# VEGETATION OF THE SOUTH SHETLAND ISLANDS

*By* D. C. LINDSAY

ABSTRACT. A general account is presented of the vegetation of the South Shetland Islands which comprises seven sub-formations, six being dominated by cryptogamic plants. The sociations recognized within each sub-formation are described and variation in their composition is related to environmental and habitat conditions. An algal sociation, of *Nostoc*, previously recorded only from continental Antarctica, is also described. The absence of large banks of *Polytrichum alpinum* in comparison with other areas in the maritime Antarctic is noted. The influence of environmental factors on the development of vegetation is discussed and an attempt is made to correlate aspects of plant succession in the coastal areas with factors such as exposure, salt spray and nitrogen supply.

THE South Shetland Islands lie about 770 km. south-east of Cape Horn and about 160 km. north of Trinity Peninsula, the northernmost part of the Antarctic Peninsula. The island group extends for nearly 530 km. in a south-west to north-east direction parallel with the trend of the Antarctic Peninsula. Since the islands lie between lat. 61° to 63°S. and long. 53° to 63°W., they occur within the limits of the Antarctic botanical zone as defined by Greene (1964), and its sub-division, the maritime Antarctic of Holdgate (1964).

During the 1965–66 austral summer, the author, accompanied by a zoologist, was able to join two geomorphologists examining raised beaches and other phenomena throughout the South Shetland Islands, and carry out a primary floristic survey of as much as possible of the island group. The itinerary followed is given in Table I. Transport between the various localities was provided by R.R.S. *Shackleton*, R.R.S. *John Biscoe* and the helicopter flight of H.M.S. *Protector*.

Detailed ecological studies were only possible on Byers Peninsula, Livingston Island, where the field party camped for 6 weeks. Most of the 34 other localities visited were examined for only a few hours at most, and, as they were usually chosen primarily for their geomorphological interest, often provided ice-free areas of limited extent. However, brief notes were made on the type and distribution of vegetation, and collections were obtained of the dominant and commonest plants at each locality. A special search was made in all localities for *Colobanthus quitensis* and *Deschampsia antarctica*.

Nomenclature of cryptogams follows that in the recent monographs of Lamb (1948, 1964, 1968), Llano (1950), and Greene and others (1970). The collection of plants, consisting of 534 lichens, 305 bryophytes, 23 flowering plants and 12 terrestrial and marine algae has been deposited in the British Antarctic Survey herbarium, at present housed in the Department of Botany, University of Birmingham.

## TOPOGRAPHY, GEOLOGY AND CLIMATE

The island group consists of about ten large islands with numerous offshore islets and rocks. Elephant and Clarence Islands lie about 130 km. north-east of the main group, the largest of which are Snow, Deception, Livingston, Greenwich, Robert, Nelson and King George Islands. Smith Island is the southernmost member of the group, lying about 53 km. south-west of Snow Island. The localities visited are all in the main group of islands, and are shown in Fig. 1. Place-names not shown in this figure will be found on the 1 : 200,000 maps (Directorate of Overseas Surveys, D.O.S. 610 (Series D.501), sheets W 62 56, W 62 58 and W 62 60, edition 1, 1968).

The two largest islands visited during the survey were King George and Livingston Islands. Both are about 65 km. long and vary between 5 and 40 km. in width, being elongated in a south-west to north-east direction. They both have deeply indented and embayed coastlines, usually of ice cliffs (Fig. 2) or rocky headlands. Livingston Island is very mountainous towards its eastern end, its highest peak (Mount Friesland) being over 1,760 m. King George Island is much less mountainous, reaching a height just over 610 m. The largest summer ice-free area in the South Shetland Islands is Byers Peninsula (Fig. 3), which forms the western tip of Livingston Island. This peninsula measures about 14·5 by 5 km. and, apart from a few small glaciers near its north-western tip, it has no permanent ice cover. However, during summer,

TABLE I. LOCALITIES VISITED DURING THE BOTANICAL SURVEY OF THE SOUTH SHETLAND ISLANDS

| *Locality* | *Date* | *Time in field* |
|---|---|---|
| *Livingston Island* | 1965–66 | |
| Byers Peninsula | 28 November–2 January | 25 days |
| Johnsons Dock | 28 November | 1 hr. |
| Barnard Point | 24–28 November | 3 days |
| Williams Point | 8 January | 3 hr. |
| *Islands in McFarlane Strait* | 1966 | |
| Cave Island | 8 January | ½ hr. |
| Half Moon Island | 4–5 January | 6 hr. |
| *Greenwich Island* | | |
| Duff Point | 4 January | 2½ hr. |
| Yankee Harbour | | |
| Triangle Point | 3 January | ½ hr. |
| Spit Point | 3 January | 3 hr. |
| Discovery Bay | | |
| Spark Point | 6 January | 5 hr. |
| Ash Point | 16 January | 1 hr. |
| *Islands in English Strait* | | |
| Dee Island | 16 January | ½ hr. |
| Cecilia Island | 8 January | 2 hr. |
| *Robert Island* | | |
| Mitchell Cove | 16 January | 3 hr. |
| Edwards Point | 5 January | 2 hr. |
| *Heywood Island* | 6 January | 1½ hr. |
| *Nelson Island* | | |
| Harmony Cove | 8–13 January | 5 days |
| Strachan Hill | 31 January | 1 hr. |
| Rip Point | 29 January | 3 hr. |
| *King George Island* | | |
| North Spit and environs | 26 January | 3 hr. |
| Barton Peninsula | 14–15 January<br>17–26 January | 9 days |
| Three Brothers Hill and environs | 31 January–1 February | 8 hr. |
| Stranger Point | 29 January | 2 hr. |
| Admiralty Bay | | |
| Sphinx Hill | 29 January | 2 hr. |
| Point Thomas | 14 January | 5 hr. |
| Crépin Point | 29 January | 1½ hr. |
| Keller Peninsula | 28 January | 6 hr |
| Ullmann Spur | 28 January | 1 hr. |
| Point Hennequin | 29 January | 2 hr. |
| Lions Rump | 26 January | 3 hr. |
| Turret Point | 27 January | 3 hr. |
| Penguin Island | 27 January | 3 hr. |
| North Foreland | 7 January | 3 hr. |
| False Round Point | 7 January | 3 hr. |
| Tartar Island–Round Point | 7 January | 3 hr. |

large snow banks may remain in the valleys and in depressions between raised beach crests.

The other islands of the main group are much less mountainous than Livingston Island, and only Greenwich Island has peaks over 610 m. Nelson, Robert and Greenwich Islands have large ice caps extending to the sea, terminating as ice cliffs, and they can best be described as domes of ice with occasional rock outcrops. Such exposures are usually coastal and rarely of any extent. The largest such area is found at Harmony Point (Nelson Island) and is 3·2 by 1·6 km. Dee, Tartar, Heywood, Cecilia, Penguin and Half Moon Islands are all less than

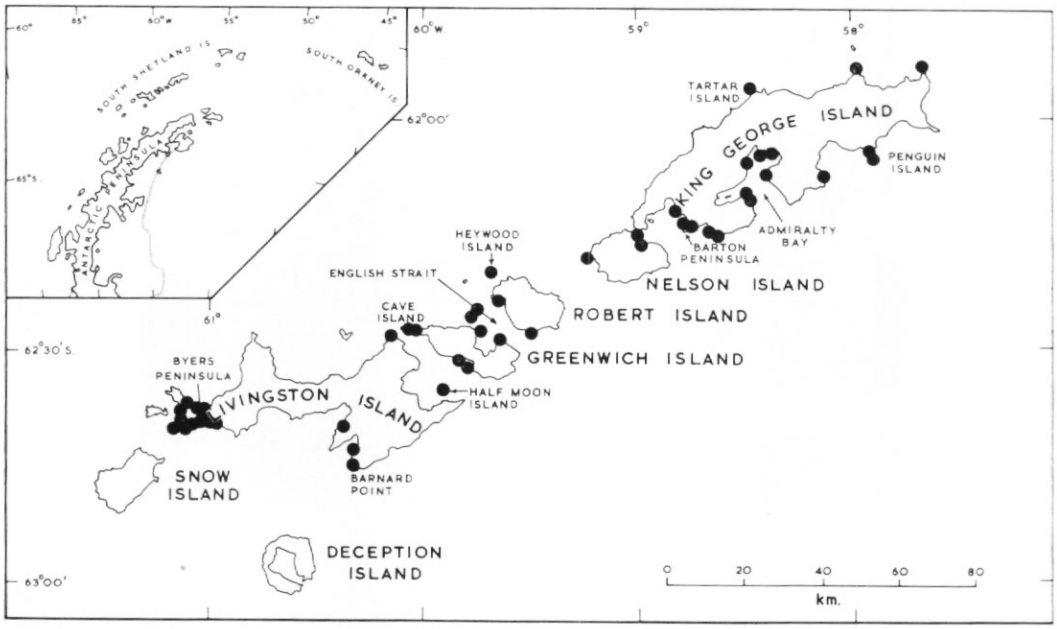



Fig. 1. A map showing the localities visited in the South Shetland Islands during 1965–66.

1·6 km. in length or breadth, and Cave Island is less than 460 m. in diameter. None of these smaller islands support an ice cap or rise above 170 m., though deep and possibly permanent snow banks occur on Half Moon Island. Most of the localities visited on Greenwich, Robert and Nelson Islands are rocky headlands less than 0·8 km. in width or breadth. Harmony Cove (Nelson Island), Mitchell Cove (Robert Island) and Keller Peninsula (King George Island) are all about 2·4 by 1·6 km. in extent, affording some comparison with Byers Peninsula (Livingston Island).

Fig. 2. Part of the mountainous eastern end of Livingston Island, viewed from Hurd Peninsula. (Photograph by G. J. Hobbs.)

Fig. 3. South Beaches, Byers Peninsula, Livingston Island. (Photograph by G. J. Hobbs.)

All the coastal areas examined show various geomorphological features, principally raised beaches (Fig. 4) and raised marine platforms (Fig. 5). Morainic debris may cover large areas, notably around Three Brothers Hill and Lions Rump (King George Island).

*Geology*

Most of the geological work has been centred on the main group of islands, principally King George Island (Barton, 1965), Livingston Island (Hobbs, 1968) and Deception Island (Hawkes, 1961). Notes on the stratigraphy and structural geology of the other islands in the group have been given by Ferguson (1921) and Tyrrell (1945). The rocks are mainly volcanic with subsidiary metamorphic and intrusive rock types, but there are a few occurrences of sediments as on Livingston Island. Basalts are the commonest rock in the western half of the

Fig. 4. Raised beaches at Barnard Point, Livingston Island. (Photograph by G. J. Hobbs.)

Fig. 5. Raised marine platform; Fildes Peninsula, King George Island. (Photograph by C. M. Barton.)

main group, i.e. on Livingston, Greenwich and Robert Islands, frequently occurring as flows and plugs, whereas in the eastern half of this group, i.e. on Nelson and King George Islands, andesitic rocks form most of the exposures. A summary of the whole group has been published by Adie (1964).

*Climate*

The main parameters of temperature, amount of cloud, sunshine and wind are given in Table II. Complete data for the two British stations, one at Whalers Bay (Deception Island) and the other at Admiralty Bay (King George Island) have been given by Pepper (1954) for the years 1944–50, by the *Falkland Islands Dependencies Annual Meteorological Tables* for the years 1951–59 and by the *British Antarctic Annual Meteorological Tables* for 1960 and 1961.

The South Shetland Islands are typical of the maritime Antarctic as defined by Holdgate (1964). Thus in summer there is at least 1 month when the mean air temperature is above 0° C though, in some years, the mean for the 4 month period from December to March may exceed this figure. Precipitation is high, mostly falling as snow and therefore liable to drifting, but most estimates are about 400 mm. annually. The cloud cover is high, being greater in summer than winter (Longton, 1967) and rain has been recorded in all months at both British stations.

## Previous Botanical Work

The first record of vegetation was that of Miers (1950), who had reported the appearance of trees in the South Shetland Islands in 1820. However, as pointed out in the notes which accompanied the re-publication of his paper, no trees are known from any of the islands. The earliest collections, apart from the single lichen described by Torrey (1823), appear to be a few specimens of lichens, bryophytes, marine algae and grass collected by Eights in 1829–30 (Eights, 1833; Llano, 1950; Lamb, 1964), but no serious botanical work was undertaken in this region until Skottsberg visited Harmony Cove (Nelson Island) and the east coast of Livingston Island with the Swedish South Polar Expedition, 1901–03 (Skottsberg, 1912). A detailed taxonomic account of his collection was published by Cardot (1908) on mosses, Darbishire (1912) on lichens, and Stephani (1905) on hepatics. Since that time various expeditions have made general collections of plants, details of some of which have been published by Darbishire (1923), Lamb (1948, 1964, 1968) and Dodge (1965, 1966), but no account of the vegetation of the group as a whole has yet been provided. Some aspects of lichen ecology in the South

TABLE II. METEOROLOGICAL DATA FOR THE SOUTH SHETLAND ISLANDS

| | *Whalers Bay, Deception Island* (mean annual values from 1944 to 1961 inclusive) | | | *Admiralty Bay, King George Island* (mean annual values from 1948 to 1960 inclusive) | | |
|---|---|---|---|---|---|---|
| Cloud amount (oktas) | 6·7 | | | 6·5 | | |
| Sunshine (hr./day) | 1·5 | | | 1·9 | | |
| Wind speed (m./sec.) | 7·5 | | | 6·4 | | |
| *Temperature* (°C) | *Mean daily* | *Mean daily maximum* | *Mean daily minimum* | *Mean daily* | *Mean daily maximum* | *Mean daily minimum* |
| January | 1·4 | 1·7 | −0·4 | 1·3 | 3·3 | −0·4 |
| February | 1·2 | 3·4 | −0·8 | 1·3 | 3·5 | −0·3 |
| March | 0·0 | 2·1 | −2·0 | 0·2 | 2·4 | −1·9 |
| April | −2·2 | −0·1 | −4·3 | −2·1 | 0·9 | −4·2 |
| May | −4·7 | −2·3 | −7·2 | −4·8 | −1·7 | −7·7 |
| June | −6·8 | −3·8 | −9·8 | −6·3 | −3·2 | −9·7 |
| July | −8·2 | −4·6 | −11·5 | −8·0 | −4·2 | −11·4 |
| August | −7·8 | −4·0 | −10·6 | −6·9 | −3·5 | −10·2 |
| September | −4·9 | −2·0 | −8·0 | −4·2 | −1·0 | −7·1 |
| October | −2·6 | −0·5 | −5·1 | −2·2 | 0·1 | −4·8 |
| November | −1·2 | 0·7 | −3·6 | −0·7 | 1·6 | −2·5 |
| December | 0·4 | 2·3 | −1·4 | 0·5 | 2·3 | −1·2 |
| *Mean annual* | −2·8 | −0·5 | −5·4 | −2·7 | 0·0 | −5·1 |

Shetland Islands and at localities along the west coast of the Antarctic Peninsula have been published by Follmann (1965), while Longton (1966, 1967) has given an account of the vegetation of Deception Island. More recent information on the plant communities on Deception Island has been provided by Collins (1969).

## THE PLANT ASSOCIATIONS

### *Classification*

The classification of the vegetation types seen in the South Shetland Islands is given in Table III. The sub-formations recognized, while similar to those described by Longton (1967), approach more closely those of Gimingham and Smith (1970); for example, a crustose lichen sub-formation, which is the dominant vegetation over large areas of exposed rock, especially near sea-level, is recognized. However, the encrusted moss sub-formation described by Longton as typical of volcanic ash on Deception Island was not seen in the South Shetland Islands by the author.

TABLE III. CLASSIFICATION OF VEGETATION IN THE SOUTH SHETLAND ISLANDS

A. **Antarctic non-vascular cryptogam tundra formation**
  I. Fruticose lichen and moss cushion sub-formation
    a. *Andreaea–Usnea* association
      1. *Usnea fasciata–Himantormia lugubris* sociation
      2. *Usnea antarctica–Omphalodiscus antarcticus–Dicranoweisia* sociation
      3. *Andreaea* sociation
      4. *Andreaea–Ochrolechia frigida* sociation
      5. *Himantormia–Andreaea* sociation

II. Crustose lichen sub-formation
  a. *Caloplaca–Xanthoria* association
    1. *Verrucaria* sociation
    2. *Caloplaca* sociation
    3. *Xanthoria elegans–Haematomma erythromma–Mastodia tesselata* sociation
    4. *Ramalina terebrata–Haematomma erythromma* sociation
    5. *Caloplaca regalis–Buellia* sociation
  b. *Placopsis contortuplicata* association

III. Moss turf sub-formation
  a. *Chorisodontium aciphyllum–Polytrichum alpinum* association
    1. *Chorisodontium aciphyllum* sociation
    2. *Chorisodontium aciphyllum–Polytrichum alpinum* sociation
    3. *Polytrichum alpinum–P. piliferum* sociation

IV. Moss carpet sub-formation
  a. *Drepanocladus uncinatus–Brachythecium–Calliergon* association
    1. *Drepanocladus uncinatus* sociation
    2. *Brachythecium* sociation
    3. *Calliergon* sociation

V. Moss hummock sub-formation
  a. *Brachythecium* association

VI. Algal sub-formation
  a. *Prasiola crispa* association
  b. *Nostoc* association

B. **Antarctic herb tundra formation**
  I. Grass and chamaephyte cushion sub-formation
    a. *Deschampsia antarctica–Colobanthus quitensis* association
    b. *Deschampsia antarctica* association
    c. *Deschampsia antarctica–Polytrichum piliferum* association

*Fruticose lichen and moss cushion sub-formation*

This is the most widely distributed sub-formation, occurring on most of the rock exposures throughout the South Shetland Islands. It is typified by fruticose and foliose lichens and small acrocarpous mosses. An underlayer of crustose lichens occurs which may be prominent but never dominant. This sub-formation is characteristic of inland and upland areas unaffected by large bird and seal aggregations or salt spray, so that the constituent species appear to be both halophobous and nitrophobous. It is usually well developed on boulders, inland cliffs and other stable rock surfaces which are not liable to much frost-shattering. Soil, if present, is mineral with little or no humus and it occurs only as small quantities in crevices and pockets between rocks.

Five distinct sociations are recognized within the single *Andreaea–Usnea* association, and they form a series of plant assemblages typical of nitrogen-poor habitats. The distribution of the sociations appears to be determined primarily by exposure and secondarily by water supply.

The *Usnea fasciata–Himantormia lugubris* and *Himantormia–Andreaea* sociations have the greatest altitudinal ranges of the community types known in the South Shetland Islands extending from 3 m. to over 305 m. on King George Island.

The two dominant lichens of the *Andreaea–Usnea* association, *Usnea fasciata* Torr. and *Himantormia lugubris* (Hue) M. Lamb, are markedly halophobous and nitrophobous. *Himantormia*, in particular, is rarely found below 15 m. altitude, except on very sheltered coastal rocks away from bird and seal colonies. On the sheltered north coast of Barton Peninsula (King George Island), which projects into the almost land-locked Maxwell Bay, *Usnea fasciata*, *Himantormia* and other inland and upland "montane" lichens are found within 2·5 m. of high-tide mark. This is almost certainly due to the lack of salt spray and bird rookeries along this shore. Because of these two factors, this sociation is rarely found at this low altitude and it usually becomes dominant at altitudes over 30 m., for example at Harmony

Cove (Nelson Island) (Fig. 6), a locality visited by Skottsberg in 1902. Skottsberg (1912) did not report the presence of *Usnea–Himantormia* communities and only referred to a moss tundra which is, in fact, confined to the higher raised beaches around Harmony Cove. Giant petrels, skuas and snow petrels with nesting sites inland may influence the development of sociations in this sub-formation, but their effect is local.

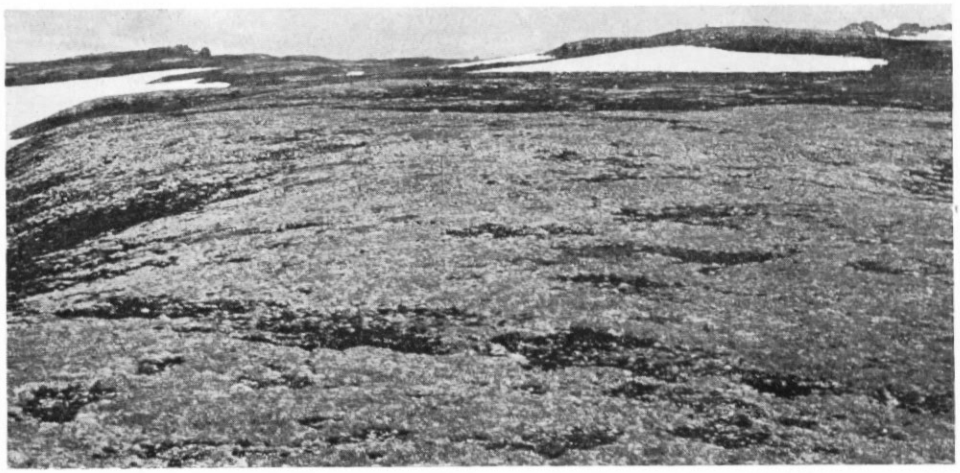


Fig. 6. *Usnea fasciata–Himantormia lugubris* sociation on raised marine platform; Harmony Cove, Nelson Island.

The most important sociation is itself characterized by the two dominant lichens *Usnea fasciata* and *Himantormia lugubris*, and is abundant and widespread over much of the exposed stable substrata of inland and upland areas. For example, the two lichens cover much of Barton Peninsula with a shaggy growth, which, when viewed from a distance, presents the appearance of partially burnt coarse grass. Usually, *Usnea fasciata* has 60–65 per cent cover with *Himantormia* giving 25–30 per cent cover. Species of *Andreaea*, *Rhizocarpon*, *Catocarpon* and *Lecidea* are constant associates.

On less exposed, stable rock surfaces that are slightly irrigated by non-nitrogenous melt-water trickles, the *Usnea fasciata–Himantormia lugubris* sociation is replaced by one composed of *Usnea antarctica* Du Rietz, *Omphalodiscus antarcticus* (Frey and Lamb) Llano and a species of *Dicranoweisia*. The cover abundance of the predominant species of this sociation is rather variable; *U. antarctica* is the more prominent lichen on dry surfaces, but *Omphalodiscus* and *Dicranoweisia* increase as melt water becomes more available. Aspect has a greater influence on the dominance of the various species within this sociation than the others in the *Andreaea–Usnea* association. On north-facing boulders, *Omphalodiscus antarcticus* is dominant with large thalli up to 30 cm. in diameter, but on south faces, thalli of this lichen become much less frequent, rarely more than 10 cm. in diameter, and are replaced by *Usnea antarctica*. *Omphalodiscus decussatus* (Vill.) Schol., a common associate of this sociation in the South Orkney Islands, was found in only one locality in the South Shetland Islands but in moderate abundance. Possibly this lichen, which is widespread throughout the Antarctic Peninsula and adjacent islands (Llano, 1950; Lindsay, 1969), occurs in other localities in the South Shetland Islands but it was overlooked.

The *Usnea antarctica–Omphalodiscus antarcticus–Dicranoweisia* sociation is well developed inland below 60 m. and appears to be halophobous, although it shows some tolerance to nitrogenous melt water. Above 60 m., the characteristic species of this sociation become increasingly confined to sheltered depressions, ledges or large cracks in rocks, while crustose lichens, which are never prominent elsewhere, achieve an appreciable amount of cover in the more exposed situations. *Alectoria pubescens* (L.) Howe jr. and *A. chalybeiformis* (L.) Gray

are frequent associates at all altitudes, the latter often growing epiphytically on both *Usnea antarctica* and *Omphalodiscus antarcticus*.

The *Andreaea–Ochrolechia frigida* sociation is found on large dry boulders, usually with a northerly aspect, which have a small amount of mineral soil. However, it was noted as being prominent only on the granodiorites of King George Island. The *Andreaea* is colonized by small orbicular crusts of *Ochrolechia frigida* (Sw.) Lynge, which may achieve 50 per cent cover over the moss. Species of *Caloplaca* (Sect. *Caloplaca*) and *Cladonia* are frequent associates.

In localized areas, such as dry shallow depressions, *Himantormia* may increase to as much as 80 per cent of the total plant cover, forming a *Himantormia–Andreaea* sociation with either *Andreaea gainii* Card. or *A. depressinervis* Card. In this sociation, *Usnea* and crustose lichens are scarce.

Species of *Andreaea* are dominant in dry rock crevices, ledges and depressions, where small quantities of mineral soil accumulate, with slight shelter from wind. The mosses usually develop as small, compact discrete cushions in inland and upland areas, from 30 m. to over 310 m. In exceptionally favourable habitats, the individual cushions of *Andreaea gainii* or *A. depressinervis* may coalesce to form carpets over 50 cm. in diameter. *Ochrolechia frigida* and a species of *Caloplaca* (Sect. *Caloplaca*) were the only epiphytic lichens noted but a species of *Bartramia* was found amongst the moss cushions and pockets of soil.

The most sheltered habitats in rock crevices support several bryophytes such as species of *Brachythecium*, *Bartramia* and *Barbilophozia hatcheri* (Evans) Loeske, with a few crustose lichens such as species of *Lepraria*. However, the crevice flora is more or less transitory since the rock is liable to frost shattering. The extremely friable basalts occurring on Byers Peninsula (Livingston Island) support a very meagre crevice flora, comprising a thin film of green alga and occasionally a leprous lichen and a few stems of moss. On the other hand, the crevice flora of the harder andesites of Barton Peninsula (King George Island) comprised *Barbilophozia hatcheri*, *Cephaloziella varians* (Gottsche) Steph., together with species of *Dicranum*, *Bartramia* and *Drepanocladus uncinatus*.

Small acrocarpous mosses, such as species of *Grimmia* and *Tortula*, but not *Andreaea*, were never noted as being prominent or abundant. Species of *Grimmia*, *Ceratodon* and *Tortula* were found in small quantities in sociations within the *Andreaea–Usnea* association and in *Drepanocladus* carpets, but never in sufficient abundance to justify separation of a different sociation type.

*Crustose lichen sub-formation*

The sociations in this sub-formation are composed mainly of crustose lichens, although fruticose lichens may attain appreciable cover, and they occur on rock surfaces, particularly those subjected to wind and salt spray. More sociations than those listed in Table III were noted in the South Shetland Islands, e.g. a *Verrucaria elaeoplaca* Vain. sociation of nitrogenous melt-water runnels, but they are not dealt with in detail since their ecological importance is minimal compared to the main sociations.

The sociations may be aggregated into two types: those found in nitrogen-rich habitats and those in nitrogen-poor habitats. Those of the former group are typified by the presence of species of *Caloplaca* or *Xanthoria*, either of which may be replaced by other species under certain conditions, while the second type of association is characterized by *Placopsis contortuplicata* M. Lamb and is found in inland and upland areas.

The two hygrohaline sociations of the *Caloplaca–Xanthoria* association occur on all stable rock surfaces, just above high-tide level, which are not subject to abrasion by brash ice. The *Verrucaria* sociation forms a zone which normally extends from just below high-tide level to about 2 m. above it, but the upper limit depends on the degree of exposure. On very exposed shores, this zone may extend upwards to 4·5 m. *Verrucaria psychrophila* M. Lamb is extensive around high-tide level on andesites, covering large areas of boulders, particularly at Barnard Point (Livingston Island) but it is apparently absent from the basalts of the same island.

About 0·5 m. above high-tide level, *Verrucaria ceuthocarpa* Wahlenb. and *V. tesselatula* Nyl. become the dominant species. These two lichens form small patches on rock without the continuity of cover typical of *V. psychrophila*. *V. tesselatula* seems to prefer slightly sheltered positions, occurring in hollows and underhangs, whereas *V. ceuthocarpa* is found on the more

exposed parts of boulders and cliffs. Generally, at about 2 m. above high-tide level, the *Verrucaria* zone changes rather abruptly into an orange *Caloplaca* zone which usually extends up to 3 m. but may reach 5 m. on very exposed shores. Of the two species of *Caloplaca* present, *C. cirrochrooides* (Vain.) Zahlbr. is the more prominent. No other species were noted in this zone, apart from a few thalli of *Verrucaria tesselatula* at its lower limit. About 3·5 m. above high-tide level, the *Caloplaca* zone merges with various nitrophilous lichen sociations on rocks near seal or bird rookeries or with a *Buellia–Lecanora–Lecidea* community in nitrogen-poor habitats.

On cliffs and boulders in or adjacent to seal, penguin and other bird rookeries, several intergrading sociations composed of ornithocoprophilous lichens are encountered. The main factors influencing the development of these sociations are the amount of nitrogenous material dissolved in melt water and amount of dunging or trampling. Since most bird and seal populations aggregate in the vicinity of the shore, salt spray may be an additional but subordinate factor determining the development of these sociations. However, in the absence of a quantitative assessment, it cannot be stated whether or not salt spray influences the distribution of ornithocoprophilous lichens. Some data on the vertical distribution of nitrophilous species in the South Shetland Islands have been published by Follmann (1965).

The most prominent ornithocoprophilous lichen sociation is formed by *Xanthoria elegans* (Link) Th. Fr., *Haematomma erythromma* (Nyl.) Zahlbr. and *Mastodia tesselata* (Hook. f. & Harv.) Hook. f. & Harv. This occurs at low altitudes on moderately exposed boulders and coarse rock fragments mainly near penguin rookeries and occasionally near seal colonies. Both *Xanthoria elegans* and *Haematomma* are found with *Ramalina terebrata* Hook. & Tayl. on slightly damp sloping rock faces which receive some salt spray.

The *Caloplaca regalis–Buellia* sociation is composed of a fruticose lichen, *Caloplaca* (Sect. *Thamnoma*) *regalis* (Vain.) Zahlbr. with an accompanying underlayer of various crustose species, mainly species of *Buellia*. It is confined to rock faces and cliffs above the spray zone, with *C. regalis* forming small clumps on sloping, dry rock surfaces near to bird-nesting sites. Infrequently, *C. regalis* may form more or less pure stands over considerable areas. *Buellia coniops* (Wahlenb. ex Ach.) Th. Fr., *B. russa* (Hue) Darb., *Rinodina petermannii* (Hue) Darb., *Catillaria corymbosa* (Hue) M. Lamb, *Microglaena antarctica* M. Lamb, *Acarospora macrocyclos* Vain, and *Xanthoria candelaria* (L.) Th. Fr. are more or less constant associates of this and the *Xanthoria elegans–Haematomma erythromma–Mastodia tesselata* sociation.

The *Ramalina terebrata–Haematomma erythromma* sociation is of similar composition physiognomically to the *Caloplaca regalis–Buellia* sociation, but it is found at slightly higher altitudes, 4·5 to 30 m., particularly on north faces of sea stacks and sheltered sea cliffs and it has fewer associated crustose lichens. *Haematomma*, *Buellia coniops* and a species of *Caloplaca* are the main associated lichens, of which *Haematomma* is the most prominent.

Since the habitat requirements of these three sociations appear to be very similar and may overlap, all have many associates in common. However, the dominant species, of foliose or fruticose growth form, were rarely found together. *Ramalina* was never found with *Mastodia*, though these two were noted occasionally growing separately with *Caloplaca regalis*.

The *Placopsis contortuplicata* association is found in inland and upland habitats lacking in nitrogen, and it is typical of substrata with some degree of disturbance such as solifluction. It is in many situations the only plant to colonize the small rock fragments of stone stripes and frost-heave polygons, but it also occurs, as large thalli up to 30 cm. in diameter with concentrically arranged cephalodia, on basalt blocks and boulders on exposed slopes near the summit of hills. It is usually found growing alone, though very rarely with species of *Andreaea* and *Usnea*.

This association was noted in many localities throughout the South Shetland Islands, particularly Byers Peninsula (Livingston Island) and Rip Point (Nelson Island).

*Moss turf sub-formation*

This sub-formation comprises turves of tall, sparsely branched acrocarpous mosses which develop on well-drained slopes irrespective of aspect, although the deepest banks were found on south-facing slopes. The two major sociations within the *Chorisodontium aciphyllum–Polytrichum alpinum* association are dominated by *Chorisodontium aciphyllum* (Hook. f. &

Wils.) Broth. on the one hand and *Polytrichum alpinum* Hedw. and *P. piliferum* Hedw. on the other. A few other mosses and liverworts, together with numerous foliose and fruticose lichens, occur as associates.

The *Chorisodontium aciphyllum* sociation forms a shallow peat over stable rocks and soil, seemingly with preference for south-facing aspect but not for slope. Turves are formed on north- and south-facing slopes on gradients varying from 1° or 2° to 30°. However, this sociation is local in its distribution, never forming the extensive undulating banks that are encountered on various islands in the South Orkney Islands. The deepest peat accumulation beneath *Chorisodontium* turf was 17 cm., on the steep (*c.* 30°) south-facing slope of a nunatak to the north of Edwards Point (Robert Island).

*Barbilophozia hatcheri* and *Cephaloziella varians* are constant associates of *Chorisodontium*, both occasionally forming pure stands within shallow turves. Only a few epiphytic lichens were found, the most frequent being *Sphaerophorus globosus* (Huds.) Vain., *Cornicularia aculeata* (Schreb.) Ach., *Cladonia vicaria* R. Sant., *Alectoria chalybeiformis* and *Ochrolechia frigida*.

The *Chorisodontium aciphyllum–Polytrichum alpinum* sociation is even more localized in its distribution than the *Chorisodontium* sociation, although it occupies similar habitats. The relative abundance of *Chorisodontium* and *Polytrichum* is variable, the two species often forming pure stands with a mixed bank. *Pohlia nutans* (Hedw.) Lindb. is an almost constant associate while epiphytic lichens are rare.

The *Polytrichum alpinum–P. piliferum* sociation is the most widespread community of the present sub-formation in the South Shetland Islands. These two mosses do not form extensive turves but occur as small colonies which occasionally coalesce to form low irregular mounds. Such colonies are found on dry, level stony ground some distance inland, usually on the crests of the highest raised beaches, where quantities of mineral soil have accumulated. The largest mounds seen were about 1·5 m. in diameter and 15 cm. in depth, much of the accumulation being peat. R. I. L. Smith (personal communication) recorded a peat depth of 50 to 60 cm. in a fairly extensive (10 by 6 m.) *Polytrichum alpinum–P. piliferum–Drepanocladus uncinatus* (Hedw.) Warnst. turf at Coppermine Cove (Robert Island) but this appears to be exceptional. *Pohlia nutans* and a species of *Ceratodon* are frequent associates while epiphytic lichens are rare.

*Moss carpet sub-formation*

This sub-formation is largely restricted to areas where water accumulates during the summer, such as hollows, depressions between raised beaches, edges of snow patches and melt-water streams, and so is encountered more frequently on flat coastal areas rather than inland. The sociations represented in this sub-formation are typified by more or less pure stands with prominent zonations between species.

The most prominent sociation is formed by *Drepanocladus uncinatus*, which typically forms saturated spongy carpets up to 5 cm. in thickness to produce almost pure stands, which may cover considerable areas on flat ground along the coasts of Livingston and King George Islands. Where the melt water is slightly nitrogenous, *Prasiola crispa* occurs as small patches on the surface and lines streams flowing through the carpets. Towards drier ground, the *Drepanocladus* carpets become patchy, thinner and more open with an increase in the frequency of epiphytic lichens. Small colonies of *Pohlia nutans*, a species of *Bryum*, *Polytrichum alpinum* and *Deschampsia antarctica* occur at the edges of such carpets, finally being replaced by *Chorisodontium aciphyllum* or *Polytrichum piliferum* on dry ground.

*Cephaloziella varians* occurs locally as very small mats in drier parts of *Drepanocladus* stands but it is more frequently found with small acrocarpous mosses in damp rock crevices. A sociation composed of a species of *Brachythecium* is found in similar habitats to the *Drepanocladus* sociation, but the carpets formed are of no great extent and rarely have the cover typical of *Drepanocladus* carpets. However, the *Brachythecium* was also found on wet slopes as well as flat areas and, in such situations, it appeared that the more rapid the flow of the melt water, the more luxuriant the growth of the moss.

The *Calliergon* sociation was noted only infrequently in the field, being found mainly in rock crevices and damp pockets of soil. However, it formed carpets in some localities, merging abruptly with both the *Drepanocladus* and *Brachythecium* sociations. Insufficient observations were made on this species to determine its precise habitat requirements, which seem to overlap

those of *Drepanocladus* and *Brachythecium*. A typical zonation of these three pleurocarous mosses around a slightly nitrogenous melt stream on Byers Peninsula (Livingston Island) is shown in Fig. 7, although the factors causing the abrupt transitions between the sociations are not known.

The *Brachythecium* was never found above 75 m., whereas both *Drepanocladus* and *Calliergon* were noted in damp hollows at 177 m. on Clark Nunatak (Livingston Island) and at 245 m. on Noel Hill (King George Island).

Saturated carpets of *Brachythecium* and *Drepanocladus* were never observed to have any epiphytic lichen growth; however, such carpets nearly always had fungal rings. With decrease in water content there is an increase in the cover of epiphytic lichens. Two species of *Psoroma* were found towards the wettest parts of the carpets, and with progressive decrease in water content crustose lichens, mainly species of *Lecanora*, appear. Fruticose lichens such as species of *Cladonia*, *Sphaerophorus globosus*, *Cornicularia aculeata* and *Stereocaulon alpinum* Laur. appear on the driest parts of such carpets. Species of *Tortula* and *Bryum* are found as infrequent associates at the edges of *Drepanocladus* carpets.

Small stands of *Drepanocladus* growing on well-drained substrata show a small amount of peat accumulation and assume a hummocky type of growth form. On such hummocks, there may be up to 80 per cent lichen cover comprising *Alectoria chalybeiformis*, *A. pubescens*, *Stereocaulon alpinum* and species of *Cladonia*, *Parmelia* and *Physcia*.

*Moss hummock sub-formation*

In contrast to the observations of Longton (1967) and Gimingham and Smith (1970), large spongy hummocks of a species of *Brachythecium* were found to replace *Drepanocladus* in dry, rather than wet, habitats. Such hummocks were usually found on steep gradients on scree slopes, though never in abundance. On more level ground, the hummocky growth form showed a tendency to assume the characteristics of a thick *Drepanocladus* carpet. However, quantitative work is necessary before it is possible to state whether or not this is a result of differences in water supply. Nowhere in the South Shetland Islands was this sub-formation found to cover any extent of ground.

*Algal sub-formation*

The sub-formation contains purely algal associations, of which two are recognized, one dominated by the parenchymatous *Prasiola* and the other by the colonial filamentous *Nostoc*. In both associations, which are unique in having no associated species, there is often more bare ground than plant cover.

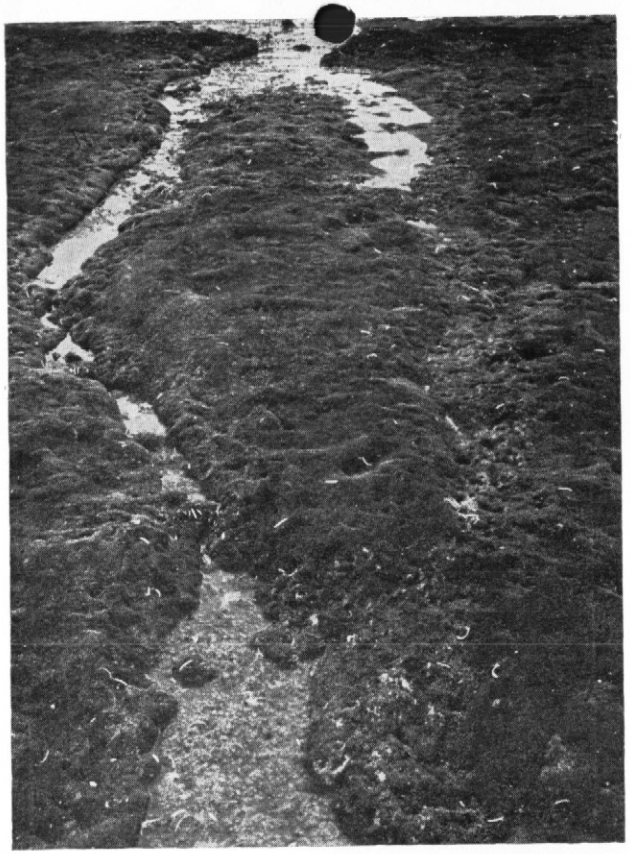
In the *Prasiola* association, the alga forms thin sheets over extensive flat areas of ground in or adjacent to penguin and seal rookeries where there is an abundance of nitrogenous melt water. At the edges of nitrogenous melt-water streams, it forms somewhat thicker robust mats. *Prasiola* was rarely found as extensively in the South Shetland Islands as Longton (1967) noted it in similar localities in the South Sandwich Islands; in fact, in only two localities, Barnard Point and Byers Peninsula (Livingston Island), was it seen to cover more than a few hundred square metres.

Small isolated thalli of *Prasiola* are found in many other sociations, particularly on the surface of moss carpets and in wet runnels on rocks.

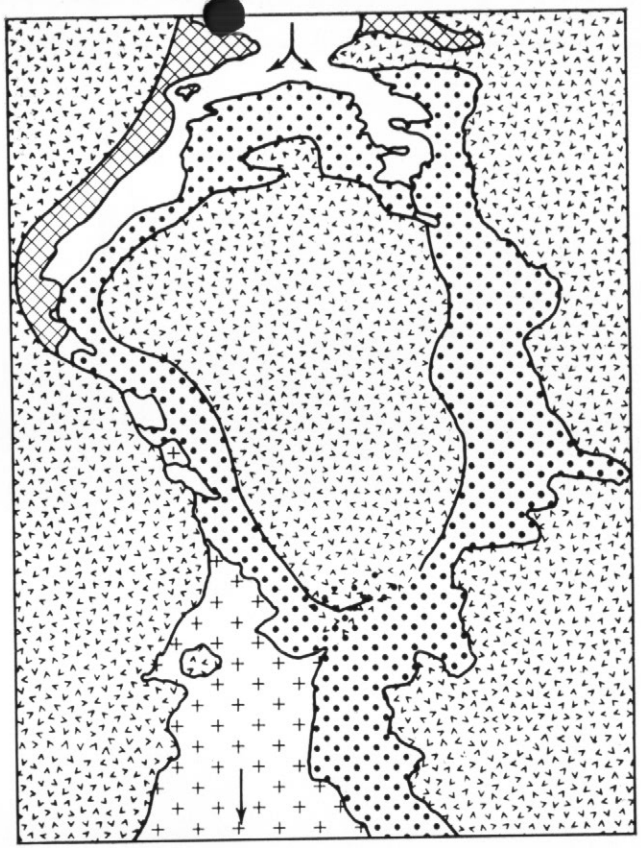
The *Nostoc* association is developed inland at altitudes from 60 to 150 m., on level or slightly undulating fine clayey soil that is saturated by almost stagnant non-nitrogenous melt water. The alga forms discrete rosettes about 5 cm. in diameter, growing almost equidistant (10–20 cm.) from each other. This association covers much of the level saturated boulder clay inland on Byers Peninsula (Livingston Island) and near The Triplets (Robert Island) and is very similar, if not identical with, the community described by Llano (1962) from Victoria Land, east Antarctica.

*Grass and cushion plant sub-formation*

Both *Deschampsia antarctica* and *Colobanthus quitensis* are frequent associates of moderately dry *Drepanocladus* carpets and *Polytrichum alpinum–P. piliferum* turves, but they rarely become the dominant species, although Longton (1967) recorded an extensive pure stand of



a




b

Fig. 7a and b. Moss carpet sociations fringing a melt-water stream; Byers Peninsula, Livingston Island.

*Colobanthus* from Deception Island. *Deschampsia antarctica* is widely distributed throughout the South Shetland Islands (Fig. 8) in contrast to *Colobanthus* (Fig. 9). Both species are found as small tufts or cushions up to 15 cm. in diameter but only *Deschampsia* showed any tendency for these tufts to coalesce to form an extensive turf (Fig. 10).

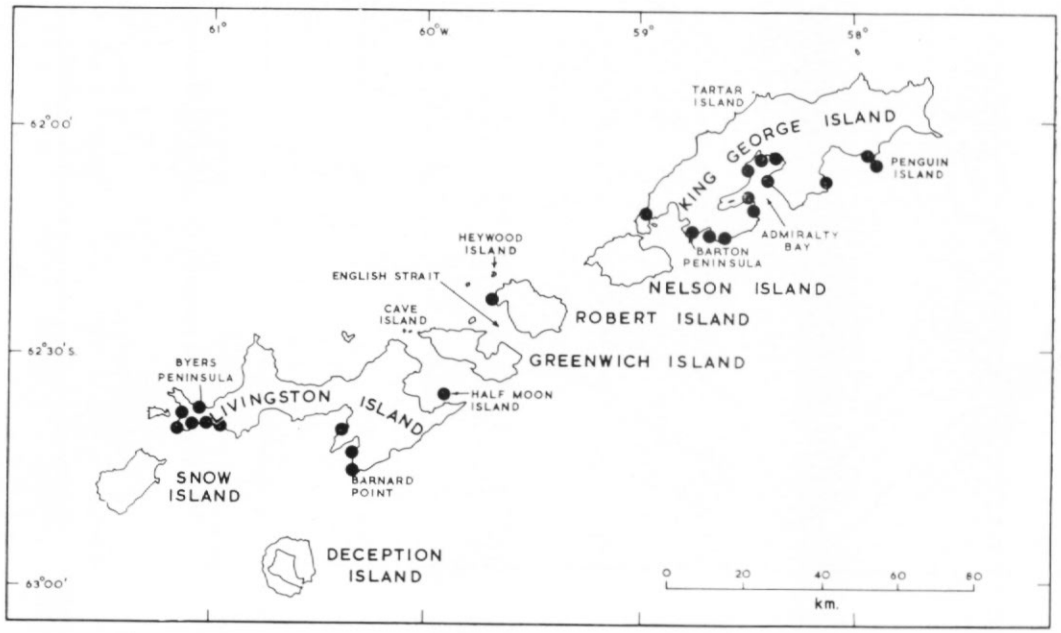



Fig. 8. Observed distribution of *Deschampsia antarctica* in the South Shetland Islands.

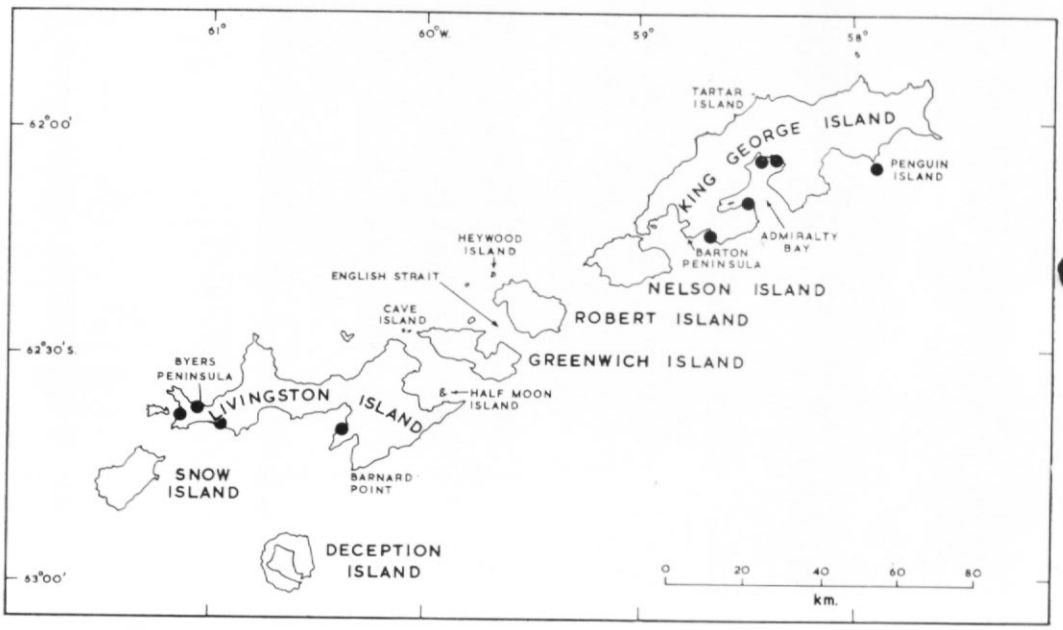



Fig. 9. Observed distribution of *Colobanthus quitensis* in the South Shetland Islands.

Fig. 10. Turf of *Deschampsia antarctica* with *Colobanthus quitensis* and *Drepanocladus uncinatus*; near Vietor Rock, Byers Peninsula, Livingston Island. The hammer shaft is 60 cm. long.

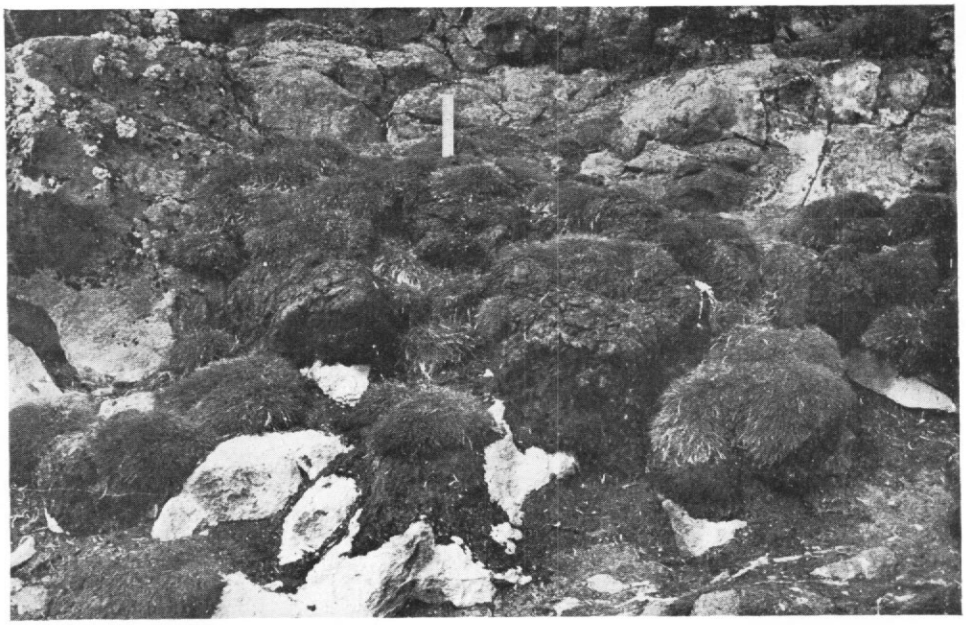


Fig. 11. Tufts of *Deschampsia antarctica* showing peat accumulation; Point Thomas, Admiralty Bay, King George Island. The ruler is 15 cm. high.

The largest turves were seen at Point Thomas (Admiralty Bay), an almost land-locked inlet on King George Island. Here the grass forms extensive swards in which individual tufts were up to 15 cm. tall and 30 cm. in diameter with about 20 cm. of peat accumulation beneath them (Fig. 11). In this locality, *Colobanthus* was found over a wide area but nowhere was there any tendency for a pure stand to form.

Both plants were found within 4·5 m. of high-tide level in sheltered localities, such as Point Thomas, and only rarely were they found above 50 m., being more or less confined to radiation traps at low altitude on the south coasts of the islands. In the South Shetland Islands, such radiation traps are most commonly found on south coasts between the inland faces of sea cliffs or old sea stacks and the rising ground to the north, leading to the interior of the islands.

## Distribution of Vegetation

### *King George Island*

The most striking feature of the island's vegetation is the much greater development of bryophyte communities on the southern than on the northern coasts. Also, the two species of flowering plant seem to be absent from the north coast except for a single locality at the south-western tip of Fildes Peninsula at the western end of the island. Although there is a wide range of rock types exposed on this island and available for plant colonization, there appears to be very little difference in the development of lichen communities on the different types. Nevertheless, the harder, more weather-resistant and more acid rocks on Barton Peninsula had a greater plant cover than the basaltic plug of Three Brothers Hill.

On False Round Point, on the north coast of the island, there is little *Drepanocladus* or *Chorisodontium* growth in comparison with the amount of lichen vegetation. *Drepanocladus* was seen as small mats at the periphery of the penguin rookery with other bryophytes very sparse on the inland undulating hills. Similarly, Tartar Island (about 24 km. west of False Round Point) also had very sparse bryophyte growth, although ornithocoprophilous lichens such as *Mastodia tesselata*, *Caloplaca regalis*, *Xanthoria candelaria*, *X. elegans* and *Lecania brialmontii* (Vain.) Zahlbr. are prominent in and around the penguin rookery. A pebble spit now joins Tartar Island to Round Point (King George Island) but it appears to be devoid of plants. North Foreland, at the north-eastern end of King George Island, is the area on the north coast most extensively colonized by plants. North Foreland consists of a narrow raised platform about 25 m. high running out for nearly 1·5 km. from the mainland. At the northern tip of this promontory there is a penguin rookery with the usual assemblage of nitrophilous plants, particularly *Prasiola crispa*, *Mastodia*, *Caloplaca regalis*, *Haematomma erythromma* and *Lecania* together with *Lecanora aspidophora*. A few small scattered carpets of *Drepanocladus* also occur at the edge of the rookery. At some distance from the penguins, the hummocks up to 50 cm. in diameter with some intermixed *Chorisodontium*. On such hummocks there is at least 70 per cent epiphytic lichen cover of species of *Cladonia* and *Ochrolechia*, together with *Sphaerophorus globosus* and *Stereocaulon alpinum*. On boulders, *Usnea fasciata* and *Himantormia lugubris* are dominant with the latter often forming dense carpets on *Drepanocladus*.

In spite of their abundance, the development of bryophytes and lichens at North Foreland is not as extensive as at comparable sites on the south coast. For example, exposed localities, such as Turret Point and Mersey Spit, show a similar range of communities but both of the flowering plants are present, though only as straggling tufts in *Drepanocladus* carpets or pockets of soil on raised beaches. *Polytrichum piliferum* is prominent on the south coast, forming a community with *P. alpinum* on dry, well-drained sandy slopes. Where a series of raised beaches is backed by a steep cliff line surmounted by the edge of the island's ice cap, such as at Stranger Point, extensive carpets of *Drepanocladus* cover the raised beaches. *Deschampsia* occurs as small scattered tufts but nowhere forms a pure stand of any size.

The most extensive bryophyte and phanerogam growth on King George Island is to be found in the sheltered area of Admiralty Bay. This south-facing bay is enclosed on three sides by mountain ranges varying in height from 300 to 610 m. with the fourth side open to the sea; the bay is thus well protected from the prevailing north-westerly winds. At Point Thomas, the

luxuriance of the grass turf has already been noted. Lichen growth at this locality is extensive with large clumps of *Caloplaca regalis* and other nitrophilous lichens surrounding the Adélie penguin rookery. However, *Deschampsia* with associated *Colobanthus* is the most prominent plant over nearly all the snow-free soil, occurring along almost 1·5 km. of coastline to within 5 m. above high-tide level on a substratum composed of beach pebbles with a little humus.

Of the other localities visited in Admiralty Bay, Keller Peninsula, Ullmann Spur, Point Hennequin and Sphinx Hill have plant communities resembling those at Turret Point and other sites on the south coast of King George Island with *Deschampsia* and *Colobanthus* both fairly widespread. Crépin Point, on the western shore of Admiralty Bay, consists of an undulating mass of loose rocks and morainic debris fringed by a series of raised beaches. Small colonies of *Drepanocladus* and *Sphaerophorus globosus* were found on the raised beaches, while *Usnea fasciata* and *Himantormia lugubris* were the dominant lichens on stable substrata inland with *Polytrichum piliferum* and *Andreaea gainii* as the most prominent mosses. It is of interest to note that *Alectoria minuscula*, a lichen of continental Antarctic distribution (Lamb, 1964), was seen here, the first record for the South Shetland Islands.

Barton Peninsula, at the south-western end of King George Island, was the area studied most intensively. This area showed greatest development of the moss carpet and the lichen and moss cushion sub-formations. Extensive carpets of *Drepanocladus* and *Brachythecium* cover the wide flat series of raised beaches fringing the western end of the peninsula. Inland, the "montane" *Usnea fasciata–Himantormia lugubris* community is dominant so that from a distance the whole of the peninsula appears dark green, as though covered by a thick layer of a coarse grass. In this locality, lichen growth does not appear to be reduced by altitude and, particularly with *U. fasciata* and *H. lugubris*, was as profuse and vigorous at the summit of Noel Hill at over 300 m., the highest point on Barton Peninsula, as at only 50 m. However, *Drepanocladus* and other bryophytes typical of the moss carpet sub-formation were not found over 100 m., although several melt streams were seen above this altitude.

Vegetation on sea stacks and raised beaches at Barton Peninsula is also well developed; *Ramalina terebrata*, *Xanthoria elegans* and species of *Parmelia*, *Physcia*, *Grimmia*, *Dicranoweisia*, *Barbilophozia* and *Cephaloziella* are prominent, being typical of the vegetation found on sea stacks and maritime outcrops throughout the South Shetland Islands. However, there are some slight differences caused by aspect and exposure. *Caloplaca regalis*, *Omphalodiscus antarcticus*, *Lecanora aspidophora* and *Polytrichum alpinum* are rare or absent on sea stacks on the south coast of the peninsula but they become more prominent and occasionally dominant on progression from the exposed south coast to the sheltered, almost land-locked north coast. A similar effect was noted on the "montane" vegetation.

*Livingston Island*

Livingston Island, at the south-western end of the South Shetland Islands, shows the same distribution of vegetation as seen on King George Island. Both *Deschampsia* and *Colobanthus* are more or less restricted to the south coast (Figs. 8 and 9) and similar distribution patterns were found in bryophytes such as *Polytrichum piliferum*, a species not noted at any locality on the island's north coast.

The difference in development of vegetation between north and south coasts is shown well on Byers Peninsula at the south-western end of Livingston Island. Here, the north and south coasts of the peninsula are separated by only about 4·8 km. but the difference in amount of vegetation is striking. On the south coast, *Deschampsia*, *Colobanthus* and *Polytrichum piliferum* are widely distributed. The two flowering plants are quite abundant in gullies with a steep north-facing slope, i.e. in radiation traps, and both form large, occasionally pure, stands with thick carpets of *Drepanocladus* and *Brachythecium*. *Deschampsia* and *P. piliferum* form an open community on the sandy, dry, flat raised beach crests on the south coast, for example at South Beaches, where it extends for several kilometres. On the north coast, *Deschampsia* was seen in only one locality, Lair Point, where it formed small straggling moribund-looking tufts quite unlike the thick turves occurring on the south coast. The absence of some species from the north coast may be correlated with the lack of radiation traps, where only a few were noted, their vegetation being reduced to thin patchy carpets of *Drepanocladus* with a few encrusting

lichens. On the south coast, corresponding carpets have many epiphytic lichens, such as *Peltigera spuria*, species of *Leptogium*, *Collema*, *Psoroma*, together with *Cornicularia epiphorella* and *C. aculeata*.

The inland "montane" flora of Livingston Island is similar to that found on King George Island. Clark Nunatak, inland from Byers Peninsula, had plant communities typical of all inland rock exposures. *Usnea fasciata* and *Himantormia lugubris* are the dominant lichens, growing with *Andreaea gainii* over much of the exposed rock and giving up to 80 per cent cover over much of the substratum. In sheltered pockets harbouring small accumulations of mineral soil, *Barbilophozia* and *Cephaloziella* are found as small colonies but more frequently intermixed with cushions of *Ceratodon*, *Pohlia cruda*, *Dicranoweisia*, *Tortula* and *Grimmia*. *Drepanocladus* and *Calliergon* form small stands up to 25 cm. in diameter, possibly correlated with the absence of large snow patches and associated melt streams. *Polytrichum alpinum* forms small inconspicuous cushions in hollows but it may merge with *Andreaea gainii* cushions in favourable situations. Crustose lichens are mainly species of *Lecidea*, *Buellia* and *Placopsis* growing on rock with species of *Stereocaulon* and *Caloplaca* (Sect. *Caloplaca*), encrusting bryophytes, particularly *Andreaea*.

*Other islands*

The distribution of plant communities on the other members of the South Shetland Islands composed mainly of igneous rocks is believed to show a broadly similar pattern to that just described for King George and Livingston Islands but too little time was spent surveying them botanically (Table I) to allow a detailed comparison. However, the volcanic Penguin Island and Deception Island (according to Collins (1969)) with mostly ash or lava surfaces present a different situation.

Penguin Island, a small island situated about 1·6 km. south of King George Island, consists of two volcanic cones of ash with a lava flow forming its northern end. The dry, porous unstable lava supports no plant growth but on the lower gentler slopes of the main cone there are a few scattered turves of *Polytrichum alpinum*, *P. piliferum* and *Ceratodon*. A few scattered squamules of a *Cladonia* were seen on the ash but no other lichens were seen. The lava flow, producing a stable but very dry substratum adjacent to a penguin rookery, had an extensive lichen flora dominated by *Usnea antarctica*, *Caloplaca regalis*, *Ramalina terebrata*, *Xanthoria elegans*, *Lecanora aspidophora* and numerous other nitrophilous lichens, *Deschampsia* and *Colobanthus* occurring as small clumps. *Drepanocladus* was the only prominent moss, forming very thin, sparse small carpets. Nowhere is there enough water to support any extensive bryophyte growth.

## Plant Succession

*On raised beaches*

One of the prominent geomorphological features in the South Shetland Islands is the raised beach, which shows a succession of vegetation types with increasing distance from the sea as illustrated in Fig. 12. Transects from the storm beach across a series of raised beaches were made in a number of localities and the pattern of vegetation was found to be basically similar in each case.

The first raised beach, behind the storm beach (beach 2), usually has a few crustose lichens, particularly species of *Verrucaria* and *Acarospora*, sparsely scattered over the unstable pebble substratum (Fig. 12, vegetation type 1). In the depression between this beach and the crest of the next raised beach, colonies of *Drepanocladus* straggle between the pebbles but they are not usually of sufficient thickness to form a continuous carpet over them (Fig. 12, vegetation type 2). On the crest of the second raised beach (beach 3), the pebbles are colonized by *Usnea antarctica* and numerous crustose lichens with a scant growth of *Drepanocladus* between pebbles (Fig. 12, vegetation type 3). In the hollow behind this beach, where some mineral soil and water accumulates, *Drepanocladus* forms carpets up to 5 cm. thick intermixed with species of *Brachythecium*, *Calliergon*, *Pohlia* and *Bryum*. Encrusting lichens, such as species of *Psoroma* and *Cladonia*, are rare (Fig. 12, vegetation type 4). The crests of the third and successive raised beaches are normally increasingly dominated by "montane" species such as

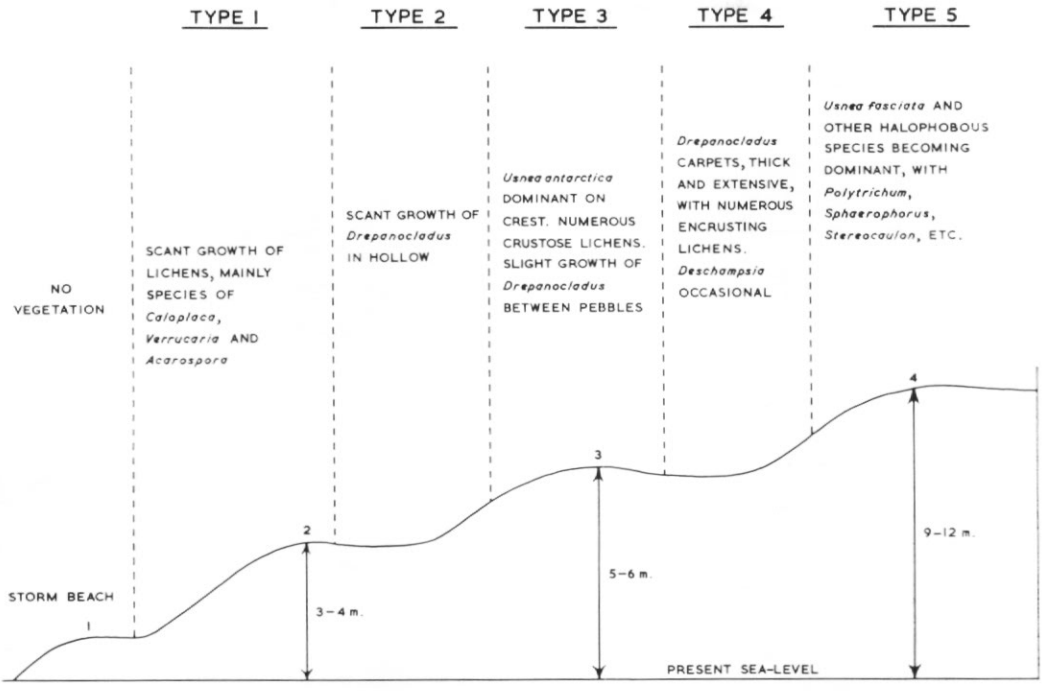



Fig. 12. Diagrammatic representation of typical plant zonation across a series of raised beaches in the South Shetland Islands.

*Usnea fasciata*, *Polytrichum alpinum* and species of *Andreaea* (Fig. 12, vegetation type 5) where the substratum is coarse, but on sand or fine gravel *Polytrichum piliferum* and *Deschampsia* are abundant.

Variations of this succession occur throughout the island group, reflecting changes in topography and exposure. For example, on the sheltered north shore of Barton Peninsula, halophobous species typical of vegetation type 5 of the raised beach succession, such as *Himantormia lugubris* and *Alectoria pubescens*, grow within 3 m. of high-tide mark (Fig. 13), whereas on the exposed Robbery Beaches on the north coast of Livingston Island such plants are not found within 230 m. of the shore, being replaced by an alternation between vegetation of types 1 and 2. The raised beach succession on moderately sheltered sites as at Barnard Point (Livingston Island) follows the typical form very closely. On sheltered but wet coasts, e.g. Stranger Point (King George Island) in contrast to the sheltered dry shore of Barton Peninsula, *Drepanocladus* carpets become the dominant plant form (vegetation type 4).

*On sea cliffs*

Sea stacks and sea cliffs show an almost constant zonation of plants (Fig. 14). A blackish zone of *Verrucaria psychrophila* occurs just above high-tide level, extending upwards for about 1 m. with an abrupt transition into a bright yellow *Caloplaca* zone above this. The succession above this is greatly influenced in its vertical range by exposure to wind and salt spray. In very exposed situations the *Verrucaria* and *Caloplaca* zones may extend up to 3·5 m. before grading into more typically terrestrial vegetation. Above the yellow *Caloplaca* zone, nitrophilous lichens become dominant, since sea birds such as cape pigeons (*Daption capensis*) and Wilson's petrels (*Oceanites oceanicus*) nest on or near sea stacks and cliffs. *Xanthoria elegans*, *Polycaulionia regalis* and *Haematomma erythromma* are typical of this situation, rapidly grading into the *Ramalina terebrata*–crustose lichen community of dry rocks.

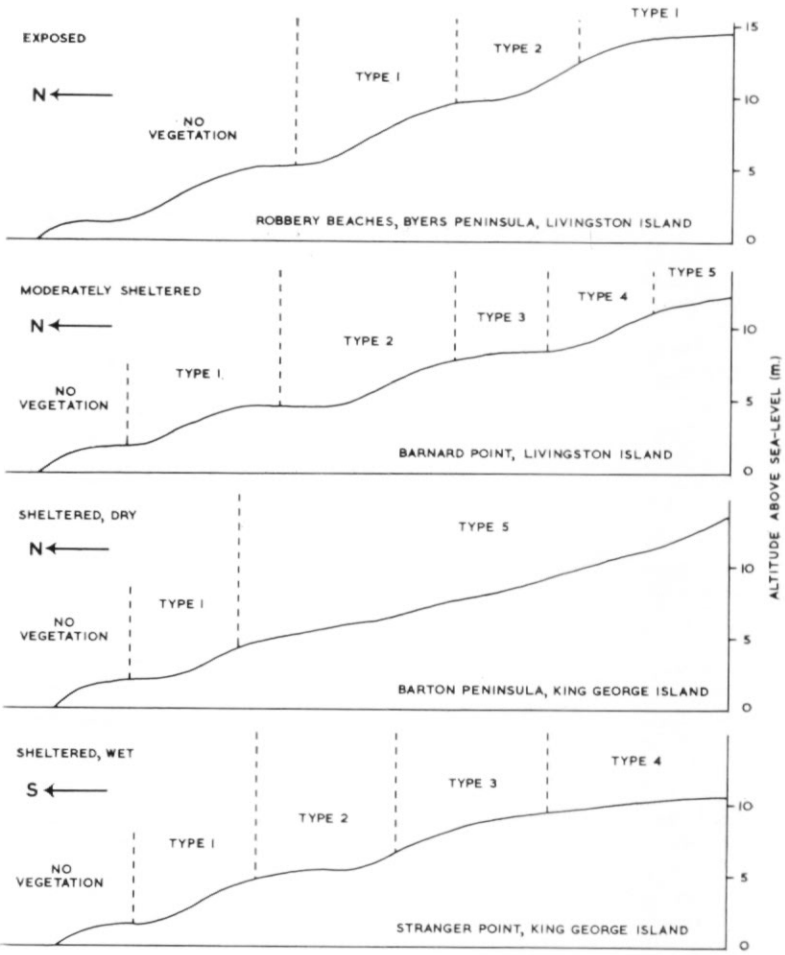



Fig. 13. Plant zonation along a series of raised beach transects at various localities in the South Shetland Islands.

On coasts where there are no sea-bird aggregations, the *Caloplaca* zone merges into an open crustose lichen community consisting of species of *Lecidea*, *Lecanora* and *Buellia* which in turn develops into an *Usnea antarctica–Omphalodiscus antarcticus–Dicranoweisia* community that is found on inland cliffs. Wet runnels in most stacks were colonized by *Prasiola crispa*, *Verrucaria elaeoplaca* and various other crustose lichens.

*On moraines*

Although many moraines occur in the South Shetland Islands, only a few, on King George and Livingston Islands, were studied in any detail. The moraines around the base of Buddington Peak (King George Island) appear to be freshly deposited and are almost wholly devoid of plant growth. A few small thalli of *Rhizocarpon*, *Caloplaca* and *Usnea antarctica* were found with a few small shoots of *Drepanocladus*. The inner moraines of the glacier south of Point Thomas (Admiralty Bay) were colonized by *Drepanocladus*, *Deschampsia*, *Bryum* and *Usnea antarctica*, though on older moraines bryophyte growth is less extensive although crustose lichens are widespread. It appears that bryophytes are the first plants to colonize moraines in

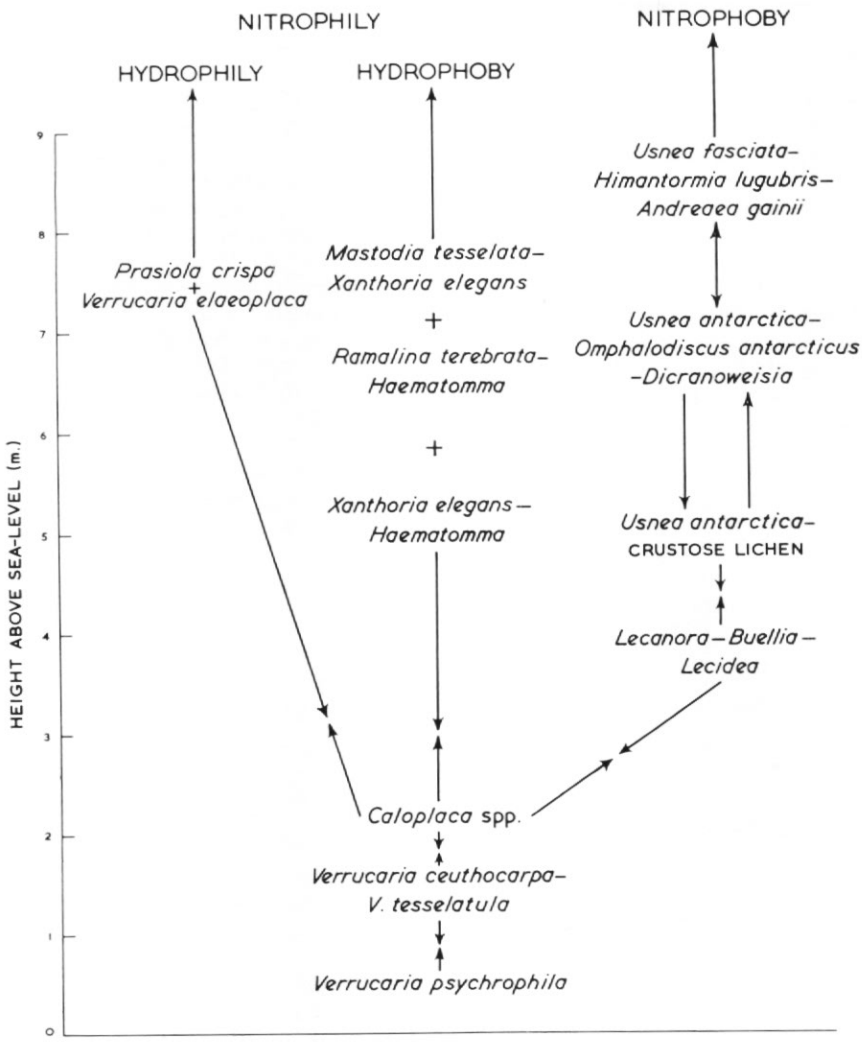



Fig. 14. Diagrammatic representation of plant succession on maritime cliffs in the South Shetland Islands.

the South Shetland Islands, *Drepanocladus uncinatus* and a species of *Bryum* rapidly filling wet hollows with *Deschampsia* following soon after. Rock surfaces appear to be colonized more slowly than the soil. *Usnea antarctica* may colonize the rocks at the same time that *Drepanocladus* appears on the soil but crustose lichens only establish themselves some time later.

### Influence of Environmental Factors

Brown (1912) and Siple (1938) were some of the earliest authors to discuss the effects of physical factors on the development of Antarctic vegetation. Holdgate (1964) and Longton (1967) have provided additional information and have also considered the edaphic and biotic factors influencing plant growth in the Antarctic Peninsula region.

In the South Shetland Islands, the main factors affecting plant growth and distribution appear to be degree of exposure, water availability, stability of substrata and availability of nitrogen, the last correlated with degree of disturbance by animals. The influence of these

factors is further complicated by the hydrophily, nitrophily, hydrophoby or nitrophoby of the plants themselves.

Exposure, a complex factor made up of such components as wind direction, aspect and altitude, does not appear to restrict the distribution of the "montane" lichens such as *Usnea fasciata* and *Himantormia lugubris* or the moss *Andreaea gainii*, all of which grow well in the most exposed situations. On the other hand, it appears that the two flowering plants and most of the bryophytes are more influenced in their growth by wind direction than aspect. For example, the deepest peat deposits under *Chorisodontium* were found under a hummock growing on a steep south-facing slope. Similarly, both *Deschampsia* and *Colobanthus* were found growing well and forming turves in a variety of aspects, but with bryophytes, such as *Polytrichum piliferum*, the best growth was attained on the southern coasts of the islands. Since it appears that the majority of gales come from the north (Table IV) and blow with unabated force from Drake Passage, it may well be that the north coasts of the South Shetland Islands are too exposed for the development of many species, thus restricting their presence to the south coasts where there are numerous sheltered radiation traps. Hence the warmest situations in the South Shetland Islands occur on the south coasts in contrast to the situation in the South Orkney Islands, where north coasts provide the warmest sites.

TABLE IV. FREQUENCY OF GALE (days/yr.) WITH DIRECTION IN THE SOUTH SHETLAND ISLANDS

| *Wind direction* | *Whalers Bay, Deception Island* (from 1944 to 1961 inclusive) | *Admiralty Bay, King George Island* (from 1948 to 1960 inclusive) |
|---|---|---|
| 350–040° | 11 | 56 |
| 040–100° | 44 | 7 |
| 100–160° | 1 | 1 |
| 160–220° | 1 | 0 |
| 220–280° | 13 | 27 |
| 280–340° | 2 | 4 |

The only species that appeared to be affected primarily by aspect was *Omphalodiscus antarcticus*, which was restricted to the north sides of boulders and cliffs which slope more or less steeply and are irrigated by slightly nitrophilous water. *O. antarcticus*, which may be expected to be a component of the "montane" lichen flora from the account of its distribution given by Llano (1950), was not observed above 50 m. However, it has been reported from the Theron Mountains (*c.* lat. 79°S., long. 29°W.) at altitudes ranging from 450 to 660 m. above sea-level, and at numerous localities in the South Orkney Islands and along the Antarctic Peninsula (Lindsay, 1969). Its absence from the "montane" flora of the South Shetland Islands is, therefore, surprising.

Since few sites favourable for water accumulation occur above 100 m., large moss carpets are more or less restricted to the raised beaches, which are usually backed by the steep slopes of old sea cliffs. Large drifts of snow accumulate at their bases during the winter, thus providing an ample source of melt water for the summer.

*Drepanocladus* and *Brachythecium* have slightly different growth forms when growing in habitats drier than normal. *Drepanocladus* tends to form small discrete hummocks, occasionally with a small amount of peat accumulation, a feature usually associated with mosses in the moss turf sub-formation. *Brachythecium* also tends to form hummocks in drier habitats but such hummocks are larger and more spongy than the dense compact *Drepanocladus* carpets.

The most extensive *Drepanocladus* carpets seen were those on the flat coastal area between Stranger Point and Three Brothers Hill (King George Island). In this area, the carpets are almost continuous for about 2·4 km. over a substratum of sand and pebbles saturated and dissected with numerous melt streams from the cliffs inland. The drier hummocks of these carpets are colonized by *Deschampsia*.

The transition of the free-living alga *Prasiola* into its lichenized form *Mastodia* was observed at several localities and it also appears to be influenced by water supply. *Mastodia* growing in *Prasiola* mats or in damp situations was invariably sterile, whereas thalli on dry boulders were almost always found with numerous perithecia. Thus the amount of water present seems to control the reproductive state of *Mastodia* and may have a similar effect on other ornithocoprophilous lichens.

Soil movement is another factor influencing the development of vegetation. The vegetation of ground disturbed by solifluction and frost heave consists of few lichens and bryophytes. The main lichen colonizing this unstable habitat is *Placopsis contortuplicata* which occurs on the smallest fragments in solifluction slopes. Larger fragments are colonized by species of *Andreaea* and various crustose lichens, while stones at the edges of such disturbed areas are colonized by plants typical of the surrounding communities such as species of *Usnea* and various acrocarpous mosses. Frost-heave polygons, which were noted over wide areas on Nelson Island and Barton Peninsula (King George Island), are characterized by abundant growth of *Usnea fasciata* and occasionally *Himantormia* on the large rock fragments at the edges. *Andreaea gainii* and *A. depressinervis* form a zone within this with a narrow band of *Drepanocladus* covering the smallest fragments. The centre of the polygon, where particle movement is most active, is devoid of any vegetation.

The main biotic factors of large seal and penguin aggregations are restricted to coastal areas as their rookeries are never found in any quantity inland. The effects of trampling and dunging have been discussed by Holdgate (1964) and Longton (1967). *Prasiola crispa* is often the only plant occurring on wet gravel and sand in penguin rookeries but the dry boulders towards the periphery of the colonies support extensive growth of ornithocoprophilous lichens such as *Catillaria corymbosa*, *Lecania brialmontii*, *Lecanora aspidophora*, *Acarospora macrocyclos*, *Microglaena antarctica*, *Lecidea agellata* and species of *Haematomma*, *Buellia* and *Physcia*. The composition of the crustose lichen communities on dry boulders varies but usually foliose lichens such as *Xanthoria elegans*, *X. candelaria* and *Mastodia tesselata* are the dominant species. *Verrucaria elaeoplaca* covers large areas of rock which are inundated by nitrogenous melt water. The ornithocoprophilous lichen communities were noted at all localities in the South Shetland Islands where large penguin and seal colonies were found, although *Lecania brialmontii* and particularly *Catillaria corymbosa* appear to show the same distribution pattern as the two flowering plants in being widespread along the south coasts and sparse along the north coasts.

Other birds such as giant petrels and skuas appear to have only local effects on vegetation. Skuas, for example, may scoop hollows in *Chorisodontium* banks and also collect stones to form nests but such activities have very little effect except on the vegetation in the immediate vicinity.

Observations made at many localities in the South Shetland Islands, indicate that *Deschampsia* produces its best vegetative growth around the periphery of penguin rookeries. Plants found at some distance from nesting sites, as on Byers Peninsula, show very stunted, straggling, yellowish grey growth and appear moribund. Moreover, almost all such tufts produce inflorescences, whereas none of the lush turves seen at Point Thomas around the penguin rookery were flowering. It thus appears that nitrogen enrichment results in the maximum vegetative growth but in some way has an inhibitory effect on flowering. This does not seem to be true for *Colobanthus*, which was found flowering freely in nitrogenous and non-nitrogenous habitats.

### Comparison with Other Areas

The vegetation of the South Shetland Islands resembles that found on the South Orkney Islands and the northern part of the Antarctic Peninsula but the bryophyte communities are less well developed. In particular, the moss turf sub-formation does not reach the extensive

development with deep peat accumulation as in the South Orkney Islands (Holdgate, 1964). *Polytrichum alpestre*, a prominent associate of *Chorisodontium aciphyllum* and a major contributor to the development of peat in the banks of moss turf in the South Orkney Islands and other localities in the maritime Antarctic, is quite rare in the South Shetland Islands, which may in itself explain the lack of any significant depth of peat in these islands. Similarly, *Omphalodiscus decussatus*, a prominent lichen of the *Usnea antarctica*–crustose lichen communities of the South Orkney Islands and localities on the west coast of the Antarctic Peninsula, was seen in only one locality in the South Shetland Islands, nor are there any records for it from this area in Llano (1950). However, like *Polytrichum alpestre*, it may have been overlooked in several localities which were only cursorily examined during the survey.

The main points of difference between the vegetation of the South Shetland Islands and the rest of the maritime Antarctic are summarized in Table V. Of interest is the *Nostoc* community, on saturated inland clayey soil, which is comparable to a *Nostoc* community reported from Victoria Land by Llano (1962). Small patches of this community occur on Deception Island and Signy Island but their development is very limited (personal communication from R. I. L. Smith).

TABLE V. DIFFERENCES IN VEGETATION BETWEEN THE SOUTH SHETLAND ISLANDS AND OTHER AREAS OF THE MARITIME ANTARCTIC

| *South Shetland Islands* (excluding Deception Island) | *Maritime Antarctic* |
|---|---|
| Peat banks localized and shallow; maximum depth 17 cm. | Extensive and deep peat deposits; to 170 cm. depth |
| *Polytrichum alpestre* localized and rare | *Polytrichum alpestre* widely distributed and often abundant |
| *Nostoc* community covering large areas | *Nostoc* localized in non-lichenized form; never a prominent part of the vegetation |
| *Omphalodiscus decussatus* localized and rare; never prominent | *Omphalodiscus decussatus* widespread; prominent associate of *Usnea antarctica–Omphalodiscus–Dicranoweisia* community |
| *Polytrichum piliferum* forming widespread community with *P. alpinum* | *Polytrichum piliferum* widespread but never prominent |

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