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AN INTRODUCTORY GUIDE TO THE FLORA OF ANTARCTICA

Florence Thame

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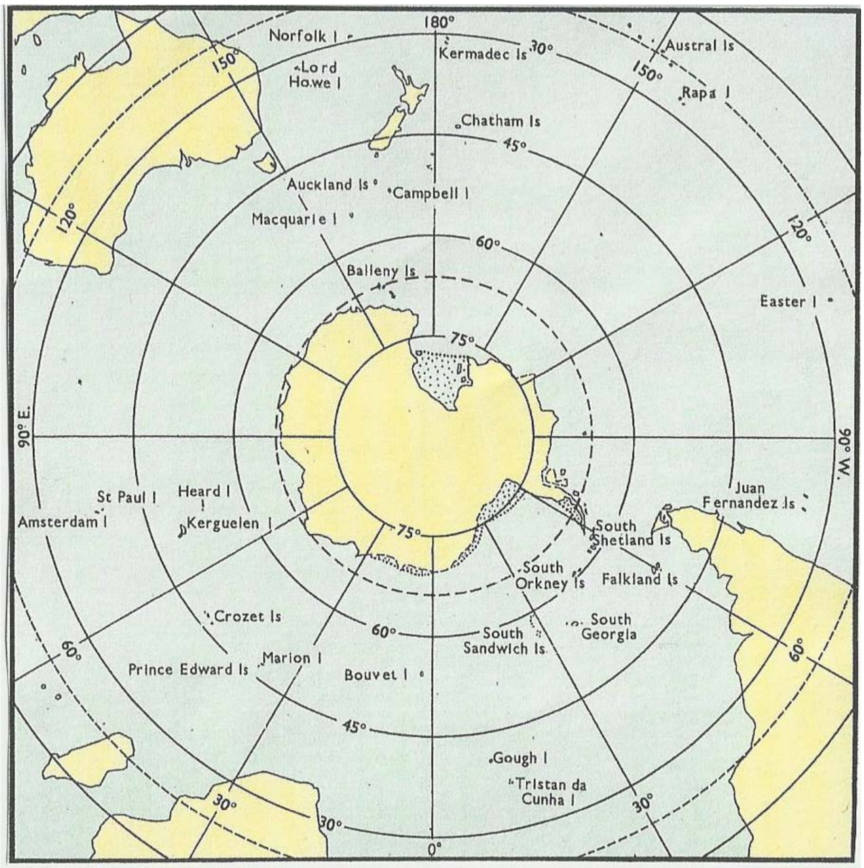

NZMS 173 map of Antarctica drawn by the Department of Survey and Land Management taken from the Flora of New Zealand Lichens Vol. II, Galloway, 2007.

“Look deep into nature and you will understand everything better”

Albert Einstein

This book is dedicated to the memory of Leon Phease

AN INTRODUCTORY GUIDE TO THE FLORA

OF

ANTARCTICA

AN INTRODUCTORY GUIDE TO THE FLORA OF ANTARCTICA

by

FLORENCE JOSEPHINE THAME

BSc, PGDipSci, MSc

2015

PCAS ANTA604 SUPERVISED PROJECT

UNIVERSITY OF CANTERBURY, NEW ZEALAND

CONTENTS

PLATES

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INTRODUCTION

Antarctica is the southernmost continent on Earth and is well known for its extreme cold conditions (Singh and Singh, 2011). The terrestrial biodiversity of the Antarctic is relatively low and simple compared to that of regions at higher latitudes on Earth, with many higher taxonomic groups not represented (Chown, 2007; Bednarek-Ochyra et al., 2000; Hughes and Convey, 2010; Pisa et al., 2014). There are no terrestrial vertebrates in Antarctica, and faunal communities consist of invertebrates: Diptera (two species of midges), Acari (mites), Collembola (springtails), Nematoda, Rotifera, Tardigrada and Protista (Convey, 2007; Hughes, 2010). Antarctica is the only continent in the world to have a flora that is dominated by lower plant groups, predominantly Cryptogams (Peat et al., 2007). There are no trees or shrubs in Antarctica and the diversity of terrestrial vegetation is restricted to five major plant groups: phanerogams (seed-producing flowering plants); and the spore producing Cryptogams bryophytes (mosses and liverworts), lichens, algae and blue-green algae or cyanobacteria (Coenraads and Koivula, 2007; Lewis-Smith, 2007[1]). Cryptogams play a vital role in the energy flow and nutrient cycling of the Antarctic terrestrial ecosystem. They also provide viable habitat for invertebrates, and can influence soil moisture and temperature regimes, e.g. moss communities create their own microclimates (Bednarek-Ochyra et al., 2000). Fungi, algae and cyanobacteria also play a central role in the stabilisation of mineral soils, which are a key prerequisite for the secondary stages of plant colonisation and community development (Wierzchos, 2007).

In general terms, the development and complexity of terrestrial biological communities declines with increasing latitude (Hughes and Convey, 2010). This is due to the geographic isolation of the continent, the severe climatic conditions there, and the scarcity of viable habitat suitable for colonisation (Chown, 2007; Hughes and Convey, 2010). All but one percent of the 14 million km^2 of the Antarctic land mass is permanently covered by ice and snow, therefore a favourable habitat for the colonisation of plant life in Antarctica is restricted to the available exposed coastal and inland outcrops, nunataks, and mountain ranges (Lewis-Smith, 2007[1]; Seppelt, 1984). Species that have established themselves and survive in Antarctica must be tolerant of the extreme environmental conditions (notably low summer temperatures and short growing season, long periods of desiccation, high levels of ultra violet radiation and solar irradiance, long winters with long periods of darkness and continual summer daylight south of 67°S) and must have evolved special physiological adaptations and / or must possess an effective dispersal and establishment mechanism (Lewis-Smith, 2007[1]; Waterhouse, 2001).

Various systems have been used to separate Antarctica into biological regions based on a combination of prevailing climatic and biotic characteristics, namely plant distributions (Lewis-Smith, 2007[1]; Peat et al., 2007). Classically, the Antarctic continent is divided into two broad phytogeographic regions: the first encompasses the maritime Antarctic, which includes the South Shetland Islands, South Orkney Islands, South Sandwich Islands, Bouvetøya and the western Antarctic Peninsula down to approximately 72° S; the second comprises continental Antarctica, which includes the eastern side of the Antarctic Peninsula south of 63°S, and the remainder of the Antarctic continent (Bednarek-Ochyra et al., 2000; Lewis-Smith, 2007[1]; Peat et al., 2007).Within Antarctica the decline in terrestrial biodiversity is apparent also, and decreases from the maritime Antarctic to the continental Antarctic and it is particularly pronounced between the Antarctic Peninsula and continental Antarctica (Chown, 2007). The milder, wetter climate of maritime Antarctica provides more favourable conditions for life to occur and supports two flowering plants as well as a wide range of bryophytes, lichens, algae, and invertebrates, including the only two Antarctic higher insects (Lewis-Smith, 2007[1]; Seppelt, 1984). By comparison, the colder, drier environment of continental Antarctica has a reduced faunal and floral diversity where flowering plants are absent, bryophytes are restricted in diversity and distribution, and lichens, fungi, algae and cyanobacteria become more dominant in plant community structure (Lewis-Smith, 2007[1]; Seppelt, 1984; Wierzchos, 2007).

Botanical “hot spots” which are known to have high vegetation coverage and species diversity are to be found in the following areas: Taylor Valley; Canada Glacier; Wilkes Land; the Windmill Islands; Botany Bay, Granite Harbour (in southern Victoria Land); Birthday Ridge and Cape Hallett (in northern Victoria Land); Edmonson Point (in central Victoria Land); and Beaufort Island in the Ross Sea (Seppelt et al., 2010). Botanical surveys have largely been carried out only where accessibility is feasible (generally in areas with stations), and more surveys in a wider range of areas will ensure a more detailed knowledge of the diversity and biogeography of the Antarctic flora (Peat et al., 2007). This book is designed to be an introductory guide to the ecology of the flora of the Antarctic maritime and continental regions. It contains overviews of the following botanical groups: flowering plants; mosses; liverworts; lichens; fungi; algae (including cyanobacteria); and the future of Antarctic plant ecology and diversity.

FLOWERING PLANTS

There are only two flowering plants which have successfully colonised and survived in the Antarctic: the endemic Antarctic Pearlwort (*Colobanthus quitensis*) and the Antarctic Hairgrass (*Deschampsia antarctica*) (Antarctic Division Pamphlet, 1980; Coenraads and Koivula,, 2007; Holderegger et al., 2003; Rosa et al., 2009). A dispersal of other species adapted to the Antarctic climate has not happened, with the exception of the human mediated introduction and subsequent colonisation of expansive weeds such as *Poa annua* and *Poa pratensis* in maritime Antarctica (Parnikoza et al., 2011). *C. quitensis* is a perennial flowering plant which forms small (approximately 5 cm high), compact hemispherical cushions, and it has small white flowers on elongated stalks; *C. quitensis* is capable of self-pollination and reproduces predominantly by seed (see **Plate I.** a), b), c)) (Parnikoza et al., 2011). The Antarctic Pearlwort, which can live up to 35 to 40 years, is cold-resistant and has biochemical adaptations to survive in the extreme Antarctic conditions. These include: resistance to repeated freeze–thaw cycles; ultraviolet radiation; low water availability; and osmotic stresses (Parnikoza et al., 2011; Rosa et al., 2010). *C. quitensis* is often found growing in association with *D. antarctica* and typically occurs in similar habitats (Longton, 1988; Sadowska, 1998). *D. antarctica* is the only grass species to occur in Antarctica. It is a perennial freeze tolerant tussock and is a small plant approximately 3-5 cm high (see **Plate I.** d)). It occurs usually in or near moss carpet communities, or as small tufts living amongst rocks in soil filled cracks, on rock ledges, or stony ground. In drier sites it may also form low mats which may extend over several square meters (Cuba et al., 2005; Holderegger et al., 2003; Longton, 1988; Park et al., 2012; Parnikoza et al., 2011; Sadowska, 1998).

Both species extend as far as 68°42´ S and are found only in maritime Antarctica (Holderegger et al., 2003; Lewis-Smith, 2007[1]). Antarctic Hairgrass has a wider ecological tolerance than the Antarctic Pearlwort and therefore a wider distribution throughout maritime Antarctica (Vera et al., 2013). *D. antarctica* is capable of vegetative propagation by means of tuft outgrowth and split-off of the tuft parts. It is thought that Skuas and gulls may be responsible for much of the spread of Antarctic Hairgrass throughout maritime Antarctica, as they often pull up rooted pieces of the grass for nesting material from locations which may be several kilometres from their nest sites (Lewis-Smith, 2007[1];

Parnikoza et al., 2011). Antarctic populations of *C. quitensis* and *D. antarctica* have recently increased in number and size. This phenomenon has been attributed to the warming of air temperatures (by 1-2°C) in maritime Antarctica over the past 50 years (Holderegger et al., 2003).

a)

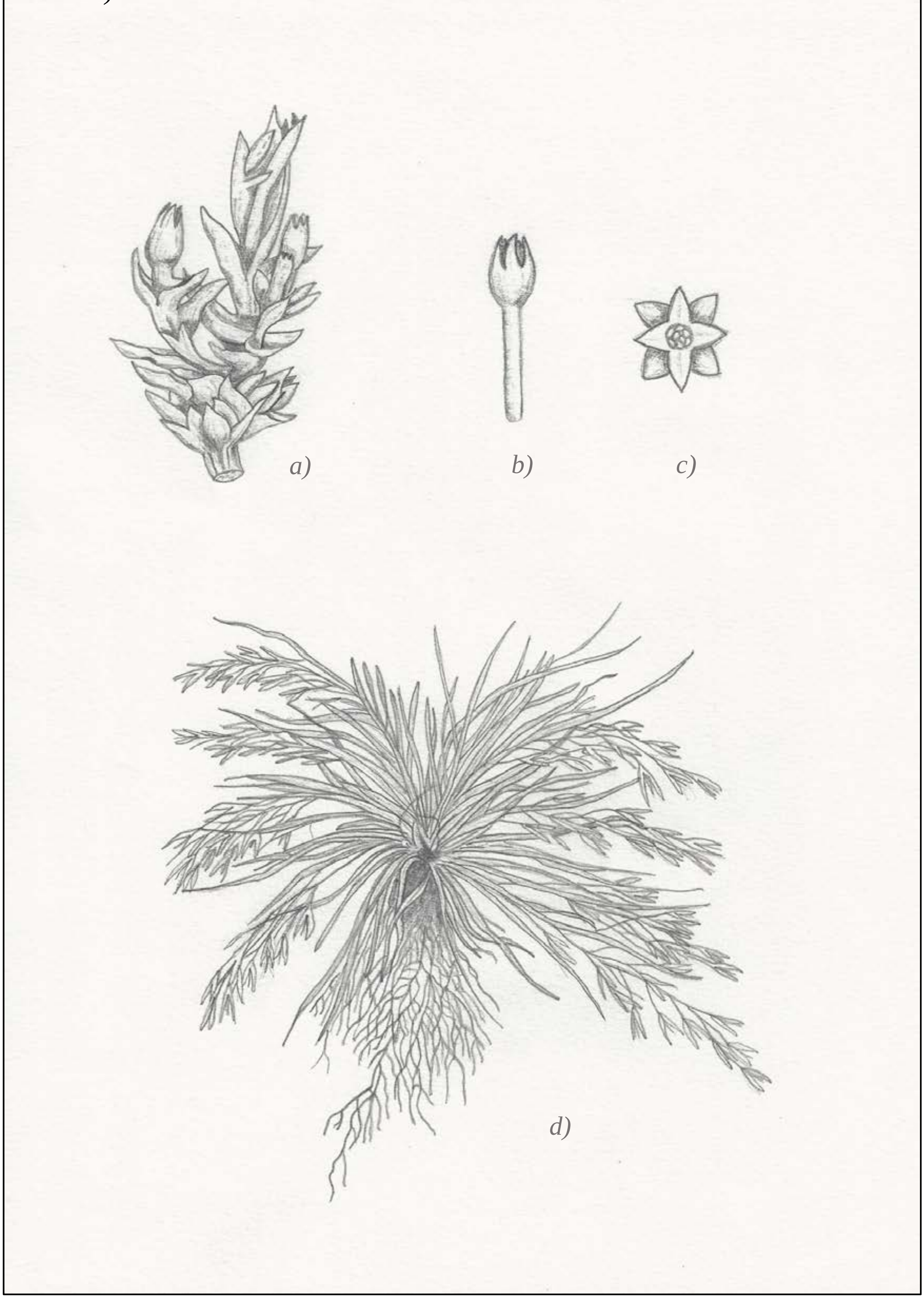

Plate I. Depicting: a) A segment of Antarctic Pearlwort (*Colobanthus quitensis*) (adapted from Mantorani and Cardoso Vieira, (2000)); b) A lateral view of Antarctic Pearlwort flower; c) An aerial view of an open Antarctic Pearlwort flower; d) Antarctic Hairgrass (*Deschampsia antarctica*) in flower.

MOSSES

Mosses belong to the Plant Kingdom division Bryophyta. Mosses are anatomically simple, and they do not have specialised water conducting tissues (i.e. xylem). Accordingly, they cannot control their uptake or loss of water and are therefore prone to desiccation. Water uptake occurs passively via absorption of either ground water or atmospheric precipitation through their leaves and stems. This restricts most species to wet or moist habitats, but some are tolerant of arid conditions, obtaining their moisture from rare precipitation events (Allison and Child, 1971; Lewis-Smith, 2007[2]). Most mosses tend to be loosely attached to their substrate by a mass of root-like rhizoids. Mosses have two main morphological forms which consist of many individual leafy branched shoots that typically form a colony of shoots. Pleurocarps (prostrate spreading carpet forming colonies) tend to grow in moist or wet habitats whereas, acrocarps (short erect colonies) often grow in drier habitats. There are several other growth form variations of acrocarps, such as cushions (with shoots extending from a central point), which are common on rocky substrates, and turves (vertical and parallel arranged shoots), which commonly grow on soil (Lewis-Smith, 2007[2]).

The lifecycle of mosses has two stages comprising a vegetative stage and a sexual stage. The vegetative stage, otherwise known as the gametophyte, produces the leafy shoot that is the typical "moss" part of the moss. This gives rise to sexual structures called gametangia that comprise the sexual stage (sporophyte) (Lewis, Smith, 2007[2]). The sporophyte consists of a spore-producing capsule borne on a short stalk (seta). When the capsule is ripe it releases spores that germinate and develop into a branched protonema which then develops into the leafy gametophyte. The sporophyte is formed via cellular mitosis when the male (antheridium) and female (archegonia) structures on the gametophyte (moss shoot), respectively, form sperm and egg cells. The sperm cells fertilise the egg cell to form a zygote and this process is facilitated by the presence of water (Lewis-Smith, 2007[2]). Most Antarctic moss species reproduce and colonise via vegetative propagules which range from specialised structures to detached fragments of shoot which develop into new plants.

Mosses are one of the most conspicuous terrestrial life forms in the Antarctic, particularly in the wetter maritime Antarctic and coastal areas around the continent (Pisa et al., 2014). No Antarctic species have common names. There are approximately 113 species of mosses, of which 18 occur in continental Antarctica (Lewis-Smith, 2007[2]). Only five moss species have been recorded beyond 80°S, all of which occur in the Trans Antarctic Mountains, which are in southern Victoria Land (Lewis-Smith, 2007). Five species have also been recorded at altitudes above 1500 m (including those from geothermal areas). Mosses are not widely distributed in Antarctica because of their dependence on water availability to survive and therefore are largely restricted to coastal areas (Antarctic Division Pamphlet, 1980). However, there are some xerophytic species that can grow in the extreme dry windswept areas (Lewis-Smith, 2007[2]). For example, some mosses occur only as chasmoliths (living in between fissure or cracks in the rock surface) or on soil in between rocks where there is some residual moisture. Some species occur also in areas where there is volcanic steam warmed ground, for example, *Campylopus pyriformis* which is found growing in snow-free ground near the summit (2733 msl) of Mount Melbourne in northern Victoria Land (Lewis-Smith, 2007[2]; Skotnicki et al., 2001). Other species of *Campylopus* have been found also on heated ground on Deception Island and South Shetland Island, and on the South Sandwich Islands in Maritime Antarctica (Skotnicki et al., 2001). Growth is enabled by the supply of melt water and condensing steam and is therefore most abundant in the vicinity of fumaroles (Skotnicki et al., 2001). The most extensive stands of moss, often covering more than a hectare, occur in maritime Antarctica. It is common for stands to be dominated by one or two species. It is a noted feature of Antarctic mosses that no more than twelve species accomplish widespread dominance over more than about 25 m^2 (Lewis-Smith, 2007[2]). However, many species may attain dominance on a small scale forming almost pure stands of a few m^2 within more complex communities (Lewis-Smith, 2007[2]).

Antarctic moss species have adapted to the extreme cold and dry environment providing them with the ability to grow and reproduce where they would otherwise be limited. Mosses can photosynthesise (a process which provides energy for growth and reproduction) and some species can photosynthesise at low temperatures (the optimum being 10-15°C), or in some species at or just below freezing point (Lewis-Smith, 2007[2]). Periods of intense sunshine may lead to desiccation which will cause photosynthesis to stop. Growth is therefore intermittent and the annual growth rate is often only a few millimetres. Some genera i.e. *Ceratodon* and *Grimma* (see **Plate II.** a), b)), which occur in exposed habitats (particularly where the level of solar irradiance is high) are dark coloured owing to the synthesis of specialised ultraviolet- protective pigments (Lewis-Smith, 2007[2]).

Mosses communities can influence both microclimate and soil processes to such an extent that they can be considered to be engineers of the Antarctic plant community (Casanova-Katny and Cavieres, 2012). Mosses also support communities of lichens. For example, the moss turf banks in the northern maritime Antarctic formed by *Chorisodontium aciphyllum* and *Polytrichum strictum* support an association of fruticose (i.e. *Usnea aurantiaco-atra* see **Plate IV.** e)) and crustose lichen species (Lewis-Smith, 2007[2]). Moss turfs in the South Orkney Islands also support a high abundance of green algae *Pseudococcomyxa simplex,* while wetter moss carpets host a diverse community of cyanobacteria, green algae, and diatoms (Broady, 2007). Park et al. (2012) found that there was a statistically significant association between mosses and the distribution and successful establishment of *D. antarctica*. This association may occur because of an overlap in environment preference or because moss covering may improve soil properties for *D. antarctica* by maintaining optimal water levels and supplying organic matter (Park et al., 2012). Similarly, Casanova-Katny and Cavieres (2012) found also that moss carpets may help facilitate the growth of Antarctic Hairgrass. Moss communities provide important habitat they have their own microclimates which provides invertebrate fauna with protection from the extreme environment) and food (via decomposers first) for invertebrate fauna such as mites and springtails (Waterhouse, 2001).

Those species depicted in **Plate II** are described in more detail below:

Ceratodon purpureus is a cosmopolitan moss which is common and widely distributed in a variety of habitats in both the maritime and continental Antarctic. It forms dense yellowish-green to brownish-green tufts or turfs, occasionally in extensive patches (Pannewitz et al., 2005; Seppelt, 1984). Its stems are approximately 10-20 mm high and its leaves are 0.8-1.5 mm long (Seppelt, 1984).

Grimmia antarctici forms dense dark green to yellowish-green tufts or turfs, sometimes forming extensive patches. Its stems are approximately 10-50 mm long and its leaves are 1.5 mm in length (Seppelt, 1984).

Bryum argenteum is a cosmopolitan species that forms low dense yellowish-brown to dark brownish-green turfs. Its stems are reddish and approximately 10 mm in length and its leaves are 0.5-1.0 mm long (Seppelt, 1984). It has been found at an elevation of 1540 m on Mont McGee in Victoria Land (Lewis-Smith, 2007[2]).

Sarconeurum glaciale forms low, loose or dense dull green mats. Its stems are approximately 2-6 mm in length and it leaves are 1-2 mm long (Seppelt, 1984).

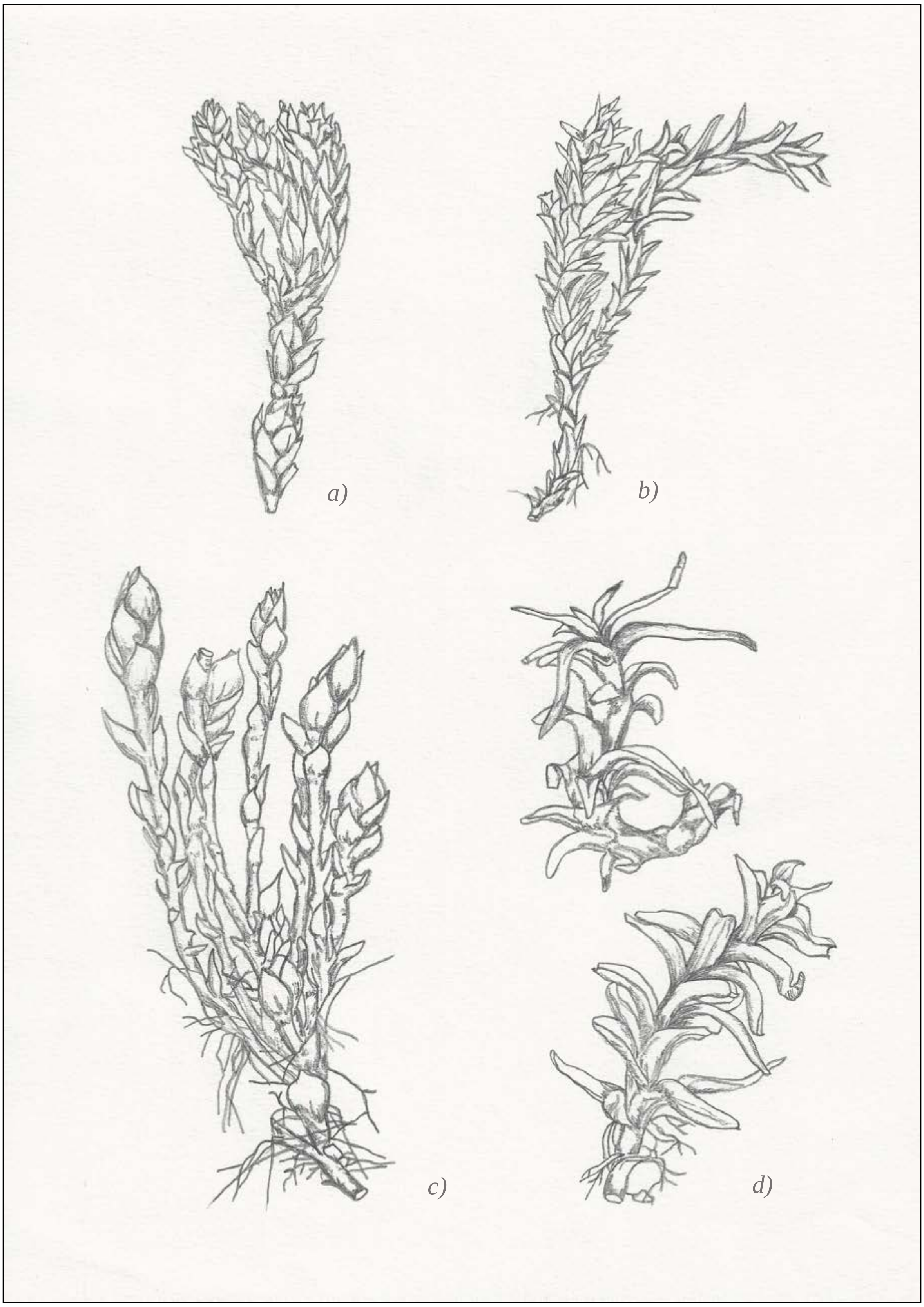

Plate II. Depicting shoot segments of: a) *Ceratodon purpureus*; b) *Grimmia antarctici*; c) *Bryum argenteum*; d) *Sarconeurum glaciale* (images adapted from Seppelt (1984)).

LIVERWORTS

Until recently, liverworts and their close allies mosses were both classified as belonging to the Phylum Bryophyta. However, liverworts are now a separate Phylum (the Marchantiophyta) but are still collectively referred to as Bryophytes (Lewis-Smith, 2007[3]). The physiology, growth, and reproduction of liverworts are very similar to those of mosses (Lewis-Smith, 2007[3]). Like mosses, liverworts lack specialised water-conducting tissues and this restricts them to moist habitats, from which they passively and uncontrollably absorb water and nutrients through their leaves and stems (Lewis-Smith, 2007[3]). Liverworts have two growth forms. The predominant growth form comprises many separate leafy, often unbranched, shoots, which typically form erect colonies of shoots (see **Plate III.** a), b), c), and e)) The other growth form is referred to as thalliod, and this is characterised by prostrate shoots that form small flat strap like interwoven mats which adhere to the substrate (e.g. *Clasmatocolea rigens* see **Plate III.** d)) (Allison and Child, 1975; Lewis-Smith, 2007[3]). Very few Antarctic species reproduce sexually, and most species rely on dispersal and establishment by vegetative means, for example, via detached shoot fragments, tubers and gemmae (small multi-celled propagules that can develop into new plants in favourable conditions) (Lewis-Smith, 2007[3]).

There are approximately twenty-seven species of liverworts in maritime Antarctica and only one species, *Cephaloziella varians*, (see **Plate III.** b)) occurs in continental Antarctica (Lewis-Smith, 2007[3]). This is less than a quarter of the moss flora for the biome and seventy-five percent of the Antarctic liverwort species occur on the tiny Signy Island in the South Orkney Islands. Many species are rare and are only known to exist at a few sites. There are no common names for Antarctic species of liverworts. Due to their physiological intolerance of dry cold conditions, liverworts are predominantly restricted to low-altitude habitats, mainly in coastal areas, with very few extending more than 2 km inland (Lewis-Smith, 2007[3]). The three main habitats occupied by liverworts are geothermal areas, moss turf banks and various fellfield communities (Bednarek-Ochyra et al., 2000). Several species are restricted to, and occur in, geothermal habitats on the South Sandwich Islands (Lewis-Smith, 2007[3]). The liverwort *Campylopus pyriformis* also occurs on the geothermal heated ground of Mount Melbourne, Victoria Land (Skotnicki et al., 2001). Liverworts are very inconspicuous and typically they are associated with mosses and often found to be living amongst them. They rarely form their own communities but sometimes they can achieve small scale dominance within moss-dominated communities (Bednarek-Ochyra et al., 2000; Lewis-Smith, 2007[3]).

Those species depicted in **Plate III** are described in more detail below:

Cryptochila grandiflora forms medium-sized to relatively large, 1-8 cm long, glistening, yellowish-green to greenish- to blackish-brown or reddish- to yellowish-brown, sometimes blackish loose tufts Stems are reddish- or blackish-brown, and leaves are approximately 1-1.5 mm in length (Bednarek-Ochyra et al., 2000). It can be found growing on volcanic ash and debris, on rock ledges, and on gravel in protected moist areas. It occurs mainly in the South Sandwich Islands and on the volcanic Deception Island in the South Shetland Islands (Bednarek-Ochyra et al., 2000).

Cephaloziella varians forms small and delicate lustrous compact patches that are either intertwined with other bryophytes or form their own separate compact patches that are green, yellow-green to brown-green, or deep violet to red-brown or black in colour. The stems are brownish and approximately 2-8 mm in length, and the leaves are 0.1-0.25 mm long. It occurs in moist to wet habitats, commonly as a part of turf and carpet forming moss communities. It is the most common and widespread species of liverwort in the Antarctic and is the only known species to occur in continental Antarctic (Victoria Land, Wilkes and Princess Elizabeth Lands) (Bednarek-Ochyra et al., 2000). It has been found up to 350 msl and on geothermal ground near the summit (2700 msl) of Mount Melbourne in Victoria Land (Lewis-Smith, 2007[3]). Here the temperature may reach over 30°C, maintaining a warm and humid environment for growth.

Barbilophozia hatcheri forms small to large sized, generally robust thin, green, yellowish-green or brownish mats, and its stems are approximately 3 mm in length with leaves that are 1-1.5 mm long. It can be found growing in association with mosses and can also be found on soil, and protected gravelly ground and rocks crevices. It is common and widespread throughout maritime Antarctica (Bednarek-Ochyra et al., 2000).

Clasmatocolea rigens is small, fragile, and may form either dense mats or be scattered amongst mosses. It is pale green to yellowish-brown in colour and the stems are approximately 3-8 mm in length. The leaves are 0.5-0.8 mm long. It occurs on volcanic deposits around fumaroles moistened and warmed by steam. It is a rare species and is only known to exist on two small islands in the South Sandwich Islands from sea level to 135 m (Bednarek-Ochyra et al., 2000).

Marchantia berteroana forms medium to large sized, conspicuous prostrate mats of overlapping strap-shaped stems. It is dull to shiny green, yellowish- to blueish-green in colour and often tinged with brown or purple. The thalli are leathery and approximately 3-5 cm long and 0.6-1 cm wide. It occurs on wet or moist soil, along stream edges; rocks; gravel; cliff ledges; volcanic deposits; on heated ground near fumaroles; on mosses; and amongst *D. antarctica*. It is widely distributed throughout the northern maritime Antarctic and is common on some volcanic islands in the South Sandwich Islands and Deception Island in the South Shetland Islands (Bednarek-Ochyra et al., 2000; Lewis-Smith, 2007[3]).

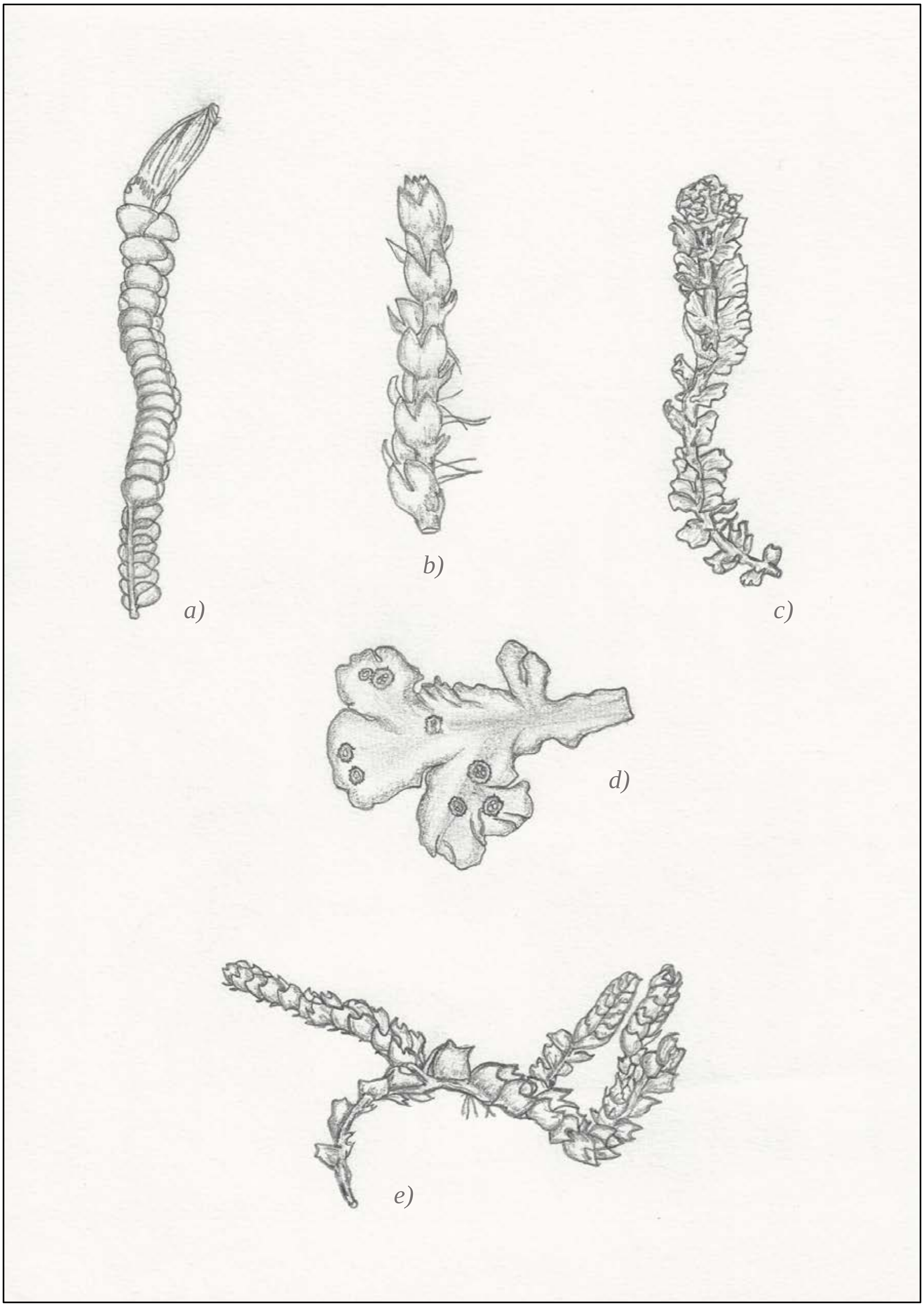

Plate III. Depicting shoot segments of: a) *Cryptochila grandiflora*; b) *Cephaloziella varians*; c) *Barbilophozia hatcheri*; d) *Clasmatocolea rigens*; e) *Marchantia berteroana* (images adapted from Bednarek-Ochyra et al. (2000)).

LICHENS

Lichens predominantly belong to the Phylum Ascomycota (some are Basidiomycetes) based on their fungal component (Lewis-Smith, 2007[4]). Lichens are dual organisms that are formed through a relationship between two symbionts, i.e. a colony of algal cells (photobiont), and a fungus (mycobiont) (Lewis-Smith, 2007[4]; Martin and Child, 1972). This symbiotic relationship is formed when the early developing stages of a fungus captures free living algae cells from the environment and essentially envelops them in a web of mycelium thereby stimulating them to multiply via cell division (Martin and Child, 1972). The algal cells form the photosynthetic component providing energy for growth, while the fungus provides the main structure (thallus) which is responsible for the uptake of nutrients and water from its substrate and the atmosphere (Lewis-Smith, 2007[4]). The thallus is also responsible for reproduction, which can occur either sexually via spores or asexually by various vegetative structures which contain both the fungal and algal components, and are therefore ready to develop into a thallus when conditions are favourable (Lewis-Smith, 2007[4]). Since the fungus (a microorganism that derives its energy saprophytically from decaying organic matter) is the dominant component of a lichen, lichens should strictly be referred to as lichenized fungi and not as plants (which contain chlorophyll and produce their own food via photosynthesis) (Martin and Child, 1972).

The structural form and appearance of lichens are quite distinct from either symbiont living independently and from other plants (Martin and Child, 1972). The growth form of the lichen thallus is dependent on which species of fungus and alga combine (Lewis-Smith, 2007[4]). There are a wide range of growth forms, usually only a few centimetres in diameter and/ or height. The bulk of Antarctic lichen species have a micro foliose (minutely leaf-like) or crustose (encrusting) growth form which ~~closely~~ adheres to the substrate (see **Plate IV.** a) and c)). Other growth forms which typically grow on rocks (attach via root-like rhizines) include the following: larger foliose (leaf-like) (see **Plate IV.** b)), squamulose (thallus consisting of a mass of scale-like lobes); umbilicate (attached by a central stalk) (see **Plate IV.** d)); and fruticose (bushy and greatly branched) (see **Plate IV.** e)). Fruticose species may also colonise mosses and are one of the most common Antarctic lichen growth forms, being found predominantly in maritime Antarctica (Lewis-Smith, 2007[4]).

Lichens are by far the most widespread form of vegetation in Antarctica and occur in ice free areas (Antarctic Division Pamphlet, 1980; Lewis-Smith, 2007[4]). There are approximately 420 species of lichen in the Antarctic, seventy-five percent of which occur in maritime Antarctica (Lewis-Smith, 2007[4]). There are 90-100 species of lichen known from continental Antarctica, 25 of which have been recorded at altitudes above 2000 m. They are generally long-lived and slow-growing, and some large thalli have been estimated to be of ages from 500 to over 5000 years old and may be the oldest living plants on the planet (Lewis-Smith, 2007[4]). Lichens are well adapted to freezing conditions and can still photosynthesise below 0°C but stop photosynthesising when they are exposed to very intense sunlight causing them to become very warm and dry out (Lewis-Smith, 2007[4]). Therefore, growth is restricted to the intermittent periods when lichens are able to photosynthesise effectively. Some species such as *Umbilicaria decussate* and *Buella frigida*, contain dark photo-protective pigments which shield the lichen thallus from potentially damaging ultraviolet radiation, which is greater at the higher altitudes and latitudes of continental Antarctica (Lewis-Smith, 2007[4]).

Lichens may be found growing on soil, rocks, moss turfs, or on volcanically heated ground. For example, one species has been reported on the summit of Mount Melbourne in Victoria Land (Lewis-Smith, 2007[4]; Pannewitz et al., 2005; Skotnicki et al., 2001). Lichens are found in a wide variety of habitats such as, on rock, sand, mosses, weathered bones, feathers, and wood (from historical sites), and they can also occur within rocks as chasmoendoliths and cryptoendoliths, and in the dry valleys, they are the predominant vegetation type and cover large areas of the valley floors, especially north facing aspects (Lewis-Smith, 2007[4]; Seppelt et al., 2010). Cryptoendolithic lichens colonise the subsurface of the Beacon Sandstone in the Trans Antarctic mountains by entering the airspaces of the porous rock as a means of protection against what is considered to be the most hostile environment on Earth (Coenraads, and Koivula, 2007; Lewis-Smith, 2007[4]; Wierzchos, 2007). The mineral content of sandstone is somewhat translucent and thus the lichens can still photosynthesise. They appear under the rock surface as a conspicuous band up to 10 mm deep consisting of distinctive bands of colour. Generally there is first an upper zone comprised of black fungal hyphae, and below this is a white zone of colourless fungal filaments forming a hyphal mesh around the crystals in the rock (mycobiont). Below this is the green zone formed by abundant algal or cyanobacterial cells (photobiont) (Lewis-Smith, 2007[4]). The black pigmentation of the mycobiont hyphae may be an adaption to the environment as it absorbs light, thereby increasing the temperature of the air spaces in the rock (Wierzchos, 2007). The structure of cryptoendolithic lichens differs to that of other lichens in that it grows between and around the crystals of the rock, and is embedded in the rock matrix.

Those species depicted in **Plate IV** are described in more detail below:

Caloplaca sp. and *Xanthoria elegans* are both crustose lichens and are nitrophilous (nitrogen loving) and are brightly coloured yellow and orange respectively. *Xanthoria* sp. have been found growing on moss cushions in continental Antarctica (Lewis-Smith, 2007[4]).

Umbilicaria antarctica is pinky-grey in colour and is one of several umbilicate species of lichen occurring in Antarctica and are particularly abundant on sheltered coastal cliffs in the maritime Antarctic, and can grow to exceptional sizes (Lewis-Smith, 2007[4]).

Usnea aurantiaco-atra is a large bushy grey-yellow coloured common fruticose lichen that festoons cliffs and covers rocky hillsides (Lewis-Smith, 2007[4]).

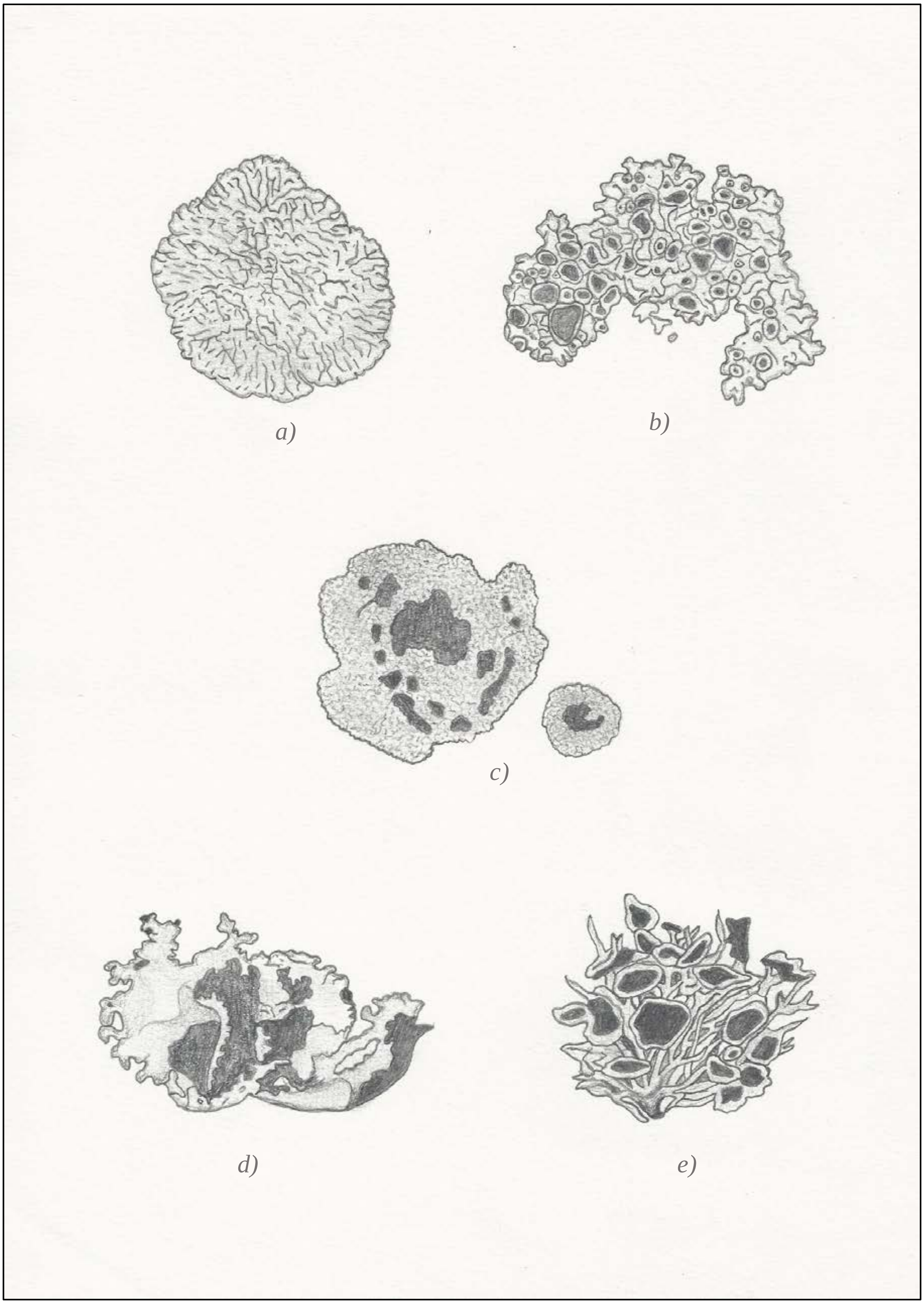

Plate IV. Depicting: a) *Caloplaca* sp.; b) An example of a foliose growth form; c) *Xanthoria elegans*; d) *Umbilicaria antarctica*; e) *Usnea aurantiaco-atra*.

FUNGI

Fungi exhibit characteristics of both plants and animals, but they are not classed as belonging to either group. Fungi are such unique organisms that they have been given their own Kingdom- the Kingdom of Fungi (Raven et al., 2005). Fungi are one of the primary decomposers of dead organic matter in the biosphere and play a significant role in ecosystem functioning (Raven et al., 2005). The most evident Antarctic fungi are those forming lichens. There are however, other types of fungi found in the Antarctic. There are many different groups of fungi which can range from simple yeast cells to complex fruiting bodies (e.g. common mushrooms which are absent from Antarctica) (Bridge, 2007). There are at least 870 species of fungi found within the Antarctic Polar front. In general most macrofungi and basidiomycetes are restricted in their distribution to the sub-Antarctic and the Antarctic Peninsula (Bridge, 2007). Microfungi, particularly ascomycetes, zygomycetes, and yeasts are widespread throughout the maritime and continental Antarctic ecosystem (Bridge, 2007). Fungi are well known in the rock-dwelling cryptoendolithic communities and some fungi, particularly yeasts are prevalent in Antarctic soils. One species *Lecanicillium lecannii* has been found living together with bacteria and algae in mineral crusts (Bridge, 2007). Thermophilic (heat-loving) fungi have been isolated from soil taken from Mt Erebus (Bridge, 2007). Fungi are be found also living within moss vegetation for example, *Phoma* sp. (Bridge, 2007; Rosa et al., 2010).

The extent of the ecological role of fungi within the Antarctic ecosystem is largely unknown. Fungi can impact on the ecology, fitness, and shaping of plant communities, conferring resistance to abiotic (temperature, pH, osmotic pressure) and biotic stresses (Rosa et al., 2010). Some fungi form mycorrhizal associations with plants. Recent studies have found unique potentially mycorrhizal relationships on the Antarctic Peninsula between the fungus *Hymenoscyphus ericae* and the liverwort *Cephaloziella exiliflora*; the fungi *Glomus antarcticum* and the grass *D. antarctica*; and mycorrhizal associations have been identified from the roots of Antarctic Pearlwort (Bridge, 2007; Rosa et al., 2010). Fungi probably represent an important part of the food chain by utilising carbon directly from primary producers or when it has been released by decomposition processes, and then are consumed by invertebrates (Bridge, 2007). New molecular studies elude to the possibility that there may be many more species of Antarctic fungi that have not yet been formally identified. Identifying their ecological role will also be of importance to furthering our knowledge of how fungi contribute to ecosystem functioning in the Antarctic (Bridge, 2007).

ALGAE

Algae are photosynthetic eukaryotic organisms (Raven et al., 2005). It is estimated that there may be as many as 700-1000 species of algae occurring within maritime and continental Antarctica (Broady, 2007). Apart from the algae living within lichens there are many other forms of terrestrial algae living within Antarctica such as cyanobacteria (also known as "blue-green algae" which are primitive oxygen-producing photosynthetic organisms); green algae (Chlorophyta); diatoms and yellow-green algae, all of which are probably the major primary producers in the terrestrial ecosystems of Antarctica. They are abundant in moist mineral soils (often formed as crusts;, as epiphytes in moss-dominated systems; in any wet area on, under, and beside stones; in the cryptic habitats forming chasmoendolithic (in narrow fissures penetrating the rock surface); and cryptoendolithic communities (Broady, 2007). Six algae species and six cyanobacteria species have been found living on volcanically heated ground on Mount Melbourne, Victoria Land (Skotnicki et al., 2001). The ability of algae, especially cyanobacteria, to inhabit cryptic habitats makes them the dominant vegetation type in the extensive cold deserts, for example, in the dry valleys of southern Victoria Land and at the Vestfold Hills (Broady, 2007).

Surface algal crusts can support diverse communities of microorganisms, nematodes, tardigrades and protozoa (Waterhouse, 2001). Together with fungi, the algae are probably an important component of the food chain of Antarctica, acting as food for fauna (Davidson and Broady 1996). Direct herbivory of bryophytes and lichens is not common in Antarctica, possibly due to energetic constraints of the bryophytes and lichens which is common for these plant groups, but secondary herbivory after organic matter is broken down by decomposers is more common (Waterhouse, 2001).

FUTURE OF ANTARCTIC PLANT ECOLOGY AND DIVERSITY

A better knowledge of Antarctic terrestrial plant ecophysiology and composition of the flora and plant community structure is required, as it is thought that the terrestrial ecosystem may provide early indicators of the effects of climate change, particularly through the effects of increased temperatures (Pannewitz et al., 2005; Seppelt et al., 2010). As mentioned previously, regional climate change in the maritime Antarctic has seen an increase in the mean annual temperature and it is now 1-2°C higher than it was 50 years ago and this trend is predicted to accelerate over the main part of the continent over the next century (Guglielmin et al., 2014; Hughes and Convey, 2012; Lewis-Smith, 2007[1]). This has led to more ice free areas available for plant colonisation. The regional warming of maritime Antarctica, in particular the Antarctic Peninsula, and to a lesser degree across the West Antarctic, may see new species colonise and become components of established communities, while the status of some existing species may change, causing a shift in dominance (Lewis-Smith, 2007[1]). For example, populations of the Antarctic Pearlwort and the Antarctic Hairgrass have increased in both number and size and this has been attributed to regional warming (Holderegger et al., 2003). If the warming trends start to influence continental Antarctica it is likely that there will also be a significant increase in the extent of moss cover (Seppelt et al., 2010). Regional warming may also lead to changes to the local environmental conditions which in turn may increase the likelihood of the establishment of exotic species. This is because, the existing establishment barrier for natural and introduced species will be reduced thereby making it easier for invasions to happen and increasing their chances of colonisation and filling empty niches (Bednarek-Ochyra et al., 2000; Hughes et al., 2010; Wierzchos, 2007). For, example, according to the Global Invasive Species Database (which lists the most environmentally damaging invasive species on Earth), two of the most damaging invasive species are already found in Antarctica (the grasses *Poa annua* and *Poa pratensis*) and their distribution could increase with conditions becoming more favourable for them (Hughes and Convey, 2012).

Other threats to the flora or Antarctica include anthropogenic (human-mediated) disturbance. For example, recent increases in the presence and activities of national Antarctic programmes and the number of tourists landing in the maritime Antarctic, particularly on the Antarctic Peninsula, may lead to greater ground disturbance of these fragile Antarctic plant communities and increase the potential for introduction of exotic species or cross contamination between native plant communities from different areas (Hughes and Convey, 2012; Terauds et al., 2012). Anthropogenic activities that interact with Antarctic plant communities are currently managed and protected by the Protocol on Environmental Protection to the Antarctic Treaty, and some areas that contain extensive plant communities with diverse flora (deemed of scientific interest) have been designated as Antarctic Protected Areas or Specially Protected Areas, and to enter these areas requires permits (Bednarek-Ochyra et al., 2000). However, there are concerns that this protected area system needs further refinement (Hughes et al., 2013).

Continued research into the current and future effects of climate change, introduction of non-native species, and increased human activity on the plant communities of Antarctica is urgently required.

Such research would provide robust baseline data, and on-going monitoring of particularly high risk locations. This information, could then be utilised by policy makers who might then be able to make informed judgements about what actions need to be taken (Hughes and Convey, 2012). The future of the Antarctic flora depends on several factors: the rate of increase of anthropogenic activities in Antarctica; the effectiveness of intercontinental and inter-regional biosecurity protection measures applied by all national Antarctic programmes and other visiting parties to the Antarctic; the strengthening of protected area system legislation; and the amount of long-term investment in biosecurity measures and monitoring. It is necessary for the Antarctic community (Committee for Environmental Protection, Antarctic Treaty Parties and other organisations such as the Scientific Committee on Antarctic Research) to recognise the current threats facing the Antarctic flora and to take a united widespread approach, adopting practises and taking action, in order to prevent and mitigate these impacts. Only then will the effective protection and preservation of the ecological integrity and function of these fragile plant communities be achieved, before they are irrevocably damaged and their use for current and future science is compromised (Hughes and Convey, 2010; Hughes and Convey, 2012; Hughes et al., 2013).

GLOSSARY

B

Biodiversity- the degree of variation of life. It is a measure of the variety of organisms present in different ecosystems. This can refer to genetic variation, ecosystem variation, or species variation (number of species) within a prescribed area.

Biotic- relating to life.

Biosphere- the zone of air, land, and water at the surface of the Earth that is inhabited by organisms.

C

Cryptoendoliths- are organisms that live inside rocks or in pores between mineral grains.

Chasmoendoliths- are organisms that live in fissures and cracks in the rock.

E

Eukaryote- a cell that has a membrane-bounded nucleus, organelles and chromosomes in which the DNA is associated with proteins.

F

Fellfield- is typically a slope, usually in an alpine or tundra environment, where the dynamics of frost (freeze and thaw cycles) and of wind give rise to characteristic plant forms in scree (lose rock) gaps.

K

Kingdom- the highest of the seven chief taxonomic categories.

M

Mycelium- a mass of fine elongate, segmented thread like fungal cells.

Mycobiont- the fungus component of a lichen thallus.

Mycorrhiza- a symbiotic relationship between certain fungi and plant roots.

N

Nunataks- are exposed, often rocky part of a ridge, mountain, or peak that is not covered with ice or snow within (or at the edge of) an ice field or glacier.

P

Photobiont- the algal component of a lichen thallus.

Phylum- a taxonomic rank below kingdom and above class.

S

Saprophytic- living on dead organic matter as a source of nourishment.

Symbiont- one of two dissimilar organisms living together with mutual benefit.

T

Thallus- the vegetative part of a lichen and/or a liverwort.

X

Xeric- an environment or habitat containing very little moisture, very dry.

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Plate IV. a) *Caloplaca* sp. - image adapted from: http://www.racerocks.com/racerock/eco/taxalab/2008/caloplacav/caloplaca2.jpg. Retrieved February 24, 2015 from: http://www.racerocks.com/racerock/eco/taxalab/2008/caloplacav/caloplacav.htm.

Plate IV. b) An example of foliose growth form- image adapted from: https://encrypted-tbn3.gstatic.com/images?q=tbn:ANd9GcS1UKqIv-FgIidofULByIIGwjUfbcTfUclStnzD0yKj_JypGe-13BETlA. Retrieved February 24, 2015 from: http://www.stridvall.se/lichens/gallery/Xanthoria/NIKB0224?full=1.

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Plate IV. e) *Usnea aurantiaco-atra* - image adapted from: http://i.colnect.net/images/t/1567/948/Usnea-Aurantiaco-Atra.jpg. Retrieved February 24, 2015 from: http://colnect.com/en/stamps/list/series/114140-Lichens/country/19449-British_Antarctic_Territory_BAT.