Lichen Life in Antarctica

A review on growth and environmental adaptations of lichens in Antarctica

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Contents

Antarctic Vegetation

Antarctica is a harsh environment with very little vegetation. The Antarctic continent and the surrounding areas can be divided into two or three general regions. Most often the continental area of Antarctica is identified, with the Antarctic Peninsula being included as the maritime Antarctic due to oceanic influences (Lindsay, 1978; Sancho and Pintado, 2004). Usually a third area is also identified as being separate from the maritime antarctic, the sub antarctic (Robinson et al., 2003). The focus of this review is the continental and maritime regions.

There are only two native flowering plants in Antarctica, with the terrestrial vegetation being primarily composed of cryptograms. Lichen are the most species rich, with 350 species currently described (Kappen, 2000; Robinson et al., 2003). However, there is some debate about this total, depending on classifications, with a more conservative total also being put forward (Lindsay, 1978).

The Basics of Lichen Life

Lichens are well adapted for life in Antarctica. They can cope with long periods of drought, have protective mechanisms to avoid damage from high radiation, and can withstand freezing temperatures (Bartak et al., 2007; Kappen, 2000; Ovstedal and Lewis-Smith, 2001; Robinson et al., 2003). These adaptations all have implications for growth and survival, particularly in response to climate change and human activities. Lichen growth is in particular, important as it varies between regions and species, and there is little known about this aspect of Antarctic lichen physiology (Green et al., 1999; Ovstedal and Lewis-Smith, 2001).

The Lichen Symbiosis

Lichens are a mutualistic symbiosis between algal and fungal components. These components are known as the phycobiont and mycobiont, respectively. The phycobiont is the photosynthetic component of the lichen. The mycobiont almost always dictates the form of the lichen thalli (Raven et al., 2005). Sometimes cyanobacteria (prokaryotic algae) are the photosynthetic component, known as the cyanobiont (Kappen, 2000). Generally only eukaryotic algae are the photosynthetic component of lichens in Antarctica (Kappen, 2000). When cyanobacteria are used, lichens do not select for particular species of cyanobionts, as an adaptation to distribution in harsh environments rather than to metabolic mechanisms. (Wirtz et al., 2003). The structure of the lichen mutualism is summarised in Figure 1.

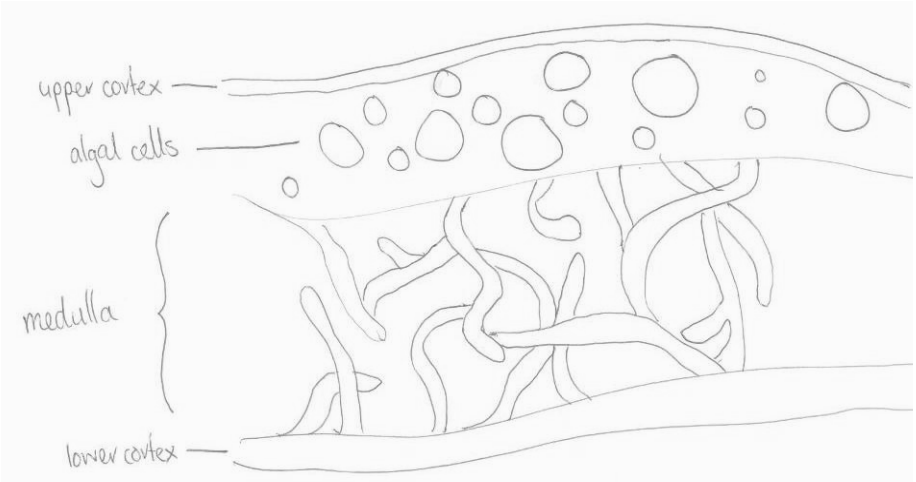

Figure 1. Diagram illustrating the general structure of a lichen mutualism. The cortex is made of closely packed fungal hyphae. The algal cells are dispersed within a hyphal layer and the medulla is made up of intertwined hyphae.

Lichen Growth Forms

Lichens occur as three different growth forms; crustose, foliose and fruticose. Crustose lichens grow encrusted on the substrate; foliose lichens have large, leaf-like branches, while fruticose lichens have thinner, stringier branches. Examples of all growth forms can be found in Antarctica, however sometimes the differences can be hard to detect. *Xanthoria elegans*, a common Antarctic lichen, is defined as a foliose lichen, however due to environmental pressures , its growth in Antarctica is more similar to that of crustose lichens, (Hooker, 1980b). *Usnea antarctica*, an ecologically important lichen in Antarctica (Lindsay, 1978), has a fruticose growth form. This species colonises a wide variety of habitats, and is generally found to grow to 40mm in length (Schroeter et al., 1995). Lichens are found all over the world in many different environments, due to their ability to survive environmental extremes. They are significant components of Antarctic vegetation, where they have an altitudinal limit in Antarctica of 2500m (Ovstedal and Lewis-Smith, 2001), and can be found up to 86°S (Broady and Weinstein, 1998).

Lichen Reproduction

Lichen can reproduce sexually through the dispersal of ascospores, or vegetatively through the release and dispersal of soredia (Marshall, 1996). Soredia are clusters of algal cells and associated fungal hyphae, which are released and dispersed through wind (Green et al., 1999; Kappen, 2000; Raven et al., 2005). Isidia are also vegetative reproductive organs, which protrude from the lichen thallus and break off (Seymour et al., 2005). This form of reproduction has an advantage in extreme habitats as the thallus can quickly become established (Seymour et al., 2005).

Importance of Lichens in Antarctica

The growth of lichen is vital to Antarctic ecosystems, where vegetation is limited, as they are involved in soil processes, nutrient cycling and are the initial colonisers in successions (Lindsay, 1978). Lichens are well known as successful agents in the weathering of rocks (Chen et al., 2000) and can break down rock substrate as the first stage of soil formation, which also allows other species to grow. However, it is thought that in Antarctica, this process is completed through physical weathering, rather than being attributed to lichens (DeLosRios et al., 2005). Lichens can provide a habitat and shelter for other organisms, such as mite and tardigrade species (Green et al., 1999; Ovstedal and Lewis-Smith, 2001).

Growth in the Antarctic environment can be considered impressive, as it is the coldest, and driest place on earth (Sancho et al., 2007), however, it has been identified that for lichen species these are “normal” conditions for growth (Robinson et al., 2003). Lichens tend to inhabit the more exposed areas(Marshall, 1996), whereas other vegetation such as mosses, grow in sheltered areas, with more constant available water (Ovstedal and Lewis-Smith, 2001).

Most lichen species inhabit areas such as bare rock and stable soil surfaces (Kappen, 2000). However, they also occupy habitats which are sheltered and have an available water source (Kappen, 2000). These different substrate and habitat preferences are due to different responses to environmental factors.

Environmental Influences

Nutrients

Available nutrients will impact on the presence of lichen species in areas of continental and maritime Antarctica (Robinson et al., 2003). Terrestrial environments generally have low available nutrients, aside from those derived from sea spray and weathering, and areas near penguin and seal colonies (Lindsay, 1978). High levels of nutrients, particularly nitrogen, can be found near penguin and seal colonies. Some species of lichens are adapted to high nitrogen levels, whereas others are adapted to low levels of nitrogen. These are known as nitrophilous and they are found near penguin colonies (Ovstedal and Lewis-Smith, 2001). Salinity levels can also affect lichen growth, as many species grow near the Antarctic coast. Some crustose species have been found to tolerate high salt levels around the coastal areas, whereas the fruticose and foliose lichens were more restricted. For example, on Ross Island, *U. antarctica* can be restricted to areas where there is little wind blown salt (Broady, 1989).

Water Relations and Temperature

Antarctica is the driest continent in the world, and this means that lichens need to have mechanisms in place to survive long periods of dehydration combined with freezing temperatures, and intense radiation at certain times of the year. Lichens are poikilohydric organisms, that is they have the ability to dehydrate, and implement mechanisms to survive long periods of dessication (Kappen, 2000). Generally lichens receive water from snow melt in spring and summer conditions, but they can also utilise water vapour from clouds (Green et al., 1999). The ability to survive dehydration contributes to lichens remaining viable after being covered by snow during winter (Schlensog et al., 2004). Dehydration also prevents of damage of cells from ice crystal formation in freezing temperatures (Raven et al., 2005). As cellular mechanisms are shut down during dehydration, they should remain relatively undamaged during the period of dehydration, even if they are subject to high radiation and freezing temperatures. This does not lessen the importance of human impacts on lichen, as any damage that occurs while in the dehydrated state will not be able to be repaired until rehydration occurs (Robinson et al., 2003).

UV-B Radiation and Climate Change Effects

Ozone depletion has caused increased UV-B radiation to reach the surface of Antarctica, particularly in spring (Robinson et al., 2003), which can influence the growth of vegetation. Mechanisms to protect against damage from ultra violet (UV) radiation are necessary adaptations in the Antarctic environment.

The three types of growth forms seen in lichens could have implications with UV tolerance. In all of these growth forms, the phycobiont forms a distinct layer within the thallus, which will impact the amount of UV radiation that reaches these photosynthetic components. This affects what mechanisms are needed for UV protection and could contribute to lichen success (Ott, 2004).

Antioxidants are also used as defence from radiation damage, UV-B in particular. They are used as protection from free radicals and active oxygen species which can damage cell membranes and DNA (Robinson et al., 2003). The levels of antioxidant activity in lichen species could be used as a measure of the UV-B radiation reaching the surface of the terrestrial environment in Antarctica. The investigation of antioxidants in Antarctic lichens has found strong antioxidant activity compared to those from temperate regions (Paudel et al., 2008). Antioxidants are activated in hydrated cells, and water availability, another environmental factor influenced by climate change and this will have more of a physiological impact on lichens than UV-B alone (Robinson et al., 2003). Because dehydrated lichens are often not greatly affected by UV-B due to decoupling of photosynthetic systems, increased precipitation (Lemke et al., 2007), could impact on lichen growth as lichen thalli will be exposed to potential damage from UV-B radiation during hydration.

Lichens are also highly dependent on protective screening pigments, such as melanin (causes brownish colouring) and parietin, which are both induced in response to UV radiation (Solhaug et al., 2003). Another protective compound is usnic acid, typical to *Usnea spp.*, in which it causes a yellow pigmentation (Ott, 2004). This compound is thought to have potential use in human sunscreens due to its UV filtering capacities (Rancan et al., 2002).

Antarctica has been identified as being a significant area for research into climate change (Robinson et al., 2003). Temperature changes are predicted to be greater in polar regions than in temperate regions (Lemke et al., 2007), therefore lichens could be used to monitor these changes as any effects will be seen in polar vegetation before they are observed elsewhere (Lemke et al., 2007; Sancho et al., 2007). Lichens have been used as bioindicators in other regions, for example to monitor radiation after nuclear explosions in the northern hemisphere, and they are used to monitor persistent air pollutants around Antarctic bases (Raven et al., 2005; Tin et al., 2009). Their use as bioindicators in Antarctica could become more prominent (Sancho et al., 2007).

Variations in Lichen Growth and Colonisation

Growth rate

The rate at which lichen growth occurs, and the mechanisms that control and aid growth are important factors in the colonisation of new areas by lichens. Little is known about the growth rate of lichens in Antarctica (Ovstedal and Lewis-Smith, 2001), and there are still relatively few studies into this aspect of lichen physiology (Robinson et al., 2003).

Knowledge of lichen growth rates is important in relation to lichenometry, where the rock, or substrate being considered is dated relative to the presence and size of lichens inhabiting it (Valladares and Sancho, 1995). Some lichen thalli found in Antarctica are of an impressive size, (possibly due to gigantism), and are assumed to be much older than smaller lichen thalli, with ages of individual thalli from approximately 500 – 5000 years being suggested (Ovstedal and Lewis-Smith, 2001).

There has been broad research into the growth rate of *Rhizocarpon geographicum*, which is generally found in temperate areas (Ovstedal and Lewis-Smith, 2001). This lichen is often used in lichenometry, and has been identified in alpine and polar regions (Sancho and Pintado, 2004). *R. geographicum* was included in a study on the Antarctic Peninsula, and it was found that it grew much faster than earlier growth rate estimates (Sancho and Pintado, 2004). This has significant implications not only for lichenometry studies in Antarctica, but also because the growth of other Antarctic crustose lichens can be compared and relative growth rates calculated. Growth rates of some Antarctic lichen species are compared in Table 1, and it can be seen that there is a wide range to the rate of growth.

Table 1. Compilation of calculated and observed growth rates of some Antarctic lichen species from published literature. Growth rates in mm per year.

Species	**Growth type**	**Continental Antarctica**	**Maritime Antarctica**	**Specific locality**	**Reference**
Usnea antarctica	Fruticose		2.0 mm	Livingston Island	Sancho and Pintado, 2004
Rhizocarpon geographicum	Crustose		0.025 – 0.5 mm 0.1 – 1.4 mm*	Signy Island, Livingston Island *Antarctic and Arctic growth rates	Lewis-Smith, 1995, Sancho et al., 2007, Sancho and Pintado, 2004, Sancho and Valladares, 1993
Xanthoria elegans	Placodioid[1] crustose		0.2 – 0.5 mm	Signy Island	Hooker, 1980b, Lindsay, 1973
Acarospora macrocyclos	Placodioid crustose		1.0 – 1.2 mm	Signy Island Livingston Island	Lewis-Smith, 1995, Hooker, 1980a, Sancho and Pintado, 2004
Caloplaca subobulata	Crustose		0.82 – 0.95 mm	Livingston Island	Sancho and Pintado, 2004, Sancho and Valladares, 1993
Buellia frigida	Crustose	0.01 – 0.07 mm		Dry Valleys Cape Hallett	Sancho et al., 2007
Buellia latermarginata	Crustose		0.5 – 0.87 mm	Livingston Island Signy Island	Sancho et al., 2007, Sancho and Pintado, 2004
Bellemerea sp.	Crustose		0.75 mm	Livingston Island	Sancho and Pintado, 2004

[1] Placodioid: crustose lichen that is areolate in the center, but foliose at margin Ovstedal, D., and Lewis-Smith, R. (2001) Lichens of Antarctica and South Georgia, A guide to their identification and ecology. Cambridge: Cambridge University Press.

Table 2. Some extremes in Antarctic lichen sizes (from Lewis-Smith, 1995) and estimated ages based on growth rates taken from Table 1[2].

Species	Size	Estimated age
Bryoria chalybeiformis	450 mm length	225 years (based on growth 2.0 mm per year)
Umbilicaria antarctica	350 mm diameter	467 years (based on average growth rate for crustose species shown above)
Usnea antarctica	250 – 670 mm length	125 to 335 years (at 2.0 mm per year)
Usnea aurantiaco-atra	200 mm length	100 years (based on 2.0 mm per year)
Placopsis contortuplicata	780 mm diameter	1044 years (based on average growth rate for crustose species shown above)

The ages presented in Table 2 are estimates. Similar growth forms have been grouped together, however differences between species need to be taken into account, as do the environment that these examples inhabit. The average growth rate of all the maritime crustose species from Table 1 was calculated and this rate (0.747 mm per year) was used to estimate the ages of the crustose species above. As the exact environmental conditions are unknown, these ages are not definitive.

[2] Age of crustose lichen (years) = Diameter (mm) / Rate (mm/year). For other growth forms, age (years) = length (mm) / Rate (mm/year).

Case Studies of Antarctic Lichens

Photographic methods of measurements are a popular manner in which to assess lichen growth (Hooker, 1980a; Hooker, 1980b). Lichens present in pictures from Antarctic expeditions can possibly give some insight into the rates of growth of various species when compared to modern photographs. As can be seen in the photos below, the crustose lichen in the lower figure is not much different in size to the upper figure. This would imply that the growth rate of this species is slow (minimal change over 83 years). As growth can be extremely slow, the human impact on lichens in frequented areas can be quite significant .

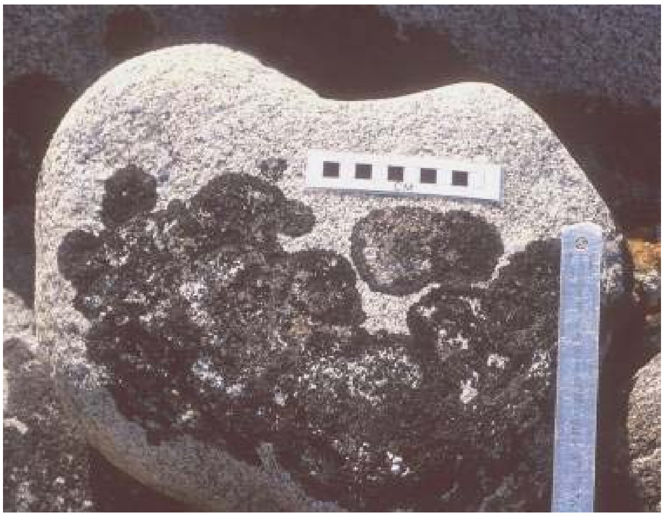

Figure 2. A crustose lichen species on a rock outside Granite House. Upper figure is from 1911 (Schroeter et al., 1993) the lower figure indicates the same rock with lichen growth as 1994 (Paul Broady).

It has been seen for *Xanthoria elegans*, from the Signy Islands, South Orkney Islands, that the growth of the lobes is progressing on a yearly scale as can be seen in Figure 3 (Hooker, 1980b). Crustose lichens grow through expansion of the lobes and increases in circumference (Hooker, 1980b). This is different to growth of foliose and fruticose lichens, which have a branching structure and a distinct lower cortex (Hooker, 1980b). This growth is much faster than that of the crustose lichen in Figure 2. This is probably due to differences in environmental factors.

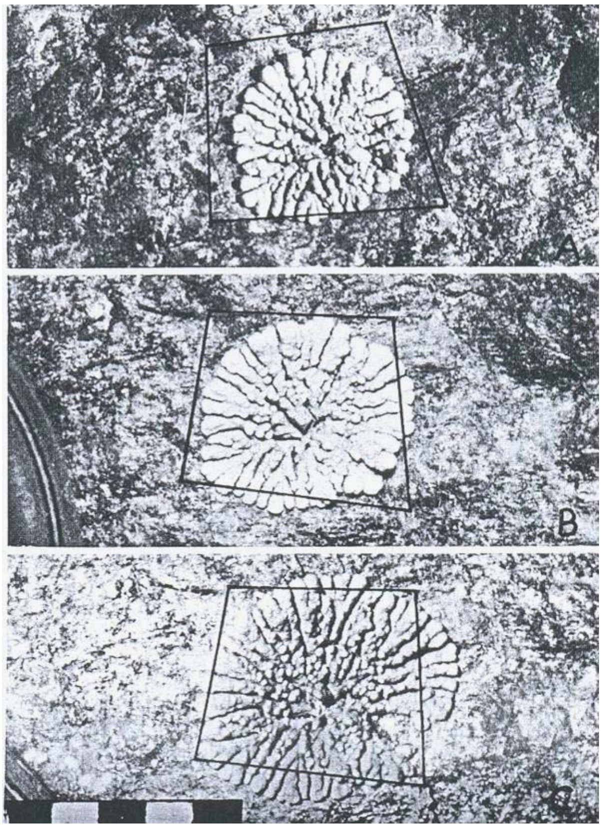

Figure 3. Growth of *X. elegans* on Signy Island over three years, showing a lot of growth in a relatively short period of time. From Hooker (1980b).

In comparison to *X. elegans*, it was found that *Usnea antarctica* had a high growth rate at Livingston Island, South Shetland Islands, of 2.0 mm per year (Sancho and Pintado, 2004). This is based on measurements of the branches, which are not present in crustose lichen forms. However, fruticose branch measurements could potentially be compared to crustose lobe growth, allowing further comparisons to be made. The external branches of fruticose lichens are likely to be affected by environmental factors such as wind, or the weight of snow, therefore impacting growth rate. Crustose lichens may not be subjected to the same effects as they do not stick up so much from the rock. The differences in growth form will need to be considered when attempting to apply a measurement method across different species and growth forms. Crustose lichens have been suggested to grow faster than the other growth forms (Lewis-Smith, 1995). Contrary to this, Sancho and Pintado (2004) found that crustose species in Antarctic Peninsula had a mean growth rate of 0.5 – 0.87 mm per year, whereas *U. antarctica*, with fruticose growth form had a mean growth rate of 2.0 mm per year.

The relatively warmer temperatures of the Antarctic Peninsula compared to continental Antarctica, could be an explanation of the relatively high growth rate of lichens found in some areas (Sancho and Pintado, 2004), due to suitable moister conditions for lichen growth (Green et al., 1999; Sancho et al., 2007). However, it is likely there are differences within local habitats as well as large regional differences in lichen growth based on environmental factors. The difference and gradient of growth rates found by Sancho et al. (2007) is assumed as there are gradual changes in environmental conditions along the Antarctic Peninsula (Ott, 2004). Regardless, further investigation and monitoring of growth rates needs to be accomplished before accurate statements can be put forward in regards to lichen growth rates in Antarctica.

Colonisation

The initial colonisation of lichen vegetation is also not well known. It can be considered however, that colonisation by lichens is occurring much slower in the continental antarctic area compared to the maritime antarctic (Lindsay, 1978). Terrestrial algae in Antarctica have been found to use airborne propagules as a method of dispersal to new areas (Marshall and Chalmers, 1997). However the manner in which lichens, made up of algal and fungal components, colonise new areas is thought to vary. Vegetative reproduction in lichens has been found to be more important than sexual reproduction in colonising new sites, as more soredia than ascospores are found in studies of airborne propagules (Marshall, 1996). This is because in the Antarctic environment, vegetative propagules are more likely to be successful than sexual reproduction occurrences. While sexual reproduction requires the necessary components to meet and combine (Marshall, 1996), with vegetative reproduction, the propagule is ready to begin growing when it reaches a suitable area. Many species in Antarctica only reproduce asexually, such as *Peltigera didactyla* (Lewis-Smith, 2005), which produces wind-dispersed soredia.

Also the rate at which colonization occurs is relatively unknown (Lindsay, 1978), with it likely to vary between the type of substrate being colonised and the type of lichen colonising the substrate. On Deception Island, volcanic ash is thought to have been colonised by *P. didactyla* very recently due to the suggested rapid growth of depauperate morphs of the lichen (Lewis-Smith, 2005). However, this is only considering one species, and some variations of growth rate and colonisation manner can occur.

It is known however, that lichens are the primary colonisers of deglaciated areas on the Antarctic Peninsula (Sancho and Pintado, 2004). This is likely to be due to removal of snow and ice cover, providing suitable substrate and conditions for growth to occur. Propagules that have dispersed from other nearby lichen populations are more likely to colonize due to more favourable environmental conditions such as warmer temperatures and greater water availability. It has been identified that snow cover can have an impact on lichen development and colonization (Valladares and Sancho, 1995). As lichens colonise areas which are free of ice and snow, due to the retreat of glaciers on the Antarctic Peninsula (Sancho and Pintado, 2004) it is possible that a shift in species distributions could occur, with indigenous lichens moving further south, or colonising higher altitudes. Lichen colonisation in some areas has been found to have increased in response to increasing temperatures (Sancho et al., 2007).

The lichens found on the Antarctic Peninsula are growing at a faster rate than those found on the continent, and a gradient between the two areas can be seen (Sancho et al., 2007). This gradient could be used as a manner in which to monitor climate change. It was found in this study that the amount of precipitation in the areas was a vital aspect of lichen growth, because cellular processes are not functioning during dehydration.

Due to the relatively slow development and growth of lichen structures, damage from human activity could have detrimental effects on the entire lichen community (Johansson and Thor, 2008). This is of great importance as under the Protocol on Environmental Protection to the Antarctic Treaty (1998), appropriate vital environmental aspects must be monitored to assess impacts of human activities in the area. Lichens, and moss, are key vegetation that can be used as environmental monitors (Johansson and Thor, 2008). *U. antarctica* is thought to be a prominent species which could be monitored to assess tourism impacts. This species is commonly found in coastal regions, and these areas are where tourists are often being taken to view Antarctic wildlife and the environment (Schroeter et al., 1995).

Human activities can affect the rate of lichen growth in Antarctica. Vehicle wheel tracks, footpaths and ground equipment can all affect lichen growth (Johansson and Thor, 2008; Tin et al., 2009). It is possible that different growth forms will be impacted differently by these forms of activity. Foliose and fruticose lichens are likely to be more at risk from damage by human activity such as people walking past, whereas crustose lichens are more likely to be damaged through scraping effects from boots, wheels or equipment. Even if damage to lichen communities is restricted to local areas around bases and human activity, it will leave a “long lasting footprint due to the slow growth rates in continental Antarctica”(Johansson and Thor, 2008).

Conclusion

In conclusion, lichens are significant aspects of the Antarctic vegetation. Their growth is controlled through environmental influences such as water availability and temperature. As these environmental factors are predicted to change drastically in response to climate change, the impact on lichen growth needs to be assessed. Lichens could then be used as bioindicators of climate change in Antarctica.

Although there is extensive knowledge of *R. geographicum* growth rates, knowledge of other lichen species growth in the Antarctic is necessary in relation to lichenometry and climate change assessments. Growth rates of eight lichen species have been presented, however this is in no way comprehensive when compared to the approximately 350 identified species for Antarctica. The growth rates have been found to vary between regions and immediate environments, as indicated by the ranges in growth rates.

Most of the research into growth and colonisation has focussed on maritime Antarctic and the surrounding islands, and more work is needed on the lichens that inhabit continental Antarctica, as it is likely that the growth rates and colonisation of these species will differ quite considerably from those under relatively mild environmental conditions. Also research into the impact of fungal parasites on the growth of lichens could be significant. Although the presence of these is often noted, their effect has not been assessed in detail.

There is little known about Antarctic lichen species growth, reproduction and the method they use to colonise new areas. Further research into the growth rate of lichen species is needed, particularly if it is intended to use lichen growth rates in climate change assessments.

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