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# The effect of abiotic factors on chlorophyll *a* in attached algae and mosses in the Sucha Woda stream (High Tatra Mts, southern Poland)

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Abstract - In the Sucha Woda stream the content of chlorophyll *a* in the periphyton changed along the course of the stream, the lowest being found in the high mountain part and the highest in the middle part of the stream. In spite of significant differences in the insolation of the stream in its middle part, light did not significantly affect the chlorophyll *a* content in the attached algae, mosses, or the concentration of organic components in the algal envelopes. A positive correlation between the chlorophyll *a* content in the periphyton and N-$NO_3$, and a negative one between the water temperature and pH were shown. A significant effect of the water level on the concentration of chlorophyll *a* in the algae was observed.

Key words: montane stream, attached algae and mosses, chlorophyll *a*, light, nutrients.

## 1. Introduction

In the streams of the Tatra National Park many hydro-chemical and hydro-biological investigations have been carried out (Kawecka 1965, 1969, 1971, 1980, Bombówna 1968, 1971, 1972, Kownacka, Kownacki 1969, Kownacki 1971, 1977, Pasternak 1971, Galas 1993). In the algological aspect, these were mainly quality investigations concerning determination of the qualitative composition, structure, and seasonal variability of the species of attached algae against the background of the physico-chemical parameters of the stream waters. Investigations regarding the quantitative description of primary producers were seldom undertaken. Comparatively few investigations concerned the significant problem of determination of the interdependence between the algal biomass (expressed in mg chlorophyll *a* $m^{-2}$) and the quantity of nutrients dissolved in the water (Bombówna 1977, Kawecka 1993). In the Tatra streams investigations dealing with the effect of light on the qualitative composition of algae were carried out (Kawecka 1985, 1986), but this effect on the content of chlorophyll *a* in algae has not hitherto been studied.

The aim of the investigations carried out in the Tatra Sucha Woda stream was to determine:

a) changes in the content of chlorophyll *a* in the periphyton along the course of the stream,
b) the effect of light on the content of chlorophyll *a* in attached algae and mosses and on that of organic components in algal envelopes in shaded and unshaded sites,
c) the relation between certain selected physico-chemical factors of water and the chlorophyll *a* content in the periphyton.

## 2. Study area

The investigation covered the Czarny Potok stream flowing out of Lake Czarny Staw Gąsienicowy (alt. 1620 m) and joining the dry bed of the Sucha Woda stream at an altitude of 1435 m. From this place until the Filipczański Potok stream (826 m) the stream is called the Sucha Woda after joining the Cicha Woda. The Cicha Woda stream runs into the Poroniec stream at an altitude of 750 m (fig. 1). In the present work the whole water course has been called the Sucha Woda stream.

A typical feature of the Sucha Woda stream is the complete disappearance of its water in crevices rifts in the bedrock in a few places (especially in periods of smaller water discharge). The stream is 15.5 km long, and the catchment area is 68 $km^2$. The geological substratum of the catchment changes along the stream course; in the upper stream it is built of crystalline rocks, in the middle stream of sedimentary rocks, and in the lower stream of flysch rocks (Pasternak 1971). In its upper part the stream flows over an unshaded area (the alpine zone and the dwarf pine zone, altitude above 1530 m), and then over a shaded area (the montane and submontane forest zones). The bottom of the stream is stony.

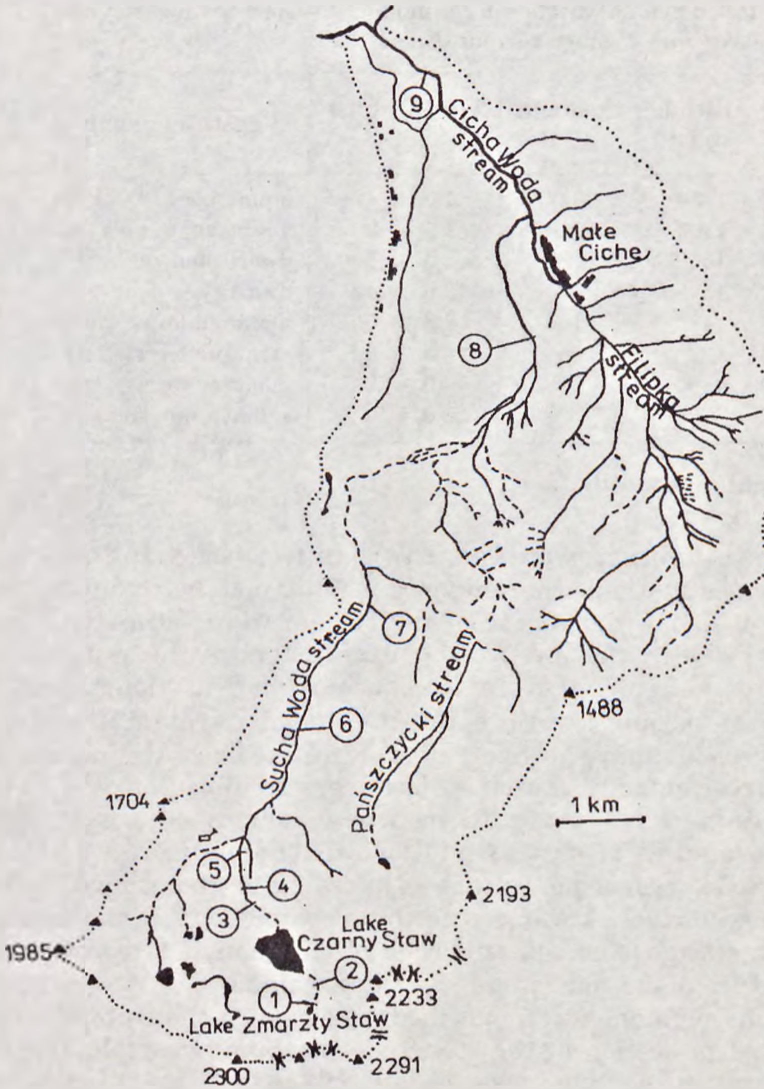


Fig. 1. Catchment area of the Sucha Woda stream showing the location of the eight sampling stations. Dotted lines indicate periodically dried up sections

The investigations were carried out at eight stations, a precise description of which is presented in Table I. Stations 1 to 3 were situated in the upper (altitude above 1550 m), temporarily flowing part of the stream, Station 4 in its spring section, surrounded by dwarf pine, above the upper forest line, and Stations from 5 to 8 in the forest zone of the stream.

Table I. Selected abiotic variables for sampling stations - the measurements concern places with average current (Galas 1993)

| Station | Altitude (m) | Gradient (%) | Width range (m) | Vegetation zone | Dry period |
|---|---|---|---|---|---|
| 1 | 1780 | 344 | 1.0 – 1.5 | alpine zone | XI – VI |
| 2 | 1700 | 210 | 1.5 – 2.5 | alpine zone | XI – VI |
| 3 | 1560 | 80 | 2.0 – 5.0 | dwarf pine zone | XI – V |
| 4 | 1540 | 100 | 3.5 – 4.0 | dwarf pine zone | |
| 5 | 1460 | 100 | 5.0 – 6.5 | montane forest zone | |
| 6 | 1330 | 66 | 4.5 – 6.5 | montane forest zone | |
| 7 | 860 | 20 | 6.0 – 9.0 | montane forest zone | |
| 8 | 775 | 20 | 8.0 – 10.0 | submontane zone | |

## 3. Material and methods

The investigations were carried out in two series. In the first year of the investigations the changes in chlorophyll *a* content in the periphyton along the course of the stream were estimated, and the relation between the physico-chemical factors of the water and the content of chlorophyll *a* in the periphyton was determined. The samples of periphyton were taken from all eight stations once a month from January to September 1991. At each station the algae from three randomly chosen stones, were scrubbed off with a brush into containers. At the stations where mosses occurred, a fourth stone, covered in moss, was additionally chosen. Care was taken to find a stone with a percentage of moss cover corresponding to the percentage of moss cover of the investigated section of the stream. At these stations the concentration of chlorophyll *a* in the material obtained from the four stones was determined.

The chosen stones were outlined, after which their projection area (a vertical projection of the stone onto a plane) was calculated. The chlorophyll *a* content was calculated per 1 $m^2$ of this area. Altogether, 186 samples of periphyton were collected. The qualitative composition presented in Results was given on the basis of investigations by Kawecka (1980, 1993).

Water for chemical analyses was taken seasonally from all the stations on the following dates: 26.01, 23.04, 17.06, and 12.08.1991. The results of the investigations are presented in Table II (Wojtan unpubl.).

In the following year the effect of light on the content of chlorophyll *a* in the algae and mosses and on organic components of

Table II. Range of variation of physical and chemical factors in the water of the Sucha Woda stream at 1991 (Wojtan unpubl.)

| Station | Temp. °C | pH | Dissolved oxygen mg $dm^{-3}$ | Ammonia $N-NH_4$ mg $dm^{-3}$ | Nitrite $N-NO_2$ mg $dm^{-3}$ | Nitrate $N-NO_3$ mg $dm^{-3}$ | Phosphate $PO_4$ mg $dm^{-3}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.9-6.9 | 6.1-6.4 | 9.6 | 0.22 | 0.001 | 0.56-1.06 | 0.02-0.15 |
| 2 | 1.5-2.5 | 5.3-5.8 | 9.4-10.9 | 0.20-0.26 | 0.001-0.003 | 0.31-0.89 | 0.02-0.03 |
| 3 | 2.0-5.0 | 6.0-6.5 | 9.3-10.2 | 0.19-0.27 | 0.003 | 0.60-1.13 | 0.02-0.03 |
| 4 | 3.5-4.0 | 6.2-6.5 | 9.9-11.2 | 0.18-0.22 | 0.002-0.003 | 0.58-0.80 | 0.01-0.04 |
| 5 | 1.0-9.1 | 6.3-6.6 | 9.8-12.2 | 0.19-0.22 | 0.001-0.003 | 0.58-0.84 | 0.01-0.07 |
| 6 | 2.0-7.9 | 6.6-6.9 | 10.4-11.7 | 0.17-0.21 | 0.001-0.003 | 0.56-1.09 | 0.01-0.04 |
| 7 | 1.2-8.5 | 7.2-7.4 | 10.4-12.6 | 0.18-0.21 | 0.001-0.004 | 0.51-1.06 | 0.01-0.03 |
| 8 | 0.2-12.8 | 7.2-7.6 | 10.1-13.0 | 0.17-0.22 | 0.001-0.003 | 0.62-0.90 | 0.01-0.04 |

algal envelopes at the shaded (Station 4) and unshaded (Station 5) was investigated. The samples of attached algae and mosses were taken at two-monthly intervals from November 1992 to December 1993. The samples of algae were collected according to the method described above. Additionally, three 900 $mm^2$ samples of mosses were cut out with a cylinder from three different stones and then scraped off. The results are given as calculated per 1 $m^2$. In all, 42 samples of algae and 42 samples of mosses were taken. The samples of water for chemical analysis were collected from both stations on dates analogical to the collecting of samples of algae and mosses.

At Stations 4 and 5 the measurements of photosynthetic active radiation (PAR) were carried out throughout the day using a phytophotometer on the dates 26.03, 25.06, and 14.09.1993, and on 11.01.1994. The results were registered in $\mu E\ m^{-2}\ s^{-1}$, and then calculated into diel doses of PAR, expressed in $E\ m^{-2}\ day^{-1}$.

Chlorophyll *a* in the attached algae and mosses was determined according to the ethanol method of Arvola (1981) modified by Sartori (1982), and the concentration of organic matter (loss of ignition) by calcining a dried sample at 550°C. In the water the following parameters were determined: pH, temperature, dissolved $O_2$, $N-NO_3$, $N-NO_2$, $N-NH_4$ and $PO_4$ according to the methods of Just, Hermanowicz (1964), and APHA (1971) (Tables II, III).

The statistical estimations comprised calculations of the mean values, ranges, standard deviation, correlation coefficient (using the one-way analysis of variance), and significance coefficient for correlated pairs (Student's - t, Wilcoxon's test).

Table III. Range of variation of physical and chemical factors in the water of the Sucha Woda stream at Stations 4 and 5 in 1992-1993

| Station | Temp. °C | pH | Dissolved oxygen mg dm$^{-3}$ | Ammonia $N-NH_4$ mg dm$^{-3}$ | Nitrite $N-NO_2$ mg dm$^{-3}$ | Nitrate $N-NO_3$ mg dm$^{-3}$ | Phosphate $PO_4$ mg dm$^{-3}$ |
|---|---|---|---|---|---|---|---|
| 4 | 2.0-6.8 | 6.2-7.5 | 10.2-11.7 | 0.088-0.240 | 0.001-0.003 | 0.633-0.846 | 0.012-0.048 |
| 5 | 0.6-6.0 | 6.2-7.8 | 10.2-11.8 | 0.104-0.220 | 0.001-0.003 | 0.558-0.760 | 0.018-0.060 |

The diel doses of PAR were calculated according to the formula:

$$DD = \Delta t \, [\, x_1 + 2\,(x_2 + \ldots + x_{n-1}) + x_n \,]$$

where:

DD – the diel dose,
$\Delta t$ – time between the measurements,
$x_1$ – first measurement,
$x_2 \ldots x_n$ – subsequent measurements.

In the investigations the time between the measurements was constant and amounted to 1 hour.

## 4. Results

The waters of the Sucha Woda stream were characterized by a neutral or slightly acid reaction (pH 5.3-7.6) and a low concentration of biogens (Tables II, III). They were well oxygenated (9.3-13.0 mg $O_2$ dm$^{-3}$), with a temperature from 0.9 to 12.1°C. Neither the quantity of biogens nor the oxygenation of the waters changed significantly along the course of the stream. However, certain differences in the reaction of the water occurred (pH at Stations 1-3 amounted to 5.3-6.5, at Stations 4-6 to 6.2-6.9, and at Stations 7-8 to 7.2-7.6).

On the particular dates of investigation changes in the chlorophyll *a* content were found in the periphyton along the course of the stream (fig. 2). At the stations with a dry period (Stations 1-3) the content of chlorophyll *a* in the algae was lowest (from 2.6 to 16.2 mg m$^{-2}$). Blue green algae prevailed (mainly *Chamaesiphon polonicus*). At Stations 4 and 5, where algae and mosses grew abundantly, the concentrations of chlorophyll *a* in the periphyton were high. In this section of the stream the dominant algal species were *Hydrurus foetidus* and *Homoeotrix janthina* with accompanying diatoms *Achnanthes minutissima*, *Diatoma hyemalis*,

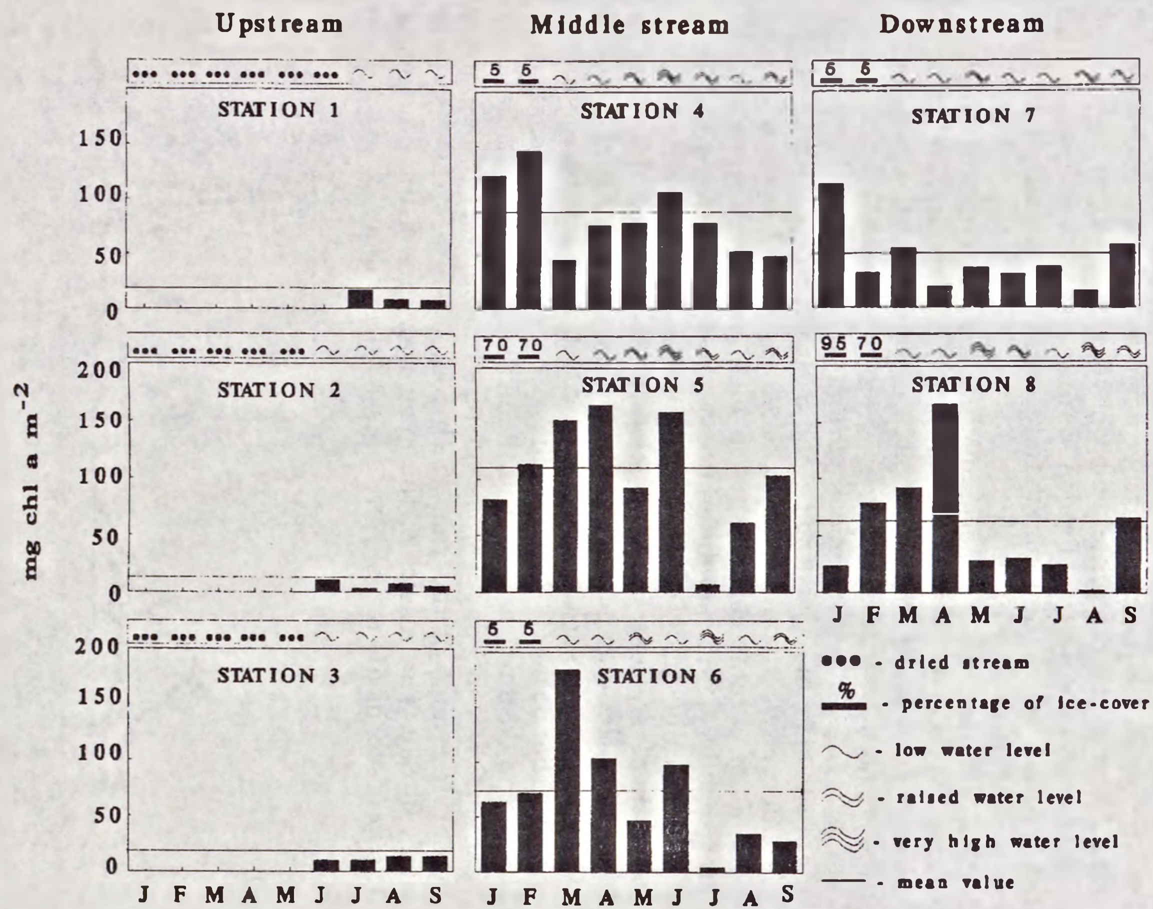


Fig. 2. Content of chlorophyll *a* in the periphyton in the Sucha Woda stream in 1991

and *Gomphonema angustum*. Further down the stream, especially at Stations 7 and 8, the content of chlorophyll *a* in the algae was lower than at Stations 4 and 5. Predominating species of algae at the Stations 7 and 8 were diatoms (mainly *Diatoma vulgaris*, *Cymbella silesiaca*, and *Cymbella affinis*).

At those stations with a permanent water discharge the highest content of chlorophyll *a* was registered in the winter months. A pronounced decrease in the chlorophyll *a* content in the periphyton occurred at high water level.

The level of physico-chemical parameters was similar for the waters of the stream at Stations 4 and 5, at which the effect of light on the chlorophyll *a* content in attached algae and mosses and on the content of organic components in algal envelopes were studied (no statistically significant differences were found). However, there were statistically significant differences in the amount of PAR reaching these stations ($p<0.001$, $t=7.44$, $N=94$). The diel dose of PAR reaching the unshaded site (Station 4) amounted to 6.1-35.4 E $m^{-2}$ $day^{-1}$, and that reaching the forest site (Station 5) to 2.7-10.4 E $m^{-2}$ $day^{-1}$. The dose of PAR reaching the forest site constituted 12-31% of the dose reaching the unshaded site. The lowest diel dose of PAR, i.e. 2.7 E $m^{-2}$ $day^{-1}$, was registered in January 1994 on one of the shortest days of the year, with completely overcast sky and snowfall all day. The results of the measurements of the amount of PAR (expressed in $\mu E$ $m^{-2}$ $s^{-1}$) are presented in figure 3.

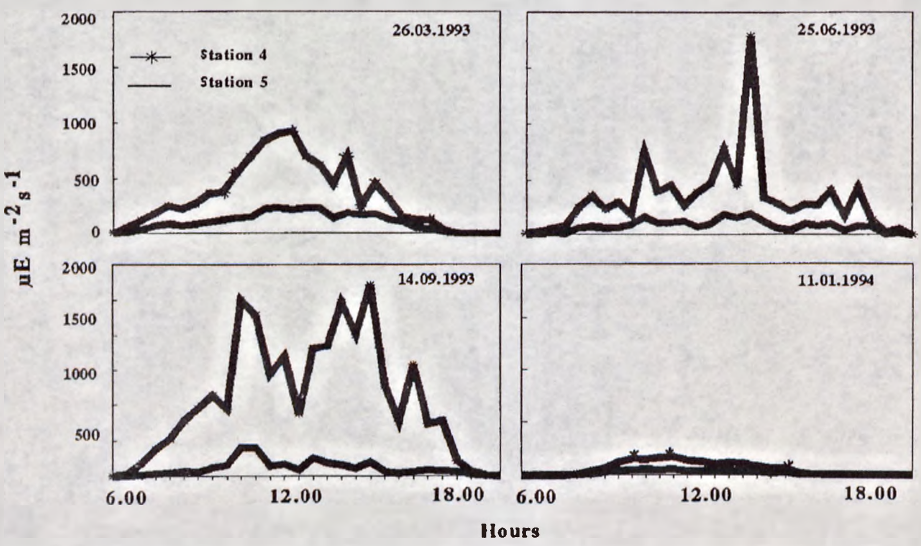


Fig. 3. Doses of phytosynthetic active radiation (PAR) reaching Stations 4 and 5 on the particular dates of the investigations

In spite of considerable differences in the insolation, no statistically significant differences in the content of chlorophyll *a* in the attached algae and mosses or in the concentration of organic components in the algae envelopes at the two stations were found. The concentration of chlorophyll *a* in the attached algae, mosses, and the content of organic components in the algae envelopes at Stations 4 and 5 on the particular dates of investigations are given in figure 4.

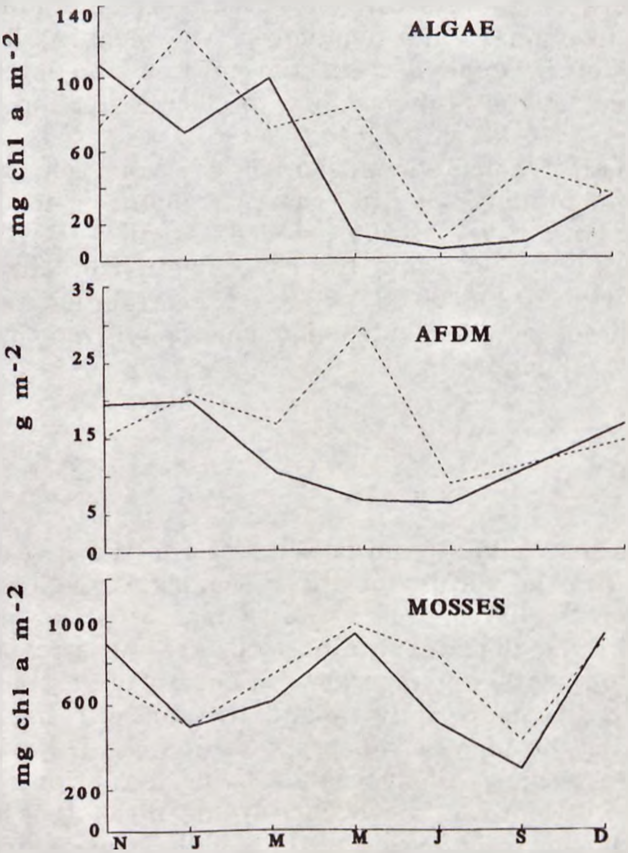


Fig. 4. Content of chlorophyll *a* in atttached algae and mosses and the concentration of organic matter in the algal envelopes (AFDM) at Station 4 (dotted line) and Station 5 (continuous line)

The content of chlorophyll *a* in the algae at these stations was high from November to May. In May there occurred a drastic decrease caused by a very high water level at Station 5. From this date the chlorophyll *a* content was lower than in the winter (except for December 1993) at both stations. The content of chlorophyll *a* in the algae at Station 4 amounted to 9.6-125.7 mg $m^{-2}$ but at Station 5 to 5.1-107.1 mg $m^{-2}$.

The content of organic components in the algae envelopes at the stations mentioned above amounted to 8.8-29.4 g $m^{-2}$ and to 3.5--19.9 g $m^{-2}$, respectively. They were definitely higher values than those registered at Stations 1 to 3 (1.6-4.9 g $m^{-2}$).

The content of chlorophyll *a* in the mosses at Stations 4 and 5 was high. At both stations similar changes in the concentration of chlorophyll *a* in the mosses were observed throughout the year, the highest values being in November, December and May, and the lowest ones in January and September. The mean annual value of the content of chlorophyll *a* in the mosses amounted to 710.1 ± 204.5 mg $m^{-2}$ at the Station 4, and to 666.5 ± 252.5 mg $m^{-2}$ at the Station 5.

The statistical calculations showed a correlation between the content of chlorophyll *a* in the periphyton and the water temperature (negative) ($N=50$, $r=-0.32$, $p<0.05$), pH (negative) ($N=45$, $r=-0.44$, $p<0.01$), and the concentration of nitrates in the water (positive) ($N=20$, $r=0.53$, $p<0.05$). No correlation between PAR and the content of phosphates and chlorophyll *a* content in the periphyton was found.

## 5. Discussion

In the Sucha Woda stream on the basis of the investigations of chlorophyll *a* in the periphyton three sections can be distinguished. This division was introduced by Kownacki (Kownacki et al., 1993). In the high mountain section of the stream (altitudes above 1550 m) with a temporary water discharge the content of chlorophyll *a* in the periphyton and the concentration of organic components in the algae envelopes were lowest. This was brought about the extremely unfavourable living conditions, i.e. small amounts of nutrients in the water, drying up of the stream, and icing over. In the section covering the middle stream attached algae and mosses grew abundantly (especially at the stations above and below the upper forest line, at which a high content of chlorophyll *a* was found in the periphyton). In the lower stream a decrease in the content of chlorophyll *a* in the periphyton was observed, which can be explained by great fluctuations in the water level and the increased velocity of the current at high water level. In favourable physico-chemical water conditions, i.e. a low water level, an appropriate current velocity, at the stations of the lower stream an abundant growth of algae and a high content of chlorophyll *a* in them occurred.

The shading by the tree canopy (Station 5) did not effect the chlorophyll *a* content in the attached algae, mosses or the concentration of organic components in the algal envelopes. Only in the winter, in extremely unfavourable weather conditions (short day, heavy overclouding, snow falls) did the small dose of the PAR reaching the stream bottom (the lowest PAR dose amounted to 2.7 E $m^{-2}$ $day^{-1}$) inhibit the growth of the attached algae and mosses. Hill and Knight (1988), among others, observed the importance of light as the main factor limiting the growth and biomass of algae in an extremely oligotrophic stream, Fox Creek in California. The diel dose of PAR reaching the stream amounted to $2.5 \pm 0.6$ E $m^{-2}$ $day^{-1}$. The increase in nutrients with such intensive shading of the stream did not lead to an increase in the algal biomass. A positive correlation between the amount of accessible light and the primary production and biomass of algae was found by, among others, Keythan and Lowe (1985) and Paaby and Goldman (1992). In their investigations in a Californian stream, Hill and Harvey (1990) found that the abiotic factor (light) regulated the biomass and productivity of algae loosely attached to the ground, but the biotic factor (scraping off the organisms) affected the firmly based algae.

Statistical calculations showed that in the Sucha Woda nitrates, pH, and water temperature have a significant effect on the content of chlorophyll *a* in the periphyton. A positive effect of nitrates on the algae biomass was found in experimental investigations by, among others, Bothwell (1989), Coleman and Dahm (1990), Hill and Harvey (1990), and Paaby and Goldman (1992). They showed that an increase in biogens in a stream deficient in nutrients causes an increase in algal biomass. Besides, Biggs and Gerneaux (1993) found that the algal biomass occurs only up to a certain level (a saturation point). Gregory (1980) believed biogens to be the most significant (after light) factor affecting the growth and biomass of algae in an oligotrophic stream.

For the growth of most algae the most favourable pH lies in the range between 6.5-8.5 (Kawecka, Eloranta 1994). In the Sucha Woda stream a more abundant growth of algae (the content of chlorophyll *a* in the periphyton) occurred at lower pH values and lower water temperatures.

The factor most strongly affecting the content of chlorophyll *a* in the periphyton was the water level. In the months with a distinctly higher water level, i.e. in May, July, and September (snow melt, long-lasting rainfall and storms), a drastic fall in the chlorophyll *a* content was found. It was caused by the mechanical destruction of the periphyton. The high water level had a decidedly greater effect on the biomass of algae than on the biomass of mosses. In situations of extremely low content of algal chlorophyll *a* mosses can constitute an essential nutritional basis for the primary consumers. In her studies of the productivity of a montane stream Bombówna (1972) observed the destructive effect of a high water level on the algal biomass in the River Raba. Disturbances in the functioning of a stream ecosystem resulting from sudden floods may explain the lack of strong interdependencies in the relation, e.g., between the content of chlorophyll *a* in the periphyton and biogens.

The present investigations showed that in the Sucha Woda stream:

- the content of chlorophyll *a* changed along the course of the stream,
- the light conditions at the shaded station did not affect the chlorophyll *a* content in the attached algae, mosses, or the content of organic components in the algal envelopes,
- nitrates, pH, temperature and water level significantly affected the content of chlorophyll *a* in the periphyton.

## 7. Polish summary


### Wpływ abiotycznych czynników na ilość chlorofilu *a* w glonach osiadłych i mchach w potoku Sucha Woda (Tatry Wysokie, południowa Polska)

W tatrzańskim potoku Sucha Woda (tabela I, ryc. 1) ilości chlorofilu *a* w glonach osiadłych i mchach zmieniały się wraz z jego biegiem (ryc. 2). W wysokogórskim odcinku potoku (stanowiska 1-3), o okresowym przepływie wody, ilości chlorofilu *a* w peryfitonie były najniższe. W odcinku obejmującym środkowy bieg potoku (stanowiska 4-6) glony osiadłe i mchy rozwijały się bujnie (wysokie ilości chlorofilu *a* w peryfitonie, szczególnie na stanowiskach powyżej i poniżej górnej granicy lasu). W dolnym biegu potoku (stanowiska 7-8) zaobserwowano zmniejszenie ilości chlorofilu *a* w peryfitonie w porównaniu do stanowisk 4 i 5, spowodowane dużymi wahaniami poziomu wody oraz zwiększeniem prędkości prądu przy wysokich stanach wód.

Zacienienie spowodowane koronami drzew (stanowisko 5) nie miało wpływu na ilość chlorofilu *a* w glonach osiadłych, mchach i na zawartość składników organicznych w powłokach glonowych. Wody potoku na stanowiskach odsłoniętym (stanowisko 4) i zacienionym (stanowisko 5) miały podobny poziom parametrów fizyko-chemicznych (tabela III). Dawki dobowe promieniowania fotosyntetycznie czynnego dochodzącego na stanowiska odsłonięte i zacienione różniły się istotnie statystycznie. Wyniki pomiarów PAR z poszczególnych terminów badań na

stanowiskach 4 i 5 przedstawiono na rycinie 3, natomiast ilość chlorofilu *a* w glonach osiadłych, mchach oraz zawartość składników organicznych w powłokach glonowych na rycinie 4.

Przebadane parametry fizyko-chemiczne wody (tabele II i III) miały wpływ na ilość chlorofilu *a* w peryfitonie. Obliczenia statystyczne wykazały ujemną korelację między ilością chlorofilu *a* w peryfitonie a pH i temperaturą wody i dodatnią z azotanami w wodzie.

Czynnikiem najsilniej wpływającym na ilość chlorofilu *a* w peryfitonie był poziom wody. W miesiącach o znacznie podwyższonym poziomie wody stwierdzono drastyczny spadek ilości chlorofilu *a* w peryfitonie.

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