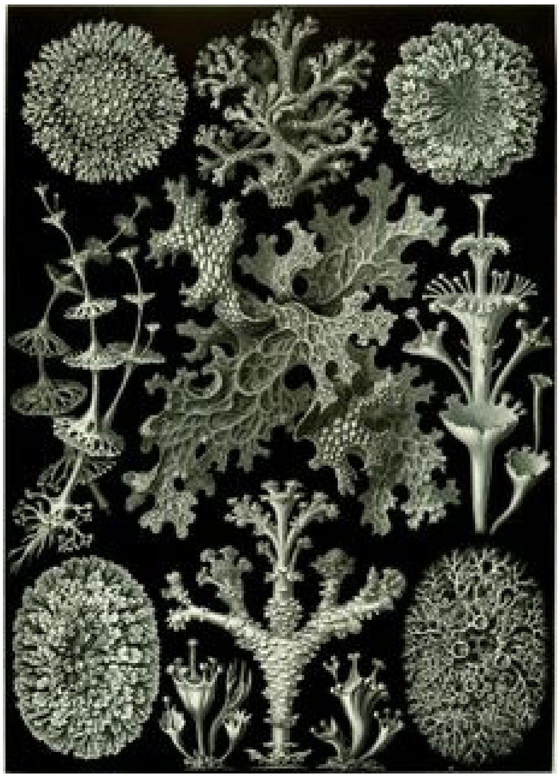
Plant Survival in Antarctica:

The Lichens of Continental Antarctica



"Lichenes" from Ernst Haeckel's *Artforms of Nature*, 1904

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Introduction

Antarctica is not the sort of place you would expect to find plants, yet it has an extremely interesting variety of vegetation. Antarctic flora has been studied extensively, with the most intense focus over the last forty years (Green et al. 1999). It is an interesting area of study because of both the isolation and extreme growing conditions of the area (Brabyn et al. 2005). The ability to survive in the terrestrial habitats of Antarctica requires organisms to possess a wide variety of unique adaptations.

This report is an introduction to the terrestrial vegetation found in Antarctica, with a more in-depth focus on the adaptations of lichens. Extensive literature exists in the areas of Antarctic botany and ecology and these topics are becoming even more relevant with the threat of global environmental changes. Many scientists (Brabyn et al. 2005, Green et al. 1999, Robinson et al. 2003) have stressed the importance of understanding Antarctic terrestrial ecosystems, in order to ensure their continued management and protection.

Antarctic climate

Antarctica is known as one of the world's harshest environments. It is difficult to summarise the Antarctic climate as it is a huge area with a wide range of climatic conditions. In particular, factors such as temperature, precipitation and day-length are very different when comparing different latitudinal areas (Ovstedal & Lewis Smith 2001). However, there are some generalisations that can be made about the continent.

Even during the summer, temperatures in most areas of Antarctica are usually below freezing. Due to Antarctica's location in the southern latitudes, it experiences months of complete darkness followed by months of continuous sunlight. It is the driest continent in the world, with most precipitation occurring only in coastal areas. Most precipitation falls as snow and therefore there is a severe lack of free water. Antarctica also experiences the strongest winds in the world.

Climatic zones

Some widely agreed climatic zones have been established for the Antarctic continent. Green et al. (1999) note that these zones reflect separations in both climate and vegetation.

The first zone is referred to as the maritime Antarctic and includes the western side of the Antarctic Peninsula, north of Alexander Island and its adjacent islands. This area is relatively warm and receives some rain in summer.

The other zone is the continental Antarctic, also referred to by Longton (1988) as the frigid Antarctic. This area includes the main Antarctic continent, including the eastern section of the Antarctic Peninsula. Continental Antarctica is much colder than the maritime zone and receives less precipitation. In the McMurdo area annual precipitation is about 120mm, while in the Dry Valley region it can be as low as 10-50mm (Green et al. 1999).

Terrestrial Vegetation

The diversity of terrestrial vegetation in Antarctica is limited by the harsh climate. Conditions are not typically ideal for vegetation growth. The majority of the continent (98%) is covered in ice, with the remaining area consisting of bare rock (Brabyn et al. 2005). Terrestrial vegetation is limited to small, isolated, ice-free areas on the continent and the islands adjacent to the Antarctic Peninsula (Kappen 2000).

There are only two species of vascular plants in Antarctica and both are found in the warmer maritime zone, where conditions are much more suitable for vegetation growth. One of these plants, *Deschampsia antarctica*, is a small grass and the other, *Colobanthus quitensis,* is a cushion plant. Kappen (2000) notes that vascular plants have never evolved mechanisms for avoiding cold stress, and are therefore not able to survive in the continental Antarctic.
The dominant vegetation in Antarctica are the lichens and mosses. Currently, 360 taxa of lichens and 104 taxa of moss are recognised. There are also 25 liverwort taxa and about 200 taxa of terrestrial algae (Kappen 2000). Although algae are not plants, they are an important part of the terrestrial ecosystems

and as discussed later, play an important role in the formation of lichens. Other micro-organisms such as fungi and bacteria also feature in terrestrial communities.

Biodiversity is dramatically affected by climate and obvious trends can be seen when moving to higher latitude areas. Green et al. (1999) notes that overall there is an 80% loss of species between the peninsula and the main continent. Whereas 90 species of moss and 200 species of lichen grow in parts of the peninsula, this drops to only 7 and 33 on the continent. Generally, moss species are found closer to coastal areas and the lichen vegetation is more dominant further inland. Lichens predominate in drier and exposed areas, while mosses are restricted to more sheltered areas with higher precipitation (Robinson et al. 2003).

Antarctic Lichens

"Every visitor to the Antarctic will agree that lichens are among the most obvious and therefore successful organisms on land…"

Kappen (1993)

Morphology

Lichens could be referred to as the ambiguous plants, as they fit into a category quite distinct from typical classification. They are actually composed of two species living in a symbiotic relationship. The main part of the lichen is a fungus, which acts as a host to an algae or cyanobacteria. The combination of the two looks quite different from either fungi or algae on their own. Both species benefit from the arrangement and it has been suggested that the success of lichens is related to their symbiotic nature (Kappen 1993).The relationship between fungi and algae is like a small ecosystem, suggesting that lichens are able to survive more easily in a range of habitats, particularly extreme environments such as Antarctica (Kappen 1993).

In terms of scientific classification, lichens are not actually regarded as plants, as they are considered more closely related to the fungi kingdom. However, as noted by Green et al. (1999), they are still included in discussions of Antarctic plants, due to their ability to photosynthesise and their abundance in Antarctic terrestrial ecosystems.

The fungal component of the lichen, or mycobiont, usually provides the overall shape and structure (Campbell & Reece 2005). It is composed of "densely packed hyphae" (Longton 1988) which can absorb minerals and water. The algal component, or photobiont, is able to photosynthesise and therefore provides the food for the lichen. The main body of the lichen is called the thallus and it is fixed to the substrate by structures called rhizines (part of the fungi). The thallus is often composed of many layers, with hyphae surrounding the algae (Campbell & Reece 2005).

The overall structure of lichens varies and three main growth forms are recognised (see Figure 1). Crustose lichens grow in a thin crust on the surface of the substrate. Foliose lichens form leaf-like lobes, and fruticose lichens have a shrub-like growth.

Figure 1: Photos of the three lichen growth forms. From left: crustose, foliose and fruticose lichens. (http://eve.kean.edu/~breid/Botany/botlab11.html)

Colonisation and Growth

Lichens reproduce both sexually and asexually. The fungal component can produce spores which are carried to a new location. In order for a new lichen to become established, the spore must find a suitable photobiont (algae). As Kappen (1993) points out, these algae are rarely found free-living in Antarctica, so it seems unlikely that this would be a successful form of reproduction. However, most lichens in Antarctica are of the crustose form, which usually produce spores in order to reproduce (Kappen 2000).

Asexual reproduction of the lichen is accomplished through production of vegetative propagules, which contain both fungi and algae. This occurs either by fragmentation of the original lichen or by the formation of small clusters of hyphae with algae contained inside, called soredia (Campbell & Reece 2005). Laboratory investigations have found that few lichens will re-establish from a cultured fragment (Graham & Wilcox 2000). Graham and Wilcox (2000, pp 62) note that “in many cases the associations must re-form in nature by accidental contact between fungi and appropriate algae”. However, Kappen (2000) suggests that this form of vegetative reproduction is the most successful in terms of the establishment of lichens in Antarctica.

Lichens are able to colonise any solid substrate, such as rock, concrete, bones, wood and dead moss (Kappen 2000). Growth is restricted to ice-free areas, known as oases, in continental Antarctica. These include small rocky outcrops on the coast, the Dry Valleys and inland nunataks, which are the tops of mountains sticking through the ice (Robinson et al. 2003). Lichens do not need to grow in areas with soil, as they have no roots (Kappen 2000). They have very low mineral requirements and are able to obtain necessary nutrients through the precipitation they absorb (Robinson et al. 2003).

Lichens grow extremely slowly, with those in warmer areas growing about one centimetre a year. The few species of lichens growing in the Dry Valleys will take about a thousand years to grow the same amount (Trewby 2002). With increasing latitude, lichens become the dominant form of vegetation, as they are not competing with mosses (Kappen 2000). Lichens have been found growing as far south as 86˚. Crustose and foliose lichens are the main growth forms found in continental Antarctica (Longton 1988) and in areas with less precipitation only crustose species are found (Green 2001).

The limiting factors for growth of lichens are the same as for other plants. In order to photosynthesise, suitable levels of light are required, as well as the presence of water and carbon dioxide. Other factors, such as temperature and protection from the wind are also important for the survival of lichens. In Antarctica, the presence of vegetation, such as lichens and mosses, relies most strongly on the availability of moisture (Green et al. 1999).

Lichen Adaptations

"Antarctica is the coldest, driest, highest, and windiest continent; the lichens and mosses grow where it is warm, wet, low, and protected."
Green et al. (1999)

Survival in an environment such as Antarctica relies on lichens possessing certain adaptations. Green et al. (1999) note that many Antarctic lichens show the same abilities as those found in temperate climates and do not necessarily possess special adaptations for the region. However, strong selection exists for species that can tolerate the Antarctic conditions. This is demonstrated by the drop in species numbers at higher latitudes and further inland (Green et al. 1999).

Desiccation Tolerance

Much of continental Antarctica is considered a cold desert, with long periods of little or no precipitation. Lichens, as well as other vegetation such as mosses, can only grow where liquid water is available for some of the year (Green et al. 1999). During the summer months this water can come from sources such as glacier and snow melt. Kappen (2000) refers to the work of Schlensog et al. (1997), who found snow melt to be the major source of hydration for the productivity of lichens.

Lichens are known as poikilohydrous, or resurrection plants. This means they have no mechanisms for controlling water loss, but rather exist in an equilibrium with the moisture in the air or substrate (Kappen 1993). They are able to withstand long periods of desiccation by shutting down all metabolic activities and entering a "dormant state of physiological inactivity through controlled dehydration of their cells" (Robinson et al. 2003). Lichens are able to survive water loss of more than 95% (Kappen 1993)

In order to resume metabolic activities, such as photosynthesis, the thalli must become rehydrated. This can occur when wind blows snow over the lichens and some melting occurs, or when moisture is gained from the humidity at the edge of snow patches on rocks (Kappen 2000), as seen in the photo below (Figure 2).

Rehydration begins in spring and is followed by a short summer growing season of between one to four months (Robinson et al. 2003). This explains the slow growth of many lichens, particularly in the driest areas of Antarctica such as the Dry Valleys. However, it should be noted that higher temperatures are not always required for rehydration to occur. Kappen (2000) discusses the ability of some lichens to become activated by water vapour from snow at temperatures as low as -20°C.

Figure 2. Granitic rock with partial snow cover in the early summer season (November) near the beach of Botany Bay, south Victoria Land. Snow melts off within a period of 3-4 days and irregular trickles of meltwater soak the thalli of *Buelliafiigida* on the rock surface. (Kappen 2000)

There are important links between precipitation and temperature. During the warmer summer months, water is quickly evaporated by high light conditions. As water loss inactivates the thalli of lichens, it thereby acts as a mechanism for avoiding heat-induced respiratory loss (Kappen 1993). Desiccation is one of the means used by poikilohydric plants to avoid high light and high temperature stress (Kappen 1988).

During the winter, lack of water is due to moisture being held as snow and ice. It has been suggested that tolerance to desiccation has the same physiological basis as tolerance of subzero temperatures. This could explain why similar organisms, such as lichens, are found in both deserts and polar regions (Green et al. 2003).

Temperature Tolerance

Lichens in Antarctica are able to withstand an extreme range of temperatures. Although the ambient temperature in continental Antarctica usually stays below 0°C, lichens are exposed to higher temperatures on the substrata on which they grow. They must also be tolerant to freezing conditions during the long winter season.

In summer, the surface of dark-coloured rocks can reach temperatures of 30°C (McGonigal & Woodworth 2001). This warmth is mostly beneficial to the growth of lichens, but higher temperatures also coincide with water loss, as discussed previously. The associated water loss inactivates the thalli of the lichen, thus preventing heat stress damage. Kappen (1993) states that lichens are able to tolerate heating to temperatures over 30°C. A range of laboratory and field investigations have looked at the optimal temperature for photosynthesis in various lichen species, finding a range of between 11°C and 20°C (Kappen 2000).

One of the most interesting adaptations of polar organisms is their ability to tolerate being frozen. This characteristic of lichens has been investigated quite extensively (Kappen 2000). Impressively, lichens can tolerate gradual or rapid freezing down to – 196°C (Kappen 1993). Even though water freezes at 0°C, lichens and other polar vegetation are able to lower the freezing point of their cellular fluids. They accomplish this by having dissolved ions and molecules in their cells (McGonigal & Woodworth 2001).

Lichens are widely known to photosynthesise at temperatures below zero, with species such as *Umbilicaria aprina* doing so at – 17°C (McGonigal & Woodworth 2001). The lowest recorded temperature at which lichens have been found to photosynthesise is – 24°C (Green et al. 1999). As thawing begins at the end of winter, lichens are able to begin photosynthesising again very rapidly. Kappen (1993, pp 459) refers to investigations of several lichens that were able to resume normal photosynthesis within a few hours of being rewarmed to 10°C, after being frozen at – 196°C. This ability is extremely important, when combined with the desiccation tolerance of lichens. Green et al. (2003) suggests that it is not enough for lichens to be either resistant to desiccation or low temperatures, but they must have the ability to photosynthesise by utilising humid air during subzero conditions.

Light Protective Pigments

The extremes of light in Antarctica pose some serious issues for photosynthetic organisms. The ability of lichens to remain metabolically inactive during the dark winter months has already been discussed. Lichens are able to store enough carbohydrates to ensure cell structures are ready to resume photosynthesis when spring arrives (McGonigal & Woodworth 2001).

Summer months in Antarctica are characterised by continuous high light levels, while temperatures remain relatively low on the continent. This combination can be harmful for plants and often causes photoinhibition in higher plants (Green et al. 1999). Low temperatures cause cell reactions, such as photosynthesis, to slow down. If this coincides with strong levels of radiant energy, chlorophyll can become damaged easily (McGonigal & Woodworth 2001).

Investigations of lichen species have found that they do not suffer from photo stress in strong light (Kappen 2000). Lichens respond to these extreme conditions by producing pigments that act to absorb most of the damaging light (McGonigal & Woodworth 2001). The fungal component of the lichen produces the pigments, which protect the photobionts (Green et al. 1999). This is an important adaptation, as lichens are most active during the summer months when light levels are high and temperatures are often low. These pigments, called anthocyanins, cause the characteristic lichen colours, such as orange, yellow and black.

Endolithic Lichens

One of the most interesting examples of Antarctic adaptations is that of the endolithic species. Endolithic organisms are those that live either under the surface of rocks or in small cracks in rocks (Green 2001). In Antarctica this includes both lichens and algae and there are many advantages to this interesting way of life.

Endolithic lichens are found in areas of Antarctica with low precipitation, such as the Dry Valleys (Green et al. 1999). The rocks provide some shelter, warmth and moisture, and lichens are still able to receive enough light for photosynthesis. More moisture is received than from the open air, as the rocks are porous and help trap water (McGonigal & Woodworth 2001, Green et al. 1999).

Aspect is important in the establishment of endolithic communities, as they must be able to receive enough sunlight. For this reason they are only found on North facing or horizontal surfaces of rocks where insolation is received (Green et al. 1999). Rock type is also important and lichens will only grow within porous rocks such as sandstone and limestone (Green et al. 1999). The most studied lichens in this group are the cryptoendolithic lichens, which can penetrate up to 2 cm into sandstone in the Dry Valleys (Green 2001).

Conclusion

There are many reasons to study terrestrial vegetation in extreme environments such as Antarctica. Green et al. (1999) suggest that we still do not have “a good understanding of both the distribution and functioning” of many organisms in the area. They conclude that this knowledge is of increasing importance, as there is potential to use vegetation to help detect environmental changes. Others, such as Brabyn et al. (2005) would agree with this conclusion, and they believe lichens are of particular interest due to their sensitivity to “subtle climatic and chemical changes”. Lichens are already used as indicators of air pollution in many parts of the world (Trewby 2002)

Environmental changes are already being seen in Antarctica, such as temperature increases in the Antarctic Peninsula region and increased levels of ultraviolet B radiation due to the depletion of the ozone layer. Many scientists have agreed that the Antarctic is an ideal system for detecting future environmental changes (Robinson et al. 2003). With continued research and interest in this area, our knowledge of the ability of organisms to adapt to changes in their environment will become increasingly valuable.

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