THE USE OF ARTIFICIAL SUBSTRATES IN DIFFERENT GROWTH CONDITIONS

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Abstract

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The aim of the study is to compare natural and unnatural substrates in order to get a maximal amount of information about availability of an artificial substrate, which is very close to the natural one for water pollution assessment. The used „unnatural" substrates were rectangular shaped plates made of fresh granite. These were placed into the river channel and exposed there for various time periods. The fresh granite material had several limitations for periphyton growth and indication of the water pollution. The most important processes are: differently proceeding succession and different growth conditions. Investigation of four localities was made including as concerns biome characteristics, species composition and semiquantitative species abundance. The ordination statistical methods were used for evaluation of the indication ability of this method. It is impossible to use artificial substrates for determination of pollution in bad conditions for sufficiently fast assemblage development. The possible solution is to install the substrates one year before sampling which can possibly equalize the succession development. The CCA is a good method to test possible use of artificial substrates under specific conditions.

Key words: periphyton, artificial substrate, succession timing, pollution indication, CANOCO

Introduction

Artificial substrates were traditionally used in many studies concerning periphyton and the impact of point – source disturbances on periphyton development (Sládečková, 1962; Hansmann, Phinney, 1973; Lowe, McCulough, 1974; Stevenson, Lowe, 1986; Morgan, 1987). The substrates were of various types: cover slips (Mc Intire, 1964), pieces of sandstone or silt stone (Antoine, Benson-Evans, 1985), and the marsh plant *Eleocharis baldwinii* (Brown, 1976). These were exposed in water for various time periods, from few days to several weeks. Most of these studies were focused only on the colonization of substrates and did not deeply investigated problems concerning the impact of physicochemical factors, especially nutrient concentration which was one of the main factors influencing the development of the attached algal community.

The succession of algae is the process of colonization of new substrates in water environment. Although the colonization can proceed very rapidly in good conditions, for any community, it is always selective (Kann, 1958). Similar situation we can see at periphyton from the bottom layer of the river (Hoagland et al., 1982; Steinman, McIntire, 1986). Also difference in the final stage of succession between original and artificial substrates depends on the similarity of the substrate material type. It means that unnatural substrate may be finally occupied by similar species composition in the final stage of succession after the assemblage oversteps the selectivity of the substrate.

The speed of succession depends mainly on conditions in the studied locality. The better conditions for algal growth are, the faster the succession is (Peterson et al., 1990; Peterson, Stevenson, 1992; Hoagland et al., 1982; Steinman, McIntire, 1986). In order to recognize whether the community already finished the succession process and reached a stable state, "the climax", we can use comparison between the communities on artificial substrates and on original (natural) substrates at the sampling site. Algal composition on a natural substrate is also influenced by factors connected with the seasonal change (ex. Hynes, 1970; Ward, 1992; DeNicola, 1996). Main changes are dependent on light intensity, discharge and light quality available for algae. Light conditions depend on to the surrounding vegetation stage and geographical position (increasing leaf area index during summer and finally de-foliage at the end of the season) (Stevenson, 1996; Hill, 1996). Another factors influencing succession can be predation of grazers or other biotic effects (Steinman et al., 1987a; DeNicola et al., 1990; Tuchman, Stevenson, 1991). All these factors complicate the use of algae from periphytic assemblages on artificial substrates for indication of toxic and organic pollution (Lowe, Pan, 1996).

We describe the possibility of use the artificial substrate and periphyton analysis for indication of water quality of the recipient in a temperate zone at the river Chrudimka (B4 – B5 class according to the American Rivers Classification, Rosgen, Silvey,1996).

Area of study

Sampling sites were established at the river Chrudimka. The river is situated in the southern part of eastern Bohemia, the Czech Republic (Fig. 1). It springs in the forest land of the Czech – Moravian Highlands at an altitude 675 m a. s. l., then it flows to the Labe (Elbe) lowland. It forms the left tributary of the river Labe. The total length of the Chrudimka river is 104.4 km and the catchment area is 872.6 km^2. The river has a sub-mountainous character with numerous rapids and stony – gravel or sandy – mud bottom. The flow rate was between 0.2 –0.6 m/s during the study period. Banks of the river are natural, covered with vegetation. Mineral deposits in the study area are mostly granodiorite and granite.

Four sampling sites were selected along the river. The first and the second sampling sites (Vortová and Blatno) were situated in the upper part where the river was relatively slightly loaded by nutrients and the water temperature was low. The third and the fourth sampling sites (Stan and Horní Bradlo) were more affected by anthropogenic pollution

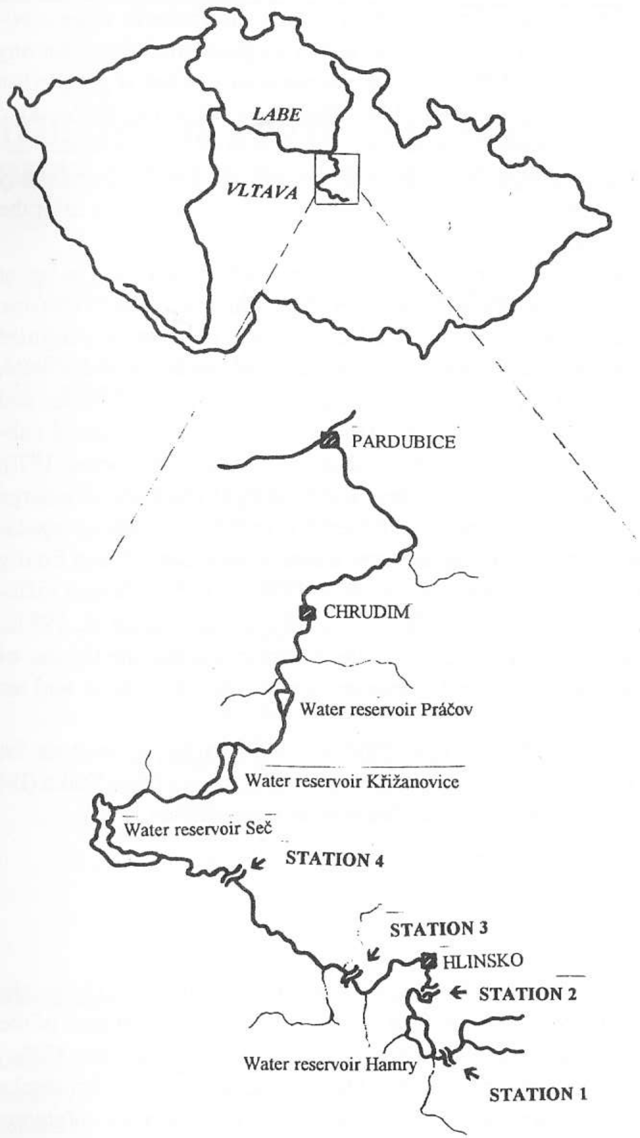

Fig. 1. The map of studied area.

which the river received during its flow through the town of Hlinsko. However, the major portion of polluted water was received from an outlet of the town waste water treatment plant situated above the sampling site number 3.

Materials and methods

In each of the four sampling sites artificial substrates were exposed. These were granite plates held in a wooden frame. Stony plates were used because of their flat surface. It is easy to scrap off the sample and simple to measure the sampled area. The granite type of substrate was at the major part of bedrock of the river Chrudimka. The investigation was separated into two periods. The first period lasted from May to July 1996 while the second one from August to October 1996. In each investigation period new experimental substrates were exposed in the localities. Periphyton samples were collected from artificial substrates as well as from the natural ones in a period of three weeks except for the first set of samples, which was sampled only after two weeks of exposition. Algal samples were preserved in 4 per cent formaldehyde solution. Algal taxa abundance was assessed using the method of cover estimating. The individual cover area was assessed for each species in a following way: we assumed how many fields of micrometric net (placed in a microscope eyepiece) were covered by each individual species. The appurtenant areas were summed and expressed in per cents of the total coverage of all the species. These values of individual covers were used in a Canonical Correspondence Analysis (CCA). The similarity index was calculated basely according to Sorensen (1948).

Statistical evaluation of data was done by multidimensional statistical methods using the CANOCO 4.5. software (Terr Braak, Šmilauer, 1998). The ordination method Canonical Correspondence Analysis CCA was used for estimating Species / factors / localities relationships. In both situations the "Forward selection" and the "Monte Carlo Permutation test" with manual selection at the level of significance P = 0.05 were used. The settings were a symmetric focus on scaling and a biplot scaling. Neither transformations nor deleted or weighted samples or species or environmental factors settings were used in the CCA analysis.

Following factors were submitted to the statistical analyses: water temperature, pH, N-NH_4, N-NO_3, N-NO_2, P-PO_4, Ca, Mg, Na, K, Fe, Mg and values of covers of each species area.

Results

Species composition and evaluation due to the similarity index

We identified more than 40 species with predominance of diatoms. Nearly all the taxa present in natural samples colonized also artificial substrates but in different colonization rates (Table 1). The succession of colonization on granite plates was very similar in all four localities. At the first one, small diatoms were present in large abundance in the community though these were not frequently observed in the natural community. Species present were: *Fragilaria capucina var. vaucheriae*, *Gomphonema parvulum*, *Cymbella minuta* and *Achnanthes lanceolata*. After a 5 weeks exposition, the granite desks were colonized by the Rhodophyte *Audouinella chalybea* associated with common species of diatoms (for example *Navicula avenacea*, *N. rhynchocephala*) followed by *Cladophora glomerata* after another 6 weeks. The similarity of algal communities developed on natural and artificial substrates was expressed by the similarity index as well as by the Ca-

Table 1. Species richness on the localities in Spring (cold) and Autumn (warm) part of season

Spring season

Sampling station	Sampling time			
	11.5.1996	1.6.1996	24.6.1996	14.7.1996
Vortová Nat.	18	18	x	x
Vortová Art.	8	12	x	x
Blatno Nat.	9	17	21	22
Blatno Art.	10	11	16	9
Stan Nat	17	19	18	19
Stan Art.	14	10	14	8
Horní Bradlo Nat.	12	17	18	16
Horní Bradlo Art.	11	10	15	11

Autumn season

Sampling station	Sampling time			
	26.8.1996	16.9.1996	5.10.1996	2.11.1996
Vortová Nat.	15	13	13	20
Vortová Art.	15	13	14	16
Blatno Nat.	22	23	24	25
Blatno Art.	12	15	18	14
Stan Nat	17	14	21	14
Stan Art.	10	11	16	14
Horní Bradlo Nat.	25	20	17	16
Horní Bradlo Art.	12	10	12	11

T a b l e 2. Percentage of similarity index on the localities in Spring (cold) and Autumn (warm) part of the season

Spring season

Sampling station	Sampling time [%]			
	11.5.1996	1.6.1996	24.6.1996	17.4.1996
Vortová	45	36		
Blatno	26	64	49	37
Stan	73	66	53	40
Horní Bradlo	53	74	48	20

Autumn season

Sampling station	Sampling time [%]			
	26.8.1996	16.9.1996	5.10.1996	2.11.1996
Vortová	23	31	25	62
Blatno	40	17	53	58
Stan	45	80	77	99
Horní Bradlo	50	60	77	88

nonical Correspondence Analysis (CCA) Values of similarity indexes concerning the localities are given in Table 2.

Evaluation by the Canonical Correspondence Analysis

The Canonical Correspondence Analysis (CCA) was used to evaluate the reaction of the attached algae to the anthropogenic pollution. We compared changes of attached algae assemblages developed on artificial substrates during spring and autumn seasons along the river profile with those obtained from natural substrates at the same localities.

Evaluation of algal communities on natural substrates

The CCA was used to evaluate changes of species composition of algal communities along the river profile. Fig.2 (CCA diagram) describes distribution of species based on factors statistically significant for the distribution along the first and the second ordination axis. The distribution of species indicates the dependence on higher concentrations of factors selected by the Monte Carlo permutation test. In the right part of the graph there are separated diatoms *Fragilaria pulchella* and *Fragilaria capucina*, which shows high dependence on Mn concentration. The species *Surirella angusta* and *Oedogonium sp.* are separated in the left corner of the graph, which shows dependence on Fe concentration.

Another such relation shows *Cymbella minuta* depending on $N\text{-}NO_3$ concentration. In the central part of the graph there are species *Surirella ovata*, *Fragilaria ulna*, *Achnanthes lanceolata*, *Melosira varians*, *Navicula rhynchocephala* etc. Their positions do not demonstrate any information inside the chosen set of variables.

Samples are classified according to localities in Fig. 3. This classification shows that highest difference among the natural substrate samples indicates differences between the polluted and unpolluted localities. The polluted localities are situated in the direction of $N\text{-}NO_3$ concentration. Seasonal changes are characterized more by high concentration of Mn during spring and high concentration of Fe during autumn than by other conditions (the results of the Monte Carlo permutation test) (Table 2).

The classification of samples by seasonal changes from May to October tend to diminish the variability during summer, but data from May, June and October show high variability of conditions considering the localities (Fig. 4). This means that development of algal assemblages at the beginning of the year depends also on local conditions (temperature and light penetration to the river bottom). There also exist differences in the succession process which is increasing due to specific conditions at the locality.

Classification of samples according to cold and hot parts of the season and polluted and unpolluted localities (Fig. 5) shows separation of the polluted localities in the upper part of the graph of increasing $N\text{-}NO_3$ concentration.

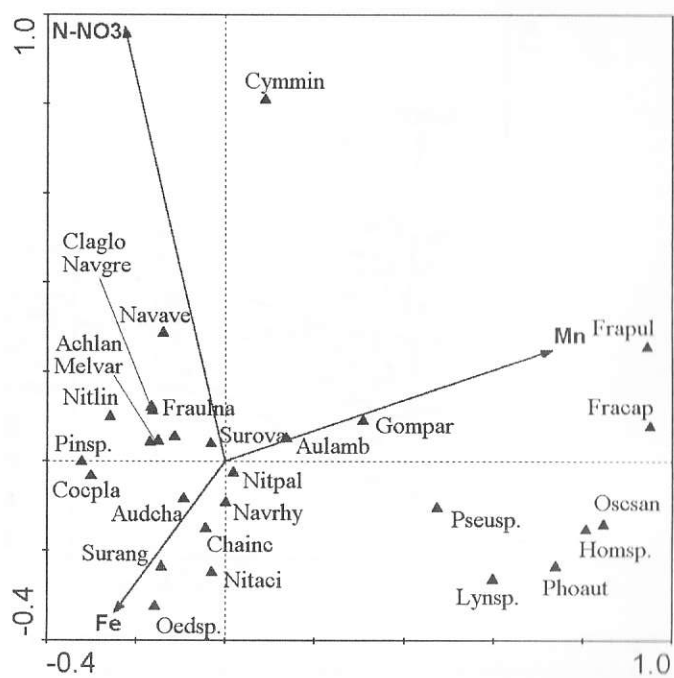

Fig. 2. The CCA diagram of species and statistically significant factors distribution on **natural substrates** over first and second ordination axis. Abbreviation: Achlan – *Achnanthes lanceolata*, Audcha – *Audouinella chalybea*, Aulamb – *Aulacoseira ambigua*, Chainc – *Chamaesiphon incrustans*, Claglo – *Cladophora glomerata*, Cocpla – *Cocconeis placentula*, Cymmin – *Cymbella minuta*, Fracap – *Fragilaria capucina* var. *vaucheriae*, Frapul – *Fragilaria pulchella*, Fraulna – *Fragilaria ulna*, Gompar – *Gomphonema parvulum*, Homsp. – *Homoeothrix* sp., Melvar – *Melosira varians*, Navave – *Navicula avenacea*, Navgre – *Navicula gregaria*, Nitaci – *Nitzschia acicularis*, Nitlin – *Nitzschia linearis*, Nitpal – *Nitzschia palea*, Navrhy – *Navicula rhynchocephala*, Oedsp. – *Oedogonium sp.*, Oscsan – *Oscillatoria sancta*, Phoaut – *Phormidium autumnale*, Pinsp. – *Pinnularia* sp., Pseusp. – *Pseudanabaena* sp., Lynsp. – *Lyngbya* sp., Surang – *Surirella angusta*, Surova – *Surirella ovata*.

Samples from unpolluted localities are situated in the lower part of the graph. Natural substrate samples are able to indicate fine differences in species composition caused by water quality. Species composition of an algal community reacts in a different way to water pollution during hot and cold part of the year.

By the next selection by Monte Carlo permutation test only three first factors were found significant for the species and samples distribution in ordination space (see Table 3).

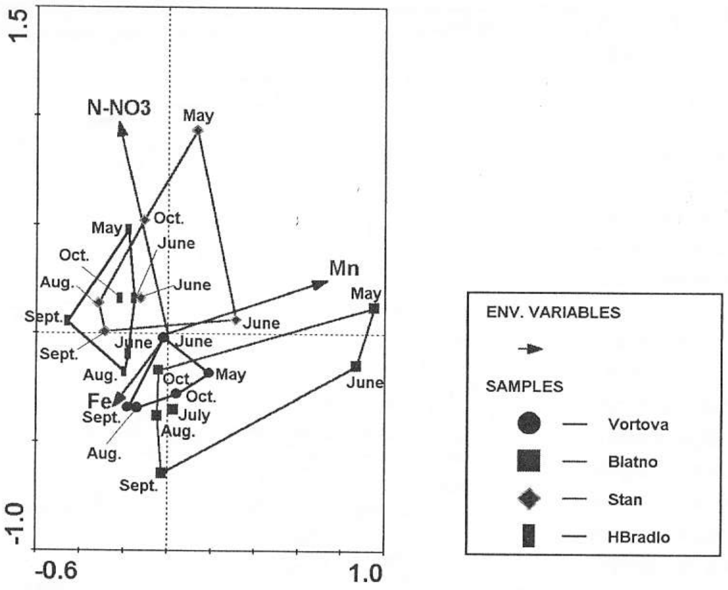

Fig. 3. The distribution of the factors and samples on **natural substrates** over first and second ordination axes of CCA. The samples are classified due to localities.

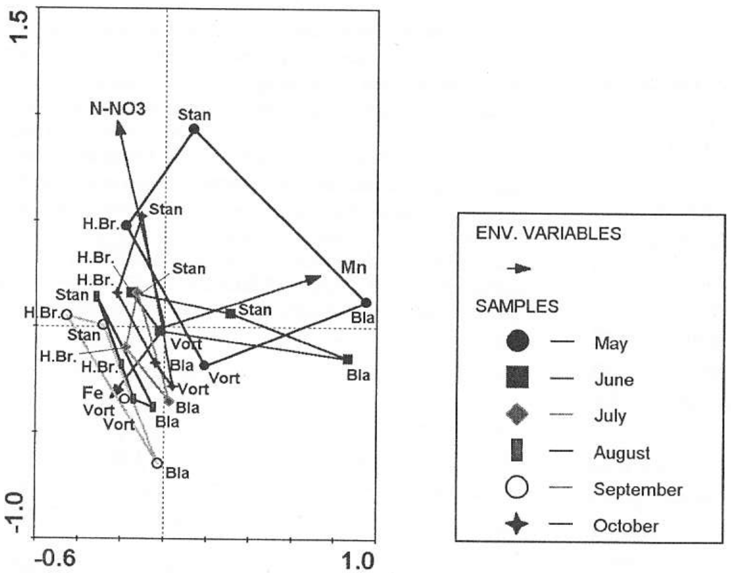

Fig. 4. The distribution of the factors and samples on the **natural substrate** over first and second ordination axes of CCA. The samples are classified due to sampling time.

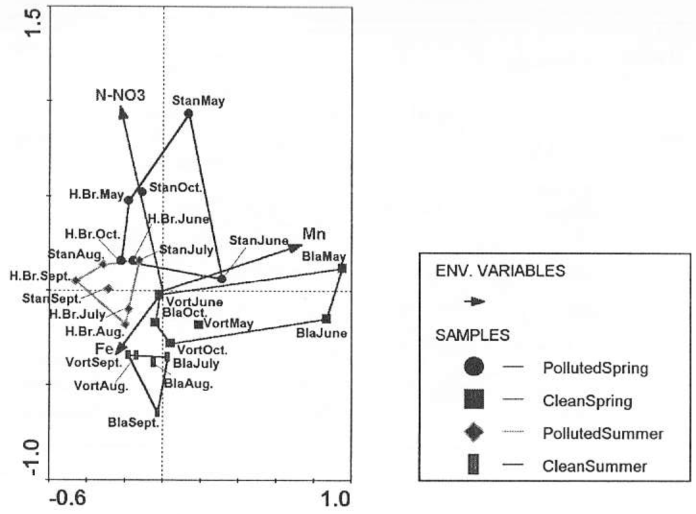

Fig. 5. The distribution of the factors and samples on the **natural substrates** over first and second ordination axes of CCA. The samples are classified due to cold and hot parts of season and dirty and clean localities.

We also used the same method (CCA) to evaluate the species composition of the algal communities developed on artificial substrates and their development along the river in time. The CCA diagram (Fig. 6) describes important factors and species distribution along the first and the second ordination axes.

The level of influence of the factors for species distribution corresponds to the lengths of factor arrows. In comparison with the following diagrams, samples classification describes the appearance of the spring species (*Hydrococcus sp.*, *Fragillaria capucina*, *Fragilaria pul-*

T a b l e 3. The result of forward selection and Monte Carlo permutation test for CCA analysis

Marginal effects				
Variable	Var. N	Lambda 1		
Mg	7	0.32		
Mn	11	0.29		
Ca	6	0.26		
$N-NO_3$	3	0.24		
$N-NO_2$	4	0.22		
pH	12	0.22		
$N-NH_4$	2	0.17		
K	9	0.15		
Temperature	1	0.11		
Fe	10	0.11		
Na	8	0.10		
$P-PO_4$	5	0.08		
Conditional effects				
Variable	Var. N	Lambda A	P	F
Mg	7	0.32	0.010	13.48
Mn	11	0.26	0.037	12.81
Fe	10	0.15	0.130	11.78
Temperature	1	0.17	0.189	11.96

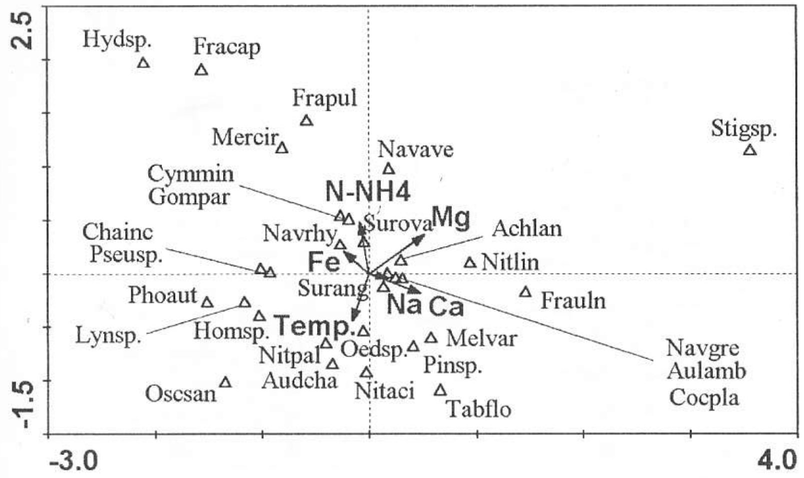

Fig. 6. The CCA diagram of the species and statistically significant factors on **artificial substrates** distribution over first and second ordination axis. Abbreviation: Achlan – *Achnanthes lanceolata*, Audcha – *Audouinella chalybea*, Aulamb – *Aulacoseira ambigua*, Chainc – *Chamesiphon incrustanc*, Cocpla – *Cocconeis placentula*, Cymmin – *Cymbella minuta*, Fracap – *Fragilaria capucina* var. *vaucherie*, Frapul – *Fragilaria pulchella*, Frauln – *Fragilaria ulna*, Gompar – *Gomphonema parvulum*, Hydsp – *Hydrococcus* sp., Homsp. – *Homoeothrix* sp., Melvar – *Melosira varians*, Mercir – *Meridion circulare*, Navave – *Navicula avenacea*, Navgre – *Navicula gregaria*, Nitaci – *Nitzschia acicularis*, Nitlin – *Nitzschia linearis*, Nitpal – *Nitzschia palea*, Navrhy – *Navicula rhynchocephala*, Oedsp. – *Oedogonium* sp., Oscsan – *Oscillatoria sancta*, Phoaut – *Phormidium autumnale*, Pinsp. – *Pinnularia* sp., Pseusp. – *Pseudanabaena* sp., Lynsp. – *Lyngbya* sp.,Stisp. – *Stigeoclonium* sp., Surang – *Surirella angusta*, Surova – *Surirella ovata*, Tabflo – *Tabellaria flocculosa*.

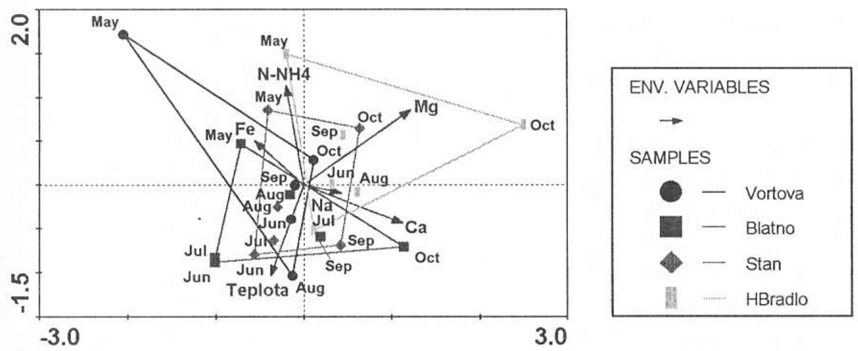

Fig. 7. The distribution of the factors and samples at the **artificial substrates** over first and second ordination axes of CCA. The samples are classified due to the localities.

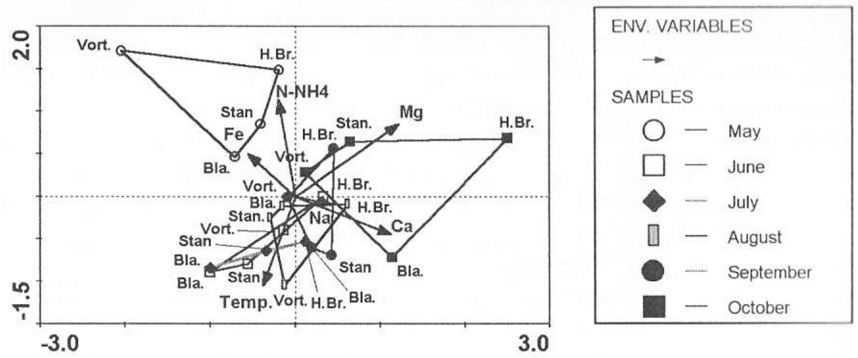

Fig. 8. The distribution of the factors and localities from **artificial substrates** over first and second ordination axes of CCA. The samples are classified due to sampling time.

chella and *Meridion circulare*) at the left upper quadrant, summer species (*Phormidium autumnale*, *Lyngbia sp.*, *Homeothrix sp.*, *Nitzschia palea*, *Audouinella chalybea* and *Oscillatoria sancta*) at the left bottom quadrant and long lasting advanced summer and autumn species (*Stigeoclonium sp.*, *Fragilaria ulna* and *Nitzschia linearis*) situated in the right upper quadrant.

Figure 7 shows the classification of samples according to the localities. Unlike the classification in the case of natural substrates at the localities (Fig. 3) the artificial substrates (Fig. 7) do not separate localities from each other. The central part is the border of many lines, which make a star structure. The interpretation of groups positions is that localities according to species composition are spread and all influenced by the same kind of seasonal development (they did not reach the steady state during the season).

Similar results can be seen in Fig. 8 where samples are classified according to sampling time. May and October samples are separated from each other here. The rest of the samples is in groups in the central and the lower part of the graph.

When using the CCA for classification according to cold and hot part of the season and polluted and unpolluted localities (Fig.9), the analysis did not separate polluted and unpolluted localities samples from each other. This last figure demonstrates the solution. The attempt to classify and to describe localities according to pollution was the main goal of this method. However, the periphyton developed on experimental plates sampled in spring and autumn didn't have enough energy (or time) to develop sufficiently quickly in order to respond in a different way to different environmental conditions = different load of pollution. The development of periphyton assemblages on experimental substrates through all the localities in summer is extremely diverse because individual substrates are in different succession stage, at the time of sampling.

Considering the length of the exposition periods of the plates, the periphyton analysis of such an artificial substrate does not allow to describe pollution influence in the river.

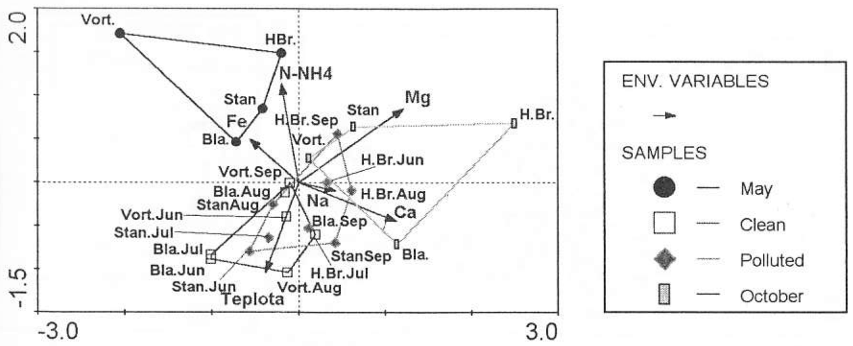

Fig. 9. The distribution of the factors and localities over first and second ordination axes of CCA. The samples are classified due to cold and hot parts of season and dirty and clean localities.

Table 4. The Forward selection results of Monte Carlo permutation test

Marginal effects				
Variable	Var. N	Lambda 1		
Mg	7	0.37		
pH	12	0.31		
$N\text{-}NO_2$	4	0.31		
Temperature	1	0.31		
Ca	6	0.30		
Mn	11	0.30		
$N\text{-}NO_3$	3	0.28		
$N\text{-}NH_4$	2	0.27		
Fe	10	0.23		
K	9	0.20		
Na	8	0.14		
$P\text{-}PO_4$	5	0.13		
Conditional effects				
Variable	Var. N	Lambda A	P	F
Mg	7	0.37	0.002	2.12
Temperature	1	0.32	0.011	1.89
Ca	6	0.30	0.011	1.87
$N\text{-}NH_4$	2	0.30	0.014	1.94
Fe	10	0.25	0.030	1.74
Na	8	0.24	0.048	1.72

The results of the next selection and the Monte Carlo permutation test can be seen in Table 4. The significant level for distribution of algae and samples in ordination space follows much more factors. It means two things. First, that there are more factors influencing occurrence and distribution of algae and second, that they are not in any correlation but in an interaction.

Discussion

Artificial substrates are chosen, tested and studied in experiments mainly because of an effort of researchers to standardize methods for indication of different complex stages of river environments. The most serious problem not solved yet is a variable approach of individual species of algae to a natural and/or artificial substrate.

Many studies on algal colonization of various substrates have been done and described in literature (Sládečková, 1962; Mc Intire, 1964; Brown, 1976; Antoine, Benson-Evans, 1985). We described similar course of colonization as Mc Intire (1964) reported for slides. According to him, the first colonization species of artificial substrates were *Achnanthes lanceolata* and small species of *Navicula* followed by large diatoms and finally by green filamentous algae. Our results are in accordance to his findings. Cox (1990) described great success of small species of diatoms in a colonization process thanks to their high turnover. Rapid cellular division qualifies for advantageous colonization of new substrates. We found out that values of the similarity index were lower at the localities in the upper part of the river than at the localities in the central part of the river. Small similarity between natural and artificial substrates of the upper and lower localities is due to different growth conditions at both parts of the river. Low temperature and relatively very low nutrient supply, characterize sites in the upper part of the river. According to the ecological succession theory (ex. Begon et al., 1990), succession on artificial substrates would proceed relatively slowly and the differences in the community structure would be relatively great in conditions of low nutrient supply and in places occupied by submersed vegetation. Assemblages of artificial substrates have neither time nor the opportunity to reach the succession level of the periphyton on natural substrates before they are supposed to be sampled.

Polluted localities in the lower part of the river are warmer then unpolluted and the development of communities is faster there. Higher input of nutrients from the waste water treatment plant to the recipient increased the speed of the community development and together with higher temperature and access of the light to the stream allowed the algae to succeed much better.

Based on our results, the succession on an artificial substrate gets closer to the natural ones only in summer period and after 11 weeks of exposition in our conditions. Time of succession was slower at the locality in the central part of the river and even more at the locality in the upper part of the river.

Thinking about the method of exposition of granite plates, we must stress the importance of environmental conditions during the exposition. We achieved positive (comparable with natural substrates) results mainly in summer and autumn periods.

Other results from the CCA analyses showed negative influence in postponed succession in using artificial substrates to monitor the river pollution. In that case the algae community on the artificial substrata did not get separated to indicate the pollution and the localities. In the early stages of algal community development, artificial substrates were colonized by same species nearly at all the localities. These species of the early colonization phases can be characterized as the r – strategist or pioneer species (Begon et al., 1990) with a lower ability to indicate waste water and pollution (Rott, 1997). The intermediate stage of colonization is hard to interpret and the distribution of species is given by the spectrum of conditions over all of the localities in time of the season and time of the succession on artificial substrates.

An artificial substrate is a new item in a locality and therefore it reacts to much wider spectrum of conditions. Postponed periphyton development on a freshly sterilized substrate, although it is of the same chemical composition, in comparison with a natural stone, is surely due to the absence of a bacteria film that speeds up the further colonization. This is a different interaction between the succession response and locality stage conditions.

Artificial substrates in the expositions used in this study were not found available for assessment of the water quality in the localities studied, as the successive processes had two different ratios and even very small differences lead to high differences between locality assemblages in the period of sampling.

Data from natural substrates samples could be used to recognize differences in species composition caused by a different water quality using the CCA ordination methods. For any conditions this must be based on the large comparative database of the influenced and untouched localities. The general approach to data suggests that the summer and spring samples ought to be interpreted separately as they show different responses to pollution both in the factors and in species occurrence. The alternative to use soon algae succession data for quantification of pollution in rivers needs deeper study focused on the autecology of chosen r-strategist species and growth response to specific kinds of pollution.

Conclusion

The use of artificial substrates made of bedrock material is limited to rivers with high productivity (fast turnover) where conditions, comparable with natural substrates, can be achieved relatively quickly. The compared situations must be similar in most of the features and different only in the feature we concern, to make significant and interpretable results gained from the analysis of periphyton on artificial substrates. These substrates can be used in combination with controlling sampling of natural substrates or data about the local periphyton succession already known.

As far as we are concerned, the bottom substrate is very heterogeneous. Also light and flow conditions are very heterogeneous which needs a large amount of repetition within one profile in case the original substrate is studied, but the use of an artificial substrate does not simplify the study. The succession must be faster than 2 weeks in order to reflect local actual conditions, because conditions change quickly during the whole year in the temperate zone.

Nevertheless the artificial substrates data can be efficiently used for succession studies of the cyanobaceria/algae communities in the temperate zone conditions. This can bring new information about river periphyton mats succession and evolution during special events (flood, pollution, drought etc.). In case of the point source perturbation studies we suggest to expose artificial substrates longer than 3 months before the investigation. The succession study can also give interesting information in such situation, however, there must be also taken comparative data and the interpretation is more complicated for a monitoring study.

Translated by the authors

References

Antoine, S.E., Benson-Evans, K., 1985: Colonisation rates of benthic algae on four different substrata. Limnologica , *16*, p. 307-313.

Begon, M., Harper, J.L., Towsend, C.R., 1990: Ecology: individuals, populations and communities. Blackwell Scientific Publications, 986 pp.

Brown, H.D., 1976: A comparison of the attached algal communities of a natural and an artificial substrate. J. Phycol., *12*, p. 301-306.

Cox, E., 1990: Studies on the algae of a small softwater stream. III. Interaction between discharge, sediment composition and diatom flora. Arch. Hydrobiol. Suppl. Monogr. Beitr., *83*, p. 567-584.

DeNicola, D.M., McIntire, C.D., Lamberti, G.A., Gregory, S.V., Ashkenas, L.A., 1990: Temporal patterns of grazer-periphyton interactions in laboratory streams. Freshwater Biol., *23*, p. 475-489.

DeNicola, D.M., 1996: Periphyton Responses to Temperature at Different Ecological Levels. In Stevenson, R.J., Bothwell, M.L., Lowe, R.L. (eds): Algal Ecology – Freshwater Benthic Ecosystems. Academic Press, *6*, p. 149–181.

Hansmann, E.V., Phinney, H.K., 1973: Effect of logging on periphyton in coastal streams of Oregon. Ecology, *54*, p. 194-199.

Hill, W.R., 1996: Effects of light (Chapter 5) in Algal Ecology, Freshwater Benthic Ecosystems. Section Two – Factors affecting benthic algae. Academic Press, 753 pp.

Hoagland, K.D., Roemer, S.C., Rosowski, J.R., 1982: Colonization and community structure of two periphyton assemblages with emphasis on the diatoms (Bacillariophyceae). Am. J. Bot., *69*, p. 188-213.

Hynes, H.B.N., 1970: The ecology of running waters. Liverpool University Press. 123 Growe Street, Liverpool L7 7AF, 555 pp.

Kann, E., 1958: Der Algenaufwuchs in der eulitoralen Zone alpiner und norddeutscher Seen. Verh. I.V.L., *13*, p. 311-319.

Lowe, R.L., Pan, Y., 1996: Benthic Algal Communities as Biological Monitors (Chapter 22) in Algal Ecology. In Stevenson, R.J., Bothwell, M.L., Lowe, R.L. (eds): Freshwater Benthic Ecosystems. Section Three – The niche of benthic algae in freshwater ecosystems. Academic Press, 753 pp.

Lowe, R.L., McCulough, J.M., 1974: The effect of seawage-treatment-plant effluent on diatom communities of the Portage River, Wood Country, Ohio. Ohio J. Sci., *74*, p. 154-161.

Mc Intire, C.D., 1964: Some effects of current velocity on periphyton communities in laboratory streams. Hydrobiologia, *27*, p. 559-570.

Morgan, M.D., 1987: Impact of nutrient enrichment and alcalinization on periphyton communities in the New Jersey Pine Barrens. Hydrobiol., *144*, p. 233-241.

Peterson, C.G., Hoagland, K.D., Stevenson, R.L. , 1990: Timing of wave disturbance and the resilience and recover of a freshwater epilithic microalgal community. J. North Am. Benthol. Soc., *9*, p. 54-67.

Peterson, C.G., Stevenson, R.J., 1992: Resistance and resilience of lotic algal communities: Importance of disturbance timing and current. Ecology, *73*, p. 1445-1461.

Rosgen, D., Silvey, H.L., 1996: Applied River Morphology. Wildland Hydrology Books. Printed Media Companies, Mineapolis, Minesota, 198 pp.

Rott, E., 1997: Ecophysiological profiling of phycoperiphyton species, a useful approach to qualify river ecosystem health. Phycologia, *36*, Suppl. 4, p. 94-95.

Sládečková, A., 1962: Limnological investigation methods for the periphyton ("Aufwuchs") community. Bot. Review, *28*, p. 286-350.

Sorensen, T., 1948: A method of establishing groups of equal amplitude in plant society based on similarity of species content. K. Danske Vidensk. Selsk., *5*, p. 1-34.

Steinman A.D., McIntire, C.D., Gregory, S.V., Lamberti, G.A., Ashkenas, L., 1987a: Effect of herbivore type and density on taxonomic structure and physiognomy of algal assemblages in laboratory streams. J. North Am. Benthol. Soc., *6*, p. 175-188.

Steinman, A.D., McIntire, C.D., 1986: Effects of current velocity and light on the structure of periphyton assemblages in laboratory streams. J. Phycol., *22*, p. 352-361.

Stevenson, R.J.,1996: The stimulation of Drag and Current (Chapter 11) in Algal Ecology, Freshwater Benthic Ecosystems. Section Two – Factors affecting benthic algae. Academic Press, 753 pp.
Stevenson, R.J., Lowe, R.L., 1986: Sampling and interpretation of algal patterns for water quality assessment. In "Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Ecosystems" (B. Isom, ed.), ASTM STP 894, Am. Soc. Test. Mater., Philadelphia.
Terr Braak, C.J.F., Šmilauer, P., 1998: CANOCO reference manual and user's guide to Canoco for Windows. Centre for Biometry, Wageningen, 351 pp.
Tuchman, N.C., Stevenson, R.J., 1991: Effects of seléctive grazing by snails on benthic algal communities. J. North Am. Benthol. Soc., *10*, p. 430-443.
Wetzel, R.L., 1979: Methods and Measurements of periphyton communities: A Review, ASTM 690, 1916 Race Street, Philadelphia, Pa. 19103.
Ward, J.V., 1992: Aquatic Insect Ecology. 1. Biology and Habitat. J. Wiley & Sons, Inc., 428 pp.

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Komárek O., Sukačová K.: **Použití umělých substrátů v různých růstových podmínkách.**

Cílem této studie bylo srovnání přirozených a umělých substrátů pro získání maxima informací o vhodnosti materiálů blízkých přírodním pro hodnocení znečištění vody v tocích. Použité umělé substráty jsou hranaté desky z čerstvě nalámané žuly. Tyto byly vloženy do říčního koryta a exponovány v různých časových intervalech. Čerstvý žulový materiál má několik omezení pro růst perifytonu a indikaci znečištění vody. Z těch nejdůležitějších jsou to různě rychlá sukcese a rozdílné podmínky na lokalitách. Výzkum byl prováděn na čtyřech lokalitách a zahrnoval charakteristiku biotopu, druhové složení a semikvantitativní druhovou abundanci doplněnou o chemická data. Ordinační statistické metody byly použity pro hodnocení indikační schopnosti této metody. Z výsledků vyplývá, že je nevhodné použití umělých substrátů pro určení znečištění v podmínkách nevhodných pro dostatečně rychlý rozvoj společenstva. Možným řešením je instalace substrátů celý rok před vlastním hodnocením, což umožní vyrovnat sukcesní rozvoj. CCA je dobrou metodou pro testovaní možnosti použít umělé substráty ve specifických podmínkách.

METABOLIC RATES IN PASSERINE BIRDS: EFFECTS OF ADAPTIVE STRATEGIES AND TAXONOMY

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Abstract

Cierlik G., Tworek S., Makomaska-Juchiewicz M., Profus P.: Metabolic rates in passerine birds effects of adaptive strategies and taxonomy. Ekológia (Bratislava), Vol. 23, No. 2, 207-224, 2004

The hypothesis that the metabolic rates of birds are convergent and depend on functional adapta tions was tested as an alternative that taxonomic affiliations sufficiently account for variation i metabolism. Basal metabolic rates (BMR) of 122 species from six families (*Corvidae, Emberizidae, Fringillidae, Muscicapidae, Nectariniidae,* and *Parulidae*) of passerine birds were take from literature and compared with data on their life history traits: food habits, climate, habitat biotope, type of nest and migrations. Using factor analysis and clustering procedures differen strategies were distinguished according to assortment of traits – food strategies: "nectarivorous" "insectivorous", "granivorous", "omnivorous"; environmental strategies: "terrestrial", "tropical" "boreal" and strategies based on analysis of food and remaining traits together: "group 1", "group 2", "group 3". These sets are only partly congruent with taxonomic classification. All group demonstrate similar dependence of BMR on body weight but "granivorous" have a significantly higher BMR than "nectarivorous" and "tropical" has lower BMR than "terrestrial" and "boreal" In contrast, *Fringillidae* have significantly higher BMR than *Muscicapidae, Emberizidae, Nectariniidae* and *Parulidae*. Analysis of residuals within ANCOVA for strategies and for familie indicates that taxonomic affiliation exerts greater influence on BMR values than adaptive strategy

Key words: passerine birds, metabolic rates, functional adaptations, taxonomic affiliation, lif strategy

Introduction

Relationships between metabolic rate and body mass in birds have been studied by many authors (e.g. Lasiewski, Dawson, 1967; Calder, 1984; Scott et al., 1996) and nowadays it is generally known that this dependence accounts for most of the interspecific variation o metabolism. The residual variation (with regard to body mass effect), however, is still enormous and demands explanation. Some authors checked which species have metabolic rat