

Oceanological and Hydrobiological Studies  
Vol. XXXII, No. 1

Institute of Oceanography

(27-38)  
2003

University of Gdańsk

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Research Article

**RESPONSE TO DRYING OF CYANOBACTERIA AND ALGAE  
COMMUNITIES IN TATRA MTS STREAM (POLAND)**

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**Key words:** Tatra Mts streams, Cyanobacteria, sessile algae, ecology, drying.

**Abstract**

The structure, dynamics and chlorophyll *a* content of lithoreophilous communities of Cyanobacteria and algae in two periodically drying sectors of the stream: in its upper (alpine), and middle part (forest) zones were investigated. In both sectors the diversity of species was low. After snow melt, in the upper part, the stones were successively colonized by Cyanobacteria (with *Chamaesiphon polonicus* (Rostafiński) Hansgirg prevailing), and green alga *Klebsormidium rivulare* (Kütz.) Starmach, finally obtaining stable and abundant communities. In the middle part of the stream, a spring explosion of *Klebsormidium rivulare* and species from the Chlorococcales group was observed. They developed temporary, since they disappeared after the June spate. Later this area was colonised mainly by *Homoeothrix janthina* (Bornet et Flahault) Starmach, *Hydrurus foetidus* (Villars) Trevisan, and diatoms, coming from a neighbouring non drying part of the stream. The chlorophyll *a* content in both sectors was low (2 - 55.8 mg m<sup>-2</sup>).

**INTRODUCTION**

Changes in water level are a very important ecological factor particularly concerning the development of organisms. In extreme cases a periodical desiccation of the whole stream, or of some parts of it is observed; it causes dramatic stress for the organisms living there, and obviously affects the character

of biocenosis. The streams periodically drying up and the Cyanobacteria and algae communities described here or their productivity come mainly from a warm (Busch & Fisher 1981, Peterson, Grimm 1992, Aboal *et al.* 1996) and cold (Broady 1982, 1989, Vincent & Howard-Williams 1986, Howard-Williams *et al.* 1986, Howard-Williams & Vincent 1989, Hawes 1989, Kawecka, Olech 1993, Sheath, Müller 1997) climatic zone. The environments mentioned above are also to be found in high mountains (Kawecka 1971, 1980, Kawecka *et al.* 1971, Kownacki *et al.* 1997).

In the present work the study of structure, dynamics and chlorophyll *a* content of Cyanobacteria and algae communities in two periodically dried up sectors of a Tatra Mts stream was undertaken. It is part of a series of observations concerning the little-known ecological requirements of Cyanobacteria and algae such as light (Kawecka 1985, 1986, 1989, 2003) and biogens (Kawecka 1977, 1993). They have been for many years carried out in the Polish part of the High Tatras in order to learn more about the mechanisms of zonal distribution of organisms along a Tatra Mts streams (Kawecka 1965, 1971, 1980, 1981, Kawecka *et al.* 1971).

## MATERIAL AND METHODS

The investigations were carried out in 1992 and 1993 in two drying sectors of the stream in the course Czarny Potok-Sucha Woda. The first situated in the upper part of the Czarny Potok stream below the outlet of the lake Czarny Gąsienicowy (stations 1-3), and the second one in the middle part of the Sucha Woda stream (Station 4); Fig. 1. The material was collected about 2 weeks after snow melting. The drying sector in the upper part (Czarny Potok) was investigated from spring to autumn 1993 at monthly intervals, but already in August the water at Station 3 dried out.

The material from the drying sector in the middle part (Sucha Woda) was collected only from May to July 1992 at 2 week intervals, because in August this part of the stream had totally dried.

The collection and description of material were made according to methods recommended by Starmach (1969); see also Kawecka (1980). The materials were taken from the stones, and preserved in 4 % formalin solution. The covering of organisms forming a macroscopic aggregation on about 4 m<sup>2</sup> of the stream bottom was estimated using a 5 - score scale as follows: 1- organisms form small aggregation, 2- cover less than 25 % of bottom area, 3- cover 25-50 %, 4- 50-75 %, and 5- 75-100 % of bottom area. The chlorophyll *a* contents were measured using SCOR - UNESCO (1971) methods. The materials were collected from the surface of 3 random taken stones. The projection of stones on the surface was computed, and the results was given in 1 m<sup>-2</sup> unit. In the upper part crusts of

Cyanobacteria and filaments of Chlorophyceae formed separate aggregations, hence it was possible to calculate the Chlorophyll *a* individually for both groups of organisms.

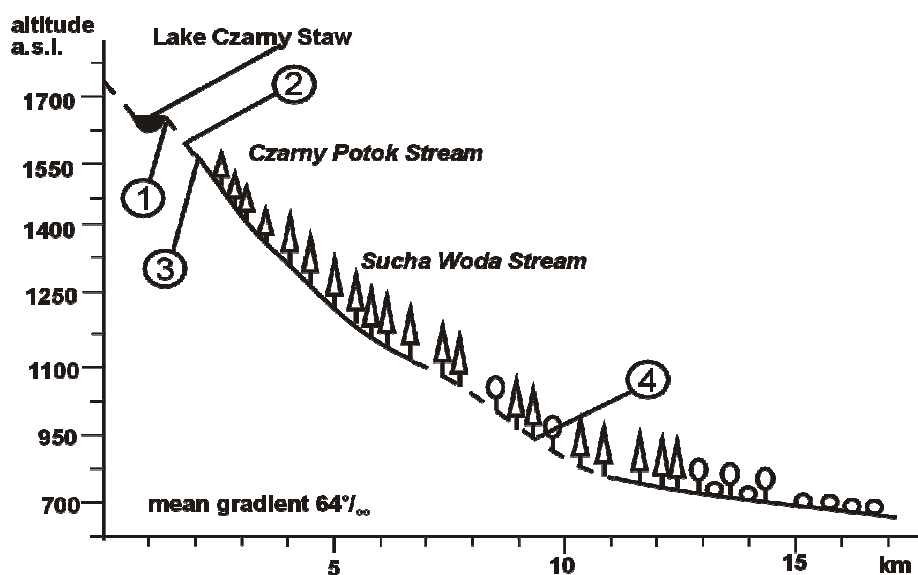


Fig. 1. Localisation of sampling stations.

### Study area

The investigations were carried out in the Polish part of the High Tatras, i.e. the highest part of the Carpathian (max. alt. 2663 m.), and entirely protected as a National Park. Two periodically drying sectors of the stream being situated in the course of the Czarny Potok- Sucha Woda stream were investigated. (Fig. 1).

Czarny Potok drains Czarny Gąsienicowy lake situated in alpine zone (alt. 1620 m.). The water of the stream disappears periodically over a distance of approx. 1 km. starting at the outlet of the lake. At an altitude of about 1530 m. the stream is fed by the moraine springs which arise in the stream bed. Farther down the stream (known as Sucha Woda) flows through the forest zone.

In the middle part (of about 1100 m.) the water again disappears in a sector of about 2,5 km., and the stream is fed by large vauclusian springs situated at an altitude of about 920 m. The stream (in the lower part known as Cicha Woda) leaves the Tatra Mts and feeds Poroniec (a tributary of the Biały Dunajec) at altitude approximately 750 m.

The stream bed is stony, with rocks and boulders. The loss of water is caused by karstic phenomena. In autumn a decrease in water flow can be observed, and from November to May (or June in the upper part) total desiccation. Total drying also occurs in some parts of the stream in a hot summer, as occurred in 1992 and 1993.

The stream is filled with water after snow melting, the water level is high, and in June regularly spate occurs. In July the flow has been stabilised. The chemical composition of the stream water correspond with geological structure of its catchment (Pasternak 1971, Bombówna 1971, Szarek 1994). In the upper part built with crystalline rocks (granite) the water is extremely poorly mineralised. In the middle and lower parts, where sedimentary rock (mostly limestones and dolomites) occur more frequently, an increase in electrolytes is observed. Among the cations, calcium and magnesium prevail in comparison with potassium and sodium which occur in extremely small quantities. Bicarbonates prevail among anions, the content of sulphates and chlorides being very low. The amount of mineral forms of nitrogen and phosphates is poor, while oxidability and BOD<sub>5</sub> are low. The water of the stream is well oxygenated, with pH ranging from 5.3 to 8.5.

## RESULTS

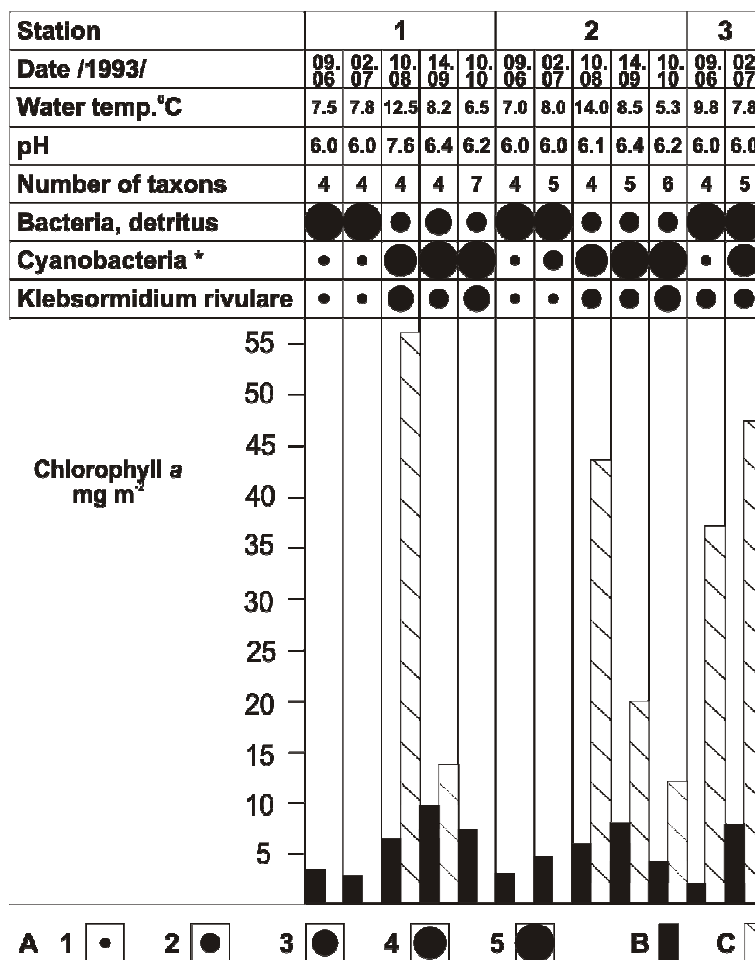
### **Lithoreophilic communities of Cyanobacteria and algae in a drying sector of the upper part of the course Czarny Potok – Sucha Woda stream (fig. 2)**

In the communities only a few species of organisms were encountered. The structure was similar over the whole length of this area. The Cyanobacteria was prevailed, mainly *Chamaesiphon polonicus*, and also green alga *Klebsormidium rivulare* being common there. Diatoms were only sporadically found (*Diatoma hyemalis* (Roth) Heiberg, *D. mesodon* (Ehr.) Kütz., *Fragilaria arcus* (Ehr.) Cl., *Meridion circulare* (Greville) Ag.)

After snow melt, the stream bed was colonised by bacteria, forming a slimy coating with embedded detritus particles. Cyanobacteria and *Klebsormidium rivulare* were found in small amounts. Later an abundant development of Cyanobacteria was noted, very soon covering bottom of the stream, and remaining there throughout the period of investigation. *Klebsormidium rivulare* was less spread, but formed thick aggregations on stones in the environment of splashing water.

The chlorophyll *a* contents were from 2 to 56 mg m<sup>-2</sup> and distinctly depended on the species composition, and the season. The lowest value of chlorophyll *a* concentration was noted in Cyanobacteria aggregations during the

colonisation period, and the highest in *Klebsormidium rivulare* thalli during the summer.



**Fig. 2.** Community structure of Cyanobacteria and algae, and the content of chlorophyll *a* in periodically drying sector in the upper part of the course of Czarny Potok – Sucha Woda stream.

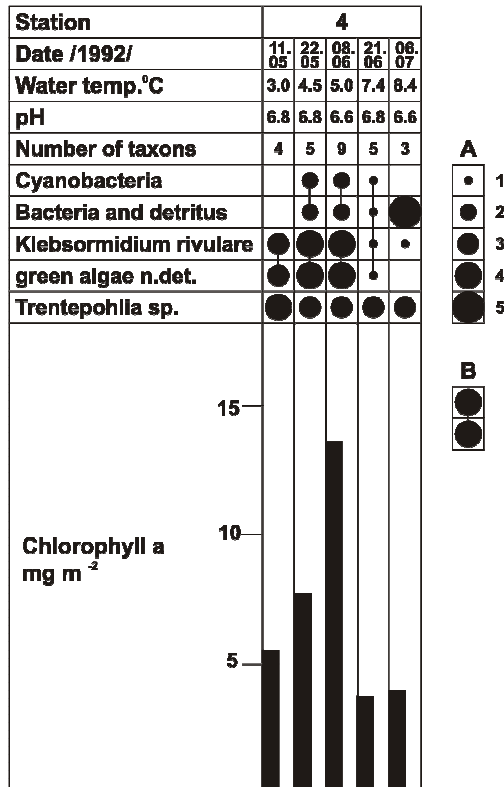
A. Scale of covering: 1 – organisms form small aggregations, 2 – cover less than 25% of the bottom, 3 – 25-50%, 4 – 50-75%, 5 – 75-100%

B. Chlorophyll *a* content in Cyanobacteria aggregations

C. Chlorophyll *a* content in green algae aggregations

\* *Chamaesiphon polonicus* with accompanying *Calothrix* sp., *Phormidium* sp., *Pleurocapsa* sp.

### Lithoreophilic communities of Cyanobacteria and algae in a drying sector of the middle part of the course Czarny Potok – Sucha Woda stream (fig. 3)



**Fig. 3** Community structure of Cyanobacteria and algae, and the content of chlorophyll *a* in periodically drying sector in the middle part of the course of Czarny Potok-Sucha Woda stream.

- A. Scale of covering: Scale of covering: 1 – organisms form small aggregations, 2 – cover less than 25% of the bottom, 3 – 25-50%, 4 – 50-75%, 5 – 75-100%
- B. The covering includes a group of organisms

\* cells like *Chamaesiphon* sp.

In the communities only a few species of organisms were found. The most numerous were green-algae, diatoms (*Diatoma hyemalis*, *D. mesodon*, *Fragilaria arcus*, *Meridion circulare*), encountered sporadically, and richest in summer. In the development of algae two periods were distinguished. The first covered the period of early spring, when the bottom was successively emerging from under the snow. At this time a dynamic development of green algae was observed. At first, the community was richer in unicell Chlorophyceae (with the Chlorococcales group), after which *Klebsormidium rivulare* prevailed. Dispute the fact that the green algae achieved considerable cover, they only formed a thin layer on the bottom, and chlorophyll *a* concentration was low (only to 13.5 mg m<sup>-2</sup>). However, after a spate in the second half of June, the algae were almost totally drained out, and in consequence the concentration of chlorophyll *a* was drastically reduced.

In the second stage (July) when the water flow had stabilised after June spate, the stream-bed was colonised by mucilage aggregations of bacteria, in which the particles of detritus as well as single cells of diatom were accumulated. The

unusually dry season of 1992 led to the stream's drying out so early that the communities of blue-green and algae characteristic for these areas has no chance to develop. In normal conditions *Homoeothrix janthina*, *Hydrurus foetidus*, and diatoms mainly *Achnanthes minutissima* Kütz., *Diatoma hyemalis*, *D. mesodon*, *Fragilaria arcus* accompanying them prevail there. *Klebsormidium rivulare* developed only in small amounts on wet stones. It increases its cover by the autumn, when the water level falls. At that time, also blue-green *Chamaesiphon polonicus* starts to develop well (Kawecka 1971, 1980).

## DISCUSSION

The drying sectors of the stream belong to astatic environments, where extreme variation of environmental conditions is a characteristic feature. Drying is the important factor controlling the development of communities of Cyanobacteria and algae in the upper part of the stream. In its middle part it only temporally affects the character of phytocenosis developing there.

The diversity of litorheophilic communities of both drying sectors was very poor, and could only be compared with the scarce numbers of species in glacial streams flowing *e.g.* in Swedish Lapland and in the Alps (Kawecka 1980). This habitat was characterised by very scarce diatom taxa, whose occurrence definitely affects the species diversity of algal communities in mountain streams (Kawecka 1980). It seems that neither drying should limit the development of diatoms owing to the ability of these organisms to survive a drought (Evans 1958, 1959, Hostetter, Hoshaw 1970, Kawecka, Eloranta 1994) nor the temperature which plays no important role in the differentiation of diatom communities (Cholnoky 1968). The poor development of diatoms may rather be attributed to deficiency in some microelements. It shows that in general the chemical composition of waters is similar in the drying environment and in the neighbouring areas with a constant water flow fed from sources rising in the stream bed (Szarek 1994); however, the diatom communities differ considerably (Kawecka 1971). It is interesting that only a few species and cells of diatoms are found on stones while in moss turf they form communities of rich taxonomic composition, though not very abundant ones (Kawecka 1971). In mountain streams the moss turf is among the habitats with the most numerous occurrence of diatoms (Kawecka 1980). For these organisms it is both a trap and a shelter (owing to the reduced current). The rough surface of twigs favours their colonisation and it seems that there also develop beneficial nutritional conditions for diatom growth. In the drying area of the mid-course of the Sucha Woda stream a scarce occurrence of diatoms was also recorded, although only in early spring when this area was filled with

water from thawing snow, it was isolated from the remaining sectors of the stream. It may be that this was due to nutrient deficiency.

In the upper drying sections of the High Tatra streams the crustacean Cyanobacteria with the dominant *Chamaesiphon polonicus* occur abundantly, forming a characteristic zone (Kawecka 1965, 1971, 1980, Kawecka *et al.* 1971). *Ch. polonicus* also dominates in the upper courses of streams in the Western Tatra Mts (Wasylik 1971) and at banks of alpine streams (Kann 1978). Cyanobacteria also occur abundantly in the streams of the Antarctic Circle (Broady 1982, 1989, Vincent, Howard-Williams 1986, Howard-Williams *et al.* 1986, Howard-Williams & Vincent 1989), of the Arctic Circle (Sheath & Müller 1997), and in the streams of hot deserts (Busch & Fisher 1981).

The occurrence of Cyanobacteria in streams of temporary water flow is justified since these organisms are characterised by a great tolerance of environmental conditions. They frequently colonise environments presenting extreme living conditions (Whitton & Sinclair 1975) and are particularly resistant to drying and freezing and to the cycles of defrosting and freezing. With the occurrence of favourable conditions they rapidly regain their metabolic activity (Kawecka, Eloranta 1994)

The drying areas in the upper course of the Czarny Potok stream and in the middle course of the Sucha Woda stream are also colonised by the green alga *Klebsormidium rivulare*. This organism frequently appears in astatic environments and in the soil (Kawecka, Eloranta 1994), showing a capacity for tolerating the stress connected with the decreasing water flow (Morison, Sheath 1985). It is fairly frequent in the streams of the Tatra Mountains, developing on wet boulders lying in the splash zone. This green alga occurs in alpine streams (Kann 1978), is abundantly represented in the mountain streams of British Columbia (Wehr 1981) and in frosted rapidly flowing streams of the Antarctic Circle (Hawes 1989).

In neither of the investigated drying sectors was the occurrence of *Hydrurus foetidus* recorded in spite of the beneficial living conditions. It should be stressed that this species is known as a stenothermic organism living in cold waters (Kawecka 1981) and preferring good solar illumination (Parker *et al.* 1973, Kawecka 1981, 1985, 1986). Nor was *H. foetidus* recorded in other temporary streams of the Tatra Mountains, *e.g.* in a stream flowing from Lake Zmarzly Staw (Kawecka 1980), or in the drying sections of the Waksmundzki stream. It does not occur in the frosting streams of the Antarctic (Broady 1989) or the Arctic Circle (Sheath, Müller 1997). The mass occurrence of *H. foetidus* was recorded in Tatra streams with a constant flow (Kawecka 1971, Kawecka *et al.* 1971, Kawecka 1980). It may be supposed that this organism does not

tolerate desiccation, as found by Kann (1978) in her study on *H. foetidus* in alpine streams.

The dynamics of communities of Cyanobacteria and algae occurred differently in the temporarily drying upper course of the Czarny Potok stream and in the middle course of the Sucha Woda stream. In both sectors bacteria, the very important component of water ecosystems (Blinn *et al.* 1980, Geesey *et al.* 1977, 1978) began the colonisation of the substratum. In the Czarny Potok stream Cyanobacteria and algae successively colonised the environment, reaching the highest development in summer and autumn. This type of community has continued here for years (see Kawecka 1971), hence it is stable in character. In the middle course of the Sucha Woda stream the explosion of green algae development in spring was ephemeral, since these organisms disappeared after the passage of the spate, regularly occurring in the Tatras in June. After this disturbance the environment is colonised by organisms coming from neighbouring non-drying parts of the stream, as *Homoethrix janthina*, *Hydrurus foetidus*, and numerous diatoms chiefly *Achnanthes minutissima*, *Diatoma hyemale*, *D. mesodon*, *Fragilaria arcus*, and *Cymbella minuta* Hilse. The community developing here is characteristic of the forested part of the Tatra Mts streams (Kawecka 1971, 1980).

The chlorophyll *a* concentration of the drying sectors of the streams was low. The highest concentration was noted in the upper course of the Czarny Potok stream in the agglomerations of green algae (56 mg m<sup>-2</sup>). This value is important for the productivity of the investigated water areas since the abundance of these algae has been observed to increase in the next years. The chlorophyll *a* concentration in areas with a permanent water flow was many times higher. According to Szarek (1994), in the middle course of the Sucha Woda the concentration of chlorophyll *a* in the periphyton exceeded 150 mg m<sup>-2</sup>. These values are higher than those recorded in the eutrophic Tatra streams flowing across the Zakopane Basin (Kawecka 1996)

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