Abstract

This paper discusses the environment and ecology of moss community and microoganisms of East Ongul Island, West Ongul Island, Ongul Kalven Island and Sôya Coast, in the Antarctic.

Moss community was distributed mainly on the west side of the islands and developed on the southwest slope. Growth form of cushion of moss community is discussed. Blue green algae coexisted with these mosses and restrained the growth of each individual. Microclimate of moss cushion was measured with a self-recording thermistor throughout the year. Various microorganisms were found in the water contained in the moss community and ecological observations were conducted. Discussions were given to ecosystem existing among the terrestrial vegetations, sea birds and sea creatures.

I. Introduction

Six Japanese Antarctic Research Expeditions were sent to the area of Lützow-Holm Bay, Antarctica, during the period from 1956 to 1962 (Fig. 1).

These expeditions consisted of 6 summer missions and 4 wintering parties at Syowa Station which was established on East Ongul Island in 1957. The research area covers East Ongul Island, West Ongul Island, their immediate vicinity, Prince Olav Coast (mainly Sôya Coast) and Prince Harald Coast. Biological specimens collected during these expeditions were subjected to detailed analyses by many specialists at various research institutions.

East Ongul Island, where Syowa Station is maintained, is located at 69°S and 39.5°E. This island is in an exposed rock area on the coast of the Antarctic Continent (Fig. 2). The continent is covered with snow and ice of about 2,000 to 3,000 meters thick and the temperature is low, but the climate is gentle in

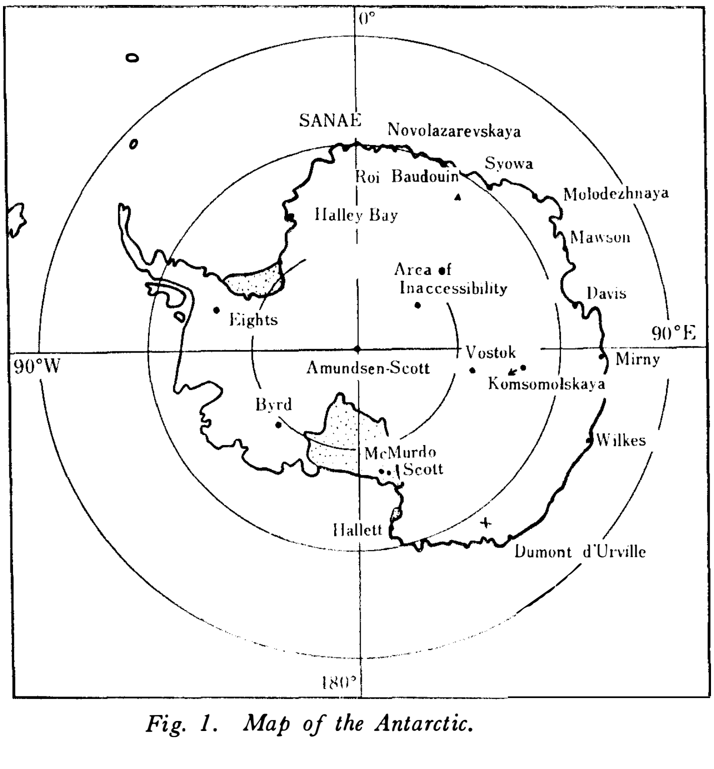


Fig. 1. Map of the Antarctic.

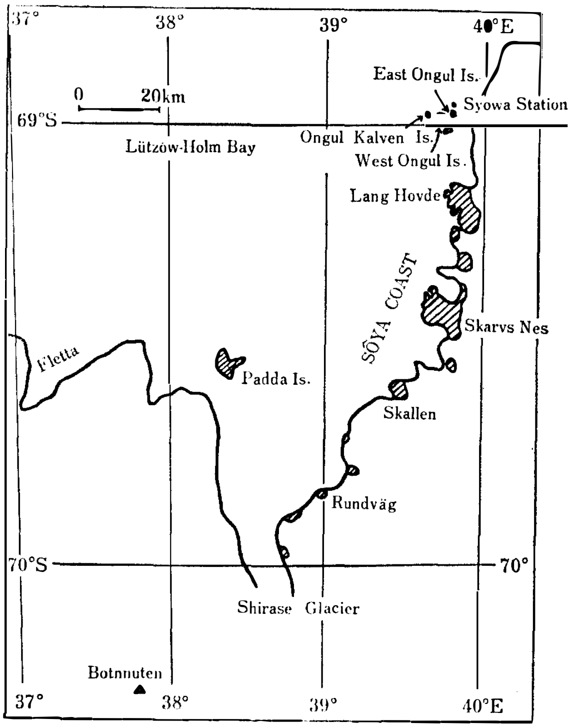


Fig. 2. Map of Sôya Coast.

the marginal areas. Especially, East and West Ongul Islands are not influenced by katabatic wind, which is common in the Antarctic, and so it is warmer there than in the continent.

Lützow-Holm Bay is covered with ice about one to two meters thick, and East Ongul, West Ongul, Ongul Kalven and Teöya Islands are in the frozen sea for the most part of the year. The fast ice is developing about 100 km from these islands to the north, followed by pack ice farther north, the width of which is about 200 km even in late summer. Therefore, the islands are not likely to be influenced by the open ocean.

Various kinds of low order plants grow in exposed area of Ongul Islands under non-oceanic environment, and many reports were presented concerning those plants. FUKUSHIMA (1961, 1962, 1963) conducted a taxonomic research on diatoms, mainly of fresh-water algae. KO-BAYASHI (1963 a, b) made a research on the variations of fresh-water diatoms. HIRANO (1959) reported on fresh-water algae; SONEDA (1961) on yeast, TSUBAKI (1961) on fungi, and WATANABE (1961) on cultivation of microalgae. HORIKAWA and ANDO (1961) conducted a taxonomic research on mosses. The present writer is conducting an ecological research on moss community and the microclimate of moss community (1963, 1964 a, b).

MORIKAWA (1962) reported the species of tardigrada. SUDZUKI (1964 a, b, c, d) made a taxonomical study of rotifer, tardigrada and protozoa living in the moss-water. TORIUMI and KATÔ (1961) observed the living condition of micro fauna and flora among the mosses, and comparing them with protozoa of Japan, made an ecological analysis of the Antarctic protozoa. AOKI (1961, 1964) reported on the frost-resistance of the rotifer living in moss community, describing that when the rotifers were slowly frozen only a few of them were found dead even at −80°C, and that when they were rapidly frozen the death-rate became higher, even at −20°C.

The writer carried out the observation of the moss community growing on East Ongul Island and Lang Hovde area, and made an ecological study of the moss community and the microorganisms living in the moss community.

HORIKAWA and ANDO (1961) stated that there are only four species of mosses on Ongul Island and in its vicinity. They are *Ceratodon purpureus*, *Bryum argenteum*, *Bryum inconnexum* and *Bryum ongulense*, and no other species were found ever since. *Bryum argenteum* and *Ceratodon purpureus* are cosmopolitan species, while *Bryum inconnexum* and *Bryum ongulense* are found only in the Antarctic. Especially *Bryum ongulense* found on East Ongul Island is listed as a new species. TATSUNO (1963) conducted a cytological research on these mosses.

SUDZUKI (1964 a, b) made an investigation of the microorganisms, such as rotifer, tardigrada and protozoa living in the moss community.

The writer wintered at Syowa Station from January 1961 to February 1962 and carried out a survey of the distribution of moss community on East Ongul Island. The temperature of moss community on East Ongul Island was continuously measured with a recording thermistor thermometer. The growing process of moss community living on exposed rock in the Lang Hovde area on the coast of Lützow-Holm Bay was observed, and their growing process in coaction with blue green algae was clarified. The writer also studied the ecology of protozoa, tardigrada and rotifer living in the standing water of moss community and the ecosystem of moss community in the Antarctic tundra. Detailed description of ecosystem of moss community in the Antarctic tundra will be given in the following chapters.

2. Distribution of Moss Community (East Ongul Island)

Many mosses are growing on East Ongul Island where Syowa Station is located, and on West Ongul Island and Nesöya Island. But, it is striking that no moss was found on Paul-Holmen Island though it is located quite near those islands (Fig. 30). Mosses are found on Padda Island in the southernmost part of Lützow-Holm Bay and the exposed rock zone on the Sôya Coast which forms the eastern coast of Lützow-Holm Bay.

In the exposed rock zone on East Ongul Island, *Ceratodon purpureus* was most abundant, intermingling with lichens (ASAHINA, 1962). Lichens are found on rocks, whereas mosses dominate on the sands deposited on leeward side of rocks or in the crevices of rocks.

A well-grown moss community is found in the Lang Hovde area which has a large exposed rock zone on the Sôya Coast. Also, moss community, several centimeters thick, looking like a thick carpet, covers an area of about 500 m^2. Detailed description will be given in a later chapter. *Ceratodon purpureus*, *Bryum inconnexum* and *Bryum argenteum* dominate in this area.

HORIKAWA and ANDO (1961) made taxonomical and morphological researches on the mosses collected in the Antarctic region. LLANO (1962) described the general distribution of mosses in the Antarctic. Both mosses and liverworts are aboundant in the Antarctic Peninsula, but liverworts are few on the continent and even mosses are limited to the exposed rock zones around the continent. RICHARD (1927) concluded that successions of cryptogam on the sands and gravels start with the dominance of mosses and end with the dominance of mosses. LEACH (1931) stated that in various kinds of soils *Ceratodon purpureus* has a feature of a pioneer in plant community. GIMINGHAM and BIRSE (1957) conducted research on the relation between the natural habitat of mosses and their growth form. BIRSE (1957) carried out an experimental study on the growth of mosses by controlling light and temperature.

The growing condition and distribution of moss community in exposed rock zone on the Sôya Coast and on the islands in Lützow-Holm Bay were not hitherto studied, which has led to the present investigation of moss ditribution in this area.

From December 31, 1961 to January 5, 1962, an investigation of moss community over the whole East Ongul Island was carried out.

The most part of East Ongul Island is covered with snow during the winter but in summer, especially from January to February, the ground is exposed in many places. During the summer season sufficient samples were obtained to describe moss habitats on East Ongul Island. Since the present study was carried out only for one year, some changes might occur in other years. The writer surveyed throughly the exposed area on East Ongul Island, inspecting habitats of mosses and collecting specimens at every habitat.

2.1. Method of survey

East Ongul Island, where Syowa Station is located, is a small island, the diameter of which is about 2 km. The sea in this area is frozen all the year round, therefore it is possible to walk on the ice to the Sôya Coast located east of the station, or to West Ongul Island in the southwest. Some parts of this island are exposed throughout the year, but the rest is covered with snow from autumn to spring. When summer comes (from December), snow begins to melt gradually and the area of exposed rock enlarges. Most of mosses living on East Ongul Island are buried under snow during the winter, but are exposed in the summer. It is, therefore, almost impossible to check the mosses during the winter. The best season for the observation of their distribution is between December and February when the ground is exposed. The writer carried out the general survey of habitats of mosses in February 1961, and after passing the winter, the detailed observation of habitats and collection of specimen were conducted from the end of December 1961 to the begining of January 1962. On East Ongul Island, most of their habitats are on the sands except a few of them living in crevices of rocks. Stems of moss stick together and mass of stems is growing on the sands (Figs. 6, 8, 10).

When snow melts and moss community appears, the mosses contain much water in them. During the night, they are almost frozen so that it is hard to collect them with an ice axe; during the daytime, however, they are soft and not frozen, making collection easy. Collected mosses were classified into specified groups by their habitats, and in a frozen state (−20°C) they were sent to Japan and subjected to the specific classification. At the time of collection, the size of habitats, the topography of habitats, the soil and snowdrifts were observed for the comparison of different growing conditions.

Five areas were examined in February 1961 and about 30 areas were surveyed between December 1961 and January 1962.

2.2. Results and discussion

2.2.1. Distribution, habitats and topography

Three species, *Ceratodon purpureus*, *Bryum argenteum* and *Bryum inconnexum*, were found from the areas. Locations of these mosses collected were plotted on the topographic map of East Ongul Island (Fig. 3).

As Fig. 3 shows, the distribution areas are mostly in the western part of

Fig. 3. Distribution of mosses on East Ongul Island.

Table 1. Relation between the occurrence of mosses and the direction of the slope.

Direction of slope (Mosses habitat)	SW	SE	NW	NE
Frequency	23	3	3	1
Total area (m^2)	50.1	4.1	5.1	0.3

East Ongul Island. There are also exposed rocks and exposed sands in the eastern part, but few mosses were discoverd. According to the topography shown in the map, the most of moss habitats should be found in the south and west sides of hills. In order to examine this, the occurrence of moss habitats was calculated to find out in which quadrant of the hills the habitats were located. Table 1 indicates the frequency of occurrence with respect to the direction and the total area of moss habitats in each quadrant. Fig. 3 and Table 1 indicate that moss habitats are located almost exclusively on the southwestern slope of the hills. Only one habitat found on the northeast slope was in a hollow area, different from dominant topographic features of the northeast quadrant.

Investigations of areas occupied by the community revealed that the majority of them are smaller than 1 m^2, as shown in Fig. 4. It is, however, to be noted that some areas are larger than 15 m^2. The total area in each quadrant was indicated in Table 1. A large habitat, 15 m^2 in area, was found on the peninsula southwest of the island, occupying the southwest slope of a hill. Judging from the above, it seems that the sands on the southwest slope is suitable for

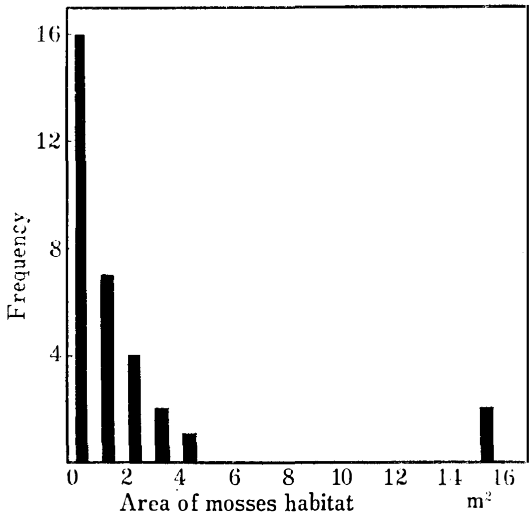


Fig. 4. Frequency of areas of mosses habitat.

the growth of mosses.

Figs. 5, 6, 7, 8, 9 and 10 show the habitats of mosses and their relation with the topography. The north direction is indicated by an arrow-figure of measure. Common features among them are as follows; (1) a higher place exists in the northeast of habitat, and (2) snowdrift exists near the habitat. During the winter, this snowdrift became wider and covered the grounds where mosses grew, but in the summer the mosses began to be exposed gradually at the edges of the drift.

The whole moss community shown in Figs. 5 and 6 was not exposed completely when the photographs were taken. In Figs. 7 and 8 the whole moss

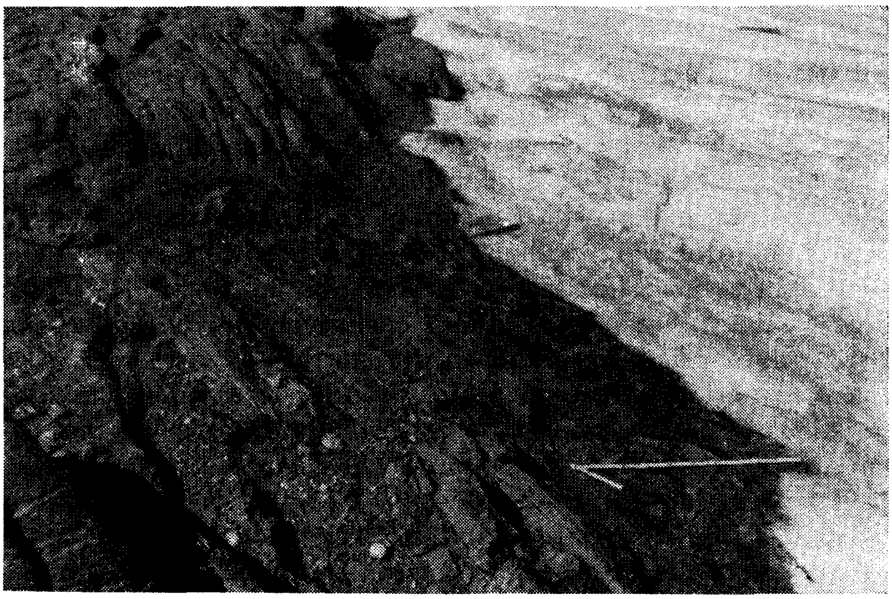


Fig. 5. Moss community at Station A. Arrow indicates north (one-metre measure).

Fig. 6. Close-up view of Station A (Fig. 5).

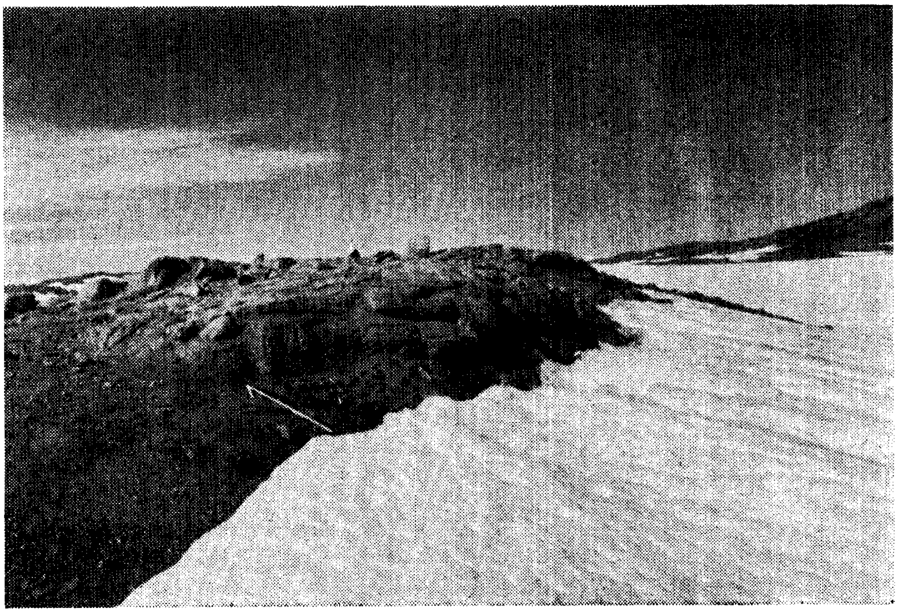


Fig. 7. Moss community at Station B. Arrow indicates north.

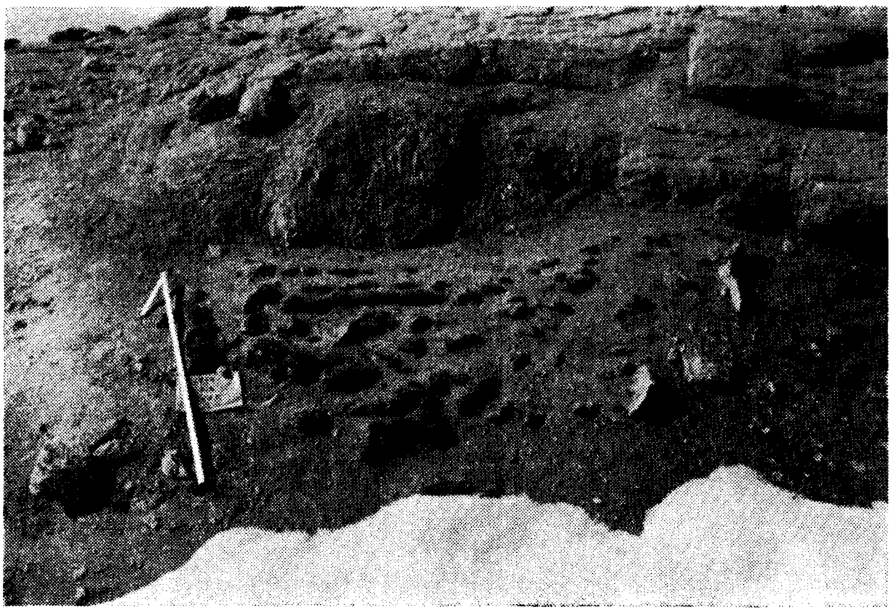


Fig. 8. Close-up view of Station B (Fig 7).

Fig. 9. Moss community at Station C. Arrow indicates north.

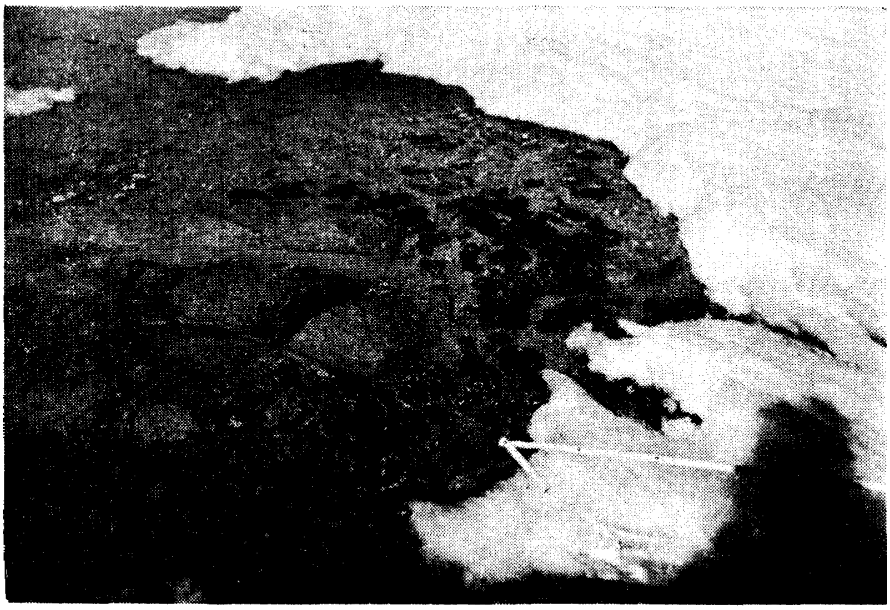


Fig. 10. Close-up view of Station C (Fig. 9).

community is exposed. Generally speaking, it seems that mosses will not grow on the grounds where the snowdrift covers all the year round. In the cases of Figs. 5, 6, 9 and 10, only a few more mosses were found under the snow.

Snowdrifts on East Ongul Island develop largely to the southwest (leeward side) of the hills, but as will be seen in the photographs, most of moss communities were found on the west side of snowdrift. This may be attributed to the effect of afternoon sunlight in the Antarctic which comes from the northwest direction.

2.2.2. Distribution, habitat and wind regime

Many moss habitats are found on the west side of East Ongul Island. Detailed examination of the habitats showed that they were located on the southwest slope of the hills. It was, moreover, found that moss community grows well on the sands beside snowdrift which extends to the southwest of the hills.

Table 2. Frequency of the wind direction and velocity at Syowa Station (After MURAKOSHI, 1958).

Wind velocity m/s	Wind direction																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	SWS	W	WNW	NW	NNW	Calm
<5.0	59	60	111	42	65	24	38	36	72	16	29	6	23	4	8	7	50
5.0~ 9.9	12	52	106	54	27	2	1	8	44	5	2					2	
10.0~14.9	1	37	83	51	30					1							
15.0~28.9		28	107	28	7												
29.0>			2														
Total	72	177	409	175	129	26	39	44	116	23	31	6	23	4	8	9	50

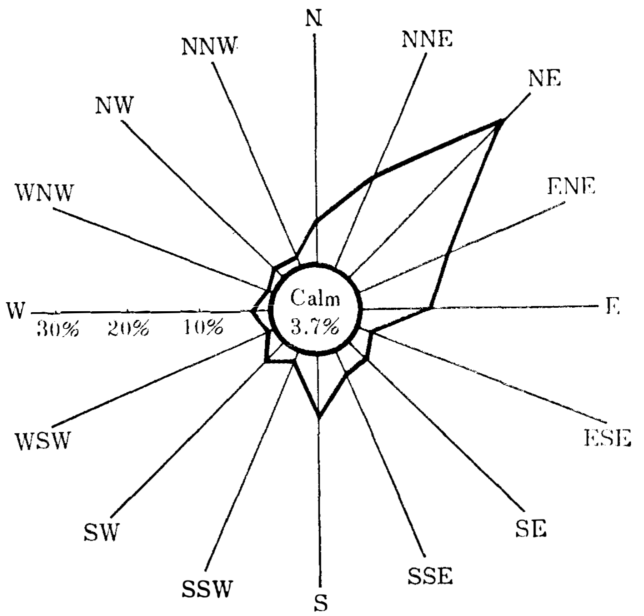


Fig. 11. Wind rose at Syowa Station (after MURAKOSHI, 1958).

Data of wind direction and speed observed at Syowa Station are shown in Fig. 11 and Table 2 (MURAKOSHI, 1958). As there is no major change from year to year, the record for 1957 was shown. The prevailing wind direction is NE and strong winds also come from N or E. Snowdrift formed by the wind naturally extends to SW.

On East Ongul Island, the northeast wind is blowing all the year round and is fairly strong. Therefore, the ground slopes facing to the north or the east are always windswept with snow. It is easily recognized that the northeast slope is not a suitable area for the growth of plants, whereas the leeward sides with many sand spots are favourable for the growth of plants.

It seems that supply of water is necessary for plants in the Antarctic where it does not rain much. Many areas on the northeast slope have little snow, so supply of water is not sufficient in contrast with the southwest slope where snowdrifts are formed. In the summer, the water from melted snow soaks into the slope and runs down, giving rise to the growth of moss community under the snowdrift.

The sun does not set from December to the middle part of January, which accelerates the melting of snow. Description will be given later concerning the duration of sunshine, the air temperature and temperature of mosses in relation to the moss habitat. It seems that the west and south sides of snowdrift formed on the slope on the west are the best places for the growth of plant, because the slope receives enough sunlight in the afternoon (Figs. 5, 6, 7, 8, 9 and 10). That is, the sands beneath the snowdrift are exposed fast and the water from melted snow will be infiltrated. Judging from these situations, moss community is considered to grow and develop on the slopes facing to the southwest on East

Ongul Island.

2.2.3. Distribution area of each species of mosses

It was mentioned previously that three species of mosses were found in this investigation; *Ceratodon purpureus*, *Bryum argenteum* and *Bryum inconnexum.*

HORIKAWA and ANDO (1961) recorded *Bryum ongulense* which was collected by KAJI at 300 meters east of Syowa Station, but this species was not found during the investigation in 1961. It seems that individuals are few and the distribution area is small. Therefore, the distribution of the above-mentioned three species only is hereby recorded.

Ceratodon purpureus (Fig. 12) : This species seems to spread over the whole island. HORIKAWA and ANDO (1961) reported that *Ceratodon purpureus* is seen mainly on East and West Ongul Islands and the vicinity, and the area of its distribution is wide.

Bryum argenteum (Fig. 13): This species is seen mainly in the nothern part of East Ongul Island.

Bryum inconnexum (Fig. 14) : This species is seen mainly on the peninsula in the southwestern part of the island, and only a few are distributed in the northern part, being found in the crevices of rocks in a small amount. One habitat found on the peninsula was the largest in size, forming a huge carpet-like community intermingling with *Ceratodon purpureus* on the sandy gentle slope facing to the southwest.

Those three species are not distributed exactly in the same places and areas.

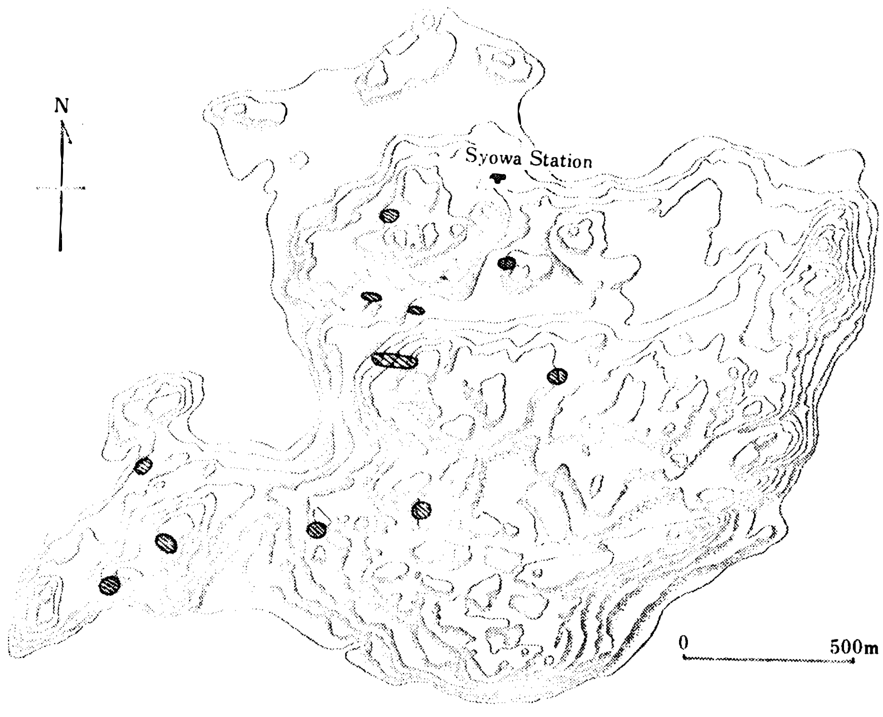


Fig. 12. Distribution of Ceratodon purpureus.

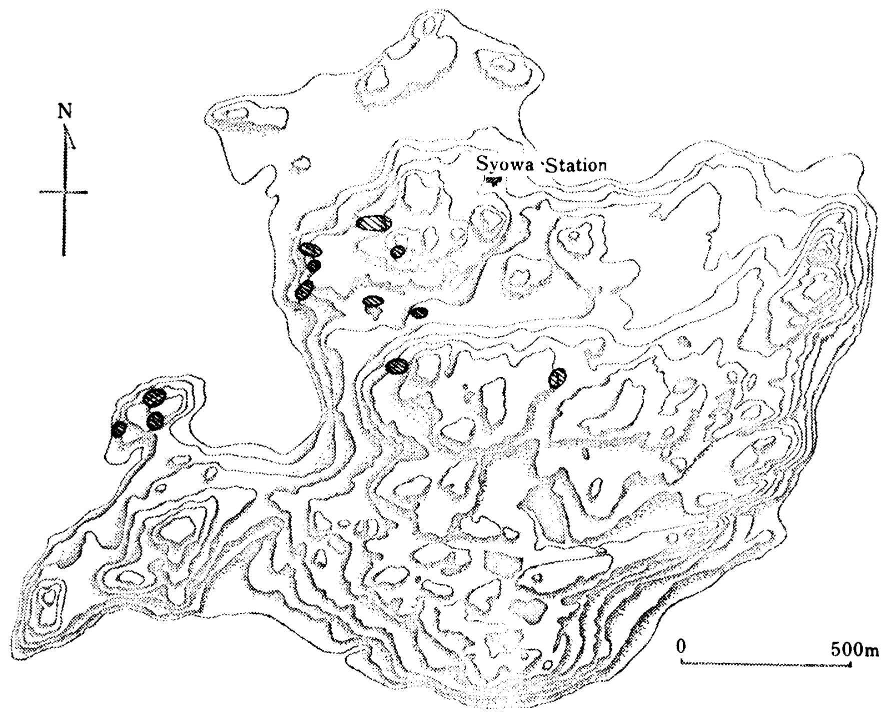


Fig. 13. Distribution of Bryum argenteum.

Fig. 14. Distribution of Bryum inconnexum.

3. Growth Form of Cushion of Moss Community

Several investigators have reported on the growth of mosses in the Antarctic. HORIKAWA and ANDO (1961) reported the multiplication of specimens collected around Syowa Station, attributing it mainly to asexual reproduction rather than sexual. After the living mosses were brought back to Japan, TAKAGI (1962) cultivated them for 2 years and found that they have grown by asexual reproduction. SAVICZ-LJUBITZKAJA and SMIRNOVA (1961) have, however, revealed different modes of the vegetative reproduction of *Sarconeurum glaciale* and traced its developmental stages from the rhizoid protonema to the leafy plant. Bryo-

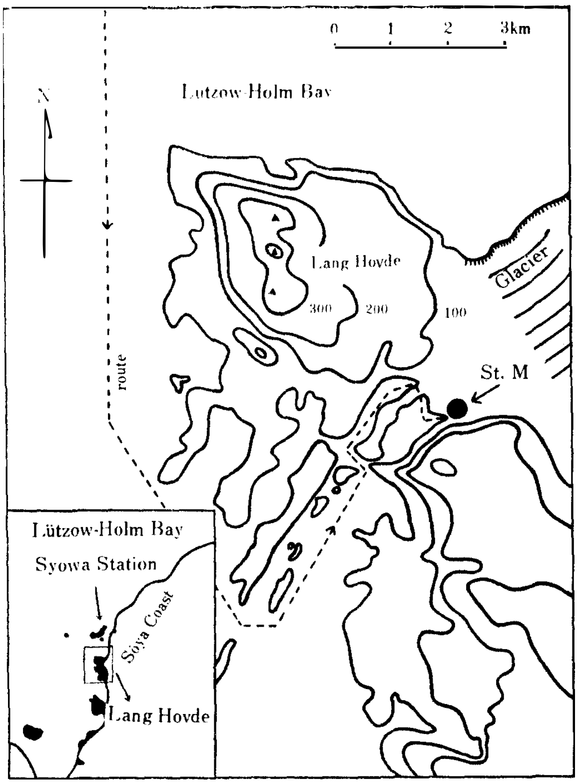


Fig. 15. Map of Lang Hovde. St. M: Koke Daira.

phyte ecology on Signy Island was reported by GIMINGHAM (1967). The investigation of growth and reproduction of *Polytrichum alpestre* on South Georgia was carried out by LONGTON and GREEN (1967). Moss turf, moss carpet and moss hummock subformation in Antarctic cryptogam formation have been reported by LONGTON (1967).

It is to be worthy of note that many researches on the growth of mosses have been carried out except in the Antarctic. HAGERUP (1935) and LACKNER (1939) ascertained about many species of Bryophytes that the growth of leaves had annual periodicity. GIMINGHAM (1948) discussed the role of mosses that was played in fixation of the dune surface, and he showed in the figures the growing process of mosses buried in the sands and the formation of new shoots breaking out. BIRSE, LANDSBERY and GIMINGHAM (1957) discussed the effect of burial in sand, by burying some species of mosses in sand at different depths when new shoots came out.

During May 9–13, 1961, the writer conducted an investigation of mosses and snow petrel (*Pagodroma nives*) in the exposed rock zone of the Lang Hovde area on the Sôya Coast, about 35 kilometers south of East Ongul Island where Syowa Station is located (Fig. 15). Mosses collected at this time were subjected to the study of growth and community formation.

3.1. Method of investigation and materials

The Lang Hovde area is characterized by exposed rocks, with an areal extension about 10 × 15 km. The climate is fairly moderate, so that there are several rookeries of snow petrel and Adélie penguin.

When the investigation of this exposed area was started on May 9, though it was behind the season, many exposured of the ground were observed. The investigated place shown in Fig. 15 is characterized by a large sandy terrain, where mosses were exposed without snowcover.

As shown in Fig. 16, tents were set at Koke Daira in a flat sandy place. The rookery of snow petrels is located on the steep slope with many boulders, to the southeast of the tents (Fig. 17). Nests are found under large boulders.

When the present writer was investigating this area, ten snow petrels returned to their nests at night. They lay eggs and hatch them in summer which can easily be concluded as there were remaining eggs and dead chicks. The lower part of the slope where the rookery is located turns to a large broad sandy flat area leading to the coast. The shore was completely frozen at that time. On the flat sands, a moss community, 30 × 50 m in size, looking like a large carpet was found (Fig. 16). Therefore, the water from melted snow containing the percolated substance of birds' droppings had reached the place where moss community existed, receiving nutrient materials in a certain season.

This moss community was not only by far larger in area than those on East Ongul Island, but also the carpet was compact with a thickness of 5 to 9 cm. A close examination of this community revealed the existence of green, white, and brown parts in the carpet. The surface of the carpet was not flat but

Fig. 16. Moss community at St. M, Lang Hovde, indicated by an arrow.

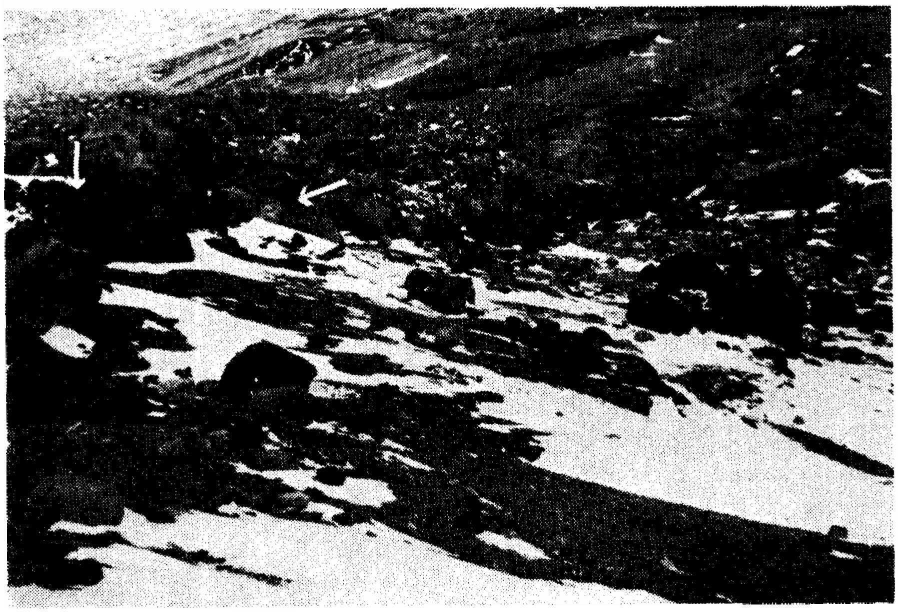


Fig. 17. Nests of snow petrels indicated by arrows.

undulated as if some spherical cups had been turned down. The majority of mosses found here were *Ceratodon purpureus* and *Bryum inconnexum*, followed by *Bryum argenteum*.

Several stems of *Ceratodon purpureus* were collected from greenish part ; the number of its leaves and rhizoids was counted, and its growing status was observed. A lump of *Ceratodon purpureus* was picked out and was cut. Schizophyceae in it was observed and the growing condition of the community was also studied. Schizophyceae sticking to mosses was identified as *Gloeocapsa* (FUKUSHIMA, 1959).

The growth of leaves and rhizoids of *Bryum inconnexum* was also examined, and its growing condition was recorded every year and the process of its cushion subformation was studied.

All the materials used in the above observations were collected on May 12, 1961. The air temperature at this time was about −20°C. Moss community in this area is considered to be exposed and dried well. As it is conjectured that this community grows between January and February like those in East Ongul Island, these specimens are considered to pass the winter frozen and dried after growing in the preceding summer. Therefore, it seems that the period of observation was optimum. As these specimens were studied at Syowa Station during June and July 1961, this investigation can be regarded as an observation made under the natural condition.

3.2. Results and discussion

3.2.1. Growth and cushion subformation of *Ceratodon purpureus*

Three species of mosses do not mix together and each species makes its own cushion. But, in the border line occasionally 2 or 3 species are found mixed together. It is easy to pick out a lump of only *Ceratodon purpureus* and separate one stem from another. Mosses which have stems lacking black *Gloeocapsa* appeared to have green leaves its top portion. There are old foliages containing no chlorophyll in the lower part of several green leaves. A detailed examination of old foliages disclosed that its lower part had no foliages and only stem and rhizoids were remaining.

Several green leaves were found at the top of *Ceratodon purpureus* (Fig. 18). Since it seemed likely that there was a limitation in the number of green

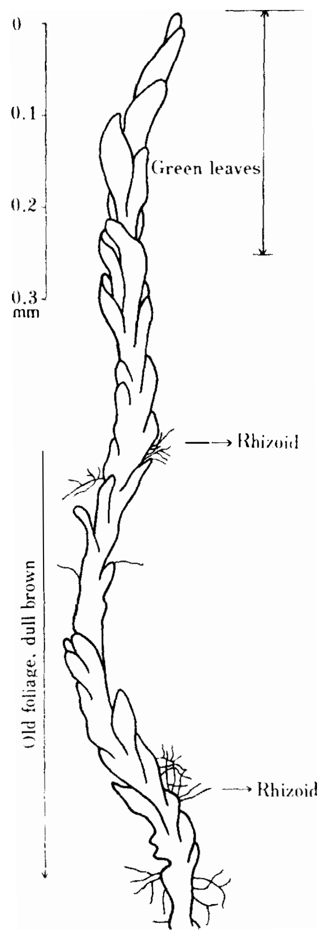


Fig. 18. Ceratodon purpureus.

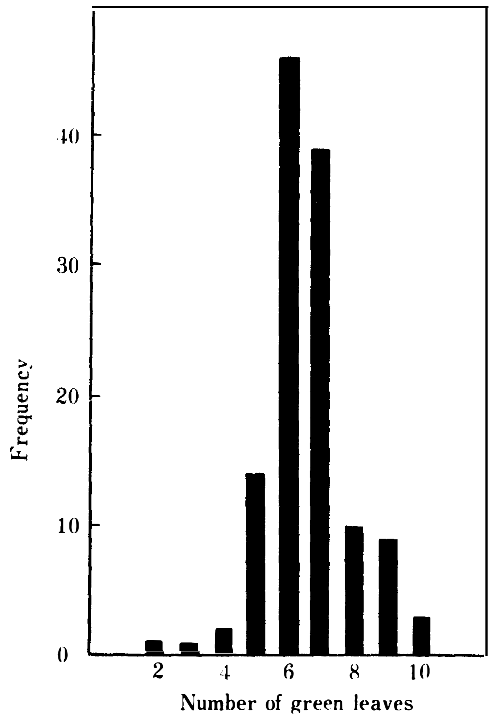


Fig. 19. Frequency distribution of the number of green leaves of Ceratodon purpureus.

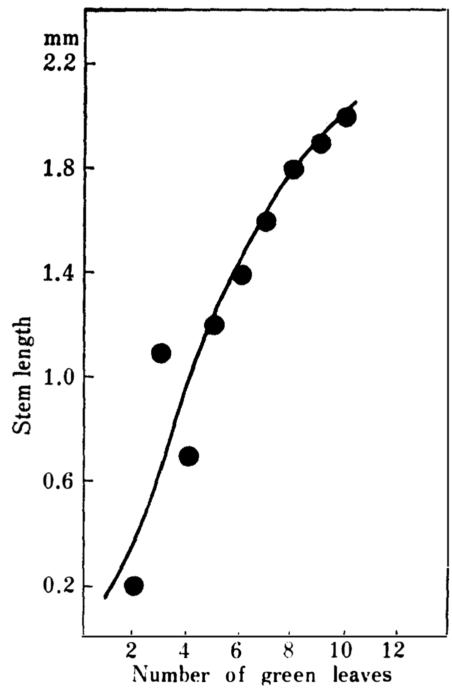


Fig. 20. Relation between the stem length with green leaves and the number of green leaves of Ceratodon purpureus.

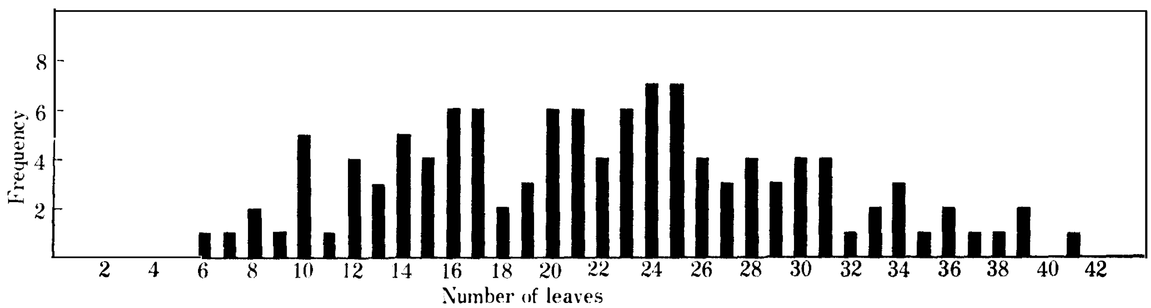


Fig. 21. Frequency distribution of the number of leaves counted from the top to the rhizoidal part on stem.

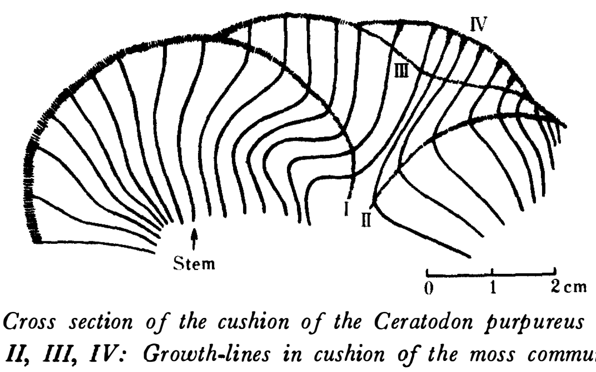


Fig. 22. Cross section of the cushion of the Ceratodon purpureus community. I, II, III, IV: Growth-lines in cushion of the moss community.

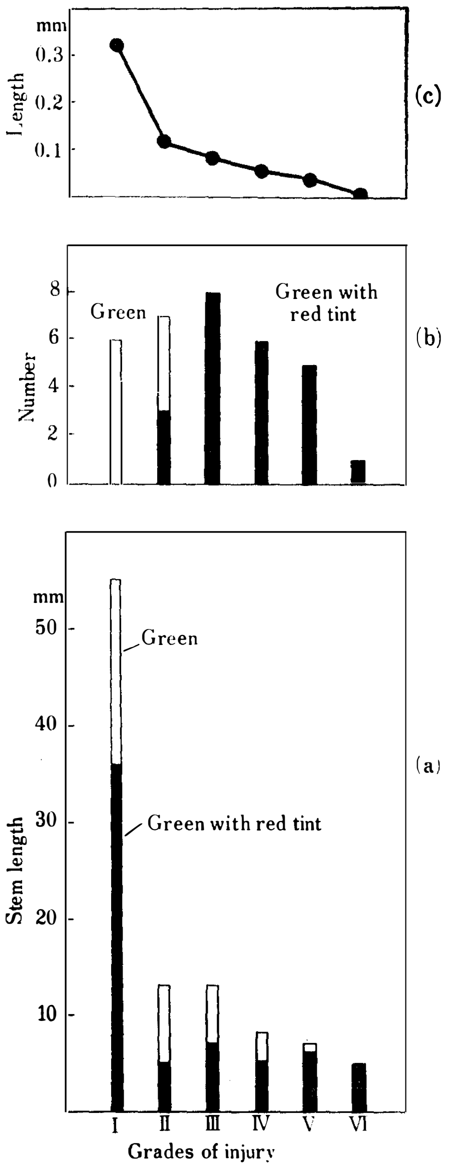


Fig. 23. (*a*) *Relation between the grade of injury caused by blue green algae and the stem length from the top of the rhizoidal part.*
(*b*) *Relation between the grade of injury caused by blue green algae and the number of green leaves.*
(*c*) *Relation between the grade of injury caused by blue green algae and the internode length.*

leaves, their number was counted. The result is shown in Fig. 19. Six to 7 green leaves are common. It seems that the number of green leaves must have a relation with the growth within one year period.

The length of stem having the green leaves was measured. The more the leaves, the longer should be the green portion. Fig. 20 shows the relation between the stem length and the number of green leaves of healthy *Ceratodon purpureus.* It is interesting that the graph shows an "S" curve and not a straight line. If *Gloeocapsa* sticks to it, it will grow in a different way. The lower part of green leaves has old foliages as mentioned above, and thin rhizoids are found between the leaves. The stem has the rhizoids, but it was not proved that all parts of the stem have rhizoids. Fig. 21 shows the results of observation on the location of rhizoids. Some rhizoids were found at the 6th green leaf from the top. On some stems, rhizoid can be found after counting 40 green leaves. Most of stems had rhizoids between the 10th leaf and the 30th leaf and there is no specific spot on the stem where rhizoid grows. Cross section of cushion of *Ceratodon purpureus* does not show a striped pattern in the shape of concentric-circles as seen in *Bryum inconnexum.* But, as shown in Fig. 22, a pattern that looks as if hills had been doubled is seen.

A close examination of the surface of cushion of *Ceratodon purpureus* revealed that the black portion has full of *Gloeocapsa* sp., but the greenish portion has no *Gloeocapsa* and it is thought to be a healthy part. Some changes are noted in the extent of adherence of *Gloeocapsa* in some of *Ceratodon purpureus,* which has healthy stems and leaves on which a lot of *Gloeocapsa* were attached. The extent of adherence *Gloeocapsa* was classified into six categories after visual inspection, ranging from healthy stage denoted by I, to stage VI. The results are shown in Fig. 23 (a), (b) and (c).

Fig. 23(a) shows the length from the top of stem to the rhizoidal part, averaging the measurements of 10 stems. This figure indicates that a short stem is to be interpreted as an injured one. Healthy stems are ten times the length of injured ones. The same can be said to the length of stems having green leaves.

Fig. 23(b) shows the number of green leaves of samples which were classified by the grade of injury. Although it has a greenish part, the stem injuried by *Gloeocapsa* gives a red tint. Healthy stems do not restore the red tint. Seriously injured stems have few green leaves and the leaves around green ones are not in normal shape because of *Gloeocapsa*. TAKAGI (1962) reported on the effect of the blue green algae upon mosses. In the case of *Ceratodon purpureus* in the Antarctic hereby discussed, *Gloeocapsa* completely destroyed the normal stems. It might be considered that those stems could not grow normally, due to the adherence of *Gloeocapsa*. Therefore, the distance between one leaf and another is very short, and where lots of *Gloeocapsa* grow, leaves are growing closely.

Such a cross section shown in Fig. 22 is ascribed to the degree of the adherence of *Gloeocapsa* on stems and leaves. Observation of the growth of *Gloeocapsa* disclosed that there is a certain inclination in the condition from the seriously injured part to the uninjured part. Therefore, the seriously injured part does not grow at all and the uninjured part grows well, resulting in such a hill-shaped pattern shown in the cross section (Fig. 22). The left part of Fig. 22 was seriously injured by *Gloeocapsa*, on line "I" lots of *Gloeocapsa* strongly adhered to the whole stem at a certain time of the year and obstructed the growth of mosses as a whole. But, in the next year the right part of line "I" started growing. With the elapse of time, the left part will start to grow again gradually. On line "II," the right part had stopped to grow and the left part recovered to grow, then the right part started growing gradually. On line "III", a comparatively large amount of *Gloeocapsa* is noted, and the stem did not grow, but soon the middle part regained the function to grow. At the time of the present observation, a newly grown part was seen within line "IV".

Thus, adherence of *Gloeocapsa* to *Ceratodon purpureus* is an important factor to form their cushion.

3.2.2. Growth of *Bryum inconnexum* and its cushion

One of the most widely distributed mosses in Lang Hovde area is *Bryum inconnexum*, as well as *Ceratodon purpureus*. *Bryum inconnexum* is rather large in size. Some of upper parts are extended from cushion of *Ceratodon purpureus* or *Bryum argenteum*, but the cushions formed only by *Bryum inconnexum* are most common. Fig. 24 shows the well-grown stem and leaves of *Bryum inconnexum*.

Leaves growing on a certain stem have two portions; one with green leaves and the other with old foliages. Rhizoids are seen among the leaves, as in the case of *Ceratodon purpureus*. In the case of *Bryum inconnexum*, however, 12 leaves are counted, as shown in Fig. 25, which indicates that this species has more green leaves than *Ceratodon purpureus*.

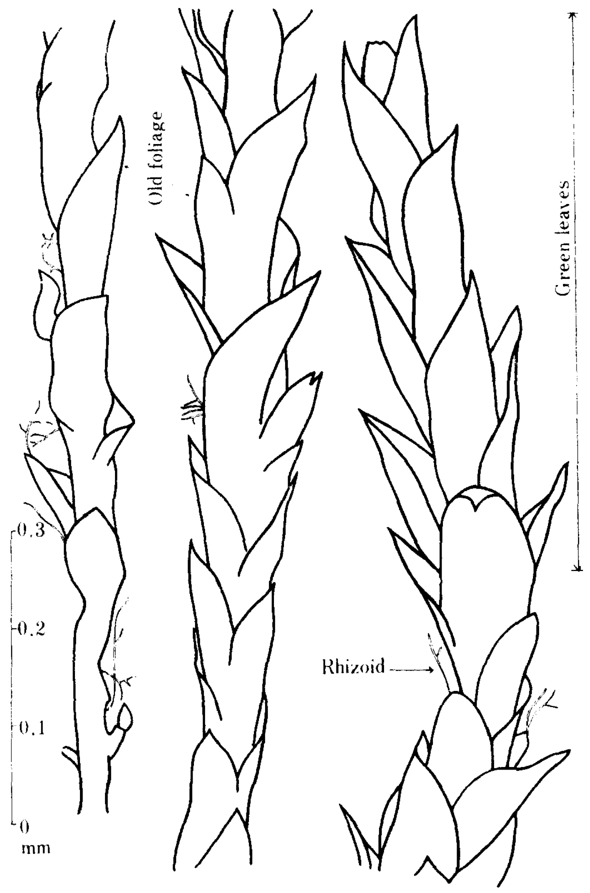


Fig. 24. Bryum inconnexum.

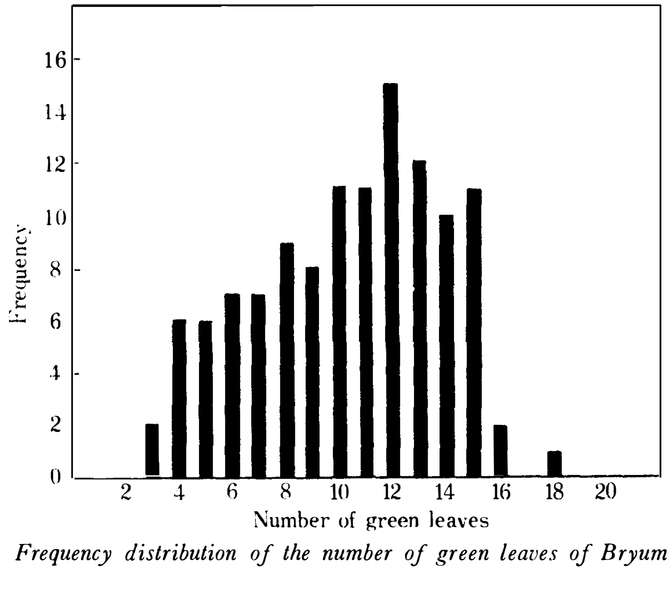


Fig. 25. Frequency distribution of the number of green leaves of Bryum inconnexum.

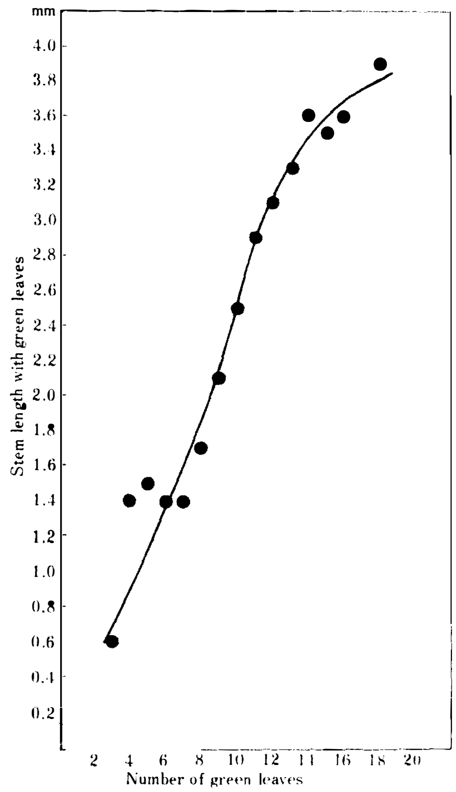


Fig. 26. Relation between the stem length with green leaves and the number of green leaves.

Fig. 26 shows the relation between the number of green leaves on each stem and the length of green leaves. It is easily noted that the longer stem has more green leaves.

Fig. 24 also shows rhizoids at many spots on the stem. In order to find out how close to the top of stem the first rhizoid grows, the number of leaves between the top and the first rhizoid was counted, with the results given in Fig. 27. Rhizoids were seen mostly between the 14th and the 17th leaf, and the position of rhizoid on a stem was the same as the case of *Ceratodon purpureus*. It is worthy of note that rhizoids were again found at the 30th leaf, indicating twice the 15 leaves.

Thus, the position of rhizoid in each moss might give an important effect on the growth of cushion of *Bryum inconnexum*. Fig. 28 shows the cross section of cushion of *Bryum inconnexum* community. Line "I" in the figure denotes the curved growth line due to the adherence of *Gloeocapsa* to *Ceratodon purpureus*, and line " II " marks the next growth surface. But, in the case of *Bryum inconnexum*, different from *Ceratodon purpureus*, several less pronounced striped patterns are observed other than the curved line "II" caused by the existence of *Gloeocapsa*. Those striped patterns were counted from the outside (line "II"), and were numbered as was noted in Fig. 28. Mi-

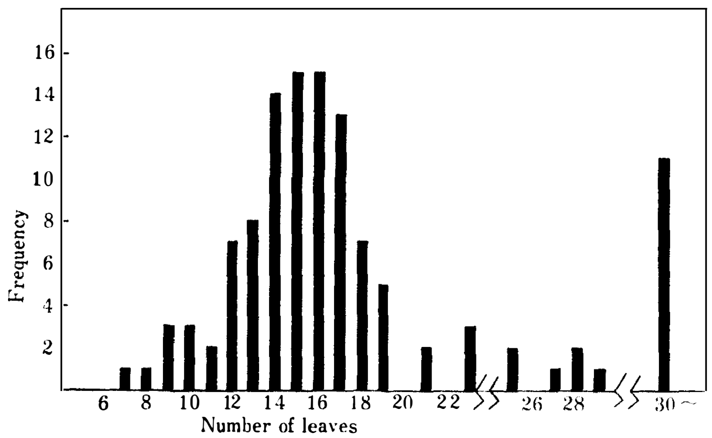


Fig. 27. Frequency distribution of the number of leaves counted from the top to the rhizoidal part on stem.

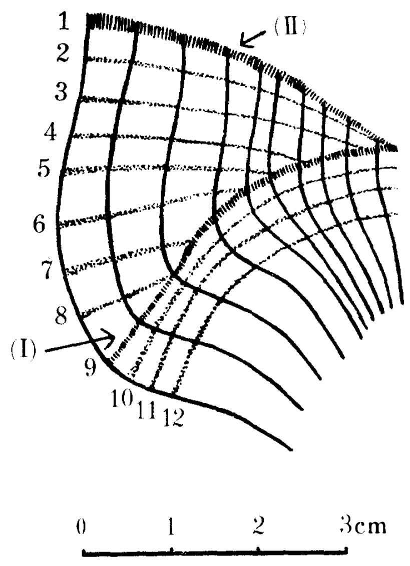


Fig. 28. Cross section of the cushion of the Bryum inconnexum community.
I, II: Growth lines in the cushion of moss.
1, 2, 3, . . . , 12: Rhizoidal belts.

croscopic examination revealed that each stem has many rhizoids forming a fine structure of striped pattern. Those parallel lines are believed to be formed by the rhizoids growing at the same level on neighboring stems, and the rhizoidal part is widened in a belt shape, which is to be called "rhizoidal belt." As this rhizoidal belt keeps the same distance between each, it looks like a striped pattern. As was shown in Fig. 28, it appears that the growth was temporarily retarded because of the adherence of *Gloeocapsa* at line "I," and the left part began to grow and gradually moved to the right. The process of recovery from line "I" to the present state can be traced by examining (counting) annual layers of rhizoidal belt.

3.2.3. Subformation of moss cushion

Appropriate samples for the study of the cushion formation were not obtained on East Ongul Island. However, favourable circumstances for the growth of plants were found in the Lang Hovde area, where the writer investigated cushion subformation of mosses. It seemed that there were several patterns; one was the case of *Ceratodon purpureus*, the growth process of which showed precisely the curved-line pattern caused by the adherence of *Gloeocapsa*, and the other case of *Bryum inconnexum*, the growth process of which was indicated by the curved line caused by parasitism of *Gloeocapsa* and the annual growth was deduced from the existence of the rhizoidal belt. It is thought that these patterns are the same in their substances. Though the rhizoidal belt of *Ceratodon purpureus* is not apparent, the plant seemed to have grown regularly every year. The amount of growth of *Ceratodon purpureus* is not so easily estimated as the rhizoidal belt. In the case of *Bryum inconnexum*, rhizoids were noticed at every 15 leaves, so, it was easy to identify annual layers.

HAGERUP (1935) and LACKNER (1939) stressed that the annual periodicity in the growth of mosses, the number of green leaves of mosses in the Antarctic, cannot be proportional to the grown part in the period less than a year. Probably a year or more than a year was required for the growth of greenish portion. The present writer believes that their conclusion is not so definite, because they did not carry out detailed observations. No sexual reproduction was observed in any cases in the present study, and stems were really observed for a long period in asexual generation system. If one assumed that the distance of each rhizoidal belt corresponds to its annual growth, he can count about 100 belts including remnants of old belts. This might lead to that the root part of the stem should be at least 100 years old.

The subformation of cushion means that each cushion of the thickly growing mosses grows regularly every year. When *Gloeocapsa* comes to live upon the mosses the growth will be disturbed in a certain season. However, a part of cushion withstands the disturbance and continues to grow, then, the recovery of growth takes place in all parts of cushion and the moss cushion begins to grow as before.

The present study will lead to a conclusion that the used sample had once formed a carpet about 100 years ago, blue green algae had restrained the growth of mosses, the mosses had grown continuously when blue green algae had not lived upon them and the mosses attained their present shape.

Observing the colour of mosses growing in a large area, the writer noted a greenish part in it. Some samples of moss cushion (about $20 \times 20\ cm^2$) were collected, and the percentage of the area of greenish part against the whole area was calculated. The thickness of moss cushion was also measured to know

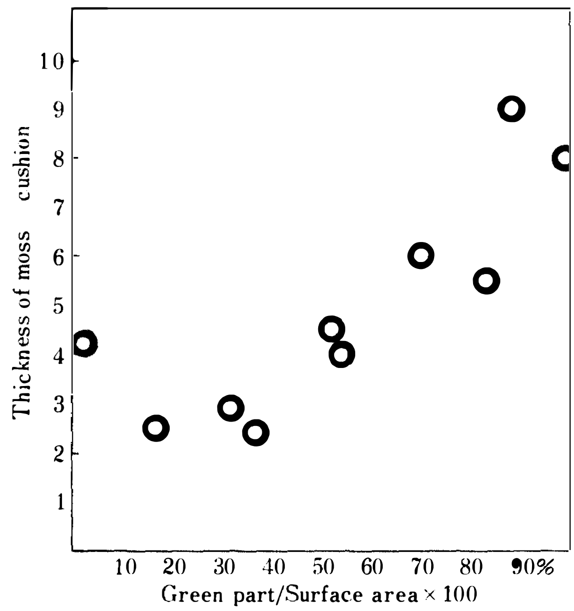


Fig. 29. Relation between the green part of the moss cushion surface and the thickness of the cushion.

the growth process of mosses. Those two quantities are plotted in Fig. 29.

Fig. 29 indicates a fairly established linear relationship between the greenish part and the thickness of the moss cushion. A lot of *Gloeocapsa* was found in the black part of cushion and the mosses were restrained in their growth. The green part contained only a few *Gloeocapsa*, and so mosses had grown without serious hindrance. It seemed that the thick moss cushion was formed after many years in spite of the effect of parasitism of *Gloeocapsa*. The percentage of green part at the present time is in inverse proportion to the parasitic effect of *Gloeocapsa*, but the percentage does not represent the whole parasitic condition of *Gloeocapsa*. In the moss cushion of 9 cm thick *Gloeocapsa* did not harm much the mosses and the mosses grew well. It will be assumed that the parasitic area of *Gloeocapsa* was unevenly distributed. The area of mosses which was examined was $15 \times 30\,m^2$. It was noted that the mosses found in an area close to the slope of mountains were more disturbed by *Gloeocapsa*. A further investigation must be conducted to elucidate the above problem.

With regard to the mutual coactions of three species of mosses, *Ceratodon purpureus*, *Bryum inconnexum* and *Bryum argenteum*, and their succession to form the present shape, more detailed research of this aspect will be required in future.

4. Microclimate in Moss Cushion around Syowa Station

As previously stated, every kind of moss grows and lives together in such an environment suitable for each life in the Antarctic.

In the Arctic and Point Barrow in Alaska, SCHOLANDER (1953) presented some materials in regard to the microclimate. LONGTON and HOLDGATE (1967) discussed the temperature relationship of Antarctic fumarole vegetation, and the temperature in vegetation was reported by HOLDGATE (1964). PRYOR (1962) discussed the environment and ecology of soil arthropods at Hallet Station.

In the Antarctic, it is also necessary to analyze the physical and chemical environment of creatures. As the first step of measuring the environment, the writer observed the temperature of living moss community and the temperature around the area of growth.

For the discussion of the temperature and the duration of the sunshine, the meteorological data at Syowa Station was used. The data was collected by meteorologists, Messrs. SEINO, SAEGUSA, SUZUKI and SAKAGUCHI.

Discussions on temperature regime will be given mainly on three locations; (M_1) temperature on the surface of the moss cushion, (S_1) temperature on the surface of sandy soil, (S_2) soil temperature under the moss community. Temperature in the moss cushion (M_2) was a little lower than that at (M_1) in the summer, but was almost the same during the rest of the year, so only the temperature at (M_1) is discussed here. Because the site (A) had been covered with snow throughout the year except two summer months, this location was not suitable to represent the air temperature. The annual mean temperature of ice (I) was exactly the same as the air temperature at Syowa Station.

In June 1961, the thermistor cable was broken by a strong blizzard with the maximum velocity of 39 m/s. However, the recording was kept except the 24-hour interruption by this incident.

4.1. Method of observation

A living moss community was found at about 500 m southwest of Syowa Station (Fig. 30). This community consisted mainly of *Bryum argenteum* and partly of *Ceratodon purpureus*. As shown in Figs. 31 and 32, the community grows in

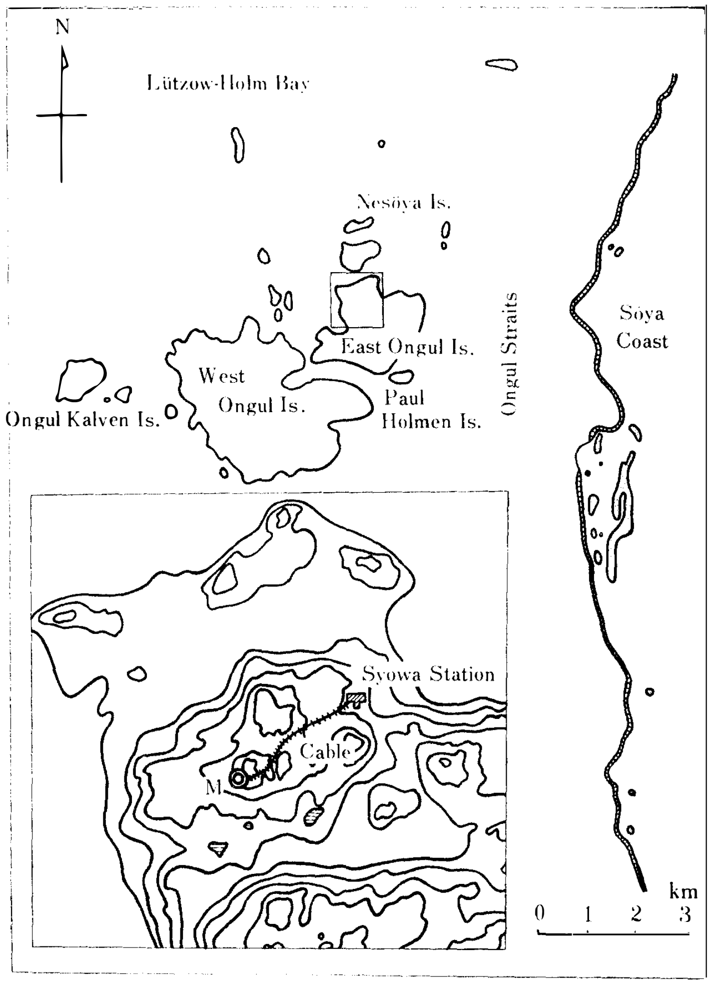


Fig. 30. The Ongul Islands and the location (M) of the microclimatic observations.

the area of 2 to 3 m² on the sand. The surface of the community was uneven flat, and many cushions, 10 to 20 cm in deameter, were seen grow thickly.

A thermistor temperature recorder was installed in the communication hut at Syowa Station and thermistor sensors were placed at the moss community. In order to measure temperature continuously in the moss community and its surroundings, the following 6 places were selected. Records were obtained from February 23, 1961 to January 13, 1962 (Figs. 31, 32 and 33).

(M_1): Temperature on the surface of the moss cushion.
(M_2): Temperature in the moss cushion (about 1 cm below the surface).
(S_1) : Temperature on the surface of sandy soil (about 5 meters apart from the community; snowcover was less there than on the community).
(S_2) : Soil temperature under the moss community (depth 10 cm).
(A) : Air temperature about 3 cm above the cushion.

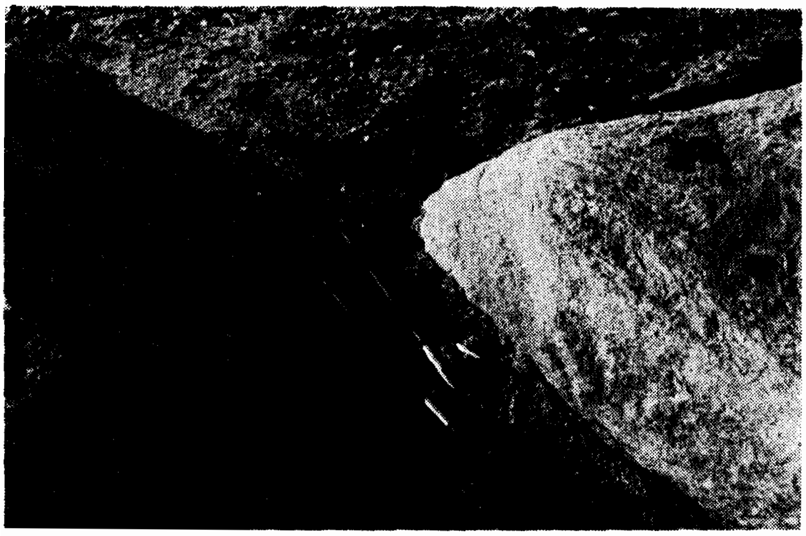


Fig. 31. Moss community and thermistor instrument (February 22, 1961).

Fig. 32. General view of observed area (March 18, 1961).

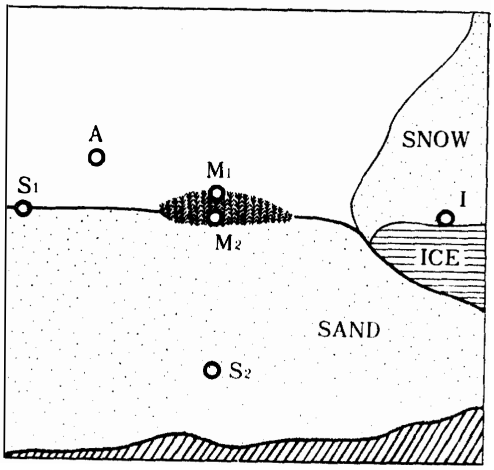


Fig. 33. Schematic cross section of observed area.
A: Position of thermistor measuring air temperature (height: 3 cm).
I: Temperature in the snow drift.
M_1: Temperature on the surface of the moss cushion.
M_2: Temperature in the moss cushion (depth: 1 cm).
S_1: Temperature on the surface of sandy soil.
S_2: Soil temperature under the moss cushion (depth: 10cm).

(I) : Temperature of ice at 80 cm deep, at a distance of 4 m from the community. (The snow drift near the moss community was always frozen, down to a depth about 50 cm even in the summer).

In response to the hours of surface synoptic meteorological observations, readings of recording paper were made four times a day, that is, at 0300, 0900, 1500 and 2100 (Local Time). In this report, the writer will discuss the temperature obtained from this reading. The air temperature and the duration of sunshine measured at Syowa Station during the same period were also quoted. In January and February, the instrument recorded only for 12 days and 5 days respectively, so the temperature and the duration of sunshine in these months were discussed on the basis of data taken at Syowa Station.

The snow covered the observed area in the last part of March and its thickness increased and attained the maximum of 30 cm in October. It is probable that the deposition of snow differs every year. The ground was exposed during January and March. Therefore, this area was covered with snow during the most part of the year.

4.2. Results and discussion

4.2.1. Annual changes in the temperature

Monthly average temperature of the moss community environment are shown in Fig. 34. The temperature (X) and the duration of sunshine (Y) in this figure were calculated from the meteorological data of Syowa Station. MURAKOSHI (1958) reported that the monthly mean temperature in January was below 0°C. But the mean temperature of the moss surface was higher than 0°C in January (Table 3). Especially, the temperature at the surface of sandy soil was higher than that of any other parts. The mean ground temperature at 10 cm depth was below 0°C.

The minimum temperatures were recorded in July and August. Fig. 33 also indicates that the temperatures of moss cushion (M_1) and soil temperatures (S_2) were 2°C to 3°C higher than air temperature or soil surface temperature. It seems that the moss habitat did not get as cold as the outside because the habitat was covered with snow 30 cm thick.

The air temperature of -29°C was measured on May 12, 1961 at a large snow-free moss community in the exposed rock area of Lang Hovde. At this place, in the summer, the sands and moss community soaked the water running down from the mountains, but in winter, mosses were not covered with snow and were in a state dried and frozen to the cold air.

It seems that the mosses on East Ongul Island were not cooled extensively, because most of them are covered with snow. Besides, they will pass the winter, not being dried but frozen, as they have the water in them that they received during the summer

The soil temperatures about 10 cm below the mosses did not show a very remarkable seasonal change, which was different from other places. A great deal of changes in the surface temperature of sandy soil were noted. The thermistor sensor at (S_1) was placed on the sandy surface in the area about 5 meters from the moss community, in an attempt to measure the temperature of exposed area, but snow covered thinly during the period of April to November. The temperature of the area was higher in the summer and lower in the winter than any other places.

The effect of solar radiation should be taken into account when one observes the annual changes in the temperature at Syowa Station. The monthly mean duration of sunshine is also shown in Fig. 34. In June, the sun does not appear at all, but in December the sun never sets. In November, the duration of sunshine is somewhat shorter than in December and a long period of inclement weather takes place. As a whole, a parallel relationship between the duration of sunshine and the above-mentioned mean temperatures is recognized in Fig. 34.

In order to discuss more in detail, the readings of temperatures were listed in Tables 3, 4, 5, 6 and 7, which show not only the average temperatures but

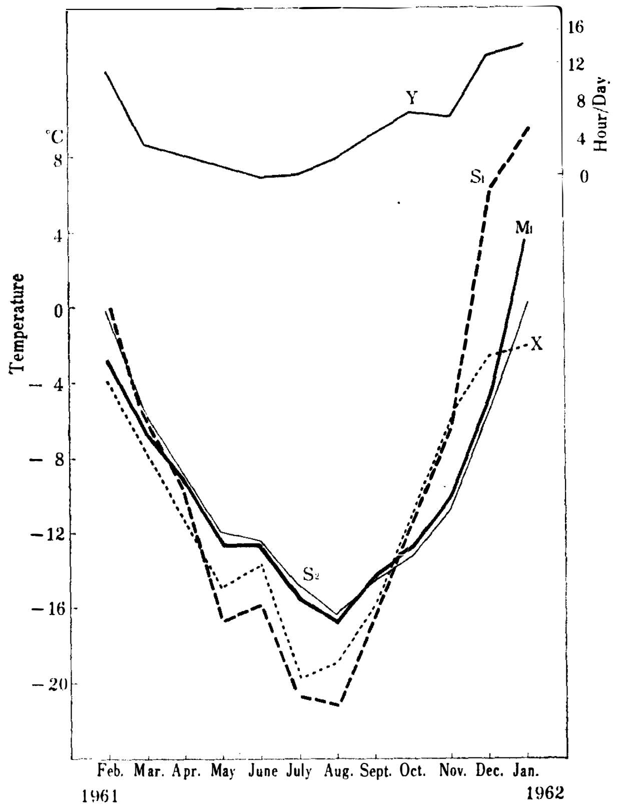


Fig. 34. Seasonal change in the mean temperature in the moss community (M_1), soil surface (S_1), in the soil (S_2), the air (X: at Syowa Station) and the duration of sunshine (Y: at Syowa Station).

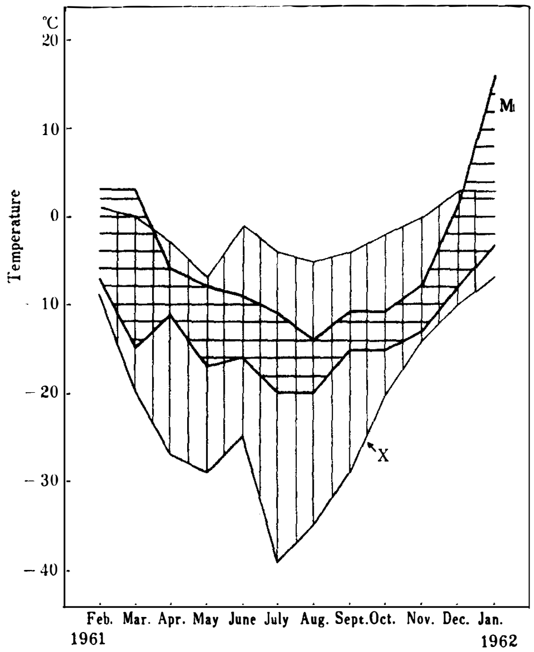


Fig. 35. Seasonal change in the range between the maximum and minimum temperatures in the moss community (M_1) and of air (X).

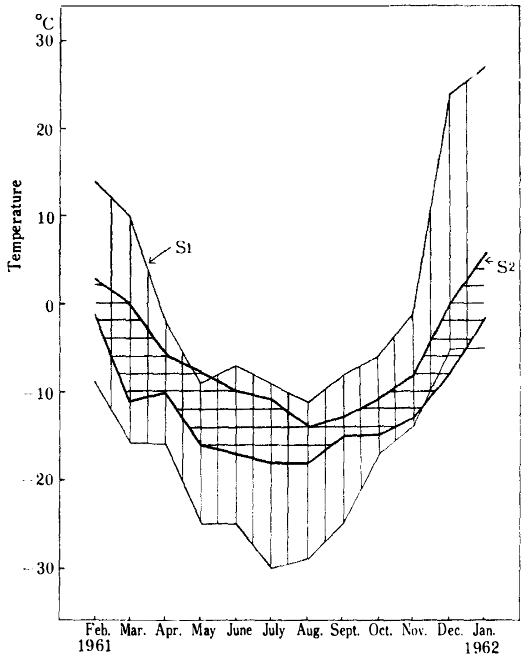


Fig. 36. Seasonal change in the range between the maximum and minimum temperatures at the soil surface (S_1) and in soil (S_2).

also the range of temperature changes.

Table 3 shows the temperaure of moss cushion (M_1). Fig. 35 shows the maximum and minimum temperatures in this cushion. Table 4 shows the temperature of the soil surface (S_1) (refer to Fig. 36), Table 5 shows the temperature in the soil (S_2) 10 cm deep (refer to Fig. 36), Table 6 shows the temperature of snow drift (I), and Table 7 shows the air temperature of Syowa Station (X) (refer to Fig. 35). There was much difference in the maximum and the minimum temperatures of air and the soil surface within the same month, and there was a little change in the temperature of moss cushion and the sandy soil.

In the winter, the air temperature became −40°C but the temperature of moss cushion did not go below −20°C. In the summer, the air temperature was not higher than +3°C, but the temperature of moss cushion was often higher than +16°C and for a short period of time it became as high as +19°C (Fig. 43). In October and November, from spring to summer in the Antarctic, the rise of the air temperature preceded the rise of the temperature of moss cushion, but in other months, the temperatures of moss cushion were higher than the air temperature. It must be noted that the temperature of moss cushion was 1°C higher than the air temperature in the annual mean.

Not only the temperature of moss cushion, but also the water temperature of pond was higher than the air temperature. For example, FUKUSHIMA (1961) reported that the temperature of small pond on East Ongul Island indicated

Table 3. Frequency distribution of the temperatures at M_1 measured four times (every six hours) a day.

M_1 °C	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
16												1
15												1
14												2
13												2
12											1	1
11												
10												2
9												2
8												1
7												1
6												
5												
4												1
3	1	2										4
2	1											3
1	2	2									1	8
0	1	4									6	5
1		2									14	
−2	4	9									3	6
−3	1	3										
−4	3	9									8	2
−5	1	13									8	
−6	3	20									18	
−7	3	9	6								10	
−8	1	5	17								32	
−9		2	27	12						4	23	
−10		14	42	20	7					48		
−11		10	22	4	6					4		
−12		10	6	4	44	1		5	15	56		
−13		3		16	18	6		9	49	1		
−14		3		26	13	22		9	55	7		
−15		2		19	5	22	10	51	4			
−16		1		16	16	31	23	46	1			
−17				5	7	22	41					
−18				2		5	25					
−19						4	16					
−20						10	8					
−21						1	1					

Table 4. Frequency distribution of the temperatures at S_1 measured four times (every six hours) a day.

S_1 °C	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
27												3
26												
25												2
24											1	1
23											1	
22												
21											2	2
20											4	2
19												
18											3	1
17											3	2
16											3	3
15											3	1
14	1										4	2
13											3	2
12	1										4	2
11	1										4	
10		1									1	
9	1										3	
8	1	3									5	2
7											2	
6		1									4	
5											4	2
4	1										3	1
3	1	2									7	1
2	1	2									4	2
1		5								1	13	4
0	1	2								3	9	3
−1		5								5	6	2
−2		6								4	5	1
−3	3	1	1							7	6	2
−4		7	1							13	12	4
−5		12	2							12	4	2
−6	5	22	7							18	1	1
−7	1	10	9						1	10		
−8		2	3		3				6	9		
−9	2	4	29		3			3	13	14		
−10	1	8	15	7	4	1		7	21	15		
−11		8	17	7	8	2		2	22	3		
−12		8	15	15	7	1	3	1	23	3		
−13			7	3	2	2	1	1	13	2		
−14		5	4	10	14	2	1	4	14			
−15		2	6	14	18	6		2	3	1		
−16		4	3	9	10	13	7	10	6			
−17		3	1	2	8	6	11	12	1			
−18				6	6	8	11	12	1			
−19				2	5	3	5	15				
−20				12	3	9	8	19				
−21				8	6	6	10	12				
−22				12	3	16	13	7				
−23				3	5	5	7	3				
−24				8	5	14	11	4				
−25				3	5	5	14	3				
−26				3	1	4	11	3				
−27						9	5					
−28						4	1					
−29						4	3					
−30						3	2					
−11						1						

Table 5. Frequency distribution of the temperatures at S_2 measured four times (every six hours) a day.

S_2	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
°C												
6												2
5												5
4												9
3	1											3
2												1
1												11
0	6	3									5	18
−1	10	3									1	
−2	4	10									18	
−3		6									1	1
−4		23									6	
−5		23									9	
−6		11									8	
−7		5	1								21	
−8		1	24								32	
−9		8	43	24						4	23	
−10		21	42	10						48		
−11		8	10	4	17					4		
−12		1		15	48	3			2	51		
−13				16	14	7			44	6		
−14				34	15	29		21	64	7		
−15				16	8	31	8	66	11			
−16				4	14	34	40	33	3			
−17				1		6	45					
−18						9	24					
−19						5	7					

Table 6. Frequency distribution of the temperatures at the snow drift (I) measured four times (every six hours) a day.

I	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
°C												
0		1										8
−1	2	1										34
−2	5	2										4
−3	1										1	2
−4	5	13									17	2
−5	2	24									5	
−6	4	26	1								22	
−7	2	10	12								24	
−8		2	7								32	
−9		9	47							4	23	
−10		15	28	26						48		
−11		7	20	6	12					4		
−12		6	5	3	17					48		
−13		3		6	25				40	9		
−14		3		12	23	7			64	7		
−15		1		22	12	31	6	19	12			
−16				12	8	44	63	99	8			
−17				7	10	10	55	2				
−18				13	9	13						
−19				13		4						
−20				4		5						
−21						10						

Table 7. Frequency distribution of the air temperatures at Syowa Station (X) measured four times (every six hours) a day.

X	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
°C												
3											1	
2											2	
1	1										6	2
0		1								3	8	5
−1	2	1								2	12	9
−2	2	5			2					4	24	10
−3	3	8			1				1	16	22	9
−4	2	7	5		3				4	15	15	5
−5	5	17	10		2	1		2	4	13	13	3
−6	1	8	10		5	1	1	5	8	14	5	5
−7		19	6		3	2		6	6	8	8	1
−8	4	10	11	4	4			3	6	13	5	1
−9	1	9	8	14	3	1	2	1	11	9	3	
−10		5	10	6	5	5	3	3	12	6		
−11		6	5	14	9	5	3	2	12	7		
−12		9	5	9	11	2	7	6	9	3		
−13		8	8	7	6	4	6	5	10	5		
−14		4	5	7	10	5	10	12	12			
−15		2	4	6	12	9	8	8	9	2		
−16		3	4	7	7	5	9	8	6			
−17		1	5	4	5	6	8	6	1			
−18			8	11	3	11	1	8	9			
−19			1	10	2	12	3	7	2			
−20		1	6	6	5	5	6	9	1			
−21			1	5	6	4	8	7	1			
−22			4	4	3	4	14	8				
−23			1	2	5	3	8	5				
−24				3	6	7	1	1				
−25				2	1	3	6					
−26			1	1	1	6	6	5				
−27			1			4	3	2				
−28			1	1		2	1					
−29						1	4					
−30				1				1				
−31						5	1					
−32						2	1					
−33							2					
−34						3	1					
−35						1						
−36						1	1					
−37						1						
−38						1						
−39						1						
−40						1						

+10°C in the summer. It must be noted that the temperature of biological environment was fairly higher than the air temperature which was lower than +3°C.

It is natural that the change of the temperature in the soil (S_2) was small. But, it is to be remarked that the temperature on the soil surface was +30°C at its maximum (the extreme was +34°C for a short period on January 4, 1962). Such a high temperature might give an important effect upon the growth of bacteria in the tundra of the Antarctic. The temperature of the soil surface during the winter was −30°C, and if the soil surface was not covered with snow, the temperature would become lower.

4.2.2. Diurnal changes in the temperature

The annual changes of temperature are important for biological environment, and another important factor will be the diurnal changes.

The results of observations were illustrated in Fig. 37. They show the typical diurnal changes in clear days in March, May, July, September and November, 1961 and January 1962. On January 10, 1962, the sun did not set, but it was very close to the horizon in the south during the night. Therefore, in the night, the temperature became lower than the daytime. In the daytime, the temperature of the soil surface was +30°C and the temperature of mosses was +15°C, but in the night, the former was −3°C and the latter was 0°C. Similar changes were observed in other places, except for the ice (I).

The daytime changes of temperatures in moss cushion (M_2) had a lag from that of moss surface (M_1). But, during the night, the temperatures were almost the same, being 0°C. The air temperature at this site (A) was rather higher than that of Syowa Station but was in most cases lower than those at (M_1), (M_2) and (S_1).

Temperature in the snowdrift (I) was always 0°C in summer. The changes of the temperature in the soil (10 cm) were not significant in the summer.

In March 1961, the duration of sunshine became shorter and the highest temperature of mosses was 0°C while it was −10°C in the morning. Only the temperature on the soil surface indicated higher than 0°C.

In May, July and September, all the thermistor sensors were buried in the snow and the diurnal changes of the temperature were hardly noted. The temperature of the soil surface (S_1) was low, which might be attributed to the loss of heat through thin snow cover.

The lowest temperatures were recorded in July and August. Even in this period, the temperature of mosses was over −20°C and no diurnal changes were noted. Disappearance of diurnal changes might be explained by the presence of thick snow cover, about 50 cm.

In November, the amount of snow decreased, and the temperature of the soil surface indicated the diurnal change. In fact, all the snow disappeared from the soil surface (S_1) on November 30, and the surface was almost exposed from December to March. January and February were the only months when

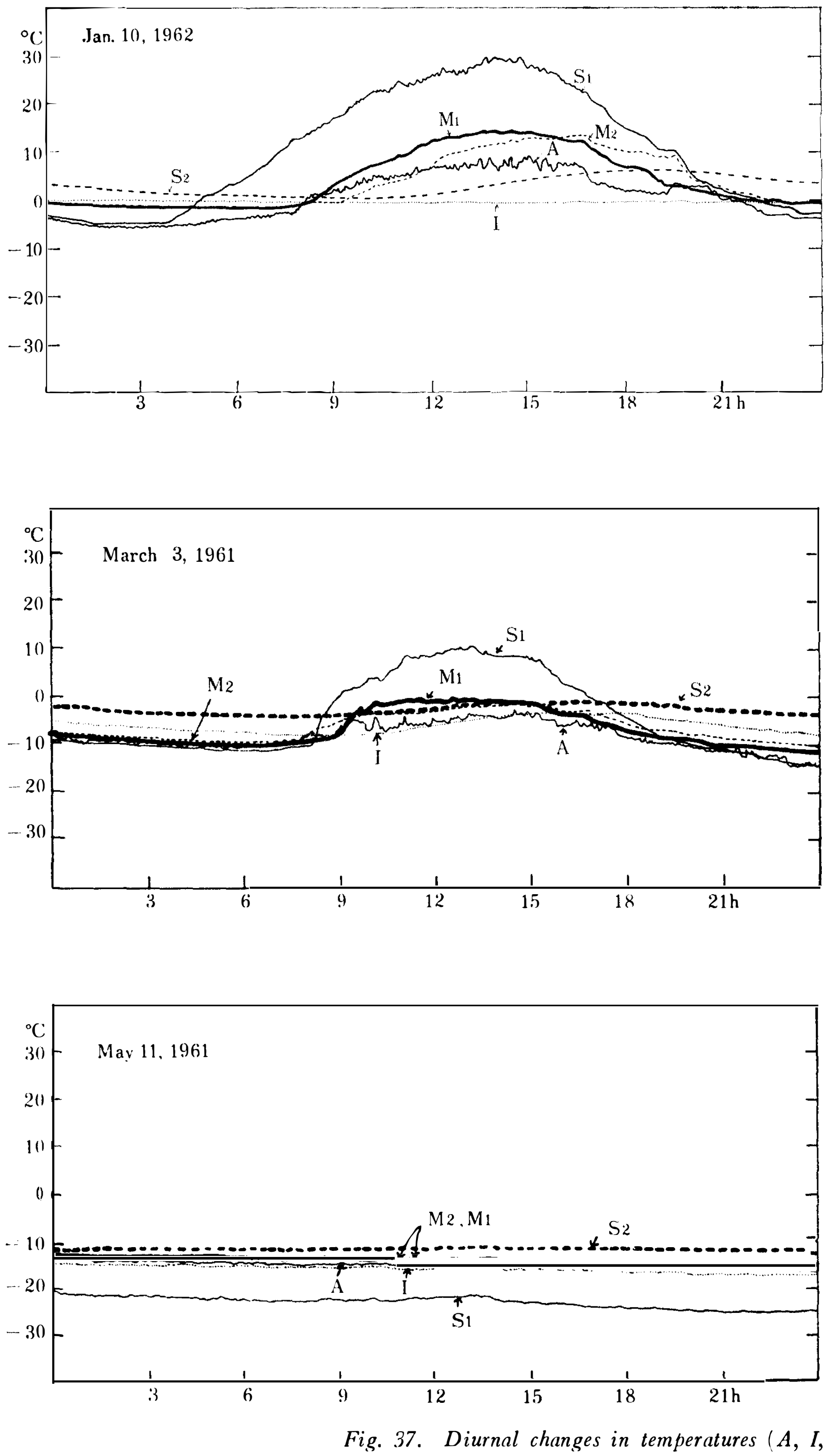
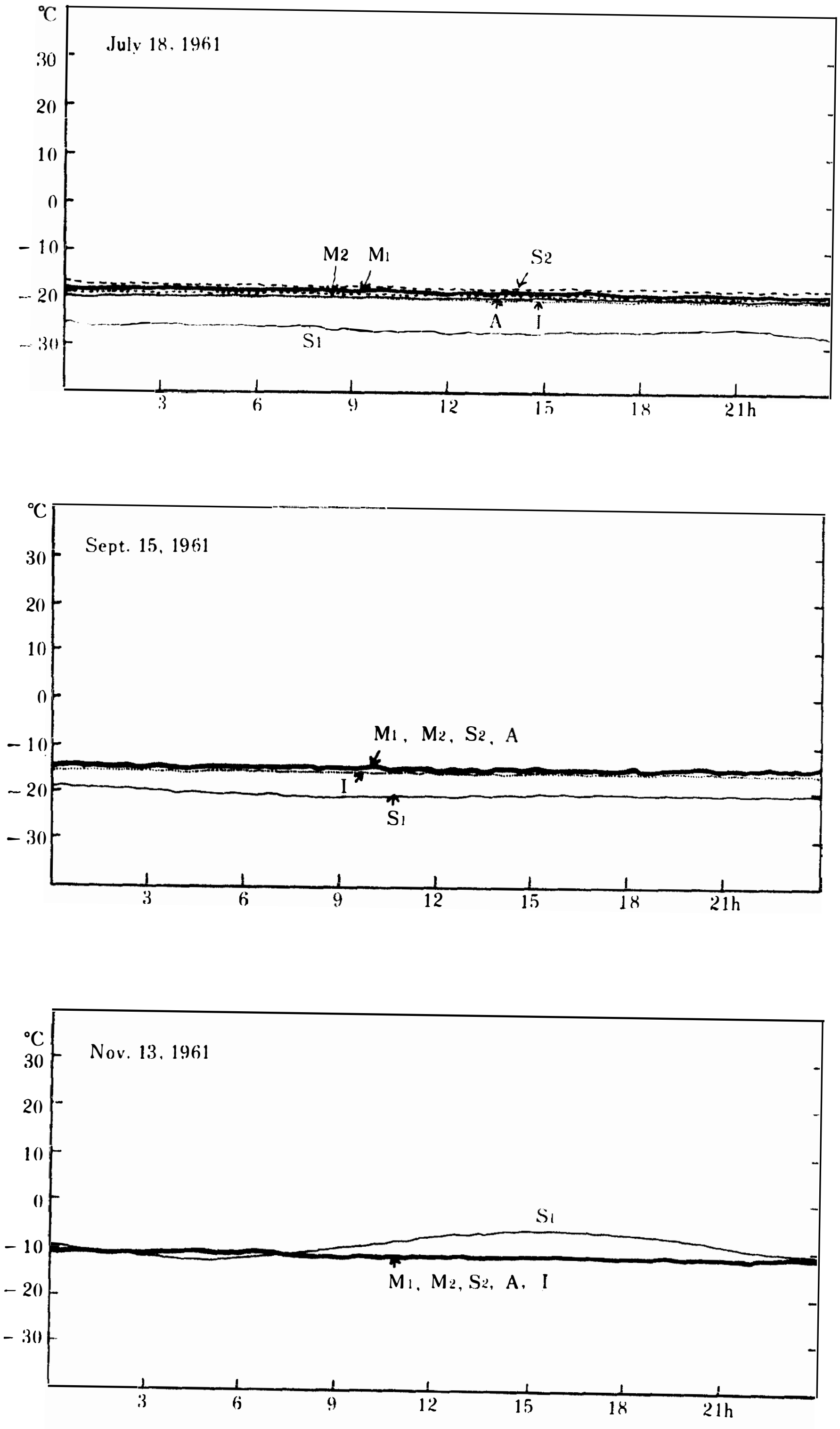


Fig. 37. Diurnal changes in temperatures (A, I, M_1, M_2,



S_1, and S_2). Letterings as in Fig. 4.

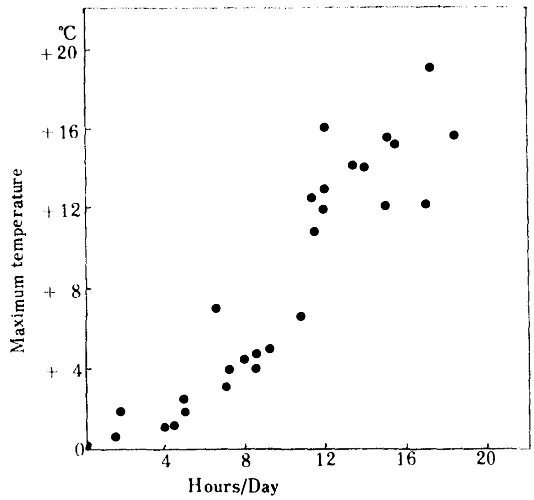


Fig. 38. Relation between the maximum temperature and the period in hours when the temperature was above 0°C within a day.

moss habitats are exposed completely. Diurnal change in the temperature of mosses was observed during 2 months (January and February) in the summer.

The writer examined the days when the temperature of the moss surface was higher than 0°C, and the relation between the maximum temperature and the period in hours during which the temperature was higher than 0°C in a day was shown in Fig. 38. The most important factor for the growth of plants in the Antarctic will be the number of hours in a day with the temperature above 0°C. Also, it is important to know the maximum temperature of mosses in relation to their growth. According to Fig. 38, the period of positive temperatures lasted for about 20 hours in some cases, with the maximum temperature +19°C. Even in such a high temperature, the moss cushion was not dried, because the mosses have been absorbing the water from the snowdrift. The figure also shows that there is a fairly definite linear relationship between the hours in which the temperature was above 0°C and the maximum temperature. This relationship will indicate that a long warm period is necessary for the growth of plants.

The temperature reached its maximum around the noon, and its minimum in the night. Rates of temperature changes from minimum to maximum and maximum to minimum within a day were calculated. They were 1–2°C/hour and seldom 3°C/hour. Aoki (1961) made experiments on the survival of rotifers and reported that a high rate of mortality was obtained when they were subjected to rapid freezing. The rates of cooling in the experiments of Aoki were greater than the above-mentioned natural rate of changes. Therefore, it seems that those diurnal change will not harm the lives of microorganisms living in the moss community.

5. Plant Community Consisting Mainly of Mosses, Microorganism Community in It and Their Lives

5.1. Microorganisms in the standing water (usually called "moss water") in the moss cushion

Table 8. Numbers of microfauna and microflora in moss samples (from Toriumi *and* Katô*, 1961).*

	C. purpureus		*B. argenteum*	
	Material No. 105	Material No. 112	Material No. 108	Material No. 111
Diatom a, *Pinnularia*	392(76%)	819(91%)	655(69%)	318(60%)
Diatom b, *Hantzschia*			86(9%)	
Diatom c, *Navicula*	1	2	7	12(2%)
Nostoc	25(4%)	21(2%)	93(10%)	156(29%)
Synechococcus	12(2%)		1	
Penium	23(4%)			
Nodularia	+			
Oscillatoria	+			
Chroococcus			+	
Unidentified green alga				+
Thecamoeba a, *Euglypha*	1	10(1%)	22(2%)	13(2%)
Thecamoeba b, *Assulina*	21(4%)	44(5%)		7(1%)
Thecamoeba c, *Difflugia*	10(2%)		43(4%)	
Thecamoeba d	20(4%)			19(3%)
Thecamoeba e, *Arcella*	3(1%)		24(3%)	
Amoeba	+	1	4	+ +
Volticella	+			
Nematode	2			1
Rotifer	5(1%)	1	4	4
Tardigrada			1	

The number of the individuals are represented by the means of those on six slide glasses.

TORIUMI and KATÔ (1961) observed the microorganisms living in the standing water (usually called "moss water") of moss community obtained by the present writer on East Ongul Island in February 1960 and brought back to Japan, kept frozen at $-20°C$. Distribution and microclimate of the moss community were already described in Chapters 2 and 4. TORIUMI and KATÔ washed the mosses with the underground water at Tôhoku Universtiy, Sendai City, and found about 20 species under the microscope, Rotifer, Tardigrada, Nematoda, Protozoa, Diatom, blue green algae, etc., as shown in Table 8.

In May 1962, SUDZUKI (1964 a) investigated microorganism community in the moss community samples collected by the present writer in the Lang Hovde area and brought back to Japan in frozen state at $-20°C$. This moss community is composed of the same species described in Chapter 3. He identified 7 classes and 91 species of microorganisms; Rhizopoda (36 species), Ciliata (22), Tardigrada (6), Zoomastigophorea (5), Phytomastigophorea (4), Nematoda (3), Gastrotricha (1) and Actinopodea (1). He also found several new species and varieties in them; 2 species (Rotifer), 1 species (Tardigrada), 3 varieties (Rhizopoda, Rotifer and Tardigrada) (SUDZUKI, 1964 b).

5.2. Distribution of microorganisms in standing water in mosses

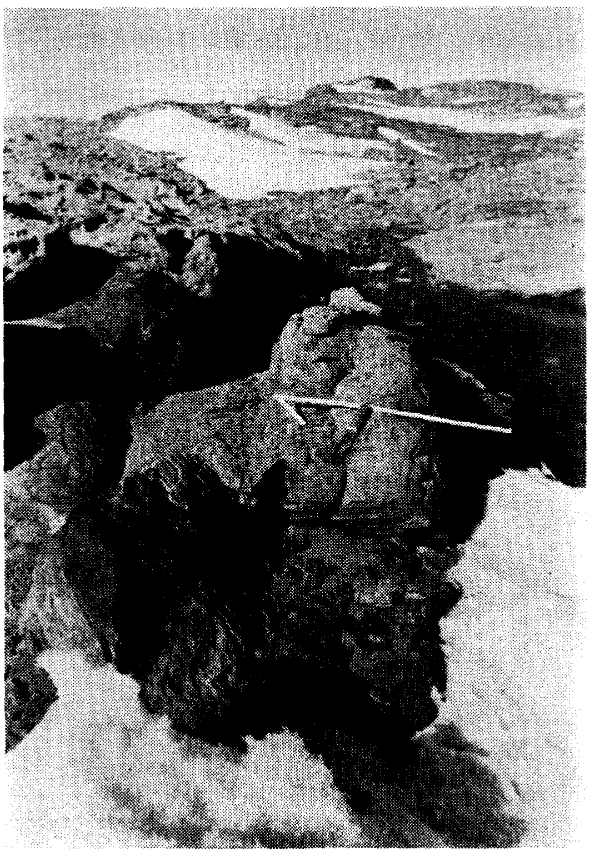


Fig. 39. Moss community at St. 35 (north indicated by arrow).

TORIUMI and KATÔ (1961) also studied the distribution of microorganism community, by dividing mosses into upper part (greenish part) and lower part. The lower part contained less organisms than in the upper part and organisms were seldom or never found in sandy soil samples.

The writer already mentioned in Chapter 3 that the growth of mosses is restrained by blue-green algae and it could be divided into several stages. Dividing the mosses into two parts, that is, healthy and injured ones, the writer compared the living *Pinnularia* sp. with the dead ones, which supplemented the results obtained by TORIUMI and KATÔ (1961).

The mosses kept at −20°C in a refrigerator were brought to +5°C within a day and then gradually melted. The following day, water was added to them and the microorganisms collected in the water were cultured in a glass flatware under the same environmental conditions as at Syowa Station. In order to supply a proper amount of water to the mosses, a filter paper was placed under a lump of mosses. The cultivation was finished in a refrigerator kept at +5°C, and after about 20 days, microscopic examination was carried out. The results of examination of samples taken at St. 35 (Fig. 39) and St. 51 (Figs. 5 and 6) are shown in Table 9. As was mentioned in Chapter 2, the moss communities at these two stations consisted mainly of *Ceratodon purpureus* and *Bryum argenteum*, and a few of *Bryum inconnexum*. It was noticed that living *Pinnularia* sp. is abundant in the healthy mosses than in the injured mosses. Upper part of stems, namely, the stems that are now growing, showed high percentage of living individuals (Fig. 39, Table 9).

Table 9. Ratio of living Pinnularia sp. to the total shell number found in mosses.

	St. 35		St. 51	
	Upper part	Lower part	Upper part	Lower part
In the moss community (healthy)	103/182 (57%)	62/307 (20%)	61/79 (77%)	84/150 (56%)
In the moss community stunted by the blue green algae	12/38 (32%)	6/96 (6%)	8/22 (36%)	30/140 (21%)
Species of the mosses	*C. purpureus* *B. argenteum* *B. inconnexum*		*C. purpureus* *B. argenteum*	

Fig. 40 gives a visual aid to interprete Table 9 and shows the confidence interval of occurrence probability (confidence coefficient 60%). If the confidence intervals of both do not overlap, the difference between these confidence intervals should be recognized within the level of significance of 4% (OGAWARA, 1945). Although the lower part contained a larger number of individual organisms than in the upper part, it is to be said from a statistical viewpoint that the living individuals were more in the upper part. It seems that the existence of many living individuals in the upper part indicates the movement of habitat

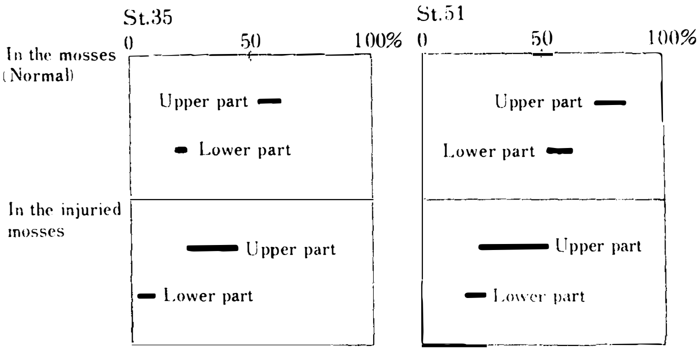


Fig. 40. Survival ratios of Pinnularia sp., which are shown with the confidence intervals of occurrence probability of the living individuals under four categories.

of *Pinnularia* sp. 1 from the lower part to the upper part.

The percentages of living individuals were higher in the normal mosses than in the injured mosses (Table 9). This tendency is to be seen in both upper and lower parts at these two stations.

The microorganisms living in moss community on East Ongul Island (reported by TORIUMI and KATÔ, 1961) were far less than those living in the moss community in Lang Hovde area. The species of microorganisms found at St. 35 and St. 51 are follows; *Pinnularia* sp. 1; *Pinnularia* sp. 2; *Navicula muticopsis*; *Euglypha tuberculata*; *Assulina muscorum*; *Difflugia manicata*; *Wailesella* sp.; *Cyphoderina laevis*; Ciliata sp. 1; Ciliata sp. 2; *Mniobia* sp.; Rotifer sp. 1; Nematoda sp. 1.

Table 10. Number of species of microorganisms found in the moss community (on two slide glasses).

	St. 35		St. 51	
	Upper part	Lower part	Upper part	Lower part
In the mosses (healthy)	5	3	3	3
In the injured mosses	6	5	7	2

Table 10 shows the number of species of microorganisms at Sts. 35 and 51. The upper part of the injured moss community has more Ciliata, Rotifer, etc., and the healthy mosses have a few species. It is considered that micro-distribution of microorganism community is different in each part — withered part, healthy part, and injured part. More extensive samples will be necessary for detailed discussions.

5.3. The life of microorganisms

AOKI and KONNO (1961, 1964) studied the frost-resistance of rotifers living in the mosses which were collected by Dr. FUKUSHIMA and the present writer. They reported that if the freezing temperatures were −20°C, −40°C, and −80°C and the freezing speed was less than 14°C/min, the rotifers were not harmed in the freezing stage, but when the freezing speed was greater, they were apparently harmed. They considered that when the rotifers are freezing rapidly, there will be more chances that the rotifers are mechanically harmed due to heavy supercooling. Therefore, when the rotifers were frozen at −80°C, they are seldom found dead so far as the freezing took place gradually without supercooling (freezing speed 4.2°C/min). It can be said that if freezing begins at a high temperature without supercooling a creature will not be seriously injured. In other words, as long as the freezing is processed gradually, the rotifers will remain in the active forms and be able to endure the freezing.

Under the natural climatic conditions of Syowa Station or its vicinity, the freezing speed of creature, as was described in Chapter 4, is slower than under the afore-mentioned experimental conditions, so that the formation of ice will be slow. Because it can be thought that the minimum temperature is within the endurable temperature-range for the survival of rotifers, there are a few possibilities that the rotifers are harmed by freezing in its vicinity (AOKI and KONNO, 1961, 1964). But, there still remains some unsolved problems; how do those microorganisms live, grow and breed while being frozen and melted in the field?

It is again to be remarked that they keep up living in the summer at +19°C and they are frozen in some stage of life history in winter at −20°C. SCHOLANDER *et al.* (1953) described that gas may be exchanged through ice pertaining to the breathing of animals and plants which are in the frozen condition. The moss community samples brought back from the Antarctic by the writer is presently kept at −20°C for the past 4 to 5 years (in the laboratory). He intends to activate those samples for the further studies.

Further observation and experiment will solve the questions about the mechanisms in the life of microorganisms communities which have lived in several years in their frozen condition.

6. Consideration on the Ecosystem of the Exposed Rock Area in Relation to Sea Birds in the Polar Region

Many research workers discussed the distribution of plants in the tundra area of the Antarctic Continent, which is separated by the sea at a great distance from other continents where various creatures are living in warm climate (Brown, 1964; Laws, 1956; Gressitt and Leach, 1961; Tayler, 1955).

They discussed about the origins of plant and animals currently found. Some assumptions are necessary in discussing whether they moved or were carried into the Antartic Continent from other continents: (1) To be carried by wind, the plants should have been in the shape of seeds or spores when carried. Micro-organisms might have been in the stage of egg or cyst. (2) They might have floated with the ocean current all the way to the Antarctic. (3) They might have been carried by the sea animals like seals or fur seals. (4) They might have been carried by birds either on their bodies or in their stomachs and discharged on the Antarctic Continent.

According to the theory of continental drift, the climatic condition in the past may have been different from the present, so the plants which were prosperous in those days had possibly come in the past ages. But, no satisfactory answers for the distribution of plants have been given up to the present. The present writer collected samples of air-borne organisms at Syowa Station and analysis was made by Dr. M. Shimada who found the spores of Pteridophyta and the pollen of composite plant, which are believed to have come from South Africa. It seems that some species of plants, bacteria and algae might have been carried into the Antarctic Continent by wind. But, it may not be safe to apply the above assumption to all terrestrial vegetation and microorganisms in the Antarctic Continent.

Some creatures are endemic in the Antarctic, but the following questions arise: Are they remaining only in the Antarctic? Or, were they specially differentiated in the Antarctic?

The terrestrial ecosystem in the maritime Antarctic has been reported by Holdgate (1967). Physical and chemical factors, and fauna and flora of the fresh water lakes of Signy Island have been reported by Heywood (1967).

It is a matter of course that these creatures are strictly limited in occurrence, due to such a cold climate of the Antarctic. Whether or not the nourishing elements exist in this cold region is an important problem for the creatures to maintain their lives (FREUCHEN and SALMONSEN, 1959).

The writer hereby will describe the results of the general survey pertaining the existence of the terrestrial plants and microorganisms, in connection with some species of sea birds.

6.1. Relation between the rookery of snow petrel and the moss community

The moss community growing at Koke Daira of the Lang Hovde area was already described in Chapter 3. The flat sandy ground, where moss community was located, extends to the coast and the other side is limited by a cliff 300 meters high (Figs. 16 and 17). On this cliff, nests of snow petrels (Fig. 17) were found and the birds were believed to spend the night in their nests (Figs. 42 and 43).

The present writer observed the activity of snow petrels near the nests from May 9th to 13th (Fig. 41). In the night, they returned to the rookery, entered the nests under a big rock (Fig. 43) and stayed over night, cooing like pigeons all night long. In the morning they flew out from their nests and were flying around the rookery, but disappeared around the noon. The duration of sunshine was nearly 5 hours, and their diurnal activities were in proportion to the changes of duration of sunshine. Also, it was found that they laid eggs and feed their young ones.

Members of the Japanese Expedition have observed that snow petrels flew all the way to the open water or sea for food, and sometimes to such an inland area as the Yamato Mountains (300 km from Syowa Station).

Much droppings were seen at this rookery, as was shown in Figs. 42 and 43. The droppings of snow petrels flow downward with melting snow. It is conjectured that the water flowing down to the flat sands contains nutriments needed for the growth of plants (see Fig. 44).

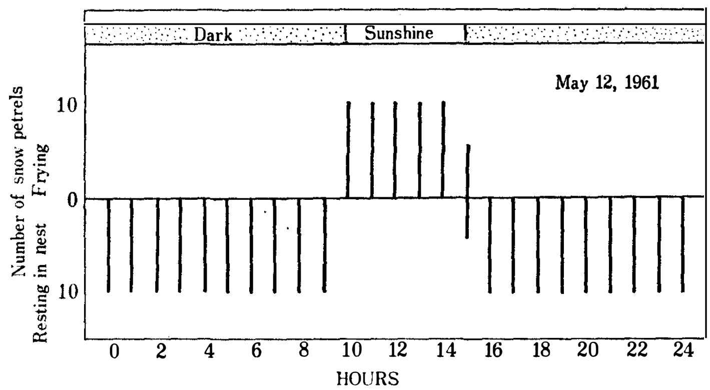


Fig. 41. Diurnal rhythm of activity of snow petrel.

Fig. 42. Nest of snow petrels.

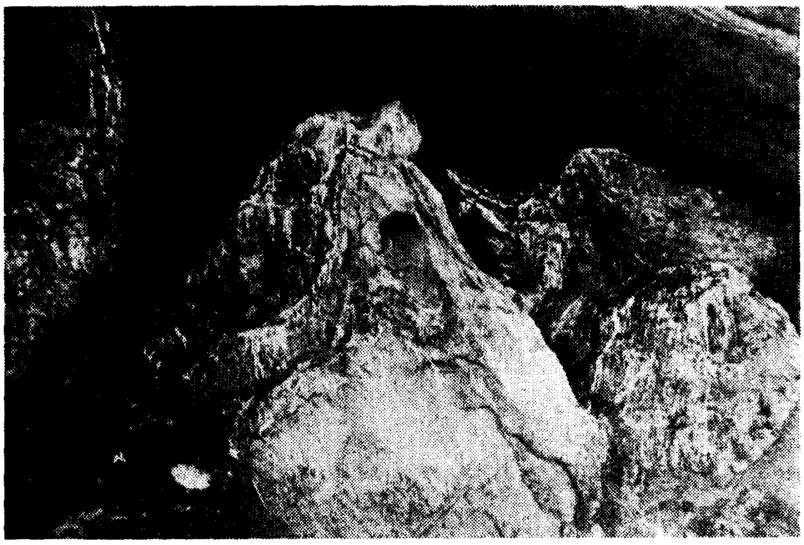


Fig. 43. Detailed of nest of snow petrels.

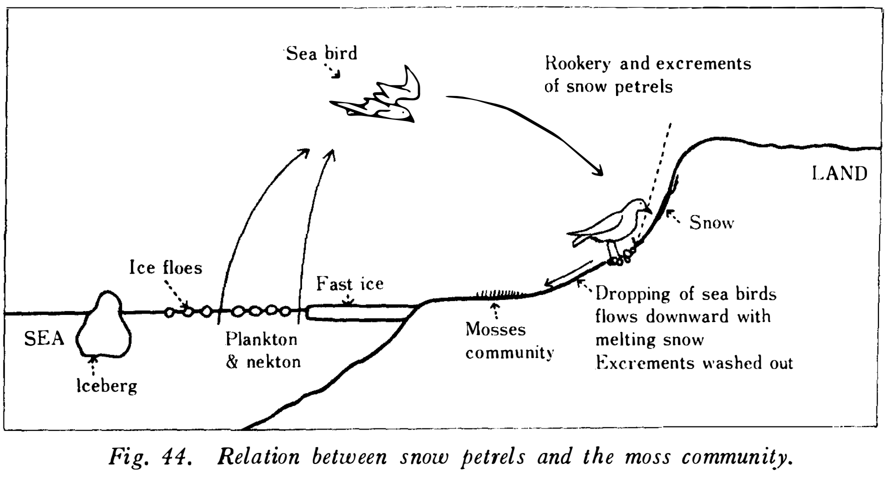


Fig. 44. Relation between snow petrels and the moss community.

As was explained in Chapter 3, the large moss community is growing in this area. SUDZUKI (1964) and HADA (1964) identified many microorganisms from this moss community. Moss community growing on the Antarctic Continent and the microorganism communities form one of the typical ecosystems in the Antarctic.

6.2. Relation between the sea bird and the growth of algae in pond

FUKUSHIMA (1959) reported on algae in many ponds on East Ongul Island. He and the present writer brought frozen samples to Japan. AOKI and KONNO (1961, 1964) conducted an experiment on the frost-resistance of rotifer living in the algae.

Many feathers of McCormick's skua (*Stercorarius s. maccormicki*), Wilson's storm-petrel (*Oceanites oceanicus*) and snow petrel (*Pagodroma nivea*) were found around

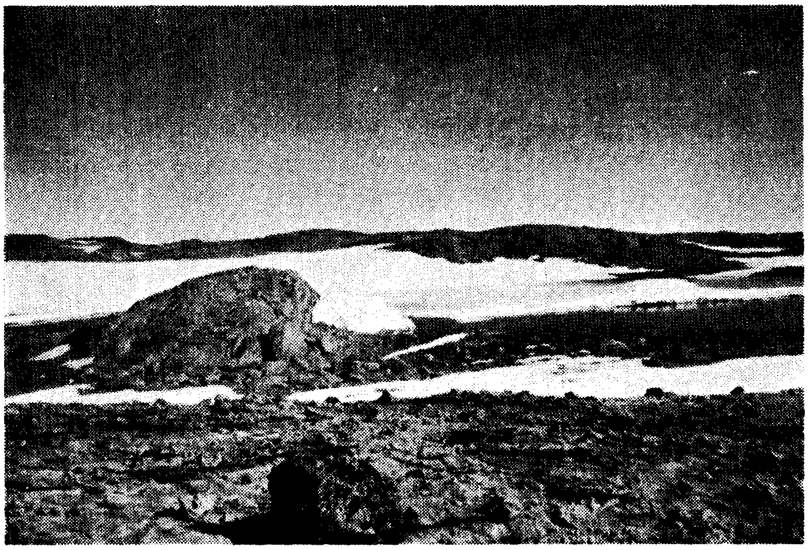


Fig. 45. Small pond "Kamome Ike" on East Ongul Island.

Fig. 46. Fresh water algae in Kamome Ike.

the ponds. Their droppings also were often found around the ponds. SUGAWARA (1961) pointed out that much phosphorus was unexpectedly found in the snow or in the water of the ponds around Syowa Station. Judging from the above, it seems that the droppings were soluble in water.

At the waterside of these ponds, lumps of blue green algae 1cm thick were growing (Figs. 45 and 46). FUKUSHIMA (1959) observed the pond at St. 20, shown in Figs. 45 and 46, and the following plants were identified: *Chroococcus*, *Microcystis*, *Nodularia*, *Nostoc*, *Oscillatoria*, *Phormidium*, *Synechococcus*, *Chramydomonas*, *Hantzschia amphioxys*, *Navicula* sp. 1, *Navicula* sp. 2. Also, in these fresh water algae, such microorganisms as Ciliata sp., Rotatoria, *Lepadella*, Nematoda, etc., were found.

FUKUSHIMA made an examination around McMurdo Station and found blue green algae in fresh droppings of McCormick's skua and the newly grown algae around the droppings. This indicates that McCormick's skua eats algae and distribute them into another area by discharging. The algae and the birds in the Antarctic should be studied jointly.

6.3. Living organisms around Adélie penguin rookery

The writer already reported on the ecology of Adélie penguin at the rookery on Ongul Kalven Island (MATSUDA, 1964 a). There was the Adélie penguin rookery located at the northwest end of Ongul Kalven Island, and in the central part of this island old nests believed to be used by Adélie penguins were found. It was made of gathered stones and it could be used as a nest any time. The bones of chicks and old dropping were found in several places.

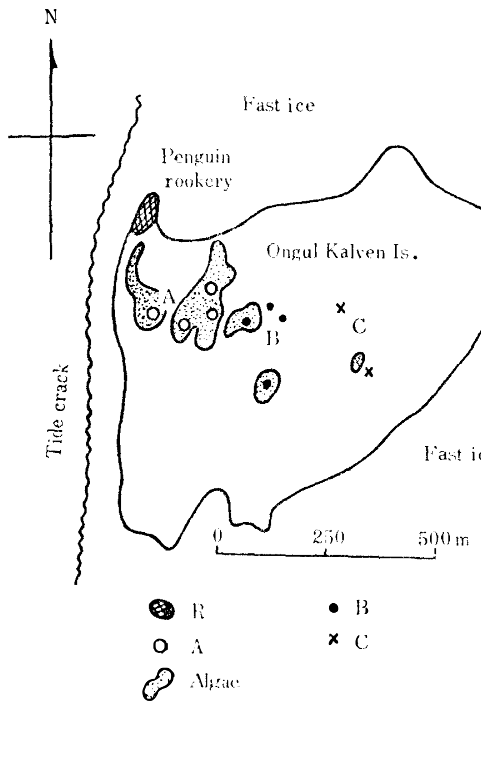


Fig. 47. Relation between the Adélie penguin rookery and algae.
R: Rookery (now inhabited)
A: Old rookery (abandoned)
B: Oldest rookery (abandoned)
C: One or two nests of the penguin (abandoned)

Speaking of old nests, some are found to have been used until recently since fresh bones of chicks were found, while some others are thought to be very old. Fig. 47 shows the results of observation on these nests on Ongul Kalven Island. "R" indicates a new rookery investigated in 1961–62. "A" indicates an old rookery nestled until recently (Where bones of chicks are left). "B" indicates the oldest rookery not nestled now. "C" indicates one or two nests of penguins.

Blue green algae and green algae grew around these rookeries. Table 11 shows the results of observations of plants living around the rookery, microorganisms living in the area and pH of the pool water.

Table 11. Relation between the penguin rookery and the flora and fauna.

Penguin rookery	pH	Flora	Fauna
R	7.6–8.3	*Nostoc* sp. (++) *Prasiola crispa* var. *Antarctica* (+)	Ciliata sp. 2
A	6.3–6.7	*Prasiola crispa* var. *Antarctica* (++) *Nostoc* sp. (+)	Ciliata sp. 1, Ciliata sp. 2 Ciliata sp. 3 (*Opisthotricha* sp. ?) Ciliata sp. 4 Ciliata sp. 5 (*Balantidioides* ?) *Euglypha* sp. *Amoeba proteus*
B	7.0	*Nostoc* sp. (+)	
C	No water		

R: Rookery (now occupied) A: Old rookery (abandoned)
B: Oldest rookery (abandoned) C: One or two nests of the penguin (abandoned)

The melting snow around the presently used rookery (R) is dirty with melted droppings of penguins, and it contains nutriment as was deduced from the values of pH. Accordingly, blue green algae grew well. Ciliata sp. 2 propagated itself so well that it seems to be a dominant species in this area. In the water-pool near "R", only blue green algae were growing, but the water flows slowly, and at a site 50 meters from the pool, *Prasiola crispa* var. *antarctica* was found.

At site "A", the water was very clear and *Prasiola crispa* var. *antarctica* was abundant, and a few blue green algae existed. Five species of Ciliata and other complicated protozoan fauna, such as *Euglypha*, *Amoeba*, etc., were found at this site.

The water around "B" was much clearer, pH being 7.0, and no *Prasiola crispa* var. *antarctica* was seen, but a few blue green algae were seen at a small wet spot. No microfauna was found.

In the vicinity of "C", there was no water-pool, but a few wet spots without plants existed.

Creatures are living in proportion to the extent of remaining nutriments from penguin's droppings. It seems that the succession of fauna and flora in these areas can be investigated depending upon the age of remnants left by penguins and new environments left behind by the penguins. It is clear that penguin's droppings are rearing these microorganisms, and it is a good example for understanding the relationship between the creatures living on the lands and penguins who carried the nutriments from the sea. From another point of view, if one observes the creatures living around rookeries, he may be able to determine the age of rookeries.

7. Conclusion

After examining the moss community and microorganism community at East Ongul Island, West Ongul Island, Ongul Kalven Island and Sôya Coast, the following results were obtained:

(1) Moss community consisting mainly of *Ceratodon purpureus*, *Bryum argenteum* and *Bryum inconnexum* on East Ongul Island is distributed on the west side of the island and developed on the slope facing SW. Because the direction of prevailing wind at East Ongul Island is northeast, the southwest slope that receives more sunlight and snow melt water is a good place for the growth of plant. The development of moss community on the west side of snowdrift was attributed to the afternoon sunshine. The distribution of the above-mentioned 3 species was not exactly identical.

(2) A survey of growing condition of mosses was carried out on the moss community at Lang Hovde. *Ceratodon purpureus* and *Bryum inconnexum* were especially examined. The number of green leaves on the stems was almost the same in these two. *Ceratodon purpureus* has 6 to 7 leaves, and *Bryum inconnexum* about 12 leaves.

The stem has rhizoid. In the case of *Ceratodon purpureus*, the growing place of rhizoid was indefinite, but in the case of *Bryum inconnexum*, rhizoid was seen between the 14th and 17th leaf from top of the stem. In the case of *Bryum inconnexum*, rhizoid grows at a definite place on the stem and the stem grow closely, so the rhizoidal belts are seen on the cross-section of the cushion. So, the growing process of moss community can be traced back into the past.

Gloeocapsa sp. sticks to these mosses and restrains the growth of each individual. But, gradient of it is noted in the growth of sticking *Gloeocapsa* sp. Cross-section of moss cushion showed the annual changes due to the adherence of *Gloeocapsa* sp. Mosses grow closely and the moss community looks like a carpet, but the carpet appears to have an undulating surface and the cross-section of moss cushion shows the curved stripes. These feature indicated the growth of *Gloeocapsa* sp. on mosses.

(3) Microclimate of the moss community growing on the slope of the sandy soil about 500 m southwest of Syowa Station was measured by the use of self-

recording thermistor. The moss community was exposed during the summer, but was buried under the snow during the winter.

The maximum temperature of the moss community was +19°C in summer, but even when the air temperature was −40°C, the temperature of the moss community was not below −20°C, because it was buried under snow. The temperature in the moss community was higher than the temperature of air outside and the environmental condition was much better for the growth of mosses.

The annual mean temperature of the moss community was 1°C higher than the annual mean air temperature. It was found that through the year the temperature of the moss community was not the same as the temperature of air. The growth of plants cannot be discussed only with the temperature of air. The micro-temperature environment in and near the moss community must be measured.

During the winter, the diurnal changes of temperature of the moss community were not recognized, but in the summer many changes were observed. In many cases, the temperature was over 0°C in summer, and in January it kept 0°C occasionally for nearly 20 hours. In the daytime the temperature was higher than +15°C and in the night it decreased to −5°C to −10°C. Water changes into ice according to the change of the temperature. The rate of change in temperature was only about 1°C to 2°C in an hour, so that it did not fatally influence upon the life of creatures.

(4) Ecological observations were conducted mainly of the moss community growing on the land around Syowa Station, and various microorganisms were found in the water contained in the moss communiy and algae living in ponds. They are Rotatoria, Tardigrada, Nematoda, Ciliata, Rhizopodea, Zoomastigophora and Phytomastigophorea, and many cosmopolitan species among them were found in the Antarctic tundra zone.

TORIUMI and KATÔ (1961) and SUDZUKI (1964 a, c, d) found similarity in the microorganisms in the moss community in Japan to that in the Antarctic. TORIUMI and KATÔ (1961) showed that *Bryum argenteum* and *Ceratodon purpureus* are both living in Japan but the habitat is limited on roofs or stone-embankment. They were looking for the mosses living on the sands as in the Antarctic, and discovered *Bryum argenteum* growing on the sands in Hachinohe, and compared the microorganisms living there with the microorganisms in the Antarctic. After investigating them, it was assumed that the living creatures in the moss community were spread throughout the world, regardless of their habitats in the cold region or the warm region.

The mosses in the Antarctic increase asexually and old leaves and stems remain in the lower part for many years, without being withered. The growth of moss community is restrained by *Gloeocapsa* sp., and the changes in the number of microorganisms distributed among the environmental water of the leaves and stems were noticed. More microorganisms were found living on the presently growing parts of mosses than on the old withered part.

(5) The moss community and the algae community were found in the

tundra zone of the Antarctic and the microorganisms were found in the water contained in these communities.

Discussion was made on the relations of the mosses and snow petrel rookery, skua and algae in the ponds, and penguin rookery and algae living around it. It seemed that in some cases the terrestrial plants and microorganisms in the exposed rock zone near Syowa Station coexisted with sea birds and sea-creatures.

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