

**Ecological characteristics of sessile algal communities
in streams flowing from the Tatra Mountains in the area
of Zakopane (southern Poland) with special consideration
of their requirements with regard to nutrients**

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Abstract - In montane streams with enriched nutrient content changes were observed in the structure of algal communities as compared with unpolluted waters, especially during autumn and winter, characterized by intensified tourism and low water level. The numbers of *Achnanthes minutissima* var. *minutissima* and *A. biasolettiana* var. *biasolettiana* fell while those of *Cymbella affinis*, *C. silesiaca*, *C. sinuata*, *Navicula cryptocephala*, *Nitzschia palea*, *Cladophora glomerata*, *Ulothrix zonata*, and species of the order Chlorococcales rose. The increase mass of algae was expressed by a higher index of diatom biomass and a higher content of chlorophyll *a*.

Key words: The Tatra Mts, Zakopane Valley, montane streams, sessile algae, ecology, nutrients.

1. Introduction

For many years Tatra streams have played the role of testing grounds for investigation of the ecology of algae. In the first stage the differentiation of the communities of sessile algae along the stream courses was investigated, their zonal development being assessed (Wasylik 1971, Kawecka 1965, 1971, 1980, Kawecka et al. 1971). Further studies concerned the effect of various ecological factors such as light, temperature (Kawecka 1985, 1986, 1989), and nutrients (Kawecka 1977, 1993) on the structure and growth of algal communities.

In the present work the role of nutrients in the differentiation of algal communities in montane streams was investigated on the example of the eutrophicating effect of Zakopane.

2. Study area

The Zakopane Valley lies in the Podhale region at the foot of the Western Tatras. The town of Zakopane with a population of 47 209 is among the largest tourist centres of Southern Poland, accommodating more than 2 million tourists every year, chiefly in the summer, autumn, and winter months.

The subject of the present investigation were the streams in the Biały Dunajec catchment. These streams flow out from sources in the Western Tatras in the montane forest zone: the Strążyski stream at an altitude of 1190 m and the Małotański stream at 1140 m. They leave the territory of the Tatra National Park at about 900 m alt. and flow into the Zakopane Valley. The Strążyski stream flows through the area of Zakopane as the Młyniska stream and the Cicha Woda stream as the continuation of the Małotański stream. They merge into the large Zakopianka stream which is one of the more important affluents of the Biały Dunajec River.

Six stations lying along the stream course were selected (fig. 1). The upper water sectors (Stations 1 and 4), of natural character, in the territory of the National Park just above the southern town boundary, were used as points of reference for waters enriched with nutrients in the streams flowing through the town of Zakopane (Stations 2, 3, 5, and 6).

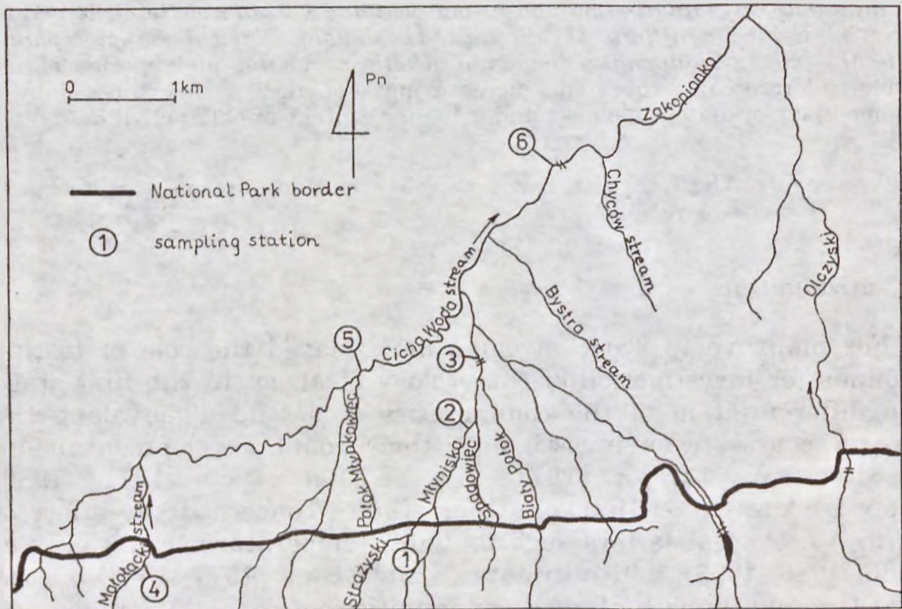


Fig. 1. Location of sampling stations in streams in the area of Zakopane

The stream waters are cold (0.1-12.7°C) and very well oxygenated, with a pH of 7.0-7.8. In the area of the Park they are oligotrophic and change into mesotrophic in the Zakopane Valley (Table I). In the pattern of water levels two maxima, in spring and in summer, are recorded, while in autumn and winter the water level falls considerably.

3. Material and method

The investigation was carried out in 1987-1988, algae being sampled from stones and the mud surface; mosses were also collected. The material was preserved in 4% formalin solution.

In the laboratory treatment and quantitative elaboration of the algal communities methods developed by S t a r m a c h (1969) and K a w e c k a (1980) were used. The communities were described by the number of taxa, their abundance, and the index of diatom biomass. The number of taxa was characterized according to a 5-score scale, being determined as small when 30-70 taxa occurred in the community.

The estimation of the coverage of algae forming macroscopic aggregations and of mosses on about 4 m² of the stream bottom was carried out using a 5-score scale of coverage. The abundance of diatoms was determined by counting the cells of each species in 10 microscopic fields at a magnification of 40 x 17, and computing their percentage occurrence in the community. The numerous species distinguished included diatoms showing at least a 5% share in the community and organisms which attained at least grade 2 in the scale of coverage. The remaining species were determined as sporadic. The coefficient of coverage was computed as a quotient of abundance and cell size; cell size was determined as a fraction or multiple of the mesh of the micrometric net (Zeiss produce) built into the eyepiece. The index of diatom biomass was determined by summing the coefficient of coverage of all species in a sample, and multiplying this value by two. The index of diatom biomass was used for comparing communities at the particular station and was determined as very low with values up to 400, low from 400-800, medium from 801-1200, high from 1201-1600, and very high above 1600.

Diatoms were identified using K r a m m e r, L a n g e - B e r t a l o t keys (1986, 1988, 1991a, b). Chlorophyll *a* was investigated at four stations along the following water course: the Strążyski, Młyniska, and Zakopianka streams. At each station 3 samples were taken from stones previously very scrupulously cleaned, marked,

Table I. Chemical composition of waters of streams flowing through the Zakopane area; analyses made by Wójcik (06, 08, 1987) and Kyselá (10, 1987, 01, 1988)

Stream	Strazyski			Młyniska						Małotański			Cicha Woda						Zakopianka						
	1			2			3			4			5						6						
Date	06	08	10	01	06	08	10	01	06	08	10	01	06	08	10	01	06	08	10	01	06	08	10	01	
Conductivity $\mu\text{S } 18^\circ\text{C}$	286.1	294.0	254.0	256.9	306.0	310.0	272.5	269.0	297.6	315.0	277.1	283.9	-	-	248.4	-	-	415.0	328.8	338.1	204.8	270.0	342.8	284.9	
Potassium mg K dm^{-3}	2.1	0.5	0.5	2.0	0.85	0.8	0.5	2.0	1.05	0.8	0.5	1.6	-	-	0.5	-	-	3.6	2.2	1.2	2.4	1.65	1.8	0.8	
Sodium mg Na dm^{-3}	1.4	0.6	0.7	0.6	1.0	1.4	0.9	0.6	1.75	1.5	1.4	1.9	-	-	0.7	-	-	11.0	5.6	4.1	1.4	4.3	5.2	3.5	
Ammonium $\text{mg N-NH}_4^+ \text{ dm}^{-3}$	0.12	0.15	0.229	0.219	0.18	0.20	0.214	0.235	0.11	0.16	0.254	0.443	0.18	-	0.209	-	-	0.72	0.392	0.525	0.20	0.24	0.290	0.326	
Nitrite $\text{mg N-NO}_2 \text{ dm}^{-3}$	0.003	0.00	0.001	0.003	0.007	0.030	0.004	0.005	0.004	0.004	0.008	0.006	0.112	-	0.001	-	-	0.003	0.041	0.022	0.008	0.013	0.012	0.010	
Nitrate $\text{mg N-NO}_3 \text{ dm}^{-3}$	1.50	1.30	1.565	1.635	1.57	1.45	1.740	1.682	1.60	1.58	1.682	1.916	1.31	-	1.419	-	-	1.12	2.78	2.208	1.945	1.09	1.22	2.967	1.857
Phosphates $\text{mg PO}_4 \text{ dm}^{-3}$	0.007	0.008	0.058	0.038	0.013	0.021	0.270	0.063	0.010	0.035	0.239	0.221	0.016	-	0.013	-	-	0.004	0.070	0.511	0.380	0.028	0.033	0.359	0.310

and exposed in the stream for a month. The algal growth was taken from the whole upper surface of the stones. The surface area of the stones was computed by projecting it on a plane. Chlorophyll *a* was determined using SCOR-UNESCO (1971) methods.

4. Results

In sectors of the streams within the area of the National Park (Stations 1 and 4) the number of species was fairly small with the diatoms *Homoeothrix janthina* and *Hydrurus foetidus* prevailing. Among diatoms the greatest populations were formed by *Achnanthes minutissima* var. *minutissima* with *A. biasoletiana* var. *biasoletiana*. Also species of the genus *Gomphonema* (chiefly *G. angustum*), *Cocconeis placentula* var. *euglypta* with *C. pediculus* and *Fragilaria capucina* var. *vaucheriae* were quite frequently encountered. At these stations the mean annual index of diatom biomass was low, usually remaining low in the annual cycle but increasing considerably at Station 4 in January, while its lowest values were noted in June (fig. 2).

In the streams flowing through Zakopane (Stations 2, 3, 5, and 6) the number of species remained small. From the group of numerous species *Homoeothrix janthina* disappeared and the green algae *Ulothrix zonata*, *Cladophora glomerata*, and unidentified species of the order Chlorococcales appeared in its place. Diatoms developed abundantly. The numerous occurrence of species of the genus *Gomphonema*, among them *G. angustatum*, *G. angustum*, and *G. olivaceum*, was continued. Species of the genus *Achnanthes* showed a tendency to decreasing abundance and those of the genus *Cymbella* to an increase as compared with stations within the Park. In the group of organisms determined as numerous, *Diatoma ehrenbergii*, *Nitzschia dissipata*, *Nitzschia palea*, *Navicula cryptocephala*, *N. lanceolata*, *N. veneta* were recorded (fig. 2).

At Station 2 in the upper part of the town the mean index of diatom biomass was as low as in the Tatra sectors. It reached its lowest annual value in June but showed a considerable rise in autumn. At the remaining three stations lying in the central part of Zakopane (Stations 3, 5, and 6) the mean index of diatom biomass was doubled in relation to the stream sectors in the Tatra Mts. At Stations 3 and 6 its lowest values were recorded in June, after which it gradually rose to a very high level in April of the following year. At Station 5 a contrary tendency was observed, i.e. in June the values was very high and decreasing throughout the year, reached a minimum in April (fig. 2).

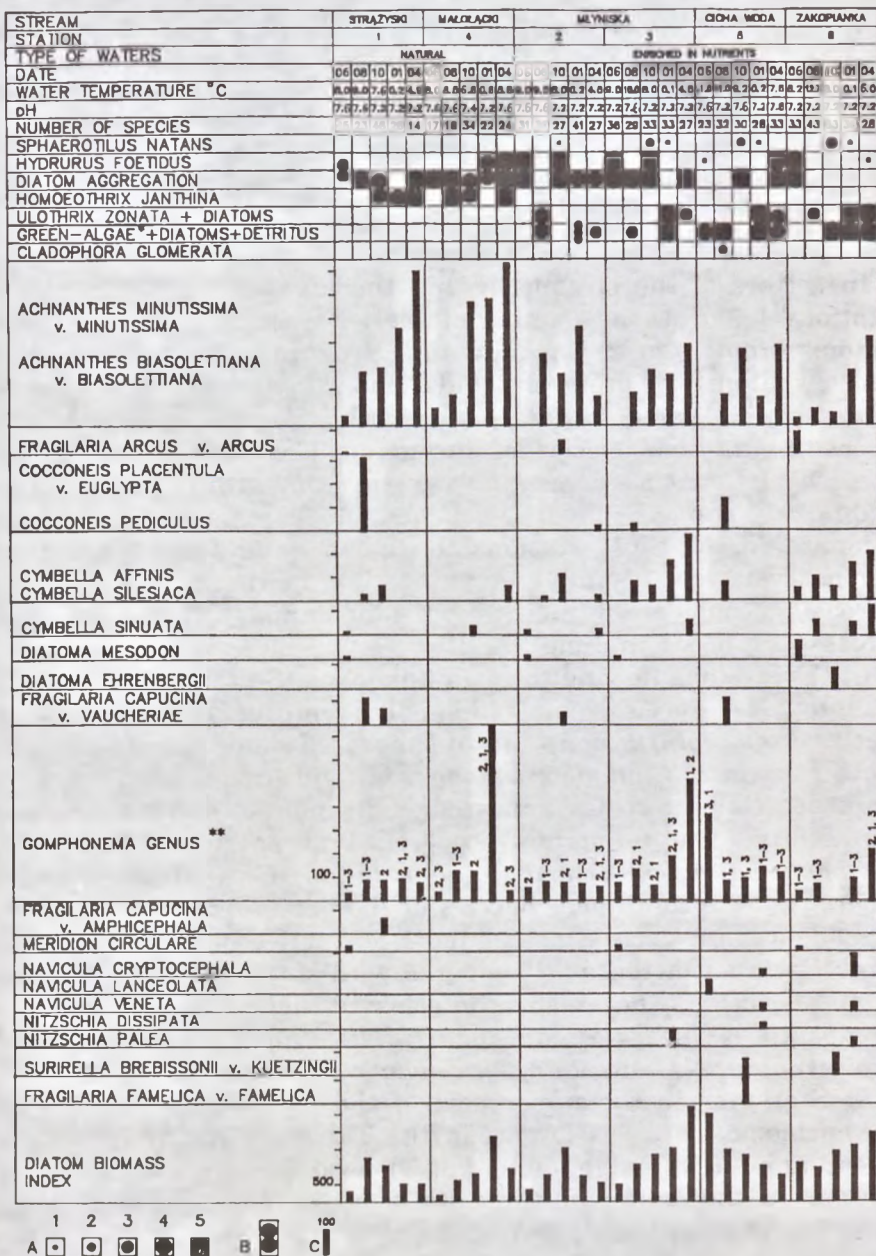


Fig. 2. Communities of sessile algae in streams in the area of Zakopane. A - scale of coverage; B - the coverage includes a group of organisms; C - 100 diatom cells in 10 microscopic fields. * - aggregations of green algae: *Ulothrix* sp., species of the order Chlorococcales; ** - species of the genus *Gomphonema*: 1 - *G. angustatum*, 2 - *G. angustum*, 3 - *G. olivaceum*

In the investigated streams no distinct regularities in the seasonal development of the different species of algae were observed. It may only be said that most diatoms showed a tendency to increase in numbers in January and April. August was unfavourable for the development of *Hydrurus foetidus* and October for *Ulothrix zonata*.

The concentration of chlorophyll *a* was very low at Station 1 in the area of the national Park. It rose along the stream course and in the Zakopianka stream attained its highest values, particularly high in July and January. Along the entire course of the streams the lowest values of chlorophyll *a* content were noted in June and August (fig. 3).

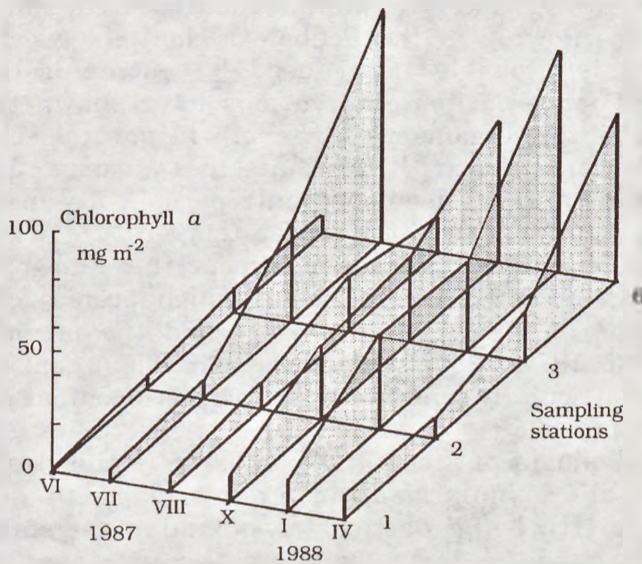


Fig. 3. Content of chlorophyll *a* along the course of the Strążyski, Młyniska, and Zakopianka streams (Stations 1-3 and 6) in the annual cycle

5. Discussion

In high mountain streams the communities of algae develop zonally on account of the differentiated environmental conditions (temperature, chemical composition of the water, insolation, and the volume and current velocity) in the passage from the peaks to the foothills. Zone I includes the upper stream courses lying in the alpine zone, zone II streams in the area of the montane forest zone, and zone III those in the Podhale region (submontane zone) (K a w e c k a 1965, 1971, 1980, W a s y l i k 1971, K a w e c k a et al. 1971).

The upper stations (1 and 4) in the investigated streams have an undisturbed character, lying in the Tatra National Park in the lower part of zone II. The areas of streams flowing through Zakopane (Stations 2, 3, 5, and 6) belong to zone III of the longitudinal development of algae. The town enriches the water environment of the streams with nutrients, particularly in autumn and winter, this being distinctly connected with the increase in tourism at time when the water level is low. In spring and in summer nutrients are washed out by the stronger water discharge.

Algal communities characteristic of zone II with *Homoeothrix janthina* and *Hydrurus foetidus* as the leading species developed in the streams flowing in the montane forest zone. In the area of the Zakopane Valley *Homoeothrix janthina* disappeared, similarly as in other streams flowing in the Podhale region (K a w e c k a 1965, 1971). This is probably not caused by eutrophication of the environment since earlier observations have shown that in the Tatra streams this organism occurs both in natural environments and in those enriched with nutrients (K a w e c k a 1980, 1981). Here *Hydrurus foetidus* developed only periodically in the winter and spring months, when the water temperature was low, and disappeared in summer. This confirms the known ecological requirements of the discussed alga, which prefers cold waters (K a w e c k a 1981). Both the present and the previous studies (K a w e c k a 1974, 1980, 1981) show that this organism does not seem to be particularly sensitive to an increased content of nutrients in the environment.

The development of green algae occurred in the streams of the Zakopane Valley similarly as in other streams in the Podhale region (zone III), being particularly abundant at stations lying in the centre of the town owing to the increased content of nutrients. *Cladophora glomerata*, which is noted here, prefers rich waters and avoids those with a very small content of nitrates and phosphates (W h i t t o n 1970), hence is never encountered in the poor streams flowing in the Tatras. *Ulothrix zonata*, whose development is observed here, in general occurs in waters with a poor content of nutrients but is also capable of developing in an environment polluted by organic matter (S t a r m a c h 1972). Species of the order Chlorococcales, known as organisms of eutrophic waters, also developed abundantly. In the autumn and winter the characteristic occurrence of the sewage bacterium *Sphaerotilus natans* was chiefly observed in the Cicha Woda and Zakopianka streams.

The environmental conditions of the investigated streams favoured the development of diatoms. In the area of the National Park *Achnanthes minutissima* var. *minutissima* and *A. biasolettiana* var. *biasolettiana*, two organisms frequently encountered in mountain streams, played an important role (K a w e c k a 1980, 1981). Their abundance distinctly fell in streams flowing in the area of the Zakopane Valley. This shows the sensitivity of the two organisms to the increased content of nutrients and confirms numerous observations concerning the negative response of the species *Achnanthes minutissima* var. *minutissima* to this ecological factor (B a c k h a u s 1968 b, B e s c h et al. 1972, K a w e c k a 1974, 1980, 1981, K r a m m e r, L a n g e - B e r t a l o t 1991 b).

In streams flowing through Zakopane *Diatoma ehrenbergii* and *Nitzschia dissipata* occurred in the group of numerous species; being characteristic of zone III of the zonal development of algae (K a w e c k a 1965, 1971, 1980, 1981), they did not form any great populations there. Both species of the cosmopolitan distribution range prefer waters with a rich nutrient content (L o w e 1974). In this environment *Cymbella sinuata* showed an tendency to increase. This organism is widely distributed in montane streams, both in a natural state and with an enriched nutrient content, but it is more frequently encountered in lower sectors (K a w e c k a 1980, 1981). There also occurred other species of cosmopolitan distribution range, such as *Navicula lanceolata*, an organism with a wide ecological spectrum also found in a mesosaprobic waters (K r a m m e r, L a n g e - B e r t a l o t 1986), besides *Fragilaria famelica* var. *famelica* and *Surirella brebissoni* var. *kuetzingii*, both preferring waters rich in electrolytes (K r a m m e r, L a n g e - B e r t a l o t 1988, 1991 a).

In the investigated streams the abundance of *Cymbella silesiaca* rose. This species has wide ecological spectrum, but nevertheless is classified by B a c k h a u s (1968 a) in the group of organisms characteristic for small and well-oxygenated streams carrying large amounts of mineral and organic matter - as is confirmed by observations of the development of *C. silesiaca* in montane streams fed with domestic sewage (K a w e c k a 1974, 1977, 1980, 1981).

In the winter flora of streams in the Zakopane Valley organisms preferring fertile waters occurred in species determined as numerous. Among them was *Nitzschia palea*, an indicatory species of running waters rich in organic matter (B a c k h a u s 1968a, L o w e 1974) which dominates in heavily polluted waters with a high content of nitrogen (S c h o e m a n 1976).

In sectors of the Tatra streams in a natural state *Nitzschia palea* occurred sporadically but appeared in great numbers, e.g., in the Rybi Potok stream below the inflow of sewage from the lodge at Lake Morskie Oko (K a w e c k a 1977). *Navicula cryptocephala*, in general sporadically encountered in the Tatra streams, was recorded in this group. Like *Nitzschia palea*, it forms fairly large populations in the Rybi Potok stream in the zone of mineralization of domestic sewage (K a w e c k a 1977). There is an opinion that this organism has a wide ecological spectrum and is able to live in heavily eutrophicated waters as well (C h o l n o k y 1968). Also the development of *Navicula veneta*, classified in the group of species resistant to pollution, (K r a m m e r, L a n g e - B e r t a l o t 1986) was observed there.

In the streams flowing in the territory of the National Park small cells of species of the genus *Achnanthes* prevailed, hence the index of diatom biomass usually reached only low values. In the Małolącki stream (Station 2) the index rose very distinctly in January owing to the development of species of the genus *Gomphonema*, i.e. *G. angustum* with *G. angustatum* and *G. olivaceum*. Such an exceptionally high index of diatom biomass as was noted in the Młyniska stream (Station 3) in April 1988 has never before been recorded in mountain streams (K a w e c k a 1974, 1980). Also here the chief role was played by *Gomphonema angustatum* with *G. angustum*. The latter prefers oligotrophic waters, while the former is widely distributed in waters with various content of electrolytes, though it avoids a heavily polluted environment and *G. olivaceum* occurs both in oligotrophic and eutrophic waters (K r a m m e r, L a n g e - B e r t a l o t 1986).

Along the course of streams with an increasing density of buildings, and therefore greater amounts of nutrients, the content of chlorophyll *a* rose in parallel, particularly in the tourist seasons in summer, autumn, and winter. The lowest value of chlorophyll *a* content was noted in June and August in a distinct correlation with the high water levels and washing out of nutrients at this time (fig. 3). Similar dependences have been observed in other Carpathian rivers of Southern Poland (B o m b ó w n a 1972).

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6. Polish summary

Ekologiczna charakterystyka zbiorowisk glonów osiadłych w potokach spływających z Tatr na teren Zakopanego (Polska południowa) ze szczególnym uwzględnieniem ich wymagań w stosunku do biogenów

Kotlina Zakopiańska z dużym ośrodkiem turystyki Zakopanym usytuowana jest na terenie Podhala u podnóża Tatr Zachodnich. W latach 1987-1988 przeprowadzono badania zbiorowisk glonów potoków przepływających przez teren miasta. Punktem odniesienia były zbiorowiska glonów rozwijające się na terenie TPN, na styku środowiska naturalnego i północnej granicy miasta (ryc. 1, tabela I). W środowisku naturalnym przeważał *Homoeothrix janthina*, *Hydrurus foetidus*, a wśród okrzemek gatunki z rodzaju *Achnanthes* (głównie *A. minutissima* var. *minutissima*, *A. biasolettiana* var. *biasolettiana*). W potokach płynących na terenie Kotliny Zakopiańskiej zanotowano zmiany w strukturze zbiorowisk glonów w stosunku do środowiska naturalnego, wskazujące na eutrofizację środowiska wodnego potoków, szczególnie w okresie szczytu turystycznego przy równocześnie niskim przepływie wody (jesień, zima). Zmiany szły w kierunku rozwoju organizmów preferujących środowisko bogate w materię organiczną (np. *Cladophora glomerata*, *Ulothrix zonata*, gatunki z rzędu Chlorococcales, *Nitzschia palea*, *Navicula cryptocephala*, *Cymbella silesiaca*, *C. sinuata*) oraz spadku populacji gatunków charakterystycznych dla naturalnych wód np. *Achnanthes minutissima* var. *minutissima*, *A. biasolettiana* var. *biasolettiana* (ryc. 2). Nastąpiło też zwiększenie masy glonów, wyrażone wzrostem wskaźnika biomasy okrzemek oraz zawartości chlorofilu *a* na stanowiskach w centralnym i dolnym obszarze Zakopanego (ryc. 2, 3).

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