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Distribution of soil algae at the monitoring sites in the vicinity of Syowa Station between austral summers of 1992/1993 and 1997/1998

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Abstract: Distribution of soil algae was studied in the vicinity of Syowa Station in Lützow-Holm Bay, Antarctica between the austral summers of 1992/1993 (JARE-33) and 1997/1998 (JARE-38) from the viewpoint of environmental monitoring. Soils were collected from 10 monitoring sites. Sites 1-4 were within Syowa Station. Sites 1-3 were close to a urinal tank. Six sites (sites 5-10) were several km from the station. Site 10 was in a penguin rookery.

Twenty-one soil algae were identified: eight of Cyanophyceae, eight of Chlorophyceae, three of Xanthophyceae and two of Bacillariophyceae. *Leptolyngbya* cf. *battersii, Phormidium autumnale, Navicula muticopsis, Xanthonema* spp., *Botrydiopsis* spp. and *Macrochloris multinucleata* were common. An ornitho-coprophilous alga, *Prasiola crispa*, was found in cultures of soils from sites 1-3 and at site 10.

Total carbon contents (TC), total nitrogen (TN) and total phosphorus (TP) in soils ranged from 0.04 to 0.991%, 0.002-0.401% and 0.161-0.809%, respectively. Maximum TC, TN and TP were observed at site 10. Relatively high values of TC (0.301%) and TN (0.016%) were detected at site 2.

Presence of *P. crispa* at sites 1-3 and higher values of TC and TN at site 2 indicated that eutrophication of surface soils occurred near the urinal tank. The results of cluster analysis showed that most soil algal assemblages at sites 1-3 were grouped together. No clear changes in soil algal communities were observed during the study period at any of the monitoring sites.

key words: soil algae, distribution, human impact, monitoring, Syowa Station

Introduction

Soil algae are widespread and occur in ice-free areas in both maritime and continental Antarctica (Broady, 1996). In the vicinity of Syowa Station, Akiyama (1967) was the first to study soil algal flora. He recognized 32 taxa from 28 genera in total. Since this study, most studies of soil algae around Syowa Station have been carried out from an ecological viewpoint. Akiyama (1974) produced a preliminary report on soil algal genera isolated from sandy soils collected from ice-free areas in Lützow-Holm Bay. Matsuda (1968) studied the distribution of *Prasiola crispa* at Ongulkalven with reference to locations of Adélie penguin rookeries. The relationships

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among soil nutrients, water contents of soils and distribution of soil algae have been studied in the Ongul Islands (Yamanaka and Sato, 1977; Hoshiai and Matsuda, 1979; Akiyama *et al.*, 1986b). Akiyama *et al.* (1986a, b) reported allelopathic effect of penguin excrements on soil algae distribution. Ohtani *et al.* (1991) applied the contact slide method to detect soil algae *in situ* at Langhovde. We, however, still have little information on the distribution of soil algae in the vicinity of Syowa Station.

Lindsay (1973) showed examples of introductions of lichens to the sub-Antarctic Island of South Georgia from the Northern Hemisphere by human activities. Broady and Smith (1994) reported that human activities in Antarctica are considered as an effective vector for the long range dispersal of microalgae. They found several soil algae on vegetables transported from New Zealand to Scott Base and from soils attached to boots of expeditioners before departure for Antarctica. Boyd *et al.* (1966) found high numbers of thermophilic bacteria in soils from areas where contamination from man and other animals had occurred in the Ross Sea area, Antarctica. They considered that man and other animals are sources of these thermophilic bacteria. Yamamoto *et al.* (1991) reported that cellulose decomposition activities by bacteria in soils were much higher near the urinal tank in Syowa Station than at sites remote from the station. These studies showed both the possibility of long range dispersal of microorganisms and environmental changes by human activities in the Antarctic region.

We have studied the distribution of soil algae at monitoring sites in the vicinity of Syowa Station from the viewpoint of environmental monitoring from the austral summer of 1992/1993 to that of 1997/1998 (33rd–38th Japanese Antarctic Research Expeditions). In the present study, we describe characteristics of soil algal communities at 10 monitoring sites during these six years with reference to soil properties.

Materials and methods

Study site

Syowa Station is situated at the northern part of East Ongul Island (69°00′S, 39°35′E) in Lützow-Holm Bay, Antarctica. 10 sites were established for monitoring soil algae in the vicinity of Syowa Station in January 1993 (Fig. 1). There was no vegetation at any of these sites except site 1 where macroscopic colonies of *Prasiola crispa* occurred. Four sites (sites 1–4) were situated within Syowa Station. Sites 1–3 were close to a simple urinal tank in a building that was constructed in 1971 (JARE-13). Site 1 was closest to this (Fig. 2A). Sites 2 and 3 were set up at 2.5 m and 5 m from Site 1, respectively. Site 4 was near a stream in Syowa Station (Fig. 2B). Sites 5 and 6 (Fig. 2C) were situated near the water's edge of Lake Midori, 1 km south of the station. Sites 7 and 8 (Fig. 2D) were at Kitami Beach, 1.5 km southwest of the station. Site 9 (Fig. 2E) was 60 m south-southwest of Adélie penguin rookeries at Ongulkalven. Site 10 (Fig. 3F) was closest to the rookery where it might be influenced by penguin excrements. There were no sea bird nests around any sites except site 10 and no artificial construction around sites 5–10.

Sampling and culture methods

Wintering members of JARE aseptically collected surface sandy soil samples (*ca.*

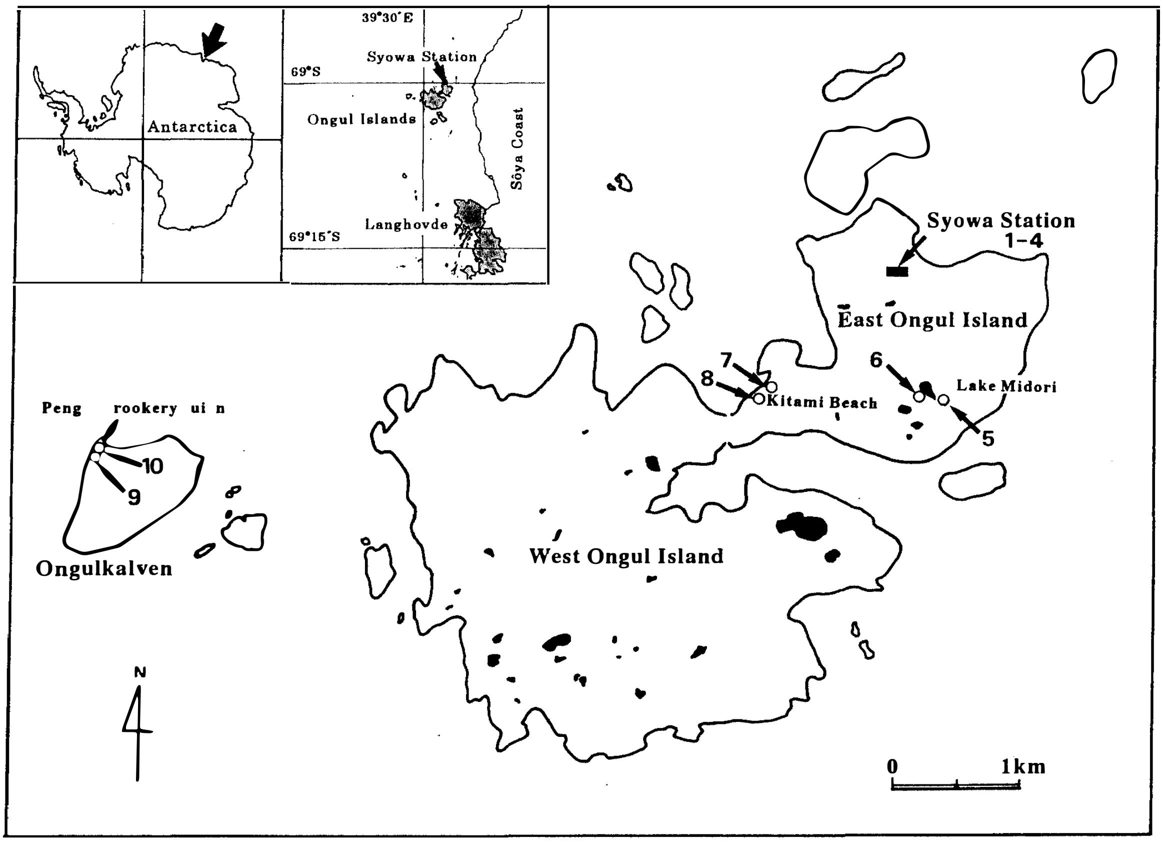

Fig. 1. Map showing the 10 soil algae monitoring sites in the vicinity of Syowa Station, Antarctica.

100 g) from monitoring sites using a sterilized spoon during austral summer. In JARE-37, sites 2 and 3 were moved to adjacent sites because of building reconstruction. In JARE-37 and 38, site 6 was moved to an adjacent site because of heavy snow cover. Sampling sites of surface soils with their water conditions or moisture weights between JARE-33 and JARE-38 are shown in Table 1.

Samples were put into sterilized plastic petri dishes and preserved in freezers (−15~−20°C) until used in experiments in Japan. After melting of soil samples at room temperature, a small amount of the material was inoculated into a test-tube containing 10 m*l* of sterilized Bold's Basal Medium (BBM) (Bischoff and Bold, 1963) except for samples of JARE-37. Sterilized 1.5% agar plates of BBM were used for all samples of JARE-37, site 8 of JARE-33 and for some samples of every expedition in order to isolate unialgal strains of soil algae. The standard growth conditions were 700–1000 lux illuminated by cool-white fluorescent lamps on a 12 hr light and 12 hr dark cycle at ca 15°C. After 2 to 3 months (one month for JARE-35) incubation, soil algae were grown in test tubes and on agar plates. Then, test tubes and agar plates were put in the dark in order to prevent further growth of algae. Colonies of soil algae were picked up by Pasteur pipette from test tubes or by a needle from agar plates and were observed by light microscope (OLYMPUS BH1 and BX60) for identification. We have described the presence or absence of each taxon for all samples. No attempt was made to estimate their abundance.

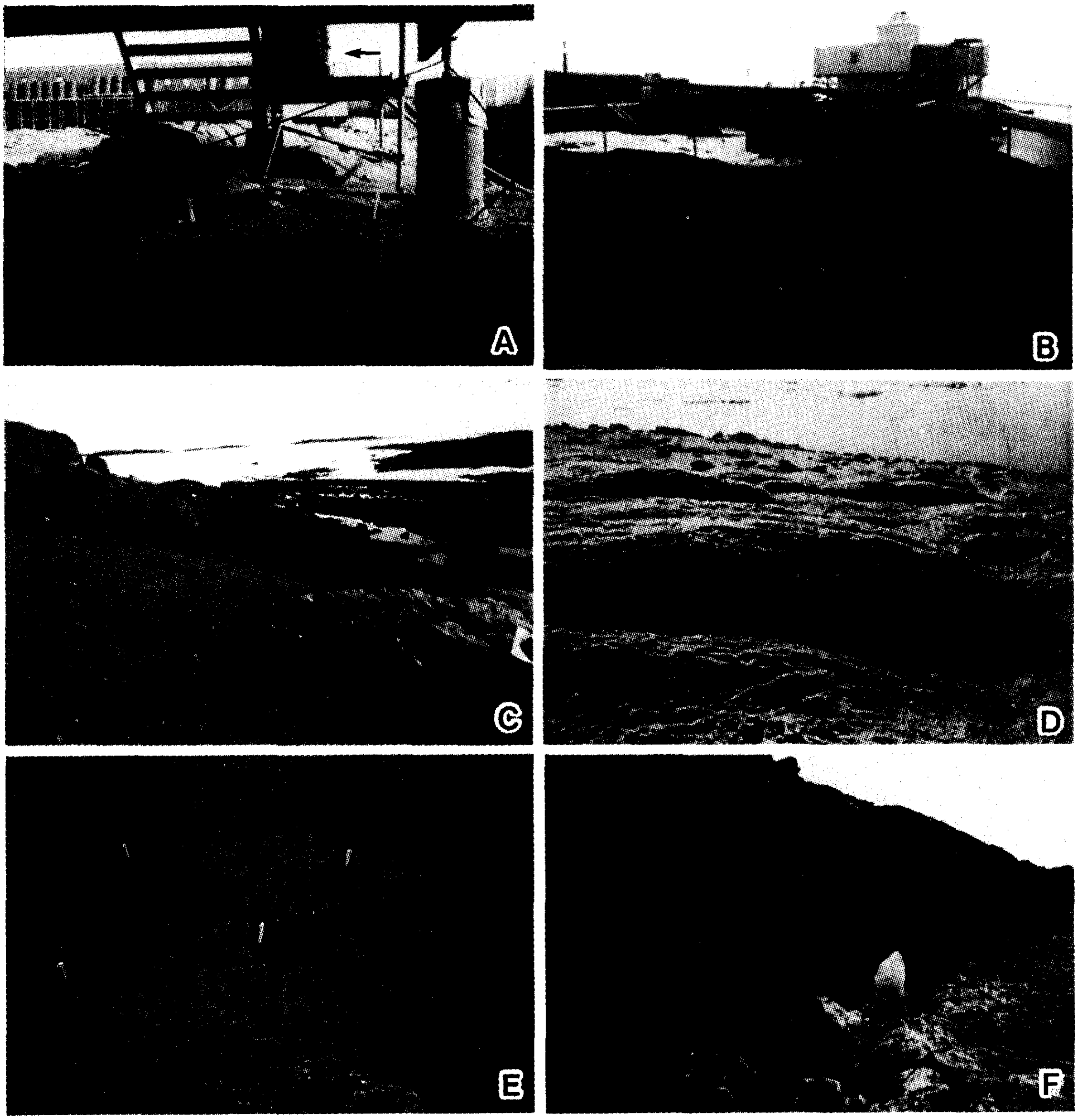

Fig. 2. Landscapes of monitoring sites of soil algae in the vicinity of Syowa Station. A: Site 1 closest to a urinal tank in a building in Syowa Station. The arrow shows a urinal tank; B: Site 4 near a stream in Syowa Station; C: Site 6 at Lake Midori; D: Site 8 at Kitami Beach; E: Site 9 at Ongulkalven; F: Site 10 in the penguin rookery at Ongulkalven.

Soil analyses

Water content was determined by oven-drying at 105°C for 24 hr. Soil pH and electric conductivity were determined with glass electrodes using 1 : 2.5 and 1 : 5 soil water ratio, respectively. For ATP content measurement, 1 g of soil was suspended in a 10 *ml* ice-cold TCA solution (0.5 M-trichloroacetic acid and 0.25 M-disodium hydrogenphosphate 12-water), sonicated for 2 min and centrifuged (1500 G) for 5 min. The supernatant was diluted 100-fold with HEPES-NaOH buffer (25mM, pH 7.0). The measurements were made using an ATP analyzer (AF-100, TOA Electronics Ltd.).

Total carbon and nitrogen contents were measured by a dry combustion method using an automatic NC analyzer (Sumigraph NC-90A, Sumika Chemical Analysis Service, Ltd.). Total phosphorus content was measured by the perchloric acid digestion method (Olsen and Sommers, 1982).

Statistical analysis

In order to classify the soil algal assemblage, cluster analysis using the UPGAM method was performed based on Jaccard's coefficient of community. As no algae occurred in soil at site 6 in JARE-35, this sample was omitted from cluster analysis. Correspondence analysis among the 10 monitoring sites was performed based on the relative frequency (%) of presence of each taxon for the total number of samples between JARE-33 and JARE-38.

Results

Soil properties

Water conditions of most samples were dry or moist (Table 1). Only four wet samples were collected from sites 4 and 6. Moisture weights of soils at JARE-37 and JARE-38 ranged from 0.2 to 2.6%.

Table 2 shows the physical and chemical properties of surface soils of JARE-37 and JARE-38. Gravel weights ranged from 9.5 to 54.2%. Electric conductivity values ranged from 119 to 730 μS/cm. A maximum value of 730 μS/cm was observed at site 10 in the penguin rookery. The pH (KCl) values ranged from 6.0–9.6. The pH values at sites 2 and 3, close to the urinal tank, were higher (8.3 and 9.6) than values at the other sites. Total carbon contents (TC) ranged from 0.023 to 0.991%, with maximum at site 10. Relatively high values were observed at sites 2 (0.301%) and 3 (0.201%), while low values (0.023–0.043%) were obtained at sites 7 and 8 on Kitami Beach and at site 9 in Ongulkalven. ATP contents ranged from 20 to 1962 pmol/g soil.

Table 1. Sampling sites of surface soils and their water conditions or moisture weights (%) between JARE-33 and JARE-38.

Site	1992/1993 JARE-33	1993/1994 JARE-34	1994/1995 JARE-35	1995/1996 JARE-36	1996/1997 JARE-37	1997/1998 JARE-38
1	Dry	Moist	Moist	–	–	–
2	Dry	Moist	Moist	–	1.6	–
3	Dry	Moist	Moist	–	2.6	–
4	Wet	–	–	Wet	–	–
5	Dry	–	Moist	–	–	–
6	Dry	Moist	Wet	Wet	0.2	0.4
7	Dry*	Moist	Moist	Dry	0.2	0.3
8	Dry	Dry	Dry	Dry	0.2	0.3
9	Dry	Dry	Dry	Moist	0.9	–
10	Moist*	Dry	Moist	Dry	0.7	–

–: Sampling was not done because of bad snow or sea ice conditions.

* Soil algae were not studied.

Table 2. Chemical and physical properties of surface soil samples from monitoring sites in the vicinity of Syowa Station in JARE-37 and JARE-38.

Site	G.W. %	E.C. (μS/cm)	pH (H_2O)	pH (KCl)	TC %	TN %	TP %	C/N ratio	ATP pmol/g soil
JARE-37									
2	39.9	171	9.2	8.3	0.301	0.016	0.200	18.8	280
3	29.8	619	9.4	9.6	0.201	0.006	0.161	33.5	129
6	11.0	352	7.9	6.8	ND	ND	ND	ND	ND
7	9.5	472	7.4	7.5	0.041	0.003	0.196	12.7	20
8	31.8	145	7.5	6.5	0.043	0.004	0.200	10.8	116
9	36.1	119	7.3	6.0	0.023	0.003	0.222	7.7	43
10	54.2	730	7.8	7.6	0.991	0.401	0.809	2.5	1962
JARE-38									
6	16.1	444	7.8	7.2	0.060	0.002	0.181	30	33
7	5.3	364	7.9	7.6	0.040	0.003	0.197	13.3	55
8	45.6	119	7.2	6.6	0.048	0.006	0.233	8	139

ND: not determined.

A maximum value was observed at site 10. The next highest value of 280 pmol/g was at site 2. Much lower ATP values (20–55 pmol/g) were obtained at sites 6, 7 and 9. Total nitrogen contents showed similar tendency to the total carbon and ATP contents. A maximum value of 0.401% was observed at site 10. A relatively high value of 0.016 % was obtained at site 2, while values at sites 7, 8 and 9 were much lower (0.003–0.006 %). Total phosphorus contents ranged from 0.161 to 0.222% with the one exception of 0.809% at site 10, about 4 times higher than values at the other sites. These results show that soils at sites 2 and 10 contained the highest nutrients and organic matter. On the other hand, nutrients and organic matter were much lower at sites 6–9. Although soils at both sites 2 and 10 were eutrophicated, C/N ratios at sites 2 and 10 were remarkably different from each other. A relatively high value of 18.8 was observed at site 2, while the lowest value of 2.5 was obtained at site 10. As extremely high total nitrogen of 0.401% was observed at site 10, the C/N ratio became much lower compared with other sites.

Distribution of soil algae

The distribution of soil algae is shown in Table 3. The data indicate the relative frequency (%) of presence of each taxon.

There were 21 taxa in total, eight of Cyanophyceae, two of Bacillariophyceae, three of Xanthophyceae, and eight of Chlorophyta (Table 3). The number of species at each site ranged from 4 to 14 with maxima at sites 3 and 7, and a minimum at site 10. Taxa indicated by "spp." in Table 3 were counted as one taxon. Unidentified taxa were omitted from the totals.

Among Cyanophyceae, filamentous forms of oscillatoriacean algae, such as *Leptolyngbya* cf. *battersii* (Gom.) Anag. et Kom. (Fig. 3A, B), *Leptolyngbya tenuis* (Menegh. ex Gom.) Anag. et Kom. (Fig. 3C) and *Phormidium autumnale* (Ag.) Gom. (Fig. 3D), occurred widely around Syowa Station. Relative frequencies of *L.* cf.

Table 3. Relative frequencies (%) of occurrence of soil algae at monitoring sites in the vicinity of Syowa Station between JARE-33 and JARE-38.

Taxa	S.S				L.M.		K.B.		O.K.	
	S1 (3)[1]	S2 (4)	S3 (4)	S4 (2)	S5 (2)	S6 (6)	S7 (5)	S8 (6)	S9 (5)	S10 (4)
CYANOPHYCEAE										
Aphanocapsa cf. *muscicola*	0	25	0	0	0	17	20	17	40	25
Leptolyngbya cf. *battersii*	0	25	25	**100**	**50**	**50**	**80**	**83**	**100**	**100**
Leptolyngbya tenuis	0	25	**50**	0	0	**50**	20	0	**60**	0
Phormidium autumnale	**67**	**75**	**75**	**50**	0	33	40	0	0	0
Crinalium cf. *epipsammum*	0	0	0	**50**	**50**	0	20	17	40	0
Nostoc cf. *microscopicum*	0	0	0	0	0	17	0	0	0	0
Nostoc cf. *sphaericum*	0	0	0	0	0	0	20	17	20	0
Nostoc sp.	0	25	0	0	**50**	33	40	33	40	0
BACILLARIOPHYCEAE										
Navicula muticopsis	33	**75**	**75**	**100**	0	**50**	**60**	17	0	0
Achnanthes sp.	0	0	0	0	0	0	**60**	0	0	0
XANTHOPHYCEAE										
Botrydiopsis spp.	**100**	**75**	**75**	**100**	**100**	**83**	**60**	**100**	**100**	**50**
Xanthonema spp.	**100**	**100**	**100**	**50**	**100**	**83**	**100**	33	0	0
Heterococcus spp.	0	**50**	25	0	0	0	0	17	0	0
CHLOROPHYTA										
Chlamydomonas spp.	0	0	**50**	0	0	0	0	0	0	0
Oocyctis sp.	0	0	25	0	0	0	0	0	0	0
Macrochloris multinucleata	**100**	**75**	**100**	**50**	0	33	**100**	17	40	0
Stichococcus bacillaris	0	0	0	**50**	0	17	20	0	40	0
Raphidonema pyrenoidifera	0	25	**50**	0	0	33	20	20	**60**	0
Raphidonema spp.	0	0	25	0	**50**	0	0	0	0	0
Klebsormidium sp.	0	0	25	0	0	0	0	0	0	0
Prasiola crispa	**100**	**75**	25	0	0	0	0	0	0	25
Unidentified unicellular algae	33	**75**	**50**	0	0	0	20	**50**	20	25
Unidentified colonial algae	0	0	25	**50**	**50**	17	40	33	**80**	**50**
Unidentified branched algae	0	0	0	0	0	0	0	17	0	0
Total number of taxa	6	12	14	8	7	12	14	11	10	4

S.S.: Syowa Station; L.M.: Lake Midori; K.B: Kitami Beach; O.K.: Ongulkalven.
[1] Parentheses show total numbers of samples between JARE-33 and JARE-38.
Bold-faced figures indicate relative frequencies of more than 50%.

battersii were higher than 50% at sites 7–10, while those of *P. autumnale* were high at sites 1–3 within Syowa Station. *Nostoc* cf. *sphaericum* Vaucher (Fig. 3F) and *Crinalium* cf. *epipsammum* Winder *et al.* (Fig. 3E) occurred at sites 7–9, and 4–9, respectively where soils contained low level of total nitrogen and total carbon. A pennate diatom, *Navicula muticopsis* van Heurck (Fig. 3G) commonly occurred at sites 1–8, while *Achnanthes* sp. (Fig. 3H, I) occurred only at site 7. *Botrydiopsis* spp. (Fig. 4A) were the most common and occurred at all sites, their relative frequencies were

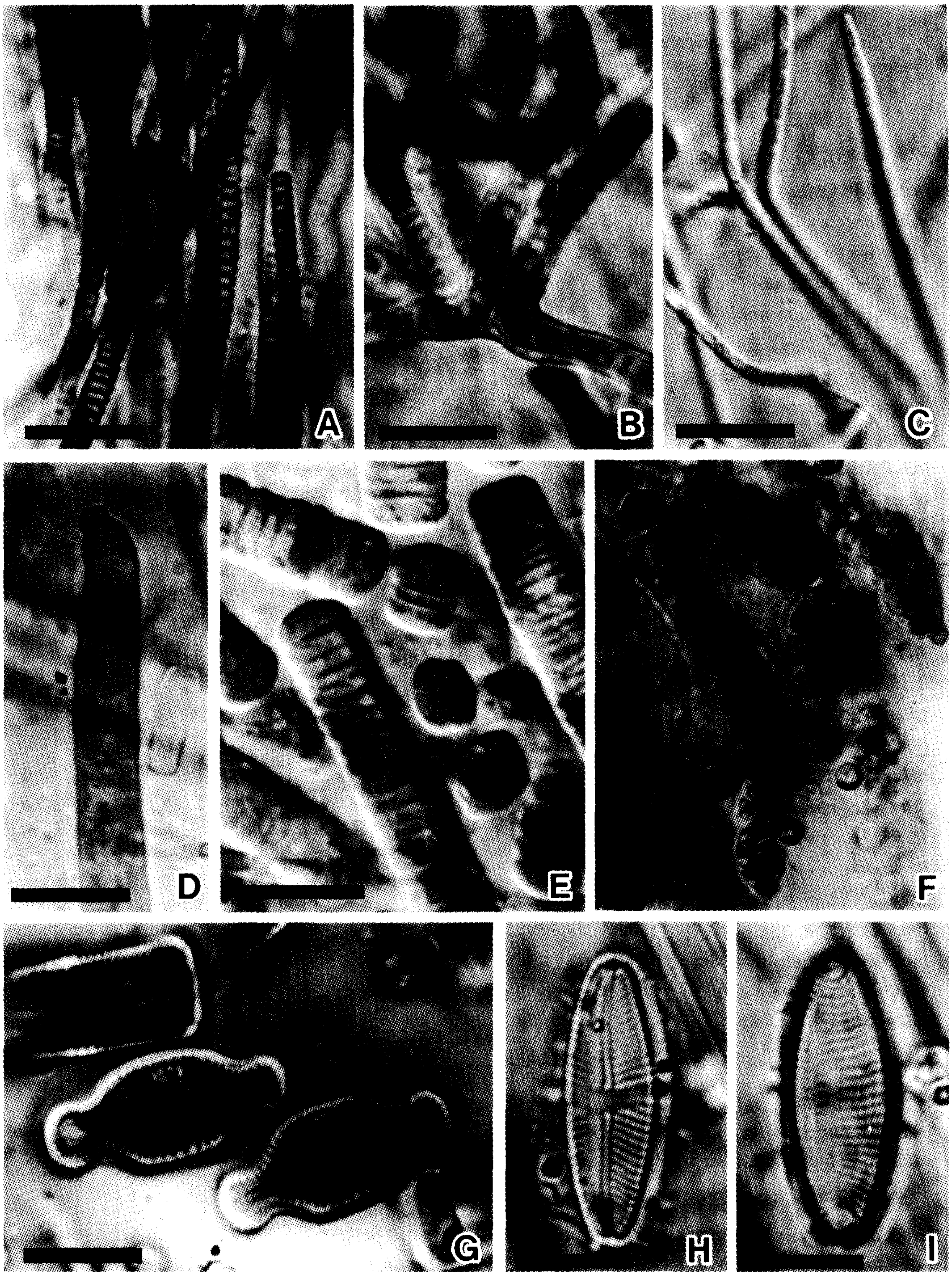

Fig. 3. Soil algae from monitoring sites in the vicinity of Syowa Station. A, B: *Leptolyngbya* cf. *battersii*; C: *Leptolyngbya tenuis*; D: *Phormidium autumnale*. E: *Crinalium* cf. *epipsammum*; F: Young stage of *Nostoc* cf. *sphaericum;* G: *Navicula muticopsis*; H, I: *Achnanthes* sp. Scale bars 10 μm for all figures.

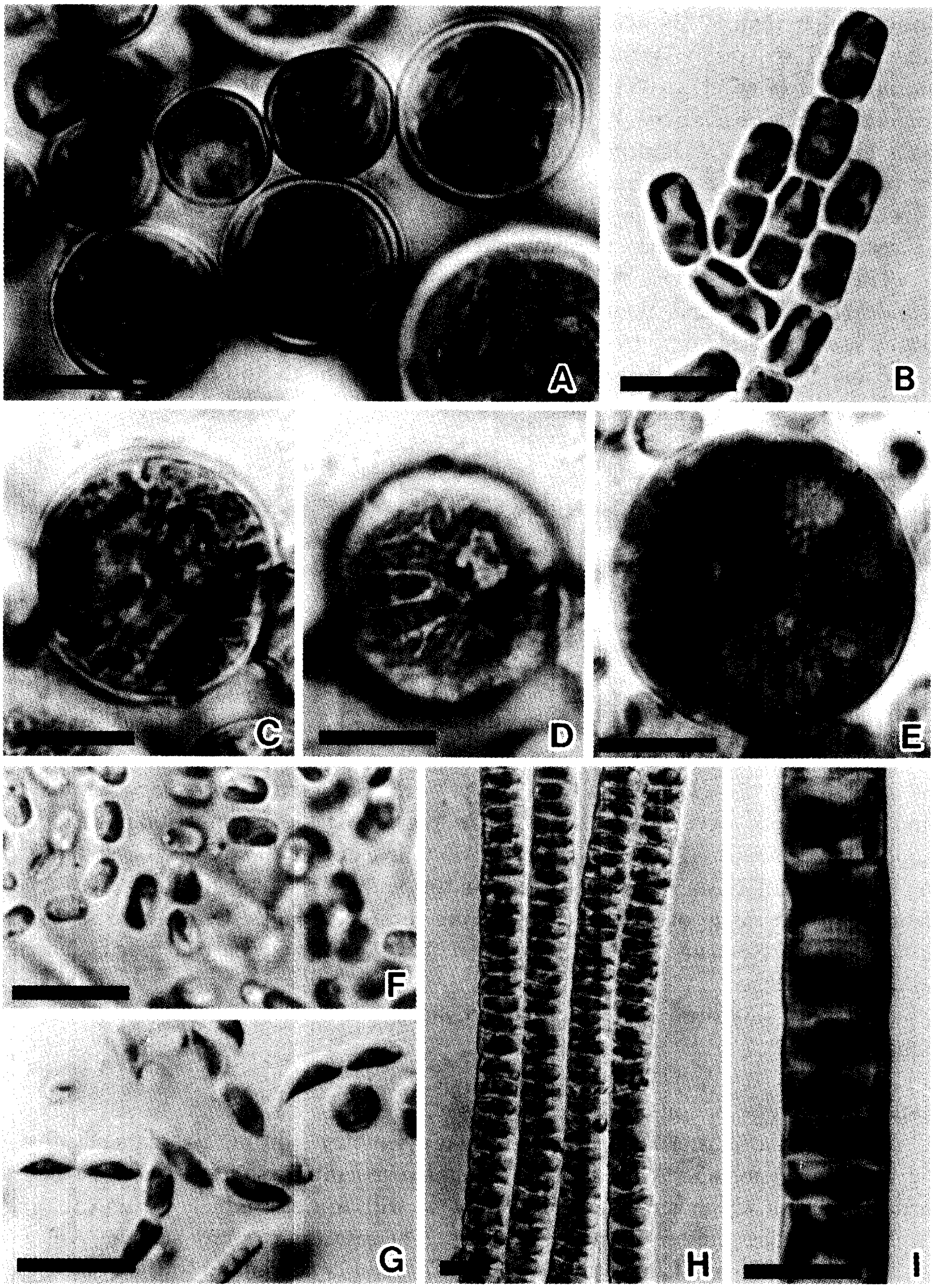

Fig. 4. Soil algae from monitoring sites in the vicinity of Syowa Station. A: *Botrydiopsis* sp.; B: *Xanthonema* sp.; C–E: *Macrochloris multinucleata*. Arrows show nuclei; F: *Stichococcus bacillaris*; G: *Raphidonema pyrenoidifera*; H, I: Uniseriate filamentous forms of *Prasiola crispa*. Scale bars 10μm for all figures.

always higher than 50%. *Xanthonema* spp. (Fig. 4B) were observed from sites 1-8. *Heterococcus* sp. rarely occurred at sites 1-3. Among chlorophytes, *Macrochloris multinucleata* (Reisigl) Ettl et Gärtner (Fig. 4C-E) occurred at all sites except site 10. *Raphidonema pyrenoidifera* Korschikov (Fig. 4F) were sporadic. *Chlamydomonas* spp., *Oocystis* sp., *Klebsormidium* sp. were rarely detected from site 3. An ornithocoprophilous alga, *Prasiola crispa* (Lightf.) Menegh., was found at sites 1, 2 and 3 around a urinal tank in the station (Fig. 4 H, I). During JARE-33 and JARE-34, macroscopic colonies of this species were collected from site 1.

The paucity of species at site 10 in the penguin rookery was noteworthy. Only *Leptolyngbya* cf. *battersii* dominated. Diatoms and chlorophytes, which occurred at sites 1-9, were never found from site 10. A small number of *Botrydiopsis* spp., *Prasiola crispa* and unidentified colonial algae were found. On the other hand, the highest numbers of species were observed at sites 3 and 7. This was due to sporadic occurrences of chlorophytes at site 3 where soil contained high TC and relatively high TN, and to the sporadic occurrence of cyanophytes at site 7 where the soil contained low values of TC and TN.

Occurrence of soil algae between austral summers 1992/1993 (JARE-33) and 1997/1998 (JARE-38)

Occurrences of soil algae at sites 2, 6, 8 and 10 during the studied years are shown in Table 4.

At site 2 near the urinal tank, the number of species changed in the range of four to eight during the five years. Only *Xanthonema* spp. were present all five years. At site 6 in Lake Midori, the number of species changed in the range of zero to nine during the six years. In JARE-35, no algae were observed. *Botrydiopsis* spp. and *Xanthonema* spp. were present during five years. At site 8 on Kitami Beach, the number of species changed in the range of two to five during the six years. *Botrydiopsis* spp. were present all six years. At site 10 in the penguin rookery, the number of species changed in the range of one to three during the four years. Only *Leptolyngbya* cf. *battersii* was present all four years, associated with a few species of green algae and yellow-green algae.

The remaining sites, 1, 3, 4, 5, 7 and 9, showed no clear yearly changes of species composition.

Statistical analyses of soil algal assemblages

The result of cluster analysis of soil algal assemblages during six years is shown in Fig. 5. All assemblages from sites 1-3 except two assemblages (site 2 JARE-33 and 35) formed a cluster which is indicated by an arrow, with four assemblages from sites 6 and 7. No other clear clusters were recognized. The result of correspondence analysis of soil algal assemblages (Table 5) showed that this can be attributed to the high relative frequencies of *Prasiola crispa* and *Phormidium autumnale*, and absence of species such as *Crinalium* cf. *epipsammum* and *Nostoc* cf. *sphaericum*, at sites 1-3.

Table 4. Occurrences of soil algae at sites 2, 6, 8 and 10 during the study years.

Taxa	Site 2				Site 6						Site 8						Site 10			
	33*	34	35	37	33	34	35	36	37	38	33	34	35	36	37	38	33	35	36	37
CYANOPHYCEAE																				
Aphanocapsa cf. *muscicola*	−	−	−	+	−	−	−	−	−	+	−	−	−	−	−	+	−	−	+	−
Leptolyngbya cf. *battersii*	−	−	−	−	+		−	+		+	+	+	−	+	+	+	**+**	**+**	**+**	**+**
Leptolyngbya tenuis	+	−	−	−	−	+	−	−	+	+	−	−	−	−	−	−	−	−	−	−
Phormidium autumnale	+	+	−	+	+	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−
Crinalium cf. *epipsammum*	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−
Nostoc cf. *microscopicum*	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−
Nostoc cf. *sphaericum*	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−
Nostoc sp.	−	−	−	+	−	+	−	−	−	+	−	−	−	−	+	−	−	−	−	−
BACILLARIOPHYCEAE																				
Navicula muticopsis	+	+	−	−	+	+	−	−	−	+	−	−	−	+	−	−	−	−	−	−
XANTHOPHYCEAE																				
Botrydiopsis spp.	+	−	+	+	+	+	−	+	+	+	**+**	**+**	**+**	**+**	**+**	**+**	−	+	+	−
Xanthonema spp.	**+**	**+**	**+**	**+**	+	+	−	+	+	+	−	−	+	−	−	+	−	−	−	−
Heterococcus spp.	+	−	−	+	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−
CHLOROPHYTA																				
Macrochloris multinucleata	+	+	+	−	−	+	−	+	−	−	−	−	+	−	−	−	−	−	−	−
Stichococcus bacillaris	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−
Raphidonema pyrenoidifera	−	−	+	−	−	−	−	+	+	−	−	−	−	−	+	−	−	−	−	−
Prasiola crispa	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−
Unidentified unicellar coccoid algae	+	−	+	+	−	−	−	−	−	−	+	−	−	−	+	+	+	−	−	−
Unidentified colonial algae	+	−	+	+	−	−	−	−	+	−	−	−	−	+	+	−	+	+	−	−

+: presence; −: absence. * JARE

Bold-faced marks indicate taxa which occurred all years.

Description of taxa and remarks

CYANOPHYCEAE

Aphanocapsa cf. *muscicola* (Menegh.) Wille

Cells blue-green, single or in pairs, spherical, 1.5–2 μm in diameter, embedded in gelatinous common layer.

Diameters of our specimens were smaller than the diameter of 2–3 μm described in Geitler (1932). Broady (1979) also described smaller cell size of this species (1.5–2.5 μm) from Signy Island, Antarctica.

Leptolyngbya cf. *battersii* (Gom.) Anagn. et Kom. (Fig. 3A, B)

Syn.: *Plectonema battersii* Gom.

Filaments blue-green to yellowish brown, densely entwined with each other. Trichomes sometimes falsely branching, constricted at the cell wall, 2–3 μm wide, cells 1/3–1 as long as broad, 1.5–3 μm long.

Our specimens sometimes had false branching. However, no characteristic differences of trichomes were observed between specimens with false branching (Fig. 3B) and specimens without it (Fig. 3A). Specimens without false branching were identical to *Phormidium priestleyi* Fritsch (1917). Broady *et al.* (1984) pointed out the resem-

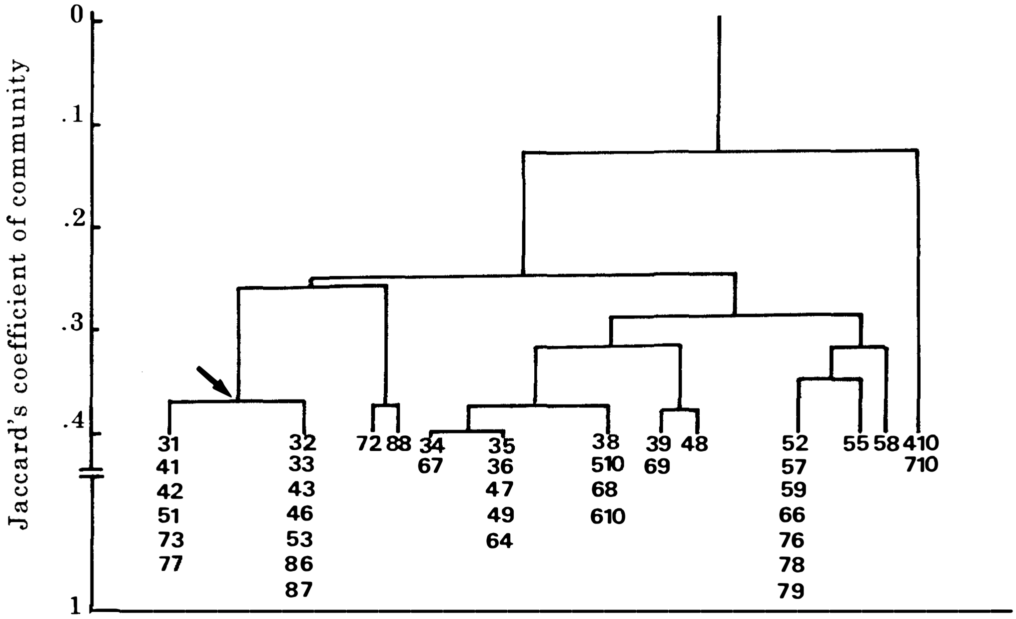

Fig. 5. A dendrogram of cluster analysis using the UPGAM method. Abbreviations of sample names are arranged in order of the last number of the expedition year and monitoring site. For example, sample number 3.1 indicates data in JARE-33, site 1. The arrow shows a cluster which groups together most assemblages at sites 1–3.

blance between *Phormidium priestleyi* and *Plectonema battersii*. Anagnostidis and Komárek (1988) considered that false branching was not a valid taxonomic character to separate the genus *Phormidium* from *Plectonema*. They defined a new genus, *Leptolyngbya*, and transferred *Plectonema battersii* to *Leptolyngbya*. We agree with the treatment of Anagnostidis and Komárek (1988). This species has been reported from a pond on West Ongul Island (Oguni and Takahashi, 1989), from streams in Langhovde (Hirano, 1979) and in Skarvsnes (Hirano, 1983).

Leptolyngbya tenuis (Menegh. ex Gom.) Anagn. et Kom. (Fig. 3C)
Syn.: *Phormidium tenue* (Menegh.) Gom.

Filaments blue-green, straight or entwined with each other. Trichomes 1.5–2 μm wide, not attenuated, slightly constricted at transverse walls, terminal cell sometimes conical, without calyptra, cells quadrate or 2 times longer than broad, 1.5–3 μm long.

Although Geitler (1932) described cells 2.5–5 μm long, up to 3 times longer than broad, specimens obtained in the present study showed somewhat shorter cells. Apices of terminal cells were round or conical, not attenuated as the figure in Geitler (1932, page 1003, Fig. e). Akiyama (1967) reported this species as a common species from sandy soils in the Ongul Islands. This species has been reported from a pond on West Ongul Island (Oguni and Takahashi, 1989) and from a stream in Skarvsnes (Hirano, 1983).

Phormidium autumnale (Ag.) Gom.(Fig. 3D)
Syn.: *Phormidium uncinatum* Gom.

Filaments blue-green to yellowish brown, straight, 5.5–8 μm wide. Trichomes attenuated, without both constriction and granules at transverse walls, terminal cell with

Table 5. Correspondence analysis based on the relative frequency of taxa (%) at the 10 monitoring sites in the vicinity of Syowa Sation between JARE-33 and JARE-38.

Taxa	St. 1 (3)	St. 3 (4)	St. 2 (4)	St. 6 (5)	St. 7 (5)	St. 4 (2)	St. 5 (3)	St. 8 (6)	St. 10 (4)	St. 9 (5)	Weight
Chlamydomonas spp.	0	50	0	0	0	0	0	0	0	0	100
Klebsormidium sp.	0	25	0	0	0	0	0	0	0	0	100
Oocyctis sp.	0	25	0	0	0	0	0	0	0	0	100
Prasiola crispa	100	25	75	0	0	0	0	0	25	0	80
Heterococcus sp.	0	25	50	0	0	0	0	17	0	0	70
Phormidium autumnale	67	75	75	33	40	50	0	0	0	0	69
Macrochloris multinucleata	100	100	75	33	100	50	0	17	0	40	58
Raphidonema spp.	0	50	0	0	0	0	50	0	0	0	56
Navicula muticopsis	33	75	75	50	60	100	0	17	0	0	54
Xanthonema spp.	100	100	100	83	100	50	100	33	0	0	53
Leptolyngbya tenuis	0	75	25	50	20	0	0	0	0	60	45
Raphidonema pyrenoidifera	0	50	25	33	20	0	0	17	0	60	35
Nostoc cf. *microscopicum*	0	0	0	17	0	0	0	0	0	0	34
Botrydiopsis spp.	100	75	75	83	60	100	100	83	50	100	34
Achnanthes sp.	0	0	0	0	60	0	0	0	0	0	26
Nostoc sp.	0	0	25	33	40	0	50	33	0	40	17
Leptolyngbya cf. *battersii*	0	25	25	50	80	100	50	83	100	100	11
Stichococcus bacillaris	0	0	0	17	20	50	0	0	0	40	10
Aphanocapsa cf. *muscicola*	0	0	25	17	20	0	0	17	25	60	8
Crinalium cf. *epipsammum*	0	0	0	0	20	50	50	17	0	60	4
Nostoc cf. *sphaericum*	0	0	0	0	20	0	0	17	0	20	0
Score	100	92	83	46	40	36	27	15	6	0	

Sites and taxa are arranged in order of reciprocal-averaging-score and weight, respectively.
[1] Parentheses show the numbers of samples between JARE-33 and JARE-38.

calyptra, cells 1/2–2/3 as long as broad, 3–4 μm long.

This species, under the name of *P. uncinatum*, has been reported from ponds on East and West Ongul Islands (Oguni *et al.*, 1987; Oguni and Takahashi, 1989), and from streams in Langhovde (Hirano, 1979) and in Skarvsnes (Hirano, 1983). Davey and Clarke (1991) reported that this species is the most widespread taxon on soil polygons on Signy Island, Antarctica.

Crinalium cf. *epipsammum* Winder, Stal et Mur (Fig. 3E)

Trichomes blue-green, straight when short, slightly twisted when long, not attenuated, distinctly constricted at transverse walls, 5.5–6.5 μm wide, flattened in the transverse section, 4–5 μm wide, up to 300 μm long. Cells 1/4–1/3 as long as broad, 1.5–2 μm long, containing several granules, terminal cell without calyptra.

Winder *et al.* (1990) described a new species, *Crinalium epipsammum*, from coastal dunes in the Netherlands. Our specimens agree well with descriptions of this species except for slightly wider size (4–5 μm) in the transverse section than *C. epipsammum* (2–2.5 μm). *Crinalium glaciale* Broady et Kibblewhite from cryoconite ponds, Antarctica (Broady and Kibblewhite, 1991), shows similar cell shape to our specimens, however, it has wider trichome size (13–26 μm). The genus *Crinalium* is a new record in the vicinity of Syowa Station. This species never occurred at sites 1–3 and 10 where eutrophicated soils were developed.

Nostoc cf. *microscopicum*

Thalli bright blue green to yellowish brown, globose, with firm outer layer, colonies on BBM agar microscopic, up to 200 μm. Trichomes entangled with sheath in old culture, cells spherical to barrel-shaped, 5–6 μm in diameter, heterocysts spherical or subspherical, 6 μm wide, 5 μm long.

Our specimens had sheaths only in old trichomes near the surface of the colony. However, other characters were identical to *N. microscopicum*. Cells were a little larger than those of *N. sphaericum*.

Nostoc cf. *sphaericum* Vaucher (Fig. 4F)

Thalli bright blue green to yellowish brown, globose, with firm outer layer, colonies on BBM agar microscopic, up to 200 μm. Trichomes densely entangled without sheath, cells spherical to barrel-shaped, 3–5 μm in diameter, heterocysts spherical or subspherical, 6 μm wide, 5 μm long.

Colonies of *N. sphaericum* are up to 6–7 cm (Desikachary, 1959). Our specimens were always microscopic in size, only up to 200 μm, on BBM agar plates. However, other characteristics were identical to *N. sphaericum*. Our specimens always had no sheath. This characteristic differs from *N. microscopicum* and *N. commune*, which are similar taxa to *N. sphaericum*. This species occurred in oligotrophic soils at sites remote from Syowa Station.

Nostoc sp.

Thalli dark blue green, gelatinous, without firm outer surface, colonies on BBM agar macroscopic, up to 3 cm. Trichomes entangled with sheath in old trichomes, cells spherical to barrel-shaped, 4–5 μm in diameter, heterocysts terminal, spherical, 5–5.5 μm in diameter. Hormogones 3 μm wide, cells cylindric or spherical with conical terminal cell (7 μm long), or conical heterocyst. Akinetes frequently occurred, oval to elliptic, 4.5–5 μm wide, 6–7 μm long.

Our specimens had no firm outer layer and sometimes have conical terminal cell or heterocyst. These characteristics are similar to *N. muscorum* reported by Broady (1979). However, cell shapes of our specimens were spherical to barrel shape in the developed colony. Cells were not cylindrical like *N. muscorum*.

BACILLARIOPHYCEAE

Navicula muticopsis van Heurck (Fig. 4G)

Valves elliptical with short rostrate and slightly capitate ends, 7.5–10 μm wide 15–22 μm long, striations slightly radiate, punctate, 15–16 in 10 μm. Chloroplast with a clear pyrenoid.

Akiyama (1967) reported this species as a common species of soil algae in the Ongul Islands. This species was also recorded from ponds of East Ongul Island (Oguni *et al.*, 1987) and moss colonies at Langhovde about 20 km south of the Ongul Islands (Ohtani, 1986). Prescott (1979) showed this species widespread in Antarctica.

Achnanthes sp. (Fig. 4H, I)

Valves elliptical with rounded ends, 20–27 μm long, 8–10 μm wide. Raphe valve with filiform raphe; proximal raphe ends terminating at the margin of the central area;

distal ends indistinct. Central area transversely expanded rectangle. Striations radiate, distinctly punctate, 13 in 10 μm. Pseudoraphe valve with submarginal to marginal narrow pseudoraphe, which ends at the large terminal nodules. Striations, distinctly punctate, 12–13 in 10 μm.

XANTHOPHYCEAE

Botrydiopsis spp. (Fig. 4A)

Cells single, spherical, 3–50 μm in diameter, chloroplasts parietal, polygonal with or without pyrenoids.

From the results of the culture observation at JARE-37, several species of *Botrydiopsis* were identified such as *B. callosa* Trenkwalder and *B.* cf. *alpina* Vischer. However, identification was done to only generic level as species identification is difficult without careful observation of life cycles.

Xanthonema spp. (Fig. 4B)

Filaments short, readily fragmenting, loosely entangled each other, distinctly constricted at transverse walls. Cells cylindric, 4–5 μm wide, 6.5–11 μm long, chloroplasts parietal without pyrenoid, usually 2 to 4 in each cell.

From the results of the culture observation at JARE-37, several species of *Xanthonema* were identified such as *X. debile* (Vischer) Silva, *X. sessile* (Klebs) Silva and an unknown species. However, identification was done only to generic level because species identification is difficult without careful observation of life cycles. Although Akiyama (1967) reported *Bumilleria exilis* Klebs (=*Xanthonema exile* (Klebs) Silva) as a common species of soil algae in the Ongul Islands, we could not detect this species. *Xanthonema* spp. widely and often occurred at sites in the vicinity of Syowa Station.

Heterococcus sp.

Filaments irregularly branched. Cells spherical, 6.5–8 μm in diameter at the base, cells at the apices cylindrical, 4 μm wide. Chloroplast parietal having no pyrenoid.

CHLOROPHYTA

Chlamydomonas spp.

Cells single, elliptic, with two equal flagella and two contractile vacuoles at the anterior end, 9–10 μm wide, 14–16 μm long, chloroplasts with a pyrenoid.

Oocystis sp.

Cells single, elliptic with a papilla at one end, 10–12 μm wide, 18–21 μm long. Chloroplast with a pyrenoid.

Macrochloris multinucleata (Reisigl) Ettl et Gätner (Fig. 4C–E)

Cells single or colonial. Single cells spherical 13–62 μm in diameter, sometimes up to 88 μm, cell wall thick, 3–4 μm in adult cells. Colonial cells irregular shaped. Chloroplast parietal, cup shaped with many radial lobes (Fig. 4D) and with a clear pyrenoid. Many nuclei visible in adult cells (Fig. 4E, arrows)

Reisigl (1969) described this species under the name of *Chlorozebra multinucleata* from a soil sample without vegetation in the Himalaya at 6150 m.

Stichococcus bacillaris Nägeli (Fig. 4F)

Cells single or pairs, cylindrical with rounded ends, 3 μm in width, 4–6.5 μm in length, chloroplast single, parietal without a pyrenoid.

Akiyama (1967) reported this species as common among algae in the Ongul

Islands. This species is widespread in Antarctica (Prescott, 1979).

Raphidonema pyrenoidifera Korschikov (Fig. 4G)

Cells single or pairs, straight or slightly curved, suddenly narrowed at the pointed apices, 2.5–3 μm wide, 6–15 μm long, chloroplast single, parietal with a faint pyrenoid.

Broady (1982) described a new variety of this species, *R. pyrenoidifera* var. *elongata* from Chapman Ridge, Antarctica. This variety differs from var. *pyrenoidifera* in its longer cells (22–25 μm) in young culture. Lengths of our specimens were almost in the range of var. *pyrenoidifera* (7–13 μm) (Korschikov, 1953). Akiyama (1967) reported that this species, under the name of *Koliella helvetica* (Kol) Hindak is common in soil in the Ongul Islands. The cell morphology of his specimens was identical to that of *R. pyrenoidifera.*

Raphidonema spp.

Cells single or pairs, curved, suddenly narrowed at the obtuse apices, 2.5–3 μm wide, 6–7 μm long, chloroplast single, parietal.

Cell shape and size of our specimens from site 3 resembled *R. sempervirens* Chodat. The latter has no pyrenoids. We failed to observe whether pyrenoids were present or absent in our specimens.

Klebsormidium sp.

Filaments short, cells cylindrical, 5 μm wide, 12 μm long, chloroplast single, parietal with a pyrenoid.

Prasiola crispa (Lightf.) Menegh. (Fig. 4H, I)

Filaments straight, parallel to each other. Cells quadrate or shorter than the broad, 9–12 μm wide, 3.5–4 μm long, chloroplast single, star shaped with a pyrenoid.

In both liquid and agar BBM cultures, this species never became foliose. This species is well known as an ornithocoprophilous alga (Matsuda, 1968; Akiyama, 1974; Hoshiai and Matsuda, 1979). It is widespread in Antarctica (Prescott, 1979).

Discussion

Soil properties

The pH values (7.2–9.4) and EC values (119–730 μS/cm) in the present study were in similar ranges to those of Akiyama (1967, 1968). Akiyama (1968) attributed the difference of EC values of soils to the contents of chloride in the soils which derived from windblown sea-spray. From the results of relatively low EC value (132–730 μS/cm) in the present study, monitoring sites were not heavily affected by sea-spray. Yamanaka and Sato (1977) reported total carbon of 0.09%,total nitrogen of 0.005–0.06 % from bare soils at Teöya, one of the smaller Ongul Islands where there was no direct impact of human activities. The range values obtained the present study at monitoring sites remote from Syowa Station were of the same order as their results. On the other hand, they reported high TC (0.34–0.52%) and TN (0.059–0.094%) from soils covered by *Prasiola crispa* near the penguin rookery at Ongulkalven. Campbell and Claridge (1966) obtained both high TC and TN contents and low C/N ratio from the soils of penguin rookeries. They reported low C/N ratios of 1 and 4 at an occupied penguin rookery and a recently abandoned one, respectively. In the present study, maximum TC of 0.991%, TN of 0.401% and minimum C/N ratio of 2.5 were observed at site 10, in the presently occupied penguin rookery. These results showed that soils eutrophicated by penguins are characterized by low C/N ratio. On the other hand, C/N ratio of soils eutrophicated by human beings at Syowa Station was 18.8, which was much different from those of the penguin rookeries. Concerning phosphorus, Campbell and Claridge (1966) reported that values of P_2O_5 were much higher in recently abandoned soils and presently occupied soils than those of the oldest abandoned soils and soils remote from penguin rookeries. We also found a high TP value of 0.809% at site 10. On the other hand, a low TP value of 0.2% was obtained at site 2, despite the relatively high TC and TN which were observed at site 2. Although both soils at site 2 near the urinal tank and site 10 in the penguin rookery were eutrophicated, TP values were different from each other. Further study will be necessary to confirm these differences in quality of soils between humans and penguins.

Species composition

Although our study was six years in duration, the total taxa was less than that recorded by Akiyama (1967). He used samples collected from more diverse sites than in our study, and found 13 taxa which occurred only on West Ongul Island. Akiyama (1967) reported *Phormidium tenue, Nostoc punctiforme, Bumilleira exilis, Stichococcus bacillaris, Koliella helvetica* and *Navicula muticopsis* as the common species in the Ongul Islands. In the present study, the species reported by Akiyama (1967) such as *P. tenue* Gom. (=*Leptolyngbya tenuis* (Gom.) Anagn. et Kom.), *Navicula muticopsis, Stichococcus bacillaris* and *R. pyrenoidifera* also occurred at the monitoring sites. The species which belong to the same genera reported by Akiyama (1967), such as *Nostoc, Bumilleria exilis* (=*Xanthonema exile*), were also commonly observed in the present study. *Phormidium autumnale* is known to be widespread in Antarctica (Prescott *et al.*, 1979) and in the vicinity of Syowa Station (Hirano, 1979, 1983; Oguni and Takahashi, 1989). We also found it from 6 monitoring sites, Akiyama (1967), however, did not report it. On the other hand, we did not observe several species which were recorded from East Ongul Island by Akiyama (1967) such as *Oscillatoria agardhii, Tolypothrix fragile, Stichococcus exiguus, Pseudo-pleurochoccus printzii* etc. As no detailed taxonomic studies of soil algae with analyses of soil properties have been carried out after Akiyama (1967) on the Ongul Islands, it is very difficult to point out the reason for the difference of algal communities between these studies.

Distribution of soil algae

The ornithocoprophilous alga *Prasiola crispa* is well known to be widely distributed around Adélie penguin rookeries in the vicinity of Syowa station(Matsuda, 1964; Akiyama, 1974; Hoshiai and Matsuda, 1979). Macroscopic colonies of this species were collected at site 1 in JARE-33 and 34. Although we have no nutrient data of soils at site 1, surface soil of site 2, 2.5 m from the urinal tank, showed high total carbon and total nitrogen. In the soil cultures, this species was observed from sites 1, 2 and 3. Yamamoto *et al.* (1991) reported that cellulose decomposition activities by bacteria in the soils were much higher (9–25%) near the urinal tank at Syowa Station than at sites 120 m from the station (1.4%). It is considered that soils near the urinal tank have become eutrophic since construction of the building in 1971. The results in the present study and in Yamamoto *et al.* (1991) indicate examples of changes in terrestrial environments by human activities. As *Prasiola crispa* forms green macroscopic foliose colonies on the surface of soils and occurs in eutrophicated soils, this species can be used as a biological indicator of eutrophication by human activities.

The result of cluster analysis of soil algal assemblages indicated that community structures of soil algae at the sites 1–3 near the urinal tank were different from those at other sites (Fig. 5). As shown in the results for soil properties, soils at sites 2 and 3 contained higher values of TC and TN than those at other sites. *Phormidium autumnale* as well as *P. crispa* is a species which characterizes eutrophic sites. *Crinalium* cf. *epipsammum* and *Nostoc* cf. *sphaericum* occurred at the remote sites which contained low values of TC and TN. These two species characterize oligotrophic sites.

We observed a small number of taxa in the cultures of the surface soils collected from site 10 in the Adélie penguin rookery. Only an oscillatoriacean alga, *Leptolyngbya* cf. *battersii*, dominated in the soil associated with a small number of *Botrydiopsis* spp. and colonial algae (Table 3 and 4). *Prasiola crispa* was cultured at one time from the soil sample collected by JARE-34. Common species of chlorophytes and diatoms observed from sites 1 to 9 were never observed in the BBM cultures. Akiyama *et al.* (1986a) reported allelopathic effects of penguin excrements and guanos on the growth of Antarctic soil algae. The allelopathic substances in the excrements of Adélie penguin were acrylic acid and oxalic acid. Akiyama *et al.* (1986b) reported that free-living algal cells did not grow in cultures of soils from the center of penguin rookeries, and that chlorophyll concentrations were low, although high concentrations of phosphate and nitrate were detected from central parts of both new and old rookeries. Matsuda (1968) reported that *Prasiola crispa* was not found in a water-pool at the presently occupied rookery but occurred at a site 50 m from the pool at Ongulkalven. He also reported that this species was abundant at the recently abandoned rookery. The poor soil algal community and scarcity of *P. crispa* at site 10 might be attributed to allelopathic substances in the soils as stated by Akiyama *et al.* (1986a, b).

During the study years, no clear changes in soil algal communities were observed at any of the sites. The differences in taxa in cultures, from year to year, were probably caused by heterogeneity of propagules of soil algae in samples and by oversights of rare species. Water contents of soils probably affected the occurrence of species in the cultures because we could not detect any soil algae in the culture of one wet sample collected at site 6 in JARE-35. Water contents of soils and recovery of soil algae in deep frozen samples transported from Antarctica to Japan also requires study.

Human activity and long dispersal of terrestrial algae

Broady and Smith (1994) indicated that human activity was an effective vector for dispersal of microalgae to the Ross Sea regions of Antarctica. They found that 10 taxa at Scott Base were from genera previously unrecorded in the Ross Sea Region. They reported that *Cylindrospermum* and *Eustigmatos* could be monitored relatively easily if they become established in Antarctic habitats, because these two taxa have distinctive morphological and cytological features. They, however, found no evidence that any of the potential colonizers had been introduced into the external Antarctic environment. Broady (1996) listed other distinctive and common taxa in soils which have never been recorded from Antarctica, such as *Porphyridium purpureum*, the euglenophyte *Euglena* and the xanthophyte *Botrydium*, the chlorophytes *Protosiphon* and *Trentepohlia*. During our six years of study, we have never detected these morphologically distinctive exogenous algae from the monitoring sites in the vicinity of Syowa Station. However, *Crinalium* cf. *epipsammum* is a new record for Antarctica. All taxa observed in the present study except *C. epipsammum* are common genera and species in continental Antarctica.

As soil sampling points were not exactly recorded at each site in the present study, our data could not remove the effect of replicate sampling. We will use a more critical sampling method for future monitoring of soil algae.

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