UNIVERSIDADE FEDERAL DO PAMPA – CAMPUS SÃO GABRIEL

# FITOSSOCIOLOGIA DE VEGETAÇÃO ASSOCIADA A *Deschampsia antarctica* DESV. NAS ILHAS SHETLAND DO SUL - ANTÁRTICA

LILIAN PEDROSO MAGGIO

**São Gabriel, RS**

**2021**

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Tese apresentada ao Programa de Pós-Graduação em Ciências Biológicas da Universidade Federal do Pampa, como requisito para a obtenção do título de Doutora em Ciências Biológicas.

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*"Quando os ventos de mudança sopram, umas pessoas levantam barreiras, outras constroem moinhos de vento".*

(Érico Verissimo)

**RESUMO**

A Antártica é o segundo maior continente do planeta Terra, possui aproximadamente 14 milhões de km², coberta por uma grande e densa camada de gelo, podendo atingir 23 milhões de $km^2$ devido ao congelamento dos oceanos adjacentes durante o período de inverno. Apesar das condições ambientais severas, o que dificulta o estabelecimento de vida na Terra, existem espécies vegetais adaptadas a esse tipo de ambiente, como espécies de criptógamas e fanerógamas. Nas últimas décadas diversos estudos sobre a vegetação antártica vem sendo conduzidos, porém são restritos os trabalhos com informações mais detalhadas sobre as espécies vegetais associadas *Deschampsia antarctica* Desv. O objetivo desta tese foi reunir dados sobre os aspectos ecológicos de espécies associados a *Deschampsia antarctica*, bem como realizar levantamento fitossociológico de vegetação em substrato (ossos de animais marinho – lobo marinho e baleia), e avaliar a presença de vegetação em *pellets* (restos alimentares de pássaros carnívoros) de aves marinhas como forma de dispersão. Para isso, as coletas de dados a campo foram realizadas durante a OPERANTAR XXXVIII 2019/2020 durante os meses de fevereiro e março. Os resultados desta tese estão apresentados em forma de 4 artigos científicos.



Palavras-Chave: comunidades vegetais, biodiversidade, fanerógama, continente antártico.

## ABSTRACT

Antarctica is the second largest continent on planet Earth, has approximately 14 million km², covered by a large and dense layer of ice, reaching 23 million km² due to the freezing of adjacent oceans during the winter period. Despite the severe environmental conditions, which hinder the establishment of life on Earth, there are plant species adapted to this type of environment, such as cryptogam and phanerogam species. In recent decades, several studies on Antarctic vegetation have been conducted, but more detailed information on associated plant species *Deschampsia antarctica* Desv. The objective of this thesis was to gather data on the ecological aspects of species associated with *Deschampsia antarctica*, as well as to carry out a phytosociological survey of substrate vegetation (marine animal bones - sea wolf and whale), and to evaluate the presence of vegetation in pellets (food waste of carnivorous birds) of seabirds as a form of dispersal. For this, field data collections were carried out during OPERANTAR XXXVIII 2019/2020 during the months of February and March. The results of this thesis are presented in the form of 4 scientific articles.



Key words: plant communities, biodiversity, phanerogam, antarctic continent.

**SUMÁRIO**

# 1. INTRODUÇÃO GERAL

## 1.1 Continente Antártico

A Antártica está localizada acima do paralelo 60º Sul e compreende uma área de aproximadamente 14 milhões de $km^2$, coberta por uma grande e densa camada de gelo (Campbell & Claridge, 1987), sendo que 99% do continente permanece coberto por gelo e neve na maior parte do ano (Turner et al., 2013), podendo atingir 23 milhões de $km^2$ devido ao congelamento dos oceanos adjacentes no período de Abril a Novembro (Thomas et al., 2017).

Geologicamente, a formação da Antártica esteve associada a outros continentes ou porções continentais, sendo suas primeiras segmentações resultantes da formação da massa continental Pangeia. Com a deriva continental ocorreu a fragmentação do supercontinente Pangeia, formando outros dois continentes a Laurásia e Gondwana, este último constituindo os continentes do hemisfério Sul, e assim formando o continente antártico (Vieira, 2006; Lurcock & Florindo, 2017).

Biogeograficamente, a Antártica pode ser dividida em três regiões: Subantártica, Antártica Continental e Antártica Marítima. Esta última compreendendo o oeste da Península Antártica e grupos de ilhas ao norte, como as Shetland do Sul, Orkney do Sul, Sandwich e Bouvetoya (Lewis-Smith, 1984; Longton 1988, Ochyra, 1998).

O arquipélago das Shetland do Sul está localizado ao norte da Península Antártica, sendo constituído principalmente por 10 grandes ilhas (Putzke e Pereira, 2020), tais como: Ilha Rei George, Nelson, Robert, Greenwich, Snow, Deception, Clarence, Elefante, Smith e Livingston (Island, 2001).

A Ilha Livingston, é a segunda maior ilha das Shetland do Sul, ocupando uma área de aproximadamente 798 $km^2$, sendo separada das ilhas vizinhas Greenwich, Deception ao Sul, e Snow ao oeste-sudoeste pelos estreitos de MCFarlane, Smolensk e Morton (Ivanov, 2015).

## 1.2 Península Byers – Ilha Livingston

A Península Byers está localizada no extremo ocidental da ilha Livingston sendo a maior área livre de gelo nas Shetland do Sul, com uma área de 60,35 $km^2$, a península possui extensas áreas de praias, sendo a praia Sul com 12 km de extensão e 900 metros de largura, a maior do arquipélago (Ivanov, 2015). Além disso, possui importante valor biológico, tais como: a presença de musgos aquáticos no interior de lagos costeiros, a presença de uma vegetação bem desenvolvida em rochas basálticas, bem como espécies raras de criptógamas e a presença das duas únicas plantas vasculares nativas *Deschampsia antarctica* e *Colobanthus quitensis* (Vera et al., 2013; Quesada et al., 2009), ainda a península possui importantes valores geológicos e arqueológicos devido constituir um dos arquivos mais importantes para estudos do ambiente paleo-holoceno, bem como a maior concentração de locais históricos do início do século XIX, desta forma a península é uma Área Especialmente Protegida (ASPA- 26).

### 1.3 Comunidades vegetais

A Antártica apresenta condições ambientais severas, caracterizada como o continente mais remoto e difícil para o estabelecimento de vida terrestre (Convey, 2006), desta forma constitui um dos cenários mais estressantes a sobrevivência vegetal, devido ao elevado índice de radiação UV-B, pouca disponibilidade de água, solo oligotrófico e baixas temperaturas (Convey et al., 2013). No entanto, existem espécies vegetais adaptadas a regiões extremófilas, como espécies de criptógamas e fanerógamas nativas do continente (Singh & Khare, 2018).

Na Antártica, as áreas livres de gelo possuem uma baixa diversidade de substratos, assim as plantas desenvolvem-se sob rochas, solo, ossos, ao redor de corpos de água doce, e até em ambientes que possuem atividades geotérmicas (Câmara e Silva, 2020).

A comunidade vegetal antártica é composta por 113 espécies de musgos, dos quais duas são variedades (Ochyra et al., 2008), aproximadamente 386 espécies de fungos liquenizados (Øvstedal & Lewis-Smith, 2001) cerca de 10 espécies de fungos macroscópicos (Putzke e Pereira, 1990) e três espécies de fanerógamas, sendo nativas a *Deschampsia antarctica* Desv. e *Colobanthus quitensis* (Kunth) Bartl. (Putzke & Pereira, 2001) e *Poa annua* L. uma espécie introduzida que obteve sucesso reprodutivo (Chwedorzewska et al., 2014).

A *Deschampsia antarctica* está distribuída por quase todas as ilhas Shetland do Sul e áreas livres de gelo da Península Antártica (Barcikowski et al., 2001; Putzke & Pereira, 2020). Nas últimas décadas, pesquisadores vêm relatando o aumento e a distribuição nas populações da espécie, tendo como fator responsável pelo seu sucesso reprodutivo o aumento da temperatura média do ar no continente (Smith, 1994; Day et al., 1999; Gerighausen et al., 2003; Convey, 2006; Torres-Mellado et al., 2011; Park et al., 2018).

Nas últimas décadas, diversos autores vêm estudando as comunidades vegetais ao longo das ilhas Shetland do Sul, focando-se principalmente no grupo das criptógamas, como taxonomia de musgos e liquens, identificação e descrição de comunidades vegetais (Lindsay 1971; Redón 1985; Olech 1994; Ochyra 1998; Putzke et al., 1995; Putzke et al., 2015; Schmitz et al., 2018), enquanto estudos sobre as fanerógamas antárticas nativas concentraram-se em investigar as características anatômicas, as funções fisiológicas, a biologia molecular, a bioquímica e ecologia (Casanova-Katny et al., 2010; Amosova et al., 2015; Zúñiga-Feest et al., 2003; Parnikoza et al., 2007; Vera, 2011; Vera et al., 2013). Diante disto, estudos de vegetação associados a espécies fanerogâmicas são importantes para monitorar as comunidades vegetais e suas respostas diante as mudanças ambientais. Dados detalhados sobre a vegetação antártica ainda são escassos para regiões de difícil acesso, concentrando-se principalmente em área mais visitadas pelos pesquisadores, como ao redor das bases de pesquisas (Calviño-Cancela & Martín-Herrero, 2016).

**1. 4 Dispersão vegetal nas Ilhas Shetlands do Sul**

Nas últimas décadas o continente antártico vem sofrendo com as abruptas mudanças ambientais (IPCC, 2018). Ao longo da metade do último século, a Antártica esteve entre as regiões do planeta com o aquecimento global mais acelerado (Pritchard & Vaughan, 2007) sendo as regiões mais afetadas a Península Antártica e grande parte da Antártica Ocidental (Bromwich et al., 2013).

Durante o período de verão com aumento do derretimento da superfície, contribuiu para o colapso das plataformas de gelo, expondo novas áreas livres de gelo e assim favorecendo a colonização por plantas nativas e introduzidas, bem como alterando o local habitado por pinguins e aves para atividade de nidificação (Rintoul et al., 2018).

Em algumas regiões da Antártica Marítima, as aves são descritas como importantes vetores de dispersão vegetal, transportando sementes e fragmentos durante a atividade de nidificação em áreas livre de gelo (Vera, 2011; Parnikoza et al., 2012).

As espécies de *Catharacta* sp (Skuas) são as aves mais comuns na Antártica e ocorrem simpatricamente na região da península. Os ninhos dessa espécie são construídos com diversos tipos de substratos, comumente utilizando musgos e liquens (Burton, 1968), no entanto alguns estudos também relatam o uso de *D. antarctica* durante a atividade de nidificação dessas aves (Parnikoza et al., 2009b; 2012).

Muito embora a literatura sugira que os pássaros são importantes cooperadores para a dispersão de sementes ou propágulos de plantas (Hughes et al., 2006; Peklo, 2007), diversas hipóteses sobre o processo de dispersão vegetal têm sido sugeridas na literatura (Parnikoza et al., 2012). No entanto, estudos sobre a dispersão de fragmentos vegetais através de *pellets* de aves antárticas como uma nova fonte de disseminação de plantas ainda não foram analisados e discutidos.

Em um estudo conduzido por Putzke e Pereira (2020), os autores relatam que os musgos podem ocorrer em novas áreas, com a participação de aves, uma vez que, muitos pássaros podem ingerir fragmentos vegetais durante o transporte de alimento que é levado para os ninhos, ou até mesmo alimentarem - se de carcaças encontradas em comunidades vegetais. Desta forma, expelindo os fragmentos vegetais em forma de *pellets*. Diante disto, são necessários estudos que busquem analisar a presença de fragmentos vegetais em *pellets* de aves do continente antártico, visando avaliar a capacidade de crescimento e desenvolvimento de espécies vegetais nesse tipo de substrato.

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## 2. ARTIGOS

**2.1 Artigo 1:** PHYTOSOCIOLOGY AND DIVERSITY IN PLANT COMMUNITIES ASSOCIETD WITH *Deschampsia antarctica* (POACEAE) IN THREE REGIONS OF THE SOUTH SHETLAND ISLANDS, ANTARCTICA (Artigo submetido – Revista *Ecological Indicators*)

**2.2 Artigo 2:** PELLETS OF *Stercorarius* spp. (SKUA) AS PLANT DISPERSERS IN THE ANTARCTIC PENINSULA (Artigo aceito – Revista Anais da Academia Brasileira de Ciências)

**2.3 Artigo 3:** THE BONES OF LIVINGSTON ISLAND – HISTORY FOR PLANT SUCCESSION IN ANTARCTICA (Artigo submetido - Revista *Acta Scientiarum*)

**2.4 Artigo 4**: A NEW OCCURRENCE OF A BRYOPHILOUS FUNGUS IN ANTARCTICA: *Lamprospora cashiae* (ASCOMYCOTA - PEZIZALES) (Artigo publicado - Revista *Brazilian Journal of Development*)

**2.1 Artigo 1:** PHYTOSOCIOLOGY AND DIVERSITY IN PLANT COMMUNITIES ASSOCIETD WITH *Deschampsia antarctica* (POACEAE) IN THREE REGIONS OF THE SOUTH SHETLAND ISLANDS, ANTARCTICA.

(Artigo submetido – Revista *Ecological Indicators*)

Phytosociology and Diversity in Plant Communities Associetd with *Deschampsia antarctica* (Poaceae) in Three Regions of the South Shetland Islands, Antarctica

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**Abstract**

Studies on plant communities in the South Shetland Archipelago have been carried out in recent decades, focusing mostly on the cryptogamic communities. There are few studies of plant communities associated to *Deschampsia antarctica* Desv. (Poaceae), one of only two native phanerogams. This research aimed to carry out a comparative sampling of vegetation cover and its respective species diversity in areas of occurrence of *Deschampsia antarctica* (the Antarctic grass) in three regions of the South Shetland. The sampling effort was carried out in Ullmann Point (King George Island), Keller Peninsula (King George Island) and Byers Peninsula (Livingston Island) in the austral summer 2019/2020. The phytosociological inventory evaluated the ecological importance of the species, using the Ecological Significance Index (IES). To assess the diversity of plant communities, the Shannon-Weaver Diversity Index (H') was used. The species with the highest frequency and ecological significance index in the three regions evaluated was *Deschampsia antarctica*. Regarding the Shannon-Weaver diversity index, Ullmann Point was the region with the highest plant diversity value, followed by Keller Peninsula and Byers Peninsula.

**Keywords:** fhanerogams, ecological value index, diversity index (H’), antarctic continent.

**Running head: Ecology of the vegetal formations with** *Deschampsia antarctica*.

**Abbreviations:** Nº = number of squares Where the species was observed; F (%) = frequency of the species in each square sampled; IES = Ecological significance index.

## 1. Introduction

During the last decades the interest in the study of vegetation in the Antarctic continent has increased due to its importance for monitoring climate change (Robinson et al. 2018; Thomazini et al. 2018) and its impacts on plant diversity, especially in areas free from ice (Amesbury et al. 2017; Robinson et al. 2018). The Antarctic ice-free areas represents approximately 0.5% of the surface of the Antarctic continent (Singh et al., 2018) and the vegetation distribution and growth is shaped by abiotic and biotic factors (eg, Putzke et al., 2015; Robinson et al. 2018; Schmitz et al., 2018; Schmitz et al., 2020). These ice-free areas are mostly restricted to coastal regions, rocky slopes or nunataks, and show soils at different stages of development (Bokhorst et al. 2007).

The vegetation is mainly composed of bryophytes and lichens, with only two species of angiosperms native to the region, *Deschampsia antarctica* Desv. and *Colobanthus quitensis* (Kunth) Bartl. (Putzke and Pereira 2001; Victoria et al. 2013). Thus, differences in species composition can be found in a small area (Victoria et al., 2009; Schmitz et al., 2018) due to high environmental heterogeneity, such as microtopography, geological formation and physical and chemical properties of soils (Victoria et al. 2013; Benavent-González et al. 2018).

The characteristics and patterns of plant communities are described to various locations in Antarctica. In recent decades, many authors have studied plant communities along the South Shetland Islands, focusing on the group of cryptogams, such as the taxonomy of mosses, lichens, and the identification and description of plant communities (Redón 1985; Olech 1994; Ochyra 1998; ; Putzke et al., 1995; Øvstedal & Lewis-Smith, 2001; Victoria et al., 2013; Alves et al., 2013; Putzke et al., 2015; Schmitz et al., 2018; Schmitz et al., 2020 ).

The studies on Antarctic vascular plants have focused on investigating anatomical characteristics, distribution, physiological functions, molecular biology and biochemistry (Zúñiga-Feest et al., 2003; Giełwanowska et al., 2005; Parnikoza et al., 2007; Casanova- Katny et al., 2010; Vera 2011; Amosova et al., 2015; González et al., 2016; Nuzhyna et al., 2019).

Meanwhile phytosociological and ecological studies of phanerogamic communities in ice-free areas do not provide complete data especially in areas where vascular plants are more frequent. A more detailed survey of data in sectors such as, for example, the Byers Peninsula - Livingston Island, considered one of the Antarctic regions with the largest population of this grass species, is still necessary.

The present study aimed to compare vegetation cover and species diversity in vegetation formations associated with *Deschampsia antarctica* in three regions of the South Shetland Islands Archipelago, Antarctica.

## 2. Methods

### 2. 1 Study area

Fieldwork was carried out in three regions in the South Shetland Archipelago: on King George Island (Ullmann Point - 62° 05' 015″ S and 58° 20' 98″ W and Keller Peninsula - 62° 05' 06" S 058° 24' 12" W), and on Livingston Island (Byers Peninsula 62° 34'35" S and 61° 13'07" W), from February to March 2020 (Figure 1).

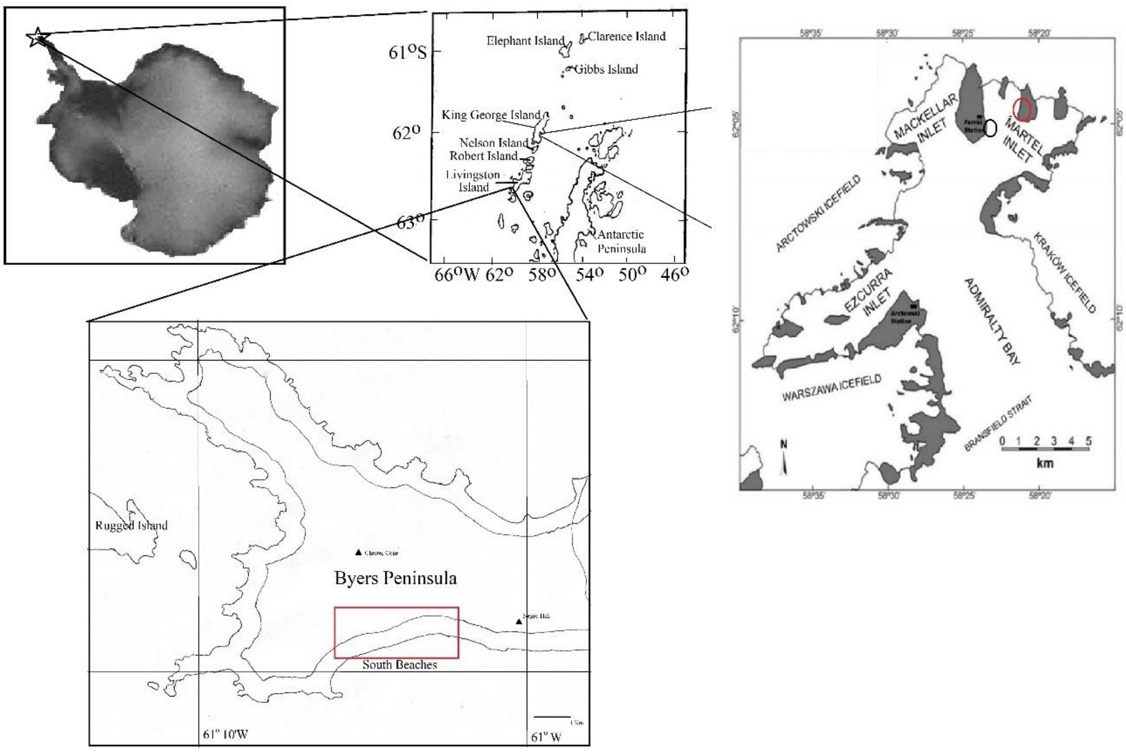


Figure 1 – Map of the studied areas in Antarctica: Byers Peninsula (red square); Ullmann Point (red circle) and Keller Peninsula (black circle).

## 2.2. Phytosociological Survey and Diversity Index

For the phytosociological sampling, data were collected using the square method of Schmitz et al. (2018) for Antarctic conditions (Figure 2). Transects were launched over the vegetation in a direction from North to South, with a distance of 5 meters one line from the other. Along each line, squares (20×20) cm, subdivided into 100 smaller squares of (2 ×2) cm (each equivalent to 1% of coverage) were placed 5 meters apart on those lines. When plant species were repeated in the last three squares, sample sufficiency was reached e the data sampling concluded. A total of 347 squares were sampled in all selected regions: 248 in Byers Peninsula, 56 in Ullmann Point and 43 in Keller Peninsula. Two categories of indexes were evaluated: Ecological Significance Index (IES) and Shanonn Diversity Index (H').

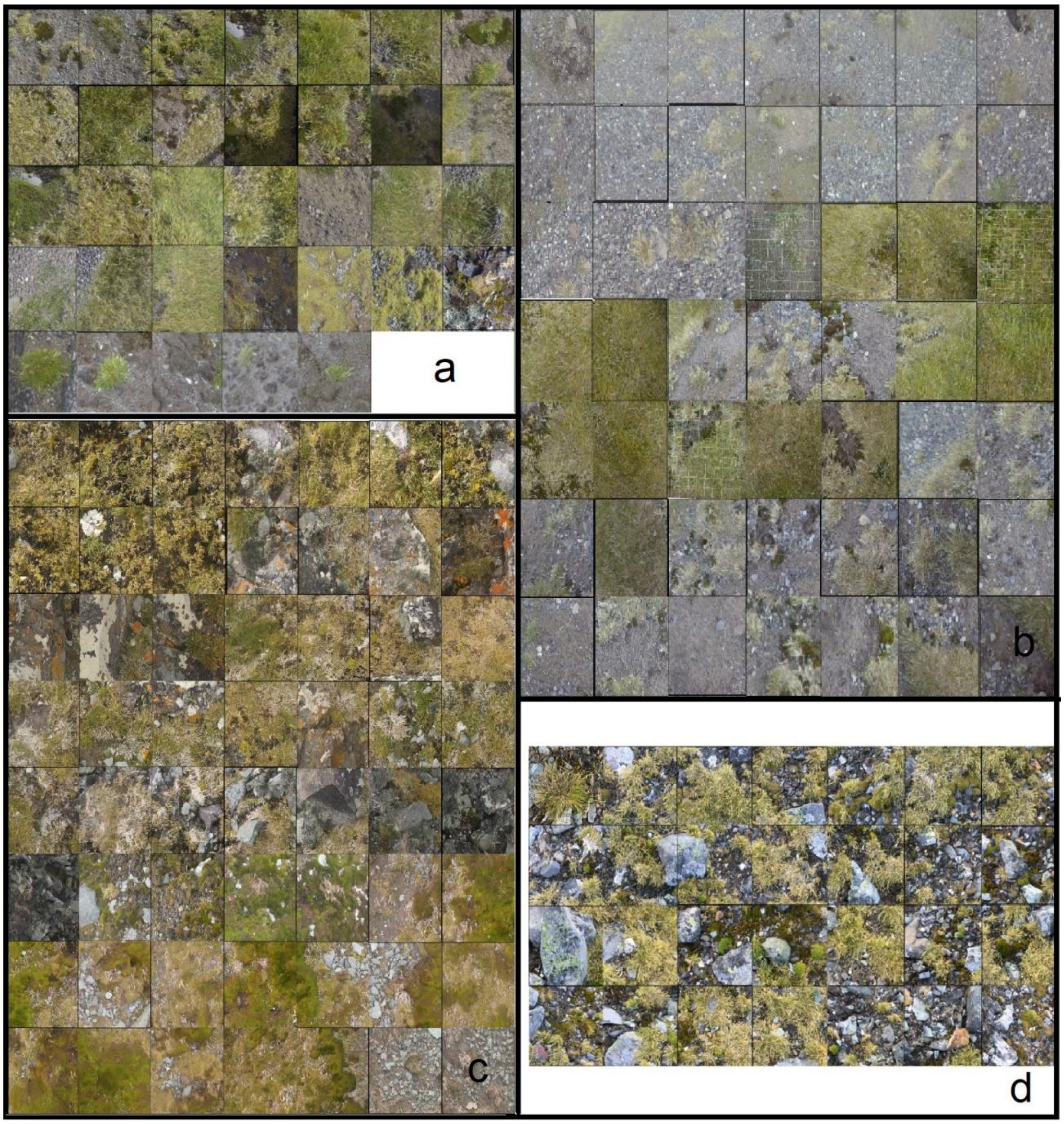

Figure 2. Sampled squares for each studied area: a - b) Byers Peninsula; c) Ullmann Point; d) Keller Peninsula.

**2.3. Species identification**

The species were identified according to the specific literature for Antarctic vegetation, such as Putzke & Pereira (2001), Ochyra (1998) and Ochyra et al. (2008) for mosses and Redón (1985), Øvstedal & Lewis-Smith (2001) and Olech (2004) for lichens. The collected specimens were dehydrated and stored at the Bruno Edgar Irgang Herbarium (HBI) - Universidade Federal do Pampa (UNIPAMPA - São Gabriel).

### 2.4. Vegetation Mapping

Vegetation mapping was carried out using a Phantom 4 drone with photographs captured from an altitude of 100 and 300 meters. The image treatment was carried out using the Agisoft program. The drone data also contributed to determining the exact location of each community and in defining the altitude and distribution.

### 2.5 Data analysis

To verify the ecological importance of the species in the total sampling, phytosociological data were used to calculate the Ecological Significance Index (IES) proposed by Lara & Mazimpanka (1998). The IES is calculated using the formula IES = F*(1+C) where (F) is the relative frequency of the species, and (C) the coverage value of each species, already replaced by the reference value. The index allows checking the scale of importance of the species in the area, with the scale ranging from 0 to 600. Values above 400 are considered very rare and above 50 reveal significant ecological importance (Marques et al. 2005). To assess the Shannon-Weaver Diversity Index for each sampled area, the formula H = - Σ Pi *logPi was used, where Pi is the probability of importance of each species, calculated by the formula Pi = ni *N-1, where "ni" is the importance value of each species and "N" is the total of importance value.

## 3. Results

In the phytosociological analysis, a total of 347 squares were sampled in three areas: Ullmann Point (King George Island), Keller Peninsula (King George Island) and Byers Peninsula (Livingston Island) with 56, 43 and 248 squares sampled, respectively.

A total of 52 species belonging to 29 families were found: 22 mosses, 27 lichens, one alga and two phanerogams (Table 1). It was possible to verify that the phanerogams *Deschampsia antarctica* and *Colobanthus quitensis* were the most frequent species for the Ullmann Point area and with the highest values of IES: (392.84) and (117.86) respectively. The families with the highest species richness were Bryaceae, Polytrichaceae and Andreaeaceae, the genus *Bryum* having the highest number of sampled species (3), followed by *Polytrichum* (3) and *Andreaea* (2), respectively (Table 2).

Table 1. List of species and families sampled for the three regions evaluated (Byers Peninsula - Livingston Island, Keller Peninsula and Ullmann Point - King George Island).

| Group/Family/Species | Byers Peninsula | Keller Peninsula | Ullmann Point |
|---|---|---|---|
| **MOSSES** | | | |
| **ANDREAEACEAE** | | | |
| *Andreaea depressinervis* Cardot | X | X | X |
| *Andreaea gainii* Cardot | X | | |
| **AMBLYSTEGIACEAE** | | | |
| *Sanionia uncinata* (Hedw.) Loeske | X | X | X |
| *Sanionia georgicouncinata* Loeske | X | | |
| *Warnstorfia sarmentosa* Hedenäs | X | | |
| **BARTRAMIACEAE** | | | |
| *Bartramia patens* Bridel | X | | |
| **BRACHYTHECIACEAE** | | | |
| *Brachythecium austrosalebrosum* (Muell.Hal.) Paris | X | | |
| **BRYACEAE** | | | |
| *Bryum pseudotriquetrum* (Hedw.) G. Gaertn., B. Mey. & Scherb. | X | | |
| *Bryum argentum* Hedw. | X | | X |
| *Bryum arechavaleti* | X | | |
| *Bryum* sp. | X | | |
| *Pohlia cruda* (Hedw.) Lindb. | X | | |
| **DICRANACEAE** | | | |
| *Dicranum* sp. | X | | |

| | | | |
|---|---|---|---|
| *Hymenoloma grimmiaceum* (Mull. Hal.) | X | | |
| **DITRICHACEAE** | | | |
| *Ceratodon purpureus* (Hedw.) Brid. Redshank | | | X |
| **POLYTRICHACEAE** | | | |
| *Polytrichum alpinum* (Hedw.) G. L. Smith | X | | |
| *Polytrichum juniperinum* Hedw. | X | X | |
| *Polytrichum piliferum* Hedw. | X | | |
| **POTTIACEAE** | | | |
| *Hennediella heimii* (Hedw.) RH Zander | X | | X |
| *Syntrichia filaris* (Müll. Hal.) R. H. Zander | X | | |
| *Syntrichia saxicola* (Cardot) R. H. Zander | X | | |
| *Syntrichia* sp. | | X | X |
| **LICHENS** | | | |
| **ACAROSPORACEAE** | | | |
| *Acarospora macorcyclos* Vain. | | X | X |
| **CALICIACEAE** | | | |
| *Buellia anisomera* Vain. | | | X |
| *Buellia latemarginata* Darb. | | | X |
| *Buellia* sp. | | | X |

| | | | | |
|---|---|---|---|---|
| **COLLEMATACEAE** | | | | |
| *Leptogium puberulum* Hue | X | X | | X |
| **CLADONIACEAE** | | | | |
| *Cladonia borealis* S. Stenroos | X | | | |
| **CYSTOCOLEACEAE** | | | | |
| *Cystocoleus niger* (Huds.) Har. | X | | | |
| **HAEMATOMMATACEAE** | | | | |
| *Haematomma erythromma* (Nyl.) Zahlbr. | | X | | X |
| **LECANORACEAE** | | | | |
| *Lecanora skottsbergii* Darb. | | | | X |
| Rhizoplaca aspidophora (Vain.) Redón | X | X | | X |
| *Carbonea assentiens* (Nyl.) Herte | | X | | |
| **OCHROLECHIACEAE** | | | | |
| *Ochrolechia antarctica* | | | | X |
| *Ochrolechia frigida* (Sw.) Lynge | X | X | | X |
| **PANNARIACEAE** | | | | |
| *Pannaria hookeri* (Borrer ex Sm.) Nyl. | | | | X |
| **PARMELIACEAE** | | | | |
| *Parmelia saxatilis* (L.) Ach. | | | X | |
| *Usnea aurantiaco-atra* (Jacq.) Bory | X | *X* | | X |
| *Usnea sphacelata* R.Br. | X | | | |

| | | | |
|---|---|---|---|
| **PHYSCIACEAE** | | | |
| *Physcia caesia* (Hoffm.) Fürnr. | | | X |
| **PROTOTHELENELLACEAE** | | | |
| *Microglaena antarctica* I.M. Lamb. | | | X |
| **RAMALINACEAE** | | | |
| *Lecania brialmontii* (Vain.) Zahlbr. | X | | X |
| **RHIZOCARPACEAE** | | | |
| *Rhizocarpon geographicum* (L.) DC. | | X | X |
| *Rhizocarpon griseolum* (Hue) Darb. | | X | |
| **TELOSCHISTACEAE** | | | |
| *Xanthoria candelaria* (L.) Th. Fr. | | | X |
| *Xanthoria elegans* (Link.) Th. Fr. | | | X |
| *Caloplaca sublobulata* (Nyl.) Zahlbr. | | X | X |
| **TRAPELIACEAE** | | | |
| *Placopsis contortuplicata* I.M. Lamb. | X | | |
| **VERRUCARIACEAE** | | | |
| *Verrucaria* sp. | | | X |
| **ANGIOSPERM** | | | |
| **POACEAE** | | | |
| *Deschampsia antarctica* Desv. | X | X | X |

| | | | |
|---|---|---|---|
| **CARYOPHYLLACEAE** | | | |
| *Colobanthus quitensis* (Kunth.) Bartl. | X | X | X |
| **ALGAE** | | | |
| **PRASIOLACEAE** | | | |
| *Prasiola crispa* (Lighfoot) Menegh. | | | X |

The sampling sufficiency for the three areas was reached between samples 10 and 15, and the survey was insisted on, threatening a return to the curve from samples 20 and 40, finally reaching stability (Figure 3).

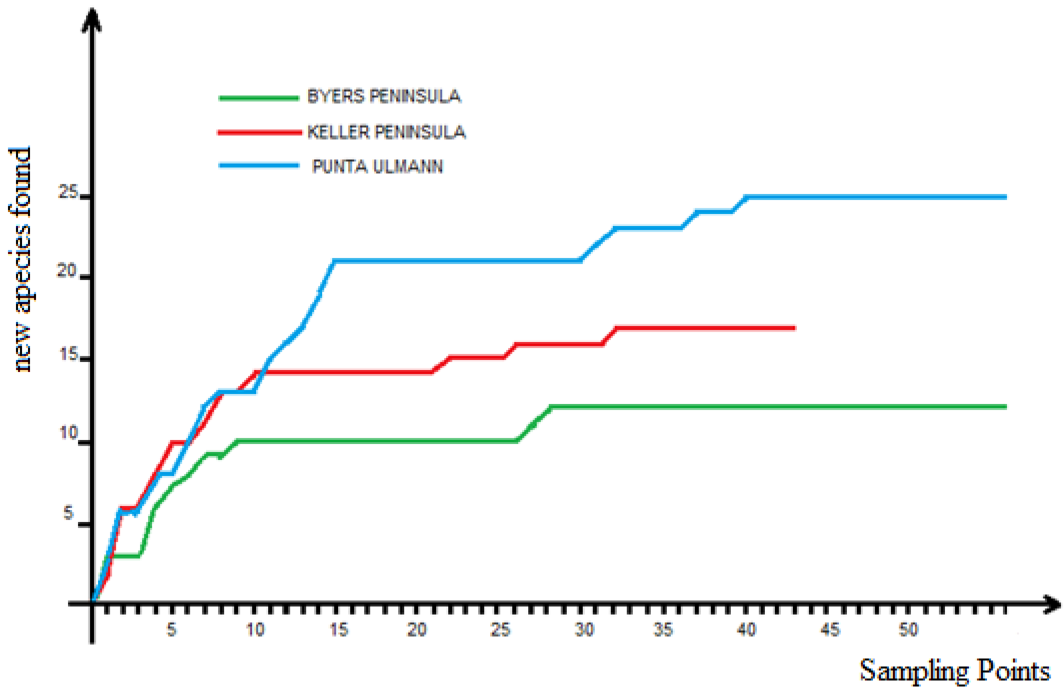


Figure 3 - Sampling sufficiency in the three sampled regions.

Table 2. Species with the highest Ecological Importance Index (IES) for Ullmann Point (King George Island), Antarctica.

| Group | Species | Nº of quadrats | F (%) | IES |
|---|---|---|---|---|
| Angiosperm | *Deschampsia antarctica* Desv. | 55 | 98.21 | 392.284 |
| Angiosperm | *Colobanthus quitensis* (Kunth) Bartl | 33 | 58.93 | 117.86 |
| Bryophyte | *Sanionia uncinata* (Hedw.) *Loeske* | 25 | 44.64 | 89.28 |
| Bryophyte | *Syntrichia* sp. | 24 | 42.86 | 85.72 |
| Lichen | *Usnea aurantiaco-atra* (Jacq.) Bory | 18 | 32.14 | 64.28 |
| Lichen | *Haematomma erythromma* (Nyl.) Zahlbr. | 15 | 26.79 | 53.58 |
| Lichen | *Caloplaca sublobulata* (Nyl.) Zahlbr. | 14 | 25.00 | 50.00 |
| Lichen | *Acarospora macorcyclos* Vain | 12 | 21.43 | 42.86 |

Nº = number of quadrats Where the species was observed. F = (%) frequency of the species. IES = Ecological significance index.

According to the IES found for the selected regions, the Byers Peninsula presents the highest frequency and value of IES for *Deschampsia antarctica* (398.40) (Table 3). For this region *Dicranum* sp. is the most frequently found moss species and IES value, followed by *Polytrichum piliferum* and *Brachythecium austrosalebrosum* mosses, with (61.30), (25.00) and (10.48), respectively. The Rhizocarpaceae family had the highest species richness (2), being represented by species of the genus *Rhizocarpon*.

Table 3. Species with the highest Ecological Importance Index (IES) for the Byers Peninsula (Livingston Island), Antarctica.

| Grupo | Espécie | Nº de Quadrados | F% | IES |
|---|---|---|---|---|
| Angiosperma | *Deschampsia antarctica* Desv. | 247 | 99.60 | 398.40 |
| Briofita | *Dicranum sp.* | 76 | 30.65 | 61.30 |

| | | | | |
|---|---|---|---|---|
| Briofita | *Brachythecium austrosalebrosum* (Miill Hal) Kindb. | 13 | 5.24 | 10.48 |
| Briofita | *Polytrichum piliferum* Hedw | 31 | 12.50 | 25.00 |

Nº = number of quadrats Where the species was observed. F = (%) frequency of the species. IES = Ecological significance index.

The species *Deschampsia antarctica*, *Acarospora macorcyclos*, *Colobanthus quitensis*, *Sanionia uncinata*, *Ochrolechia frigida* and *Polytrichum juniperinum* were identified with IES>100, with *Deschampsia antarctica* being the dominant species in the region of the Brazililan Antarctic Station Commander Ferraz (IES 390.68) (Table 4). The family with the highest species richness was Bryaceae (5 species represented by 2 genera), followed by Polytrichaceae (with 3 species of a single genus).

Table 4. Species with the highest Ecological Importance Indices (IES) for the Keller Peninsula – King George Island, Antarctica.

| Grupo | Espécie | Nº de Quadrados | F% | IES |
|---|---|---|---|---|
| Angiosperma | *Deschampsia antarctica* Desv | 42 | 97.67 | 390.69 |
| Líquen | *Acarospora macocyclos* Van | 34 | 79.07 | 158.14 |
| Angiosperma | *Colobanthus quitensis* (Kunth) Bartl | 29 | 67.44 | 134.88 |
| Briofita | *Sanionia uncinata (Hedw.) Loeske* | 39 | 79.07 | 237.21 |
| Líquen | *Ochrolechia frigida* (Sw.) Lynge | 27 | 62.79 | 125.58 |
| Briofita | *Polytrichum juniperinum* Hedwig | 24 | 55.81 | 111.62 |
| Líquen | *Rhizocarpon geographicum* (L.) DC | 19 | 44.19 | 88.38 |
| Líquen | *Carbonea assentiens* (Nyl.) Hertel | 11 | 25.58 | 51.16 |

Nº = number of quadrats Where the species was observed. F = (%) frequency of the species. IES = Ecological significance index.

Analyzing the Shannon-Weaver Diversity Index (H'), it was found that the greatest diversity of species was found for the Ullmann Point area, followed by the Keller Peninsula. The Byers Peninsula had the lowest value in the diversity index. Comparing the Shannon index between the Keller Peninsula and Ullmann Point, there is a statistical difference in the H' value between both areas (Figure 4).

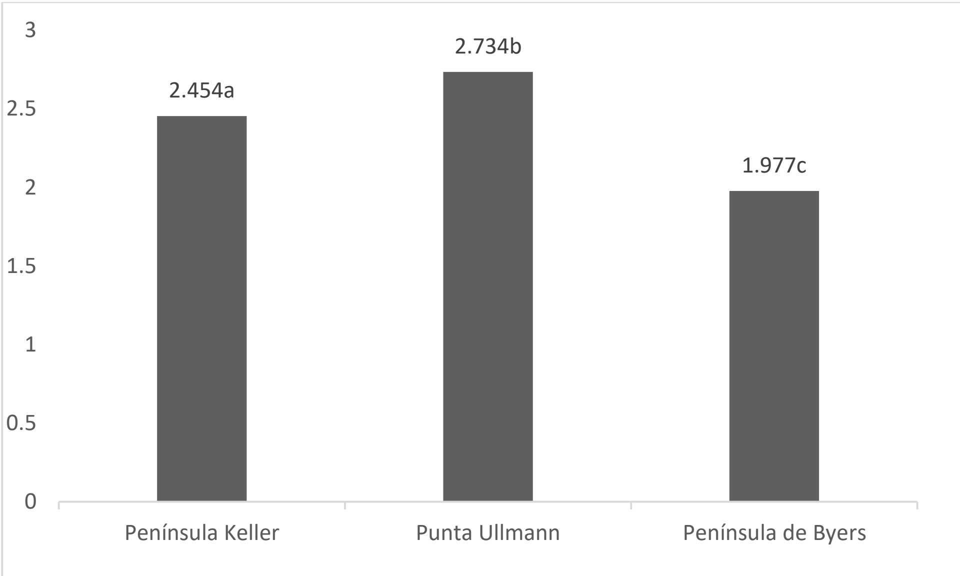


Figure 4. Shannon-Weaver Diversity Index (H') for each sampled area (different letters mean statistical differences found in sampling).

According to the data obtained, *Deschampsia antarctica* showed the highest ecological importance index (IES) in the three regions studied (Peninsula Byers, Punta Ullmann and Peninsula Keller), indicating that it is a dominant species for these areas. Data obtained by Victoria et al. (2009), D' Oliveira et al. (2012) and Pinto et al. (2013) for regions on King George Island, also indicated this species with higher IES value. However, the values obtained in this study are higher than those found by the authors mentioned above. Probably the increase in the IES value of *Deschampsia antarctica* may be related to the increase in average temperatures for the Antarctic Peninsula region. According to Lewis-Smith (1994), Walther et al. (2002) and Gerighausen et al. (2003) populations of *Deschampsia antarctica* have increased in size and number, being related to climate change in the Antarctic continent.

Pinto et al. (2013) compared the *Deschampsia antarctica* IES values obtained in 2013/2014 with values obtained in 2003/2004 by Victoria et al. (2009), demonstrating a large increase in the values for the species. Probably, this is a response to environmental changes increased with the availability of new areas for colonization by new populations, and thus facilitating the expansion of vegetation cover of the species (Vera et al., 2013). May be this could explain the increase in the value of IES of this phanerogam in regions of the South Shetland archipelago in recent years.

Another factor that can be attributed to the increased coverage and distribution of the species are biotic factors such as the type of soil, since phanerogam is normally found in nutrient-rich soils (Victoria et al., 2013), where areas with dense vegetation are often related to the local activities of birds (Simas et al., 2008) as well as marine mammals that allow fertilization and nutrient cycling from their droppings in these locations (Smykla et al., 2007). This may also help to explain the increase in the IES value of the species, since the data obtained in the study were conducted in coastal locations, where groups of marine mammals and birds are commonly found. Therefore, it is possible that the increase in *Deschampsia antartica* vegetation cover may be attributed to both abiotic and biotic factors, since the Antarctic plant communities are highly sensitive and dependent on environmental factors.

The Shannon index values obtained for the sampled areas in the study are high despite the difference in the number of species and samples for each evaluated location. The Shannon index indicates Ullmann Point, followed by the Keller Peninsula with the highest values in species heterogeneity in the plant community, despite *Deschampsia antarctica* being the most representative species. Several studies on plant communities have been conducted in recent years on King George Island, but coverage data and plant diversity indices are still scarce for some locations, such as Ullmann Point.

The values obtained from the Shannon diversity index found for the Byers Peninsula area is considered relatively low (1,977 H’), when compared with the data obtained by Putzke et al. (2015) for the studied regions of King George, Elephant and Nelson Islands (3.178 H’), (2.909 H’) and (2.839 H’), respectively. However, the Shannon diversity index values obtained in this study for the Byers Peninsula are in agreement with the value found for the Hop Bay region (1,933 H’). This low value obtained for diversity in the Byers Peninsula can be attributed to the fact that *Deschampsia antarctica* is the species with the highest frequency and coverage, thus dominating the plant community of the Byers Peninsula. Therefore, knowing the ecological factors of communities is essential to understand the effects of biodiversity on ecosystem functioning (Lee et al., 2019).

## 5. Conclusion

The study revealed that *Deschampsia antartica* is the species with the highest frequency and incidence of ecological significance for the three regions evaluated. In addition, it was possible to determine the region with the greatest diversity of species among the evaluated areas.

From the results obtained, it is possible to provide a more detailed description of phytosociological and diversity data of plant communities from the Byers Peninsula – Livingston Island, as well as to compare them with available data from plant communities already described for other Antarctic regions. Thus, it was possible to estimate the ecological importance and diversity of plant species for the evaluated regions.

Such investigations contribute to the monitoring and conservation of the Antarctic flora, especially the populations of the phanerogam *Deschampsia antartica*, which has large extensions of vegetation along the beaches of the Byers Peninsula, as it is one of the places with the largest phanerogam population on the Antarctic continent and thus deserving preservation.


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## Disclosure Statement

No potential conflict of interest was reported by the authors.

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**2.2 Artigo 2**: PELLETS OF *Stercorarius* spp. (SKUA) AS PLANT DISPERSERS IN THE ANTARCTIC PENINSULA.

(Artigo aceito – Anais da Acadêmica Brasileira de Ciências)

PELLETS OF *Stercorarius* spp. (SKUA) AS PLANT DISPERSERS IN THE ANTARCTIC PENINSULA

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Keywords: Antarctica, birds, propagation, vegetation

Running title: Skua pellets and mosses.

Academy Section: Antarctic research.

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**Abstract**

The Antarctic Peninsula has experienced some of the most accelerated warming worldwide, resulting in the retreat of glaciers and creation of new areas for plant development

exposed by the melting. Information regarding the plant dispersal processes to these new niches is scarce in Antarctica, despite birds being important vectors elsewhere. Many bird pellets (with feed remains such as bones and feathers) are generated annually in Antarctica, which are light and easily transported by the wind and include vegetation that is accidentally or purposely swallowed. The aim of this study was to analyze the presence of plant fragments within skua (*Stercorarius*/*Catharacta* spp.) pellets collected from two sampling areas in the Maritime Antarctic: Stinker Point (Elephant Island, 17 samples) and Byers Peninsula (Livingston Island, 60 samples), in the South Shetland Archipelago, during the austral summers of 2018 and 2020. In both study areas, five species of Bryophyta (*Sanionia uncinata*, *Sanionia georgico-uncinata*, *Warnstorfia sarmentosa*, *Warnstorfia fontinaliopsis* e *Hennediella heimii*) were found that were associated with the pellets and viable in germination tests in a humid chamber. The ingestion of Bryophyta for the skuas contribute to the dispersion of different moss species, including to areas recently exposed by the ice retreat. This is the first demonstration that skua pellets effectively act in the dispersion of Antarctic mosses.
Keywords: Antarctica, birds, propagation, vegetation

**Introduction**

The warming of the Antarctic Peninsula over the last 50 years has been greater than any other terrestrial ecosystem in the Southern Hemisphere, with consequences being observed in the cryosphere and biology of species. The most affected regions are the Antarctic Peninsula, Maritime Antarctic, and the majority of western Antarctic (Bromwich et al. 2013; Siegert et al. 2019). This warming has resulted in the loss of ice and glaciers, with exposure of soil and rocks (Cook et al. 2014; Convey & Lewis Smith 2006; Thomazini et al. 2014). This ice cover retreat provides new habitats for the colonization of plants, animals, and microorganisms (Parnikoza et al. 2009; Siegert et al. 2019).

Antarctic terrestrial vegetation is restricted to ice-free areas, occurring directly on rocks or soil at different developmental stages. The main plant formations are composed of bryophytes (116 species), lichens (ca. 400 species), macroscopic terrestrial algae (four species), and two species of native vascular plants, *Deschampsia antarctica* Desv. (Poaceae) and *Colobanthus quitensis* (Kunth.) Bartl. (Caryophyllaceae) and the invasive *Poa annua* L. (Øvstedal & Lewis-Smith 2001; Putzke & Pereira 2001; Ochyra et al. 2008; Pereira & Putzke 2013; Câmara & Carvalho-Silva, 2020).

Information regarding the colonization of mosses in newly exposed areas is attributed to the dispersion of fragments of bryophytes or their spores by the wind (Seppelt et al. 2004). An increase in the frequency of sporophyte formation and, consequently, spores may be occurring and would likely be expected, according to more recent studies, which is probably associated with climatic changes (Convey & Lewis-Smith, 1993; Lewis-Smith & Convey, 2002; Casanova-Katny et al. 2016; Erin et al. 2017).

Animal-mediated dispersion of Bryophyta has been discussed in numerous works around the world, including studies with mammalians (Heinken et al., 2001; Pauliuk et al. 2011; Parsons et al. 2007, Barbé et al. 2016), ants (Rudolphi et al. 2009), slugs (Kimmerer & Young 1995) and birds (Chmielewski & Eppley 2019, Wilkinson et al 2017, Osorio-Zuñiga. et al 2014, Breil et al. 1976), but only recently were studied in Antarctica.

In some regions of Maritime Antarctic, birds have been described as important vectors for the dispersion of plants and the transportation of seeds and plant fragments during nesting activity (Marshall & Convey 1997; Vera 2011; Parnikoza et al. 2012). Birds of the *Stercorarius* genus (Antarctic skuas) are an example, as they use different types of substrates to build their nests, including mosses, lichens, and angiosperms (Albuquerque et al. 2012; Costa & Alves 2008; Parnikoza et al. 2009). However, the participation of these transporting plant propagules in the Antarctic requires better evaluation (Parnikoza et al. 2012).

Evaluating hummingbird nests, it was found that incorporated bryophyte leaves and stems established and grew, suggesting that nesting behavior can disperse bryophytes (Osório-Zuñiga et al., 2014). Some experiments have demonstrated that waterfowl may be able to vector bryophyte material (spores and plant fragments) internally (Proctor 1961; Wilkinson et al. 2017). The presence of mosses associated with bird pellets has been also reported in the literature. The moss *Aplodon wormskioldii* (Hornem.) R.Br. (Splachnaceae), for example, grows in owl pellets, and uses this substrate for its growth and development in Alaska (Koponen 1990).

Skuas from the Signy Islands were observed breaking up mosses, which were then blown by the wind. This type of action is common throughout the Antarctic, with the removal of mosses to make nests or for other reasons, which can contaminate feathers, legs, and beaks and with fragments ingested probably accidentally (Davis 1981). Skuas can feed on animals or their remains, including placentas and carrion from different marine mammals, fish, and krill, which are normally also consumed on ground sometimes covered by mosses (Carneiro et al. 2014; Reinhardt et al. 2000).

Unlike other regions, in cold environments, animals ingest many mosses, which might be due to the presence of arachidonic acid that confers greater resistance to the cold environment (Prins 1982). However, some authors still believe that the ingestion of mosses by birds is incidental and do not play an important role in dietary requirements (Russo et al. 2020).

Using bryophytes as food or material to build their nests, birds can contribute to their dispersion. Spores and fragments use wind dispersal to reach other environments; however, attaching to the body of an animal may be another transport mechanism (Chmielewski & Eppley 2019; Russo et al. 2020).

Pellets are the food remains of carnivorous birds, which are composed of nondigestible parts, mainly feathers and bones that will later be "vomited" in the form of pellets (Votier et al. 2003). *Stercorarius* spp. (former *Catharacta*) pellets as vectors of plant dispersion in the Antarctic have not yet been analyzed because most studies have focused on the type of diet and foraging of the species (Votier et al. 2003; Borghello et al. 2019; Steele & Cooper 2012; Mund & Miller 1995; Malzof & Quintana 2008; Baker & Barbraud 2001).

The presence of mosses and other unidentified plant fragments in skua pellets found in the Antarctic has been mentioned, but only because they were ingested probably to clean the digestive tract of parasites (Santos et al. 2012). The marked change in the composition of *S. maccormicki* pellets from a predominance of penguin feathers at Potter Cove (King George Island) to mosses at Cierva Point (Antarctic Peninsula) suggests an alternative function of feather ingestion (Santos et al. 2012). The elimination of undigested material in pellets impedes the growth of gastric parasite populations in birds that feed on fishes (Piersma & Van Eerden 1989).

Studying areas of recent ice retreat at Stinker Point (Elephant Island) and Byers Peninsula (Livingston Island), we found a large number of pellets partially covered by associated moss formations, indicating some relationship type. The influence of this form of dispersion and colonization by mosses in environments recently exposed to de-icing is analyzed and discussed here. The present study aimed to analyze skua (*Stercorarius* spp.) pellets as a source of moss inoculum for colonization of newly exposed areas in the Antarctic region.

## Material and Methods

### Study area

The Stinker Point (Elephant Island) and Byers Peninsula (Livingston Island), 340 km apart, where chosen among the South Shetland Archipelago to do this study due to the ease of access provided by the Brazilian Antarctic Program.

The Stinker Point region (61° 13′ S, 55° 21′W) is located on the southwest coast of Elephant Island, Antarctic (Figure 1), north of the South Shetland Archipelago, approximately 153 km from King George Island. Stinker Point has a coastline that is 4,300 m in length, with 13 beaches composed of sand, pebbles, and boulders. In addition to having plateau areas with steep cliffs and large fields of moss on top (Petry et al., 2018), it is rich in floristic diversity and is composed of two vascular plant species, *D. antarctica* Desv. (Poaceae) and *C. quitensis* (Kunth.) Bart. (Caryophyllaceae), 38 moss species, seven species of liverworts, 68 species of lichens, and four species of macroscopic fungi (Pereira & Putzke 1994; Schmitz et al. 2020).

The Byers Peninsula (62°34′35″S, 61°13′07″ W) is located at the western end of Livingston Island, and is the second largest island in the South Shetland Archipelago, Antarctic (Figure 2), comprising an area of 60,35 $km^2$. This area has extensive beaches, and is 12 km long and 900 m wide (Praia Sul), and is the most extensive in the South Shetland Archipelago (Ivanov, 2015). The peninsula has a wide variety of periglacial relief forms, such as felsenmeers, terrains with patterns, rocky glaciers, and raised marine platforms (Quesada et al., 2009). During the summer, the peninsula contains many streams and more than 60 lakes and ponds (Toro et al. 2007). The vegetation cover consists of lichens that colonize inactive or weakly active periglacial landforms and rocky outcrops and moss carpets, which are abundant in poorly drained areas. There are two vascular plants, *D. antarctica* and *C. quitensis*, found in the highest marine terraces (Vera 2011). The peninsula was originally designated as a specially protected area because of its high Antarctic biodiversity levels (Toro et al. 2007).

**Sample collections**

During the southern summers of 2018 and 2020, *Stercorarius* spp. pellets were collected and analyzed in ice-free areas in the regions of Stinker Point, Elephant Island, and the Byers Peninsula, Livingston Island, approximately 340 km from each other.

The samples were collected and packed in paper bags and taken to the camp, where they were dehydrated and then transported to the Universidade Federal do Pampa laboratory in southern Brazil. They were analyzed under a magnifying glass (Olympus model SZ51), after each was disassembled in a Petri dish using tweezers and separating all the material found. The materials that adhered to the outside, including vegetal fragments, were discarded to avoid further contamination. The remains of prey, such as bones and feathers, were separated from the plant material found inside the pellet. The identification of plant species in the sampled material was based on the specific literature of Antarctic vegetation (Øvstedal & Smith 2001;

Ochyra et al. 2008; Putzke & Pereira 2001). All plant materials found inside each sample were assessed for their capacity to regenerate by the fragments being placed in a humid chamber. To this experiment the fragments isolated from each pellet were placed in Petri dishes upon several thicknesses of filter paper which had been saturated with distillated water and maintained at 25 (±2)°C and 12 h of continuous light. The experiment was weekly checked for regeneration of the fragments and maintained for three months.

A recent ice retreat area at Stinker Point (located at 61°13′36.06″ S and 55°21′15.68″ W) in an early stage of plant colonization was assessed for the presence of old pellets (that were at least partially buried in the sediment) and evaluated for the presence of associated plants. The area was entirely covered by a glacier when two of the authors (JP and ABP) visited it in 1990 and 1994, yet it was free of ice in 2012 and 2018. Pellets colonized by vegetation were counted, and the vegetation cover was estimated. Using the images captured by a Phantom 4 drone from the site (100 m high), a map was created, and three rectangles were identified to study the vegetation (Figure 1):

- Area 1: 8685.6 $m^2$, formed by a gentle slope facing southeast;
- Area 2: 5766.5 $m^2$, south of Area 1, created by a low elevation (with a top 4 m high in relation to the base);
- Area 3: 8361 $m^2$, east of Area 1, formed by an elevation with a southwest slope.

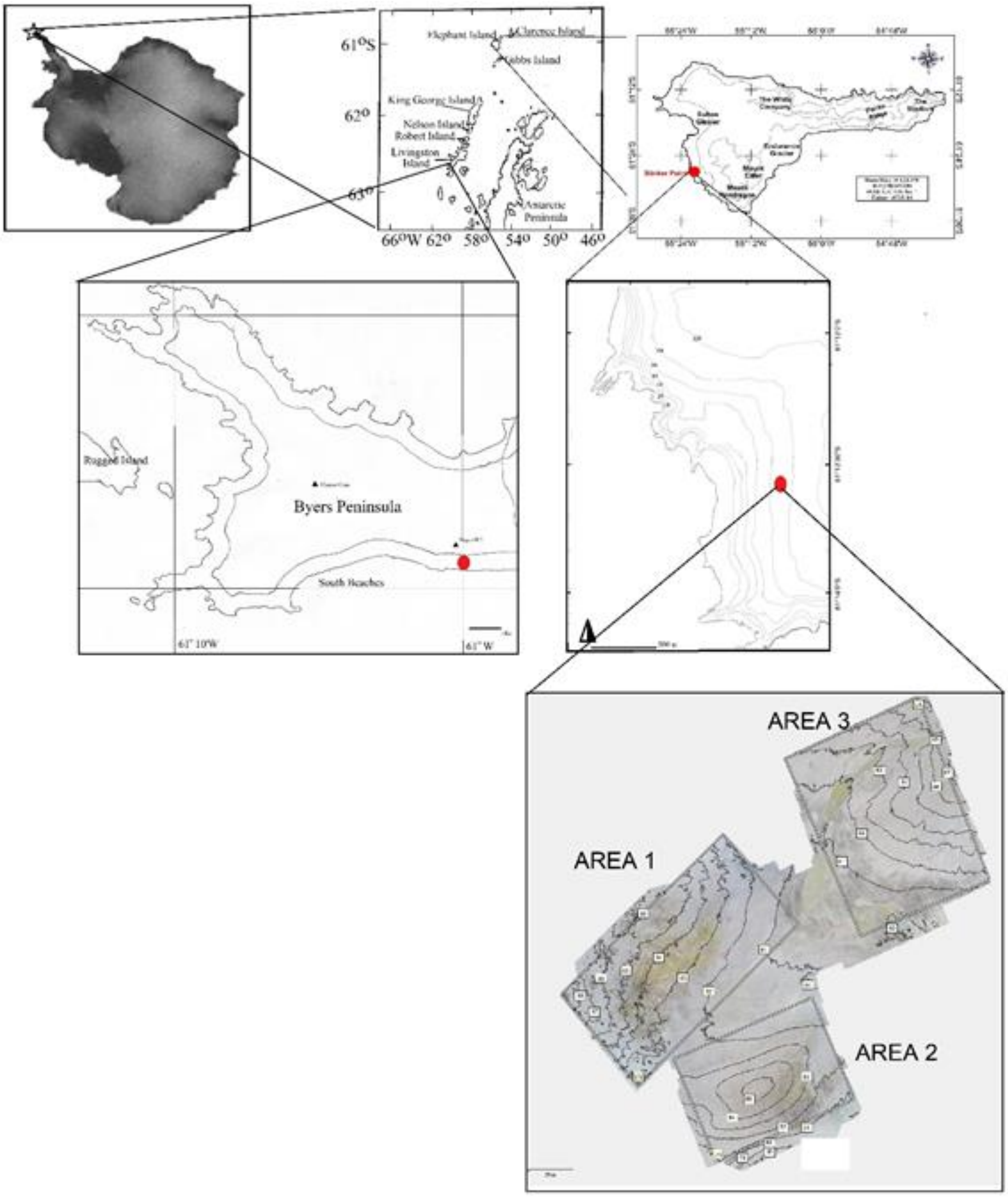


Figure 1. Location of collection areas on Elephant Island and Livingston Island (red dots) detailing the sampled areas on Stinker Point.

## Results

During field work there were collected 17 pellets in Stinker Point, Elephant Island (Figure 2) and 60 samples in Byers Peninsula, Livingston Island. The number of samples is different because the Livingston area was more protected from the direct wind interference, retaining more pellets. In all samples the plant material was restricted to small fragments (less than 1 cm long), being impossible to evaluate their proportion (or weight) in relation to the other components of the pellet. In Stinker Point 88% and Byers 91.6% of pellets presented plant fragments. One species of green algae (*Prasiola crispa*) and five moss species, S*anionia uncinata, S. georgico-uncinata, Warnstorfia sarmentosa*, *W. fontinaliopsis* and *Hennediella heimii* were found (Figure 3). In Byers, only the green algae species was absent (Table 1) being the mosses found the same.

Table 1. Plant species found inside pellets of *Stercorarius* spp. (Skua) in the Stinker Point region, Elephant Island and Byers Peninsula, Livingston Island, Antarctica.

| Species | Group | Stinker Point | Byers Peninsula |
|---|---|---|---|
| *Sanionia uncinata* (Hedwig) Loeske | Bryophyta | X | X |
| *Sanionia georgico-uncinata* (Muell. Hall.) Ochyra & Hedenäs | Bryophyta | X | X |
| *Warnstorfia sarmentosa* (Wahlenb.) Hedenäs | Bryophyta | X | X |
| *Warnstorfia fontinaliopsis* (Müll. Hal.) Ochyra | Bryophyta | X | X |
| *Hennediella heimii* (Hedw.) R.H. Zander | Bryophyta | X | X |
| *Prasiola crispa* (Lightfoot) Kützing | Green algae | X | - |

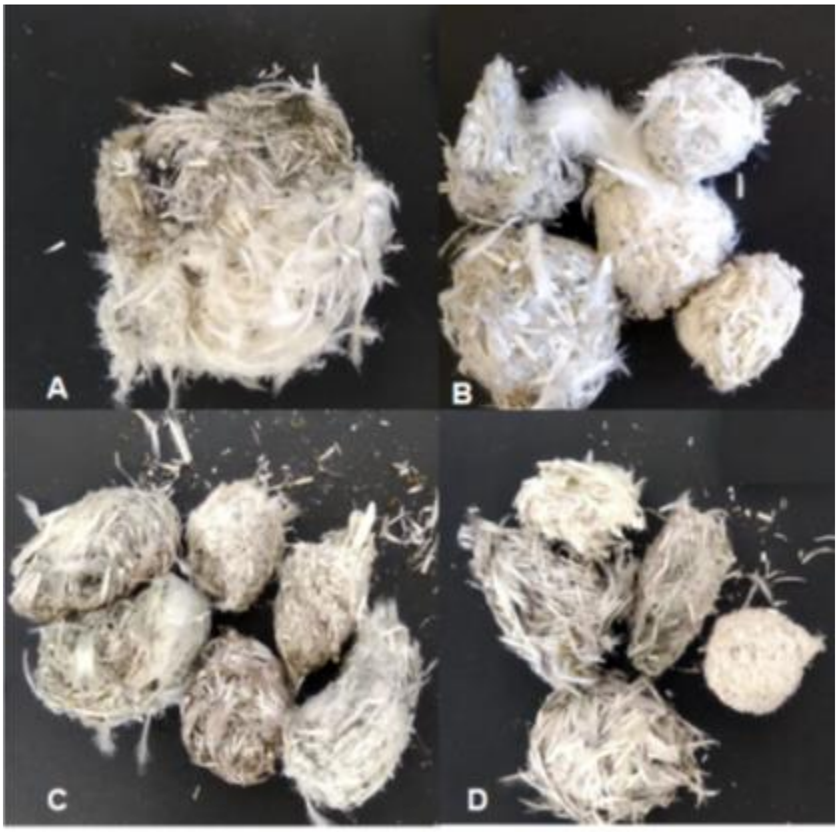

Figure 2. Samples (A–D) of pellets collected at Stinker Point, Elephant Island, Antarctica in 2018.

In the wet chamber test, all moss samples regenerate (100%), forming new branches and demonstrating their ability to survive the digestive tract of the bird and the conditions of the interior of the regurgitate. After assessing the area where the ice retreat was most recent (last 20 years) at Stinker Point, Area 1 had more developed vegetation, forming a continuous carpet, especially of *Sanionia uncinata*, whereas the other areas did not have any apparent cover. In the count of the oldest pellets, 58 samples were found in the plant formation surroundings because in its interior the carpet of mosses prevented the visualization of older regurgitates (Figure 4).

In Area 2, no old pellets colonized by vegetation were found, perhaps because this area is at the top of an elevation, preventing the stabilization of pellets. In Area 3, 38 skua pellets were found, all presenting associated growing mosses and in places that held practically no vegetation (Figure 5). In the three areas, many scattered bones were observed, indicating that the pellets had been disintegrated by the time of exposure or that they had arrived at the site by the wind regardless of being integrated into the pellets.

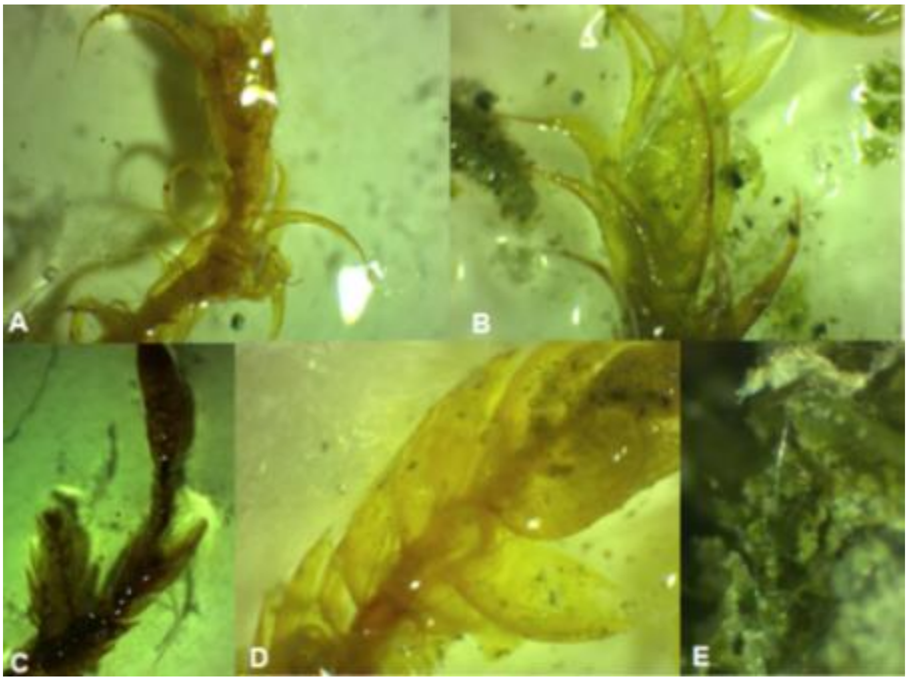


Figure 3. Species of Bryophyta/green algae found inside the pellets: A – *Sanionia uncinata*, B – *S. georgico-uncinata*, C – *Warnstorfia sarmentosa*, D – *W. fontinaliopsis*; E – *Prasiola crispa* (green algae).

Figure 4. Pellets with vegetation associated found in Area 1.


Figure 5. Seven old pellets found in Area 3, with mosses growing on and around them.

**Discussion**

During the summer period in the Maritime Antarctic region (November to March), after the melting of the ice deposited in the winter, birds migrate to the region in search of a place to rest, feed, and reproduce (Harris et al. 2011). Among these, the skua (*Catharacta/Stercorarius*) has a regurgitating feeding habit because they are carnivorous birds and eliminate feathers and bones (pellets) that are not digested (Santos et al. 2012). The kelp gull (*Larus dominicanus*) also regurgitates in Antarctica and could be investigated for plant dispersal too, despite eating more marine invertebrates (Coulson & Coulson 1993; Lindsay & Meathrel, 2008).

In the present study, we found the presence of fragments of different moss species in the pellets, which was previously noticed, but was associated with digestive tract cleaning (Santos et al. 2012). Another possibility is that during the reproductive period, these birds use plant species, such as mosses, lichens, and angiosperms to build their nests (Albuquerque et al. 2012), which is also undertaken by other birds, such as seagulls (*Larus dominicanus*) (Convey 2012) and probably they accidentally ingest fragments of these plants. In the nest, plants serve as a protective barrier for climatic variations and are a more comfortable environment than rocks (Walsberg 1985).

The Antarctic birds are efficient in the dispersion of mosses, via the transport of vegetal fragments and spores adhered to their body (Lewis et al. 2014; Schlichting et al. 1978), disregarding the possibility of mosses being associated with regurgitated pellets. The results suggest that this association might imply another form of moss dispersion for areas exposed to melting in Antarctica. The implications of this association are unprecedented in studies of moss dispersion in this region, being the percentage of pellets with mosses considerable, with our findings (88 to 91,6%) similar to those found in literature (Santos et al. 2012). Migrant birds might just potentially also bring in pellets containing material of currently non-Antarctic plant species, for instance if they eliminate those pellets with any material foraged in Southern South America or subantarctic islands, when they first arrive at the beginning of the season. But this needs to be better investigated.

Despite being formed by a pile of remains of bones, hair, and feathers that are not used in digestion, the pellets constitute an excellent source of nutrients in areas recently devoid of ice, where rocks and sandy sediments predominate. Infiltrating a pellet can allow rapid plant development, once they are partially decomposed, after being expelled, providing essential nutrients to the mosses whose fragments are inside the pellet.

Cough pellets left by raptors, such as the common kestrel (*Falco tinnunculus*), are another likely mode of secondary dispersal of many organisms, including fungi (Watling 1963). Keratinophilic fungi are commonly isolated from regurgitated pellets, indicating a close relationship with the bird and this digestion mode (Bohacz, et al. 2020). Therefore, the agents responsible for decomposition are also present in these pellets, accelerating the availability of nutrients.

Bryophytes are part of the diet of some high Andean birds and may disperse bryophytes internally, via endozoochory, in the sub-Antarctic zone, being present in 84.6% and 90.9% (white-bellied seedsnipe, *Attagis malouinus*, and *Chloephaga* spp. geese, respectively) of the fecal samples studied (Russo et al. 2020). This is also the case for Antarctic skuas, where mosses are used as gut-cleaning materials (Santos et al. 2012). In this way, the ingestion of mosses, which allow the elimination of parasites, might include fragments of mosses in the pellets.

Animals that consume mosses in cold environments are related to high concentrations of arachidonic acid in Bryophyta, which gives them higher cold resistance (Prins 1982). The ingestion of arachidonic acid can benefit animals in several ways, including it being a precursor of some prostaglandin hormones; its low melting point (-49.5 °C) means that it might contribute to lowering the melting point of fats in the animal extremities; and it protects cell membranes against the effects of cold (Feng & Bai 2011).

The presence of arachidonic acid is common in mosses, unlike other plants (Anderson et al. 1974), and it has been found in three species of Antarctic mosses (*Bryum pseudotriquetrum, Ceratodon purpureus*, and *Grimmia antarctici*) (Wasley et al. 2006). Thus, it is possible that the Antarctic skuas are making use of mosses as food, eliminating part of them in the regurgitates, and enabling the dispersion of this vegetation to new areas.

The weight of each pellet is small because they are dehydrated and formed mostly by feathers, allowing it to be carried easily by the wind. Therefore, it is highly unlikely that pellets at such concentrations were deposited directly in the area by birds, as they would be easily displaced by wind action. The pellets found partially buried in sediments must have been carried by winds to the glaciers and incorporated into the cracks, remaining stored for a long time until total melting in the area, when they grew back normally after being exposed. The Antarctic moss *Chorisodontium acyphyllum* remained alive after being frozen for more than 1500 years (Roads et al. 2014). Mosses buried for more than 600 years by a glacier were re-exposed by the retreat of the ice, and parts of the moss could activate again and grow normally "in vitro" (Cannone et al. 2017). Therefore, the resistance of these species is very high and they can remain viable for a long time, waiting for the right moment to colonize the pellet, which is its only source of nutrients.

The occurrence of mosses in pellets, from the ingestion of these by the skuas, represents another way of dispersion of Bryophyta in the Antarctic region, associated to wind and uses for nest building, reinforcing similar findings already made for the Arctic.

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## Author contributions

All authors collected field data in Antarctica, analyze and interpret the data, wrote and review the manuscript.

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Figures and table legends

Figure 1. Location of collection areas on Elephant Island and Livingston Island (red dots) detailing the sampled areas on Stinker Point.

Figure 2. Samples (A–D) of pellets collected at Stinker Point, Elephant Island, Antarctica in 2018.

Figure 3. Species of Bryophyta/green algae found inside the pellets: A – *Sanionia uncinata*, B – *S. georgico-uncinata*, C – *Warnstorfia sarmentosa*, D – *W. fontinaliopsis*; E – *Prasiola crispa* (green algae).

Figure 4. Pellets with vegetation associated found in Area 1.

Figure 5. Seven old pellets found in Area 3, covered by mosses around them.

Table 1. Plant species found inside pellets of *Stercorarius* spp. (Skua) in the Stinker Point region, Elephant Island and Byers Peninsula, Livingston Island, Antarctica.

**2.3 Artigo 3:** THE BONES OF LIVINGSTON ISLAND – HISTORY FOR PLANT SUCCESSION IN ANTARCTICA.

(Artigo submetido para *Acta Scientiarum*)

THE BONES OF LIVINGSTON ISLAND – HISTORY FOR PLANT SUCCESSION IN ANTARCTICA

Título resumido: Mammalian bones and vegetal development.

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## ABSTRACT

The bones found in the beaches of Byers Peninsula, Livingston Island - Antarctica are testimonies of almost one hundred years ago when the area was full of seals and whales hunters.

The remaining´s of that period are composed of complete skeletons and isolated bones most of them around the Southern Beach, which was surveyed in this work in 2020. The plant coverage of 33 whale bones was evaluated using a square of 20 x 20 cm, and species found were collected for identification. The soil surrounding five complete seal skeletons was studied, and its plant community evaluated. There were found 5 mosses, 12 lichens, and one flowering plant associated directly to bones and other associated with the soil in the surroundings of skeletons. The whale bones were colonized by 16 plant species, being *Pertusaria,* the most frequent and *Deschampsia antarctica* (the Antarctic grass), *Brachythecium austrosalebrosum* and *Ditrichum* sp. are reported for the first time on this substrate. Plant succession on bones in Antarctica is also occurring, and any movement of the bones caused by anthropic interference can change the community entirely. Bones are also a suitable substrate for ancient growing lichens (some thalli reaching 9.5 cm diam.), and they need to be protected. Seal skeletons with remains of skin on the carcasses are found with more luxuriant vegetation associated, being the remains of pure bones usually poorly vegetated, since the hunters collected the skin.
Keywords: plant succession; ecology; Pinnipedia; skeletons.

## INTRODUCTION

With the discovery of the South Shetland Islands - Maritime Antarctic around 1819, trips to hunt marine mammals began. About 1000 people were involved in hunting in the Shetland archipelago and as many also embarked. Precarious camps were set up on land, the main point being the Byers Peninsula on Livingston Island, but along other islands and even on the Antarctic Peninsula other groups of hunters were also established.

The hunting period ranged from ca. 1820 to 1960, and abandoned carcasses and bones that have not been carried into the sea by erosion or wind currently remain at the seashore (Villagran et al., 2013). Vegetal communities develop in bones and their surroundings, exploring what bones can offer in terms of nutrients for the environment, but little is known about these associations, their biodiversity, and ecology.

Calcium, phosphorus, carbon, nitrogen, and sulfur are nutrients found in bones and are essential for land plant communities (Rakusa-Suszczewski & Nedzarek 2002). But the pant composition covering old bones were scarcely studied. Olech (1996) reported 23 lichens and two mosses on whale bones. Albuquerque et al. (2018) cited 14 lichens and two mosses. Øvstedal & Smith (2001) make reference to only two species on whale bones [*Trimmatothelopsis antarctica* C.W. Dodge and *Lecidella elaeochroma* (Ach.) M. Choisy] and three on seal bones [*Candelariella vitellina* (Ehrh.) Mull. Arg., *Xanthoria elegans* (Link) Th. Fries and *Lecanora flotowiana* Spreng]. Putzke et al. (2020a) described modifications around a whale skeleton assembled in King George Island by Jacques Cousteau team in 1972, indicating a *Synchitria* species associated with the nutrients offered by the skeleton.

The bones can be essential substrates for vegetation and/or be mere springboards for plants to conquer other areas, and the purpose of this work is to try to elucidate this question studying the plant communities associated with them in Byers Peninsula, Livingston Island - Antarctica.

## MATERIAL AND METHODS

### Study of Whale bones:

The whale and fur seal bones were studied in the southern beaches of Byers Peninsula on Livingston Island, one of the main islands of the South Shetland Archipelago – Antarctica (Figure 1).

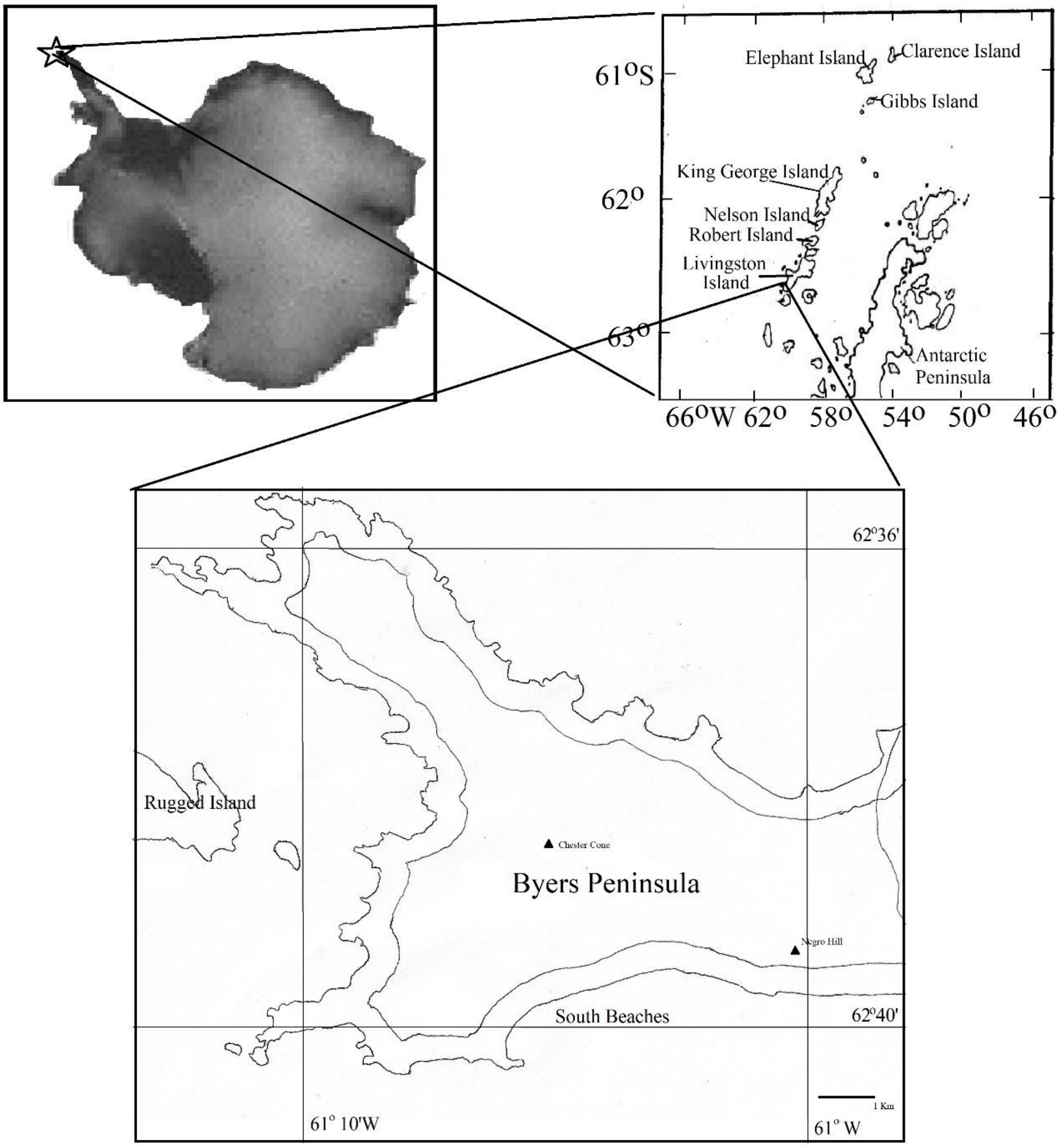


Figure 1 – Schematic map of Livingston Island location and the studied Byers Peninsula.

There were located 33 whale bones that presented some vegetal covering and then chosen to do this study (Figure 2). In the flattened part of each whale vertebra having plant communities, a wooden square of 20 x 20 cm was laid on to calculate coverage and frequency of each species using the Schmitz et al. (2018) method. In the laboratory, the data observed in the field and the photographs taken were used to hand-color the figures to study its phytosociology.

Study of Pinnipedia bones:

The vegetation surrounding five seal skeletons (two with skin remains, and three only bones) was also analyzed (Figure 3). A map of the vegetation was assembled, and the species identified.

The mosses and lichenized fungi were identified in situ, or small samples were collected to laboratory studies. The species identification was done basically following Putzke & Pereira (2001) and Ochyra et al. (2008) for mosses and Redon (1985) and Øvstedal & Smith (2001) for lichens.

Drone images (Phantom 4, flying at 100 m altitude) were collected to produce a map with the bone's location (photographs taken in February 2020). The Agisoft Program was used to assemble the photographs and draw the maps.

One complete fur seal skeleton, probably one of the oldest found in the beach (since the leather was completely decomposed already) was also studied for soil chemical composition, collecting samples and studying the vegetation associated (Figure 3).

One undisturbed soil sample was collected below the fur seal skeleton between 0 and 20 cm depth. The field-oriented and preserved block collected in field was oven dried at 40 °C for one week and vacuum impregnated (-5 kPa) with polyester resin diluted in 30% (volume) styrene monomer. The micromorphological study was done in a Transmission Electron Microscope. The description of the thin sections will follow the propositions of Stoops (2003). A micro x-ray fluorescence spectrometer Shimadzu model ATX determined the contents of Ca, Fe, K, P, and Si in the thin section. The chemical elements were quantified by the Fundamental Parameter method (Quantitative - FP). Calibration consisted of adjusting the sensitivity coefficients of each element analyzed. The sensitivity coefficients of the Quantitative were achieved by FP method, based on four reference samples: Montana Soil II - NIST 2711a, BHVO

- 2 - Basalt - USGS, COQ - 1 - Carbonatite - USGS, and SDC - 1 - Mica Schist – USGS.

One soil profile was dug, taken, and described in the site to represent the soils without the influence of bones. Diagnostic horizons, attributes, and properties were identified according to descriptions of color, texture, consistence, and thickness. The soil profile was classified according to the World Reference Base for soil resources (IUSS Working Group WRB, 2015). Soil samples were collected in each horizon, from the surface down to the lithic contact, at each pedon. The collected soil samples were sent to the Soil Laboratory of the Federal University of Viçosa – UFV.

Samples were air-dried and sieved through a 2 mm sieve before texture and chemical analyzes (Donagema et al., 2011). Coarse sand (CS), fine sand (FS), silt, and clay were determined by the pipette method after dispersion with 0.1 M NaOH. Soil pH was measured with a glass electrode in a 1:2.5 suspension v/v soil and deionized water. The potential acidity (H+Al) was extracted by 1 M ammonium acetate solution at pH 7. The content of exchangeable $Ca^{2+}$, $Mg^{2+,}$ and $Al^{3+}$ was determined in a 1 M KCl extract. Exchangeable $K^{+}$ and $Na^{+}$ were determined after Melhich-1 extraction. From these results, the sum of bases (SB), base saturation (V), equivalent cation exchange capacity (ECEC), total cation exchange capacity (CEC) were calculated.

The available phosphorus content ($P_M$) was determined by a Mehlich-1 extraction solution. The total organic carbon (C) was determined by wet combustion (Yeomans and Bremner, 1988). The P adsorption capacity of the soil was determined after stirring it for 1 hour with 2.5 g of soil in 0.01 M $CaCl_2$ containing 60 mg of P $L^{-1}$. The suspension was filtered, and the remaining P in the solution ($P_{REM}$) was determined by photocolorimetry (Alvarez et al., 2000). Therefore, the lower the value of $P_{REM}$, the higher the affinity of soils for the P in the solution.


Figure 2 – A whaler bone was chosen and under analysis in the fieldwork in Byer Peninsula.

Figure 3 – The seal skeleton area 1 studied and with soil samples analyzed.

RESULTS AND DISCUSSION

*Soil background*

The soil profile was dug in the upper marine terrace at 22 m.a.s.l. The soil is derived from marine sediments. Pedon was classified as Pantohypereutric Protic Akrofluvic Arenosol (Ochric, Pantonechic, Endoraptic). Lithic contact is at 200 cm depth. Epipedon is classified as ochric. The single grain is the structure of all horizons. The horizons are abruptly differentiated by texture and color (Table 1).

The texture is dominantly sand, and fine sand (FS) dominates fine particles. The horizons are neutral and have base saturation (V) above 80% in all horizons. $Ca^{2+}$>$Mg^{2+}$>$Na^{+}$>$K^{+}$ is the base dominance in the exchange complex. The contents of bases, soil organic carbon (SOC), total nitrogen (N), and extractable P by Mehlich-1 ($P_M$) increase irregularly with depth. This pattern suggests that parent material is the main source of these elements. High values of remaining P ($P_{REM}$) indicates a low affinity between minerals and P.

*Soil influenced by bones*

The single grain is the microstructure of thin section (Figure 4). Quartz, biotite, and plagioclase are present as silt and fine sand. Simple packing voids are between the coarse grains. Vesicular voids indicate the exclusion of gases during freezing of active layer. Coarse grains are generally coated by: a) neoformed brown clay minerals of undifferentiated birefringence; b) pink clay of crystallitic birefringence.

Table 1. Micromorphological description of the surface horizon of soil influenced by bones.

| | | |
|---|---|---|
| Microstructure | | Single grain |
| Porosity | | Simple packing voids<br>Vesicular voids |
| Groundmass | c/f Related distribution 2µm | Chitonic |
| | Coarse fraction (size, sphericity, roundness, mineralogy) | Fine sand smooth subangular quartz grains<br>Silt smooth subangular biotite grains |

| | | |
|---|---|---|
| | Fine fraction (size, limpidity, birefringence, color) | Clay dirty undifferentiated b-fabric 7.5YR 5/8<br>Clay dirty crystallitic b-fabric 7.5YR 8/3 |
| | Organic residues | Absent |
| Pedofeatures | | Typic Ca-rich coating associated with the coarse fraction<br>Link capping clay coating associated with the coarse fraction |

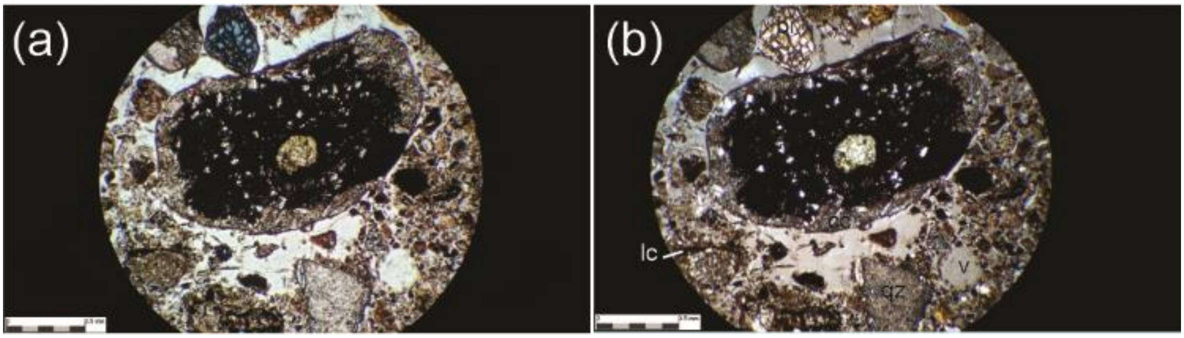


Figure 4. Thin section of soil under bones in plane-polarized light (a) and cross-polarized light (b); bi = biotite grain; cc = CaCO3 coating; lc = link capping clay coating; qz = quartz grain; v = vesicular voids.

The XRF analysis indicates that the pink clay crystallitic birefringent coating is Ca-richer than the surrounding (Figure 5). The low spatial affinity between the Ca, P, and Si suggests that $CaCO_3$ composes the coating. Weathering of bones is an additional source of Ca and $PO_4$ ions, but they have different chemical behaviors. Water percolation promotes a limited translocation of dissolved $Ca^{2+}$ ions because clay minerals strongly adsorb bivalent cations. The roots and microbiological respiration yield $CO_2$ in the atmosphere of soil. During freezing of the activity layer in winter, slowly percolating water is trapped by clasts. The residual solution becomes supersaturated and $CaCO_3$ precipitates as laminar caps in the bottom of coarse grains (Durand et al., 2010; Zamanian et al., 2016). Cryoturbation moves the grains, and, eventually, there is an alteration of $CaCO_3$ coating (Bockheim and Gennadiyev, 2000). On the other hand, the high $P_{REM}$ values indicate a low affinity between P and clay minerals. Consequently, P percolates from the surface to deeper horizons. The lower P input in soils influenced by bones compared to ornithogenic soils did not guarantee apatite formation (Michel et al., 2006).

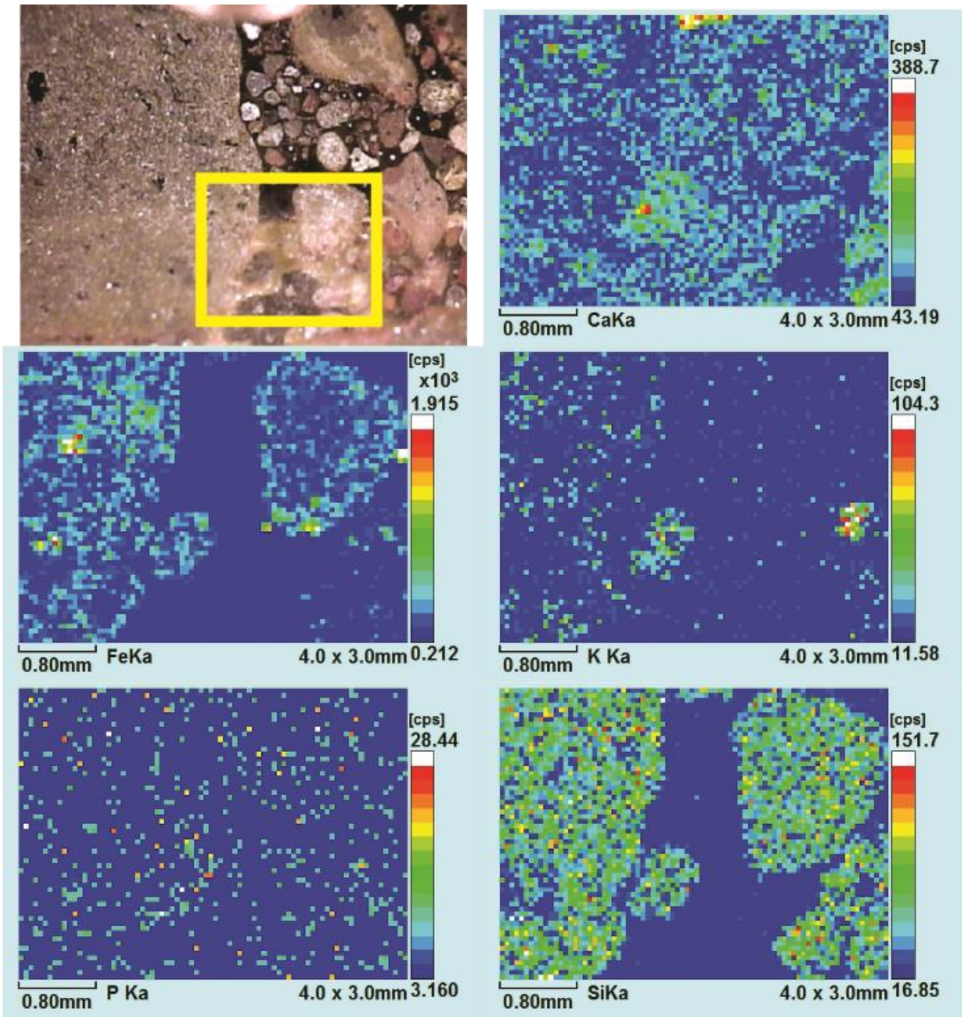


Figure 5. Spatial distribution of elements determined by XRF in thin sections.

*Vegetation composition*

In the 33 whale bones studied (Figure 6) there were found 10 lichenized fungi, 5 moss species and the Angiosperm *Deschampsia antarctica* Desv. (Table 2 and 3). This species is the Antarctic grass and was found for the first time in this substrate but sometimes with some sediments already deposited on them (Figure 8). This was also the case of *Brachythecium austrosalebrosum* and *Ditrichum* sp., both moss species found for the first time on bones. Among the mosses, *Pohlia nutans* (Hedw.) Kinb., *Brachythecium subpilosum* (Hook.f. & Wilson) A. Jaeger and *Syntrichia magellanica* (Mont.) R. I-I. Zander are cited to whale bones (Ochyra et al., 2008). *Ceratodon* sp., *Bryum* sp., *Pohlia nutans*, various *Syntrichia* spp., *Brachythecium subpilosum, Drepanocladus* sp. and *Sanionia georgico-uncinata* were found on bones of the British Antarctic Survey and Natural History Museum collections, sampled on South Georgia and South Shetland Islands (Duckett, 2017).

Table 2. Species list of plants found in the 33 whale bones studied.

| Group/Family | Species |
|---|---|
| Lichen/Caliciaceae | *Buellia 1* |
| Lichen /Caliciaceae | *Buellia2* |
| Lichen /Teloschistaceae | *Caloplaca sublobulata* (Nyl.) Zahlbr |
| Lichen | *Muscicolous lichen* |
| Lichen / Pertusariaceae | *Pertusaria sp* |
| Lichen | *Gray sterile lichen* |
| Lichen | *Placoid sterile lichen* |
| Lichen / Lecanoraceae | *Rhizoplaca aspidophora* Vain. |
| Lichen | *White sterile lichen* |
| Lichen /Verrucariaceae | *Verrucaria sp.* |
| Moss/ Ditrichaceae | *Ditrichum sp.* |
| Moss/Pottiaceae | *Syntrichia filaris* (Müll. Hal.) |
| Moss/ Pottiaceae | *Hennediella heimii* (Hedw.) Zand |
| Moss/Brachytheciaceae | *Brachythecium austrosalebrosum* (Müll. Hal.) Paris |
| Moss/ Amblystegiaceae | *Sanionia uncinata* (Hedw.) Loeske |
| Angiosperm/Poaceae | *Deschampsia antarctica* Desv. |

Table 3 – Species coverage (%) on each sampled area of the whale bones in Byers Peninsula.

| | B1 | B2 | CS | ML | PR | GL | PL | RA | WL | VR | DS | SF | HH | BA | DA | SU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | | | 2.2 | | | | | | | 0.9 | | | | | | |
| 02 | | | 0.1 | | 2.9 | 24.5 | | | | | | | | | | |
| 03 | | | | | | | | | | 25.7 | | | | | | |
| 04 | | | 0.5 | | | | | | | 19.3 | | | | | | |
| 05 | | | | | | | | | | 11.6 | | | | | | |
| 06 | | | | 12.8 | | | | | | | 18.9 | | | | | |
| 07 | 3.3 | | | | 8.1 | 1.1 | | | | | | | | | | |
| 08 | 2.2 | | | | 4.3 | 2.5 | | | | | | | | | | |
| 09 | | | | | 6.6 | | | | | | | | | | | |
| 10 | | | | | 9 | | | | | | | | | | | |
| 11 | | | | | 10.5 | | | | | | | | | | | |
| 12 | | | | | 13.3 | | | | | | | | | | | |
| 13 | | | 3.7 | | 0.9 | | | | | | | | | | | |
| 14 | | | | | | | | | | | | 6.7 | | | | |
| 15 | | | 5.7 | | | | | | | | | 6.6 | | | | |
| 16 | | | | | | | | | | | | | | | 16.2 | |
| 17 | | | | | | | | | | | | 1.6 | | | | |
| 18 | | | | | | | | | | | | | 0.6 | | | |
| 19 | | | | | | | | | | | | | | 31.9 | | |
| 20 | | 0.5 | | | | 7.2 | | | | | | | | | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | | | | | | | 3.7 | 3.1 | | | | | 0.4 | | | |
| 22 | | | | | | | | | | | | | 0.5 | | | |
| 23 | | | | | | | | 8.2 | | | | | | | | |
| 24 | | 3.3 | | | | | | | | | | | | | | |
| 25 | | 4.2 | | | | | | | | | | | | | | |
| 26 | | 0.5 | | | | 26.6 | | | 12.7 | 8.3 | | | | | | |
| 27 | | | | | | | | 9.1 | | | | | | | | |
| 28 | | | | | | | | 9.6 | | | | | | | | |
| 29 | | | | 48,9 | | | | | | | | | 7.6 | | | |
| 30 | | | | 39.3 | | | | | | | | | 4.4 | | | 4 |
| 31 | | | | 9.8 | | | | | | | 1.4 | | | | | 3.8 |
| 32 | | | | | | | | 0.4 | 16.6 | | | | 0.1 | | | |
| 33 | | | | 37.5 | | | | | | | | | 1.1 | | | 5 |
| Total | 5.5 | 8.5 | | 148.3 | 55.6 | 39.9 | 3.7 | 30.4 | 20.3 | 65.8 | 20.3 | 14.9 | 14.7 | 31.9 | 16.2 | 12.8 |

*Buellia* sp. 1 (greenish); B2- *Buellia* sp. 2 (yellowish); CS - *Caloplaca sublobulata*; ML - Muscicolous lichen; PR - *Pertusaria* sp.; GL - Gray lichen; PL - Placoid lichen; RA - *Rhizoplaca aspidophora*; WL - White lichen; VR - *Verrucaria* sp.; DS – *Ditrichujm* sp.; SF - *Synchitria filaris*; HH - *Hennediella heimii*; BA - *Brachythecium austrosalebrosum*; DA - *Deschampsia antarctica*; SU – *Sanionia uncinata*.

*Pertusaria* sp. was the species most frequently found (8 squares – 24.2%), what is not according other works published (Putzke et al., 2020a, b) (Table 4). This species had also the higher Ecological Value index (121.2).

*Verrucaria* sp. had the highest coverage, what can be justified by the disposition of bones too close to the sea shore, since *Caloplaca sublobulata* was also found in the community (three on the same square) and both are associated to high salt availability (Redon, 1985).

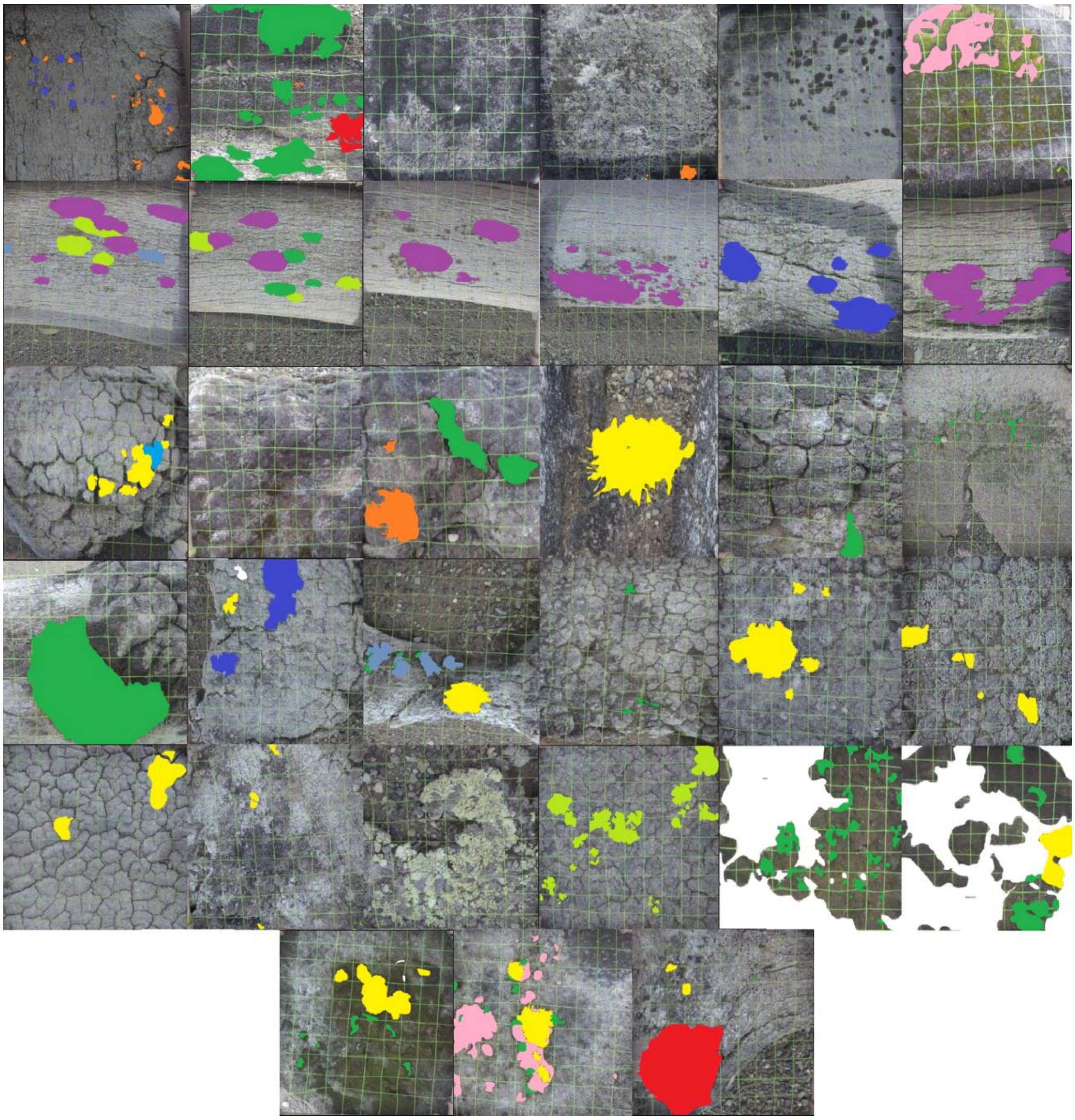

Figure 6 – Images of the 33 whale bones quadrats studied and hand colored plant coverage for phytosociological evaluation.

Table 4. Species with higher frequencies found on whale bones in Southern Beach, Byers Peninsula, Livingston Island – Antarctica.

| Species | Nº of squares | F (%) | IES |
|---|---|---|---|
| Muscicolous lichens | 5 | 15.15% | 90.9 |
| *Caloplaca sublobulata* (Nyl.) Zahlbr | 5 | 15.15% | 45.45 |
| Gray sterile lichen | 5 | 15.15% | 60.6 |
| *Rhizoplaca aspidophora* Vain. | 5 | 15.15% | 60.6 |
| *Verrucaria sp.* | 5 | 15.15% | 75.75 |
| *Pertusaria sp* | 8 | 24.24% | 121.2 |
| *Hennediella heimii* (Hedw.) Zand | 7 | 21.21% | 63.63 |
| *Deschampsia antarctica* Desv. | 1 | 3.03% | 9.09 |

Nº = number of squares in which the species was observed; F = (%) frequency of the species in 33 squares studied; IES = Ecological value Index.

In one square (bone 32) a giant thallus of *Lecidea* sp. was found, with 9,5 cm diam., in a very old and fragmentary bone. This is an indication that if bones are stabilized, lichens can grow at considerable diameters and that bones are a suitable substrate for very old growing lichens and need to be protected.

*Sanionia uncinata* was found on three bones only (9.1%), sometimes greatly covered by muscicolous lichens, differently from what was found in other islands (Putzke et al. 2020b). *Sanionia* species had the highest coverage of all species in cryptogamic communities of Antarctica (Schmitz et al. 2020a and b), but this is not the case of Whale bones in Byers Peninsula. This is probably because the bones are very old and muscicolous lichens are already colonizing the moss formations on this substrate (15 % of frequency and coverage of 148.3, the highest among all species found). This is an observation that allows us to conclude that plant succession on bones in Antarctica is also occurring and that any movement of the bones caused by Anthropic interference can change completely the community as already demonstrated (Putzke et al., 2020b).

From the five seal skeletons studied (Figure 5), three of them were represented only by pure bones and two also presented skin remains. In one skeleton without skin only *Deschampsia antarctica* was present forming up to 10 cm small tufts and in the another two only *Polytrichum piliferum* was present. When skin is still among the remains, the vegetation is dense, with *Sanionia uncinata* forming small carpets and *Polytrichum piliferum* and/or *Ditrichum* sp. forming tufts. In one of those skeletons the alga *Prasiola crispa* was also present. The muscicolous *Ochrolechia frigida* was constant in one skeleton with skin remains, indicating the old condition of this piece. Probably the skin remains contribute highly to plant establishment while pure skeletons usually have no vegetation directly associated.

The skeletons without skin are probably remains of the hunting period when this part of the seals was collected to be sold in the around the world markets. So, based on our results, probably the huge amount of skeleton without skins in South Beach of Byers Peninsula contributed very little to plant establishment.

Figure 7 – Seal skeletons studied with vegetation associated hand-colored to interpretation. Color legend: Red (bones or otherwise natural color); Brown (skin debris); Yellow (*Sanionia uncinata*); Green (*Polytrichum piliferum* except for 01 that is *Ditrichum* sp.); Pink (*Ochrolechia frigida*).

Figure 8. *Deschampsia antarctica* in sediments deposited on a whale bone in Byers Peninsula, Livingston Island, Antarctica.

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## **2.4 Artigo 4:** A NEW OCCURRENCE OF A BRYOPHILOUS FUNGUS IN ANTARCTICA: *Lamprospora cashiae* (ASCOMYCOTA - PEZIZALES)

(Artigo publicado - *Revista Brazilian Journal of Development*)

# A new occurrence of a bryophilous fungus in Antarctica: *Lamprospora cashiae* (Ascomycota - Pezizales)

# Uma nova ocorrência de um fungo briofílico na Antártica: *Lamprospora cashiae* (Ascomycota - Pezizales)

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**RESUMO**
O gênero *Lamprospora* está pobremente representado nas regiões antárticas e subantárticas. Durante trabalho de campo realizado na Ilha Livingston, Arquipélago das Shetlands do Sul, foram coletardos pequenos fungos apotecioides por entre musgos que foram identificados como *Lamprospora cashiae*. Encontrado previamente no Chile e Argentina, está é a primeira referência da espécie para a Antártica.

**Palavras chave**: musgos, Livingston, distribuição.

**ABSTRACT**
The genus *Lamprospora* is poorly represented in the Antarctic and Subantarctic regions. In a field survey done in Livingston Island - South Shetland Archipelago, a small apothecioid muscicolous fungi was collected and identified as *Lamprospora cashiae*. Found previously in Chile and Argentina, this is the first citation of this species to Antarctica.

**Keywords**: mosses, Livingston, distribution.

## 1 INTRODUCTION

The bryophilous fungi are poorly known from Antarctic areas, even being the ice-free places in this continent mostly vegetated by extensive moss fields. The most common hosts around the world are among the acrocarpous Bryophyte genera *Barbula*, *Bryum*, *Ceratodon*, *Funaria*, *Grimmia*, *Polytrichum*, *Pottia* and *Tortula*, all of them represented in the Maritime Antarctic and among the fungi Asco and Basidiomycota are involved (Benkert 2007, Ochyra et al. 2008, Jukić et al. 2018; Maggio et al. 2021).

The genus *Lamprospora* (= *Octospora,* Pezizales, Ascomycota) is represented in Antarctica by only one species, *L. miniatopsis* Spooner, reported to South Orkney and Elephant Island being considered common in the South Shetland Islands (Putzke and Pereira 1996, Olech 1990). *Lamprospora cashiae* Gamundi is found in the subantarctic islands of South Georgia, Argentina (Tierra del Fuego) and Chile (Magallanes Region) growing on a non-identified *Hepaticopsida* and on *Schistochila* sp. (Pegler et al. 1980; Gamundi et al. 2004).

While searching for fungi in Livingston Island, in the maritime Antarctic, a *Lamprospora* was found and this sample represents the second collection of a species of this genus and a new reference to Antarctica.

## 2 MATERIAL AND METHODS

The sampling of macroscopic fungi was done in Byers Peninsula, Livingston Island – Antarctica, (62°36′S 60°30′ and 62°36′S 60°30′W) in February 2010 (Figure 1).

The collection was done on a moss bank near a small stream using a knife and then it was transported to the laboratory in the field camp to preliminary data record. The microscopic studies were done in the Universidade Federal do Pampa laboratories for identification. The macro and microscopic studies were done using a Zeiss Axiostar Plus microscope and pictures were taken in Axiostar microscope.

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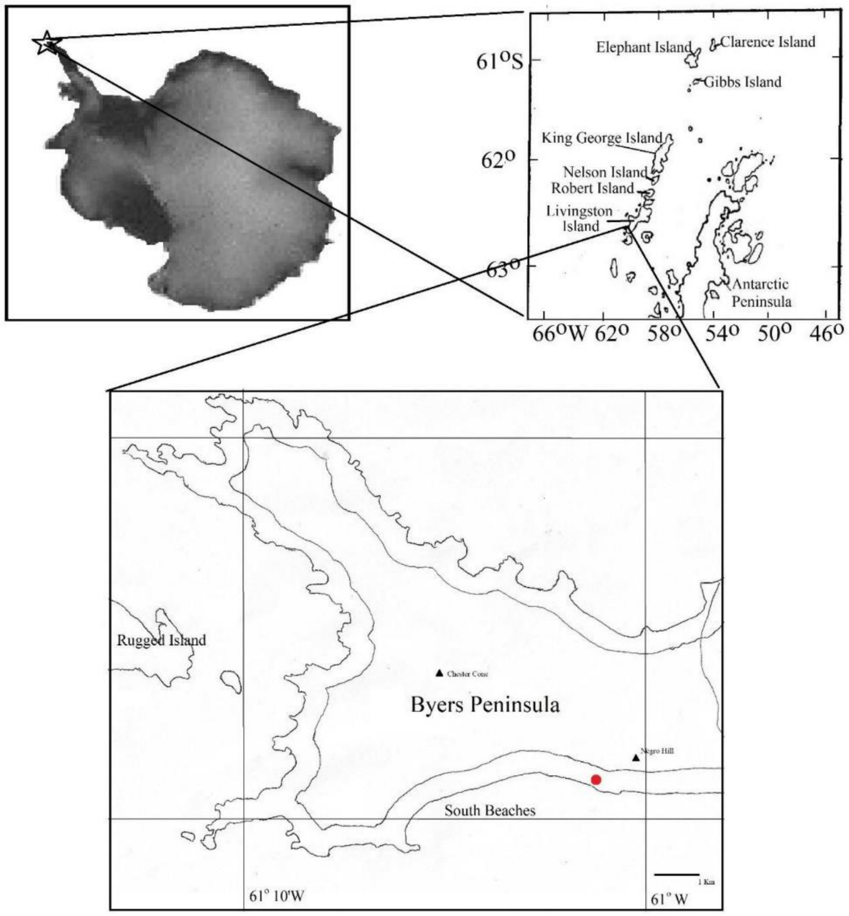
Figure 1. Schematic map with location of the sample of *Lamprospora cashiae* (red dot).




## 3 RESULTS AND DISCUSSION

The sample collected was identified as *Lamprospora cashiae* Gamundi, first citation of this species to the Antarctica.

Species description:

*Lamprospora cashiae* Gamundi, Figure 2 and 3.

Bol. Soc. Arg. Bot. 15: 89 (1973).

Apothecia 1-1.5 mm diam., flat or somewhat convex in the beginning, with orange to red disc and margin slightly dentate, with teeth elevated at right angles from the disc. Asci hyaline to reddish, 190 - 210 x 25 - 30 µm, with one series of eight spores.

Paraphyses straight, slightly inflated at apex, 180 – 190 x 5 – 8 μm, reddish to reddish brown, sometimes septate. Ascospores 16-18 μm diam., globose to subglobose, ornamented either with discrete warts or frequently with a sub-reticulate pattern, formed by the interconnection of warts at their bases.

The species was found growing on an acrocarpous moss cushion formation of *Bryum* sp. and *Polytrichastrum alpinum* (Hedw.) G. L. Smith (Bryophyta), associated to *Deschampsia antarctica* (Poaceae – the Antarctic Grass).

**Material examined**: Antarctica, Livingston Island, Byers Peninsula, Southern Beach, lat. 62° 39' 28,52" S and long 61°02' 10,68" W, leg. J. Putzke, Feb/2020, HCB (17550).

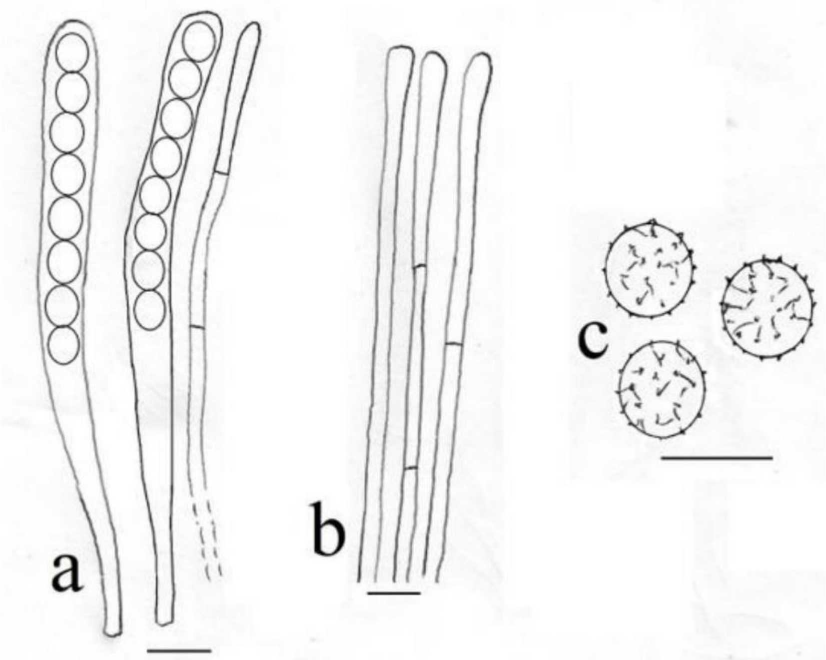
The characteristically round and ornamented ascospores associated to reddish apothecial disc are distinguishing features of this species. *Lamprospora miniatopsis* that is also found in the South Shetland Islands has orange apothecial disc and elliptical (rarely subglobose) ascospores.

This species is reported to South Georgia (Sub-Antarctic area) by Pegler et al. (1980 – as *cf.*) growing in wet *Rostkovia magellanica* (Lam.) Hook.f. (Juncaceae)-moss bog beside a stream. It is also reported form Southern South America growing only on an Hepaticopsida species (Gamundi et al. 2004). Our specimen was growing on Bryopsida.

This is the first report of this species to Antarctica. The area of our sample was besides a small stream.

Figure 2. *Lamprospora cashiae* apothecia (scale = 1 mm).

Figure 3. *Lamprospora cashiae*: a- asci; b- paraphyses; c- ascospores (scale = 20 µm).

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