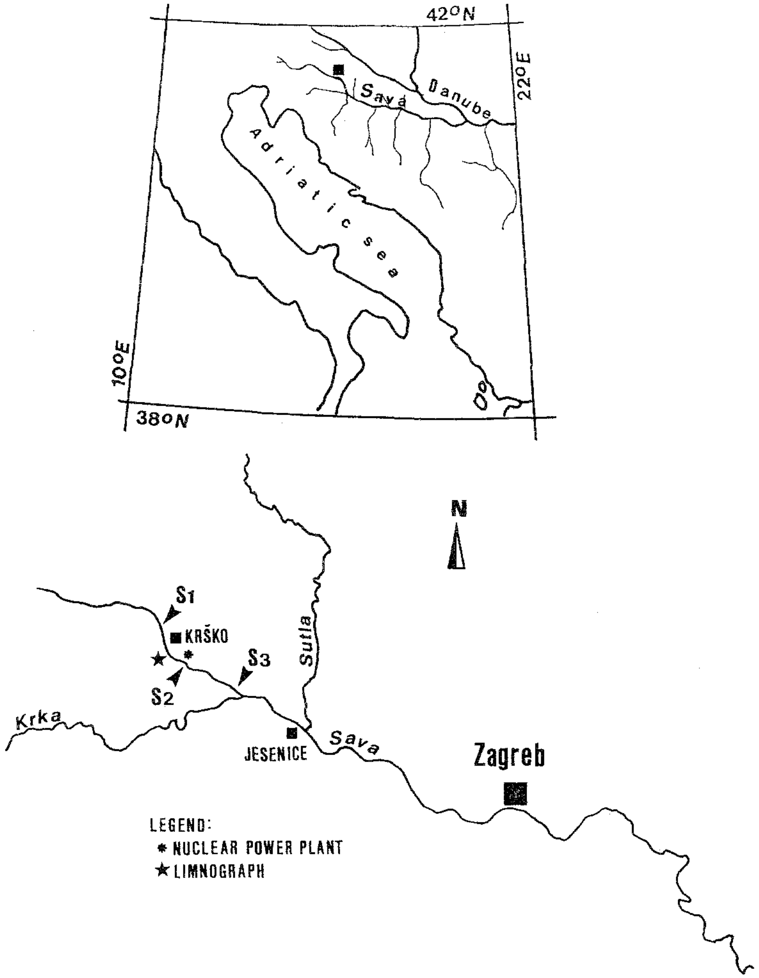

Figure 1. Position of sampling sites along the river Sava

approximately. The river bottom at the investigated sites is characterized by a substrate of large pebbles covered with periphyton and with sandy sediment in lenitic areas.

In the upper course, the river flows over a calcareous bed and in the middle and lower courses over alluvium. From the hydrological point of view, in the upper course the river Sava has a nival-pluvial regime, characterized by spring and autumn discharge peaks (Fig. 2). The flow record shows four hydrological profiles:

- the summer and winter low flow periods characterized by a mean monthly discharge from 51 to 98.9 $m^3 s^{-1}$,
- the spring and autumn high flow periods with a mean monthly discharge range from 98.9 $m^3 s^{-1}$ to 566 $m^3 s^{-1}$.

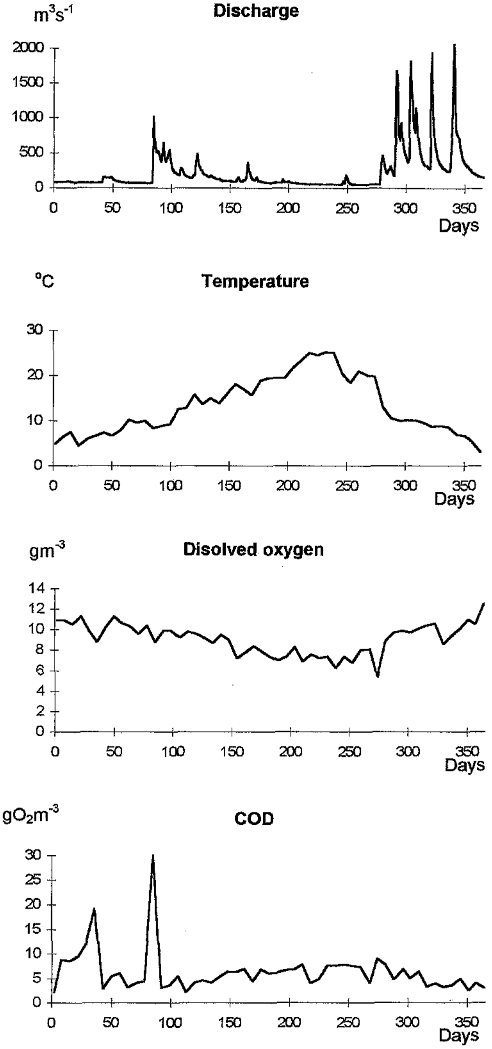

Figure 2. Seasonal discharge (Q) fluctuation (daily mean), temperature of water (weekly analysis), dissolved O_2 (weekly analysis) and COD (weekly analysis), measured at site S3

The minimal daily discharge value of 46 $m^3 s^{-1}$ was found at the beginning of September. The maximum daily discharge of 2358 $m^3 s^{-1}$ was in December.

At three sites the annual water temperature cycle can be divided as follows: spring and autumn temperatures between 10 °C and 15 °C, winter temperature below 10 °C, and summer temperature from 15 °C to 25 °C (Fig. 2).

Seasonal dissolved oxygen changes are related to water temperature and organic load. The maximal values (>10 g m^{-3}) were recorded in the winter period and the minimum (< 6 g m^{-3}) in the late summer period (Fig. 2).

COD (chemical oxygen demand by permanganate), as the measure of organic load, ranged from 2.2 to 10 g O_2 m^{-3} except two peaks in February and March (Fig. 2). The annual mean amounts to 6.26 ± 4.32 g O_2 m^{-3} (n = 156, 3 sites × 52 weekly analysis).

According to the saprobiological characteristics of benthic communities described by Meštrov et al. (1976) and Habdija et al. (1984), the section of the river studied can be classified in the mesosaprobic zone.

Results

The annual cycle of suspended matter concentration (SM) for the study period can be associated with the discharge regime (Fig. 3). The SM concentration peaks correspond with the spring and autumn discharge peaks. Based on the weekly measurements at three sites during the whole year, the annual mean amounts to 40.26 g m^{-3} ± 115. Maximum concentration of 805 g m^{-3} was recorded in March and minimum of 2 g m^{-3} in January. From April to September (more than 50% of data) SM concentration ranged below 20 g m^{-3}.

During the study period the actual monthly POM concentrations at three sites ranged from 2.7 to 39 g m^{-3}. Monthly peaks of POM correspond with discharge and SM peaks (Fig. 3). It is questionable whether correspondence between the discharge peaks and the peaks of SM and POM also indicates a significant correlation between these variables. With a view to defining the level of correlation, regression equations and an index of correlation (R^2) were calculated using the model: $y = ax^b \pm c$. Analysis of variance was used to test the level of significance. As shown in Fig. 4 the SM concentration, measured every month at three sites, correlated with discharge in the range from 50 m^3 s^{-1} to 500 m^3 s^{-1}. In the same range, POM showed a good correlation with discharge too. From an analysis of the course of presented regression curves in Fig. 4 it can be concluded that the percentage of POM in the total SM concentration decreases with an increase of discharge.

In seston samples collected at three sites located in the study section of the river Sava the ciliate density varied from 1.7×10^6 to 5.5×10^6 Ind. m^{-3} and the ciliate biomass from 7 to 43 mg m^{-3} (Fig. 5). From an analysis of the organic matter in running waters, the fact that the ciliate biomass, as a living seston component, is included in different size-fractions of particulate organic matter (POM) must be borne in mind. For this reason, it is presumed that ciliate density and biomass concentration in seston will depend upon the annual discharge fluctuations. As shown in Figs. 3 and 5, the anual POM fluctuation, ciliate density and biomass curves correspond with annual discharge changes. Ciliate density and biomass are represented as an average of three sampling sites for each month (n = 12) correlated against average daily discharge.

The temporal distribution of ciliate density and biomass suggests that the discharge regime may influence their seasonal fluctuation (Fig. 5). The spring and autumn ciliate density and biomass peaks were related to the discharge peaks. The low ciliate concentrations in summer were associated with minimum flows. In the autumn hydrological situation, characterized by an increase in discharge, the ciliate concentration in seston is significant higher than in the summer period. The ciliate

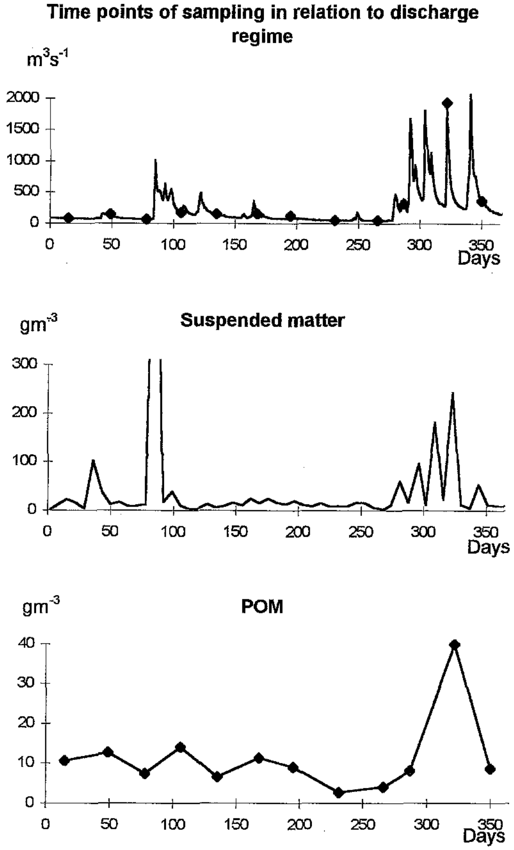

Figure 3. Seasonal fluctuation of suspended matter (weekly analysis at site S3) and particulate organic matter (POM) represented as mean of actual monthly values at three sites in relation to discharge regime

density peak came at the beginning of the autumn high discharge period, and the ciliate biomass peak conforms with the maximal discharge value of 1938 m^3 s^{-1}.

The percentage of ciliate dry bimass in total POM varied from 0.037% to 0.38% with a mean of 0.26% ± 0.09 (n = 36). As shown in Fig. 5 the peaks of percentage ciliate biomass in the total POM do not correspond with the density and biomass peaks. In general, the higher ciliate biomass conforms with a decrease of its percentage in the total POM mass.

The main question was how ciliate density and ciliate dry biomass correspond with discharge. By use of the model: $y = ax^b \pm c$ the calculated population density per volume unit did not correlated with mean daily discharge significantly ($n = 36$, $R^2 = 0.24$, $P > 0.05$). Using the same model a better correlation was found between the ciliate dry biomass and mean daily discharge (Fig. 6).

The relationship between ciliate dry biomass and POM concentration (Fig. 7) indicates a good correlation.

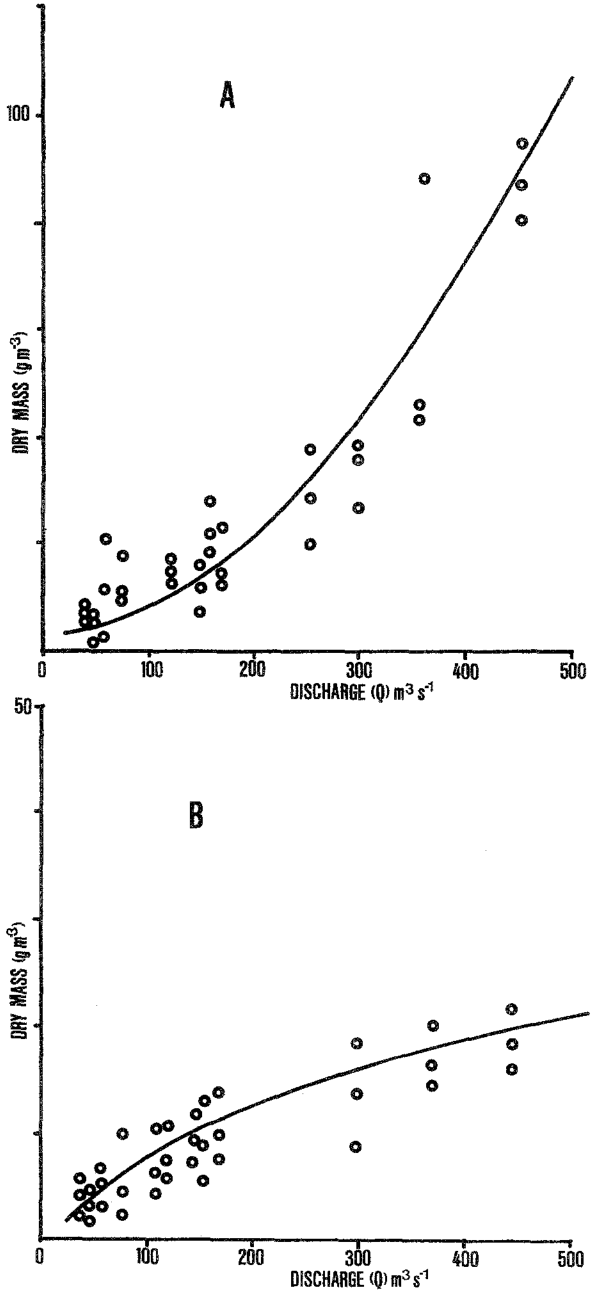

Figure 4. Concentration of suspended matter (SM) and particulate organic matter (POM) as a function of discharge (Q), calculated as 12 actual monthly values at three sites against daily mean discharge. **(A)** Regression equation: $SM = 9.54 \times 10^{-4}\ Q^{1.87} + 3.74$; $R^2 = 0.978$; ANOVA: $F > F_0$, df. 3.33, $P < 0.05$, $n = 36$. **(B)** Regression equation: $POM = 6.73\ Q^{0.27} - 15$; $R^2 = 0.966$; ANOVA: $F > F_0$, df. 3.33, $P < 0.05$, $n = 36$

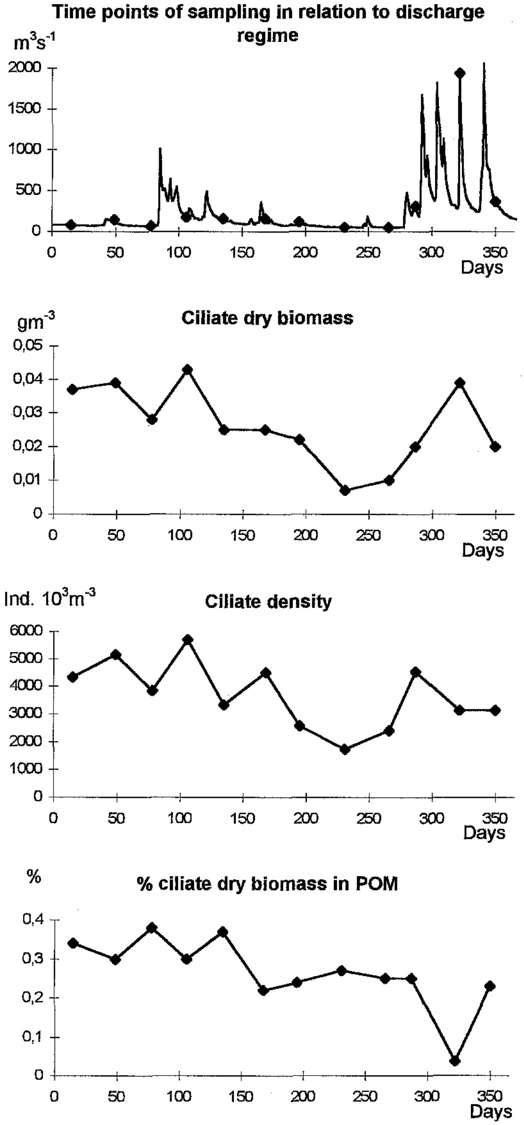

Figure 5. Seasonal fluctuation of ciliate dry biomass, density and percentage of ciliate dry biomass in the total POM (represented as mean of actual monthly values at three sites) dependent on mean daily discharge

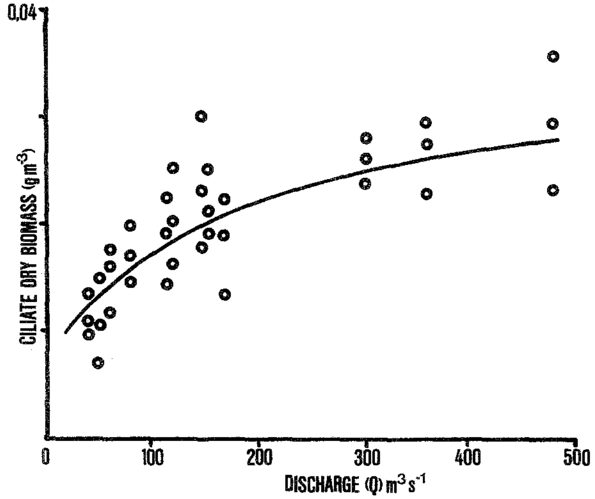

Figure 6. Ciliate dry biomass (calculated as mean of actual monthly values at three sites) as a function of mean daily discharge (Q). Regression equation: Ciliate dry biomass = 0,035 $Q^{0.106}$–0.039; $R^2 = 0.62$; ANOVA: $F > F_0$, df. = 3.33, $P < 0.05$, n = 36

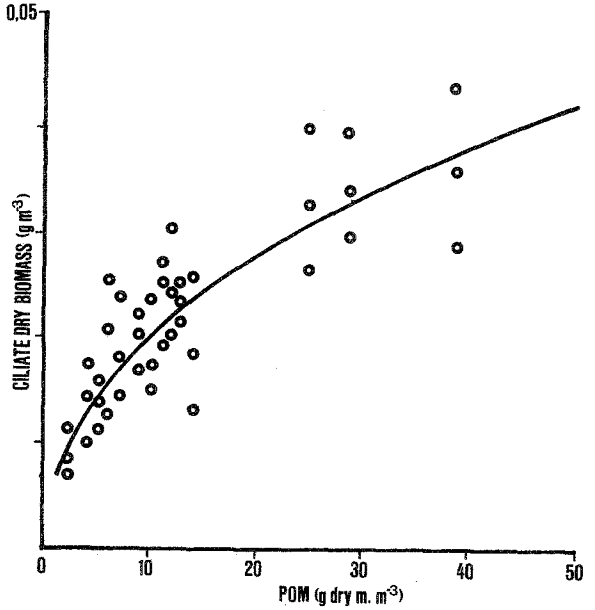

Figure 7. Ciliate dry biomass as a function of POM (calculated as mean of 12 actual monthly values at three sites). Regression equation: Ciliate dry biomass = 0,074 $POM^{0.11}$ – 0.074; $R^2 = 0.62$; ANOVA: $F > F_0$, df. = 3.33, $P < 0.05$, n = 36

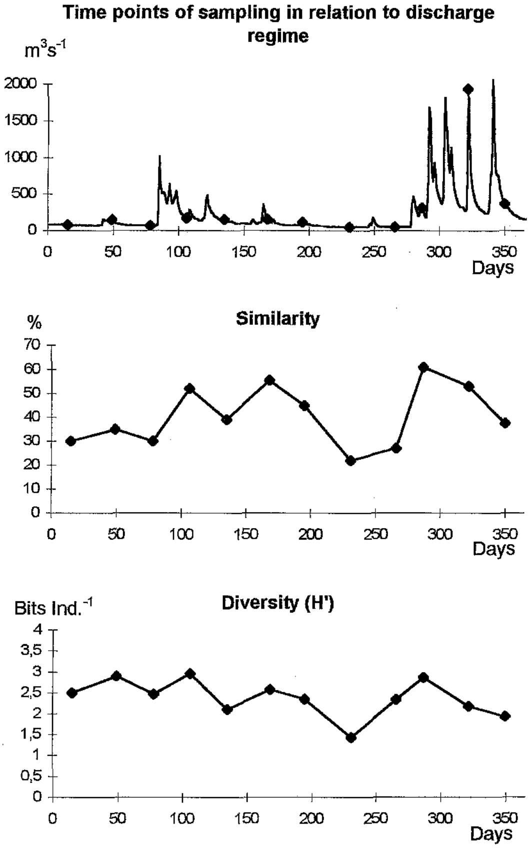

Figure 8. Seasonal fluctuation of ciliate diversity (H') in seston and similarity (S_s) between ciliate composition in fluvial drift and periphyton (calculated as mean of actual monthly values at three sites) in relation to discharge (Q)

In general, in the upper river sections, seston ciliates are river drift of predominantly benthic origin. This means that the composition and abundance of ciliates in the seston reflect temporal and structural changes in the microbenthic communities. On the other hand, the biocenotic parameters of ciliate community in seston depend upon the discharge, but also upon ciliate cell size. In addition, the ratio between sessile and vagile ciliates in seston depends significantly upon the flow rate. These statements are in line with the index of similarity (S_s), index of general diversity (H') and ciliate composition. As shown in Fig. 8, Sørensen's index of similarity (S_s) between ciliate compositon in seston and periphyton varies from 0.22 to 0.61. Higher values of simialrity correspond with discharge peaks. The minimal S_s was established in the summer period with a constant low mean discharge of below 100 m^3 s^{-1}. In addition, the Shannon diversity index (H') of the ciliate seston community also shows a correspondence with discharge peaks (Fig. 8). This suggests that an increase of discharge results in a higher ciliate drift, of which the consequence is the increased qualitative and quantitative abundance of periphytic ciliates in seston.

Information on seasonal changes of seston ciliate populations, as a mean of 3 sites (S1, S2, S3) and 3 replicate samples (n = 9) for each month is presented in Fig. 9. Species seldom found, together with those found in low abundance, as well as species which could not be determined are assembled into genera or higher taxonomic groups. The genus *Litonotus* comprises the species *L. fusidens*, *L. fasciola* and *L. lamella*. Three species: *V. campanula*, *V. convallaria* and *V. microstoma* are included in genus *Vorticella*. The family Oxytrichidae comprises 3 nondetermined species. The taxon *Strombidium* is represented by the well known species *S. humile* and by one nondetermined species.

In the interpretation of seston ciliate composition 36 taxa were taken into consideration. In general, it can be concluded that *Trochila minuta*, *Trachelophyllum pusilum*, *Uromena marinum*, *Vorticella* and *Cyclidium* species were found in the course of all four seasons. The other species were distributed only in one season or infrequently in two or three seasons. Taking into consideration the influence of discharge it was observed that the abundance of peritrichous ciliate increased in the samples collected in February at the time of a small discharge peak. The spring period was characterized by a higher discharge regime. Three seston samples were taken at intervales after peak discharge: in April, 10 days; in May, 20 days and in June, 2 days after peak discharge. In April and May the bacteriovorous peritrichids and hymenostomatids showed a higher abundance. This suggests that the concentrations of seston ciliates depend upon the time distance of sampling from the discharge peak.

With respect to ciliate composition a similar situation was found in the summer period, which was characterized by a general decrease in discharge, with two small peaks. In samples collected in August (35 days after a small discharge peak), only 5 ciliate species were found. As the representatives of the lowest size-class, *Trochilia minuta* and *Cyclidium* species were dominant. In September, at a sampling time 15 days after peak discharge, the number of species and their population densities increased again.

From the hydrological point of view, the autumn period was characterized by a constant high discharge with a maximum of 2251 $m^3 s^{-1}$. From the beginning of the autumn period to the end of December, the number of species and their concentration in seston decreased, which can be explained by the constant erosion effect, over a longer period, on the periphytic community, with its consequent faunal improverishment. In general, the dominant species were *Trachelophyllum pusillum*, *Trochilla minuta*, *Cyclidium* and *Vorticella*. They constituted approximately 60% of the total ciliate density.

As shown in Table 1 during the whole year the actual monthly density of bacterivorous ciliates constitutes the greatest percentage of the total abundance ($\bar{x} = 55.6\% \pm 11.3$, n = 12). In general, the bacteriovorous ciliate maxima correspond with the discharge peaks.

Algivorous and carnivorous species were represented by equal percentages (16.9%) of the total. It is important to emphasize that an increase of algivores was found in the summer period. The percentage of omnivorous ciliates ranged from 2.1 to 18% ($\bar{x} = 10.4\% \pm 7.6$) of the total.

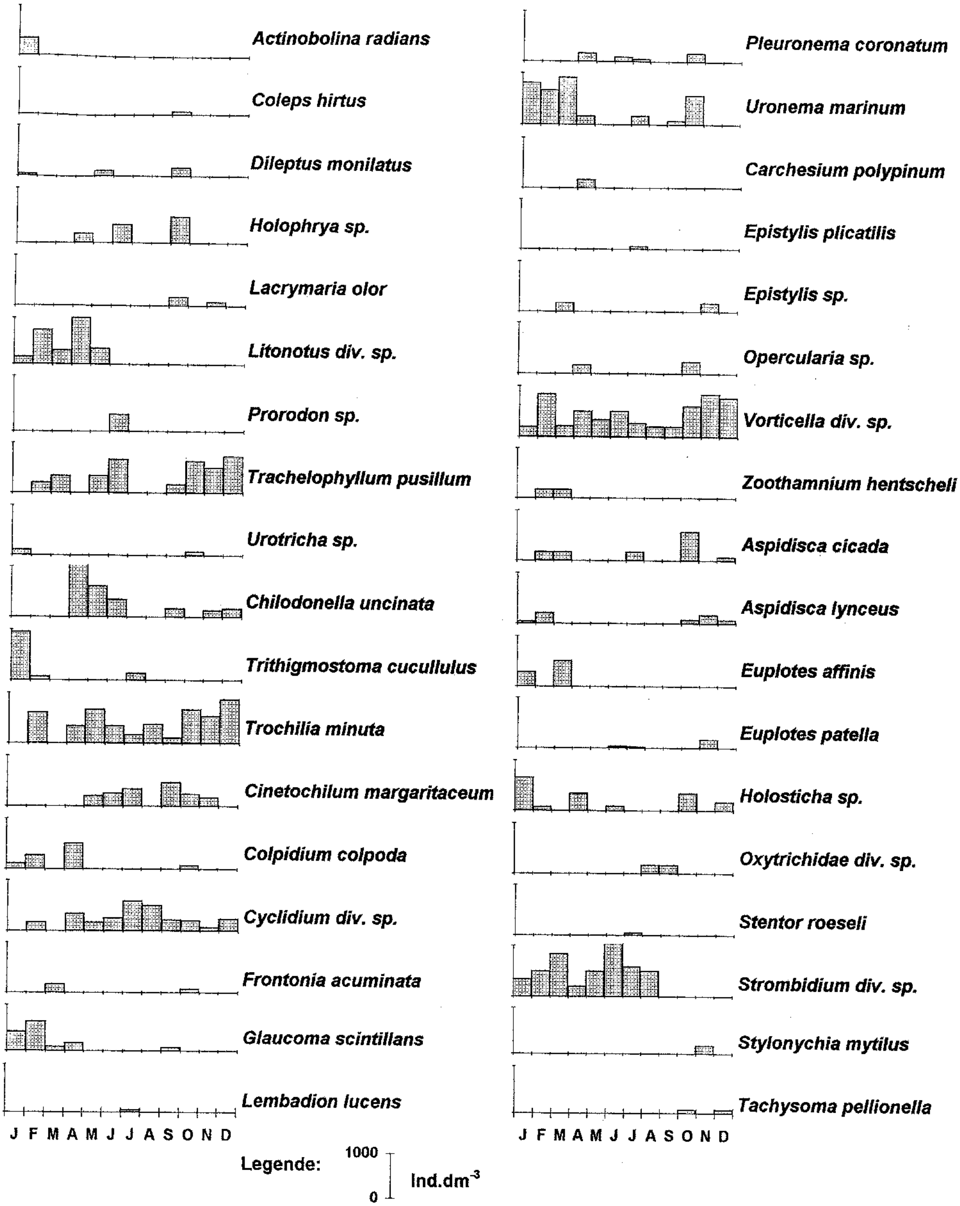

Figure 9. Composition and population density of the most abundant ciliates and their seasonal changes calculated as mean of actual monthly values at three sites (Ind. l^{-1})

Table 1. Trophic composition of seston ciliate drift (calculated as mean of actual monthly values at three sites).

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Total density Ind. · $10^3 \cdot m^{-3}$	4350	5428	3663	5396	3231	4494	2490	1733	2501	2396	2962	3132
Trophic groups												
Bacteriovores (%)	33.0	66.2	42.0	59.2	60.8	43.4	55.0	51.6	51.3	66.1	69.7	69.2
Algivores (%)	22.6	10.4	22.7	12.9	15.5	34.5	32.5	23.9	19.9	9.2	4.0	5.3
Omnivores (%)	32.7	6.1	18.2	9.3	9.5	7.3	6.5	9.5	9.2	7.3	7.2	2.1
Carnivores (%)	12.0	17.2	7.1	18.5	14.1	14.8	15.0	15.0	20.1	17.4	19.1	23.4

Discussion and conclusions

During the study period 53 ciliate taxa were found in seston in the lower rhithral area of the river Sava. The ciliate density ranged from 1700 to 5500 Ind. l^{-1}. This range is significantly higher than the values reported by Nosek et al. (1982) and lower than the ciliate density established by Gracia et al. (1989).

In this study, an analysis was made of the seasonal variation of the concentration and composition of sestonic ciliates in relation to the discharge regime. Depending on the discharge and its erosion effect, the ciliate compositon and its seasonal variation in seston are the reflection of the biocenotic spectrum of the periphytic community. On the other hand, the discharge effect on the periphyton ciliate community and its drift, as reported by Stössel (1987), is mediated by direct and indirect mechanisms.

Since ciliate fauna forms a component of POM, it was presumed that its seasonal changes in abundance and composition will be dependent upon discharge. From this study, it is evident that the monthly peaks of SM and POM concentrations do correspond with discharge peaks. In addition, a significant correlation between these variables was found using the power model: $POM = aQ^b \pm c$. This correlation can be explained by the fact that the monthly analysis of POM was carried out during a relatively stable discharge regime of below 350 $m^3 s^{-1}$, except during the autumn period. In general, the attempts to relate POM concentration to discharge have been unsuccessful (Sedell et al., 1978; Naiman and Sedell, 1979). Other authors have shown a good correlation between flow and POM concentration during seasons of normally high flow (Weber and Moore, 1967; Liaw and MacCrimmon, 1977). For the upper Mississippi River Grubaugh and Anderson (1989) reported that FPOM, as a seston component, is highly dependent upon discharge. As pointed out by Bilby and Likens (1979), POM concentration is dependent on whether samples are collected in rising, falling, or stable discharge regimes, as well as the interval between the discharge peak and the sampling time. In general, these disagreements arise from the many difficulties in interpreting available data and from broad theories concerning detrital dynamics (Newbern et al., 1981). In this study, the ciliate drift was taken as a living component of POM, and for this reason there was an attempt to find a correlation between ciliate concentration in seston and actual discharge. Regression analysis, by use of the model $y = ax^b \pm c$, shows that the ciliate density does not correlate with daily mean discharge. On the other hand, the ciliate dry biomass showed a relatively good positive correlation with discharge. This results from:

- at discharge peaks, the sessile petrichids with higher mass, constituting over 50% of the total ciliate biomass, were more abundant in seston than the smaller forms;
- erosion effect is selective on ciliate drift, influencing the higher abundance of sessile ciliates with higher biomass at the time of discharge peaks.

Stössel (1987) reported that short high water peaks hardly affect the peritrichous fauna, althoughh over a large period of a high discharge regime the crop was reduced. This hypothesis is supported by the analysis of index similarity (S_s) and index of general species divesity (H'). The correspondence between the discharge peaks, higher species diversity of sestonic ciliates and their similarity relating to periphytic ciliate composition can also be explained by the erosion effect. The higher ciliate drift results in higher ciliate similarity between seston and periphyton. In addition, the index of species diversity of the sestonic ciliates ranged from 1.5 to 3 bits $Ind.^{-1}$. In the periphytic community at investigated sites, the ciliate diversity is over 3 bits $Ind.^{-1}$ approximately (Primc Habdija et al., in press). This suggest that the seston community is more unstable than the periphyton.

The seasonal cycle in sestonic ciliate composition were characterized by the dominance of five taxa (*Trachelophyllum pusillum*, *Trochilia minuta*, *Uronema marinum*, *Cyclidium* and *Vorticella* species) in the course of all four seasons. Other species were distributed only in one season or infrequently in two or three seasons. Other studies of ciliated protozoan communities in fluvial ecosystem report on constantly appearing species (Nosek et al., 1982; Gracia et al., 1989), but the composition of the defined dominant species is very different.

In the spring period, characterized by a higher discharge regime, the composition and concentration of sestonic ciliates depend upon the time between sampling and the discharge peaks. In addition, in the autumn period the ciliate density in seston decreased in consequence of the erosion effect, over a longer period, on the periphytic community and its faunal impoverishment (sensu Stössel, 1987).

Considering the trophic importance of ciliates in riverine drift, it was attempted to establish their percentage in total POM transport. Taking into consideration the mean monthly discharge and POM concentrations calculated according to the given regression equation $POM = 6.73\ Q^{0.27} - 15$, the annual transport of POM mass amounts 136.36×10^9 g, and 2.67×10^{15} J respectively. The same calculation was carried out for the annual transport of ciliate dry biomass. Yearly, a ciliate biomass of 1.07×10^9 g, and 22.6×10^{12} J respectively was transported through the investigated section. This means that the ciliate biomass constituted 0.78% of the total POM transport. Schumann et al. (1992) reported that the ciliates constitute 2% of the total plankton fresh biomass. Despite the low percentage of ciliate biomass in the total POM transport, the transport of 22.6×10^{12} J is a large amount of energy fixed to the ciliate biomass transported along the river.

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REFERENCES

Angardi, T. R., 1991. Transport of coarse particulate organic matter in an Idaho river, USA. Hydrobiologia 211:171–183.

Bick, H., 1972. Ciliated protozoa. An illustrated guide to the species used as biological indicators in freshwater biology. WHO, Geneva, 198 pp.

Bick, H., K H. Christmann and W. Schmerenbeck, 1975. Untersuchungen über den Einfluss der Strömungsgeschwindigkeit auf die Aufwuchsentwicklung in Modellgewässern. Forschungsberichte des Landes Nordrhein-Westfalen 2498:1–38.

Bilby, R. E. and G. E. Likens, 1979. Importance of organic dams in the structure and function of stream ecosystems. Ecology 6:1107–1113.

Corliss, J. O., 1979. The ciliated protozoa: characterization, classification, and guide to the literature, Pergamon Press, Oxford, 455 pp.

Curds, C. R., 1982. British and other freshwater ciliated protozoa. Part I. Ciliophora: Kinetofragminophora. Cambridge University Press, Cambridge, 387 pp.

Curds, C. R., M. A. Gates and D. McL. Roberts, 1983. British and other freshwater ciliated protozoa. Part II. Ciliophora: Oligohymenophora and Polyhymenophora. Cambridge University Press, Cambridge, 474 pp.

Fenchel, T. and B. Jørgensen, 1977. Detritus food chains of aquatic ecosystems: the role of bacteria. In: M. Alexander (ed.), Advances in microbial ecology, Vol. I. Plenum Press: 1–58.

Finlay, B. J. and G. Uhlig, 1981. Calorific and carbon values of marine and freshwater Protozoa. Helgolaender Meeresunters. 34:401–412.

Foissner, W., 1982. Ciliaten als Leitformen der Wasserqualität – aktuelle Probleme aus taxonomischer Sicht. Decheniana-Beihefte (Bonn) 26:105–110.

Gates, M. A., A. Rogerson and T. Berger, 1982. Dry to wet weight biomass conversion constant for *Tetrahymena elliotti* (Ciliophora, Protozoa). Oecologia 55:145–148.

Gislason, G. M., 1985. The life cycle and production of *Simulium vittatum* Zett. in the River Laxa, northest Iceland. Int. Ver. Theor. Angew. Limnol. Verh. 22:3281–3287.

Golterman, H. L., 1969. Methods of chemical analysis of freshwater. IBP Handbook no. 8, Blackwell Scientific Publ., London, 398 pp.

Gracia, P., C. Castellon and R. Sunyer, 1989. Ciliated protozoan communities in a fluvial ecosystem. Hydrobiologia 183:11–31.

Grubaugh, J. W. and R. V. Anderson, 1989. Upper Mississippi River: seasonal and floodplain forest influences on organic matter transport. Hydrobiologia 174:235–244.

Habdija, I., 1987. Untersuchung des Sestons in der Save unter trophischen und energetischen Gesichtspunkten. IAD 26:362–365.

Habdija, I., I. Matoničkin and B. Primc, 1984. Makrozoobenthos als Indikator der Wassergüte in oberem und mittlerem Lauf des Flusses Sava. IAD 24:151–155.

Kahl, A., 1930–1935. Urtiere oder Protozoa. I: Wimpertiere oder Ciliata (Infusoria). In: Dahl, F.: Die Tierwelt Deutschlands, G. Fischer, Jena, 886 pp.

Liaw, W. K. and H. R. MacCrimmon, 1977. Assessment of particulate organic matter in river water. Int. Revue ges. Hydrobiol. 62:445–463.

Maciolek, J. A., 1966. Abundance and character of microseston in a California mountain stream. Verh. Internat. Verein. Limnol. 16:639–645.

Meštrov, M., I. Dešković and V. Tavčar, 1976. Pollution of the river Sava – According to the several years' ecological researches (in Croatian). Ekologija 13:61–79.

Morin, A. and R. H. Peters, 1988. Effect of microhabitat features, seston quality, and periphyton on abundance of overwintering black fly larvae in southern Quebec. Limnol. Oceanogr. 33:431–446.

Naiman, R. J. and J. R. Sedell, 1979. Characterization of particulate organic matter transported by some Cascade Mountain streams. J. Fish. Res. Bd Can. 36:17–31.

Newbern, L. A., J. R. Webster, E. F. Benfield and J. H. Kennedy, 1981. Organic matter transport in an Appalachian Mountain river in Virginia, U.S.A. Hydrobiologia 83:73–83.

Nosek, J. N., M. Cs. Bereczky and N. Oertel, 1982. Die Tiefenschichtung des Protozoenplanktons in der Donau. IAD 23:116–119.

Pace, M. L. and J. D. Orcutt jr., 1981. The relative importance of protozoans, rotifers, and crustaceans in a freshwater zooplankton community. Limnol. Oceanogr. 26:822–830.

Pratt, J. R. and J. Cairns jr., 1985. Functional groups in the protozoa: Roles in differing ecosystems. J. Protozool. 32:415–423.

Primc-Habdija, B., I. Habdija and I. Radanović, in press: Seasonal changes in trophic structure of periphytic ciliates in relation to discharge regime, Verh. Internat. Verein. Limnol.

Schönborn, W., 1982. Die Ziliatenproduktion in der mittleren Saale. Limnologica (Berlin) 14: 329–346.

Schumann, R., C. Sievert and U. Schiewer, 1992. Structural composition of pelagic communities in the river Warnow and their changes. Int. Revue ges. Hydrobiol. 77:173–185.

Sedell, J. R., R. J. Naiman, K. W. Cummins, G. W. Minshal and R. L. Vannote, 1978. Transport of particulate organic material in streams as a function of physical processes. Verh. Internat. Verein. Limnol. 20:1366–1375.

Shannon, C. E. and W. Weaver, 1949. The mathematical theory of communications. University of Illinois Press, Urbana, 117 pp.

Sørensen, T., 1948. A method of establishing groupes of equal amplitude in plant sociology on similarity of species content and its application to analyses of the vegetation on Danish commons. Vid. Selsk. Biol. 4:1–34.

Stössel, F., 1987. Effect of the coefficients of discharge on ciliate populations of a running water contaminated by municipal wastewater. Arch. Hydrobiol. 108:483–497.

Taylor, W. D., 1979. Sampling data on the bacteriovorous ciliates of a small pond compared to neutral models of community structure. Ecology 60:876–883.

Wallace, J. B., D. H. Ross and J. L. Meyer, 1982. Seston and dissolved organic carbon dynamics in a southern Appalachian stream. Ecology 63:824–838.

Weber, C. I. and D. R. Moore, 1967. Phytoplankton, seston and dissolved organic carbon in the Little Miami River at Cincinnati, Ohio. Limnol. Oceanogr. 12:311–318.

Webster, J. R. and S. W. Golladay, 1984. Seston transport in streams at Coweeta Hydrologic Laboratory, North Carolina, U.S.A. Verh. Int. Ver. Limnol. 22:1911–1919.

Webster, J. R., E. F. Benfield, S. W. Golladay, B. H. Hill, L. E. Hornick, R. F. Kazmierczak jr. and W. B. Perry, 1987. Experimental studies of physical factors affecting seston transport in streams. Limnol. Oceanogr. 32:848–863.

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