ACTA HYDROBIOL.	32	3/4	345—354	KRAKÓW 1990

The effect of flood-control regulation of a montane stream on the communities of sessile algae

Barbara Kawecka

Polish Academy of Sciences, Institute of Freshwater Biology, ul. Sławkowska 17, 31-016 Kraków, Poland

Manuscript submitted October 9, 1989, accepted June 26, 1990

Abstract — The differentiation of algal communities in a natural and a regulated streambed was studied in two montane streams. In stream with regulated bed *Hydrurus foetidus* did not occur while *Prasiola fluviatilis*, *Chamaesiphon polonicus*, and *Phormidium favosum* developed abundantly. In both streams *Diatoma hiemale*, *Achnanthes minutissima*, *A. pyrenaica*, *Ceratoneis arcus*, and *Cymbella ventricosa* prevailed, though the index of diatom biomass attained higher values in stream with regulated bed.

Key words: running waters, regulated streams, sessile algae, ecology of algae.

1. Introduction

Hydrotechnical regulation of montane streams and rivers facilitates the utilization of their water resources; however, at the same time it interferes with natural biocoenoses whose value is sometimes unique in the biological sense.

Analyses of the development of algal communities in montane streams with regulated beds are few and concern areas below dam reservoirs (Ward 1976, Ross, Rushforth 1980, Kawecka 1990) and water intakes (Jäger et al. 1985).

The aim of the present work was to investigate the effect of flood control regulation in a montane stream, particularly of lining the bed, on the communities of sessile algae. This type of regulation consists of building small dam reservoirs in streams and of lining the bottom and banks of the bed. Such regulation prevents too high rises in water

level, threatening floods, and protects the streambeds against the eroding action of floodwaters.

2. Study area

The investigation was carried out in the Bystra stream flowing in the western Tatras. The mountains are chiefly built of limestones and dolomites. The stream flows out of karst sources, called the vaucluse springs of the Bystra stream (at an altitude of 1168—1175 m). The stream flows across an afforested valley and then enters the area of Zakopane. About 1 km below Kuźnice (a district of Zakopane) a dam was constructed in the stream, originating a small reservoir. The water from the reservoir flows out through two parallel courses, the Folusz and Bystra streams. The Folusz stream, which flows in the riverbed of a former millrace, has a natural bottom with the prevalence of medium sized stones while sand and thin mud collect at the banks. The width of the stream and of the water surface amounts to about 4 m. The Bystra stream has a regulated bed in the form of a stony channel with a span of about 6 m between the banks and width of the water surface of 1.5—2 m. The investigation was carried out in the two streams, that with the natural bed being regarded as the point of reference. The streams drain their waters to the Cicha Woda (Zakopianka) stream at two different places. Permanent and regulated sluice-gates in the dam allow the waters to be directed to two channels or to only one of them. Hence, the pattern of flow beneath the dam is not natural and depends on manipulation of the gates. The narrowing of the bed and the smoothing of the bottom in the regulated stream brought about an increase in the current rate to 0.8—2.6 m s^{-1} (2 m s^{-1} on the average). In the stream with the natural bottom the current rate was 0.7—1.1 m s^{-1} (1 m s^{-1} on the average). In both streams the water temperature varied from 4.8—9.2°C. The reaction of water was 7—7.4. The waters of the streams were well oxygenated (content of dissolved oxygen — 10 mg O_2 dm^{-3}). The water of the reservoir had a mesotrophic character (Table I) and affected the chemistry of the stream waters.

3. Material and methods

The material was sampled several times in the course of a few years (1984—1987). In each stream the sampling was carried out at one station lying about 200 m below the dam. When the stream with the regulated bed carried great amounts of water, the collection of material became impossible. The investigation could be carried out only

Table I Chemical composition of water in the dam reservoir on the Bystra stream on June 20, 1987 according to Wróbel (unpubl .data)

Parameter		Value
Total hardness	°G	3.00
Chloride	mg Cl dm^{-3}	2.38
Sulphate	mg SO_4 dm^{-3}	14.00
Calcium	mg Ca dm^{-3}	30.00
Magnesium	mg Mg dm^{-3}	7.810
Kalium	mg K dm^{-3}	1.500
Natrium	mg Na dm^{-3}	0.450
Oxidability	mg O_2 dm^{-3}	7.280
Conductivity	μS 18°C	104.900
Ammonia	mg N-NH_4 dm^{-3}	0.125
Nitrite	mg N-NO_2 dm^{-3}	0 003
Nitrate	mg N-NO_3 dm^{-3}	0.100
Phosphate	mg PO_4 dm^{-3}	0.009
Total phosphorus	mg P dm^{-3}	0.008
Alkalinity	mg HCO_3^{-1} dm^{-3}	1 000

in periods when in both streams water discharges were fairly stabilized and the water level medium or low. Algae were taken from stones and from the surface of the mud. The sampling also included mosses. The material was preserved in a 4% formalin solution.

Laboratory processing and quantitative elaboration were carried out according to methods developed by Starmach (1969) and Kawecka (1980). The assumption was that with 30—70 taxa in the environment their number was determined as small, with 71—110 as medium, 111—150 as large, and with their number exceeding 150 as very large. The coverage of algae which formed macroscopic concentrations and of mosses was evaluated on an area of about 2 m^2 of the stream bottom, using a 5-degree scale of coverage: 1. the given organism occurs in scarce numbers, 2. covers less than 25% of the bottom, 3. 25—50%, 4. 50—75%, 5. 75—100%. The number of diatoms was determined by counting the cells of each species in 10 fields of vision at magnification 40 × 17.

The field of vision was determined by the contour of the Zeiss graticule installed in the eyepiece. The percentage of diatom occurrence in the environment was calculated. Diatoms whose share in the community amounted to at least 5% and organisms which attained at

least degree 2 in the macroscopic scale of coverage, were determined as numerous species. The remaining species were regarded as sporadic. The size of diatom cells was evaluated by comparing them with the size of the graticule mesh, and expressed in multiples or fractions of the mesh. The numbers of diatom species were multiplied by the average size of their cells, this yielding the coefficients of coverage of organisms. By summing the coefficients of coverage of all species in the sample and conventionally multiplying this value by 2, the index of diatom biomass was obtained. In the accepted scale the index of diatom biomass was low with values from 400—800, medium from 801—1200, high from 1201—1600, and very high above 1600.

4. Results

In the stream with the natural bed algal communities were characterized by a medium number of taxa. Diatoms prevailed with regard not only to the number of taxa (Table II) but also to their abundance.

Table II. Floristic spectrum (number of species/percentage of occurrence) in streams with natural and regulated beds

Taxa	Streambed	
	natural	regulated
Cyanophyta	1 / 1.5%	3 / 4.3%
Chrysophyceae	1 / 1.5%	
Chlorophyta	2 / 3%	2 / 2.8%
Bacillariophyceae	63 / 94%	65 / 92.9%
Total	67	70

Among them, species of the genus *Achnanthes* (chiefly *A. minutissima*), *Diatoma hiemale* with the variety *mesodon*, *Ceratoneis arcus*, and *Cymbella ventricosa* were most frequently encountered. The mean value of the index of diatom biomass was high. Periodically, *Hydrurus foetidus* also developed very abundantly and *Ulothrix zonata* occurred in large numbers (fig. 1).

In the stream flowing in the regulated bed algal communities were also characterized by an average number of taxa. Diatoms prevailed quantitatively (Table II) but rarely developed larger populations. Periodically *Prasiola fluviatilis* occurred in fairly abundant concentrations while the development of *Ulothrix zonata* was poorer than in

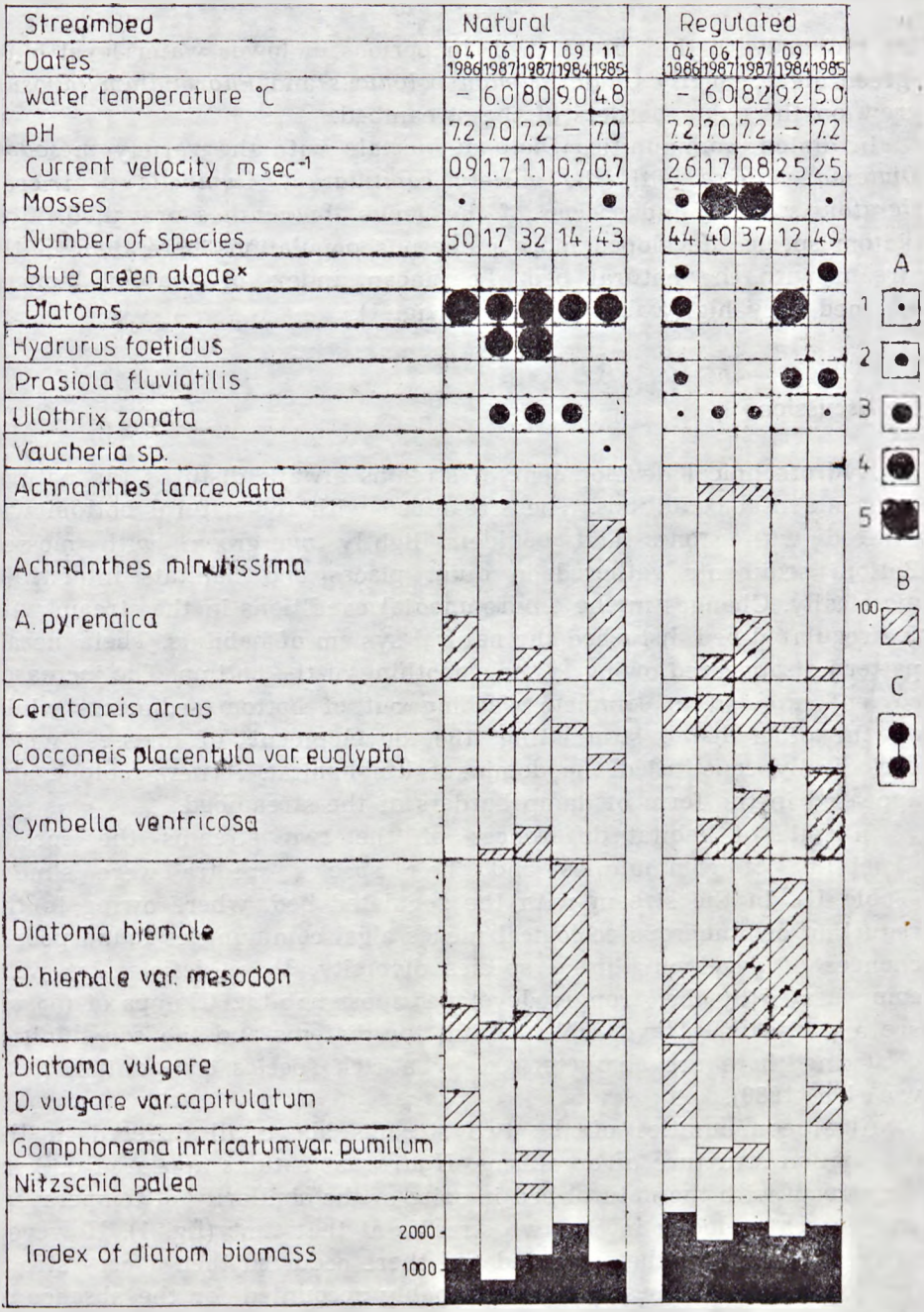

Fig. 1. Algal communities in streams with natural and regulated beds: species forming macroscopic concentrations and numerous diatom species. A, C — scale of coverage; C — the covering includes a group of organisms; B — 100 cells in 10 fields of vision; * — *Chamaesiphon polonicus*, *Homoeothrix janthina*, *Phormidium favosum*

the stream with the natural bed. In periods of lower water level blue-green algae, chiefly *Chamaesiphon polonicus* and *Phormidium favosum* grew on the damp borders of the streambed.

In diatom communities *Diatoma hiemale* with the variety *mesodon*, *Diatoma vulgare* with the variety *capitulatum*, *Cymbella ventricosa*, *Ceratoneis arcus*, and species of the genus *Achnanthes* prevailed. Most diatom species developed more numerous populations here than in the stream with the natural bed. The mean index of diatom biomass attained very high values here, too (fig. 1).

5. Discussion

Hydrotechnical development of streams always disturbs the natural environmental conditions. The streambed with the natural bottom was covered with stones and boulders lightly overgrown with mosses. Bottom sediments gathered in quiet places and habitats interwined mosaically. Changes in the environmental conditions in the stream with the regulated bed disturbed the natural system of habitats. Their mosaic pattern disappeared owing to the smoothing of the bottom. The increased current rate led to complete washing out of bottom sediments while, on the other hand, stimulating the development of mosses which periodically constituted the dominant life habitat. A new biotope also appeared in the form of damp borders of the streambed.

In spite of habitat differences of the two streams the species variability of communities and their species spectra were similar (Table II). In the stream with the regulated bed, where owing to the reduction of numerous ecological niches algal communities found poorer chances of developing great species diversity, these deficiencies were compensated by the strongly developed moss habitat. Clumps of mosses are a particularly favourable habitat for diatoms and the communities occurring there are characterized by a rich species composition (K a w e c k a 1980).

Algal communities of the two streams above all differed in the domination structure of organisms. *Hydrurus foetidus* appeared only in the stream with the natural bed in spite of the similarity of temperature and current velocity in the two streams at that time (fig. 1). However, in the stream with the regulated bed there occurred then a very strong development of mosses and this probably accounted for the absence of *Hydrurus foetidus*. Observations on the development of this species in montane streams showed that it formed abundant concentrations directly on stones and disappeared when they were overgrown by mosses or covered with layer of mud (K a w e c k a 1981). Similarly, H o l m e s and W h i t t o n (1981) stated that below the dam in the River Tees the

inhibition in the development of *H. foetidus* might have been caused by the increased growth of mosses.

Prasiola fluviatilis occurred only in the stream with the regulated bed in periods when the current rate attained a high velocity (2.5—2.6 m s^{-1}). *P. fluviatilis* is very well adapted to life in the current since at the base of its leafy thallus this organism has a holdfast with rhyzoids, with which it attaches itself to the substratum, thus efficiently resisting the action of the current. In the case of red algae Sheath and Hambrook (1988) found that tissue-like thalli of wide cross-section constitute one of the forms of life strategy of these algae in conditions of the rapid current. It is difficult to explain why this organism did not appear in the stream with the natural bottom. The demands of this species with regard to the current have not yet been studied in detail and the lower limit of the current velocity for its growth is not known. However, observations suggest that it occurs in a wide range of current velocity, being encountered both in streams and springs (Starmach 1972). It is possible that in the stream with the natural bed the absence of *P. fluviatilis* in the period of abundant development of *Ulothrix zonata* results from the competitiveness of these two organisms.

Ulothrix zonata occurred in both streams fairly numerously at a current rate of 0.7—1.7 m s^{-1}, though it formed larger populations in the stream with the natural bed. At a current rate above 2 m s^{-1} only traces of thalli were encountered. In such conditions delicate filaments of green algae are mechanically torn from the substratum. On the damp borders of the lined streambed blue-green algae developed abundantly. *Chamaesiphon polonicus* and *Phormidium favosum* prevailing among them. Communities of blue-green algae are also found numerously on the damp borders of lakes (Godward 1937, Kann 1959). The ability to withstand drying out is common in blue-green algae. *Chamaesiphon polonicus* frequently appears on damp rocks in the zones of splashing water (Starmach 1929, Kann 1973, Kawecka 1981). The very widely distributed species *Phormidium favosum* also settles damp boulders (Jaag 1945).

The domination structure of diatoms was similar in the two streams. However, in that with the regulated bed most species formed more numerous populations than in the natural stream, bringing about a distinct rise in the index of diatom biomass. This is probably associated with the increased of current velocity. The stimulating effect of the water current on the development of algae was reported by numerous authors (Butcher 1940, 1946, Blum 1960, Whitford 1960, Zimmermann 1961, 1962, McIntire 1966). It recalls the effect of eutrophication of high-mountain streams on the development of diatom

communities, since a similar increase in the index of diatom biomass was observed in such streams below the discharge of municipal sewage (K a w e c k a 1974, 1977).

Acknowledgement — The autor wishes to thank Professor Stanisław W r ó b e l for performing the water analyses.

6. Polish summary

Wpływ przeciwpowodziowej regulacji potoku górskiego na zbiorowiska glonów osiadłych

Budowę zbiorników retencyjnych oraz umacnianie dna i brzegów stosuje się przy przeciwpowodziowej regulacji potoków górskich. Potok Bystra (Tatry Zachodnie) został poddany tego typu regulacji. Z niewielkiego zbiornika retencyjnego, usytuowanego na potoku poniżej Kuźnic, woda odpływa dwoma potokami. Jeden z nich posiada koryto obudowane w formie kamiennej rynny, koryto drugiego potoku ma charakter naturalny. Traktując potok o dnie naturalnym jako punkt odniesienia, prześledzono wpływ obudowy koryta potoku na zbiorowiska glonów osiadłych. Koryto potoku o dnie naturalnym wypełniały kamienie i głazy, skąpo porośnięte mchem, w obszarach zacisznych gromadziły się osady. Srednia szybkość prądu wynosiła około 1 m s^{-1}. W potoku obudowanym szybkość prądu wzrosła do około 2 m s^{-1}, co spowodowało wypłukanie osadów dennych. Obficie rozwinęły się mchy, a przy niskim stanie wody odsłoniło się środowisko wilgotnych obrzeży. Oba potoki niosły wody zimne (temperatura 4,8—9,2°C), dobrze natlenione (10 mg O_2 dm^{-3}). Woda w zbiorniku miała charakter mezotroficzny (tabela I) i oddziaływała na chemię wód potoków.

W zbiorowiskach glonów obu potoków liczba taksonów była dość wyrównana z przewagą okrzemek (tabela II). Znaczne różnice obserwowano w strukturze dominacji gatunków (ryc. 1).

Hydrurus foetidus wystąpił tylko w potoku o dnie naturalnym. Liczniej pojawiała się tu także *Ulothrix zonata*. W potoku o korycie obudowanym obficie występowała *Prasiola fluviatilis*. Na wilgotnych obrzeżach koryta tworzyły skupienia sinice, głównie *Chamaesiphon polonicus* i *Phormidium favosum*. W zbiorowiskach okrzemek obu potoków przeważały gatunki: *Diatoma hiemale* z odmianą *mesodon*, *Cymbella ventricosa*, *Ceratoneis arcus*, gatunki z rodzaju *Achnanthes*. Jednakże w potoku o korycie obudowanym okrzemki tworzyły większe populacje i wskaźnik ich biomasy osiągał wyższe wartości.

Biorąc pod uwagę ekologiczne wymagania organizmów przedyskutowano różnicowanie się zbiorowisk glonów w obu potokach.

7. References

B l u m J. L., 1960. Algal population in flowing waters. Spec. Publ. Pymatuning Lab. Field Biol., 2, 11—21.

Butcher R. W., 1940. Studies on the ecology of rivers. 4. Observations on the growth and distribution of the sessile algae in the River Hull, Yorkshire. J. Ecol., 28, 210—223.

Butcher R. W., 1946. Studies on the ecology of rivers. 6. The algal growth in certain highly calcareous streams. J. Ecol., 33, 269—283.

Godward M., 1937. An ecological and taxonomic investigation of the littoral algal flora of Lake Windermere. J. Ecol., 25, 496—569.

Holmes N. T. H., B. A. Whitton, 1981. Phytobenthos of the River Tees and its tributaries. Freshwat. Biol., 11, 139—163.

Jaag O., 1945. Untersuchungen über die Vegetation und Biologie der Algen des nackten Gesteins in den Alpen, im Jura und im Schweizerischen Mittelland. Beitr. Kryptogamenflora Schweiz, 9 (3), 7—560.

Jäger P., B. Kawecka, M. Margreiter-Kownacka, 1985. Zur Methodik der Untersuchungen der Auswirkungen des Wasserentzuges in Restwasserstrecken auf die Benthosbiozönosen (Fallbeispiel; Radurschlbach). Oesterr. Wasserwirtsch., 37, 7/8, 190—202.

Kann E., 1959. Die eulitorale Algenzone im Traunsee Oberösterreich. Arch. Hydrobiol., 55, 129—192.

Kann E., 1973. Zur Systematik und Ökologie der Gattung *Chamaesiphon* (Cyanophyceae). 2. Ökologie. Arch. Hydrobiol., Suppl. 41, Algol. Stud., 8, 243—282.

Kawecka B., 1974. Effect of organic pollution on the development of diatom communities in the alpine streams Finstertaler Bach and Gurgler Ache (Northern Tyrol, Austria). Innsbruck, Ber. nat.-med. Ver., 61, 71—82.

Kawecka B., 1977. Biocenosis of a high mountain stream under the influence of tourism. 3. Attached algae communities in the stream Rybi Potok (the High Tatra Mts, Poland) polluted with domestic sewage. Acta Hydrobiol., 19, 271—292.

Kawecka B., 1980. Sessile algae in European mountain streams. 1. The ecological characteristics of communities. Acta Hydrobiol., 22, 361—420.

Kawecka B., 1981. Sessile algae in European mountain streams, taxonomy and ecology. Acta Hydrobiol., 23, 17—46.

Kawecka B., 1990. Le communità algali dei torrenti d'origine glaciale nei loro aspetto estivo: Rio Plima e Rio Forcola del Parco Nazionale dello Stelvio [Communities of sessile algae in the summer aspect in streams of the Stelvio National Park (Ortles Alps, Italy): The Plima stream with the affluent Furkel]. Quad. Parco Nat. Stelvio, (in press).

McIntire C. D., 1966. Some effects of current velocity on periphyton communities in laboratory streams. Hydrobiol., 27, 559—570.

Ross E., S. R. Rushforth, 1980. The effect of a new reservoir on the attached diatom communities in Huntington creek, Utah, U.S.A. Hydrobiol., 68, 157—160.

Sheath R. G., J. A. Hambrook, 1988. Mechanical adaptations to flow in freshwater red algae. J. Phycol., 24, 107—111.

Starmach K., 1929. Über polnische *Chamaesiphon* Arten. Acta Soc. Bot. Pol., 6, 30—45.

Starmach K., 1969. *Hildenbrandtia rivularis* i glony towarzyszące w potoku Cedronka koło Wejherowa (województwo Gdańsk) — *Hildenbrandtia rivularis* and associating it algae in the stream Cedronka near Wejherowo (Gdańsk voivode). Fragm. Flor. et Geobot., 15, 387—486.

Starmach K., 1972. Chlorophyta 3. Zielenice nitkowate. Flora Słodkowodna Polski [Filamentous green-algae. Freshwater Flora of Poland]. 10, Warszawa-Kraków, PWN, 750 pp.

Ward J. V., 1976. Comparative limnology of differentially regulated sections of a Colorado mountain river. Arch. Hydrobiol., 78, 319—342.

Whitford L. A., 1960. The current effect and growth of freshwater algae. Trans. Amer. Micros. Soc., 79, 302—309.

Zimmermann P., 1961. Experimentale Untersuchungen über die ökologische Wirkung der Stromgeschwindigkeit auf die Lebensgemeinschaften des fliessenden Wassers. Schweiz. Z. Hydrol., 23, 1—81.

Zimmermann P., 1962. Der Einfluss der Strömung auf die Zusamensetzung der Lebensgemeinschaften in Experiment. Schweiz. Z. Hydrol., 24, 403—411.