Chapter

The Vegetation of the South Shetland Islands and the Climatic Change

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Abstract

Antarctica allows at the same time to study the effects of change on the environment with minimal anthropic interference and in the least modified conditions in the world regarding biodiversity and its relations. At the same time, it allows assessing its effects on an ecosystem of few species and with a food web that directly links the oceans to terrestrial organisms. The South Shetland Islands are located further north within Antarctic Maritime and are therefore more vulnerable to climate change. Part of the studies already carried out with vegetation in this archipelago are discussed with a focus on the effects already generated and on predictions about future changes in the structure and plant diversity of Antarctica.

Keywords: vegetation, ecology, ice retreat, Antarctica, cryptogams

1. Introduction

The South Shetland Archipelago is located in the northern part of Antarctic Peninsula and is formed by 10 large islands (some reaching 100 km of lenght) and many smaller ones. The Maritime Antarctica, especially near the Antarctic Peninsula, have recorded the most significant temperature increases in the entire Southern Hemisphere, with 0.34° C per decade in the South Shetland Islands and between 1 and 1.4° C per decade (recorded since 1980) at the Rothera research station on the Antarctic Peninsula [1]. Data indicate that the marine water around the Antarctic Peninsula is up to 3° C warmer on average, contributing up to 50% of the ice melting already recorded [2].

The Antarctic Peninsula region had one of the most intense climatic warming trends over the last decades (increase of 0.56° C/decade in air temperature and 3°C in surface temperature since 1950) [3–5]. A statistically significant (at 3%) increasing trend in temperature was observed during the years 1944–1996, when the temperature increased by 1.6° C by analyzing the temperature in King George and in Deception Islands, from the South Shetland Archipelago. But in regions as the Admiralty Bay in King George Island the mean temperature was higher than 0.7° C, and the Wanda Glacier located there is retreating fast, having lost already 31% of its volume (compared to 1979) attributed to the regional warming [6].

The use of modeling proved that the ice river of the Thwaites Glacier that drains into the Amundsen Sea, in Western Antarctica, is already destabilized. The melting of these glaciers will raise the sea 1.2 meters on the planet, but the process will be very slow, probably hundreds of years [7].

Radar data proved that Pine Island Glacier retreated 31 km between 1992 and 2011, but has now reduced this speed. Until 2009 nothing was recorded about this retreat, when the melting and destabilization of glaciers suddenly began. The Larsen Glacier was one of the first to indicate a retreat (having persisted for 10,000 years), started to fall apart in 2002, collapsing in a period of 35 days and it is expected to disappear in 18 years [2].

In a reconstruction of changes in ice since the last glacial maximum, having studied at least 674 glacier data across the Antarctic Peninsula, it has been demonstrated as an environmental factor (the increase in the temperature of seawater rather than the atmosphere), was directly related to the retreat of glaciers [8]. The north–south gradient of increased retreat in the glaciers has a high correlation with ocean temperatures, since the water is cold in the Northwest and becomes progressively warmer at depths below 100 meters to the south. These waters of medium depth in the southernmost regions have been warming up since the 1990s, at the same time that the acceleration in the retreat of the glaciers began. And these waters are reaching lower and lower depths and affecting the emerged parts, as they heat up the platform. Almost all of the glaciers studied have declined since 1940.

The eastern region of the Antarctic continent, on the other hand, is slightly different from the region of the peninsula, since it is on dry land and has very thick ice. But because it is a more remote region, few scientists venture into the area and little data has been collected. However, data recently gathered from satellites and airplanes show another scenario. The Totten Glacier, for example, seems to be one of the most vulnerable, with the radar showing that there is a channel in the depths of it, which allows the entry of hot sea water that melts the ice and explains the loss of mass. This glacier can contribute to an increase of up to 3.5 meters in sea level [9].

Plant species on this continent are restricted to ice-free areas (except for microscopic algae that can grow directly on the ice) and are formations very threatened by climate change, as they do not support temperature changes very well. At the same time, plant communities are advancing in areas recently exposed by the retreat of ice and more favorable temperatures, resulting in the so-called "Antarctic greening". Analyzing five cores at three sites over 150 years, revealed increased biological activity over the past ca. 50 years, in response to climate change, suggesting that terrestrial ecosystems will alter rapidly under future warming, resulting in a greening similar to that registered to the Arctic [10].

It is important to note that a considerable carbon reservoir exists in cryobiont algae, which form extensive colonies directly on the ice. With the increase in temperature, it is expected that 62% of the blooms of small islands (like in the South Shetland archipelago) of low altitude will disappear [11].

There are at least 3 ways in which organisms can adapt to changes in the environment: 1- they can use the margins of physiological flexibility and then support changes. 2- can change the range of biological capacity which is highly dependent on the magnitude and rate of change. This ability is linked to the organism's reproductive capacity, but mutation rates, number of reproductive events and generation time are also linked. 3- they can migrate to have more favorable conditions. For Antarctic plants, the problems to be faced are greater to adapt, as they do not have an efficient disperser except the wind for lichen and moss spores, and must compensate locally for the differences to survive. And perhaps one of the big problems is getting nutrients. These are brought to the continent basically by animals, from their diet consisting of marine organisms [12]. A schematic of the flow of nutrients to the terrestrial environment can be seen in **Figure 1**.

Penguins are climate indicators and changes in their populations have been described over the past 50 years, mainly associated with changes in ice dynamics [13, 14]. *Pygoscelis adeliae* (Adélie penguin) is the most dependent on ice and the most

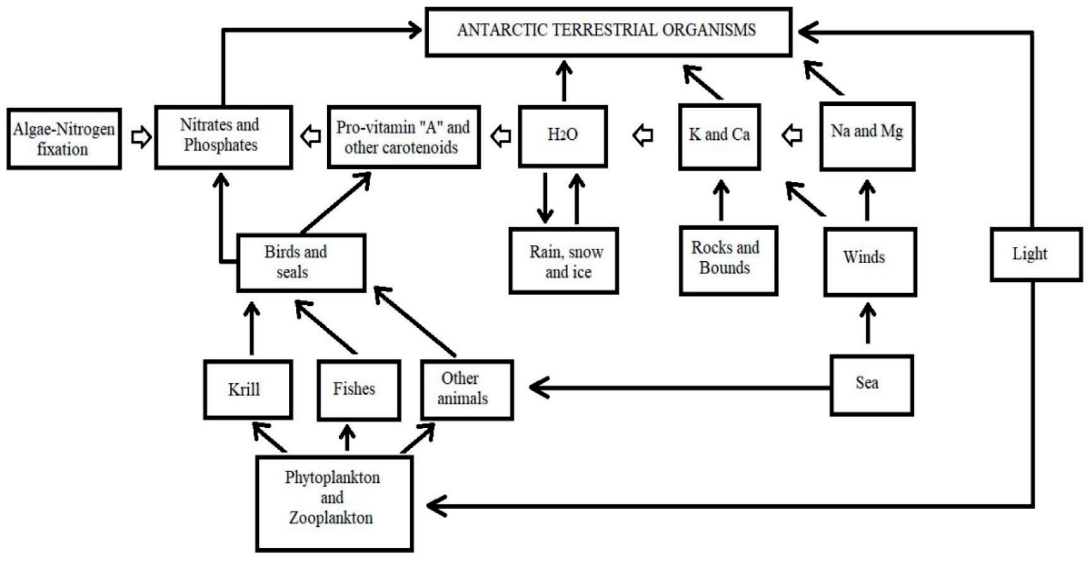

Figure 1.
Schematic view of the contribution of nutrients for the terrestrial ecosystems (adapted from [12]).

widely distributed species, occurring throughout the continent, as it is circumpolar. *P. antarctica* (the Antarctic Penguin) is found almost exclusively in the Antarctic Peninsula [15] and *P. papua* (the Papua Penguin) occurs in both the Antarctic peninsula and sub-Antarctic islands. The latter species has been showing its Antarctic populations expanding rapidly in the last 50 years, which is being associated with the increase in temperature in the region. Changes in ice dynamics have allowed the species to move further south, while *P. adeliae* and *P. antarctica* had a decrease in their populations mainly because availability of Krill, its main food. Adélie penguin populations are decreasing throughout the Antarctic Peninsula but they have remained stable on the east side of the continent, where the influences are still not so felt. In the past this species seems to have resisted climate change better. If it continues at this rate, it is estimated that populations can be reduced by 30% by 2060 and 60% by 2099 [16].

Fewer penguins means less availability of nutrients as they are one of the main sources of guano for the continent. Therefore, changes in plant communities that depend on this input may not happen. The melting of glaciers ends up exposing areas with rocks and sediments that will allow the installation of terrestrial vegetation, but nutrients must be available specially for the nitrophilic species.

Even cryobiont algae are found in ice, because it receives a spray of nutrients from penguins existing at least 5 km away [11]. The melting of the ice allows the melting water flows to carry these nutrients to the plants that grow on its banks, especially species like *Wanstorfia* spp., *Brachythecium* spp. and *Sanionia* spp. [17].

The Pinnipedia also have their contribution to the terrestrial environment, especially during periods when they are on land to rest. The deposition of feces and urine helps to nitrify the ground, but trampling can be harmful. A case described for the Signy Islands exemplifies this aspect, where the population of *Arctocephalus gazella* (fur seal) has greatly increased in recent years, completely destroying the existing vegetation in an area of about 80 hectares [18–21].

2. Plants with flower from Antarctica

Antarctica has only two native plants forming flowers: *Deschampsia antarctica* Desv. (Poaceae - **Figure 2**) and *Colobanthus quitensis* Kunth. (a Caryophyllaceae - **Figure 3**). There are already records of other Angiosperms occurring in the region, but these have been introduced by man, such as *Poa annua* L., and climate change can contribute to

Figure 2.
Deschampsia antarctica*, the Antarctic grass. Scale = 20 cm.*

Figure 3.
Colobanthus quitensis *among mosses and rock fragments.*

the occurrence of more plants in the region [22]. These two plants compete for space with all other species, but because they are larger and more complex, they need a large availability of nutrients and water. Therefore, they are usually found close to sources of nitrogen, such as in the vicinity of penguin rockeries or nests of other birds. Both have a chemical arsenal to survive the conditions of the Antarctic cold, especially a reasonable concentration of sugars in their cells: there is at least ten times more sugar in vacuoles than in sugarcane, foreseeing a potential use of this source in future. This accumulation of sugar is a protection against very cold periods in Antarctica [23].

Regarding the distribution of these phanerogams in the study area, it is possible to mention their occurrence in almost all the South Shetland Islands and areas of the Antarctic Peninsula free of ice. They can occur as small isolated tufts of a maximum of 15 cm, or forming fields of a few meters, but almost always associated with different Bryophyta and Marchantiophyta. Carpets even seem to stimulate grass development, but not its survival [24].

There are studies reporting the photoprotective effect of *Deschampsia antarctica* and *Colobanthus quitensis* extracts against UVB. The photoprotective properties have been attributed to several molecules, such as flavonoids and carotenoids, which absorb UV and act as antioxidants [25, 26].

It is possible that changes in temperature may interfere with the growth and development of populations of these species as has been shown experimentally [27, 28]. In the Argentine Islands, an increase of 25 times for *D. antarctica* and 5 times for *C. quitensis* was recorded in 30 years of observation [29]. Data collected in 2009 and historical data since the 1960s on the distribution of the two Antarctic vascular plants on Signy Island revealed that *D. antarctica* increased its coverage by 191% and the number of occurrence sites by 104%. *C. quitensis* increased its coverage by 208% and the number of occurrence sites by 35%. All due to the increase of 1.2° C in the air temperature and all the changes that this caused in the region [30].

Studying the formations of these phanerogams in the Fildes and Coppermine Peninsulas, in addition to locations in the Antarctic Peninsula in order to assess their responses to the increase in local temperatures, it was discovered that the populations of *D. antarctica* are expanding in the South Shetland Islands, but this expansion is not continuous in the Antarctic Peninsula, as the plants disappeared at 3 points, suggesting that there are other biotic and abiotic factors involved [31].

The fauna and flora associated with these plants is also very rich. There are bacteria, fungi and microscopic animals, many with a symbiotic or survival relationship with these plants. A high mortality of terrestrial microbial communities was detected along the South Shetland Islands. These communities are said to be dying from physiological problems and lack of nitrogen, in addition to changes in their microstructure, which seems to be associated with the rupture of the biogeochemical gradient of the microbial ecosystem. Caused by a strange but high abundance (explosion) of the associated fungi and the physical changes caused by them. All of these changes are related to the high temperatures recorded in the region. Some new diseases have been registered, especially for Antarctic grass, indicating that something is making possible the occurrence of these phytopathologies, but more studies are needed [32, 33].

There are also birds, of which at least the skuas (*Catharacta* spp.) and the gulls (*Larus dominicanus*) use these plants more frequently to make their nests. In a survey, scientists identified the seagull's preference for *Deschampsia antarctica* at Cierva Point in the Antarctic Peninsula [34]. More or less availability of this raw material can affect the reproduction of these birds.

These plants can be found in reproduction, but in general they are sterile. But higher average temperatures can contribute to increasing seed maturation, germination and seedling survival, although this has not yet been proven experimentally [35, 36].

3. Mosses and hepatics

Among the species that most stand out on more consolidated areas and even on Antarctic rocks, are mosses. The group that represents the bryophytes also has some liverworts occurring, but in this text, all will be commonly called mosses. There are, therefore, Marchantiophyta, popularly called hepatics, and the representatives of the genus

Marchantia are those that present the largest gametophyte (**Figure 4**), although small species of other genera sometimes take very large areas. Large populations have been found recently, such as the rare *Hygrolembidium isophyllum* in Harmony Point - Nelson

Figure 4.
Two Marchantiophyta, the thallose Marchantia berteroana *(above) and the leafy* Cephalozia *sp. (below).*

Island [37]. *Marchantia* is thallose, reproducing basically by direct fragmentation of the thallus or by specialized structures, the propagules, formed in receptacles such as in the figure (called conceptacles). But the group most represented in species in the area are the leafy liverworts (about 22 species). They even have a relationship with other organisms, as in the case of *Cephaloziella varians*, which is associated with a mycorrhizal fungus *Rhizoscyphus ericae* (ericoid symbiosis) throughout Antarctica [38–40].

Many species of liverworts are associated with dominant species in the plant community, and this reflects an interdependence. If the dominant species are threatened, by climate change, for example, their dependents will also be [41].

Bryophyta, or mosses themselves, have so far collected 113 species, within 55 genera and 17 families [18, 42]. The mosses present two main forms of growth: the pleurocarpic, where the moss stalk is prostrate, forming continuous carpets and in general covering more extensive areas if they are available (**Figures 5** and **6**);

Figure 5.
A moss carpet moved by wind being fixed by a scientist.

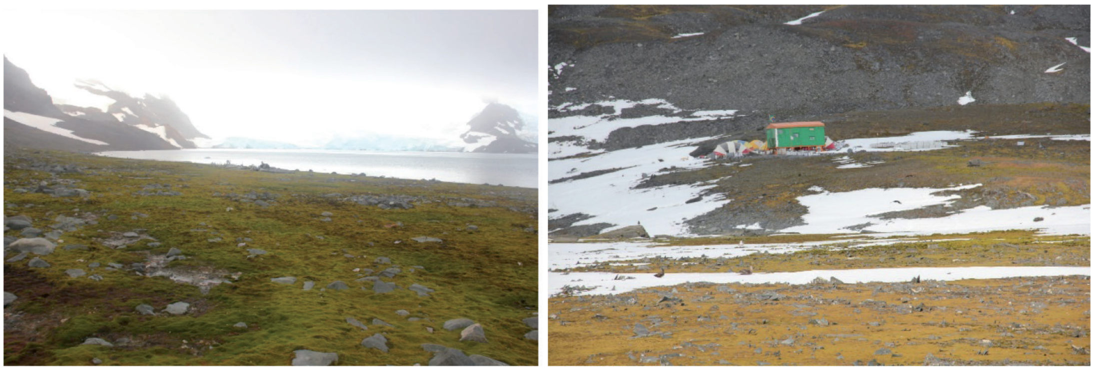

Figure 6.
Two large carpet of Sanionia uncinata *associated to* Warnstorfia sarmentosa *in the wettest areas.*

and the acrocarpic form, where the mosses grow upright, forming tufts or smaller cushions (**Figures 7–11**). The moss species with the highest occurrence and highest biomass in all ice-free spots is the pleurocarpic *Sanionia uncinata*, a carpet former with curved leaves, twisted like a scythe [18].

Antarctic moss fields can be very old and even deeper layers of growth can be alive even though they have been buried for over a thousand years by acrocarpic development. In 2014 research showed that the moss *Chorisodontium acyphyllum* remained alive after remaining frozen for more than 1500 years. A 1.4-meter-thick tuft was

Figure 7.
Tufts of the moss Syntrichia *sp. (red circles) growing among whale bones and a carpet of* Sanionia uncinata.

Figure 8.
Polytrichastrum alpinum, *one of the tallest moss (left) and* Pohlia cruda *(right).*

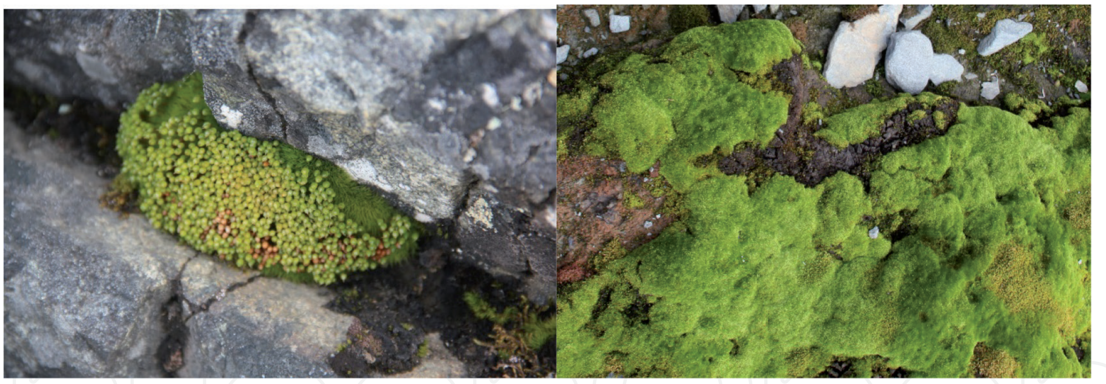

Figure 9.
Bartramia patens, *with sporophyte (left) and* Bryum palescens *(right).*

Figure 10.
Hennediella heimii *with sporophyte.*

Figure 11.
Chorisodontium acyphyllum, dull green and acrocarpic surrounded by a light green carpet of Sanionia uncinata *(pleurocarpic).*

sectioned every 20 cm (layer by layer) and placed to germinate under ideal conditions. In up to 8 weeks everyone started growing. The deepest layer was dated by radiocarbon and estimated between 1533 and 1697 years [43]. Acrocarpic and pleurocarpic mosses buried under more than 600 years by a glacier were re-exposed by the retreat of the ice and parts of the moss were able to activate again and grow normally "in vitro" [44].

The most available substrate in Antarctica is rock, but there are species that grow in soil. *Andreaea*, with four acrocarpic species occurring in Antarctica, for example, is exclusively saxicolous (name given to species that grow on rocks) [18].

Mosses are capable to colonize areas such as those closest to the sea and even receiving splashes of salt water waves, to the interior of the continent and including areas of recent exposition by ice retreat. The species *Muelleriella crassifolia* P. Dusén requires at least some contact with marine spray to develop, which is achieved in some coastal rocks. Eventually it can be found with other groups that have species with this preference, called halophytes, such as some of the lichens of the genus *Verrucaria* [45, 46]. The alterations in sea level will affect directly this community.

The rise in temperature in Antarctic regions has been accelerating the growth of mosses in particular since the late half of the 20th century. A study of 5000 years old population of *Polytrichum strictum* (in Lazarev Bay, on Alexander Island), dated by radiocarbon millimeter by millimeter, demonstrated that the population accumulated around 1.25 mm/year in the 19th and early 20th century and then increased its growth from 1955 until reaching 5 mm per year until the end of 1970, currently reducing growth to 3,5 mm/year. The authors also found that the associated amoeba population also increased considerably over the same period [47].

Studying a 1500 km gradient from Antarctic Maritime to the south of the Antarctic Peninsula (in the region of Lazarev Bay, Alexander Island) the accumulation in the banks of moss began to increase around the 1950's, reaching peaks in the Lazarev Bay in the 1970's (about 0.1 g of dry matter/cm^2/year) and Signy Island in the 1990s (0.06 g/DM cm^2/year); the most recent measurements indicate around 0.04 g of dry matter/cm^2. In continental Antarctica the growth of mosses is inversely proportional to the speed of the summer wind and proportional to the number of days above 0° C and the temperature of the summer [48].

Data collected in the Windmill Islands show evidence that the endemic moss *Schistidium antarctici* is likely to be more susceptible to climate change than the co-occurring and cosmopolitan species such as *Ceratodon purpureus* and *Bryum pseudotriquetrum*. And this in particular due to the habitat requirements, much more associated with water in the endemic species [49]. The rapid permanent ice-melting in areas like the South Shetland can result in dryer areas and reduction of plant communities.

Antarctica was the last continent discovered and in the first botanical studies the samples revealed one main taxonomical difficulty: no fertile mosses were found. Among the Antarctic mosses only 22 are found commonly fertile [18] despite some of these species are relatively rare. Reproduction by spores is only possible with water in liquid form, since the antherozoid needs to swim to the correspondent archegonia, fertilize it to form sporophyte and then finely the spores are formed inside a capsule. Since Antarctica is known to have water mostly if form of ice and snow, and being called the biggest desert in the world, it is somewhat difficult and sometimes impossible in some areas to achieve fertilization.

There is a huge difference in precipitation from Dry Valleys at 77,8° S (50 mm) to Livingston Island at 62.6° S (80 mm) [50]. An increase in precipitation was found at Faraday Station, according to data collected from 1956 to 1992 in the Antarctic Peninsula. This increase is connected with the diminishing sea ice and the intensification of evaporation, a higher humidity of the air and more dynamic cyclonic activity, especially in the winter season [51]. All these aspects can affect directly Antarctic plants, contributing also to mosses achieve fertilization.

In tropical and temperate areas ca. 75 ± 90% of the mosses are found fertile. In the maritime Antarctic the value reduces to approximately 25 ± 33% and in continental Antarctica to only 10%. In Margerite Bay fertility of 43% was found (19 species: 17 mosses, 2 liverworts) and in Alexander Island 47% (17 species; 16 mosses, 1 liverwort). 51 sterile species were found among 111 known from Antarctica (46% with sporophyte) [18, 35].

It is interesting that mostly saxicolous mosses are found fertile (**Table 1**), and this is probably because the rock surface is hottest than the environment, melting the snow deposited and resulting in liquid water available more frequently than on other surfaces. As the species usually grow on cracks, the water is piped over them [52].

There is also some preference for the availability of nutrients, especially the presence or proximity to nesting points or with the presence of birds or mammals. These species are called ornithocoprophylous or nitrophilous and often growing on slopes bathed in the excrement of the animals that occur above. Species such as *Synchitria magellanica* and *Henediella heimii* (**Figure 10**), among others, have this preference. With the reduction of penguin populations, already mentioned above, the unavailability of nutrients will affect these species.

Another group is represented by species that do not support high levels of nitrogen and therefore occur away from places where birds or mammals occur. They are called ornithocoprophobic or nitrophobic. Examples are *Pohlia cruda* and *Bartramia patens* (**Figure 9**). These classifications can be used for lichens as well and both mosses and lichens can grow associated in these places.

Mosses can be useful for Antarctic biodiversity, serving as food, as material for making nests or as a resting place for fauna. As food, they are used for this purpose mainly by arthropods, who are permanent residents of the South Pole, as there is no way out of there in winter. In this context, several other groups of microscopic

SPECIES	ON ROCK	ON FINE SEDIMENTS	FERTILITY
Andreaea regularis	X		Frequent
Andreaea gainii		X	Frequent
Schistidium cupulare		X	Rare
Schistidium amblyophyllum		X	Frequent
Schistidium deceptionensis		X	Rare
Schistidium leptoneuron		X	Rare
Schistidium antarctici	X	X	Frequent
Schistidium hialinae		X	Frequent
Schistidium urnulaceum		X	Frequent
Schistidium steerei	Not truly saxicolous	X	Frequent
Schistidium andinum	X	X	Frequent
Schistidium praemorsum		X	Rare
Schistidium rivulare	X	X near water	Frequent
Schistidium lewis-smithii	X	X	Rare
Hymenoloma grimmiaceum		X	Frequent
Hymenoloma crispulum		X	Frequent
Hymenoloma antarcticum		X	Frequent

Table 1.
List of saxicolous/soil growing mosses frequently found fertile in Antarctica.

beings are also inserted, with nematodes or even the smaller rotifers. Another important aspect is the associated microalgae communities.

There is also important associations with large animals, such as birds, which use plants to make their nests. The most used material can be moss (**Figure 12**), there may be mixtures with lichens in different proportions or even with flowering plants, but in some cases lichens (**Figure 14**) and phanerogams may predominate. There are, of course, birds that use other materials, such as rocks, in the case of giant petrels and penguins (**Figure 13**), mud with algae as is the case of *Phalacrocorax atriceps*, etc. [53].

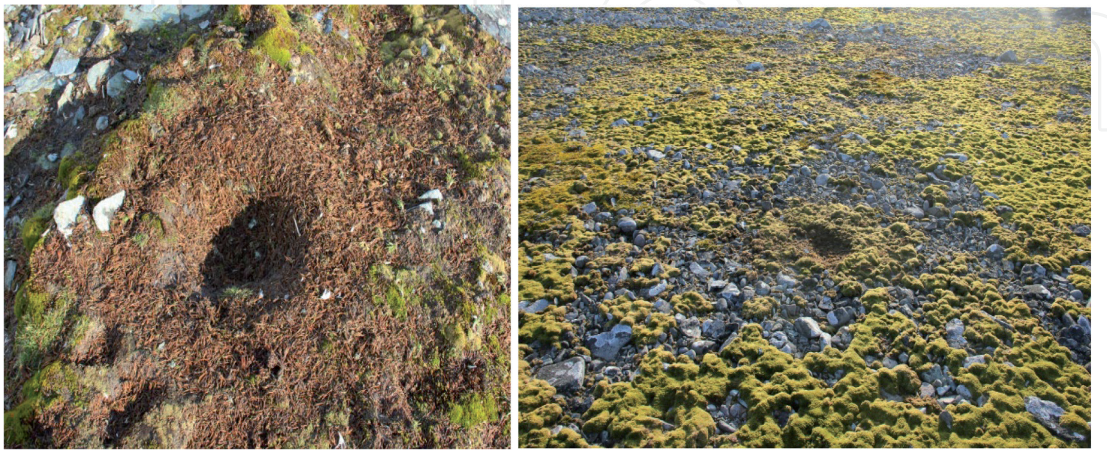

Figure 12.
Skua nest build using the moss Polytrichastrum alpinum *(above) and another using* Sanionia uncinata *(below).*

Figure 13.
*Giant petrel nest (*Macronectes giganteus*) build using rock fragments.*

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Figure 14.
Larus dominicanus *(kelp gull) nest build with mosses and the lichen Usnea.*

4. The lichenized fungi: lichens

Lichens are the most representative land group in Antarctica, despite they are not truly plants. They are formed by the symbiosis between a fungus plus an alga (most), a fungus plus a bacterium (case of *Leptogium puberulum,* as for example) or a fungus plus an alga and a bacterium (case of *Placopsis contortuplicata*). There are even lichenized mushrooms such as in *Lichenomphalia* spp. In the relationship, the photobiont provides the carbon source to the fungus, which can be polybasic alcohol (if it is green algae) or glucose (cyanobacteria). The fungus protects the algae from radiation and desiccation. The fungus still manages to reproduce in most cases through sexually formed spores or conidia (asexual), to fragments of the thallus or soredia. The algae reproduction is inhibited or suppressed [54].

To grow like a lichen, the spore needs to find the compatible algae that is rare in nature and lichenize. About 17,500 species of lichenized fungi and about 200 species of associated algae (100 green and 100 cyanobacteria) have been described. In this way, all of these fungi use algae in common and even different algae are used by the same species, in most cases even to adapt better to certain environments [55].

There are approximately between 386 to 427 species of lichens cited for Antarctica [55, 56] numbers that implies the most biodiverse group among terrestrials. In Antarctica in addition to the climate, limiting factors for lichens are the availability of substrate, which in most cases are rocks (in saxicolous species) or mosses (when species are muscicolous) and the presence of a source of nutrients, which can be originating from resting places or breeding animals, as already mentioned in the topic about mosses, above. These species are also starting competition with introduced ones which are being more and more frequent due climatic change.

5. Plant species associated with lichens

In natural environments on the planet a succession is expected to occur. But these environments generally have trees. How is the succession of species in a mainly cryptogamic community like in Antarctica?

Perhaps one of the most ignored formation in Antarctica is that of the lichen/moss association. Mosses colonize an environment first and, to be replaced, must be annihilated. Who does that? If not an animal, mostly a set of lichens. If we look at the work already done with phytosociology in Antarctica, we see that lichens have figured as one of the most important when considering the ecological significance index [17].

Figure 15 illustrates how different species are associated with a lichen which in this case is fruticose: *Sphaerophorus globosus*, which forms groups up to 10 cm in height and is generally parasitic on mosses (muscicolous). In this 20 x 30 square in the figure, there are associated eight other species, of which 3 are mosses and 5 are other lichens, demonstrating how the lichen community settles on mosses and needs them to develop, even if it results in its death. In succession, it is to be expected, therefore, that lichens from the vegetation damage or kill a previously installed moss and then gradually disappear, also due to the lack of a host.

In this community the mosses are at a disadvantage, as they are being attacked by various parasites of the lichen group. These parasites do not even care about the moss species, but it looks like the *Chorisodontium acyphyllum* moss is surviving well and unscathed. This is also noticed in other parts and perhaps indicates that this moss ends up taking the place of the other parasitized and previously killed. This may show a stage of plant succession in Antarctica, which is still poorly studied.

Lichens can also occur on rock fragments and in **Figure 16** there is a schematic drawing of the cover of round rocks, very common in uplifted areas. There are

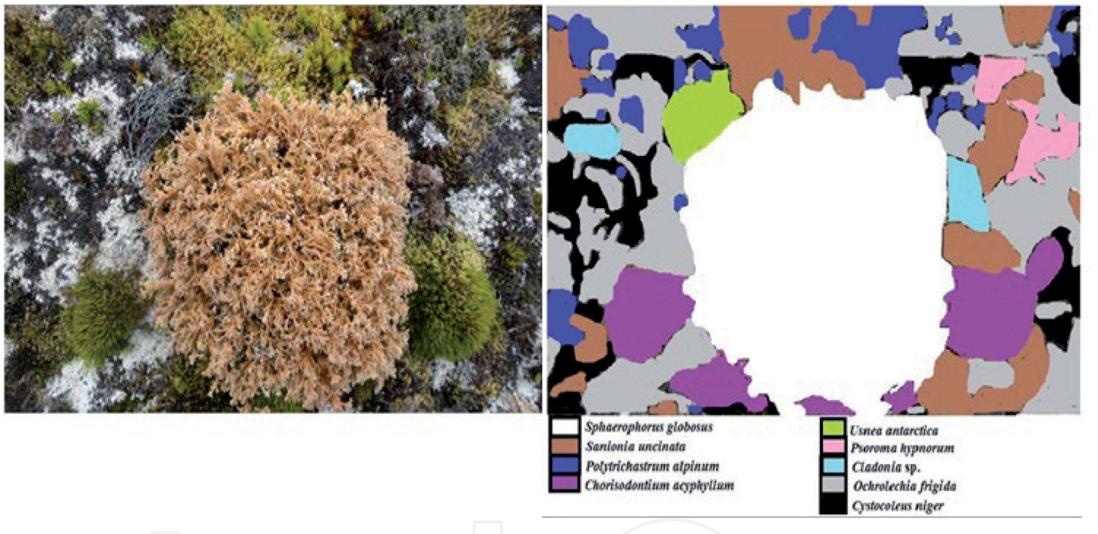

Figure 15.
Biodiversity surrounding the fruticose lichen Spaerophorus globosus.

Figure 16.
Biodiversity in a 20 x 20 cm square of rounded rocks in Henequin point, King George Island, with 18 species.

17 species of lichens and one of moss occurring on the fragments. At some distance and to the unsuspecting it seems that the rocks have no vegetation, but it has adapted very well to this surface. Vegetation-free areas are in most cases rocks turned over by an animal or researcher who passed the site. So even small areas can group a considerable richness and the Antarctica is very sensitive to any disturbance, imagine the effects of climatic change.

6. Macroscopic terrestrial algae

Prasiola is the macroscopic alga that occurs in terrestrial environments in the Antarctic region with greater frequency. Only two species were being cited for the area: *P. crispa* (nitrophilous) and *P. calophylla* (nitrophobous) (Putzke & Pereira, 2013). Studying the molecular phylogeny of these algae in Antarctica, the presence of *P. crispa* was confirmed, that *P. calophylla* is different from the same species mentioned for Europe, changing its name to *P. glacialis* and that *Prasiola antarctica* is an independent species, morphologically identical *P. crispa* [57].

These species are among the largest primary producers in Antarctica and studies have shown that *P. crispa* is very resistant to desiccation and hypersaline conditions [58–61].

In general, nitrophilic species occur near or inside bird colonies and nitrophobic in areas in contact with them. Often, some shallow pools of water have groups of *Prasiola* that prevent the growth of the surrounding mosses, demonstrating that they are somewhat allelopathic.

In several places it can be seen that the alga is lichenized, forming a different, more blackened and dotted thallus. It is the association with the fungus *Mastodia tesselata*, whose relationship is still controversial, as some authors believe it is parasitism and not a symbiosis. The lichen appears close to Verrucaria, a lichen with marine affinities [62].

In some cases, during the collections it can be seen that part of the algae stem is green and part is associated with the fungus and is already blackened, showing that the association may not be complete. Further studies are needed to elucidate what is the relationship between these two very different organisms.

P. crispa produces secondary metabolites with high toxicity and insecticidal power, and some studies on the subject have already been published [63, 64].

7. Dispersion of land plants

Birds can contribute to the long-distance dispersion of spores and seeds. In the first case, they can carry diaspores of fungi, mosses and pteridophytes trans-continentally (the latter group does not yet occur in Antarctica). Seeds in general can be carried via the digestive tract even. Some first evidences of dispersion of microscopic bryophyte spores have been published, where the case studied presents a transequatorial dispersion, with species carrying diaspores from one pole to the other or at least from the southern part of South America to the North Pole. Algae cells, fragments of moss leaves, elatheria and fungal spores have been found [65]. With the temperature registered due to climate changes, it is expected that new mosses may occur from introductions with the participation of birds in Antarctica.

Many birds carry these structures passively, as they can land on the fields, brush against them, use plants from these groups as material for their nests and even ingest material when transporting the food that is taken to the nests, or when feeding on carcasses arranged on plant communities (**Figures 12–14**). As any fragments of mosses may be sufficient to germinate and form new plants, many species in Antarctica today may have arrived there using transport in the bodies of birds and many more can be introduced in the future.

Feces can also introduce botanical material, as long as it is possible for structures to survive mechanical crushing and chemical bombardment of the digestive tract. The fact that they are eliminated with feces guarantees at least an initial supply of nutrients for their development and, since they are very small plants, the supply deposited once, may even be available for some years.

Despite this, the wind is the most important disperser of Antarctic mosses and lichens, since their main reproductive structures are spores or thallus fragments.

8. The Antarctic ice-free areas and their potential for the evaluation of climatic changes

Antarctica, despite having the largest number of superlatives, as it is considered the coldest (−89.2° C), the driest (average annual precipitation not exceeding 100 mm), the highest (average height 2300 m), the windiest (wind speed can reach 327 Km/h), is the most unknown and the most preserved continent. However, it is isolated from the rest of the world due to its geography and ocean currents. From this isolation the populations are very different, facilitating the study of biological models, whose data can help in the explanation of global biological problems. Global climate change has been a feature in polar regions and continues to be. When discussing climate change on Earth, references are always made to glaciations and ice records [66].

The environmental superlatives of Antarctica, which determine extreme abiotic conditions for the biota, led to the evolution of fragile and unique communities, which are mainly characterized have high specialization and adaptation to environmental conditions, in addition to being very sensitive to environmental impacts of anthropic origin or caused by natural phenomena.

The climatic phenomena that occur in Antarctica are the basis for describing the climate of the Southern Hemisphere, and what happens in many countries is in part also a reflection of the phenomena that occur in the South Pole. In Antarctica the so-called "fronts" are frequent, numerous and of constant formation, these are mostly ephemeral, but many reach the southern areas of South America. In addition, the Antarctic ice is considered as a climatic archive. Air bubbles found in glacial ice can identify the composition of air from past eras. Snow samples can currently demonstrate the types of gases and particles that existed in atmospheric air many years ago. This means that through isotopes, it is possible to evaluate the activity of the sun in several eras, in addition to the biological activity, obtained by the analysis of molecules of organic origin [66].

Pollution was believed to be almost exclusively a product of the Industrial Age, but ice samples demonstrated lead pollution, dating from the Roman Empire period. The snow when deposited carries with it the characteristics of the chemical composition of the atmosphere at the moment it was formed, deposited on the continent's surface air bubbles, salts, dust, volcanic ash, pollutants, among others. As snow does not melt on glaciers, the layers are deposited and compacted, keeping the record of climatic phenomena that occur over time preserved.

One of the global changes that can affect the Antarctic ecosystems is the so-called "hole in the Ozone layer", which is located at the south pole, because it brings together the coldest regions of the planet and for having a very localized circulation of air masses. This despite being on Antarctica also reaches the southern tip of South America. This phenomenon contributes to the increase in ultraviolet radiation (UV-B), which, because it is mutagenic, contributes to the genetic alteration of species. Since this radiation is very intense in Antarctica, great mutation rates are expected, but it was observed that this does not occur, since these species have mechanisms that prevent DNA damage by the formation of secondary metabolites, at least in plants, whose photoprotector effects were experimentally proven [25, 26].

The retreat of the glaciers and the reduction of snow fields expand and the consequent exposure of new habitats for colonization, and the increase in the populations of plants, has been documented. Small changes in the physiology of the Antarctic organisms can affect their life histories, with indirect effects on the dynamics of the ecosystem and trophic chains. These subtle effects can be more easily detected due to the simplicity of polar ecosystems [25].

The use of plant communities in Antarctic ice-free areas to assess climatic changes consequences can be justified by facts such as:

1. These have a small number of species when compared to periglacial and subtropical regions, since among the species mentioned and described so far there are: two species of Magnoliophyta, *Deschampsia antarctica* Desv. (Poaceae) and *Colobanthus quitensis* (Kunth.) Bart. (Caryophyllaceae), approximately 360 species of lichens [55]. Bryophytes comprise approximately 113 species of moss and 22 species of liverworts [18].

2. As biodiversity is small, populations are very numerous, facilitating their delimitation and the identification of interspecific relationships.

3. The presence of soil is an important factor, since there are species of mosses such as, for example, *Sanionia uncinata* (Hedw.) Loeske and *Chorisodontium aciplhyllum* (Hook. F et Wils.) Broth. that grow in areas where rock fragments occur, as the soil is formed these populations are replaced by other moss species such as, for example, *Polytrichum juniperinum* Hedw. and *Polytrichastrum alpinum* (Hedw.) G.L.Smith, often associated with *Deschampsia antarctica* and *Colobanthus quitensis* [45].

4. Most of the species that grow in these areas, evolved under extreme environmental conditions and under intense stress, making them very well adapted to such environmental conditions.

5. Antarctica is still a continent with an insignificant anthropic impact, so the changes that occur in communities are the result of environmental changes arising from natural phenomena. This fact is important, since environmental variables that are selected can be evaluated based on natural phenomena.

6. The importance of studying plant species that grow in ice-free areas in Antarctica are strongly related to the environment, so it constitutes a potential source for assessing global changes. It is expected that climate change will have a major impact on Antarctic land biota. Studies suggest that the increase in temperature and greater availability of water can extend periods favorable to growth, increase the rates of development and reduce the duration of the life cycle, which can alter the distribution of species [5].

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Conflict of interest

The authors declare no conflict of interest.

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