LIFE-FORMS OF MOSS SPECIES IN DEFROSTING AREAS OF KING GEORGE ISLAND, SOUTH SHETHLAND ISLANDS, ANTARCTICA

FORMAS DE VIDA DE ESPÉCIES DE MUSGOS DE ÁREAS DE DEGELO DA ILHA REI GEORGE, ARQUIPÉLAGO SHETLANDS DO SUL, ANTÁRTICA

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ABSTRACT: The colonization form of moss species depends upon the genetic and environment conditions. The life-forms of moss species in the ice-free areas of the Admiralty Bay, King George Island, South Shetland Islands, Antarctica, have been evaluated in the present work. The majority of the species occurs in tuft forms (59%), followed by cushions (31%). Few species occur in form of carpets (7%) or wefts (3%). Of the total of 58 studied species, 10 present more than one life-form, depending upon the substratum colonized. Data are presented about substratum preferences of each moss life-form observed, as well ecological data that influence the mosses growing in the ice-free areas of maritime Antarctica.

KEYWORDS: Bryophyta. Development. Ice-free areas. Antarctica.

INTRODUCTION

Analyses of moss community types occurring in different environments were used by Gimingham and Robertson (1950) for classification of Bryophyte life-forms. The sense of community derives from similar habitats, although clearly differing in specific composition, showing some structural uniformity expressed by several types of life-forms, for example, wefts, tufts and mats among others. As for communities of distinct habitats, they tend to show structurally divergent types, where life-forms may be different, such as cushions in rocky or high altitude grasslands, and mats and wefts in forests, showing a kind of dependence between life-forms and their habitats (GIMINGHAM; LEWIS-SMITH, 1970). Different characteristic life-forms of moss species can be distinguished: those growing vertically from the substrate, known as orthotropic mosses, and those growing horizontally to the substrate, known as plagyotropic mosses. For example, orthotropic mosses grow usually like tufts and cushions, and plagyotropic mosses usually develop in mats and wefts. However, many mosses can change their growth-form due to environmental changes and of their own phenotypic plasticity (SCHOFIELD, 2001).

The classification of life-forms offered by Gimingham and Robertson (1950) has been mainly created to simplify the morphological classification proposed by Meusel (1935). An essential characteristic of the former is that it is only based on morphology, hence being free from adaptable structural characteristics. In this way, for those authors the life-forms and the substrate are not related to each other, since their system do not consider the form observed in nature against the conditions observed in the field, except for Mägdefrau (1982) and Bates (1998), who still try to relate those parameters. Therefore, the idea of discussing life-forms found in phytosociological samples in King George Island, in a stressed environment like the Antarctic tundra, comes from an attempt to answer how those life-forms are distributed in distinct substrates found in this region.

MATERIALS AND METHODS

King George Island, located in the South-Shetlands archipelago, Antarctica (61º50`- 62º15`S e 57º30`- 59º00`W), is 65 km long and its width vary from 4 to 40 km, with an average temperature of 0.1 to -3.6 °C.

During the austral summers of 2002/2003 and 2003/2004, through a phytosociological survey, following the Braum-Blanquet (1932) methodology adapted to Antarctic conditions (KANDA, 1986), mosses sampling has been made in defrosted areas adjoining the Commander Ferraz Antarctic station (Brazil) and the Henrik Arctowski station (Poland), both in the Admiralty Bay (Figure 1). A total of 100 squares have been sampled within an altitude gradient, starting at the sea level of the beach

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towards spots of higher altitude, as far as the ground could still allow such technique (ca. 250 m hight). From 250 m on, only casual samples have been obtained. The life-forms presented by moss species in each of the quadrants have been examined, as well as the types of substrate they were growing on.

The field research data of mosses in the study area to be obtained will be complemented with data from Kanda (1987), Ochyra (1998) and Putzke and Pereira (2001), especially of those species that have not been sampled, but are occurring in the region of study.

Classification of life-forms followed Gimingham and Birse (1957), Gimingham and Lewis Smith (1970) and Mägdefrau (1982), with modification (Table 1).

For a better visualization and illustration of the observed life-forms, with the help of a blade, small cuts in different directions in the mosses have been made, in order to expose the gametophyte insertion, as well as its fixing point in the substrate (Figure 2).

Due to the presence of rocky and organic substrates, the distribution of the observed species and their life-forms in this study has been analyzed applying T-Student (t) test at significance level of 5% ($p>0,05$) (ZAR, 1984), using Statistic Software 8.0 (HILL; LEWICKI, 2007).

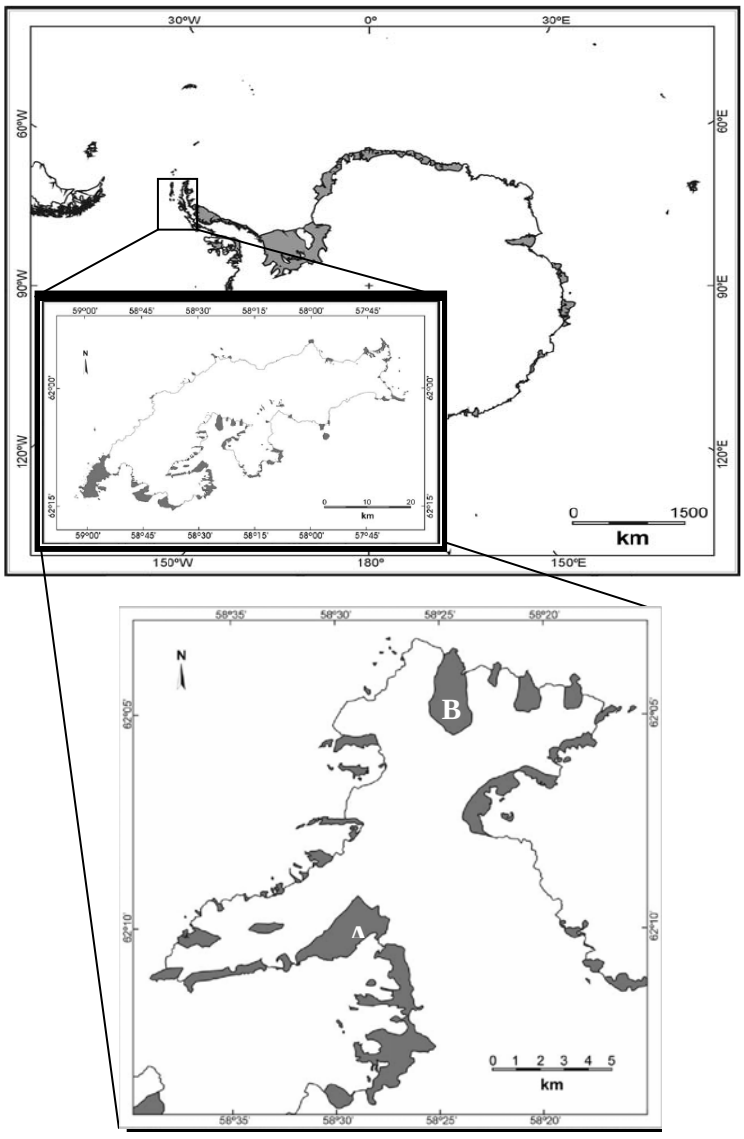

Figure 1. Study area. Antartic continent showing the South Shetlands Island (rectangle above) and King George Island (inset). The Admiralty Bay (rectangle below); the ice free areas are represented in gray. A = Arctowski region. B = Keller Peninsula (adapted from Simões et al. 2004).

RESULTS AND DISCUSSION

For the 58 moss species occurring in the area of study, 4 life-forms have been characterized: cushions, tufts, mats and wefts (Table 1 and Figure 2), where tufts (59%) and cushions (31%) were prevailing.

Table 1. Characterization of mosses life-forms in defrosting areas adjoining Henri Artowski and Commander Ferraz Antarctic stations.

LIFE-FORM DESCRIPTIONS	*CHARACTERIZATION AND SPECIES EXAMPLES*
Cushions Axis coming from a central point, growing radially, resulting in half a ball more or less compacted. Usually growing on emergent rocks or particles of that.	*(a)* Large cushions. Usually reaching more than 5 cm in diameter. Ex.: *Andreaea regularis*, *Syntrichia princeps*. *(b)* Small cushions. Never reaching more than 5 cm in diameter. Ex.: *Andreaea gainii*, *Andreaea depressinervis*, *Schistidium antarctici*.
Tufts Straight main axis with similar branches, parallel to the main axis forming contiguous tufts. Growing on soil or fine rock particles.	*(a)* Short tufts. Lower than 1 cm. It can be dense when occurring too close to each other and the leaves from neighboring plants mingle one another; or yet scattered, when each plant individually can be easily recognized. Ex.: *Brachythecium austrosalebrosum, Bryum pseudotriquetrum*. *(b)* Tall tufts. Higher than 1 cm. Usually scattered. Ex:. *Andreaea gainii*, *Polytrichum juniperinum*, *Polytrichum strictum*, *Polytrichastrum alpinum.*
Mats Main axis and secondary axis long, dense, crawler, with ascending horizontal growth. Rhizoids, if present, are restricting to the basal portion of the main axis. Growing in areas flooded by defrosted ice, usually on rocky soil.	Ex: *Brachythacim austrosalebrosum*, *Sanionia uncinata*, *Warnstorfia laculosa*.
Wefts Main axis growing horizontally to substrate, frequently subdivided, well adhered and fixed by rhizoids and secondary branches. Usually has a limited growth.	Ex: *Orthotheciella varia*, *Platydictya jungermannioides.*

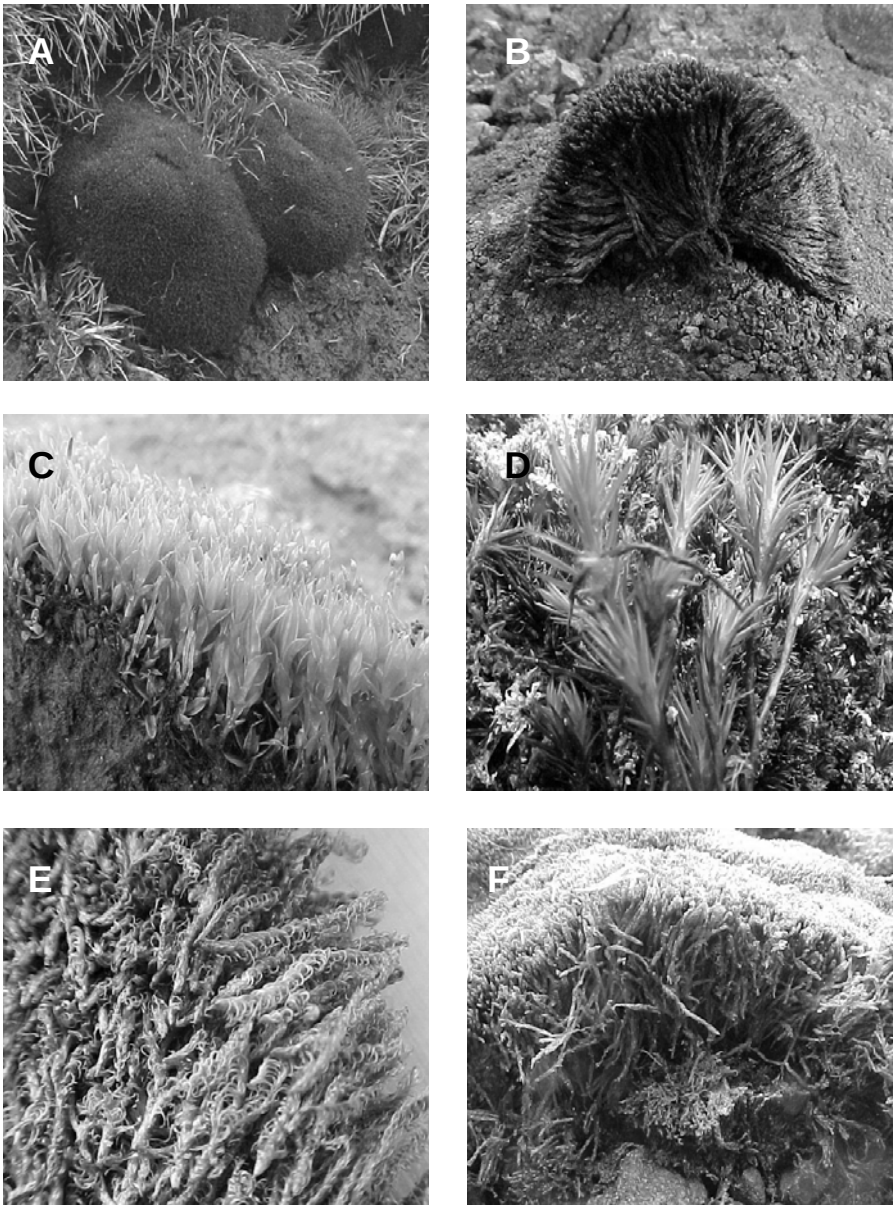

Figure 2. Moss life-forms in ice-free areas of Admiralty Bay, King George Island, Antarctica. A. Cushion. B. Cushion (transversal section). C. Short tufts. D. Tall tufts. E. Mats (in close). F. Mats (transversal section). (Photos: Filipe Victoria).

The observed predominance is related to the kind of available substrate in defrosting areas of the region (Table 2). Tufts and cushions preferably occur in rocky and stony fields (KANDA, 1986).

Table 2. List of moss species in defrosting areas adjoining Henri Artowski and Commander Ferraz Antarctic stations, with life-forms, substrate and locality where they can be found.

Specie	Life-form	Substrate	Place
Andreaea depressinervis Card.	Cushion; Tuft	Emergent rocks; Pebbles.	Hillsides; Beach (at ± 20m hight)
Andreaea gainii Card.	Cushion; Tuft	Emergent rocks; Cracks in rocks; Pebbles.	Peacks; Hillsides; Beach (at ±20m hight)
Andreaea regularis Müll. Hal.	Cushion;	Emergent rocks;	Peacks; Hillsides; Beach (at

	Tuft	Cracks in rocks; Pebbles.	±20m hight)
Anisothcecium cardotii (R. Br. bis.) Ochyra	Tuft	Pebbles and Soil	Plateau; Hillsides; Beach (at ±20m hight)
Bartramia patens Brid.	Tuft	Soil; Pebbles;	Beach (at ±20m hight); Hillsides
Brachythecium austrosalebrosum (Müll. Hal.) Kindb.	Tuft; Mat	Soil; Pebbles	Beach (at ±20m hight); Plateau
Brachythecium glaciale Shimp.	Mat	Soil; Pebbles	Beach (at ±20m hight); Plateau
Bryum amblyodon Müll. Hal..	Tuft	Soil; Pebbles	Beach (at ±20m hight); Plateau; Border of drainage lines
Bryum argenteum Hedw.	Tuft	Soil; Pebbles	Beach (at ±20m hight); Hillsides; Cracks in rocks
Bryum orbiculatifolium Cardot & Broth.	Tuft	Soil; Pebbles	Beach (at ±20m hight); Plateau; Border of drainage lines
Bryum pallescens Schelich. ex Schwägr.	Tuft	Soil; Pebbles	Beach (at ±20m hight); Plateau; Border of drainage lines
Bryum pseudotriquetrum (Hedw.) P. Gaertn., B. Mey. & Scherb.	Tuft	Soil; Pebbles	Border and inside of drainage lines
Campylium polygamus (Schimp.) C. E. O. Jensen.	Weft	Soil	Beach (at ±20m hight)
Ceratodon purpureus (Hedw.) Brid.	Tuft	Soil; Pebbles	Beach (at ±20m hight); Plateau; Border of drainage lines
Chorisodontium aciphyllum (Hook. f. & Wilson) Broth.	Tuft	Pebbles	Plateau
Conostomum magellanicum Sull.	Tuft	Soil; Pebbles	Beach (at +20m hight); Plateau; Border of drainage lines
Dicranoweisia brevipes (Müll. Hal.) Cardot	Tuft	Pebbles, Cracks in rocks	Plateau, Hillsides
Dicranowesia crispula (Hedw.) Milde	Cushion	Emergent rocks; Pebbles; Cracks in rocks	Plateau; Hillsides
Dicranowesia grimmiaceae (Müll. Hal.) Broth.	Cushion	Emergent rocks; Pebbles; Cracks in rocks	Plateau; Hillsides
Didymodon gelidus Cardot	Tuft	Pebbles; Soil	Beach (at +20m hight), Plateau; Hillsides
Distichium capillaceum (Hedw.) Bruch & Schimp.	Tuft	Pebbles; Soil	Plateau; Beach (at +20m hight)
Ditrichum hyalinum (Mitt.) Kuntze	Tuft	Pebbles; Cracks in rocks	Hillsides; Beach (at +20m hight)
Ditrichum lewis-smithii Ochyra	Tuft	Pebbles; Cracks in rocks	Plateau; Hillsides
Encalypta rhaptocarpa Schwägr.	Tuft	Pebbles; Cracks in rocks	Plateau; Hillsides
Grimmia reflexidens Müll. Hal.	Tuft, Cushion*	Pebbles; Cracks in rocks	Plateau; Hillsides; Beach (at +20m hight)
Hennediella antarctica (Ångström) Ochyra & Matteri	Cushion	Pebble; Emergent rocks	Plateau; Hillsides
Hennediella heimii (Hedw.) R. H. Zander	Tuft,	Pebble; Cracks	Plateau; Hillsides; Peacks

	Cushion	in rocks; Emergent rocks	
Holodontium strictum (Hook. f. & Wilson) Ochyra	Tuft	Pebble; Soil	Plateau; Hillsides
Hypnum revolutum (Mitt.) Lindb.	Cushion	Emergent rocks	Plateau; Hillsides
Meesia uliginosa Hedw.	Tuft	Pebbles; Soil	Beach (at +20m hight); Plateau; Border of drainage lines
Muelleriella crassifolia (Hook. f. & Wilson) Dusén	Cushion	Emergent rocks	Plateau; Beach (at ±20m hight)
Orthotheciella varia (Hedí.) Ochyra	Weft	Pebbles; Soil	Beach
Platydictya jungermannioides (Brid) H.A. Crum	Tuft*, Mat*, Weft*	Soil	Beach
Pohlia cruda (Hedw.) Lindb.	Tuft	Pebbles; Cracks in rocks	Hillsides
Pohlia nutans (Hedw.) Lindb.	Tuft	Pebbles; Cracks in rocks	Hillsides; Beach (at ±20m hight); Border of drainage lines
Polhia wahlenbergii (F. Weber & D. Mohr.) A.L. Andrews	Tuft	Pebbles; Soil	Plateau; Beach (at ±20m hight)
Polhia. drummondii (Müll. Hal.) A.L. Andrews	Tuft	Pebbles; Soil	Plateau; Beach (at ±20m hight)
Politrichastrum alpinum (Hedw.) G.L.Sm.	Tuft	Pebbles; Soil	Plateau; Hillsides
Polytrichum juniperinum Hedw.	Tuft	Pebbles; Soil	Plateau; Hillsides; Beach (at ±20m hight)
Polytrichum piliferum Hedw.	Tuft	Pebbles; Soil	Plateau; Hillsides; Beach (at ±20m hight)
Polytrichum strictum Menzies ex Brid.	Tuft	Pebbles, Soil; Cracks in rocks	Beach (at ±20m hight), Plateau; Hillsides
Racomitrium sudeticum (Funck) Bruch & Schimp.	Cushion	Emergent rocks	Plateau; Hillsides
Sanionia uncinata (Hedw.) Loeske	Tuft, Mat	Pebbles; Soil	Beach (at ±20m hight); Plateau; Hillsides
Schistidium amblyophyllum (Müll. Hal.) Ochyra & Hertel	Cushion	Pebbles; Emergent rocks	Hillsides; Peacks
Schistidium antarctici (Cardot) L.I. Savicz & Smirnova	Cushion	Pebbles; Emergent rocks	Hillsides; Peacks
Schistidium cupulare (Müll. Hal.) Ochyra	Cushion	Pebbles; Emergent rocks	Hillsides; Peacks
Schistidium falcatum (Hook. f. & Wilson) B. Bremer	Tuft	Pebbles; Emergent rocks	Hillsides; Peacks
Schistidium halinae Ochyra	Cushion	Pebbles; Emergent rocks	Hillsides; Peacks
Schistidium occultum (Müll. Hal.) Ochyra & Matteri	Cushion	Pebbles; Emergent rocks	Hillsides; Peacks
Schistidium rivulare (Brid.) Podp.	Tuft	Pebbles; Emergent rocks	Hillsides; Peacks
Schistidium steerei Ochyra	Cushion	Pebbles; Emergent rocks	Hillsides; Peacks
Schistidium urnulaceum (Müll. Hal.) B. G. Bell	Cushion	Pebbles; Emergent rocks	Hillsides; Peacks
Stegonia latifolia (Schwägr.) Venturi ex Broth.	Tuft	Soil; Cracks in rocks	Beach at sea level
Syntrichia filaris (Müll. Hal.) R.H. Zander	Tuft, Cushion	Pebbles; Emergent rocks	Hillsides; Peacks

Syntrichia princeps (De Not.) Mitt	Tuft, Mat, Cushion	Pebbles; Emergent rocks	Hillsides; Peacks; Beach (at ±20m hight)
Syntrichia saxicola (Cardot) R.H. Zander	Cushion	Pebbles; Emergent rocks	Hillsides; Peacks
Warnstorfia laculosa (Müll. Hal.) Ochyra & Matteri	Tuft, Mat	Pebbles	Beach (at ±20m hight)
Warnstorfia sarmentosa (Wahlenb.) Hedenas	Mat	Pebbles	Beach (at ±20m hight)

*Data not observed in the field, but found in literature.

Mats and wefts are less frequent in polar regions due to the environmental conditions for development of this life-forms (LEWIS-SMITH; GIMINGHAM 1976). The major part of Admiralty Bay is rough and rocky. With exception of *Sanionia uncinata*, mat moss species occur only on pebbles. Overall 7% of the species in the region can form mats and just 3% form wefts (Figure 3).

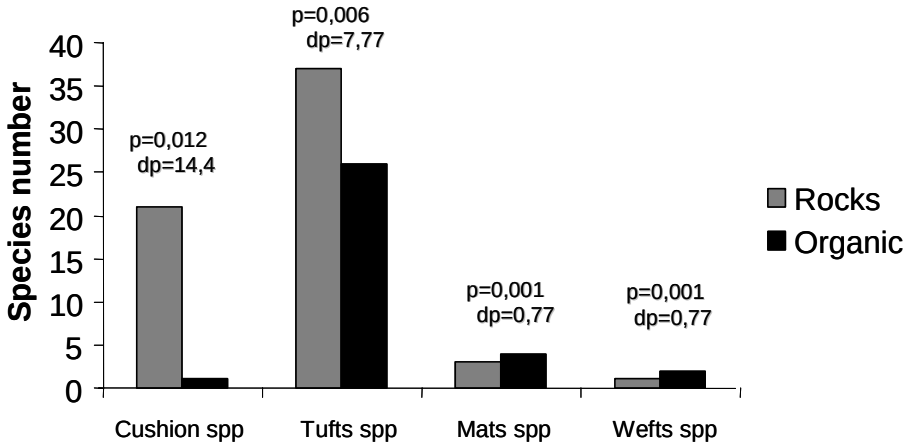

Figure 3. Species number per life-form versus substrates found in ice-free areas of Admiralty Bay (p= signifance level 5%; dp= standard deviation).

Most of the species shows one single life-form, however 10 species with more than one life form have been observed, like *Andreaea gainii* which was found in two distinct forms, and *Platydictya jungermannioides*, which has not been found in our samples, but according to Ochyra (1998), may occur in three distinct life-forms, tuft, mat and weft.The distribution of life-forms against substrate has shown that cushion-like species prefer rocky substrate (t=9,03; fd=6; p=0,012), what has also happened to tuft-like species (t=12,63; free degree=6; p=0,006), despite minor differences found for this life-form (Figure 3). Cushions occur preferably in organic substrate (t=38,5; free degree=6; p=0,0001), what has also been observed for sampled wefts-like species (t=25,42, free degree=6, p=0,0001).

The regions which have been studied present few differences in the distribution of life-forms, mainly related to the prevailing substrate at sea level. At Arctowski region (Figure 1) there is more soil available on the beaches, if compared to Keller Peninsula, which has a rocky and pebble reach substrate in its coastal line (PUTZKE; PEREIRA 1990). Some comments about life-forms which can be found in each region follow next.

Arctowski Region

At sea level, mats, tufts and wefts are predominant, mainly in areas flooded by defrosted ice, due to substrate stability, presence of organic matter and water availability. Close to the Poland station there is a vast field of mosses, mainly with *Sanionia uncinata*, *Bryum pseudotriquetrum*, *Syntrichia princeps*, *Warnstorfia laculosa* associated to lichens and grasses like *Deschampsia antarctica* Desv. (FURMANCZY; OCHYRA, 1982). Mats of *S. uncinata* are rather frequent and they overlay on other mats of the tundra, like *Brachythecium austrosalebrosum*. There are also mats of *Warnstorfia laculosa* in association with tufts of *Bryum pseudotriquetrum* and *Bryum amblyodon*, always in drainage lines or in small lakes fed by defrosting ice, like, for example, in the hillsides of Skua cliff. The only cushion found in this region was *Syntrichia princeps*, occurring closer

to penguin's nesting places, usually in fragmented rocks surrounded by countless turfts of *Deschampsia antarctica.*

Above 150 m, at the Jersak Hills plateau and on the hillsides of Jardine Peack, cushions of *Schistidium* are more frequent, being *Schistidium antarctici* the most frequent cushion in this area, mainly on emergent rocks, as this life-form is more resistant to winds and it also needs a reduced area for fixing on its substrate. On the hillsides next to Panorama Ridge and in Italy Valley, the species of the genus *Andreaea* are well represented, usually occurring in cushions, eventually in tufts inside cracks on the rocks. *Pohlia cruda* was the only tuft occurring in higher altitudes in the region, found inside fissures at an altitude above 120 m, at the apex of Jardine Peacks. Above 130 m only cushions of *Andreaea regularis* were found, usually scattered in association to fruticulose lichens *Usnea au1rantiaco-atra* (Jacq.) Bory.

Keller Peninsula

In Keller Peninsula (Fig. 1) *Polytrichastrum alpinum* dominates in rocky formations close to sea level and up to a 100 m, forming high and scattered tufts, in the areas of better drainage like in Denais Stack, as well as in short and dense tufts in rock fissures or between rocks, where there is a deposit of organic substrate. Tufts of the genus *Bryum* and *Pohlia* are frequent, in general between turfts of *Deschampsia antarctica* and *Colobanthus quitensis*, close to sea level in all the extension of the beach.

Cushions are not rare next to these tufts, however, they are limited to mineral substrate, more frequent at 120 m, where phanerogams are no longer occurring, being cushions of *Andreaea regularis* and *Andreaea depressinervis*, associated to several fruticulose lichens quite common, although those are smaller, brittle and may easily break when pulled out of the substrate. In Punta Plaza, mats of *Brachythecium austrosalebrosum* and *Sanionia uncinata* are common. The latter extents to the surroundings of the Brazilian station, forming almost contiguous mats, occurring over fragmented rocks and even on whale bones, which are very common in that region. Mats in general do not occur above 60 m, especially because that area has large extensions of mineral substrate if compared to Arctowski region.

Such results were already expected, as Bryophyta life-forms are related to environmental conditions like, for instance, the nature, humidity and light intensity of the substrate, among other factors (HORIKAWA; ANDO, 1952; GIMINGHAM; BRISE, 1956). According to Mägdefrau (1982), light represses the lengthening of the axis of the stalk. For this reason, short tufts and cushions are more frequent in habitats with higher light incidence, since growth of the main axis is smaller in relation to the secondary branches. Wefts and mats are common in wet tundra, as those life-forms present a larger number of rhizoids that allow water holding from defrosting ice and precipitation (ALLISON; LEWIS-SMITH, 1973). Dense tufts are also common in wet tundra, as they too present a large number of rhizoids allowing higher capillarity (LONGTON, 1988).

According to Vitt (1989), pleurotropic moss species are better adapted to moistened environments, occurring usually as wefts or mats, a form that allows better use of water and of leached nutrients from defrosting ice (PEREIRA; PUTZKE, 1994), since it covers a larger area over the substrate. In the Arctowski region we found the examples of *Sanionia uncinata* which practically dominates those substrates. On the other hand, achrocarpic species occur like tufts and cushions in a higher frequency, what allows water accumulation and nutrients catchment next to the their rhizoids, and reduce air movement next to their filideos (GIMINGHAM; BIRSE, 1957; LONGTON, 1988). For achrocarpic mosses, water transport in the tissues is apparently more efficient in well drained substrate, in relation to tissues of pleurotropic mosses (FREY, 1971 apud ROBINSON et al., 1989), increasing the tolerance of those mosses to hydric stress. Tufts and cushions contribute to the consolidation of the organic substrate (LONGTON, 1982), conciliating the settlement of pleurotropic species with life-forms prostrated on the substrate.

CONCLUSION

Statistical analyses show cushions and tufts preference for hillsides and emergent rocks, and a significative decrease in the frequency of those life-forms when the substrate is predominantly organic and wet, where mats and wefts occur in larger quantities. Therefore, tufts and cushions of mosses are more frequent in the defrosting areas that have been studied, due to mineral substrate with low hydric retention prevailing in this region.

RESUMO: No presente trabalho são avaliadas as formas de vida das espécies de musgos que se desenvolvem nas áreas de degelo da Baía do Almirantado, Ilha Rei George, Arquipélago Shetlands do Sul, Antártica. A maioria das espécies de musgos ocorre na forma de tufos (59%), seguido pelos coxins (31%). Poucas espécies ocorrem na forma de tapetes (7%) ou tramas (3%). Do total de 58 espécies estudadas, 10 destas apresentam mais de uma forma de vida, dependendo do substrato colonizado por estas espécies. São apresentados dados sobre o substrato preferencial para cada forma de vida observada, bem como dados ecológicos que influenciam no crescimento dos musgos nas áreas de degelo da Antártica marítima.

PALAVRAS-CHAVES: Bryophyta. Desenvolvimento. Áreas de degelo. Antártica.

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