Polar Biosci., **16**, 1–10, 2003

Distribution of aquatic mosses in the Sôya Coast region, East Antarctica

Satoshi Imura[1]*, Tadashi Bando[2], Koji Seto[3], Shuji Ohtani[4], Sakae Kudoh[1] and Hiroshi Kanda[1]

[1] *National Institute of Polar Research, Kaga, 1-chome, Itabashi-ku, Tokyo 173–8515*
[2] *Department of Biology, Kyoto University of Education, Fukakusa, Fushimi-ku, Kyoto 612–8522*
[3] *Research Center for Coastal Lagoon Environments, Shimane University, 1060, Nishi-kawatsu, Matsue 690–8504*
[4] *Department of Education, Shimane University, 1060, Nishi-kawatsu, Matsue 690–8504*

Abstract: The distribution of aquatic mosses among 73 lakes in the Sôya Coast region, East Antarctica, was surveyed. Two species of mosses, *Bryum pseudotriquetrum* and *Leptobryum* sp. were found at the bottom of lakes. *B. pseudotriquetrum* was found in 38 lakes (52.1%), mainly in freshwater lakes throughout the study area. *Leptobryum* sp. was found in 26 lakes (35.6%) in a rather restricted area, and mainly in relatively saline lakes.

key words: Antarctica, lake, aquatic moss, distribution, salinity

Introduction

Bryophytes occur in a diverse range of terrestrial and also aquatic habitats. Ignatov and Kurbatova (1990) reviewed the occurrence of aquatic bryophytes, especially in deep lakes in the world, and listed about 85 taxa of mosses and liverworts. These aquatic bryophytes, which grow on bottom substrata in lakes and streams, and permanently in submerged condition, have often been found in high altitude (*e.g.*, Light and Smith, 1976) or high latitude regions (*e.g.*, Longton, 1988), where the environmental conditions are very severe for macrophytes and aquatic seed plants.

In the Antarctic region, 15 taxa of mosses are known as aquatic plants at the bottom of lakes (Table 1). In the Maritime Antarctic, 6 taxa of mosses have been reported in a large number of lakes on Signy Island (Light and Heywood, 1973; Priddle and Dartmall, 1978; Priddle, 1979), and 5 taxa of mosses are known from lakes on Alexander Island (Light and Heywood, 1975). Even in some ice free areas in East Antarctica, the most severe terrestrial habitat on Earth, 5 taxa of aquatic mosses have been reported (*e.g.*, Savich-Lyubitsukaya and Smirnova, 1959; Kasper *et al.*, 1982; Seppelt, 1983; Kanda and Iwatsuki, 1989). Light and Heywood (1975) emphasized the luxuriance of aquatic moss communities in the lakes, contrasting strongly with the paucity of terrestrial vegetation in East Antarctica.

In the Sôya Coast region, four taxa of aquatic mosses have been reported. They

*E-mail: imura@nipr.ac.jp

Table 1. List of the aquatic mosses in Antarctic lakes.

Aquatic mosses	Signy Island	Alexander Island	East Antarctica
Ambrystegium sp.	●[1]		
Calliergon sarmentosum	●[1,2,3]		
Campylium sp.	●[1]		
Drepanocladus sp.	●[1]		
Drepanocladus cf. *aduncus*	●[1,2]		
Pohlia nutans	●[1]		
Bryum sp.		●[4]	
Campylium polygamum		●[4]	
Dicranella sp.		●[4]	
Distichium capillaceum		●[4]	
Bryum pseudotriquetrum		●[4]	●[5–12]
Bryum sp.			●[11]
Leptobryum sp.			●[11–16]
Hennediella heimii			●[10]
Plagiothecium simonowii			●[17]

1: Light and Heywood (1973), 2: Priddle (1979), 3: Priddle and Dartmall (1978), 4: Light and Heywood (1975), 5: Savich-Lyubitskaya and Smirnova (1959), 6: Savich-Lyubitskaya and Smirnova (1960), 7: Kasper *et al.* (1982), 8: Seppelt (1983), 9: Kanda and Iwatsuki (1989), 10: Kanda and Ohtani (1991), 11: Kanda and Mochida (1992), 12: Imura *et al.* (1999), 13: Nakanishi (1977), 14: Ochi (1979), 15: Imura *et al.* (1992), 16: Tewari and Pant (1996), 17: Savich-Lyubitskaya and Smirnova (1964).

are *Bryum pseudotriquetrum* (*e.g.*, Kanda and Ohtani, 1991), *Bryum* sp. (Kanda and Mochida, 1992), *Hennediella heimii* (Kanda and Ohtani, 1991 as *Pottia heimii*) and *Leptobryum* sp. (*e.g.*, Imura *et al.*, 1999; Kanda and Iwatsuki, 1989 as *Dicranella* sp.). Most of these works on aquatic mosses are reports on their occurrences in particular lakes, or taxonomical treatments. Only Kanda and Mochida (1992) discussed the distribution of aquatic mosses in a study at Skarvsnes, one of the ice free areas in this region.

Imura *et al.* (1999) described a curious aquatic moss vegetation, described as moss pillars, in some lakes in the vicinity of Syowa Station. Subsequently, a more detailed survey of the aquatic mosses in many lakes in the Sôya Coast region, East Antarctica, was carried out. In this report, we compile the results of our surveys to clarify the distribution of aquatic mosses in this region, and discuss the limiting factors governing their distribution.

Methods

The Sôya Coast is located on the east coast of Lützow-Holm Bay, Dronning Maud Land, East Antarctica (Fig. 1). Syowa Station is situated on East Ongul Island, at the north end of this region. Along the 100 km long coast from West Ongul Island (*ca.* 69°S) at the entrance of Lützow-Holm Bay, to Strandnibba (*ca.* 70°S) in the innermost part of the bay, several ice-free areas and islands are interspersed. Seven ice-free areas were

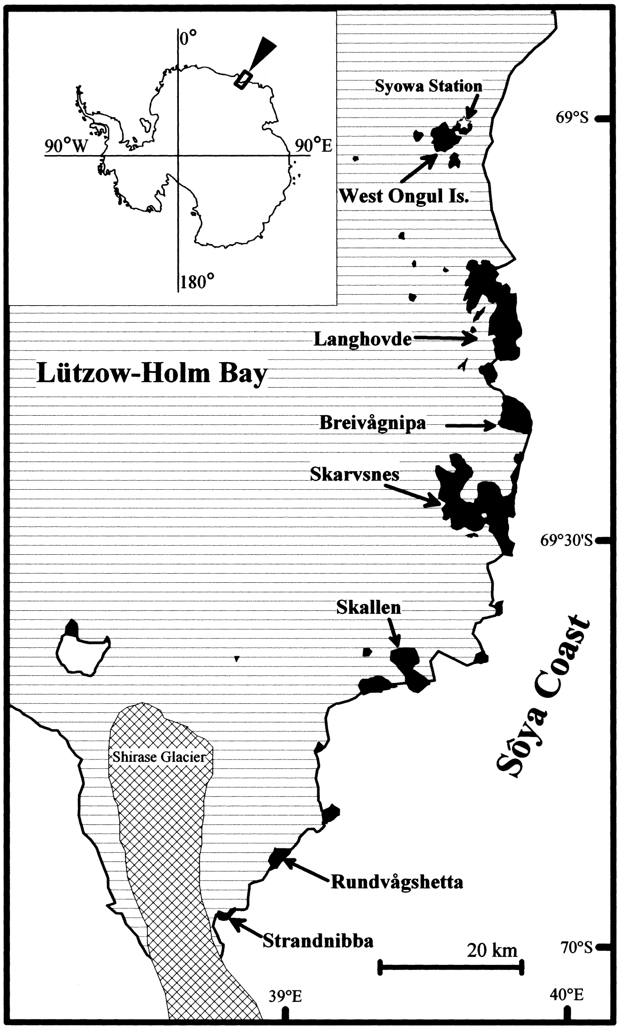

Fig. 1. Map of the study area.

surveyed: West Ongul Island, the Langhovde area (including Hamnenabben), Breivågnipa, the Skarvsnes area (including Byvågåsane), Skallen, Rundvågshetta and Strandnibba.

On the ice free area in this region, there are many lakes of various sizes, depths and water qualities. Lakes over 1 m in depth were selected in this study. In total, 73 lakes were surveyed from 1994 to 2001, during the 36th to 42nd Japanese Antarctic Research Expeditions. The name, geographical characteristics, and electric conductivity of lakes surveyed in this study are listed in Table 2. A directory and maps of each lake are shown on the web page (http://www.isc.nipr.ac.jp/~penguin/Terrestrial/regal/DataBase/index.htm).

The benthic vegetation of lakes was collected in several ways. When the lakes

Table 2. Geological and chemical characteristics of surveyed lakes and distribution of aquatic mosses.

Lakes	Alt. (m)	Distance from Sea (m)	Major diameter (m)	Minor diameter (m)	Area (m^2)	Max. Depth (m)	Electric conductivity		Aquatic mosses	
							(mS/m)	depth (m)	*Bryum pseudotriquetrum*	*Leptobryum* sp.
West Ongul Island										
Ô-ike	13	170	370	215	51,500	11.2	23.7	-3.0	-	-
Langhovde area										
Zakuro Ike	-6	150	455	215	68,750	4.6	6711.0	-3.0	-	-
Akebi Ike	-4	305	420	125	43,750	5.7	374.5	-3.0	-	○
Itiziku Ike	-14	300	20	10	200	0.2	-	-	-	-
Nakano-tani Ike*	15	390	945	775	271,000	17.5	-	-	-	-
Nurume Ike	0	30	305	155	35,000	16.6	3160.0	-3.0	-	-
Oyayubi Ike	0	25	205	110	25,000	5.2	7138.0	-3.0	-	-
Yukidori Ike	125	985	275	225	41,000	8.2	4.0	-3.0	●	-
Higasi-yukidori Ike	195	1,800	530	525	148,000	16.3	17.9	-3.0	-	-
Minami-yukidori Ike*	181	1,100	250	150	8,300	-	-	-	-	-
Hyouga Ike*	165	1,525	565	199	33,000	4.5	5.0	-1.6	-	-
Kami-kama Ike*	70	355	355	23	43,750	3.5	17.1	-2.0	●	-
Tenno-kama Ike*	165	975	435	125	35,000	3.8	4.4	-2.0	●	-
Higasi-Hamna Ike	165	915	675	325	123,000	22.7	0.6	-3.0	-	-
Gokuh Ike*	185	750	225	25	31,200	4.4	3.5	-2.0	●	-
Nisi-Hamna Ike	35	375	700	605	193,000	16.0	-	-	-	-
Breivågnipa										
Burai Ike*	40	300	150	75	12,000	-	-	-	●	-
Hiroe Ike	215	1,550	905	550	278,000	9.5	-	-	●	-
Skarvsnes area										
D-1 Ike*	30	100	500	100	14,600	-	-	-	●	○
76 Ike*	50	350	225	75	25,000	-	-	-	●	-
Hama Ike*	35	260	505	345	78,000	-	-	-	-	-
D-2 Ike*	50	300	200	100	18,750	-	-	-	-	-
D-3 Ike*	90	600	150	75	14,600	-	-	-	●	○
D-4 Ike*	110	900	100	75	14,600	-	-	-	●	○
D-5 Ike*	100	900	150	75	14,600	-	-	-	●	○
D-6 Ike*	120	1,250	175	75	14,600	-	-	-	●	○
D-7 Ike*	160	1,650	600	100	42,000	-	-	-	-	-
D-8 Ike*	20	500	300	50	14,600	-	-	-	-	-
D-9 Ike*	0	850	175	75	14,600	-	-	-	-	-
D-11 Ike*	160	600	200	20	12,500	-	-	-	-	-
Hunazoko Ike	-23	290	675	250	133,000	9.2	-	-	-	-
C-1 Ike*	70	400	75	50	500	-	-	-	●	-
B-1 Ike*	130	450	200	75	12,500	4.3	44.0	-3.0	●	◎
B-2 Ike*	120	400	50	25	6,000	2.3	30.0	-1.0	●	○

B-3 Ike*	130	500	200	50	12,500	3.1	62.0	-2.0	●	◎
B-4 Ike*	120	600	150	50	12,500	3.0	102.0	-2.0	●	◎
Kuwai Ike*	160	500	50	25	6,250	-	16.0	-1.0	●	O
Oyako Ike	5	165	430	150	54,000	8.0	54.4	-3.0	-	-
Naga-Ike*	70	900	375	150	45,800	10.0	116.2	-1.0	●	◎
A-2 Ike*	75	700	100	25	6,250	1.5	240.3	-0.5	-	-
A-3 Ike*	70	250	175	50	14,500	3.2	120.7	-0.5	●	◎
A-4 Ike*	100	850	225	100	18,750	4.0	18.0	-0.5	●	O
A-5 Ike*	100	650	50	25	6,000	3.0	75.8	-0.5	-	-
A-6 Ike*	60	450	300	75	18,750	6.0	174.0	-0.5	●	◎
A-7 Ike*	60	450	300	75	20,000	6.3	390.0	-0.5	-	O
A-8 Ike*	40	250	200	150	17,000	5.0	200.0	-0.5	●	◎
A10 Ike*	70	500	300	35	16,000	3.0	290.0	-1.0	-	-
Hyotan Ike*	75	965	370	215	56,000	10.4	210.0	-1.0	●	-
Suribati Ike	-33	400	1,070	780	406,000	31.2	10140.0	-3.0	-	-
Kobati Ike*	25	1,100	235	180	31,200	9.2	1815.0	-3.0	-	-
Magobati Ike*	60	950	200	30	18,000	5.8	290.1	-3.0	-	O
Misumi Ike*	90	500	75	75	18,000	6.3	29.5	-3.0	●	◎
Namazu Ike*	95	405	535	270	91,500	20.0	24.0	-3.0	●	O
Namagi Ike*	110	600	350	325	65,000	8.2	99.7	-3.0	●	O
Tanago Ike*	150	1,250	350	150	41,000	8.7	59.5	-3.0	●	O
Dojyou Ike*	165	1,275	715	205	115,000	5.1	15.0	-3.0	●	O
Medaka Ike*	160	1,750	630	30	53,000	2.6	53.5	-2.0	●	O
Kami-tenpyô Ike*	160	450	400	150	48,000	2.6	4.6	-2.0	●	-
Naka-tenpyô Ike*	160	300	500	30	35,000	2.7	7.2	-2.0	●	-
Shimo-tenpyô Ike*	160	100	275	100	31,000	2.5	76.5	-2.0	●	O
Maruyama Ike*	160	2,000	750	500	187,500	-	-	-	●	-
Kamino-ike*	130	2,500	1,725	730	620,000	5.5	-	-	-	-
Skallen										
Koke Numa*	35	300	187	20	6,250	3.0	15.6	-2.0	●	O
Daikei Ike*	60		100	70	7,000	2.0	-	-	-	-
Ko Ike*	48	570	180	105	18,750	6.5	8.8	-3.0	-	-
X Ike*	38	750	280	105	23,000	8.3	14.4	-3.0	-	-
Rokuban Ike*	45	815	325	120	32,000	2.7	18.8	-1.5	-	-
Skallen Ô-ike	10	135	1,180	275	209,000	8.5	18.4	-3.0	-	-
Rundvågshetta										
Maruwan Ô-ike	10	250	750	350	252,000	37.0	1.0	-3.0	●	-
Maruwan-minami Ike*	10	200	550	300	18,750	11.5	3.6	-3.0	-	-
Maruwan-kita Ike*	20	250	200	100	46,000	-	4.0	-3.0	-	-
Strandnibba										
St-1 Ike*	50	175	150	75	6,250	3.6	7.7	-3.0	●	-
St-2 Ike*	40	250	150	100	16,000	6.7	4.1	-3.0	●	-

*: Temporary name
O: Occurrence of *Leptobryum* sp. without moss pillars
◎: Occurrence of *Leptobryum* sp. with moss pillars

were ice-free, we used a rubber boat and an Ekman grab sampler or a rake with long handle to collect the vegetation. When the lakes were frozen, we made holes in the ice, and used the rake through the ice hole. In winter, we collected the mass of benthic vegetation exposed on the ice-surface of lakes. This vegetation was considered to have been growing at the bottom of lakes before being moved upward through the ice cover (Wilson, 1965). All samples were frozen at -20℃ and carried back to the laboratory, and observed by light microscope.

As the most basic measure of water quality, electric conductivity (EC) of lake water was measured *in situ* at some lakes. From each vertical profile of EC values, the deepest but in maximum 3 m in depth value was used, because the aquatic mosses were known to be most vigorous at 3 m in depth in this region (Imura *et al.*, 1999).

Results and discussion

Table 2 shows the distribution of aquatic mosses in 73 lakes surveyed in the Sôya Coast region. The aquatic vegetations of mosses were found in 41 lakes (56.2%). In the Sôya Coast region, aquatic mosses are thought to be common components of the lake bottom vegetation. These vegetations were found at the bottom of lakes from 2.0 to 14.5 m in depth, and were most vigorous from 3 to 5 m. In shallow areas, less than 2 m in depth, moss vegetations were not found, probably due to ice action, there were only fragments of algal mats. In the surveyed lakes, the maximum thickness of surface ice in winter was less than 2 m. Bodin and Nauwerck (1968) noted that ice movement in summer is the main reason to explain the absence of aquatic moss colonies in the shallow water zone down to about 2 m depth. The deepest record of aquatic mosses in East Antarctica is 32.3 m, where *Plagiothecium georgico-antarcticum* was found in Lake Glubokoye, Schirmachar Oasis, Dronning Maud Land (Savich-Lyubitskaya and Smirnova, 1964). The world's deepest record is 153 m, where mosses and liverworts have been found in Lake Tahoe, California-Nevada (Frantz and Cordone, 1967). In this study, the maximum depth for aquatic mosses was just 14.5 m, but there were only a few lakes deeper than this depth, and most of them were hyper saline lakes.

In this study, we found two species of mosses, *Bryum pseudotriquetrum* (Hedw.) Gaertn., Meyer et Scherb. and *Leptobryum* sp. at the bottom of many lakes in the Sôya Coast region. *Bryum* sp. and *Henediella heimii* were not found in the lakes surveyed in this study. Aquatic *Bryum* sp. was reported from two lakes in Skarvsnes by Kanda and Mochida (1992), but it has not been reported since then. An aquatic form of *Henediella heimii* was reported from lake Yukidori Ike in Langhovde by Kanda and Ohtani (1991) as *Pottia heimii.* In this study, floating submerged shoots of *H. heimii* were sometimes found in the lakes, but not on the bottom substrata. It is suggested that floating shoots of the species are temporarily submerged from the population growing on the soil around the lake. We have therefore excluded *Bryum* sp. and *H. heimii* from the list of aquatic mosses in the Sôya Coast region.

Bryum pseudotriquetrum has been reported in lakes in several regions in Antarctica, such as Alexander Island (Light and Heywood, 1975 as *B. algens*), the Dry Valley region (Kasper *et al.*, 1982 as *B. algens*), Vestfold Hills (Seppelt, 1983) and Bunger Hills (Savich-Lyubitskaya and Smirnova, 1959 as *B. korotkevicziae*). The morphological characteristics of aquatic *B. pseudotriquetrum* have been well described and illustrated by Seppelt (1983), Kanda and Iwatsuki (1989) and Kanda and Ohtani (1991). This species is the commonest moss around ephemeral streams in Antarctica, and also very common and widespread, mainly in wet conditions around the world.

Irregular mat-shaped vegetations of *B. pseudotriquetrum* were found in 38 of the 73 lakes (52.1%). This species was not found on West Ongul Island, but was found in all of the other areas from Langhovde (*ca.* 69°10′S) near the entrance of Lützow-Holm Bay to Strandnibba (*ca.* 70°S) in the innermost part of the bay. In the Skarvsnes area, it was found in 28 of 44 lakes surveyed (63.6%). *B. pseudotriquetrum* is thought to be a quite common and widespread species at the bottom of lakes in this region.

Leptobryum sp. at the bottom of lakes in this region was first reported by Nakanishi (1977) as *Bryum korotkevicziae* Sav. et Smirn. or its variety *hollerbachii* Sav. et Smirn. Ochi (1979) treated it as *Bryum* sp., and Kanda and Iwatsuki (1989) considered it to be *Dicranella* sp. Imura and Kanda (1985) and Imura *et al.* (1992) investigated the morphology of tubers (vegetative diaspores), and identified it as *Leptobryum pyriforme* (Hedw.) Wils. Imura *et al.* (1999) argued that the taxonomic position of this species was still uncertain, and treated it merely as *Leptobryum* sp. Recently, Arts (2001) reviewed the genus *Leptobryum* around the world, and considered the aquatic *Leptobryum* in Antarctica to be *L. wilsonii* (Mitt.) Broth. based on the illustration of aquatic plants by Kanda and Iwatsuki (1989). He described the sexuality of *L. wilsonii* as dioicous, while Imura *et al.* (1992) reported synoicous inflorescences on shoots from cultured tubers of the aquatic *Leptobryum*. Further morphological and molecular genetic studies are needed to clarify the taxonomic position and origin of aquatic *Leptobryum* sp. in Antarctica.

Leptobryum sp. was found in 26 of 73 lakes surveyed (35.6%). It was found mainly in the Skarvsnes area (24 of 44, 54.5%) and only one lake in the Langhovde area (the neighbor to the north of Skarvsnes) and Skallen (the neighbor to the south of Skarvsnes). *Leptobryum* sp. is relatively rare at the bottom of lakes in this region, and the distribution area is restricted mainly to Skarvsnes. Imura *et al.* (1999) reported curious pillar-like vegetation of this species at the bottom of some lakes in Skarvsnes. Also in this study, moss pillars were found in 8 lakes only in Skarvsnes (Table 2). In Langhovde and Skallen, *Leptobryum* sp. formed rough irregular mat-shaped vegetation.

Table 3 shows the occurrence of two aquatic mosses among 50 lakes for which electric conductivity (EC) data were obtained. *B. pseudotriquetrum* was found in lakes with quite low (1.0 mS/m, lake Maruwan Ôike) to relatively high (210.0 mS/m, lake Hyotan Ike) EC values; it was most vigorous in low salinity lakes. On the other hand, aquatic *Leptobryum* sp. was not found in lakes with very low EC values, but from relatively low (15.0 mS/m, lake Dojyou Ike) to high (390.0 mS/m, lake A-7 Ike) values. This highest EC value of lake A-7 Ike is close to one-tenth of the value in seawater.

It is noteworthy that *Leptobryum* sp. has never been found in terrestrial habitats in East Antarctica. Except in the Syowa Station area, this species has been reported only in some lakes around the Indian Maitri station (70°37′S, 08°22′E) at Schirmachar Oasis, over 1000 km west of Syowa Station (Tewari and Pant, 1996). Smith (1984) reported the occurrence of this genus from Deception Island (63°00′S, 60°40′E) in the South Shetland Islands, Maritime Antarctic, and this is the only report of this species

Table 3. Electric conductivity of lakes and distribution of aquatic mosses.

Lakes	Electric conductivity (mS/m)	Aquatic mosses	
		Bryum pseudotriquetrum	*Leptobryum* sp.
Higasi-Hamna Ike	0.6	–	–
Maruwan Ôike	1.0	●	–
Gokuh Ike	3.5	●	–
Maruwan-minami Ike	3.6	–	–
Maruwan-kita Ike	4.0	–	–
Yukidori Ike	4.0	●	–
St-2 Ike	4.1	●	–
Tenno-kama Ike	4.4	●	–
Kami-tenpyô Ike	4.6	●	–
Hyouga Ike	5.0	–	–
Naka-tenpyô Ike	7.2	●	–
St-1 Ike	7.7	●	–
Ko Ike	8.8	–	–
X Ike	14.4	–	–
Dojyou Ike	15.0	●	○
Koke Numa	15.6	●	○
Kuwai Ike	16.0	●	○
Kami-kama Ike	17.1	●	–
Higasi-yukidori Ike	17.9	–	–
A-4 Ike	18.0	●	○
Skallen Ôike	18.4	–	–
Rokuban Ike	18.8	–	–
Ô-ike	23.7	–	–
Namazu Ike	24.0	●	○
Misumi Ike	29.5	●	◎
B-2 Ike	30.0	●	○
B-1 Ike	44.0	●	◎
Medaka Ike	53.5	●	○
Oyako Ike	54.4	–	–
Tanago Ike	59.5	●	○
B-3 Ike	62.0	●	◎
A-5 Ike	75.8	–	–
Shimo-tenpyô Ike	76.5	●	○
Namagi Ike	99.7	●	○
B-4 Ike	102.0	●	◎
Naga-Ike	116.2	●	◎
A-3 Ike	120.7	●	◎
A-6 Ike	174.0	●	◎
A-8 Ike	200.0	●	◎
Hyotan Ike	210.0	●	–
A-2 Ike	240.3	–	–
A10 Ike	290.0	–	–
Magobati Ike	290.1	–	○
Akebi Ike	374.5	–	○
A-7 Ike	390.0	–	○
Kobati Ike	1815.0	–	–
Nurume Ike	3160.0	–	–
Zakuro Ike	6711.0	–	–
Oyayubi Ike	7138.0	–	–
Suribati Ike	10140.0	–	–

○: Occurrence of *Leptobryum* sp. without moss pillars.
◎: Occurrence of *Leptobryum* sp. with moss pillars.

growing on the ground in Antarctica. There is no apparent terrestrial source population from which the lake bottom population originated, at least in East Antarctica. On the other hand, *B. pseudotriquetrum* is one of the commonest moss species on the ground in Antarctica. It is thought to be one reason for the difference of the distribution of these two aquatic mosses in this region.

Acknowledgments

We wish to express our sincere gratitude to the members of the 36th to 42nd Japanese Antarctic Research Expedition teams for their devoted support to the field survey in Antarctica. This study was partly supported by a Grant-in Aid for scientific research from the Ministry of Education, Science, Culture, Sports and Technology, Japan (No. 12640691) for S. Imura and H. Kanda and a similar Grant (No. 14380258) for S. Imura, K. Seto, S. Ohtani, S. Kudoh and H. Kanda.

References

Arts, T. (2001): The moss genus *Leptobryum* and the identity of *Pohlia integra.* J. Bryol., **23**, 325–330.

Bodin, K. and Nauwerck, A. (1968): Produktionsbiologische Studien über die Moosvegetation eines Klaren Gebirgsees. Schweiz. Z. Hydrol., **30**, 318–352.

Franz, T.C. and Cordone, A.J. (1967): Observations on deepwater plants in Lake Tahoe, California and Nevada. Ecology, **48**, 709–714.

Ignatov, M.S. and Kurbatova, B. (1990): A review of deep-water bryophytes with new records from USSR. Hikobia, **10**, 393–401.

Imura, S. and Kanda, H. (1985): The gemmae of the mosses collected from the Syowa Station area, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **44,** 241–246.

Imura, S., Higuchi, M., Kanda, H. and Iwatsuki, Z. (1992): Culture of rhizoidal tubers on an aquatic moss in the lakes near the Syowa Station area, Antarctica. Proc. NIPR Symp. Polar Biol., **5**, 123–126.

Imura, S., Bando, T., Saito, S., Seto, K. and Kanda, H. (1999): Benthic moss pillars in Antarctic lakes. Polar Biol., **22**, 137–140.

Kanda, H. and Iwatsuki, Z. (1989): Two aquatic mosses in the lakes near Syowa Station, Continental Antarctica. Hikobia, **10**, 293–297.

Kanda, H. and Mochida, Y. (1992): Aquatic mosses found in lakes of the Skarvsnes region, Syowa Station area, Antarctica (Extended Abstract). Proc. NIPR Symp. Polar Biol., **5**, 177–179.

Kanda, H. and Ohtani, S. (1991): Morphology of the aquatic mosses collected in lake Yukidori, Langhovde, Antarctica. Proc. NIPR Symp. Polar Biol., **4**, 114–122.

Kasper, M., Simmons, G.M., Parker, B.C., Seaburg, K.G. and Wharton, R.A. (1982): *Bryum* Hedw. collected from lake Vanda, Antarctica. Bryologist, **85**, 424–430.

Light, J.J. and Heywood, R.B. (1973): Deep-water moss in Antarctic lakes. Nature, **242**, 535–536.

Light, J.J. and Heywood, R.B. (1975): Is the vegetation of continental Antarctica predominantly aquatic? Nature, **256**, 199–200.

Light, J.J. and Smith, R.I.L. (1976): Deep-water bryophytes from the highest Scottish lochs. J. Bryol., **9**, 55–62.

Longton, R.E. (1988): The biology of polar bryophytes and lichens. New York, Cambridge University Press, 391 p.

Nakanishi, S. (1977): Ecological studies of the moss and lichen communities in the ice-free areas near Syowa Station, Antarctica. Nankyoku Shiryô (Antarct. Rec.), **59**, 68–96.

Ochi, H. (1979): A taxonomic review of the genus *Bryum,* Musci in Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **11**, 70–80.

Priddle, J. (1979): Morphology and adaptation of aquatic mosses in an Antarctic lake. J. Bryol., **10**, 517–529.

Priddle, J. and Dartmall, H.J.G. (1978): The biology of an Antarctic aquatic moss community. Freshwater Biol., **8**, 469–480.

Savich-Lyubitskaya, L.I. and Smirnova, Z.N. (1959): New species of *Bryum* Hedw. From the Bunger Hills. Inf. Byull. Sov. Antarkt. Eksped., **7**, 34–39 (in Russian).

Savich-Lyubitskaya, L.I. and Smirnova, Z.N. (1960): New variety of *Bryum korotkevicziae* Sav. -Lyub. et Z. Smirn. Inf. Byull. Sov. Antarkt. Eksped., **17**, 25–27 (in Russian).

Savich-Lyubitskaya, L.I. and Smirnova, Z.N. (1964): A deep-water member of the genus *Plagiothecium* Br et Sch. in Antarctica. Inf. Byull. Sov. Antarkt. Exped., **49**, 33–39 (in Russian).

Seppelt, R.D. (1983): The status of the Antarctic moss *Bryum korotkevicziae.* Lindbergia, **9**, 21–26.

Smith, R.I.L. (1984): Colonization and recovery by cryptogams following recent volcanic activity on Deception Island, South Shetland Islands. Br. Antarct. Surv. Bull., **62**, 25–51.

Tewari, S.D. and Pant, G. (1996): Some moss collections from Dakshin Gangotri, Antarctica. Bryol. Times, **91**, 7.

Wilson, A.T. (1965): Escape of algae from frozen lakes and ponds. Ecology, **46**, 376.

(Received July 15, 2002; Revised manuscript accepted September 18, 2002)