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Climatic and ecological characteristics of deglaciated area of James Ross Island, Antarctica, with a special respect to vegetation cover

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Abstract

Since 2006, year-round measurements of climatic parameters of characteristic ecosystems of James Ross Island, such as (1) coastal vegetation oases, (2) volcanic mesas have been performed by automatic weather stations. Simultaneously, prospection, classification and mapping of vegetation cover have been made annually within the period of Czech Antarctic expeditions lasting from January to March. In this paper, description of the two typical terrestrial ecosystems, characteristics of their microclimate and overview of vegetation cover are given. Daily and monthly means and extreme values of 2-m air temperature, surface temperature and relative humidity are reported for coastal locations and volcanic mesas (300–400 m a.s.l.). Species composition of lichen and moss flora in coastal and mesa locations is characterized and discussed in relation to local topography and microclimate.

Key words: microclimate, air temperature, water availability, moss, lichen

Introduction

James Ross Island (JRI) is a relatively large island (2500 km^2) located near the east coast of Antarctic Peninsula at the geographical coordinates 63º47'S–64º27'S and 57º05'W–58º24'W. More than 80% of the JRI surface is covered with a number of ice caps, outlet glaciers, and alpine glaciers. The northernmost part of the island represents one of the largest ice-free areas along the northern part of the Antarctic Peninsula. The island is made of Cretaceous marine sediments cropping mostly out at the lower altitudes covered by Neogene and Quaternary volcanic sequences intercalated with glacigennic and glaciomarine sediments (Francis et al. 2006, Nývlt et al. 2011).

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The region of Antarctic Peninsula as well as JRI is presently exposed to enormous changes in climate system which consequently affects many environmental aspects and processes of these ecosystems. The western side of the Peninsula has experienced the largest annual surface air warming on the Earth over the last 50 years. Mean air temperature at Faraday/Vernadsky station has increased at a rate of 0.56°C per decade (Turner et al. 2005).

According to Bednarek-Ochyra et al. (2000), James Ross Island is located just on the southern border of Maritime Antarctica. Due to proximity of the Weddell Sea, local topography, and a shelter provided by the Antarctic Peninsula that represents a barrier for moist air masses brought by west wind, there are some strong features of continental type of climate, especially in the southern part of the JRI. Combination of oceanic and continental climate provides a unique opportunity to study distribution of vegetation cover at the island in relation to varying local microclimate.

Moss and lichen flora of the James Ross Island has been studies only sporadiccally. Most important collections were taken in 1989 and 1995 by R.I. Lewis Smith and S. Redshaw. Since the collections, specimen have been determined and stored as data base items in the British Antarctic Survey database (METADATA, see References - weblink), some 144 lichen species is reported for James Ross Island.

Majority of Lewis Smith´s collections were made, however, on neighbouring Cockburn Island (64°12'S, 56°51'W) which lies off the northeast coast of Trinity Peninsula, northern Antarctic Peninsula. Lewis Smith (1993) reported 9 moss, and 34 lichen species.

Specifically for James Ross Island, the METADATA data base reports 49 moss species. Among them, *Platydictyla jungermannoides*, is of some importance (Ochyra 1999). It was collected on the eastern side of Lachman Crags (63°53'S, 57°50'W).

Hawes et Brasier (1991) published one of pioneering studies that partly focused algal and cyanobacterial flora of streams of James Ross Island. Since that time, there has been published several papers on freshwater algae and cyanobacteria (*e.g.* Komárek et al. 2008, Komárek et Komárek 2010).

Material and Methods

Site characteristics

For this study, two different sites representing two dominant environments at the deglaciated northern part of James Ross Island (Ulu Peninsula) were chosen. The first one is a vegetation oasis located on seashore (6 m a.s.l.) in close proximity to the Czech Johann Gregor Mendel Station (hereafter the Mendel Station). The site is located on an abandoned river delta between two streams flowing to the Prince Gustav Channel (see Fig.1). During austral summer, the site is well supplied by melting water from neighboring snow patches. Therefore, rich vegetation comprising of algal and cyanobacterial mats, moss and lichen flora is found there. The area covered by vegetation is of irregular elliptic shape and estimates 1500 m^2. The site was chosen as one of long-term experimental plots at which several projects has been run, *e.g.* installations of open top chambers (OTC) over the vegetation and assessment of OTC-induced differences in microclimate and vegetation growth (Barták et al. 2009). Also some long-term measurements of photosynthetic processes in *Bryum* sp. take place there.

The second site represents volcanic mesas. In this study, we chose Berry Hill Mesa and Johnson Mesa, both located about 3 km from the Mendel Station and the seashore plot, respectively. Mesas originated by subglacial volcanic eruptions (Smellie et al. 2008). The mesa plateaus are nearly flat and are located at the mean altitude of 350 m a.s.l. Both mesas surfaces are formed by cobbles and boulders of basalts and hyaloclastite breccias sized from 10 to 150 cm, which form partly vegetated sorted polygons. Permafrost active layer thickness ranged from 30 to 80 cm (Engel et al. 2010). Vegetation cover is patterned and dependent on microrelief and the possibility of snow accumulation. It is dominated by lichen species, however, some mosses can be found mainly in shallow depressions, *e.g.* around the sorted polygons.

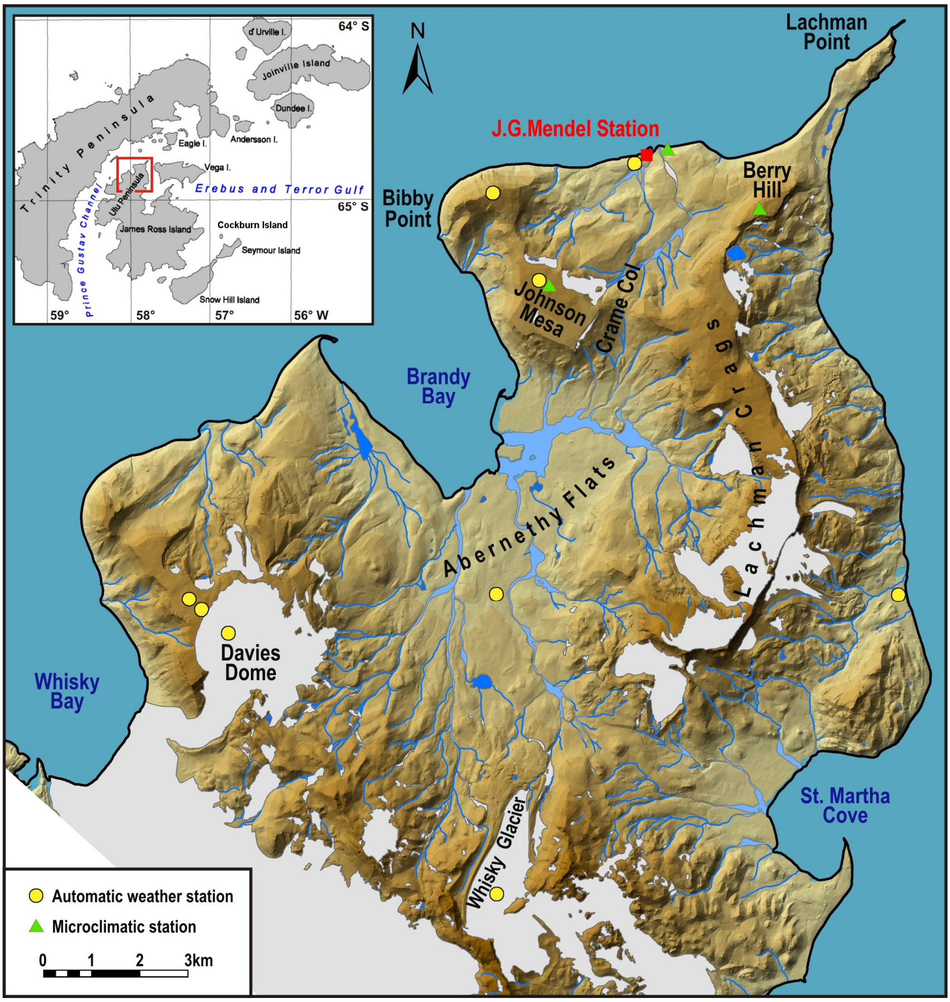

Fig. 1. The locations of the study sites and automatic weather stations on northern deglaciated part of James Ross Island. Adopted from Czech Geological Survey, 2009.

Measurements of climatic characteristics

In a close neighbourhood of the Mendel Station, there is central automatic weather station (AWS) consisting of permanent measurements of incident and reflected global solar radiation, air temperature and relative humidity at heights of 2 m, wind speed and direction at 10 m, atmospheric pressure, surface temperature, soil heat flux, and soil temperatures at depths of 5 to 200 cm. Special attention is devoted to monitoring of solar radiation and its characteristic components, particularly UVA, UVB, erythemally effective UVB and global UV radiation, and photosynthetically active radiation (Láska et al. 2009, 2011). Since 2005, several AWSs (EMS Brno, Czech Republic) have been installed at different locations of the James Ross Island. Recently, there are 9 stations situated at different altitudes ranging from seashore terraces to the altitude up to 514 m (dome glacier of the Davies Dome) – see Fig. 1. Standard AWS possesses set of the following instruments: EMS33 air temperature and relative humidity probe (EMS Brno, Czech Republic) at the height of 2 m above ground, OS-36-2 near-infrared temperature sensor (Omega, USA), Pt100/8 soil thermometers (EMS Brno, Czech Republic), Young 05103 and MetOne 034B anemometers at the height of 2 and/or 6 m above ground.

Apart of the AWSs, there are also several microclimatic stations that serve for long-term field experiment aimed to the evaluation of vegetation response to manipulated warming caused by OTCs (Barták et al. unpublished).

In this study, we used data only from three sites. The first one is located at a seashore, close to the OTC permanent installations. The second one is located on the Berry Hill Mesa, the third one on the the Johnson Mesa. The microclimatic stations consist of a VV/VX MiniCube dataloggers (EMS Brno, Czech Republic) equipped by CuCo thermocouple sensors, air temperature and relative humidity probes (Minikin TH, EMS Brno) located at the height of 30 cm above ground, at ground level (vegetation or stone surface), in soil profile at the depth of 5, 10, and 15 cm (Pt100/8 thermometers), respectively. The data from microclimatic sensors were sampled and stored throughout a year at 30 min intervals.

Vegetation cover

Since 2007, moss and lichen flora of the northern part of James Ross Island has been investigated. During field works, typical elements of vegetation were sampled, the collections of moss and lichen species were transported to the Masaryk University, Brno, Czech Republic, where determined.

In this paper, we describe only vegetation components from a seashore site (close to the Mendel Station), Berry Hill and Johnson Mesa, respectively. The sites of collections were photographed and the distribution of vegetation elements related to microrelief, availability of liquid water in particular, at the site of collection.

Results

Air temperature at 2 m above ground

A variation of daily mean air temperature and relative humidity at 2 m above ground at the Mendel Station and Johnson Mesa in the period from January 1, 2008 to February 28, 2009 is shown in Fig. 2. The mean temperature during the study period was –4.6°C (Mendel) and –5.8°C (Johnson Mesa). The warmest month was January 2009 with monthly temperature of 2.5°C (Mendel) and 0.1°C (Johnson Mesa), while the coldest one was July 2008 with temperature of –15.3°C and –11.1°C, respectively. The lowest air temperature of –35.5°C was observed at Mendel Station on July 9, 2008, while at Johnson Mesa dropped only to –19.0°C. The highest air temperature was recorded at both sites on January 25, 2008 and rose to 12.1°C (Mendel) and 12.5°C (Johnson Mesa). The large interdiurnal variability of air temperature was found from April to October at both sites. In these months, daily mean air temperature varied usually between –30°C and 5°C.

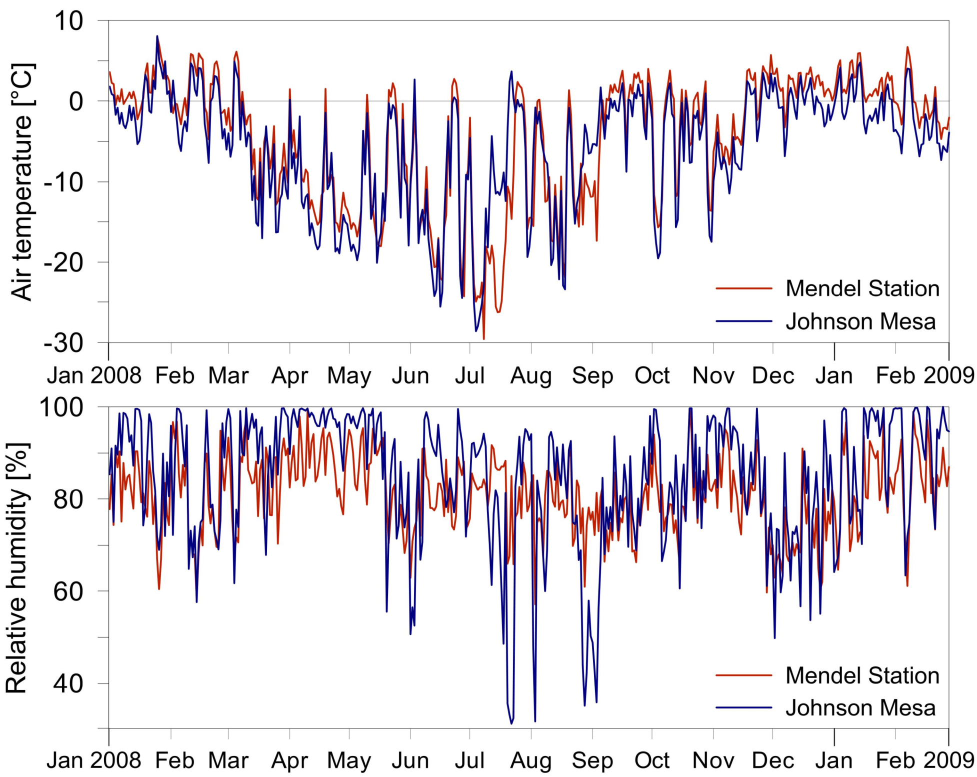

Fig. 2. Time series of daily mean air temperature and relative humidity at Mendel Station and Johnson Mesa at 2 m above the ground surface from January 2008 to February 2009.

Air humidity at 2 m above ground

In the study period, the mean relative air humidity was 81.0% (Mendel) and 84.4% (Johnson Mesa). The lowest monthly mean humidity was recorded in December 2008, being 71.2% (Mendel) and 74.7% (Johnson Mesa). Conversely, the highest monthly mean humidity was found in April 2008, being 88.1% and 97.0%, respectively. In comparison to the Mendel Station, the largest interdiurnal variability of relative humidity occurred at Johnson Mesa in winter (July–August) and mid summer (December) (Fig. 2).

Microclimate – air temperature at surface

In order to evaluate the differences in microclimate conditions at three study sites, monthly means and extreme values of surface air temperature and relative humidity were calculated for the period of September 2008–February 2009. As seen in Fig. 3, the surface air temperature rose gradually from September to January at all sites. Monthly mean temperatures strongly depended on the solar elevation angle, ranging from –11°C (September) to 6°C (January) at all sites. Therefore, the monthly mean maximum temperatures also reached up to 15.0°C (Mendel), 12.5°C (Berry Hill), and 10.9°C (Johnson Mesa) in December 2008. Variation in surface air temperature at the study sites depends on relief, snow cover occurrence and snow depth in each month. Hence, the highest temperature differences across the sites were observed in September and February depending on snow cover depth. Oppositely, the lowest differences up to 12.5°C were found in January (see Fig. 3).

Microclimate – air humidity at surface

Relative air humidity measured at a surface was strongly affected by the fact that the seashore plot differed from that located on the mesa plateaus. While relative humidity probe was placed over soil with moss thalli at the seashore plot, it was at the margin of a small depression formed by basaltic stones at the mesas. Generally, surface air humidity was 100% at all locations throughout winter and started to decrease below that value at the beginning of October for Berry Hill and Mendel Station, and beginning of September for Johnson Mesa (see Fig. 3). Relative humidity showed typical seasonal course reaching minimum values according to particular site. The lowest monthly mean humidity was recorded in December at Johnson Mesa, January at Berry Hill Mesa, and February at seashore plot. At a seashore plot, an absolute (single record) minimum was 35%, while it reached even 16% at Berry Hill Mesa.

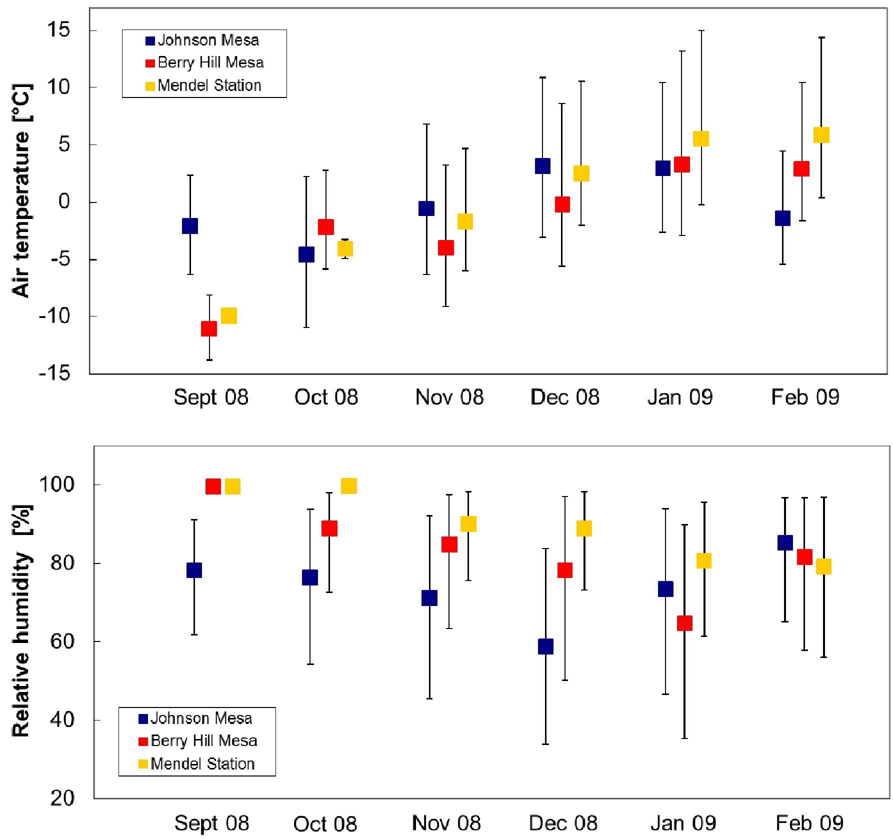

Fig. 3. Seasonal variation of monthly mean, monthly mean maximum and minimum surface air temperature and relative humidity at the three study sites from September 2008 to February 2009.

Vegetation of seashore areas

In this paper we characterize vegetation cover in the northern part of James Ross Island delimited by a seashore and the line connecting Cape Lachman – Berry Hill Mesa – Panorama Pass – Lachman Crags Mesa – Crame Col – Johnson Mesa – Bibby Point (see map, Fig. 1). The area is characterized by slightly ragged topography formed mainly by sedimentary rocks of Cretaceous formations bordered by volcanic mesas. Mosses and lichens are quite abundant at those places with sufficient water supply. Running streams and snowfields are the main sources of water available for the vegetation during summer. Apart from mosses and lichen, there is also rich algal and cyabacterial vegetation forming mats on the bottom of streams and close surroundings. Such habitats rich in water during summer might be considered seepages (Komárek et Elster 2008). They are located mainly in close neigbourhood of the lakes Big Lachman and Small Lachman, as well as close to three water streams and several sorted stripes (Øvstedal et Lewis Smith

2001) at the northern slopes of the Berry Hill Mesa (see Fig. 4). Lichen flora of the seepages is rich and dominated by *Xanthoria elegans* and *Leptogium* sp. Mosses are quite abundant. They are mainly *Bryum argenteum*, *Bryum* sp. and others, such as *e.g.* *Didymodon brachyphyllus*, *Encalypta rhaptocarpa, Hypnum revolutum* - METADATA, see References, weblink). Apart of those species that are quite abundant, some rare species with limited and distinct range in Antarctica are reported, such as *Drepanocladus longifolius* (Li et al. 2009). Biodiversity of cyanobacteria reaches high numbers. Komárek et Elster (2008) reported 9 coccoid and 21 types of cyanobacterial morphotypes in such habitat.

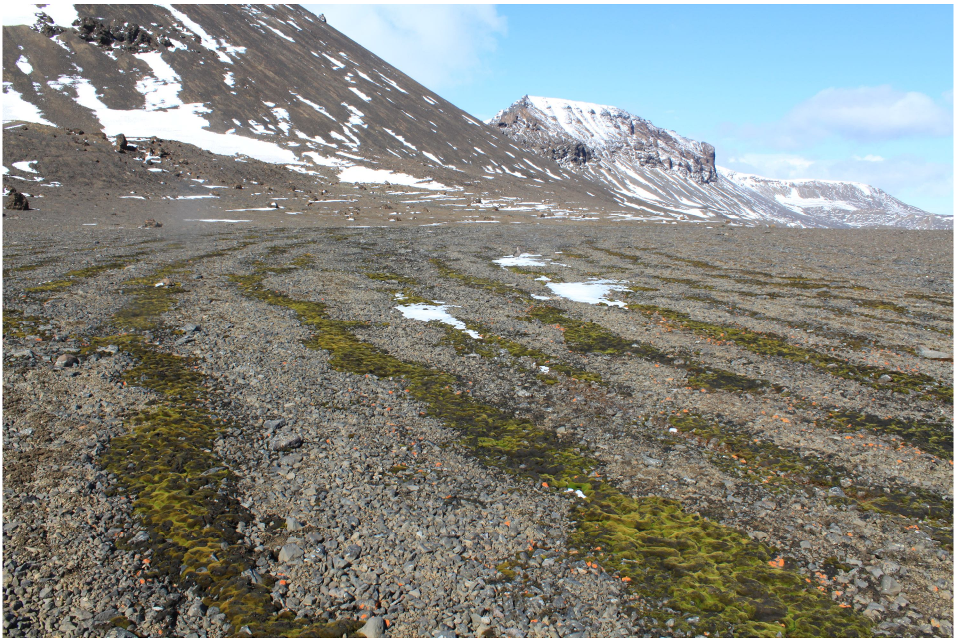

Fig. 4. Rich moss and lichen flora forms typical vegetated sorted stripes on slightly inclined areas close to a seashore where slow solifluction is possible – northern slopes below Berry Hill Mesa. Photo M. Barták

Volcanic mesas

Volcanic mesas represent prominent landforms of the northern deglaciated part of James Ross Island. Due to intensive frost weathering and thawing/freezing processes in the active layer of permafrost, the mesa surfaces are covered with stones, whose size is most frequently about 0.5 m, roughly arranged in sorted polygons. The dominant species of lichens are genera *Usnea* and *Umbilicaria*. According to our observations, the most frequent is *Usnea antarctica* and *Umbilicaria decussata*. They generally grow on the edges of sorted polygons developed on mesa surfaces. Typical locations of their oc-currence are upper surfaces of stones, but they are also abundant in shallow depression formed by polygons at the contact points of three/four neighbouring polygons. At marginal part of polygons, large gaps formed in between big stones may be found. The gaps form a sort of cavities, depth of which reaches 20–40 cm. Inside the cavities, due to less ventilation, microclimate is somewhat warmer and wetter than that of the boundary layer atmosphere. In the cavities, moreover, snow accumulation is advanced, *i.e.* the volume of the cavity is filled by snow preferentially. It means that in majority of cases, amount of snow inside and over the cavities is higher than of flat surface of mesa plateau. Therefore, more water is available in the cavities or shallow depressions than on the upper surfaces of stones. Thus, the vegetation inside cavities is dominated by moss species while stone surfaces by *U. antarctica* and *U. decussata.*

Organic matter-rich places

Nestlig sites of skua (*Catharacta maccormikii*) and Kelp Gull (*Larus dominicanus)* occur at seashore localities, however their number is not very high. In their neighbourhood, nitrophilous lichen species can be found, they form rather small-scale, randomly patterned spots than large-area lichen cover. Some other species that could be found only rarely on the island, *e.g. Rhizoplaca* sp. are also found mainly close to skua nestling sites. Nests of Southern Tern (*Sterna vittata*) are the most numerous on the northern part of James Ross Island (about 250-300) found in several colonies located in flat low-lying parts of deglaciated area (V. Pavel, K. Weidinger, personal communication). Moss and lichen flora in the neighborhood of nestling sites of Southern Tern, however, do not differ much from more distant sites.

The dead mumified bodies of pinnipeds (mainly crabeater seals – Nelson et al. 2008) can be found several hundreds of meters up to kilometers from a seashore in the interior deglaciated northern part of James Ross Island quite often. Their slowly decaying skin, skeleton and soft tissues of internal organs provide an ideal organic substrate, which is rapidly colonized mainly by lichens. Several lichen and moss species are found there, especially the lichen genera *Xanthoria* and *Caloplaca* are quite abundant forming yellow or orange layer over the skin. Moss species are found within the disintegrating soft body parts (oral cavity, rib cage interior) and in the neighbourhood of the skeleton (Fig. 5). In some cases, rich lichen flora can be found in the surrounding of seals bodies, especially where snow accumulations are formed next to the bodies. Such snow accumulation represent an important source of melting water which enables the vegetation around the seal bodies become more rich and/or abundant than in the areas without such a source of nutrients.

Fig. 5. Moss cushions growing in a neighbourhood of a dead seal in the areas rich in nutrients originating from the decaying body. Photo M. Barták

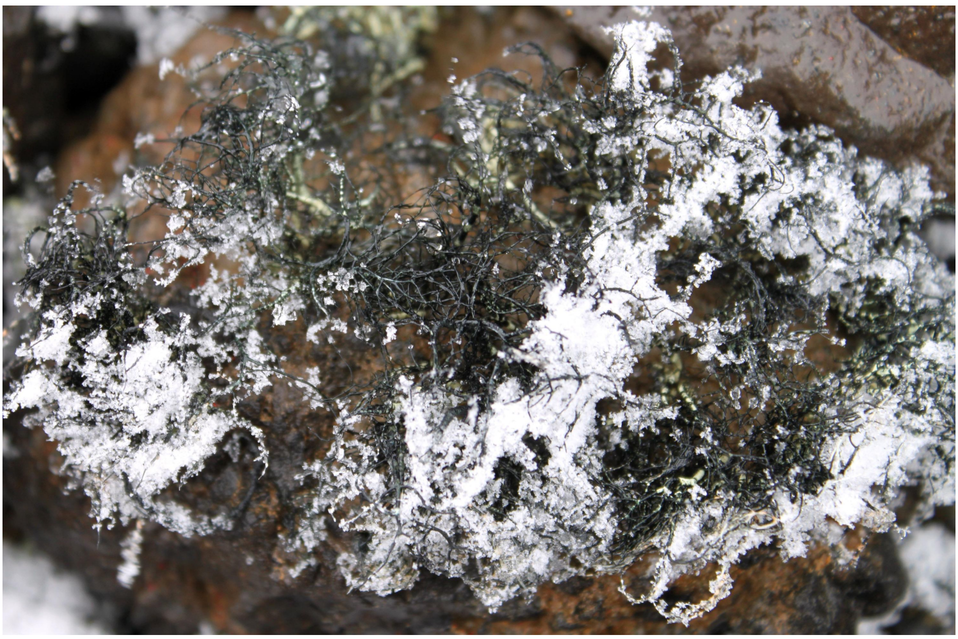

Fig. 6. Different ways of precipitation catchment and utilization by lichens at mesa plateaus: Brushing-out of snowfall by thalli of *Usnea* sp. Photo: M. Barták

Fig. 7. Different ways of precipitation catchment and utilization by lichens at mesa plateaus: Formation of ice crystals over the upper thalli parts of *Usnea* sp. when air humidity is close to 100% at freezing temperature. Photo: M. Barták

Fig. 8. Different ways of precipitation catchment and utilization by lichens at mesa plateaus: Formation of small-volume cavities (about 500 cm^3) below or within thin layer of frozen snow cover. In such cavities, a higher moisture is available. Photo: M. Barták

Fig. 9. Different ways of precipitation catchment and utilization by lichens at mesa plateaus: Exploitation of melt water from snow accumulations in shallow depressions formed at the margins of stone polygons at mesas, especially at the contact points of 3-4 neighbouring polygons. Thanks to a higher water availability in such places, moss and lichen vegetation becomes more rich. Photo: M. Barták

Discussion

In the study period, large seasonal and interdiurnal variations in 2-m air temperature, surface temperature and relative humidity were reported at all sites. As seen in Figs. 2 and 3, annual courses of 2-m air temperatures at Mendel Station and Johnson Mesa have similar features, which strongly depend on atmospheric circulation (advection of different air masses) and altitude of the study site. Therefore, mean temperature difference of 1.2°C was estimated between Mendel Station and Johnson Mesa, while negative thermal differences (–4.2°C in July 2008) can be found within several winter months due to the temperature inversion (Fig. 2).

In general, relative air humidity at 2 m above the ground surface was frequently higher at Johnson Mesa, due to the low cloud occurrence with a base height lower than 200 m (Fig. 2). On the other hand, surface air relative humidity between seashore and mesa sites differed significantly from 2-m relative humidity. The highest surface humidity was measured at seashore plot (Mendel Station) during winter and spring months, while the smallest moisture differences between all plots occurred in summer (Fig. 3). These results confirmed the essential role of local topography and surface microrelief, affecting occurrence and depth of snow cover at each plot.

Occurrence of moss and lichen species on seashore and mesa plateaus is mostly limited by availability of liquid water as shown previously for several Antarctic ecosystems (*e.g.* Melick et Seppelt 1997, Smykla et al. 2007). While at seashore plots, moss and lichen vegetation is predominantly distributed along seepages and streams supplied by melting water from neighbouring snowfields, the mesas vegetation (mostly lichens) depends on the uptake of water vapour from the air or melting water from snow accumulated in shallow depressions. Therefore, large moss cussions and carpets are developed only at a seashore, where liquid water is available for longer time during austral summer than at the volcanic mesa plateaus. There is, of course, interseasonal variability in water supply to such seashore localities. In January and February 2009, there was no snow accumulation at the permanent research plot in the neighbourhood of the Mendel Station resulting in drying out and no physiological activity of moss vegetation (fluorometric measurements, M. Barták, P. Váczi, unpublished data). Contrastingly, the same plot was supplied with such a high quantity of melting water in 2010, that the moss vegetation at the plot was saturated for several weeks. This resulted in full water saturation of moss cussion and, in stagnant water over moss carpet for few consecutive days (M. Barták, P. Váczi, unpublished data).

At the mesas, lichen flora is much more abundant than moss species. The lichens, benefiting from the fact, that they are able to obtain water from water vapour, colonize the upper surfaces of the stones (mainly *Umbilicaria decussata*), as well as the margins of polygonal structures (see Figs. 6, 7, 8). Occurrence of moss species remains limited to shallow depressions and/or small cavities in which melted water accumulates (see Fig. 9). There are two facts supporting the idea of water-limited occurrence: (1) cloud base height is frequently lower than 200 m, therefore the lichens covering stones surfaces may benefit from higher air humidity throughout the summer season (see Fig. 2), (2) snow cover depth over flat surface of mesas is smaller in comparison to coastal ragged locations. Therefore, availability of melted water is smaller at the beginning of summer at the mesas than on seashore plots. Consequently, moss species distribution on mesas is restricted to the depressions and cavities, where they benefit from melted water.

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