Algological Studies **83**	145–162	Stuttgart, Dezember 1996

Ecology of cyanophytes in mountain springs of the River Sarca catchment (Adamello-Brenta Regional Park, Trentino, Northern Italy)

By Marco Cantonati

Museo Tridentino di Scienze Naturali, Trento, Italy

Eugen Rott and Eveline Pipp

Institut für Botanik, Universität Innsbruck, Innsbruck, Austria

With 3 figures and 2 tables in the text

Abstract: Cyanophytes were sampled in two surveys, summer 1993 and 1995, in order to compare the algal flora of 19 small springs located in the upper part of the River Sarca catchment (Northern Italy). Measurement of the main physico-chemical variables of the spring water were also carried out. The springs differ largely in altitude (from 1073 to 2130 m a.s.l.), lithology of the aquifer (calcareous/dolomitic mountains in the Brenta and igneous intrusive rocks in the Adamello region), discharge (from less than 1 to 137 l s^{-1}), substrate particle size and exposure. Cyanophytes were present in all the rheocrenes and lacking in the helocrenes. Up to 40 cyanophyte species were observed. The genera *Chamaesiphon, Homoeothrix* and *Phormidium* were most frequent and rich in species, with a majority of epilithic taxa occurring mainly in oligotrophic fast flowing mountain streams. Sample grouping as obtained by numerical analysis (TWINSPAN, CANOCO) was mainly explained by lithology and conductivity (separation of siliceous from calcareous substrate). Other variables pointed out by the Canonical Correspondence Analysis were the degree of shading and altitude. Differences among springs are marked, as can be argued from the relation between the high total number of species found (40) and the low diversity (on the average six species) of the single sites. Rare species were mainly found in springs warranting low flow variability at the site of emergence.

Key words: Algae, cyanophytes, springs, numerical vegetation analysis, rheocrenes, helocrenes, *Pulvinularia, Chamaesiphon amethystinus*.

Introduction

Springs are ecotones which link the phreatic zone to the spring stream. The underground origin of their waters is responsible for the physico-chemical stability that clearly differentiates springs from other surface waters (e.g. Thienemann 1922, Illies & Botosaneanu 1963, Odum 1971). However, it is still

0342-1120/96/0117-0145 $ 4.50

unclear whether the stability of perennial springs leads, in general, to the selection of specialized organisms (BREHM & MEJERING 1982) or not (ROUND 1981). The selection of species in a stable environment related to the lack of disturbances should yield low diversity (CONNEL 1978).

Some of the few studies on periphyton algae in springs indicate that these environments host no specific spring species (e.g. WHITFORD 1956, WHITFORD & SCHUMACHER 1963); however, in the case of diatoms, spring specific communities were recorded (SABATER & ROCA 1992). In particular, the role of cyanophytes in springs is even less clear than for diatoms, since spring studies including this group are rare (e.g. DELL'UOMO 1975) and were mainly carried out in the framework of research focused on other topics (e.g. hygropetric habitat, GOLUBIĆ 1967, mountain streams, KANN 1978).

The aim of the present study was to find out whether cyanophytes were present or not in most of the springs of a pristine mountain region. To describe the habitat structure and to recognize the relationships between algae and environment, a complete set of variables was assessed, which allowed for a final selection of the most determining variables by means of numerical methods.

The case studies are identified by representative biotopes in the main side valleys of the Regional Park Adamello-Brenta. This park (surface area 618 km^2) includes mountain forests and alpine areas with elevations up to 3558 m a.s.l.. The western part consists of igneous intrusive rocks, such as granites, granodiorites and tonalites, of the Adamello mountain group, and the eastern sector of sedimentary limestones and dolomites of the Brenta group.

Methods

Nineteen small springs, ten in the Adamello and nine in the Brenta, were considered for this study (Fig. 1).

Discharge, temperature, dissolved oxygen, conductivity and pH have been measured *in situ* at least four times to obtain the annual variation ranges shown in Tab. 1. Discharge was determined directly by means of graduated vessels, in the case of smaller springs, or by the velocity-area method (with a SCHILTKNECHT current meter, Model Mini Air). Other variables were measured by Idronaut and Hydrolab-meters. Water chemical analyses were carried out for the samples collected in summer 1993, following the I.R.S.A.-C.N.R. methods (1972–1988). Alkalinity was calculated from titration to endpoint pH 4.5. Ammonia nitrogen was analysed by spectrophotometry, after reaction with sodium salicylate (VERDOUW et al. 1978), and nitrate-nitrogen by spectrophotometry after reaction with sodium salicylate Seignette salt. Soluble reactive phosphorus (S.R.P.) was determined by spectrophotometry with the ascorbic acid method and total phosphorus by spectrophotometry with the ascorbic acid method after potassium persulphate

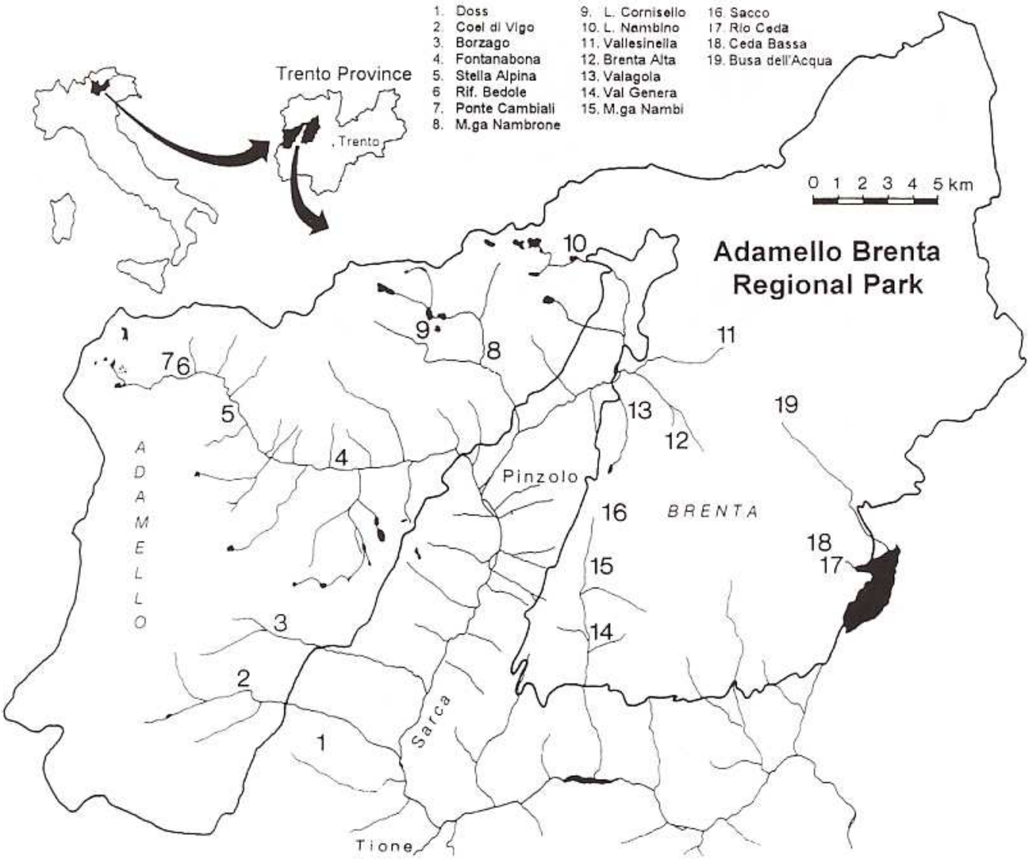

Fig. 1. Locations of the springs.

digestion. Carbon dioxide was evaluated by means of a nomographic method (A.P.H.A., A.W.W.A. & W.E.F. 1992).

Periphyton algae were sampled twice. The first screening of epilithic cyanophyte communities was carried out in summer 1993, followed by a second one, which included epiphytes, in spring/summer 1995. The site of emergence of the water (in most cases a few square meters) was carefully inspected for cyanophytes. Only the portion in which temperature increased not more than some tenth of °C in summer (usually the first 5–15 m of the spring stream) was sampled. ERMAN (1992) used the same strategy to delimit the spring habitat. Samples were taken from all substrates (stones, silt-debris and mosses) that covered the wetted perimeter of the spring. In 1993, samples had been preserved in 4% formaldehyde, whereas in 1995 living material was studied. Microscopic

Table 1. Main morphological, physical and chemical characteristics for the 19 springs.

Spring N.	1	2	3	4	5	Adamello 6	7	8	9	10
MORPHOLOGICAL FEATURES										
Altitude m a.s.l.	1120	1564	1275	1091	1438	1645	1665	1356	2130	1780
Lithology	Fillades	Tonalite	Granite	Granite/ Tonalite	Tonalite	Tonalite	Tonalite	Granite/ Tonalite	Tonalite	Tonalite
Submerged mosses %	–	70	40	–	30	–	5	20	–	30
ANNUAL VARIATION RANGES										
Discharge l s^{-1}	<0.1–0.2	10.7–120	8.5–137	0.3–1.1	1.4–2.0	8.5–14.3	81–98	4.1–29	<0.1–1.0	0.5–1.2
Temperature °C	3.6–9.6	3.9–8.2	5.8–6.1	6.3–7.1	5.1–5.5	4.9–6.0	5.8–6.4	4.9–6.2	1.9–5.9	2.1–6.3
% oxygen saturation	29–79	91–101	85–102	82–88	66–80	89–94	91–98	87–98	84–90	91–100
Conductivity µS cm^{-1}	23–38	7–13	21–26	16–25	18–22	18–20	17–18	20–30	7–9	17–18
pH	6.1–6.4	6.6–7.1	7.2–7.6	6.5–7.1	6.1–6.3	7.4–7.5	7.2–7.5	6.7–7.2	6.7–6.9	7.1–7.4
CHEMICAL ANALYSES (Summer 1993)										
Carbon dioxide mg l^{-1}	26.0	3.8	1.5	8.0	15.0	3.8	3.4	2.2	2.4	2.2
Alkalinity meq l^{-1}	0.42	0.18	0.28	0.22	0.24	0.24	0.24	0.24	0.14	0.24
Ammonia-nitrogen µg l^{-1}	69	10	18	21	22	30	25	14	23	16
Nitrate-nitrogen µg l^{-1}	350	320	430	530	430	280	330	740	150	210
Sol. React. Phosph. µg l^{-1}	3	2	3	2	1.5	<	<	2	2	3
Total phosphorus µg l^{-1}	191	3	10	3	5	<	<	5	5	7

Table 1. (continued) Main morphological, physical and chemical characteristics for the 19 springs.

					Brenta				
Spring N.	11	12	13	14	15	16	17	18	19
MORPHOLOGICAL FEATURES									
Altitude m a.s.l.	1711	1645	1317	1073	1358	1775	1200	1440	1886
Lithology	Dolomite	Dolomite	Limestones Dolomite	Dolomite Limestones	Dolo./ Limes.- Sandstone	Limestones/ Dolomite	Limestones	Limestones	Dolomite Limestones
Submerged mosses %	40	–	10	40	–	–	–	–	20
ANNUAL VARIATION RANGES									
Discharge $l\ s^{-1}$	1.4–5.7	1.0–2.2	0.2–2.1	1.0–4.3	14.0–55.7	0.2–3.5	0.1–2.6	<0.1	2.2–19.0
Temperature °C	4.3–4.9	3.6–4.2	5.3–5.6	5.9–6.4	5.4–5.7	3.7–5.5	4.5–8.0	5.8–8.3	3.0–3.3
% oxygen saturation	90–106	88–95	92–101	89–106	78–101	90–100	92–99	89–94	92–100
Conductivity $\mu S\ cm^{-1}$	142–158	101–112	71–174	147–181	159–194	127–138	141–163	130–142	92–103
pH	7.8–8.0	8.0–8.2	7.8–8.0	7.1–8.2	7.9–8.2	8.1–8.2	7.9–8.5	7.7–8.4	8.1–8.4
CHEMICAL ANALYSES (Summer 1993)									
Carbon dioxide $mg\ l^{-1}$	3.6	2.2	4.0	3.8	3.6	3.4	3.4	2.6	2.0
Alkalinity $meq\ l^{-1}$	2.60	1.84	2.50	2.60	2.38	2.34	2.54	2.04	1.72
Ammonia-nitrogen $\mu g\ l^{-1}$	30	25	9	2	2	2	22	16	15
Nitrate-nitrogen $\mu g\ l^{-1}$	230	760	570	690	460	470	580	520	730
Sol. React. Phosph. $\mu g\ l^{-1}$	<	2	3	3	6	3	9	7	2
Total phosphorus $\mu g\ l^{-1}$	<	4	7	4	8	6	22	8	4

preparations were examined under a Leitz Laborlux microscope at 400 and 1000 magnifications. Colour slides, which were subsequently used to prepare drawings, were taken by means of a semiautomatic camera system. Diacritical characters were measured several times. The literature utilized for taxonomic identification was as follows: GOLUBIĆ & KANN (1967) for *Tolypothrix*, KANN (1972) for *Chamaesiphon*, KANN & KOMÁREK (1970) for *P. autumnale* and *P. subfuscum*, KOMÁREK & KANN (1973) for *Homoeothrix* and GEITLER (1932) for all the others. When possible, revised binomials were gathered from KOMÁREK & ANAGNOSTIDIS (1986) and ANAGNOSTIDIS & KOMÁREK (1988). For quantification, estimations of the algal cover in the field, evaluations of drawings, notes and photographs and the frequency estimates of the species in several microscopic preparations were combined. Abundances are expressed according to the following 4-grade scale: (1) single or few specimens, (2) rare, (3) frequent, (4) very frequent. For quantification of epiphytes on mosses and algae, abundance values derive from the combination of the coverage of the macroscopic substrate in the field and the frequency of the epiphytes on this substrate.

The data were processed by numerical analysis. Similarities between samples and species as identified in the ordinated vegetation table (Tab. 2) were obtained by TWINSPAN (HILL 1979). Due to the small number of samples, only three division levels were considered. The impact of 14 selected, mutually uncorrelated, environmental variables on sample and species ordination was analysed using a Canonical Correspondence Analysis (C.C.A.) carried out in CANOCO (TER BRAAK 1988). With the exception of nutrients, for which the chemical analyses of summer 1993 were used, the values of the variables are those relative to the dates when cyanophytes had been also sampled. For CANOCO, ordinal variables had to be transformed into numbers. Substrate particle size was indicated by the WINGET (1985) index, calculated multiplying the portions of each size class by weights (1 to 6) increasing with size classes (from silt/debris to rock). Lithology was identified as numbers, ranging from 1 to 5 and increasing from crystalline to calcareous rocks. The degree of shading was recorded as values from 1, used for open sites facing southwards, to 4, indicative of dense forests.

Results

Two (1,5) of the studied springs are helocrenes (seepage springs) and the others rheocrenes (flowing springs, VAN DER KAMP 1995; for spring type terminology see also HYNES 1976).

The springs (Tab. 1), which are distributed over a large altitudinal range (from 1073 to 2130 m a.s.l.), are characterized by low discharge (from less than 1 to 137 l s^{-1}) and by a wide range of substrate particle sizes (from silt to boulders and bedrock). The conductivity, pH and alkalinity values of the Brenta springs are generally higher than those of the Adamello. For the majority of the rheocrene springs, oxygen saturation is between 80 and 100%, whereas for the two helocrenes oxygen undersaturation was recorded (from 30 to 80%). All the sources are supersaturated with respect to carbon dioxide, which reaches particularly high concentrations in the helocrenes. In the latter, oxygen undersaturation and high CO_2 concentrations are likely to derive from the slow seepage of the water out of the soil. Moreover, oxygen content may also be affected by the decomposition of organic debris. Seasonal variations result mainly in discharge fluctuations and, in six cases (1, 2, 9, 10, 17, 18), in temperature fluctuations larger than 2 °C. A maximum seasonal temperature variability of 6 °C was recorded in one helocrene spring (1). Phosphorus and nitrogen concentrations were commonly higher than expected for this kind of environment, and can hardly be explained exclusively as an effect of agricultural activity and cattle grazing at the sites of emergence. Nitrate-nitrogen values are in many cases high, even when soil provenance is considered. The remarkably high total phosphorus value recorded in spring No. 1, should be explained by the difficulty of sampling clear water in conditions of low flow and/or common presence of organic debris at the source.

The aspect of the periphyton was characterized by patches of algae, aquatic lichens (mainly *Verrucaria*) and/or mosses. Fifty per cent of the cyanophyte taxa formed macroscopically recognizable covers.

Cyanophytes were found in all rheocrenes, whereas the helocrenes were colonized by green algae. In spring No. 10, which is an intermediate type (a marshy flowing spring, or rheohelocrene, SCHWOERBEL 1959), only a small quantity of *Phormidium autumnale* (AG.) ex GOM. was found in 1995.

In the rheocrenes, 40 cyanophyte species were identified (Tab. 2). Species numbers ranged from two to ten, with an average of six. This result is in agreement to what was observed by GOLUBIĆ (1967), who found similar, or even lower numbers of species in springs in the Karst areas of former Jugoslavia. The minimum number of species, two, was found in a rheocrene (No. 4) which had been modified by man. In fact, a fountain had been built around the point of emergence and most of the sediments were trapped and stabilized by concrete. In an intercepted spring, GOLUBIĆ (1967) did not find any cyanophytes. The maximum number of species, ten, was found in a spring (No. 18) characterized by little discharge, where the water emerges directly from the rock (hygropetric rheocrene, SCHWOERBEL 1959). In this case, because of the small discharge (less than 0.1 l s^{-1}), species of hygropetric sites are associated to epilithic and epiphytic species (on mosses).

Among the 18 genera found, *Chamaesiphon, Phormidium* and *Homoeothrix* were most frequent and richest in species. The most common species (Fig. 2) were as follows: *Homoeothrix janthina* (BORN. et FLAH.) STARM. (on siliceous substrates), *Phormidium autumnale* and *Chamaesiphon polonicus* (ROSTAF.) HANSG. (independent of lithology), *Homoeothrix varians* GEITL. and *Leptolyngbya perforans*

Table 2. Vegetation table of rheocrene springs as yielded by TWINSPAN. Major groups are separated by thick lines. Abundance of species indicated by size of squares: ◇ = single or few specimens; ◆ = rare; ■ = frequent; █ = very frequent.

Sample group N.	1		2		3										4													5			6	
	Rheocrene springs on siliceous substrate														Rheocrene springs on calcareous substrate																	
SPRING (see Fig. 1)	3	3	9	9	7	4	6	7	8	2	4	8	2	6	19	16	19	16	11	12	15	17	11	12	13	15	17	13	18	18	14	14
Sampling year	93	95	93	95	93	95	95	95	95	93	93	93	95	93	95	93	93	95	93	93	93	93	95	95	95	95	95	93	93	95	95	93
Homoeothrix janthina (BORN. et FLAH.) STARM.	◆	◆			◆	◆	◆	■	◆	◇	◇	◇	◇	◇																		
Chamaesiphon starmachii KANN	◇	◆			■			■	◆																							
Chamaesiphon confervicola A. BR.		■			◆		◆	◆		◆			◆	◇	■																◆	◆
Pulvinularia sp.	█	█																														
Chamaesiphon investiens var. *roseus* SKUJA		■																														
Stichosiphon pseudopolymorphus (FRITSCH) KOM.					◆					◇			◆																			◇
Chamaesiphon amethystinus (ROSTAF.) LEMM.									◆																							
Xenococcus minimus GEITL.									■																							
Chamaesiphon fuscus (ROSTAF.) HANSG.				◆					■		◇	■																				
Chamaesiphon subglobosus (ROSTAF.) LEMM.													◆																			
Hydrococcus cesatii RABENH.													◆																			
Chamaesiphon sp. ad. *C. oncobyrsoides* GEITL.															◆																	
Leptolyngbya frigida (FRITSCH) ANAGN. et KOM.														■																		
Homoeothrix juliana (BORN. et FLAH.) KIRCHN.				◆																												
Phormidium sp.			◇	◇																												
Tolypothrix penicillata THUR. ex BORN. et FLAH.			■	■																												
Clastidium setigerum KIRCHN.				◆				◆							■									◆								
Chamaesiphon minutus (ROSTAF.) LEMM.			◆	■			◆		■														◆	◆			◆					
Phormidium autumnale (AG.) ex GOM.					■		■	■	■	◆		■	■	■	■				■	◆	■	◆	■	■	■	■	■					
Calothrix parietina THUR. ex BORN. et FLAH.						◆																							◆	◇		
Chamaesiphon polonicus (ROSTAF.) HANSG.				■	■	◆		■	■	■	◆	■	■		■	■	■	■	■	■		◆	■	■		◆	■	◆				
Tolypothrix distorta KÜTZ. ex BORN. et FLAH.					◆			■	◆							◆				◆							◇				◇	◇

Table 2. (continued) Vegetation table of rheocrene springs as yielded by TWINSPAN. Major groups are separated by thick lines. Abundance of species indicated by size of squares: ◇ = single or few specimens; ◆ = rare; ■ = frequent; ⬛ = very frequent.

Sample group N.	1		2		3										4													5			6	
	Rheocrene springs on siliceous substrate														Rheocrene springs on calcareous substrate																	
SPRING (see Fig. 1)	3	3	9	9	7	4	6	7	8	2	4	8	2	6	19	16	19	16	11	12	15	17	11	12	13	15	17	13	18	18	14	14
Sampling year	93	95	93	95	93	95	95	95	95	93	93	93	95	93	95	93	93	95	93	93	93	93	95	95	95	95	95	93	93	95	95	93
Phormidium subfuscum (KÜTZ.) ex GOM.										◇			◆			◆		◆									■					
Nostoc sp.									◆							◇													◆	■		
Chamaesiphon incrustans GRUN.									◆														◆	◇		◇	◆			◆		
Chamaesiphon geitleri H. LUTHER																					◆										■	■
Heteroleibleinia kuetzingii (SCHMIDLE) COMP.																											◆				◆	
Leibleinia nordgaardhii (WILLE) ANAGN. et KOM.																															◇	◇
Phormidium tinctorium KÜTZ. ex GOM.																															■	■
Clastidium rivulare HANSG.																									◆			◆			◇	
Pleurocapsa aurantiaca GEITL.															■	■																
Chroococcus turgidus (KÜTZ.) NÄG.																													◆	◆		
Leptolyngbya perforans (GEITL.) ANAGN. et KOM.																			◆				◆	◆	■			■	■	◆	◆	
Lyngbya martensiana var. *calcarea* TILDEN																													◆			
Microcystis fonticola (HANSG.) KANN																◇		◆										◆		◇		
Phormidium corium GOM.																◆		◆										◇	◆	◇		
Phormidium incrustatum (NÄG.) GOM. ex GOM.																				■			■	◆					■	■		
Xenotholos kerneri GOLD-MORGAN et al.		■														◆				■		◆					◆			◆		
Herpyzonema sp.																				◆												
Homoeothrix varians GEITL.																■	◆	■	■	■	⬛	⬛	■	■	■	⬛	⬛	■	◆	■	■	◆

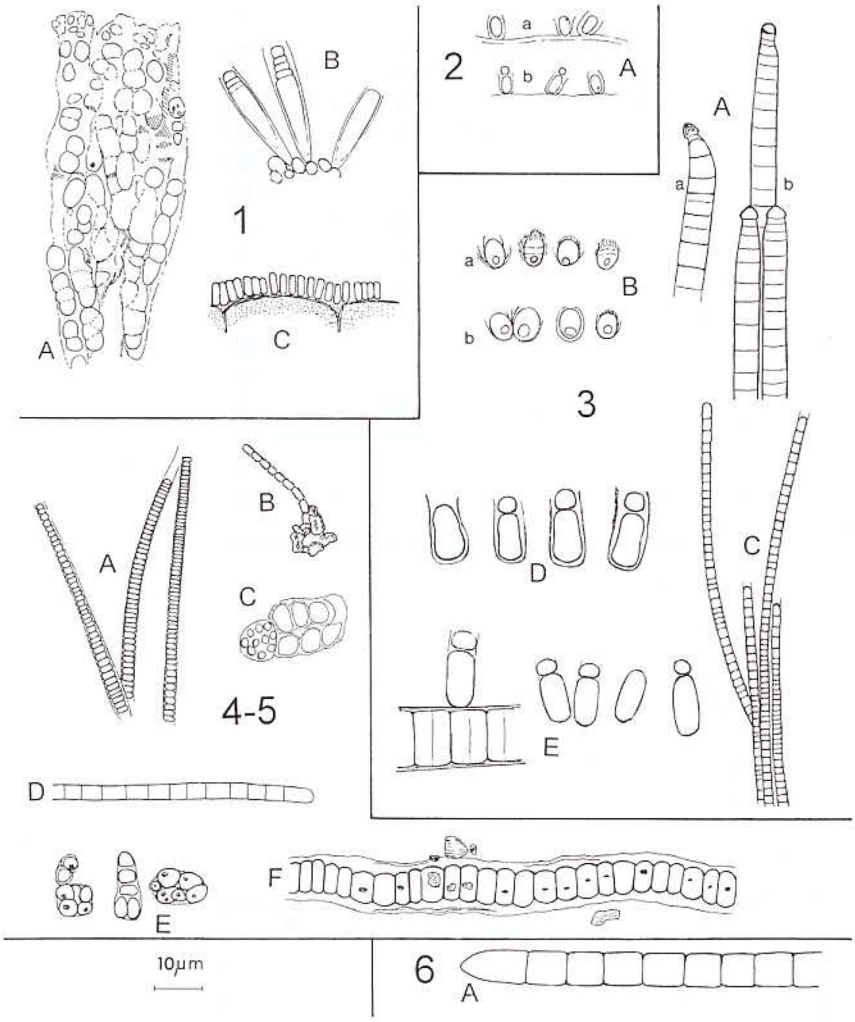

Fig. 2. Some characteristic/rare species (spring number, sampling year) arranged according to TWINSPAN groups: **1** – A: *Pulvinularia* sp. (3, 95), B: *Chamaesiphon confervicola* (3, 95), C: *Chamaesiphon investiens* var. *roseus* (3, 95); **2** – A: *Chamaesiphon minutus* (a: 9, 93; b: 9, 95); **3** – A: *Phormidium autumnale* (a: 2, 95; b: 15, 95), B: *Chamaesiphon polonicus* (a: 4, 95; b: 19, 95), C: *Homoeothrix janthina* (7, 95), D: *Chamaesiphon starmachii* (8, 95), E: *Chamaesiphon amethystinus* (7, 95); **4–5** – A: *Homoeothrix varians* (11, 95), B: *Leptolyngbya perforans* (12, 93), C: *Xenotholos kerneri* (12, 93), D: *Phormidium corium* (13, 93), E: *Pleurocapsa aurantiaca* (19, 95), F: filamentous cyanophyte (12, 93), **6** – A: *Phormidium tinctorium* (14, 95).

(GEITL.) ANAGN. et KOM. (on calcareous substrate) and *Chamaesipohon confervicola* A. BR. and *C. minutus* (ROSTAF.) LEMM. (as epiphytes).

Most of the species were epilithic. Some of them (*Homoeothrix varians, Clastidium setigerum* KIRCHN., *Tolypothrix distorta* KÜTZ. ex BORN. et FLAH., *Chamaesiphon incrustans* GRUN.) were both epilithic and epiphytic. The following species were found to be strictly epiphytic on both mosses and algae: *Chamaesiphon amethystinus* (ROSTAF.) LEMM. (only on *T. distorta!*), *C. confervicola* (on *Klebsormidium*), *C. investiens* var. *roseus* SKUJA (occasionally also on *C. confervicola*), *C. minutus* (on *Tolypothrix penicillata* THUR. ex BORN. et FLAH.), *C. subglobosus* (ROSTAF.) LEMM., *Heteroleibleinia kuetzingii* (SCHMIDLE) COMP., *Hydrococcus cesatii* RABENH., *Xenococcus minimus* GEITL.. The number of epiphytic species on mosses ranged from one to four in rheocrene springs.

Data analysis processed by TWINSPAN for the cyanophyte communities yielded the following groups of samples (Tab. 2): on the highest division level the springs lacking cyanophytes (not displayed in Tab. 2) are separated from those containing cyanophytes. On the second division level groups No. 1–3 (mainly rheocrenes on siliceous substrate) are distinguished from rheocrenes on calcareous substrate (groups No. 4–6).

Springs emerging on siliceous substrate can further be arranged in the following subgroups, typical representatives of which are depicted in Fig. 2:

- a mid-altitude spring in a spruce forest (sample group No. 1, spring No. 3). (*Pulvinularia* sp. is dominant in this spring, along with some epiphytes of the liver moss *Chiloscyphus polyanthos* var. *rivularis* (SCHRAD.) NEES: *Xenotholos kerneri, Chamaesiphon confervicola*, and *C. investiens* var. *roseus*);
- a high altitude spring with marked discharge variations (also the point of emergence changes with the seasons) (group No. 2, spring No. 9). (*Tolypothrix penicillata* and *Homoeothrix juliana* (BORN. et FLAH.) KIRCHN., with their epiphytes *Clastidium setigerum* and *Chamaesiphon minutus*);
- mid-altitude springs on tonalite, or on granite and tonalite (group No. 3). (*Phormidium autumnale, Chamaesiphon polonicus, Homoeothrix janthina, Chamaesiphon starmachii* KANN, *C. confervicola*).

Springs located on calcareous substrate can be subdivided as follows (Fig. 2):

- medium to high discharge rheocrenes emerging from limestone or dolomite and limestone (group No. 4). (*H. varians* with *P. autumnale* and *C. polonicus*. *Leptolyngbya perforans, Phormidium incrustatum* (NÄG.) GOM. ex GOM. and *Xenotholos kerneri* GOLD-MORGAN et al. are also frequent);
- a hygropetric rheocrene spring and a small mid-altitude spring (group No. 5, springs No. 18 and No. 13 respectively). (*H. varians, L. perforans, P. incrustatum* and *P. corium* GOM.);
- a very shaded, mid altitude spring (group No. 6, spring No. 14). (*Phormidium tinctorium* KÜTZ. ex GOM. and *Chamaesiphon geitleri* H. LUTHER).

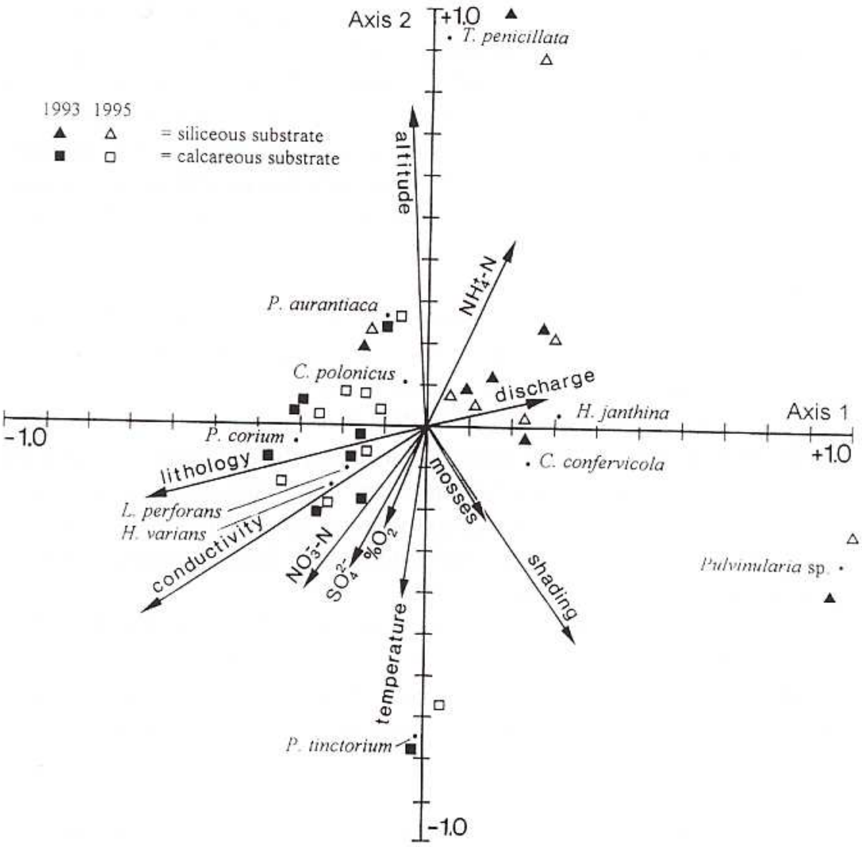

Fig. 3. Ordination of samples from the rheocrenes with respect to cyanophyte species composition (10 major indicator species according to TWINSPAN shown in the plot) and 11 selected environmental variables (arrows).

H. janthina and *C. starmachii* are restricted to the rheocrenes on siliceous substrate, whereas *P. autumnale* and *C. polonicus* are common over large parts of the springs for both substrates, where they grow with *Homoeothrix varians* and various other species.

TWINSPAN ordinates the two samples taken for each spring in adjacent positions, although the samples taken in 1993 had not been screened for epiphytes. Obviously, epiphytes are less important for the discrimination of spring groups than the more frequent epilithic species.

Because the Canonical Correspondence Analysis (C.C.A.) was carried out to show how the environmental variables influence spring ordination according to cyanophytes species, this analysis was performed only for those springs where cyanophytes were present during each sampling survey (rheocrenes). The grouping of springs according to lithology, and most of the subgroupings as arranged by TWINSPAN can be also recognized in Fig. 3. C.C.A. allows for a direct evaluation of the environmental variables which determine the subdivisions. In these waters, which are only slightly influenced by human activity, conductivity is mainly related to the lithology of the aquifers and causes the separation of the rheocrenes emerging from siliceous substrate from those originating from carbonates. The former can be observed in Fig. 3 to the right of the second diagonal of the diagram, whereas the latter are almost all grouped to the left. Another important factor is identified by the degree of shading. This is particularly marked for the shade-adapted species *Phormidium tinctorium* and, possibly, for *Pulvinularia* sp., which are the typical species colonizing two springs emerging in forests. The degree of shading also shows a very clear correlation with the abundance of aquatic mosses. The position of the vectors for NH_4^+-N and NO_3^--N derives from the fact that springs on siliceous substrate showed higher concentrations of ammonia-nitrogen (20–30 $\mu g\,l^{-1}$), whereas nitrate-nitrogen peaks (> 500 $\mu g\,l^{-1}$) were more frequent in springs on calcareous substrate (see also Tab. 1). Water temperature and conductivity are inversely correlated to altitude. Discharge is higher in springs on siliceous substrate, i.e. with lower conductivity. The position of *Homoeothrix janthina* in the diagram shows that this species is mostly present in silicate springs with high discharge. The species restricted to siliceous (e.g. *H. janthina*) or calcareous substrate (e.g. *H. varians, Leptolyngbya perforans*), are all near the lithology and conductivity vectors, and consequently show that their distribution is mainly determined by these factors. On the contrary, species indifferent to geology, such as *Chamaesiphon polonicus*, are near the origin of these vectors. Note the position of *Tolypothrix penicillata* near the top of the altitude vector: in fact, this species is one of those that characterize the spring (No. 9) situated at the highest elevation.

Some of the collected taxa deserve particular attention. The taxon temporarily named *Pulvinularia* (Fig. 2) has some resemblance with *Siphononema* and *Capsosira* and is very similar to *P. suecica* BORZI, but the basal cells are smaller than those of the trichomes and the branching is not as clear as in BORZI (1916) (HERNÁNDEZ-MARINÉ, personal comm.). *P. suecica* is a rare stigonematalean cyanophyte recently rediscovered in the littoral zone of the oligotrophic lake Fiolen in Central Sweden (ROTT & HERNÁNDEZ-MARINÉ 1994). In our study the *Pulvinularia*-like cyanophyte was found only in spring No. 3, which emerges on siliceous substrate in a spruce forest at 1275 m a.s.l., where it thrives on stones. This spring is also characterized by a rich and peculiar population of epiphytes. In a large spring of the Adamello (7) an interesting *Chamaesiphon* species (sporangia cylindrical or very slightly basaly attenuated) was found epiphytic on *Tolypothrix distorta* (Fig. 2). It was classified as *C. amethystinus*. This species was also observed on *Tolypothrix* in the headwaters of the White Vistula river (STARMACH 1929). It bears some resemblance to *C. incrustans*, but differs from it by its marked cylindrical shape and dark blue pigmentation, as already noted by GEITLER (1932) and KANN (1972). An interesting taxon was found in 1993 on the lower surface of a stone together with *Xenotholos kerneri* in Val Brenta (12). It is a filamentous cyanophyte resembling *Herpyzonema* (this rare genus includes a species recently described from cave entrances, HERNÁNDEZ-MARINÉ 1994).

Discussion

In all the rheocrenes, cyanophytes were found as visible constituents of the epilithic submerged flora. Epiphytic cyanophytes were present in most of these springs. The majority of the encountered cyanophytes were previously found in mountain streams (KANN 1978, PFISTER 1992, PIPP & ROTT 1993).

Some of the species were recorded earlier from springs (e.g. *Chamaesiphon amethystinus*, STARMACH 1929; *C. confervicola*, GOLUBIĆ 1967; *Homoeothrix juliana*, KOMÁREK & KANN 1973), but none of them seems to be restricted to the crenon. It should also be considered that specific information about these environments is not very abundant, since the krenal is the least known of the alpine stream types (WARD 1994). Aerophytic algae (algae from wet rocks) are very scarce among the encountered taxa (*Calothrix parietina* THUR. ex BORN. et FLAH., *Herpyzonema* cf.), in part because sampling efforts were concentrated inside the wetted perimeter of the springs.

The number of cyanophyte species (40) found in the 19 springs can be considered high, especially when compared to the 83 species found by PIPP & ROTT (1993) in 54 Austrian mountain rivers from a much larger altitudinal range (from 200 to 2200 m a.s.l.). In contrast to the total number of species, the quantity of species in a single spring (with an average of six), and thus their diversity, is low. These characteristics (low diversity and marked differences among the sites) meet very well with the expected features of the springs as slightly disturbed environments.

The most striking difference encountered between rheocrene and helocrene springs, is the replacement of cyanophytes by green algae in the latter. This could be attributed to the different ability of cyanophytes and green algae to use carbon dioxide. At low pH and in the presence of high amounts of carbon dioxide, green algae and mosses (GLIME & WITT 1987) should be the favourite autotrophic organisms, whereas cyanophytes are characterized by a particularly high affinity for CO_2 at high pH (SHAPIRO 1990). However significant supersaturations are found in all springs and green algae may be better adapted to muddy habitats (the dominant substrate in the helocrenes).

The more or less marked seasonal variations and altitudinal changes in temperature had no evident effects on the cyanophyte communities. On the contrary, discharge appeared to be an important variable, even if it was not represented as one of the major components by the C.C.A. (Fig. 3). This is indicated by the fact that in the rheocrenes there is a sufficient current velocity to sustain the growth of stream forms and even to select, in some springs, exclusive running water species, so called rheobionts (e.g.: *Chamaesiphon geitleri* and *Clastidium rivulare* HANSG.). Another observation supporting this view is that *Chamaesiphon polonicus*, a species which notoriously tolerates periods of dessication, is present in almost all springs with high flow variability.

The importance of light for structuring the cyanophyte communities varies among springs. Some, like the helocrenes emerging in marshy areas or those located in the subalpine vegetational zone, are virtually unshaded by trees. On the contrary others, in particular springs No. 3 and 14, originating in forests, are much more subjected to shading. At the shaded sites, mosses and shade-adapted species (e.g. *Phormidium tinctorium*) are frequent.

Lithology and the related chemical variables (alkalinity, conductivity) are important factors for the grouping of the rheocrenes according to their cyanophyte communities and it is well known that this is the case for algal communities in all kinds of biotopes (e.g. lake littoral KANN 1988, mountain streams and rivers PIPP & ROTT 1993, diatoms in springs SABATER & ROCA 1990). It is unclear if this reaction to the stone substrate is caused directly by structure or indirectly by changes in water chemistry. However, species-specific responses to geochemistry related variables (pH, alkalinity, conductivity) were found to be statistically significant for more than 10 cyanophyte species from running waters in Austria (PIPP & ROTT 1993).

Carbon is present in excess in all springs, nitrogen concentrations are high, while phosphorus concentrations indicate oligotrophic conditions in almost all the cases. Hence phosphorus is the most limiting nutrient. Nevertheless this major nutrient is not found among the variables represented as important by the C.C.A., because it has similar concentrations in all rheocrenes and can thus not act as a discriminant variable. The excess of nitrogen (specially nitrates) may explain the clear predominance of non-heterocystous forms among the species found. In spite of excess nitrogen, the cyanophytes indicate pristine conditions for the majority of the springs, documented by the dominance of epilithic and epiphytic species occurring mainly in oligotrophic mountain streams (KANN 1988, PIPP & ROTT 1993).

Due to their environmental stability, springs are supposed to be potential ecological refuges for both plant and animal communities (BOTOSANEANU & NEGREA 1961, SABATER & ROCA 1992). This should be particularly true when springs exhibit persistence and little variability of flow (VAN DER KAMP 1995). Two springs with high minimum discharges, in which the presence of a rare caddiesfly species and spring specific gastropods had been noticed, were also found to be particularly interesting from a floristic point of view, for rarely recorded cyanophyte species being present (*Pulvinularia* sp., *Chamaesiphon amethystinus*).

Beyond the coarse grouping of the cyanophyte communities, which is mainly based on geochemistry, a marked site-to-site variability of these biotopes persists, probably because of the large number of possible combinations of environmental variables. We believe that this is one of the main scientific arguments for supporting the conservation of springs in pristine conditions in different areas.

Riassunto

Le Cianofite di 19 piccole sorgenti situate nell'alto bacino della Sarca sono state campionate nell'estate del 1993 e del 1995. Sono stati anche rilevati i principali fattori chimico-fisici. Le sorgenti differiscono molto per quanto riguarda l'altitudine (da 1073 a 2130 m s.l.m.), la litologia dell'acquifero (il Brenta è calcareo/dolomitico, mentre l'Adamello è formato da rocce ignee intrusive), la portata (da meno di 1 a 137 l s^{-1}), la struttura meccanica del substrato e l'esposizione. Sono state sempre riscontrate Cianofite nelle sorgenti reocrene, mentre non ne sono state rinvenute nelle elocrene. Sono state identificate ben 40 specie, di cui alcune sono piuttosto rare (*Pulvinularia* sp., *Chamaesiphon amethystinus*). I generi *Chamaesiphon, Homoeothrix* e *Phormidium* sono quelli più frequenti e ricchi di specie. Le Cianofite rinvenute sono soprattutto specie epilitiche, tipiche di torrenti di montagna oligotrofi con acque vivaci. I gruppi di campioni ottenuti con metodi dell'analisi numerica vegetazionale (TWINSPAN, CANOCO) dipendono principalmente dalla litologia/conducibilità (separazione delle sorgenti su silice da quelle su calcare). Altre variabili evidenziate dall'analisi canonica delle corrispondenze sono il grado di ombreggiatura e l'altitudine. Vi sono notevoli differenze tra una sorgente e l'altra, come si può anche desumere dall'elevato numero (40) di specie complessivamente rinvenute e dalla contenuta diversità dei singoli siti (in media sei specie). Le specie rare sono state rinvenute principalmente nelle sorgenti in grado di garantire limitate variazioni del flusso d'acqua nel sito d'emergenza.

Acknowledgements

Special thanks are due to CARLA CONTESSI for valuable help during field work and to Dr. FLAVIO CORRADINI, Mr. CLAUDIO SANSONI, Mr. ROBERTO STOCCHETTI and Mrs. MILVA TARTER (Istituto Agrario of S. Michele all'Adige) for the carrying out of the chemical analyses.

We want to thank Prof. MARIONA HERNÁNDEZ MARINÉ for the analysis of the *Pulvinularia* like cyanophyte and Dr. PETER PFISTER for help in the solution of taxonomic problems.

We are grateful to the Adamello-Brenta Regional Park and to the Ghislieri College (Pavia, Italy), which sponsored this research.

References

ANAGNOSTIDIS, K. & KOMÁREK, J. (1988): Modern approach to the classification system of cyanophytes. 3-Oscillatoriales. – Arch. Hydrobiol./Suppl., Algological Studies **50–53:** 327–472.

A.P.H.A., A.W.W.A. & W.E.F. (1992): Standard methods for the examination of water and wastewater. – 18th Ed., American Public Health Association. Washington: 6.20.

BORZI, A. (1916): Studi sulle Mixoficee. II. Stigonemataceae. – Nuovo Giorn. Bot. Ital., Pellas, Firenze, **23** (4) (1916) and **24** (1–4) (1917): 59–166.

BOTOSANEANU, L. & NEGREA, ST. (1961): Une oasis aquatique à faune relique dans la Plaine du Danube inférieur. – Hydrobiologia **18:** 199–218.

BREHM, J. & MEIJERING, M.P.D. (1982): Fließgewässerkunde. - 311 pp., Quelle & Meyer. Heidelberg.

CONNEL, J.H. (1978): Diversity in tropical rain forests and coral reefs. - Science **199:** 1302-1310.

DELL'UOMO, A. (1975): La flora e le associazioni algali della Sorgente di Salomone (Anterselva, Bolzano). Facies estiva. - G. Bot. Ital. **109:** 257-271.

ERMAN, N.A. (1992): Factors determining biodiversity in Sierra Nevada cold spring systems. - The history of water: White Mountain research station Symposium **4:** 119-127.

GEITLER, L. (1932): Cyanophyceae. - In: RABENHORST's Kryptogamen Flora von Deutschland, Österreich und der Schweiz, Leipzig, **14:** 1-1196.

GLIME, J.M. & WITT, D.H. (1987): A comparison of biophyte species diversity and niche structure of montane streams and stream banks. - Canad. J. Bot. **65:** 1824-1837.

GOLUBIĆ, S. (1967): Algenvegetation der Felsen. - In: THIENEMANN, A. (ed.): Die Binnengewässer **23:** 183 pp., Schweizerbart's Verlagsbuchhandlung, Stuttgart.

GOLUBIĆ, S. & KANN, E. (1967): Zur Klärung der taxonomischen Beziehungen zwischen *Tolypothrix distorta* KÜTZING und *T. penicillata* THURET (Cyanophyta). - Schweiz. Z. Hydrol. **19:** 145-160.

HERNÁNDEZ MARINÉ, M. (1994): *Herpyzonema pulverulentum* (Mastigocladaceae) a new cavernicolous atmophytic and lime-incrusted cyanophyte. - Arch. Hydrobiol./Suppl., Algological Studies **75:** 123-136.

HILL, M.O. (1979): TWINSPAN - A FORTRAN Program for arranging mutlivariate data in an ordered two-way Tab. by classification of individuals and attributes. - 48 pp., Manuscript Dept. Ecology and Systematics, Cornell University, Ithaca, New York.

HYNES, H.B.N. (1976): The ecology of running waters. - 3 rd Ed., 555 pp., Liverpool University Press.

ILLIES, J. & BOTOSANEANU, L. (1963): Problèmes e méthodes da la classification écologique des eaux courantes, considerées surtout du point du vue faunistique. - Mitt. Internat. Verein. theor. angew. Limnologie, No. **12:** 57 pp.

IRSA - CNR (1972-1988): Metodi analitici per le acque - Istituto di Ricerca sulle Acque. Roma. Quaderni.

KANN, E. (1972): Zur Systematik und Ökologie der Gattung *Chamaesiphon* (Cyanophyceae), 1. Systematik. - Arch. Hydrobiol./Suppl., Algological Studies **7:** 117-171.

- (1978): Systematik und Ökologie der Algen österreichischer Bergbäche. - Arch. Hydrobiol., Suppl. **53:** 405-643.

- (1988): Zur Autökologie benthischer Cyanophyten in reinen europäischen Seen und Fließgewässern. - Arch. Hydrobiol./Suppl., Algological Studies **50-53:** 473-495.

KANN, E. & KOMÁREK, J. (1970): Systematisch-ökologische Bemerkungen zu den Arten des Formenkreises *Phormidium autumnale*. - Schweiz. Z. Hydrol. **32:** 495-518.

KOMÁREK, J. & ANAGNOSTIDIS, K. (1986): Modern approach to the classification system of cyanophytes 2 - Chroococcales. - Arch. Hydrobiol./Suppl., Algological Studies **43:** 157-226.

KOMÁREK, J. & KANN, E. (1973): Zur Taxonomie und Ökologie der Gattung *Homoeothrix* - Arch. Protistenkd. **115:** 173-233.

ODUM, E.P. (1971): Fundamentals of ecology. - 3rd. ed., 564 pp., Saunders, Philadelphia.

PFISTER, P. (1992): Artenspektrum des Algenaufwuchses in 2 Tiroler Bergbächen - Teil 1: Cyanophyceae, Chrysophyceae, Chlorophyceae, Rhodophyceae. - Arch. Hydrobiol./ Suppl., Algological Studies **65:** 43-61.

PIPP, E. & ROTT, E. (1993): Bestimmung der ökologischen Wertigkeit von Fließgewässern in Österreich nach dem Algenaufwuchs. - Blaue Reihe des Bundesministerium für Umwelt, Jugend und Familie 2, 147 pp.

ROTT, E. & HERNÁNDEZ MARINÉ, M. (1994): *Pulvinularia suecica*, a rare stigonematalean cyanophyte. - Arch. Hydrobiol./Suppl., Algological Studies **75:** 313-322.

ROUND, F.E. (1981): The ecology of algae. - 653 pp., Cambridge University Press.

SABATER, S. & ROCA, J.R. (1990): Some factors affecting distribution of diatom assemblages in Pyrenean springs. - Freshwater Biol. **24:** 493-507.

-- (1992): Ecological and biogeographical aspects of diatom distribution in Pyrenean springs. - Brit. Phycol. J. **27:** 203-213.

SCHWOERBEL, J. (1959): Ökologische und tiergeographische Untersuchungen über die Milben (Acari, Hydracnellae) der Quellen und Bäche des südlichen Schwarzwaldes. - Arch. Hydrobiol./Suppl. **24:** 385-546.

SHAPIRO, J. (1990): Current beliefs regarding dominance by blue-greens: the case for the importance of CO_2 and pH. - Verh. Internat. Verein. Limnol. **24:** 38-54.

STARMACH, K. (1929): Über polnische *Chamaesiphon* Arten. - Acta Soc. Bot. Pol. **6** (1): 30-45.

TER BRAAK, C. (1988): CANOCO - A FORTRAN Program for canonical community ordination by partial detrended canonical correspondence analysis. - Manuscript, 95 pp. Agricultural Mathematics Group, Wageningen, The Netherlands.

THIENEMANN, A. (1922): Hydrobiologische Untersuchungen an Quellen. - Arch. Hydrobiol. **14:** 151-190.

VAN DER KAMP, G. (1995): The hydrogeology of springs in relation to the biodiversity of spring fauna: a review. - J. Kansas Entomol. Soc. **68** (2) suppl.: 4-17.

VERDOUW, H.; VAN ECHTELD, C.J.A. & DEKKERS, E.M.J. (1978): Ammonia determination based on indophenol formation with sodium salicilate. - Water Res. **12:** 399-402.

WARD, J.V. (1994): Ecology of alpine streams. - Freshwater Biol. **32:** 277-294.

WHITFORD, L.A. (1956): The comunities of algae in the springs and spring streams of Florida. - Ecology **37:** 433-442.

WHITFORD, L.A. & SCHUMACHER, G.J. (1963): Communities of algae in North Carolina streams and their seasonal relations. - Hydrobiology **22:** 133-196.

WINGET, R.N. (1985): Methods for determining successfull reclamation of stream ecosystems. - In: GORE, J.A. (ed.): Restoration of rivers and streams - theories and experience, p. 165-192, Butterworth, Woburn.

The authors' addresses:

Dott. MARCO CANTONATI,
Museo Tridentino di Scienze Naturali,
Via Calepina 14,
I-38100 Trento, Italy.

Doz. Dr. EUGEN ROTT,
Dr. EVELINE PIPP,
Institut für Botanik, Arbeitsgruppe Hydrobotanik,
Sternwartestraße 15,
A-6020 Innsbruck, Austria.