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Effect of current velocity on diatom colonization on glass slides in unpolluted headwater creek

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Abstract

Background and Purpose: *The goal of this study was to determine the effect of current velocity on diatom colonization rate during the first 30 days of artificial substrate (glass slides) exposure.*

Materials and Methods: *From autumn 1990 to summer 1993 artificial substrates were submerged in an unpolluted mountain stream. The parallel oriented glass slides (against the surface) were placed 10 cm beneath the water surface (protected from debris) and exposed to different current velocities (10–30 cm* s^{-1}*, 40–60 cm* s^{-1} *and 80–100 cm* s^{-1}*). The samples were collected seasonally. To define diatom colonization, a nonlinear regressive analysis of empirical data was performed.*

Results: *A total of 71 diatom species were found. Species* Cocconeis placentula, Surirella ovata, Gomphonema olivaceum*, and* Navicula gracilis *were the most abundant, depending on different current velocity.*

Conclusions: *The time needed for reaching the equilibrium progressively increased with the current velocity (*$F= 16.7; P< 0.01$*). In the summer and autumn, the time needed for the stabilization of diatom flora was longer than in spring and winter. Concerning species abundance,* Cocconeis placentula*, and* Navicula gracilis *were independent of the current velocity, while* Surirella ovata *was abundant at lower (]30 cm* s^{-1}*) and* Gomphonema olivaceum *at higher (]60 cm* s^{-1}*) current velocities.*

INTRODUCTION

Periphyton, with phytoplankton and marcophytic vegetation, is important as energy base in lotic ecosystems *(1, 2, 3)*. Some studies on microdistribution of freshwater periphyton were primarily concerned with the epiphytic algae growing on macrophytes *(4, 5, 6),* but some also examined local distribution on rocks and artificial substrates *(7, 8, 9, 10)*.

Algal flora is an important component of the lotic ecosystem and is essential for the understanding of stream ecology. The studies of Gessner *(11),* Blum *(12)* and Backhaus *(13)* imply that water movements are responsible for microdistribution of epilithic algae in streams but they do not explain how current acts to create the observed preferences. Theoretical fluid mechanics can explain the way current influences periphytic algal communities. Horizontal surfaces are under the influence of rather stable, laminar flow while a thin layer of water was stationary in contact with surface, with a relatively small area exposed to the turbulent flow, all depending on current velocity *(14)*. The greater the current velocity, the thinner the stationary layer and the larger the area exposed to the turbulent flow. Some studies, especially those conducted in lakes, employed vertical orientation to restrict colonization to true periphytic species due to reduction of detritus and settled plankton species accumulation *(10, 15)*.

According to Zimmermann *(16),* the most important ecological factors for the development of periphyton communities in running waters are organic load and current velocity. Butcher *(17)* found reduced periphytic densities on slides in faster currents and Blum *(18)* observed that different diatoms showed different responses to current and concluded that current acted as a distribution governing factor. Mc Intire *(19)* found that faster currents apparently retarded the initial attachment of algal cells to glass slides but, after a prolonged period, faster currents produced greater biomass. Some studies have shown that early phases of colonization are characterized by relatively large araphid and biraphid diatoms (geni *Cocconeis*, *Fragilaria*, *Achnanthidium*), later phases with small mono and biraphid diatoms (*Achnanthidium*, *Navicula*) while medium-sized mono and biraphid species dominate towards the end *(20)*. Some studies also report *Cocconeis* and *Achnanthidium* species as first colonizers, followed by genera with mucilaginous pads or stalks *(21)* or attachment of horizontally positioned species as *Gomphonema*, *Nitzschia* and *Cymbella* *(22)*. Ghosh & Gaur *(23)* have shown that the number of cells decreases with increase in current velocity. There are also certain species that prefer lower (e.g. *Navicula cryptocephala* Kütz.), some medium (e.g. *Pinnularia gibba* Ehr., *Gomphonema olivaceum* Kütz.) and some tolerate high current velocities (e.g. *Rossithidium linearis* (W.Sm.) Round & Bukhtiyarova, *Gomphonema lanceolatum* Ehr., *Gomphonema parvulum* (Kütz.) Kütz.) *(23)*.

The goal of the present paper was to determine the interaction between algal colonization rate and current velocity in an unpolluted headwater stream.

MATERIALS AND METHODS

Experiment was carried out from November 1990 to August 1993 on a small mountain stream Veliki potok at Zagreb, Croatia. Observations were done at shaded spring area. Three different microhabitats were defined with regard to the current velocity. Artificial substrates (glass slides) were horizontally placed and oriented parallel to the current, 10 cm beneath the water surface. The microhabitats were made of seven glass slides which were fixed on the upper side of a brick. Diatoms were identified *(24, 25, 26)* with a Standard 20 light microscope. The abundance of species was obtained by counting specimens in 170 microscope fields, the counting was carried out after 2, 5, 10, 15, 20, 25 and 30 days of exposure on 3 repetitive slides. Microscopic examinations were performed on an exposed glass slide as long as the periphyton density allowed it and periphyton was afterwards scarped off and suspended in a determined volume. A total number of species and cells were calculated per cm^2. Current was measured directly above the brick, with a Rost's hydrometric wing.

TABLE 1

The mean values, standard deviations, variance and coefficient of variance of current velocity in cms^{-1} during the investigated period (avg.= average, STD= standard deviation, var= variance, V(%)= coefficient of variance).

	Microhabitat 1	Microhabitat 2	Microhabitat 3
Spring	25.00	60.00	90.00
Summer	10.00	40.00	60.00
Autumn	18.00	52.00	92.00
Winter	20.00	45.00	90.00
avg.	18.25	49.25	83.00
STD	5.40	7.53	13.30
var.	29.19	56.69	177.00
V (%)	29.60	15.00	16.00

To define diatom colonization in a nonlinear regressive analysis of empirical data, the following function *(27)* was used: $S_{(t)} = S_0/1–e^{-k\,(t–to)}$ / ($S_{(t)}$= number of species at time t; S_0= number of species in asymptote; t= time; t_0= beginning time of colonization; k= coefficient of colonization current). Stabilization time of diatom colonization (t_S) on artificial substrates, expressed in days, is the moment when regressive straight line align with values of S_0–0,1. According to Kvalseth *(28),* empiric F-ratio yields validity of regression (95%) like as the representation by the coefficient of determination (r^2).

The variables calculated from nonlinear regressive analysis and the measured velocities were analyzed by main effects ANOVA with post-hoc Bonferroni tests using the program Statistica, version 6.0.

RESULTS

During the research period water velocity was significantly different among three microhabitats (Anova, $p < 0.01$) (Table 1).

A total of 71 diatom species was found on glass slides. The 12 most abundant species (exceeding 5%) include: *Cocconeis placentula* Ehr., *Cocconeis disculus* (Schum.) Cleve, *Achnanthidium minutissimum* (Kütz.) Czarnecki, *Meridion circulare* (Grev.) Agardh, *Diatoma vulgare* Bory, *Navicula gracilis* Ehr., *Sellaphora pupula* (Kutz.) Mereschkowsky, *Navicula radiosa* Kütz., *Eolimna minima* (Grun) Lange-Bertalot, *Gomphonema olivaceum* Kütz., *Gomphonema parvulum* (Kütz.) Kütz., and *Surirrela ovata* Kütz. Of these 12, four species (*Cocconeis placentula* Ehr, *Navicula radiosa* Kütz., *Gomphonema olivaceum* Kütz. and *Surirella ovata* Kütz.) were dominant at different current velocities. The pioneer colonization species on glass slides, depending on current velocity, were: *Cocconeis*

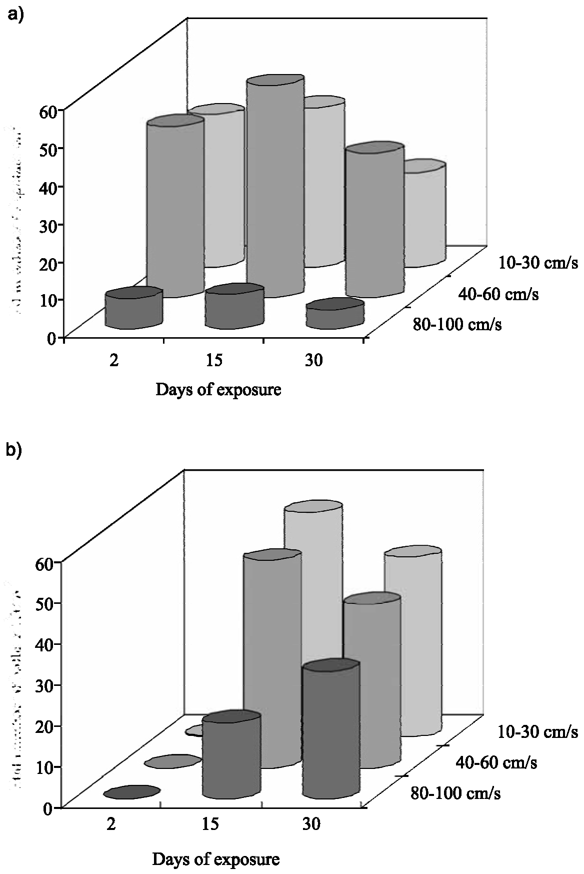

Figure 1. *Total number of species (a) and total number of cells (b) in three microhabitats with different current regimes at the beginning, at the middle and at the end of colonization period.*

placentula at velocities from 10 to 90 cms^{-1}, *Achnanthidium minutissimum* and *Surirella ovata* from 10 to 30 cms^{-1}, and *Navicula gracilis* at 40 to 100 cms^{-1}.

The highest number of diatom species at all current velocities was noted after 15 days of exposure. Concerning current velocity, the highest number of species was at medium current velocity (40–60 cms^{-1}) and the lowest at high current velocity (80–100 cms^{-1}) (Figure 1a). Species abundance showed a different pattern, with the highest number of cells per cm^2 at about the middle of exposure period (15 days) at low and medium current velocities (10–30 and 40–60 cms^{-1}, respectively). At high current velocity, species abundance peaked at the end of exposure period (30 days) (Figure 1b).

The values calculated with nonlinear regressive analysis indicate that the time needed for beginning of colonization, as well as the time needed for periphytic community stabilization increase in with increase in current velocity (Table 2). Likewise, colonization velocity coefficient decreases with increase in current velocity. ANOVA on those values indicated statistically significant differences dependant on current velocity. The time needed for the beginning of colonization process (t0) did not show any statistically significant differences whereas difference in colonization velocity coefficient and colonization stabilization time ($p<0.05$) existed only between low and high current velocities (Table 3). There was also statistically significant negative correlation ($p<0.05$, $r=-0.66$) between current velocity and colonization velocity coefficient.

TABLE 2

Regression values of diatom colonization dynamics during the investigated period (t_0=time for beginning of colonization, k=colonization velocity coefficient, S_0=number of species in asymptote, t_s=time of stabilization, r=coefficient of determination, avg=average value).

Current velocity cms^{-1}	Season	t_0 days	k	S_0	t_s days	r^2	F-ratio
10–30	Spring	1.30	0.41	4.90	10.70	0.94	259.40
	Summer	1.40	0.46	5.40	10.60	0.75	39.55
	Autumn	1.30	0.30	5.20	14.60	0.75	36.27
	Winter	1.40	0.47	5.00	9.80	0.86	94.70
	avg	1.35	0.41	5.13	11.42		
40–60	Spring	1.30	0.37	4.90	11.80	0.82	66.90
	Summer	2.10	0.24	4.90	17.80	0.67	14.40
	Autumn	1.30	0.32	6.00	14.90	0.81	58.43
	Winter	1.40	0.39	5.20	11.60	0.84	74.60
	avg	1.52	0.33	5.25	14.00		
80–100	Spring	2.20	0.31	3.50	13.40	0.66	15.98
	Summer	2.40	0.18	4.80	24.30	0.81	25.10
	Autumn	1.70	0.22	6.99	18.90	0.88	119.60
	Winter	1.40	0.23	6.40	18.20	0.95	235.60
	avg	2.00	0.24	5.00	18.70		

TABLE 3

One-way ANOVAs on t_0, k and t_s values calculated with nonlinear regression analysis (ns denotes $p>0.05$).

	1–2	2–3	1–3
t_0	ns	ns	ns
k	ns	ns	$p<0.05$
t_s	ns	ns	$p<0.05$

DISCUSSION

The type and strength of water flow as well as the shape of surface influence the composition and size of periphytic community *(15, 29)*. The colonization time of periphytic algae also depends on the abundance of algae in the water column, making substrata under the influence of lower velocity flow more exposed to potential colonizers than those under the influence of higher velocities.

The species like *Cocconeis placentula* and *Achnanthidium microcephalum* have been previously reported as pioneering species on artificial substrata *(7, 23, 30, 31),* as well as some *Navicula* species. Those species have adopted different strategies for adhering to substrate, for instance, *Cocconeis placentula* and *Achnanthidium microcephalum* are relatively small with shallow valves and girdle and adhere tightly to the substrate with their raphid valve. Also, *Achnanthidium* species are bent about the median transapical plane, which enables them to adhere more tightly to curved substrate. Some species, like *Diatoma vulgare* attach to sticky substance excreted from a pore field *(32)*. Other species, like, *Gomphonema* produce longer or shorter stalks, depending on the flow and colonization time (in time they start to produce longer stalks). High abundance and frequency of *Cocconeis placentula* and *Achnanthidium microcephalum* can be explained by their ability to respond well to disturbance and to reproduce at relatively high growth rates, which enables them to populate the surface before their competitors *(33)*. Another reason for their high abundance after short exposition periods is the fact that those species prefer artificial substrates *(7)*. Those species also prefer medium to high over low current velocities, mostly due to their small cell size and ability for strong attachment to the surface *(32)*. On the other hand, relatively big species, *Surirella ovata* was on several other occasions noted as the species tolerating low and medium velocities *(7, 23)*. This species is a poor immigrant, unable to colonize habitats under the influence of current *(34),* but it seems that higher current velocity promotes its reproduction.

Two of the dominant species from this study, *Achnanthidium minutissima* and *Gomphonema olivaceum*, were also noted as the most frequent and quite abundant species in a shallow lake *(5),* which emphasizes their competitive over strong attachment ability since later it is not essential for colonization in a shallow lake. Other dominant species, *Cocconeis placentula*, was reported as late colonist and a slow immigrant in a large river *(35, 36)* but other studies (7) report it as early colonist with good adaptation.

This study showed typical colonization sequence reported for streams *(37)* and rivers *(38)* with small monoraphid and araphid pennate diatoms (*Achnanthidium*, *Cocconeis*, and apical pad adhering *Diatoma* and *Meridion*) as dominant at the beginning of colonization and with more stalk producing species at later stages (e.g. *Gomphonema*), but without any significant contribution from planktonic diatoms since current velocity in the creek was too high to allow phytoplankton development.

This study shows inverse relationship between current velocity and periphyton abundance, especially during initial stages of colonization, as reported in some studies *(32, 39)*. This was not the case in later stages of colonization, where medium current velocities showed the greatest diatom accumulation. Abundance and composition of diatoms in this research depended on intraspecific competition which was, since all sampling sites were under influence of similar physical and chemical factors, mostly driven by current velocity conditions. High current velocity usually causes, besides washing effect, high inflow of suspended matter which can have shading effect on algae, and of floating sediment that can cause much physical damage to periphytic community *(20)*. The maximum abundance noted in medium flow velocity conditions is in concordance with some studies *(32, 39)* but it was opposite to other studies, clearly showing negative correlation of periphytic accumulation and current velocity *(23)*. This can be explained by the fact that periphytic community, especially at later stages when periphytic mat is thick and quite impermeable to nutrients from the water column, can benefit from stronger current which can enhance diffusion of nutrients from the water column but is not strong enough to cause sloughing.

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