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Epilithic algae from a freshwater stream at Hope Bay, Antarctica

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Abstract: Temporal and spatial variations of the epilithic phycoflora were studied in one of the largest streams at Hope Bay (Antarctic Peninsula) during the summer of 1992/93. A complete floristic inventory was made, and the relative frequencies of each algal taxon were estimated. Periphytic cumulative chlorophyll *a* was measured by means of artificial substrata. The stream was a typical maritime Antarctic lotic ecosystem, with evident signs of enrichment by sea-birds. Variability in discharge strongly affected the water chemistry, with the high water level periods characterized by the lowest conductivities and dissolved reactive phosphorus concentrations. Epilithic algal communities predominantly consisted of algal mats or filamentous and foliose forms of *Prasiola crispa*. Other dominant species were *Leptolyngbya fragilis, Hydrurus foetidus, Chrysococcus* cf. *rufescens* and *Phaeogloea mucosa*. Whereas *P. crispa* appeared more frequently near to the origin of the stream in Boeckella Lake, Chrysophyceae were better developed towards the mouth.

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Introduction

Previous limnological investigations carried out in Hope Bay, Antarctic Peninsula, were focused on taxonomy and ecology of phytoplankton from lakes (Corte 1962, Izaguirre *et al.* 1993, Vinocur & Izaguirre 1994, Tell *et al.* 1995). Since the summer of 1993 the epilithic phycoflora of some streams from this area has also been investigated. In the present work the algal assemblages of "Prasiola Stream" (unofficial name) are described.

Most of the studies of Antarctic streams have been confined to Continental Antarctica (Hirano 1979, Broady 1982, Howard-Williams *et al.* 1986), where perennial cyanobacteria were reported as the dominant algal component of the epilithic communities. More recently, some maritime Antarctic courses have been surveyed (Hawes 1989, Hawes & Brazier 1991), showing that these habitats were propitious for annual species, particularly some filamentous chlorophytes. Our study constitutes a further contribution to the knowledge of this kind of environment.

"Prasiola Stream" was previously studied from a taxonomic point of view, and the new records for Antarctica were reported in Vinocur & Pizarro (1995). Results of these previous investigations revealed the abundance of *Prasiola crispa* along the stream. According to Broady (1989), this species usually occurs in the vicinity of penguin rookeries, close to the coast and at low altitude, these conditions being those of the "Prasiola Stream". Moreover, a very interesting chrysophycean flora was found, in contrast with the scarcity of this algal group in other Antarctic locations.

The main objective of this study is to describe the spatial and temporal variations of the epilithic algae. Changes in chlorophyll *a* concentrations were evaluated by means of artificial substrata. The relationship between the community and some abiotic factors is also analysed.

Study area

Hope Bay contains several lakes, ponds and streams distributed over an area of about 3.8 km^2 (63°23'–63°25'S, 56°58'–57°02'W), from Mount Flora to the seashore. The region contains a large population of Adélie penguins. According to Tatur (1989) the penguin rookery is located on the rock rubble of the Trinity Formation and, in its east part, on stony-clayey moraine. The Trinity Formation is composed of strongly cemented greywackes. Moraine clays mainly contain weathered material of bituminous shales of freshwater origin (Mount Flora Formation).

Hope Bay exhibits a typical maritime climatic regime, with mean monthly summer temperatures between -1.5 and 2°C (data from Esperanza Meteorological Station). During summer periods stream discharge usually drastically increases as glaciers and snow-fields melt. "Prasiola Stream" is located near the Argentinian Esperanza Station (Fig. 1a). Its summer discharge makes it the most important stream in this area. It is also the outflow of Boeckella Lake. According to these characteristics, "Prasiola Stream" could be included in the "large streams and lake outflows" category proposed by Hawes (1989). It has a clearly defined channel with a bed of stable rocks and boulders. In some reaches the bottom has patches of fine sedimentary material and gravel. The algal mats are usually distinctly visible, especially those dominated by filamentous and foliose forms of *Prasiola crispa.* Along the stream, some reaches are directly influenced by penguins and skuas that fertilize the water. It flows from about the

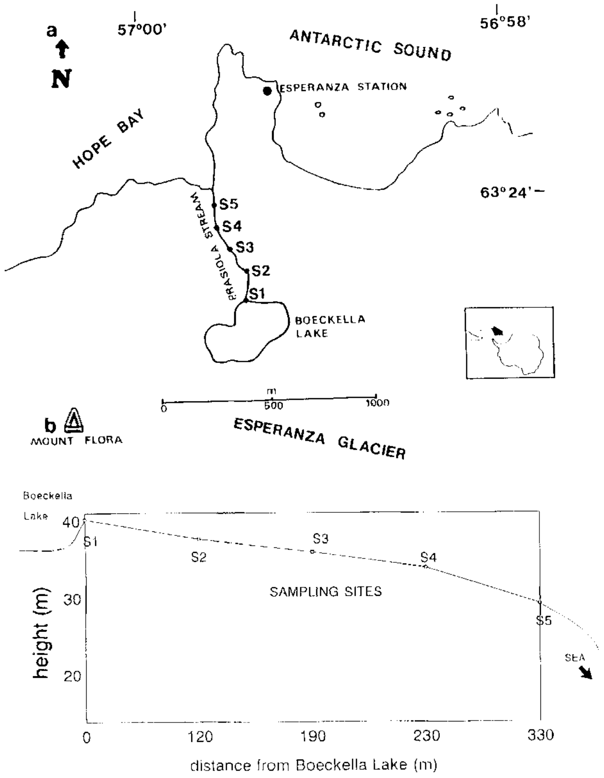

Fig. 1 a. Map showing the location of "Prasiola Stream" with the sampling sites (S). **b.** Profile diagram of "Prasiola Stream"

middle of November to the end of March, depending on the climatic conditions. Table I summarizes the main morphometric characteristics of the stream.

Methods

Sampling sites and dates

Five sampling sites were established along the stream, covering a distance of 350 m from its origin in Boeckella Lake (Fig. 1a). After S5 the stream has a permanent ice cover of *c.* 150 m length, which ends in an abrupt drop to the sea. Samples were collected weekly during the summer of 1992/93, from 28/12–2/2. The stream flowed continuously during the study period.

Physical and chemical variables

Current velocity at the central channel of the stream was estimated by using a neutrally buoyant float. Temperature, pH and conductivity were measured *in situ* with P300 and C400 Luftman combined electronic meters. Water samples for dissolved reactive phosphorus (DRP) analyses were filtered through Whatman GF/F filters. Samples were stored at −20°C for return to Argentina where DRP analyses were made according to Mackereth *et al.* (1978).

Table I. Morphometric characteristics of "Prasiola Stream".

Length (m)	515
Width range (m)	4.52–25.5
Max. obs. depth (cm)	61
Min. obs. depth (cm)	7
Mean slope $cm\ m^{-1}$	4.2
% snow/ice perm. cover	31

Algal samples

Firmly attached and accompanying algae were scraped from the entire rocks taken from random places at each sampling site. The material was removed by means of a fine brush and placed in PVC flasks. Two stones corresponding to three different levels of the stream were sampled:

1) rocks from the bottom which were permanently submerged during summer
2) almost permanently submerged stones
3) stones subjected to frequent water level changes and occasionally dried

Living specimens were examined at Esperanza Station, and then samples were preserved in 4% formalin for relative frequency analyses. Details of the taxonomic identifications have been published in Vinocur & Pizarro (1995).

Relative frequencies of each algal taxa were performed at x 1000 magnification with an optical microscope (Zeiss, Jena). At least two slides were examined to estimate the proportion of each species in random fields and assess them in the following categories:

1) scarce or rare
2) frequent
3) abundant
4) very abundant

Chlorophyll a *analyses*

At three sampling sites (S1, S3 and S5) glass slides, used as artificial substrata, were placed on 28/12 in acrylic holders anchored among stones of the stream bed (Fig. 2a, b). Chlorophyll *a* concentration was measured from one glass slide taken from each holder at intervals of 5–11 days over a period of two months. Thus, each measurement corresponded to the chlorophyll *a* accumulated from the begining of the experiment up to each sampling date. Slides were stored in 95% methanol at 4°C for 24 h for extraction of pigments. Absorbance of the extracts at 650, 665 and 750 nm was obtained spectrophotometrically. Concentrations of chlorophyll *a* were calculated using conversion factors provided by SCOR-UNESCO (1966). Chlorophyll *a* was expressed as per unit surface area of the slides.

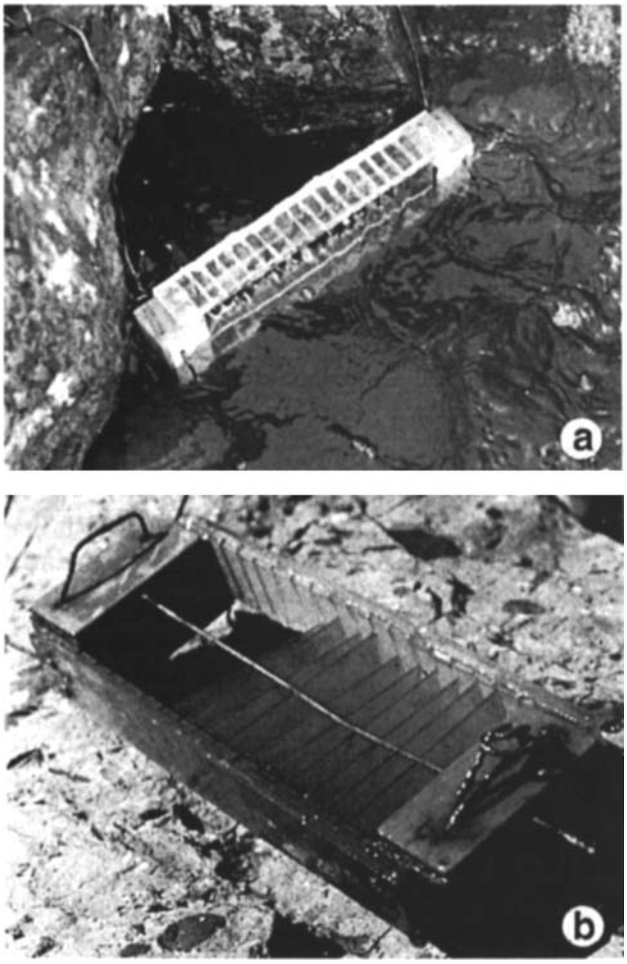

Fig. 2. Acrylic holder with the glass-slides used as artificial substrata. **a.** Anchored among stones of the stream bed. **b.** Detail of the holder.

Numerical analyses

Pairwise correlation analyses between the abiotic variables were based on Pearson's coefficient.

A principal component analysis (PCA) was performed using the variance-covariance matrix of 57 selected species. Rare taxa were removed for this analysis (those in less than two samples at low relative frequencies) (Digby & Kempton 1994).

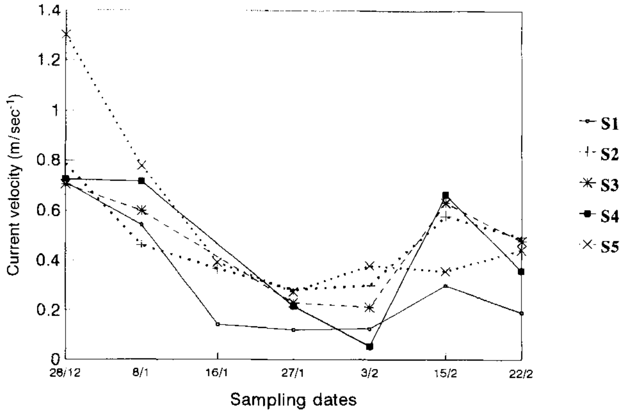

Fig. 3. Spatial and temporal changes in current velocity.

Results

Physical and chemical characteristics

Water discharge varied considerably during the study period, the mean current velocities ranging between 0.12 m sec^{-1}, during low discharge, and 0.78 m sec^{-1} during the glacier melting period (Fig. 3). The lowest values of discharge were recorded from 27/1–3/2, coinciding with low temperatures and abundant snowfalls when the stream was almost entirely covered by snow. The highest discharges were observed early in the summer (28/12), with a peak of 1.3 m sec^{-1} in current velocity at S5 when Boeckella Lake was at its maximum water level. This behaviour is confirmed by a significant positive correlation between temperature and current velocity ($r = 0.491, p < 0.01$). Current velocity of the stream generally increased slightly with distance from Boeckella Lake. Ranges of the physical and chemical features are summarized in Table II.

Water temperature varied between 0–4.6°C over the study period (Fig. 4). The highest temperatures were measured during the first week of January.

The water of the stream varied from slightly acid to circumneutral (5.2–7.05). The highest values were generally recorded at S1, reflecting the proximity of the lake, which had similar pH values (Izaguirre *et al.* 1993).

An inverse significant correlation between conductivity and current velocity values was observed ($r = -0.623$, $p < 0.001$). Conductivity ranged between 10.6–120 μS cm^{-1} (Fig. 5) and there was a direct correlation between this variable and DRP ($r = 0.48$, $p < 0.01$).

DRP varied from undetectable to 1783 μg l^{-1}. During the

Table II. Ranges of the physical and chemical features at each sampling site.

	S1	S2	S3	S4	S5
Temperature (°C)	1.8–3.9	1.4–3.9	1.0–4.2	0–4.3	0.8–4.6
pH	5.5–7.05	5.2–6.4	5.2–6.6	5.3–6.0	5.2–6.1
Conductivity (μS cm^{-1})	12.1–81.6	12.8–83.7	11.9–105.7	11.9–92.0	10.6–120.4
Current velocity (m seg^{-1})	0.12–0.71	0.28–0.79	0.21–0.70	0.05–0.73	0.28–1.30
DRP (μg l^{-1})	18.9–696.2	116.0–1318.6	48.5–1356.5	10–1426.2	14.8–1782.7

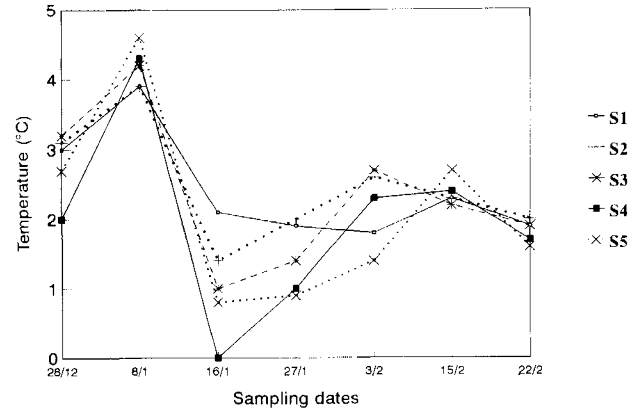

Fig. 4. Spatial and temporal changes in water temperature.

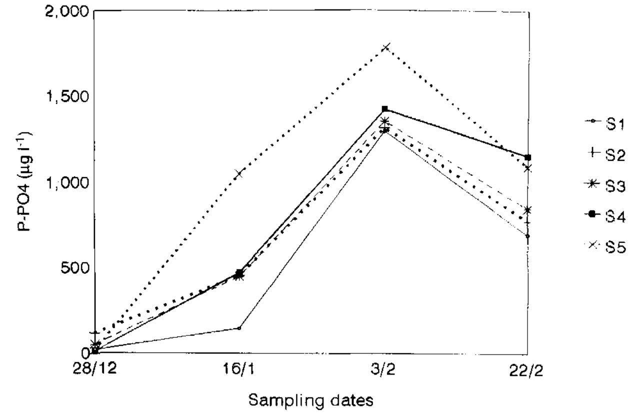

Fig. 6. Spatial and temporal changes in dissolved reactive phosphate (DRP).

melt period DRP was at a minimum with very high values during the lowest flow (Fig. 6).

Epilithic community

Taxonomic analysis revealed a relatively rich epilithic phycoflora, with a total of 87 algal taxa. The complete floristic list was detailed in Vinocur & Pizarro (1995), whereas the reduced one, with the taxa used for the numerical analyses (57) is presented here (Table III). Mean relative frequencies of the more important taxa at each sampling site is given in Table IV.

Cyanophyceae showed the highest species richness with 46% of the total taxa, followed by Bacillariophyceae (23%) and Chlorophyta (16%), while Tribophyceae and Chrysophyceae never exceeded 10% each.

Algal material occurred in the form of mats or filamentous and laminar thalli of *Prasiola crispa*. Although this species was frequently found at the different sampling sites, it was more abundant at S1 and S2 (mean value 3 according to our categories of abundance). On the other hand, the proportions of the species in the algal mats varied along the stream. At S1 and S2, together with *P.crispa*, the algal mats were dominated by *Leptolyngbya fragilis*. Chrysophyceae, represented by *Hydrurus foetidus, Chrysococcus* cf. *rufescens* and *Phaeogloea mucosa* increased their proportions from S2, constituting the more important species of the algal assemblages, together with *Leptolyngbya fragilis* and forming a visible yellow cover on the stones. As accompanying species, the following were also present in the algal mats: *Leptolyngbya lagerheimii, Chlamydomonas* sp., *Porphyrosiphon martensianus, Pinnularia microstauron, Navicula muticopsis, Achnanthes subatomoides* and *A. lapponica* var. *ninckei. Chlorogloea fritschii*, also always present, was a subdominant taxa in some samples. The remaining species appeared occasionally at low abundance.

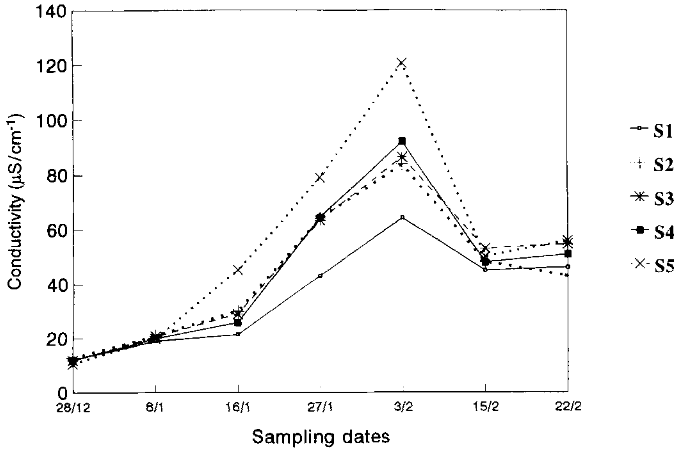

Fig. 5. Spatial and temporal changes in water conductivity.

The results of PCA confirm the spatial distribution of the algae in a gradient along the stream. The first four factors account for 49.7% of the total variance. In the first two principal components the highest weighting is given by *Chrysococcus* cf. *rufescens, Hydrurus foetidus, Phaeogloea mucosa, Prasiola crispa* and *Leptolyngbya fragilis*. Samples where the first three species were dominant ordinated towards the lower right side of the plot (Fig. 7), which correspond mainly to S4 and S5. On the lower left side, *Prasiola crispa* and *Leptolyngbya fragilis* increase their weighting, and occur in samples from S1, S2 and S3.

No vertical differences in algal composition as well as in their relative frequencies were detected between the three sampled levels.

Chlorophyll a *accumulation*

Chlorophyll *a* accumulation decreased along the stream (Fig. 8). The highest values of cumulative chlorophyll *a* were recorded near Boeckella Lake (S1) where growth began in mid January, reaching a maximum of 22.81 mg m^{-2} at the end

Table III. Floristic list of 57 algal taxa used for the numerical analyses with their abundance ranges.

Class	Sampling sites					Habitat
	S1	S2	S3	S4	S5	
BACILLARIOPHYCEAE						
Achnanthes germanii Manguin	1–2					P
A. lapponica var. *ninckei* (Guerm. et Mang.) Reim.	1	1	1	1	1	P
A. subatomoides (Hust.) L.-Bert. et Arch.	1	1–2	1	1–2	1–2	P
Fragilaria ulna var. *ulna* (Nitzs.) L.-Bert.				2		P
Navicula clementis Grun.	1			1		WS, E
Navicula multicopsis V. Heurck	1–3	1	1	1–2	1	WS, E
Nitzschia homburgiensis L.-Bert.	1	1	1	1		P
Pinnularia aff. *crucicula* Freng.	1–2	1	1	1	1	P
P. microstauron var. *microstauron* (Ehr.) Cl.	1–2	1	1	1–4	1	P
P. microstauron var. *ambigua* Meist.	1–2	1	1–2	1–2	1	P
CYANOPHYCEAE						
Aphanocapsa delicatissima W. et G.S. West	1	1	1–2	1–2	1	P
A. elachista var. *elachista* W. et G.S. West	3	1	1	2	1	P
A. elachista var. *planctonica* G.M. Smith		1	1	1	1	P
Aphanothece nidulans Richt.	1–2	1	1–2	1	1	P
A. saxicola Naeg.	1	1	1		1	P
Chlorogloea fritschii Mitra	1–3	1–4	1–3	1–3	1–2	A
C. purpurea Geitl.	1–2	1–2	2	1–2	1	A
Chroococcus minutus (Kuetz.) Naeg.		2				P
Eucapsis minuta Fritsch	1	1	1		1	P
Gloeocapsa magma (Breb.) Hollerb.	1	1			1	A
G. aff. *ralfsiana* (Harv.) Kuetz.		2	1			A
Isocystis aff. *pallida* Voronich.	1	1	1	1	1	P
Leptolyngbya lagerheimii (Gom.) Anag. et Kom.	1–4	1–3	1–2	1–3	1–3	A
L. fragilis (Gom.) Anag. et Kom.	1–4	1–4	1–4	1–4	2–3	A
Microcystis pulverea (Wood) Forti	1	1	1			P
Myxosarcina burmensis Skuja				3	1	A
Myxosarcina concinna Printz	1–2	1		1	1	A
Oscillatoria chlorina Kuetz.	1	1	1	1		P
O. fracta Carls.	1	1	1	1		P
Phormidium allorgei (Fremy) Anag. et Kom.	1	1				A
P. amoenum Kuetz.	1–2	1–2	1–2	1–2	1	A
P. deflexum (W. et G.S. West) Anag. et Kom.	1	1	1	1	1	A
P. mucicola Hueb.-Pest. et Naumann		1–2	1			A
P. priestleyi Fritsch	2	1	1	1–4		A
P. simplissisimum var. *antarctica* (Fritsch) Anag. et Kom	1–3		1	1	1	P
P. subproboscideum (W.et G.West) Anag.et Kom.	3	1	1–2	1		A
P. uncinatum Gom.	1–2	1				A, WS
Porphyrosiphon martensianus (Menegh. ex Gom.) Anag. et Kom.	1–3	1–3	1–2	1	1	P
Pseudanabaena catenata Lauter.	1–2	1	1–2	1	1	P
Synechococcus elongatus Naeg.	1	1	1	1	1	WS, E
CHLOROPHYCEAE						
Chlamydomonas nivalis (Bauer) Wille	1	1	1	1	1	C
Chlamydomonas sp.	1	1	1–2	1–2	1–2	P
cf. *Pleurococcus antarcticus* fo. *minor* Fritsch	1	1		1		P
Prasiola crispa (Lightf.) Menegh.	1–4	1–4	1–4	1–4	1–4	WS, A
Scotiella antarctica Fritsch	1	1		1		P
Ulothrix australis Gain		2	1	1		A
Uronema africanum Borge		1				A
ZYGOPHYCEAE						
Cylindrocystis brevissonii (Menegh. ex Ralfs) De Bar	1	1	1	1	1	WS, E
TRIBOPHYCEAE						
Monallantus brevicylindrus Pascher	1		1	1	1	WS, A
Tribonema australis Vinoc. et Pizarro	1–2					P
T. utriculosum (Kuetz.) Hazen	1	1		1	1	P
CHRYSOPHYCEAE						
Chromulina freiburgensis Dofl.	1	1	1		1	P
Chrysococcus cf. *rufescens* Klebs	1–2	1–4	1–4	1–4	1–4	P
Hydrurus foetidus (Vill.) Trev.	1–2	1–4	1–4	1–4	1–4	E
Ochromonas aff. *ovalis* Dofl.			1	1	1	P
Ochromonas sp.	1	1	1	1		P
Phaeogloea mucosa Chodat	1–3	1–4	2–4	1–4	1–4	A, WS

1: scarce or rare; 2: frequent; 3: abundant; 4: very abundant. Habitat: P -planktonic (tycoperiphytic); WS -wet soil; A -attached to different substrata; C -cryophilic; E -epilithic.

Table IV. Mean relative frequencies of the more abundant and constant epilithic algae at each sampling site.

Taxa	S1	S2	S3	S4	S5
Prasiola crispa (Lightf.) Menegh.	3	3	2	1	1
Leptolyngbya fragilis (Gom.) Anag. et Kom.	3	2	2	2	1
Hydrurus foetidus (Vill.) Trev.	1	2	2	1	2
Chrysococcus cf. *rufescens* Klebs	1	2	1	2	2
Phaeogloea mucosa Chodat	1	1	3	2	2
Leptolyngbya lagerheimii (Gom.) Anag. et Kom.	1	1	1	1	1
Chlamydomonas sp.	1	1	1	1	1
Porphyrosiphon martensianus (Menegh. ex Gom.) Anag. et Kom.	1	1	1	1	1
Pinnularia microstauron var. *microstauron* (Ehr.) Cl.	1	1	1	1	1
Navicula muticopsis V. Heurck	1	1	1	1	1
Achnanthes subatomoides (Hust.) L.-Bert. et Arch.	1	1	1	1	1
Achnanthes lapponica var. *ninckei* (Guerm. et Mang.) Reim.	1	1	1	1	1
Chlorogloea fritschii Mitra	1	1	1	1	1

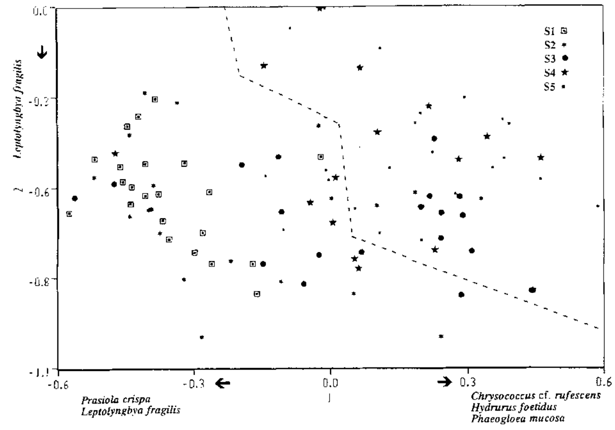

Fig. 7. Representation of the first and second components of the PCA based on the VAR-COV matrix of the epilithic taxa.

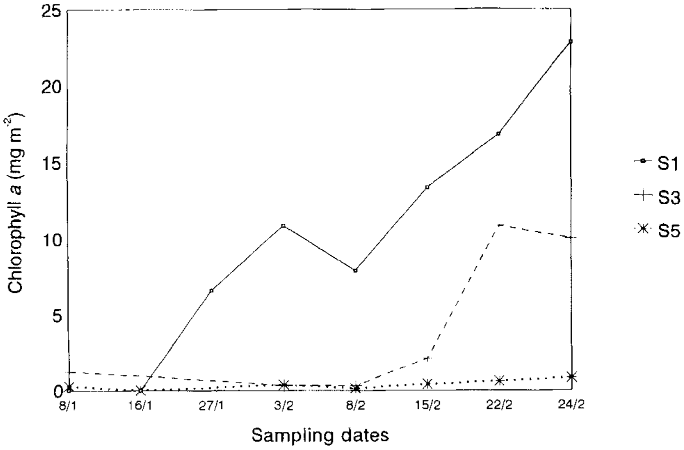

Fig. 8. Temporal changes in cumulative chlorophyll *a* concentrations (uncorrected for phaeopigments).

of the period (24/2). On the other hand, S5 showed the lowest chlorophyll *a* concentrations (0.13–0.84 mg m^{-2}).

Discussion

The limnological properties of the stream were strongly related to its water discharge, the melting periods being characterized by the highest current velocities and the lowest values of conductivity and DRP concentrations. On the contrary, during low water level periods, the highest conductivities and DRP values were observed, coinciding with the lowest temperatures, and the partially snow covered stream.

The peak of DRP is explained by the low flow, and by an additional input of organic matter during the maximum bird activity (penguins and skuas). In summer, the environmental conditions contribute to faster mineralization processes.

The gradual increase of mineralization towards the mouth of the stream was shown in the spatial pattern of conductivity; this is related to the inputs of organic (ornithogenic) and inorganic matter, combined with sea-spray.

"Prasiola Stream" is characterized by a rich and particular phycoflora, with a relevant occurrence of chrysophycean species. The most abundant taxa throughout the summer period were: *Prasiola crispa*, *Leptolyngbya fragilis*, *Hydrurus foetidus*, *Chrysococcus* cf. *rufescens*, and *Phaeogloea mucosa*.

The algal biomass in continental streams is usually dominated by perennial cyanophytes (Broady 1982, Howard-Williams *et al.* 1986, Howard-Williams & Vincent 1987). Hawes (1989) stressed the particular characteristics of the epilithon of maritime streams, where the fast growing filamentous chlorophytes are well represented. In this sense, "Prasiola Stream" shows the typical behaviour of a maritime lotic ecosystem. Most of the species can resist adverse conditions, and are able to exhibit fast growth when the environment turns favourable again. The abundant chrysophyceae in particular produce endogenous cysts, which were frequently found along the stream (e.g. *Hydrurus foetidus*) with a typical r-strategy growth (Reynolds 1991). In addition, the populations of *Prasiola crispa* were always observed in active growing phase in summer period with different forms of the species present: filamentous, laminar and other stages of its life-cycle. Nevertheless, the algal assemblages of the stream also included some perennial filamentous cyanophytes with slow growth which are more common in continental Antarctic streams.

A trend of replacements of some species towards the mouth of the stream was observed (Table IV) but neither temporal nor vertical patterns were found. At S5, where the average current velocity was higher, *Prasiola crispa* was poorly represented, probably due to the abrasive effect of the water. The better developed algae at S5 were those characterized by a mucilaginous matrix very resistant to the water flow. The clearance of filamentous chlorophytes in streams with high current velocity has been reported repeatedly, in particular for Antarctic streams (Hawes 1989).

The absence of vertical differences in algal composition could be explained by the frequent water level changes occurring at intervals of a few days. This situation would not cause strong differences in environmental conditions for algae growing at different heights above the stream bed.

Our values of accumulated chlorophyll *a* were close to the lowest figures reported from both continental and maritime Antarctic streams (Howard-Williams *et al.* 1986, Hawes 1989, Hawes & Brazier 1991). This fact could be due to the different methodology employed in this survey (artificial substrata) with an exposure time that was not enough to reach the potential maximum values on natural substrata.

Spatial differences observed in chlorophyll *a* (Fig. 8) were apparently associated with the abundance of certain algae, as well as the effects of the water flow. At S1, where *Prasiola crispa* was dominant and the mean current velocity was lowest, chlorophyll *a* reached a maximum. We suggest that current velocity and channel morphology could also be involved.

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