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SPECIAL FEATURE: 100 YEARS OF ANTARCTIC RESEARCH

Early knowledge of Antarctica's vegetation: Expanding past and current evidence

Conocimiento temprano de la vegetación en Antártica: Expandiendo la evidencia pasada y presente

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ABSTRACT

To commemorate one hundred years of Roald Amundsen's reaching the South Pole, we provide a summary of early explorations to Antarctica, in which botanists played an almost anonymous role. Based on multiple observations of vegetation they found and recorded, we review the knowledge available at the end of the nineteenth century to compare with contemporary scientific beliefs; connecting them with observations we have collected in field-work. Using the aerial photography from the end of the 1950s of sites we visited, it is noted that opportunities are arising for the understanding of colonization phenomena in areas where ice is retreating. Accounts of research on colonization of new ice-free areas are analyzed as well as how molecular genetics attempts to deduce the early settlements. Finally, an analysis of conservation in Antarctica is provided and its outlook discussed.

Key words: Amundsen, ice-free areas, moss, niche conservation, *Sanionia uncinata*.

RESUMEN

Al conmemorar los 100 años de la llegada de Roald Amundsen al polo sur, queremos entregar un resumen de las primeras exploraciones a Antártica, en el cual participaban botánicos en forma casi anónima. Basados en las múltiples observaciones de la vegetación que ellos encontraron y registraron, se revisó el conocimiento disponible al final del siglo diecinueve para compararlo con nuestra visión; relacionándolo con lo que nosotros hemos encontrado ahora en nuestros terrenos. Usando fotografía aérea de finales de 1950 de sitios que nosotros hemos visitado, es evidente que nuevas áreas del conocimiento se abren frente a estos fenómenos donde ha retrocedido el hielo. Se señalan las investigaciones que se han desarrollado en el análisis de la colonización de las nuevas áreas libres de hielo y cómo la genética molecular intenta descifrar su establecimiento. Finalmente, se hace un análisis de la conservación en Antártica y se discute sobre las proyecciones de ella.

Palabras clave: Amundsen, áreas libres de hielo, conservación de nichos, musgo, *Sanionia uncinata*.

INTRODUCTION

Scientific expeditions in Antarctica: Bases of the botanical knowledge

At the end of the nineteenth century, collection and classification were still the principal occupations for biologists and the major concerns of the leaders of biological thought were the cell theory, comparative anatomy and evolution. In the period when Roald Amundsen reached the South Pole (1911), most of the important scientific contributions took place due to a multinational agreement that encouraged countries to organize South Pole expeditions to collect scientific information on this continent.

In relation to vegetation in Antarctica, one of the first observations of the explorers hunting seals and whales referred to a strange grass, which later was recognized as patches of moss. It was not until 1820 when Edward Bransfield made the first Antarctic exploration on land, mainly in the maritime sector. He sailed the

South Shetland Islands and the Strait that bears his name (SHOA 1989). In 1829, James Eights described the first fossil and made the first botanical collection (Putzke & Pereira 2001).

Between 1838-1842 Sir Joseph Dalton Hooker, one of the greatest British botanists and explorer of the 19th century and founder of geographical botany, took part in an expedition which consisted of two ships, the HMS Erebus and HMS Terror, commanded by Captain James Clark Ross. They circumnavigated Antarctica, reaching latitude 78º04' S. It was the last major voyage of exploration made entirely under sail. Hooker made plant collections at locations such as Kerguelen, Macquaire, Falkland, Tierra del Fuego and other islands. The voyage was a success for James Clark Ross as it was the first to confirm the existence of the southern continent and chart much of its coastline. It is interesting, according to Convey (2010), that the book written by Hooker, "Flora Antarctica: the botany of the Antarctic voyage", considers mostly flora that could be considered today as part of the flora of the sub-Antarctic islands.

After Hooker's visit, the Antarctic Scientific Expeditions were interrupted and the discovery of new bryophyte species stopped. For this reason, in 1895 it was suggested during the International Geographic Congress in London that the Antarctic Continent should be explored, and recommended to the world scientific society to have more knowledge of the continent before the end of the 19th century.

One result of this proposal was the most extensive publications on the taxonomy of bryophytes at that time. The first moss Antarctic collection was made by the Rumanian Émile Racovitza, zoologists and botanists in 1898 in the Gerlache Strait, on the west side of the Antarctic Peninsula, during a Belgian expedition which visited the South Shetland and the west coast of Tierra de O'Higgins, commanded by Adrien Gerlache. In his crew was Roald Amundsen, as first mate, without pay, who learned much from his experience on this expedition, in particular how to prevent scurvy (Rubin 1996). In the same year, Racovitza made the first record of one of the only two flowering plants native to the continent when he found *Deschampsia antarctica* Desv. at 64º35' S (Fogg 1992). A great contribution in this period was the Scottish expedition commanded by William Spiers Bruce in the "Scotia"; R.N. Rudmose Brown wrote the report of that voyage with special emphasis on "The problems of the Antarctic Plant Life", and "Flora of the South Orkney". In those documents, he recorded the most relevant observations for the south polar flora and gave the botanist reason to hope for further results from future expeditions. One of the chief interests in these collections lies, of course, in the questions they give rise to in problems of geographical distribution and the origin of the Antarctic flora.

The total number of mosses brought from Antarctic regions until 1907 appears to be 52 (actually more than 80), collected in different expeditions such as the "Belgica" which collected 27 species on the west of Graham Land, the Antarctic expedition collected 23 from different parts of Louis Philippe Land, the Frangais 18 around the Gerlache Strait, and the Scotia expedition 10 species from the South Orkneys. According to Cardot (1906), cited by Brown (1907), 24 of the 52 species are endemic, 16 are northern and 12 southern species of wide distribution. Noticeable is that due to the relationship of the Antarctic moss flora with those of South Georgia and Magallanes; Brown suggested a migration from Fuegian lands as the origin of the Antarctic flora.

Moss to the limit: Discovering the survival history in Antarctica

After the work done by the mentioned scientific expeditions, who initiated botanical knowledge in Antarctica, they concluded that mosses are a major component of the flora in ice-free coastal regions of Antarctica, especially developed in the South Shetland Islands and in sites of the west sector of the Antarctic Peninsula. All these species reach here the limits of their distribution; the margins indicate which is the limit of the adaptation to the abiotic conditions (temperature, precipitation, light, soil nutrition, etc.), but also show competition with other species. Perhaps at the time of the first explorers the margins were not of particular interest, but currently they represent limits of survival and colonization, where mosses are very successful in the places where they used to be in Antarctica, from wetter areas and channel banks to dry morainic detritus and crevices of rocks, on flat or sloped surfaces. This distribution and their limits can be altered with climate change and relationships can be established among the historic periods of glaciations. But what is recognized as a distributional margin depends primarily on the object which is observed and this is the species or population in detail (Crawford 2008).

This leads to question such as, why do these plants grow in their limits, why are only few species, and which are their biological strategies for survival under these conditions?

Mosses are currently used as model organisms for physiological experiments to elucidate problems such as cold tolerance or hormones involved in the light signaling of the circadian clock (Ichikawa et al. 2004), survival mechanisms and monitoring responses to climate change (Ochyra et al. 2008); they have uses that are just beginning to emerge, such as modern genetic engineering or their use in building as effective insulation.

Mosses play an important ecological role, accumulating organic matter, colonizing ice-free terrain and providing birds and invertebrates with food and habitat resources. Moreover, mosses play an important role in the nutrient balance of ecosystems, because they bring nutrients from the atmosphere into the ecosystem and accumulate them (Frahm 2001). According to Lewis Smith (1990), some moss species are very sensitive to the smallest edaphic and microclimatic differences such as water availability, expressed in the dominance of one species and the structure of the communities.

In maritime Antarctica, wet habitats are typically dominated by four carpet-forming pleurocarpous species (*Sanionia georgica-uncinata* (Müll. Hal.) Ochyra & Hedenäs, *S. uncinata* (Hedw.) Loeske, *Warnstrofia fontinaliopsis* (Müll. Hal.) Ochyra, *W. sarmentosa* (Wahlenb.) Hedenäs (Ochyra et al. 2008). According to Pizarro & Sáiz (1977), *Sanionia uncinata* (=*Drepanocladus uncinatus*), *Andrea gainii* Cardot, *Syntrichia filaris* (Müll. Hal.) Zander (=*Tortula excelsa* Cardot), *Schistidium antarctici* (Cardot) Savicz & Smirnova (=*Grimmia antarctici* Cardot) and *Polytrichastrum alpinum* (Hedw.) G.L.Sm. are the most important species located in the Fildes Peninsula. Interestingly, one of the most widespread moss species in Antarctica is *S. uncinata*, a cosmopolitan species occurring on peri-Antarctic islands and archipelagoes as well as in the Antarctic Peninsula. In the case of *Sanionia*, *Bryum* and *Calliergon* species, the shortness of the growing season is prolonged in part by the fact that mosses occur submerged in lakes, where they can remain at 4 °C to assimilate instead of being out of water under an ice sheet. The same applies in snow valleys when mosses can photosynthesize beneath the snow (Frahm 2001).

Sanionia forms great patches close to humid environments, such as the vicinity of thaw channels, and according to Gimingham & Smith (1971) it has great morphological plasticity associated with extensive ecological amplitude. This species produces pads with 1.5-2 cm thickness; the stems adopt a turgid or ascending, very dense form that can be completely extracted. It is frequently associated with *Andreaea* and *Polytrichum alpinum* in dry habitats, or grows alone. On the other hand, a robust form exists in which the parallel stems have lateral arms with restricted growth and 3 cm or greater thickness. This form occurs in patches associated with *Calliergon* and *Brachythecium*. The plants in between these two extremes tend to occupy habitats with intermediate water availability. However, these observations can now be oriented towards the identification of two species, as suggested by Ochyra et al. 2008 (*S. uncinata* and *S. georgica-uncinata*). Moreover, according to our investigation if we accept the fact that they are two different species, all individuals collected in Antarctica would be in the lower range of size (Fig. 1) compared to individuals from the Northern Hemisphere described by these authors. Finally, *Sanionia uncinata* can

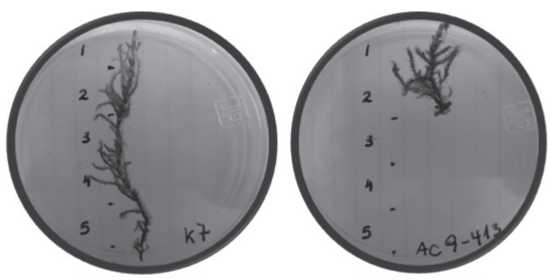

Fig.1: Gametophyte from Tierra del Fuego, Karukinka (K7) and from Fildes Peninsula (AC9-413).

Gametofito de Tierra del Fuego, Karukinka (K7), y de península Fildes (AC9-413).

be found in many places in the South Shetland Islands and the Antarctic Peninsula such as the Fildes, Ardley, Potter, Byers and Barton Peninsulas, Deception Island and Hope Bay (Antarctic Treaty Secretariat 2002a, 2002b, 2005a, 2005b, 2008 (on-line); it has also been found outside of Antarctica in the National Park Karukinka, Tierra del Fuego, in Chilean Patagonia (Larraín 2008). It is interesting to ask why *Sanionia*, a cosmopolitan species, has a wide distribution in places like Antarctica and the Northern Hemisphere. It suggests the study of the different methods of colonization of new areas by mosses in Antarctic and the significance of the possible colonization from Tierra del Fuego suggested by Jules Cardot over 100 years ago. Germination and subsequent development and survival are possible by those species genetically and physiologically pre-adapted to tolerate relatively unstable conditions, severe dehydration and abiotic stress and in particular, minimum nutrient concentrations. Thus the success in this extreme environment is not given only by the resistance or tolerance to the extreme conditions where they live, but the multiple dispersion methods they have in order to colonize free-ice surfaces.

The dispersion and establishment from local sources in Antarctica occurs mostly by vegetative gametophytes; the numerous modes of vegetative reproduction include wind dispersion of the gametes after desiccation (Fig. 2A) and gametophytes washed downstream after fast snow melting (Fig. 2B) to new habitats, developing rhizoids if the edaphic conditions, moisture, stability of the substrate and microclimate remain adequate. This allows the establishment into small colonies, which with other species, may gradually develop a distinctive community characteristic of the environmental features of the habitat (Smith 1972). Birds use mosses to build their nests; in periods when the ice had not melted we found groups of gametophytes which had birds dropped (Fig. 2C).

Few other species of Antarctic bryophytes produce sporophytes (Webb 1973), and the sporophyte state of *Sanionia* is described as very rare (Lewis-Smith 1984). According to Brown (1907), the most important evidence for the possible wind transport of Fuegian species to Antarctica is the discovery by Dr F. E. Fritschof pollen grains of *Podocarpus* (gymnosperms) among the algae found in a patch of red snow in the South Orkneys. The nearest land from which these pollen grains could have come is southern South America; several species of *Podocarpus* occur in Chile, some at high altitudes, and thus are more likely to have their pollen carried by the wind. Based on this observation, perhaps the greatest input to the gene pool of the bryophyte population is derived from exotic spores, since these haploid spores are capable of generating new plants. This hypothesis is also in part supported by many authors such as van Zanten (1978), Marshall (1996) and Hebel (1999); these spores will probably have descended into new areas perpetually over millions of years (Lewis-Smith 1984). The abundance and diversity of aerial spores is determined by the size and strength of the propagules, the diversity and distance to the source (Marshall 1996). However, dispersion

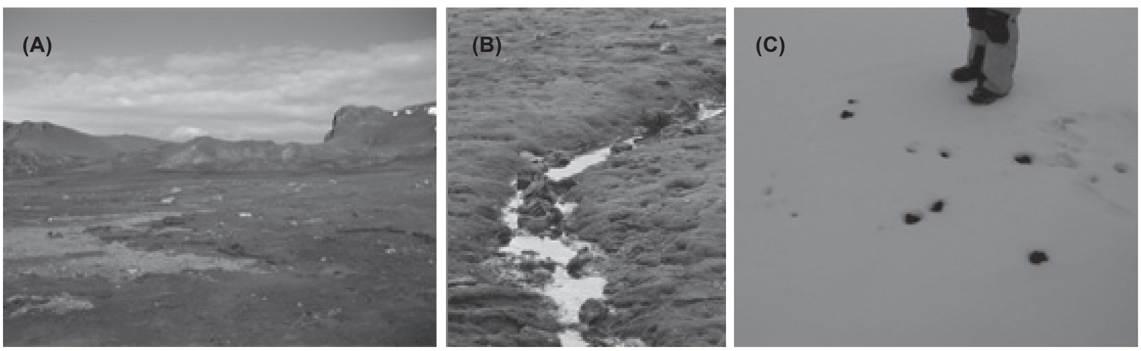

Fig. 2: Different effects that allow the dispersion of mosses in Antarctica.

Diferentes efectos que permiten la dispersión de los musgos en Antártica.

may also be favored by birds (Lewis Smith 1984), and more recently by man.

One report discussed the viability of the spores under different environmental conditions and showed that many moss species spores are capable of remaining viable after many years (about 20) of desiccated storage with or without subsequent wet or dry freezing Van Zanten (1978). Thus it is conceivable that the rain of spores on the Antarctic region creates a bank of propagules on the soil and over the mosses, and probably over the ice of glaciers draining into the crevices, some of which may remain viable for many years. If they have the fortune to be transported to ice-free niches where the temperature and humidity are favorable, these spores may be able to germinate. In general, due the infrequent sexual stages of mosses in Antarctica, a strong clonality is expected, which has an extremely high importance for the conservation and management in Antarctica. The above arguments indicate the importance of create a new viewpoint, to conserve the niches of the species of Antarctica as well as its biodiversity.

New views on conservation: The discussion of (niche) conservation and genetic diversity in Antarctica

The environmental impact of human activities in Antarctica varies considerably according to geographic location, and in some places is very important (Tin et al. 2009). Only few of the first explorers and scientists who came to Antarctica were worried about the effects of sealing and whaling in the Southern Ocean, and had little concern about pollution or conservation; international organizations working in Antarctica have recognized these problems since the middle of the last century (Fogg 1992). An urgent need exists to provide a correct environmental evaluation (Dalziell 1995); the conservation efforts of the Scientific Committee on Antarctic Research (SCAR) have addressed the direction and development of the System of Protected Areas (Fogg 1992). Their efforts resulted in the establishment of a considerable number of sites, mainly designated to protect scientific activity or to provide locations with baseline data for future use. These areas include Antarctic Specially Protected Area (ASPA), Sites of Special Scientific Interest (SSSI) and Antarctic Specially Managed Areas (ASMA) (Walton & Dingwall 1995). Nevertheless there is still much work to be done, such as determining if these zones of special protection are representative of the gene pool for many species in Antarctica. Because the history of the vegetation in Antarctica has been studied based mainly on palaeo ecological sources, establishing that the present vegetation in Antarctica has been considerably modified since 30 million years ago, it was concluded that the combination of isolation and climatic change has allowed the existence of endemic and non-endemic species.

Very few endemic mosses are present in Antarctica, while 50 % of the lichens are endemic. The periodic extensions and contractions of ice coverage produce processes of speciation and genetic differentiation between populations, such as genetic diversity within populations, which make them unique. According to Chown & Convey (2007), it is not known if there were refuges in the vegetation history of West Antarctica and thus mosses could have an "ancient" history in the region, or if they are new colonists since the Pleistocene. Perhaps the conservation of remote populations such as those from Antarctica would not benefit the genetic variability of the species, given that there is high gene flow. Less understood are the human effects on the genetic structure and consanguinity of moss populations when they make decisions for ASPA sites and non-protected communities. It is therefore relevant to review the extent of anthropogenic influence on the development of current genetic patterns. Given that the ASPA sites were created based only upon biodiversity and not on ecological, geographical and topographical aspects, it is possible that non-protected areas would be exposed to greater pressure than the ASPA sites. Thus a critical evaluation becomes necessary not only of the ASPA itself, but also its effects and buffer zones for the balance of the ecosystems and the relationship among populations of the same species that are protected or not protected.

It is not presently known whether the non-endemic species have only colonized Antarctica through propagules dispersed by wind or birds, or survived in refuges during the last glaciations. According to Lewis-Smith (1984), it is unlikely that any peat-forming vegetation survived the Pleistocene glaciations south of 60º latitude, because any organic deposit would have been destroyed by the expanding ice caps. On the other hand, Salzmann et al. (2011) suggested that for James Ross Island the presence of substantial Pliocene vegetation is unlikely. If it is assumed that the current vegetation distribution has been present only since the Pleistocene (two million years), mainly after the last glaciations 20000 years ago as suggested by Convey (2010), gene flow during the postglacial colonization apparently should be sufficient to prevent a differentiation among populations of Antarctica, sub-Antarctic islands and South America. To understand the evolution, origins and mechanisms of dispersion, as well as the responses to the climatic change, requires the analysis of the genetic structure, which is a good tool to investigate some of these questions. The powerful molecular techniques have allowed studying the correspondence between taxonomy and climatic and tectonic events, known glacial refuges, routes of dispersion and colonization of habitat; they can separate different timescales and moss species based on different markers. Some efforts have been made, mainly by Dale et al. (1999), Selkirk et al. (1997, 1999), Skotnicki et al. (1998a, 1998b, 1999) and Bradner et al. (2000). According to Skotnicki et al. (1999), the genetic differentiation between nearby populations of *Sarconerum glaciale* on Ross Island is greater compared with those more distant, which suggest long dispersion distance. In addition, the presence of somatic mutations supports the argument about the genetic diversity in populations located a few kilometers apart. Nevertheless, these previous genetic studies in Antarctic mosses have limited value due to a lack of variation in the markers or non-specificity of the methods used (Clarke et al. 2009). It is debated whether unusually elevated levels of genetic variability are artifacts from contamination from other species known to be naturally associated with Antarctic mosses. This suggests that because of contaminants, levels of genetic variation cannot be estimated accurately and reliably by non-specific PCR-based approaches (Stevens et al. 2007).

In the case of *Sanionia*, due to its wide range of distribution in Antarctica possibilities such as current gene flow (dispersion by wind, water or birds) or permanence in coastal refuges such as nunataks, perhaps near volcanic zones like Deception Island, cannot yet be determined.

According to the work of McDaniel & Shaw (2003) related to the relationship and genetic divergence of a Trans-Antarctic moss species, the niche conservatism approach may be helpful when it is used to model the tendency of species to retain ancestral ecological characteristics. According to Wiens & Graham (2005), the simple test of whether niches are conserved is not by itself particularly helpful; it is better to focus on the patterns of niche formation and conservation. The type of niche conservatism may be important also for the spread of invasive human-introduced species, responses of species to global climate change and human history.

Niche conservatism in a changing Antarctica

Holocene records of ice fluctuations in the Antarctic Peninsula are particularly important in the light of recent warming trends that have resulted in glacier retreat and ice-shelf collapse at several locations. Currently, the question of ice fluctuations on the Holocene and more ancient scales is not answered, and there is no evidence for refuges in the Peninsula region. In contrast, there is biological evidence that such refuges must have been present somewhere (Peter Convey, pers. com. 2009). According to Ingólfsson et al. (2003) the Antarctic Peninsula transition completed broadly from glacial to interglacial conditions by about 6 ka BP. More recent records of fluctuations or pulses of glacier retreat and advance were demonstrated by Hall (2008) through radiocarbon dating of incorporated moss that indicated the advance of the Collins Ice Cap on Fildes Peninsula (King George Island) during the “Little Ice Age” defined in Europe, when the glacier advanced less than 500 m beyond its present-day margin. According available data, this was the most extensive advance since the last 3500 cal. years. Thus, the ice cap most likely was behind its present position prior to ~650 cal. yr BP. Consequently for much of the past 3500 years moss has grown near the present ice margin in Valle Norte.

Currently ice-free areas represent a very low percentage of total emerged surfaces in

Antarctica; for the South Shetland Islands it has been estimated as 11 % of the surface (Serrano et al. 1998). This exposed terrain is the result of past and recent climatic variability which modulated and constrained the viability and the limits of pulsing ice masses.

Thus niche conservatism could be the explanation of the distribution of the flora in Antarctica, and supports why exotic species become established in the region, such as the patterns seen for 35 species of reptiles and amphibians in North America, in which the significant relationship implies niche conservatism in climatic tolerances (Wiens & Graham 2005). On the other hand, Lewis-Smith (1984) suggested that it is very difficult to establish the whole history of the flora in the Antarctic region, because many records are under the ice cap. Moreover, because of the great erosive power of the ice flow this niche conservatism approach will not explain the current distribution of the vegetation or the presence of endemic and non-endemic species, because of the dynamic nature that this process has; especially moraines and slopes of valleys provide conditions for the development of a flora, but it does not necessarily develop again after periods of glaciations.

In this context, mountain topography plays an important role in biodiversity; the potential floristic diversity of an ice-free area can be predicted through the shape, geology and rock structure of the mountain. Surprisingly, plant biodiversity in many high mountains is frequently much richer in alpine flora than other lower mountains (Convey 2008). Slopes, screes and terraces and also moraines may look unstable but they can provide, depending on aspect and geological structure, varied and favorable habitats that are adequate for adapted species. According to Crawford (2008), the roughness of mountain also makes abundant very small spaces where local environmental conditions can provide temperature regimes that can neutralize the effects of altitude and latitude.

Moreover, the orientation of the mountain plays a very important biogeographic role for migration. A north-south orientation is generally considered the most favorable for alterations in temperature and the concavity provides reservoirs for soil, water and nutrients (Crawford 2008). In cases such as moraines, we measured the soil temperature and it was even higher depending on the orientation of the slope, which with the diurnal variation in light intensity during summer also influences growth and development through photoperiodic responses (Holdgate 1970). Moreover, higher hills in ice-free areas in Antarctica are the first places where snow melts. All these factors could explain the high presence of sporophytes of different species in those higher parts that we observed in Punta Hanna, moraines of the Collins Glacier and Potter Bay. Otherwise the presence of moss species in the higher areas, where there is much more wind, facilitates the transport of their spores to remote areas.

Currently, rapid, recent, regional and intense climate variability affecting Antarctic Peninsula provides an opportunity to understand mechanisms and processes used by mosses when they colonize ice-free areas. It is well documented that during the last 60 years the Antarctic Peninsula region has experienced a major warming trend, based on the evidence provided by instrument records of meteorological stations since 1950. Increases of annual mean temperature up to 0.56 °C decade^{-1} were recorded at the Verdnasky/Faraday station; they describe an upper value for the general warming trend experienced in the region (Turner et al. 2005). Long-term records also show a strong rising trend in the annual duration of the melting season, representing a potential for ice and snow melt under this present environmental setting (Vaughan 2006). Nevertheless, spatial complexity also has been noted in the region because some stations show cooling trends, likely due to local factors and differences in the length of data records. This suggests that there is not a sole driver for glacier retreat in this region. According to Cook et al. (2005), about 87 % of 244 marine glacier fronts evaluated on the Antarctic Peninsula and associated islands have retreated in the last six decades, showing at the same time that a clearly marked boundary between mean advance and retreat has progressively migrated southward. Coincidently, based on geospatial data provided by aerial photography, maps and satellite imagery, the change of glacier frontal position was evaluated on the northern tip of the Antarctic Peninsula and the South Shetland Islands (Ferrigno et al. 2006). The temporal analysis between 1947 and 1999 of average coastal changes in 18 glaciers of King George Island showed a strong negative trend, with an increase in the amount of recession between 1950 and 1956 and between 1975 and 1979.

One example of ice retreat is the coastal change at Hannah Point, Livingston Island, South Shetland Islands, where significant changes may be appreciated in both glacier frontal position and ice coverage after a period of 52 years (Fig. 3). Here plant succession is expected to be developed first by soil microorganisms, lichens, mosses, etc. (Longton 1985). In this new ice-free area mosses such as *Sanionia uncinata* become established on accumulations of moist soil in between lichens on moraines (Fig. 4) approximately 50 m from the glacier. The interesting presence of *Deschampsia antartica* near the glacier

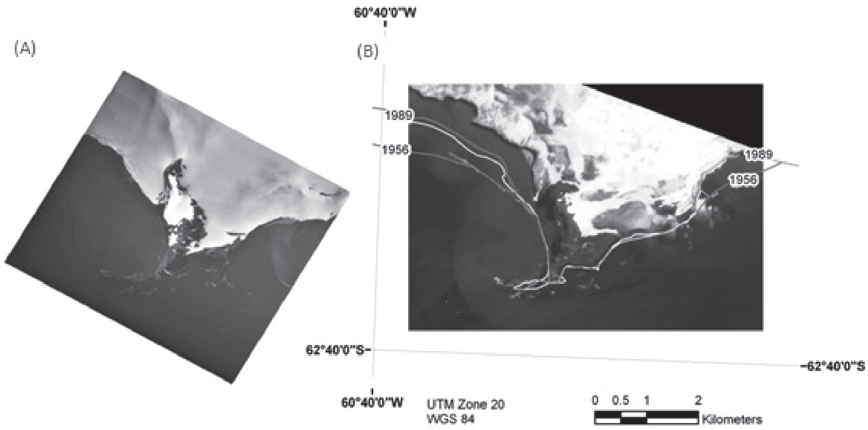

Fig. 3: Coastal change at Hannah Point, Livingston Island, South Shetland Islands. Significant changes can be appreciated in both glacier frontal position and ice coverage after a period of 52 years: (A) vertical aerial photograph taken on 1 December 1956 by 26 FID survey and (B) false color composition VNIR bands of ASTER scene taken on 25 February 2008; vegetation distributed in patches over ice-free terrain being depicted as redish color areas. Coastline (white line) and coastal change (green and orange lines) are vector coverages available in ADD version 5.0.

Cambio en las líneas de costa de punta Hannah, isla Livingston, islas Shetland del Sur. Se pueden apreciar cambios significativos tanto en la posición frontal del glaciar, como en la cobertura del hielo, en un periodo de 52 años: (A) Fotografía aérea vertical tomada en diciembre 1 de 1956 por el estudio FID y (B) Composición de falso color VNIR bandas de ASTER, imagen tomada en febrero 28 del año 2008, la vegetación se distribuye en parches sobre el terreno que se muestra de color rojizo. Las líneas de costa (líneas blancas) y el cambio de estas (líneas verdes y naranjas) son las coberturas vectoriales disponibles en la versión 5.0 de ADD.

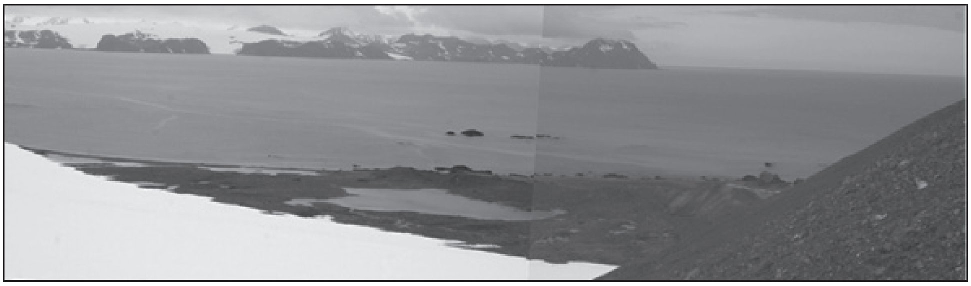

Fig. 4: Frontal moraine of the glacier of Hannah Point.

Morrena frontal del glaciar de punta Hannah.

probably shows that the reproduction of this successful species was benefitted by the climate change, which produced conditions that allowed it to colonize without a previous succession of mosses or lichens. It is given that niche conservatism would shift the margins of species in the face of global warming. Species that cannot adapt and cannot shift their geographic ranges, due to habitat destruction or geographical constraints, may be at risk of extinction. Several authors have assumed niche conservatism to evaluate the potential large-scale impact of global warming and how many species respond to climate change as predicted by niche conservatism, rather than with rapid evolution of climatic tolerances.

A more important statement is that no such approach has yet been applied anywhere in the Antarctic, the South Shetlands or the Antarctic Peninsula, and that these areas are remarkably suitable to do so.

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LITERATURE CITED

ANTARCTIC TREATY SECRETARIAT (2002) Management Plan for Antarctic Specially Protected Area No. 126 Byers Peninsula, Livingston Island, South Shetland Islands From Measure 1 (online) URL http://www.ats.aq/documents/ATCM25/fr/ATCM25_fr001_e.pdf (accessed August 23, 2011).

ANTARCTIC TREATY SECRETARIAT (2002) Management Plan for Antarctic Specially Protected Area No. 148 Mount flora, Hope Bay, Antarctic Peninsula From Measure 1 (online) URL: http://www.ats.aq/documents/ATCM25/fr/ATCM25_fr001_e.pdf (accessed August 23, 2011).

ANTARCTIC TREATY SECRETARIAT (2005) Management Plan for Antarctic Specially Protected Area No. 140. Parts of Deception Island, South Shetland Islands Measure 3 Appendix 1 (online) URL: http://www.ats.aq/documents/ATCM28/fr/ATCM28_fr001_e.pdf (accessed August 23, 2011).

ANTARCTIC TREATY SECRETARIAT (2005) Management Plan for Antarctic Specially Protected Area No. 132 PotterPeninsula, King George Island (isla 25 de Mayo), South Shetland Islands Measure 2 Annex F. (online) URL: http://www.ats.aq/documents/ATCM28/fr/ATCM28_fr001_e.pdf (accessed August 23, 2011).

ANTARCTIC TREATY SECRETARIAT (2008) Propuesta de una nueva zona antártica especialmente protegida en punta Nar bski, península Barton, isla Rey Jorge (isla 25 de Mayo). Antarctic Treaty Consultative Meeting. Kyiv, Ukraine 2-13 June, 2008. (online) URL: http://www.ats.aq/documents/ATCM32/fr/ATCM32_fr002_s.pdf (accessed August 23, 2011).

BRADNER JR, RK SIDHU,B YEE,M SKOTNICKI, PM SELKIRK & KMH NEVALAINEN (2000) A new fungal species associated with the Antarctic moss *Bryum argenteum*. Polar Biology 23: 730-732.

BROWN WSR (1907) Report on the scientific results of the voyage of S.Y. "Scotia" during the years 1902, 1903 and 1904, under the leadership of William S. Bruce. http://www.archive.org/details/reportonscientif03scot (accessed September 19, 2011).

CHOWN SL & P CONVEY (2007) Spatial and temporal variability across life's hierarchies in the terrestrial Antarctic. Philosophycal Transaction Royal Society London B 362: 2307-2331.

CLARKE L, D AYRE & S ROBINSON (2009) Genetic Structure of East Antarctic populations of the moss *Ceratodon purpureus*. Antarctic Science 21: 51-58.

CONVEY P (2010) Terrestrial biodiversity in Antarctica-Recent advances and future challenges. Polar Science 4: 135-147.

CONVEY P, JAE GIBSON, CD HILLENBRAND, DA HODGSON, PJA PUGH, JL SMELLIE & MI STEVENS (2008) Antarctic terrestrial life challenging the history of the frozen continent? Biological Reviews 83: 103-117.

COOK A J, AJ FOX, DG VAUGHAN & JG FERRIGNO (2005) Retreating glacier fronts on the Antarctic Peninsula over the Past Half-Century. Science 308: 541-544.

CRAWFORD RMM (2008) Plants at the Margins. Ecological limits and climate change. Cambridge University Press, Cambridge.

DALE TM, ML SKOTNICKI, KD ADAM & PM SELKIRK (1999) Genetic diversity in the moss *Hennediella heimii* in Miers valley, southern Victoria Land, Antarctica. Polar Biology 21: 228-233.

DALZIELL J (1995) Environmental impact assessment: discussion and recommendations. In: Dingwall PR (ed) Progress in Conservation of the Subantarctic Islands: Proceedings of the SCAR/IUCN Workshop on Protection, Research and Managment of Subantarctic Islands, Paimpont, France, 27-29 April, 1992: 147-149 IUCN--the World Conservation Union. Gland, Switzerland, Cambridge, UK.

FERRIGNO JG, AJ COOK, KM FOLEY, RS WILLIAMS, C SWITHINBANK, AJ FOX, JW THOMSON & J SIEVERS (2006) Coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands, Antarctica: 1843-2001. USGS Geologic Investigation Series, Map I-2600-A.

FOGG GE (1992) A history of Antarctic science. Cambridge University Press, Cambridge.

FRAHM JP (2001) Biologie der Moose. Spektrum Akademischer Verlag, Heidelberg, Berlin.

GIMINGHAM CH & RIL SMITH (1971) Growth form and water relations of mosses in the maritime Antarctic. British Antarctic Survey Bulletin 25: 1-21.

HALL B (2008) Late-Holocene advance of the Collins Ice Cap, King George Island, South Shetland Islands. The Holocene 17: 1253-1258.

HEBEL I & G ROJAS (1999) Estudio preliminar del contenido aerobiológico de la atmósfera de la península Antártica y su relación con el ecosistema. Serie Científica INACH 49: 141.

HOLDGATE MW (1970) Vegetation in "Antarctic Ecology" 2: 729-732. In: Holdgate MW (ed) Academic Press, New York.

ICHIKAWA K,M SUGITA, T IMAIZUMI, M WADA &S AOKI (2004) Differential Expression on a Daily Basis of Plastid Sigma Factor Genes from the Moss *Physcomitrella patens*. Regulatory Interactions among PpSig5, the Circadian Clock, and Blue Light Signaling Mediated by Cryptochromes. Plant Physiology 136: 4285-4298.

INGÓLFSSON O, C HJORT & O HUMLUM (2003) Glacial and Climate History of the Antarctic Peninsula since the Last Glacial Maximum. Arctic, Antarctic, and Alpine Research 35: 175-186.

LEWIS SMITH RI (1972) Vegetation of the South Orkney Islands with particular reference to Signy Island. British Antarctic Survey Scientific Reports 68: 1-124.

LEWIS SMITH R, DHW WALTON & PR DINGWALL (eds) (1994) Developing the Antarctic protected area system. IUCN-The World Conservation Union, Gland and Cambridge.

LEWIS-SMITH R (1990) Plant community dynamics in Wilkes Land, Antarctica. Proc. NIPR Symp. Polar Biology 3: 229-244.

LEWIS-SMITH R (1984) Terrestrial plant biology of the Subantarctic and Antarctic. In: Laws RM (ed) Antarctic Ecology 1: 61-162.

MARSHALL W (1996) Biological particles over Antarctica. Nature 383: 680.

McDANIEL SF & J SHAW (2003) Phylogeographic structure and cryptic speciation in the Trans-Antarctic moss *Pyrrhobryum mnioides*. Evolution 57: 205-215.

OCHYRA R, R LEWIS-SMITH & H BEDNAREK-OCHYRA (2008) Illustrated moss flora of Antarctica. Series: Studies in polar research. Cambridge University Press. Cambridge.

PIZARRO C & F SÁIZ (1977) Estudio de la taxocenosis muscinal de la península Fildes (isla Rey Jorge, Shetland del Sur). Serie Científica INACH 5: 81-96.

PUTZKE J & AB PEREIRA (2001) The Antarctic mosses: With special reference to the South Shetland Islands. ULBRA.

RUBIN J (1996) Antarctica: A lonely planet travel survival kit. Lonely Planet Publications.

SALZMANN U, J RIDING, A NELSON & J SMELLIE (2011) How likely was a green Antarctic Peninsula during warm Pliocene interglacials?. A critical reassessment based on new playnofloras from James Ross Island. Palaeogeography, Palaeoclimatology, Palaeoecology 309: 73-82.

SELKIRK PM, M SKOTNICKI,KD ADAM,MB CONNETT, T DALE, TW JOE & J ARMSTRONG (1997) Genetic variation in Antarctic populations of the moss *Sarconeurum glaciale*. Polar Biology 18: 344-350.

SELKIRK PM, M SKOTNICKI, KD ADAM, MB CONNETT, T DALE, TW JOE & J ARMSTRONG (1999) Genetic diversity in the moss *Hennediella heimii* in Miers Valley, southern Victoria Land, Antarctica. Polar Biology 21: 228-233.

SERRANO E & J LÓPEZ-MARTÍNEZ (1998) Caracterización y distribución de las formas y los procesos periglaciares en las Islas Shetland del Sur (Antártida). In: Gómez A, F Salvador, L Schulte & A García (eds) Procesos biofísicos actuales en medios fríos. Estudios recientes: 181 204. Universidad de Barcelona, Barcelona, España.

SHOA (1989) Derrotero de las costas de Chile. Servicio Hidrográfico y Oceanográfico de la Armada de Chile, Valparaíso, Chile.

SKOTNICKI ML, JA NINHAM & PM SELKIRK (1999) Genetic diversity and dispersal of the moss *Sarconerum glaciale* on Ross Island, East Antartica. Molecular Ecology 8: 753-762.

SKOTNICKI ML, PM SELKIRK & C BEARD (1998a) RAPD Profiling of genetic diversity in two populations of the moss *Cetarodon purpureus* in Victoria Land, Antarctica. Polar Biology 19: 172-176.

SKOTNICKI ML, PM SELKIRK & JA NINHAM (1998b) RAPD analysis of genetic variation and dispersal of the moss *Bryum pseudotriquetum* from Southern Victoria Land, Antarctica. Polar Biology 20: 121-126.

STEVENS MI, SA HUNGER, SFK HILLS & CEC GEMMILL (2007) Phantom hitch-hikers mislead estimates of genetic variation in Antarctic mosses. Plant System Evolution 263: 191-201.

TIN T, ZL FLEMING, KA HUGHES, DG AINLEY, P CONVEY et al. (2009) Impacts of local human activities on the Antarctic environment. Antarctic Science 1: 3-33.

TURNER J, SR COLWELL, GJ MARSHALL,TA LACHLAN-COPE, AM CARLETON et al., (2005) Antarctic climate change during the last 50 years. International Journal of Climatology 25: 279-294.

VAN DER VELDE M, L VAN DE ZANDE & R BIJLSMA (2001) Genetic structure of *Polytrichum formosum* in relation to the breeding system as revealed by microsatellites. Journal of Evolutionary Biology 14: 288-295.

VAN ZANTEN B (1978) Experimental studies on trans-oceanic long range dispersal of moss spores in the Southern Hemisphere. Journal of Hattori Botanical Laboratory 44: 455-482.

VAUGHAN DG (2006) Recent trends in melting conditions on the Antarctic Peninsula and their implications for ice-sheet mass balance and sea level. Arctic, Antarctic, and Alpine Research 38: 147-150.

WEBB R (1973) Reproductive behavior of mosses on Signy Island, South Orkey Island. British Antarctic Survey Bulletin 36: 61-77.

WEISING K & R GARDNER (1999) A set of conserved PCR primer for the analysis of simple sequence repeat polymorphisms in chloroplast genomes of dicotyledonous angiosperms. Genome 42: 9-19.

WIENS JJ & CH GRAHAM (2005) Niche conservatism: Integrating evolution, ecology and conservation biology. Annual Review of Ecology, Evolution and Systematics 36: 519-539.

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