Polar Biol (2000) 23: 205–211

ORIGINAL PAPER

G. Mataloni · G. Tell · D.D. Wynn-Williams

Structure and diversity of soil algal communities from Cierva Point (Antarctic Peninsula)

Accepted: 12 October 1999

Abstract Cyanobacteria and eukaryotic algae, together with bacteria and fungi, are known to be primary colonizers of mineral soils throughout Antarctica. Their species diversity and soil coverage were studied in 18 soil polygons located at Cierva Point, Antarctic Peninsula. Undisturbed assemblages were dominated by filamentous Cyanobacteria and diatoms, whilst almost 40% of the 49 species recorded were observed only after enrichment culture. Nearly all of the isolates from enrichment cultures were Chlorophyta and Tribophyceae. This revealed a higher degree of complexity than reported for similar communities on Signy Island. Water content and concentrations of nutrients were determined at four representative sites, and did not appear to account for the large inter-polygon variation found in species composition and relative frequencies of occurrence. Variables describing community development were not significantly correlated with either area of the polygons or the minimum distance between them. This suggested that these features are not an important short-range barrier to dispersal for those "weed" species dominating the community. Conversely, the relative frequencies of some of the most common species showed significant correlations with species diversity and soil coverage, and it is suggested that biotic interactions could account to a larger extent for community structure than previously reported from Signy Island fellfields.

G. Mataloni (✉) · G. Tell
Departamento Ciencias Biológicas,
Facultad de Ciencias Exactas y Naturales,
Universidad de Buenos Aires,
Pab. II – C. Universitaria –
(1428) Buenos Aires, Argentina
e-mail: gm@bg.fcen.uba.ar

D.D. Wynn-Williams
British Antarctic Survey, High Cross,
Madingley Road,
Cambridge CB3 OET, UK

Introduction

The western Antarctic Peninsula is probably the most biologically diverse and ecologically dynamic region in Antarctica (Smith 1996). In particular, soil ecosystems provide a unique opportunity for studying the links between their components and with environmental variables (Bölter 1996).

Mineral soils recently exposed by ice retreat have proved valuable subjects for research into primary colonization by bacteria, algae, and fungi. The early successional stage of these apparently barren environments permits the study of algal community structure (Davey 1988, 1991), and their dynamic feature helps the understanding of colonization processes (Wynn-Williams 1993). Moreover, sensitivity of pioneer soil algal communities to changing environmental conditions would make them valuable tools for prediction of the ecological consequences of global change on Antarctic systems (Wynn-Williams 1996).

Most work so far has been carried out at a single location (Signy Island, South Orkney Islands), hence the need for comparison with other sites on the Antarctic continent. This study investigated floristic composition and diversity of microalgal communities of soil polygons in a fellfield ecosystem from Cierva Point (Antarctic Peninsula) and their relation to both edaphic factors (water content, soluble reactive-P, NH_4-N and NO_3-N concentrations) and macro-scale factors describing polygons (area, minimum distance between polygons and days free of snow).

Study site

Located on Danco Coast, Cierva Point (64°09′S, 60°57′W), Antarctic Peninsula, has been designated as SCAR-SSSI (Site of Special Scientific Interest) no. 15 owing to its unusually rich and diverse biota (Agraz et al. 1994). The area has a mild microclimate, with a

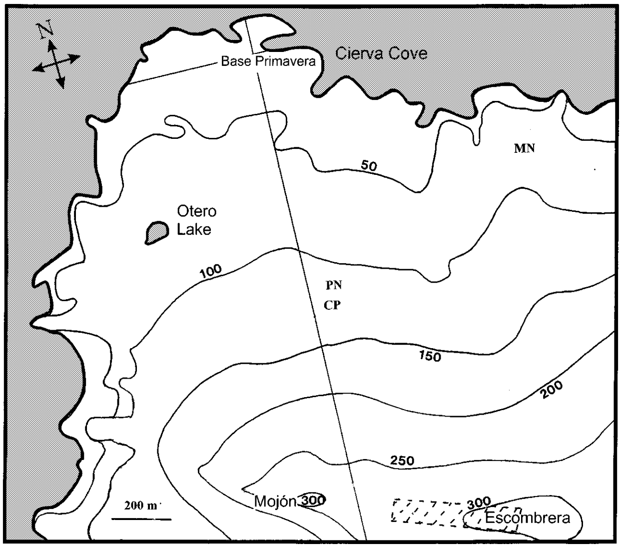

Fig. 1 Map of Cierva Point showing the location of the study area on the slope of Escombrera Peak, and peat (*MN*) and ornithogenic soils (*PN*, *CP*) at lower locations. Based on Betgen et al. (1997)

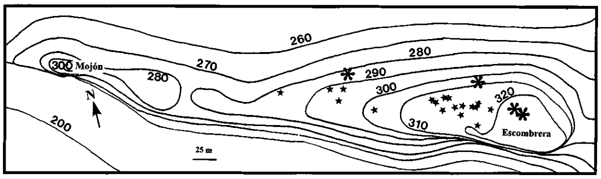

Fig. 2 Detail of the sampling area. *Stars* polygons; *asterisks* skua nests

Fig. 3 A typical frost-sorted polygon with central fines, which were examined for microalgal biodiversity and colonization. The *bar* for scale is 13 cm long

yearly mean temperature of −3 to −4°C (Reynolds 1981). During the 1996/1997 summer season, some sort of precipitation was registered in 42% of the days, 60% of this being rain (T. Betgen and D. Beppler, unpublished work) Here, freshwater and cryobiontic algal communities have been studied recently (Mataloni and Tesolín 1997; Tesolín et al. 1997; Mataloni et al. 1998).

The section of SSSI no. 15 accessible from the Argentinian Primavera Station includes the second highest peak of Cierva Point, Escombrera (Fig. 1). Its eastern gentle slope (280–330 m a.s.l.) encompasses some sparse, small soil polygons (each of < 0.5 m^2 in area) (Fig. 2). These frost-sorted polygons are composed of mineral fines at their centre and coarser particles at the edges (Fig. 3), which are sometimes colonized by mosses, mainly *Andreaea* sp. and *Polytrichum alpestre* Hopp. They are usually sheltered from erosion by surrounding groups of large granite rocks. The area is not inhabited by birds, with the exception of four couples of skuas (*Catharacta* spp.) nesting on the northern slope. Thus, the direction of drainage prevents their droppings from acting as nutrient sources in the studied area.

Materials and methods

During summer 1995, all 18 frost-sorted soil polygons in this area were studied. On 2 February 1995, soil samples were taken with sterile 20-ml syringe corers. Because of the small size of the polygons (average area = 0.18 m^2), four 1-cm-deep replicate cores (16 mm diameter) were taken at random from each for study of the algae, avoiding occasional surface stones. Preliminary inspection showed relative homogeneity of particle morphology within the naturally sorted central fines of a given polygon, as at Signy Island (Wynn-Williams 1993). A representative fifth replicate core was therefore used to analyze soil particle size. A series of six further cores was taken at each of four randomly selected polygons in order to assess water content, pH, and concentration of nutrients (PO_4-P, NO_3-N, and NH_4-N). All samples were immediately frozen to −15°C for transport to Argentina and the United Kingdom.

Nutrient analyses were performed at the University of Buenos Aires. Six cores were extracted in 150 ml distilled, deionized water for 24 h and filtered through Whatman GF/C filters (pore size = 1.2 μm). Soluble reactive phosphate was calculated following Mackereth et al. (1978). The Cd reduction method was used to calculate nitrate-N and the phenate method for ammonium-N (APHA-AWWA-WPCF 1975).

Algal samples were studied at the British Antarctic Survey (Cambridge, UK) using both epifluorescence (green excitation at 530 nm, barrier filter 580 nm) and transmitted-light microscope techniques. All four replicates from each polygon were used to capture images of phycocyanin and chlorophyll autofluorescence (at > 580 nm) produced by the undisturbed algal community. Images were analyzed using a Seescan Solitaire Plus image analyzer as detailed in Wynn-Williams (1996) in order to assess the percent coverage of the surface layer. Cores were moistened with a few drops of sterile water and then exposed to daylight at 15°C for 24 h. Coverslips were removed with algae attached to them (Broady 1979) and algae identified using light microscopy (bright field at ×1000, Nikon compound microscope). As aids for taxonomy, drawings of algae were made with a camera lucida attachment and photomicrographs taken with a Nikon camera. Average size of soil particles was calculated as the Feret diameter (Wynn-Williams 1996) by image analysis performed on a series of five images of soil from each polygon. Standard deviation for this parameter was found to be larger within than among polygons, and therefore it was discarded for further statistical analyses.

The Shannon diversity index (Magurran 1988) was used to assess algal diversity at each site. This was estimated on the basis of relative frequencies from a total of 200 individuals counted for each replicate core. Coverslips were then transferred together with the rest of the core to 30-ml universal bottles containing sterile BBM culture medium (Broady 1979). The cultures were allowed to grow for 2 weeks at 15°C in natural daylight. Following incubation, visible green areas of the enrichments were used to make algal streak plates on agarized BBM. Resulting separated colonies were then isolated and re-examined to detect rare species.

Correlation analyses were performed between parameters describing the sites (area of the polygon, minimum inter-polygon distance, number of days free of snow before collection of samples) and parameters describing the communities (species richness, diversity, and percentage colonization of the soil). A Principal Component Analysis (PCA) was subsequently performed to ordinate the 18 polygons according to those descriptive parameters shown to be independent (Digby and Kempton 1987). Values for relative frequencies were transformed using the function log (× + 1) to obtain a normal distribution of the data. Multiple regression analyses were made using the log-transformed relative frequencies of most common species as dependent variables, against the five selected descriptive parameters. Finally, a PCA was performed to analyze the ordination of the 18 sites according to the log-transformed relative frequencies of common species.

Results

Microalgal communities inhabiting fellfield soils from Cierva Point showed high species richness. A total number of 49 species has been recorded for the whole study area (Table 1). Individual polygons supported 9–26 species, of which Cyanobacteria were usually the best represented group. Most Chlorophyta and all Tribophyceae were detected only following the use of enrichment cultures. Among the blue-green filaments, *Phormidium autumnale* was present in all samples, mostly in large quantities.

To provide an edaphic background to differences in algal diversity between polygons, Table 2 shows the values for water content and concentrations of N and P nutrients in soil from four representative polygons relative to those at Signy Island and to peat and ornithogenic soils at Cierva Point. All but two pH values were circumneutral, ranging from (5.77)–6.36 to 7.34– (7.78).

Values of parameters describing the polygons and microalgal communities are presented in Table 3. Amongst these, only the minimum distance between polygons and the number of days free of snow were significantly correlated ($r = -0.71$, $P < 0.05$). One of these had then to be selected as an independent variable for further analyses. As a valuable factor in order to test hypotheses relating the Theory of Island Biogeography, the former parameter was retained.

Principal Component Analysis performed on the 18 sites on the basis of 5 independent descriptive variables (polygon area, separation, % colonization, species richness, and diversity), given in Table 3, explained 61.08% of the total variance through the first 2 components (Fig. 4). Factor 1 was significantly influenced by the percentage of algal cover and the area of the polygon (factor loadings 0.717 and 0.692, respectively). The Shannon diversity index (H) had the main loading on factor 2 (0.759). Polygons 2 and 4 had the largest areas and therefore showed the highest values along the first axis. Polygon 17, largely dominated by *Phormidium autumnale*, had the highest algal cover (6.21%). Polygon 15 had the highest value along the second axis on account of its high diversity and maximum species richness (26). Most polygons with ≤2% algal cover and diversity values ≤2 had negative values along both axes. Among them, polygons 3 and 18 are located on the inferior left corner due to their minimum diversity values.

Table 4 shows the ranks of relative abundances of algae at the different soil polygons. Most were dominated by filamentous Cyanobacteria, with the exception of polygons 6 and 8, which were dominated by two species of *Pinnularia*. Amongst the blue-green filaments, *Phormidium autumnale* was present in all samples, mostly in large quantities. The multiple stepwise regressions revealed significant r values between the transformed frequencies of *Navicula contenta*, *Lyngbya limnetica*, and *N.* aff. *agrestis* (total $r = 0.807$–0.633, $P < 0.05$). This was mainly due to diversity ($r = 0.644$, $P < 0.05$). *Hantzschia amphyoxis* decreased significantly as species richness increased ($r = -0.54$, $P < 0.05$), while *Phormidium autumnale* correlated directly with algal cover ($r = 0.518$, $P < 0.05$).

The first three components extracted from the PCA performed on log-transformed relative frequencies of species accounted for only 44% of the total variance (Fig. 5). Moreover, the loading of each species on these factors was generally low, with only eight species reaching values higher than 0.6. Nevertheless, certain trends in the spatial ordination of polygons were detected in Fig. 5. *H. amphyoxis* and *Nodularia harveyana* showed the highest loadings on factor 1 (0.767 and 0.690, respectively) at polygon 11. Polygons 3, 9, and 18 had the highest values along factor 2, owing to the high relative frequency of *Anabaena* cf. *constricta* (loading = 0.684). This species largely dominated these three polygons whilst occurring at percentages <2% in all other polygons. Conversely, *Pinnularia borealis* had a negative loading (−0.636) on this factor.

Discussion

Algal species richness found in Cierva Point fellfield systems (49 species) is notably higher than reported by Davey (1991) for mineral soils of similar frost-sorted polygons at Signy Island (14 species). However, Broady (1979) recorded a mean species richness of 26 species in a variety of mineral soils at the same location. On examining mineral soils from Signy Island, this author found almost all natural assemblages to be dominated by Cyanobacteria and diatoms, while Chlorophyta and Tribophyceae grew more efficiently in cultures. Similarly, among the 49 species recorded at Cierva Point, 38.7% were detected only by enrichment culture. All but one of these were Chlorophyta and Tribophyceae.

Different authors have already noted the dominance of Oscillatorialean species in moist mineral soils from diverse sites throughout Antarctica (Broady 1996). Their morphology and mucilaginous sheath confer an ability to

Table 1 Occurrence of microalgal taxa in frost-sorted polygons at Cierva Point (● = taxa detected microscopically; ○ = taxa identified only from enrichments)

Taxa	Frost-sorted polygons																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cyanobacteria																		
Anabaena cf. *constricta* (Szafer) Geitl.	●		●						●					●	●		●	●
Cyanothece aeruginosus (Naeg.) Kom.														○	○	●		
C. cedrorum (Sauv.) Kom.		●		●									●					
Leptolyngbya fragilis (Menegh.) Anagn. *et* Kom.	●	●		●		○	○		●					●			●	○
L. frigida (Fritsch) Anagn. *et* Kom.	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
Lyngbya limnetica Lemm.	●		●	●				●			●					●	●	●
Nodularia harveyana Thuret		●						●		●	●	●					●	
Nostoc cf. *punctiforme* (Kuetz.) Hariot										●							●	
Oscillatoria fracta Carlson	●		●	●						●	●	●		●	●	●	●	●
Phormidium autumnale (Ag.) Gom.	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
P. deflexum (West *et* West) Anag. *et* Kom.	●	●			●	●	●	○	●	●		●		●	●	●	●	
P. foveolarum (Mont.) Gom.				●	●				●				○		●	●	●	●
Phormidium aff. *subuliforme* Gom.				●											●	●	●	
Pseudanabaena catenata Lauteb.	●	○			●		○		●	●							●	
Tolypothrix byssoidea (Berk.) Kirch.						○												
Total	8	7	5	8	5	5	5	5	7	7	5	5	4	7	8	8	12	6
Chlorophyta																		
(?) Bracteacoccus sp.					○			○							○			
Chlamydomonas sp.													○		○			
Chlorella mirabilis Andr.	○		○		○					○				○	○			
C. saccharophila (Krieg.) Mig.															○			
Chlorolobion lunulatum Hindák					○													
*Cosmarium undulatum*var. *minutum* Wittr.		○															●	
Cylindrocystis brebissonii (Menegh.) de Bary				○		●	●		●						●		●	
C. crassa de Bary				○														
Klebsormidium dissectum (Gay) Ettl et Gaertner			○		○									○		●		
Pseudococcomyxa simplex (Mainx) Fott	○		●	○	○	○	○	○	○				●	●	●	○	●	○
cf. *Schizochlamydella minutissima* Broady	○					○	○				○		○			○		
Stichococcus bacillaris Naeg.				○			○	○	○	○			○	○	○			
Ulothrix aff. *quaternaria* Playf.						○								○				
U. moniliformis Kuetz.				○													○	
U. variabilis (Kuetz.) Kuetz.															○			
Cysts of Chlamydomonadales (cf. *Scotiellopsis levicostata*)				○		○		○		○				○	○		○	
Cysts of Chlamydomonadales (cf. *Trochiscia antarctica*)				○	○	○							○	○	●	●		
Total	3	1	3	7	6	6	4	4	3	3	1	0	5	7	10	4	5	1
Bacillariophyceae																		
Achnanthes laevis var. *ninkei* (Guerm. *et* Mang.) Lange-Bert.			●		●			●	●					●	●	●		●
A. montana Krasske			●	●	●	●			●				●	●	●	●	●	
Caloneis silicula (Ehr.) Cleve	●		●			●	●	○			○	○	●	●	●			
Hantzschia amphioxys Kuetz.	●	●	●					●			●	●	●					
Navicula aff. *agrestis* Hust.						○				●					○			
N. contenta Grun.	●	●		●		●	●	●		○	●		●	●	●			
N. gallica var. *perpusilla* (Grun.) Lange-Bert.	●	●		●			○	●		○			●	●			●	
N. protracta (Grun.) Cleve		●				●	●						●					
Pinnularia borealis Ehr.	●	●		●	●	●	●					○	●	●	●		●	
Pinnularia subcapitata Greg.	●	●		●			●	●					●		●		●	
Stauroneis aff. *agrestis* Petersen																	●	
S. anceps Ehr.				○		●												
Total	6	6	4	6	3	7	6	6	2	3	3	3	8	6	7	2	5	1
Tribophyceae																		
Gloeobotrys ovalis Reisigl.					○													
Heterococcus sp.											○	○						
Heterotrichella gracilis Reisigl.	○				○	○												○
Xanthonema montanum (Vischer) Silva	○		○	○	○	○	○	○		○					○			
Xanthonema sp. 1	○			○	○	○												
Total	3	0	1	2	4	3	1	1	0	1	1	1	0	0	1	0	0	1
Overall total	20	14	13	23	18	21	16	16	12	14	10	9	17	20	26	14	22	9

bind soil particles (Wynn-Williams 1990; Ohtani et al. 1991). The mesh of filaments of *Phormidium autumnale* provides physical support and protection against desiccation for other algae, mainly associated cyanobacterial filaments and diatoms (Wynn-Williams 1990). However, seasonal changes in floristic composition have been

Table 2 Values of water content and nutrients concentrations in soil polygons from Cierva Point (present work) and Signy Island (Davey and Rothery 1993) compared with peaty (*MN*) and ornithogenic (*PN*, *CP*) soils at Cierva Point

Parameter	Signy Island (Davey and Rothery 1993)		Cierva Point polygons		Cierva Point soils		
	Range	Mean ± SD	Range	Mean ± SD	MN	PN	CP
Water (% dry weight of soil)	155–207	18.4 ± 1.6	180–247	21.8 ± 2.86	–	–	–
Soluble reactive P (mg/m^2)	6.7–42	21.4 ± 7.9	3.9–10.42	8.53 ± 3.58	–	–	–
(mg/100 g dry weight)	–	–	0.25–0.65	0.52 ± 0.19	2.34	38.56	155.2
NH_4-N (mg/m^2)	0.64–5.42	2.29 ± 0.82	11.95–32.3	18.54 ± 9.32	–	–	–
(mg/100 g dry weight)	–	–	<0.1–0.18	<0.12 ± 0.04	0.6	>5	>10
NO_3-N (mg/m^2)	0.00–3.17	0.87 ± 0.72	13.1–17.3	15.88 ± 1.92	–	–	–
(mg/100 g dry weight)	–	–	<0.1–0.12	<0.11 ± 0.01	0.13	<0.1	0.17

Table 3 Values of factors describing the polygons studied and algal community development at Cierva Point

Polygon number	Area (cm^2)	Minimum inter-polygon distance (m)	Days free of snow before collection	Algal cover (% total area)	Number of species	Diversity (Shannon index)
1	450	11	22	5.12	21	1.83
2	4680	0.5	40	4.55	14	2.78
3	600	25	33	2.61	13	0.76
4	4680	0.5	40	4.76	24	2.13
5	765	6.5	40	1.19	18	2.9
6	1200	6	40	3.44	21	2.51
7	1017	6	27	3.97	16	2.84
8	580	9.5	22	3.31	16	2.03
9	1450	2	27	2.58	12	2.05
10	1140	2	22	5.04	14	2.75
11	1130	43	1	2.69	10	2.74
12	475	20	22	3.23	9	1.93
13	378	14	22	2.62	17	2.86
14	706	14	40	3.82	20	3.12
15	1820	42	5	2.36	26	2.76
16	860	2	27	2.03	14	2.13
17	750	1	40	6.21	23	1.88
18	312	2	22	3.71	8	1.5

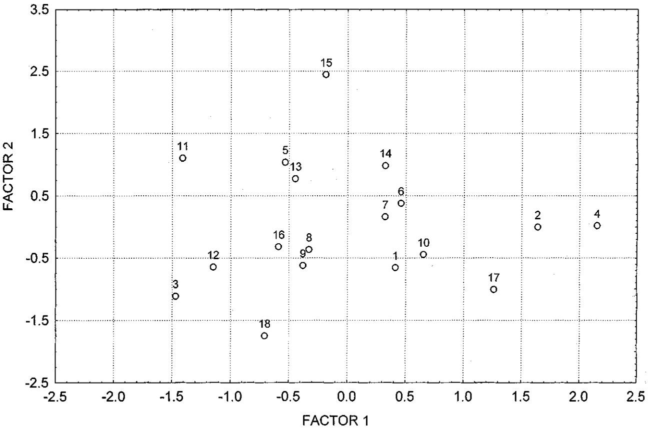

Fig. 4 Spatial ordination of the 18 polygons obtained by Principal Component Analysis performed on the 5 independent descriptive variables summarized in Table 3

reported for soil polygons at Signy Island, with filamentous chlorophytes dominating spring growth before dying out during the onset of summer (Davey 1991). This author attributes this fact to their high sensitivity to both desiccation and high irradiance. The question of whether a similar phenomenon operates in Cierva Point communities or whether their Chlorophyceae and Tribophyceae are present only as dormant propagules in the soil might be revealed by extended seasonal sampling.

Water availability is unlikely to be a limiting factor for algal biomass capacity at Cierva Point fellfields. Values from four representative polygons are higher than those given by Davey and Rothery (1992, 1993) for comparable fellfield soils at Signy Island which, according to these authors, did not appear to limit algal growth. Overall nutrient concentrations from polygons at Cierva Point were similar to those at Signy Island (Davey and Rothery 1993). When N and P nutrients concentrations from both localities were compared, the amounts of PO_4-P are slightly lower at Cierva Point, whilst NO_3-N and NH_4-N are slightly higher. Nevertheless, the N/P mass ratio for Cierva Point samples shows a potential biomass capacity limitation by N-deficiency in three out of the four polygons ($N/P < 7$). Davey and Rothery (1993) concluded that N may be similarly limiting in polygons at Signy Island. However, increase in algal cover following experimental enhancement of temperature at the same location (Wynn-Williams 1996) evidences the importance of

Table 4 Ranks of relative abundances of the most common algal and cyanobacterial species at the 18 polygons: *1* up to 10%; *2* between 10 and 25%; *3* between 25 and 50%; *4* more than 50%

Polygon	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Anabaena cf. *constricta* (Szafer) Geitl.	1	0	4	0	1	1	0	0	4	0	0	1	0	1	1	0	0	3
Cyanothece cedrorum (Sauv.) Kom.	0	1	0	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Phormidium deflexum (West & West) Anagn. & Kom.	0	2	0	1	2	1	0	1	1	2	0	1	0	1	0	2	1	1
Leptolyngbya frigida (Fritsch) Anagn. & Kom.	3	2	1	2	3	1	3	0	1	2	1	0	1	1	2	3	1	1
Lyngbya limnetica Lemm.	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0
Nodularia harveyana Thuret	1	1	0	0	0	0	1	1	0	1	3	1	0	0	0	0	0	0
Oscillatoria fracta Carlson	0	0	0	0	1	1	0	1	0	1	1	0	0	1	0	1	1	0
Phormidium autumnale (Ag.) Gom.	3	2	1	4	1	1	2	2	1	2	2	4	3	3	3	3	4	3
Pseudanabaena catenata Lauteb.	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Achnanthes laevis var. *ninckei* (Guerm. & Mang.) Lange-Bert.	0	0	1	0	3	0	1	1	3	1	1	0	0	2	1	1	0	1
A. montana Krasske	0	0	1	0	1	0	1	0	1	0	0	0	1	1	1	0	0	0
Caloneis silicula (Ehr.) Cleve	0	0	1	0	0	2	0	1	0	3	0	1	1	1	1	1	0	0
Hantzschia amphioxys Kütz.	1	1	0	1	1	0	1	1	0	0	2	2	0	0	0	0	0	0
Navicula aff. *agrestis* Hust.	0	0	0	0	1	0	1	0	0	1	0	1	1	1	1	1	0	1
N. contenta Grun.	1	1	0	0	0	0	1	1	0	1	2	1	2	1	1	0	0	0
N. gallica var. *perpusilla* (Grun.) Lange-Bert.	1	0	0	1	0	0	1	1	0	1	0	1	1	0	0	0	0	0
N. protracta (Grun.) Cleve	0	0	0	1	0	0	1	1	0	0	0	1	0	0	0	0	0	0
Pinnularia borealis Ehr.	1	1	0	1	1	4	1	0	0	0	1	1	1	1	2	0	1	0
P. subcapitata Greg.	1	2	0	1	1	0	2	4	0	0	0	0	1	1	3	0	2	0
Stauroneis anceps Ehr.	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0	0
Cylindrocystis brebissonii (Menegh.) de Bary	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0
Cyst of Chlamydomonadales (cf. *Trochiscia antarctica*)	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	0

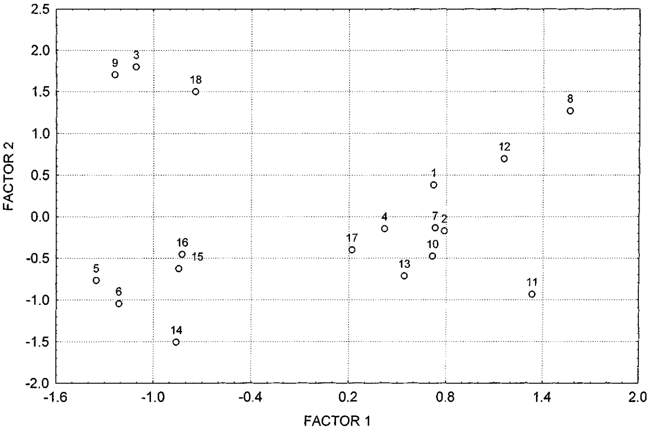

Fig. 5 Results of the Principal Component Analysis performed on log-transformed relative frequencies of the most common microalgal species

factors other than nutrients in limiting algal biomass capacity.

Both the presence and dominance of different species varied greatly among polygons at Cierva Point, as also observed by Davey and Rothery (1993) at Signy Island. Since they did not find a concomitant variation in edaphic factors, they concluded that nutrients were not responsible for the high inter-polygon variation in floristic composition. However, concentrations of nutrients in two ornithogenic soils (PN and CP) and a peaty soil colonized by hummocks of *Polytrichum alpestre* (MN) were 1–3 orders of magnitude higher than those of mineral soils. Nevertheless, 19 out of 23 algal species inhabiting site MN and some of those dominating ornithogenic soils (G. Mataloni, unpublished work) were also present in the soil polygons on Escombrera Peak. This high similarity between microalgal communities of mineral and organic soils at Cierva Point (G. Mataloni, unpublished work) reinforces the conclusion that nutrients alone do not account for inter-polygon differences in species composition.

The colonization of discrete entities such as soil polygons at Signy Island has been analyzed by Davey and Rothery (1993) in terms of the Theory of Island Biogeography (MacArthur and Wilson 1967). We attempted a further test of this idea by relating descriptors of community structure to both the area of the polygons and their minimum distance of separation. No correlation was detected. A possible reason is that colonization occurs on a restricted, local scale whereby most Cyanobacteria and Bacillariophyta found at Cierva Point are not only widespread in polygons but also in other environments at this location (Mataloni and Tesolín 1997; Tesolín et al. 1997; Mataloni et al. 1998). We could then consider them as "weed" algae (Ellis-Evans and Walton 1990), able to spread their propagules efficiently on a local scale.

Distinct differences in microalgal community structure were evident between apparently identical polygons at Cierva Point. A common factor was the dominance of Cyanobacteria, mainly *Phormidium autumnale*. The colonization ability of this species was confirmed by its presence in all polygons, although in different frequencies, and the importance of its soil-binding role for the physical structure of the community was also shown by the direct correlation of its abundance with algal cover. Most common accompanying species comprised finer cyanobacterial filaments interspersed with thicker ones (*Leptolyngbya frigida, Phormidium deflexum*, and *Lyngbya limnetica*) and pennate diatoms. Some species amongst these related to polygons with high diversity (*Navicula contenta* and *N.* aff. *agrestis*), whilst others (e.g., *H. amphyoxis*) were significantly more frequent in polygons of low species diversity. *Anabaena* cf. *cylindrica* is likewise associated with polygons of low species richness. These relationships suggest biotic interactions whereby the presence of a given species influences the establishment of a new arrival.

The reasons for the different floristic composition of the microalgal communities of small patchy habitats, such as mineral soil polygons, remains open to question. Davey and Rothery (1993) attributed them to the "stochastic element" of the colonization event. However, this does not explain the presence of many "successful" species with high colonization ability in most polygons, although in different proportions. This hypothesis was put forward on the basis that biotic interactions would be minimal for such simple communities. The details of community structure given here for Cierva Point confirm the view of Broady (1996) that biotic interactions in these habitats are, in fact, complex. On this basis, the importance of chance arrival in defining the resulting species composition of colonists on newly exposed polygons would be inversely related to the ability of species to disperse and colonize. This would be minimal for weed species. Instead, biotic interactions among recently established populations could be a major driving force in determining both community structure and future development of the system.

Acknowledgements The present research was jointly supported by the University of Buenos Aires, the Instituto Antartico Argentino, and the British Antarctic Survey. The authors are much indebted to the personnel of Base Antartica Primavera for their logistic support and to Lic. G. Tesolín for his valuable help in the fieldwork. T. Betgen and D. Beppler (IPG-University of Freiburg) kindly provided meteorological data. A Fundación Antorchas-British Council Award permitted Dr. G. Mataloni to carry out part of this work at the BAS Headquarters, Cambridge. Dr. Paul Broady and two anonymous referees made valuable comments on an earlier draft.

References

Agraz JL, Quintana RD, Acero JM (1994) Ecología de los ambientes terrestres en Punta Cierva. (Costa de Danco, Península Antártica). Inst Antart Argent Contrib 439:1–31

Betgen T, Rau F, Beppler D (1997) Topographische Karte 1:5000. Cierva Point – Antarktische Halbinsel. IPG-University of Freiburg

Bölter M (1996) Analysis of soil microbial communities (autotrophs and heterotrophs) from King George Island (Arctowski Station). Proc NIPR Symp Polar Biol 9:283–298

Broady PA (1979) The terrestrial algae of Signy Island, South Orkney Islands. Sci Rep Br Antarct Surv no. 98:1–117

Broady PA (1996) Diversity, distribution and dispersal of Antarctic terrestrial algae. Biodivers Conserv 5:1307–1335

Davey MC (1988) Ecology of terrestrial algae of the fellfield ecosystems of Signy Island, South Orkney Islands. Br Antarct Surv Bull 81:69–74

Davey MC (1991) The seasonal periodicity of algae in Antarctic fellfield soils. Holarct Ecol 14:112–120

Davey MC, Rothery P (1992) Factors causing the limitation of growth of terrestrial algae in maritime Antarctica during late summer. Polar Biol 12:595–602

Davey MC, Rothery P (1993) Primary colonization by microalgae in relation to spatial variation in edaphic factors on Antarctic fellfield soils. J Ecol 81:335–343

Digby PG, Kempton RA (1987) Multivariate analysis of ecological communities. Chapman & Hall, London

Ellis-Evans JC, Walton D (1990) The process of colonisation in Antarctic terrestrial and freshwater ecosystems. Proc NIPR Symp Polar Biol 3:151–163

MacArthur RH, Wilson EO (1967) The Theory of Island Biogeography. Princeton University Press, Princeton

Mackereth JFH, Hiron J, Talling JF (1978) Water analysis: some revised methods for limnologists. Freshwater Biol Assoc Sci Publ 36:1–117

Magurran AE (1988) Ecological diversity and its measurement. Chapman & Hall, London

Mataloni G, Tesolín G (1997) A preliminary survey of cryobiontic algal communities from Cierva Point (Antarctic Peninsula). Antarct Sci 9:250–257

Mataloni G, Tesolín G, Tell G (1998) Characterization of a small eutrophic Antarctic lake (Otero Lake, Cierva Point) on the basis of algal assemblages and water chemistry. Polar Biol 19:107–114

Ohtani S, Akiyama M, Kanda H (1991) Analysis of Antarctic soil algae by the direct observation using the contact slide method. Antarct Rec 35:285–295

Reynolds JM (1981) The distribution of mean annual temperatures in the Antarctic Peninsula. Br Antarct Surv Bull 59:123–131

Smith RIL (1996) Terrestrial and freshwater biotic components of the western Antarctic Peninsula. Antarct Res Ser 70:15–59

Tesolín G, Mataloni G, Tell G (1997) Preliminary survey of the algal communities from lentic microlimnotopes of Cierva Point (Antarctic Peninsula). IV Jornadas sobre Investigaciones Antárticas, Buenos Aires, 1–5 September 1997

Wynn-Williams DD (1990) Microbial colonization processes in Antarctic fellfield soils – an experimental overview. Proc NIPR Symp Polar Biol 3:164–178

Wynn-Williams DD (1993) Microbial processes and initial stabilization of fellfield soil. Primary succession on land. Blackwell, Oxford

Wynn-Williams DD (1996) Response of pioneer soil microalgal colonists to environmental change in Antarctica. Microb Ecol 31:177–188