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Diversity, ecology and biogeography of diatoms (Bacillariophyta) from James Ross Island (Antarctica) and Gough Island (southern Atlantic ocean)

Diverzita, ekologie a biogeografie rozsivek (Bacillariophyta)
ostrova James Ross (Antarktida)
a ostrova Gough (jižní Atlantský oceán)

DIPLOMOVÁ PRÁCE

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ABSTRACT

Recently, there has been a growing interest in polar biology related to efforts towards understanding the consequences of climate change on terrestrial and limnetic biota. Due to species specific strong relationship to physico-chemical parameters diatoms (Bacillariophyta) represent an excellent tool for studying the impact of environmental changes in polar regions.

The aim of M.Sc. thesis is to present results concerning diatom taxonomy, ecology and biogeography in Antarctic (James Ross Island) and sub-Antarctic (Gough Island) regions. Furthermore, the description of new species confirmed the highly specific character of Antarctic diatom flora. This thesis is divided into four parts.

The first part (Chapter 1) contains results of primary research on the structure of diatom communities in seepages and streams on James Ross Island (Antartica). Studied habitats were compared regarding both diatom flora and basic physico-chemical characteristics.

The second part (Chapter 2) includes the description of three new non-marine pennate diatom species (*Diadesmis inconspicua* Kopalová & Van de Vijver, *Eolimna jamesrossensis* Kopalová & Van de Vijver and *Luticola truncata* Kopalová & Van de Vijver), which were found in seepages in the vicinity of the Czech Antarctic Station "J.G.Mendel" on James Ross Island (Antarctica).

The third part (Chapter 3) presents the diatom flora in the inland streams, seepages and lakes of McMurdo Dry Valleys and James Ross Island (Antarctica). *Luticola austroatlantica* Van de Vijver et al., *L. dolia* Spaulding & Esposito, *L. laeta* Spaulding & Esposito and *Muelleria supra* Spaulding & Esposito are described as new species. A unique composition of diatom communities with high proportion of species with limited distribution is demonstrated.

The final chapter, (Chapter 4) describes a new aerophilic *Orthoseira* species, *Orthoseira gremmenii* Van de Vijver & Kopalová from bryophyte mats on Gough Island, located in the southern Atlantic Ocean.

ABSTRAKT

V současné době vzrůstá zájem o polární biologii, jejíž studium je úzce spjaté se snahami porozumět vlivu globálních klimatických změn na suchozemské i vodní organismy. Rozsivky (Bacillariophyta) jsou druhově početnou skupinou řas, jejíž jednotlivé druhy velmi specificky reagují na různé podmínky prostředí. Proto představují velmi vhodný nástroj ke studiu dopadu změn životního prostředí na polární oblasti.

Cílem této diplomové práce je představit výsledky zahrnující taxonomii, ekologii a biogeografii rozsivek v antarktických (ostrov Jamese Rosse) a subantarktických (ostrov Gough) regionech. Popis několika nových druhů potvrzuje vysoce specifický charakter antarktické rozsivkové flory. Tato práce je rozdělena na čtyři části:

První kapitola shrnuje výsledky výzkumu struktury společenstev rozsivek z mokřadů a potoků na ostrově Jamese Rosse (Antarktida). Oba studované ekosystémy byly porovnány jak z hlediska rozsivkové flory, tak i základních fyzikálních a chemických parametrů prostředí.

Druhá kapitola obsahuje popisy tří sladkovodních penátních druhů rozsivek (*Diadesmis inconspicua* Kopalová & Van de Vijver, *Eolimna jamesrossensis* Kopalová & Van de Vijver and *Luticola truncata* Kopalová & Van de Vijver), které byly nalezeny v mokřadech v blízkosti české antarktické stanice J. G. Mendela na ostrově Jamese Rosse (Antarktida).

Třetí kapitola představuje rozsivkovou floru potoků, mokřadů a jezer z McMurdo Dry Valleys a ostrova Jamese Rosse (Antarktida). *Luticola austroatlantica* Van de Vijver et al., *L. dolia* Spaulding & Esposito, *L. laeta* Spaulding & Esposito a *Muelleria supra* Spaulding & Esposito jsou popsány jako druhy nové. Zároveň je v této kapitole představeno unikátní složení společenstev rozsivek zahrnující velkou část druhů s omezeným rozšířením.

Poslední čtvrtá kapitola prezentuje nový aerofilní druh rodu *Orthoseira -O. gremmenii* Van de Vijver & Kopalová, popsaný z mechových nárostů na ostrově Gough, který se nachází v Jižním oceánu.

CONTENTS

INTRODUCTION

Diatoms (Bacillariophyta) are one of the most important groups of algae. They inhabit aquatic as well as terrestrial habitats together with marine plankton and represent main component of these ecosystems together with Eubacteria, Archaebacteria, eukaryotes and eukaryotic protists (Feller & Gerday 2003). Their cells are encased within a unique silicate cell wall comprising two separate valves and creating a withstanding outer shell.Diatoms are useful bioindicators and therefore, their frustules can be used as a memory of environmental changes, which is often used in palaeoecology (Hausmann & Pienitz 2007).

Several habitats frequently colonised by microorganisms (including diatoms) with adaptations to cold environments are recognized, such as those in polar regions. More than 70 % of the Earth ecosystem is based on cold ecosystems (Morgan-Kiss et al. 2006), which could be threatened by a climate change (Rouse et al. 1997). Due to this fact, there is recently a growing interest in research of polar ecosystems, including diatom communities (Van de Vijver et al.2001, 2002; Van de Vijver & Gremmen 2006; Van de Vijver & Kopalová 2008).

The Czech Antarctic station "J.G. Mendel" was built in the deglaciated part of James Ross Island (NW, Weddell Sea, Antarctica). Since the austral summer of 2004, primary research on cyanobacterial and algal microflora has been started there (Komárek & Elster 2008, Komárek et al. 2008). The study of diatom communities in streams, seepages and lakes in the surroundings of "J.G. Mendel station" represents one part of this research. Further, M.Sc. thesis explores in detail the structure of diatom communities and presents several new local diatom species.

To provide a comparison with the diatom flora of sub-Antarctic polar region, more than 500 samples from various terrestrial and semi-aquatic habitats from Gough Island (southern Atlantic Ocean) were collected during several field campaigns in 1999–2006. Gough Island (40°21' S, 9°53' W) is a small, uninhabited volcanic island, which is a component of Tristan da Cuhna archipelago. Due to its isolated position, volcanic origin and oceanic character, it is occupied by a large number of endemic taxa. The only survey on the non-marine diatom flora of Gough Island and Tristan da Cunha were done by John Carter in 1965 (Carter, 1966).

The aim of this thesis was to study taxonomy, ecology and biogeography of diatom communities in selected freshwater and aerophytic habitats on James Ross Island and Gough Island. The results form a part of the general survey of the Antarctic and (sub-)Antarctic diatoms.

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CHAPTER 1

Kopalová, K., Elster, J., Nedbalová, L. & Van de Vijver, B. Diatom communities in seepages and streams on the James Ross Island (NW Weddell Sea, Antarctica)

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DIATOM COMMUNITIES IN SEEPAGES AND STREAMS ON JAMES ROSS ISLAND (NW WEDDELL SEA, ANTARCTICA)

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(first draft)

Abstract

A total of 22 samples of diatom communities from seepages and streams collected during the austral summers of 2004 and 2007 in the deglaciated northern part of James Ross Island (NW Weddell Sea, Antarctica) were investigated. Altogether, 57 diatom taxa belonging to 17 generas were observed. The specificity and characteristic composition of diatom communities were demonstrated using correspondence analysis (CA), which separated samples from streams and seepages into distinct groups. The difference was obvious for example on the prevalent occurrence of *Fragilaria capucina* var. *rumpens* (Kützing) Lange-Bertalot in streams and *Eolimna jamesrossensis* Kopalová et al. in seepage areas. Basic physico-chemical characteristics of both habitats were compared, and a year-round measurement in seepages showed high temperature fluctuations. The results are compared and discussed with regard to recent data on the biogeography of diatoms in Antarctic region.

Introduction

Diatoms (Bacillariophyceae) are one of the most abundant algal group. Due to their characteristic silica outer shell and significant relationships with physical and chemical limnological variables, they are considered to be very good bio-indicators in both applied environmental and paleoecological studies (e.g., Soininen 2007, Verleyen et al. 2009). The monitoring of diatom communities should therefore represent one of the main methods for studying polar ecology and biodiversity. The ongoing climate and environmental change is supposed to have a big impact on organisms worldwide. Antarctic diatoms provide an excellent tool for detecting these changes, since their communities are very simple, species-poor and sensitive (Battarbee 2000, Passy 2007). In the past few years, there is growing interest in polar Antarctic and sub-Antarctic non-marine diatom flora. In contrast to previous studies based on force-fitting and misapplication of non-appropriate taxonomic keys, a high degree of endemism has been clearly demonstrated recently in Antarctic diatom communities (e.g., Van de Vijver et al. 2002, Sabbe et al. 2003, Fermani et al. 2007, Van de Vijver 2007).

In 2006, the first Czech Antarctic research station was completed on James Ross Island, which is situated in the north-western part of the Weddell Sea, close to the northern tip of the Antarctic Peninsula. Geologically, the northern part of James Ross Island in the area of the Czech polar station, demarcated by the Cape Lachman-Crame Col and Bibby Point is made up of a large coastal depression formed by Cretaceous sediments in the James Ross Basin rimmed with basaltic effusions of a central stratovolcano, Mt. Haddington. Cretaceous sediments of Santa Marta, Whisky Bay and Hidden Lake Formations consist mostly of siltstones, sandstones and conglomerates. Cretaceous sediments are locally covered by Tertiary and Quaternary glacial sediments (Nývlt & Mixa 2003). Geobotanically, James Ross Island belongs to a transitory zone between maritime and continental Antarctica (Øvstedal & Lewis-Smith 2001). The northernmost part of the island covering approximately 100 km^2 (Ulu Peninsula) is deglaciated. The terrestrial vegetation is only poorly developed, and seepages represent the most productive habitat (Komárek & Elster 2008).

In maritime Antarctica, communities with special species composition and structure in the form of mats develop in seepages (Komárek & Komárek 2003), and two types of seepages (moss and cyanobacterial) frequently occur in broader surroundings of the J. G. Mendel station on James Ross Island (Komárek & Elster 2008). Streams are widespread in Antarctica, flowing for a few weeks or months each year, depending on local climate. In typical cases, their flora is dominated by microbial assemblages, based either on annual, quick growing chlorophytes (Hawes 1989), or perennial blue-green algal (cyanobacterial) mats (Howard-Williams et al. 1986).

The study of non-marine diatoms in the northern part of James Ross Island was started during the field reconnaissance of this area in austral summer 2004. Until recently, the work on diatom flora of this island included only four papers, which were mainly focused on diatom composition in sediment cores, and suggested a cosmopolitan character of the flora (Hansson & Håkansson 1992, Burckle & Wasell 1995, Håkansson, Olsson & Björck 1995, Björck et al. 1996).

The current research already yielded the description of four new pennate diatom species from seepage areas, belonging to the genera *Diadesmis*, *Eolimna* and *Luticola* (Esposito et al. 2008, Kopalová et al. 2009. However, no detailed data on taxonomic structure of diatom communities in freshwater habitats have been available so far. In this study we present the first comparison of diatom flora in seepages and streams on James Ross Island.

Material and methods

The samples used in this study were obtained from James Ross Island (64°10'S, 57°45'W). Collecting of samples was done during austral summers of 2004, 2006 and 2007. A total of 22 samples included eight samples from streams and fourteen samples from seepage areas. In 2004, seepages on the northern slope of Berry Hill and moss seepages in polygon soils near Panorama pass were sampled. In 2006, six samples from Tern Creek were collected along its profile. Tern Creek was sampled again in 2007, together with Algal Creek; moreover ten samples were collected from different microhabitats in seepages below Berry Hill. An overview of sampling details is shown in Table 1.

Diatom samples collected in 2004 were kept frozen until analysis, whereas those from 2006 and 2007 were fixed with formaldehyde (3% final concentration). Diatom slides were prepared following the method of Van der Werff (1955). Small portions of samples were cleaned by adding 37% H_2O_2 and heated to 80 °C for about 1 h. The reaction was completed by dropwise addition of $KMnO_4$ till reaction was finished. Following digestion and centrifugation, the cleaned material was diluted with distilled water to avoid excessive concentrations of diatom valves that may hinder reliable observations. Cleaned diatom valves were mounted in Naphrax®. Light microscopy observation was conducted using a Nikon ECLIPSE E400 microscope equipped with Differential Interference Contrast Nomarski optics. At least 300 cells were counted in each sample. For scanning electron microscopy (SEM) we used JEOL-5800LV (National Botanic Garden of Belgium) and JEOL 6380 LV (Charles University in Prague, Faculty of Science). The stubs were sputter-coated with 50 nm of gold and studied at 20 kV to ensure correct taxonomic identification

The data analysis of relative abundances of diatom species was processed using CANOCO and Cano Draw software (ter Braak & Šmilauer, 1998, 2002). Species data were ln-transformed in order to down-weight dominant taxa. We used correspondence analysis (CA) to determine correlations among species occurrences in both habitats studied. Acronyms of diatom taxas were derived according to Lenoir & Coste (1996) or generated *ad hoc*, and are listed in Appendix 1 together with classes of relative abundances according to Kelly (2000).

Basic ecological parameters (pH, conductivity) were measured using WTW probes in 2004 and 2006 to characterise the seepage habitat below Berry Hill (samples SP2, SP3) and Tern Creek. For nutrient and chloride analysis, water samples were kept frozen (pre-filtered through 0.45μm filters in the laboratory in the case of analyses of dissolved forms). The analysis of each parameter was done using FIA and followed the methods as described in Grasshof (1983).

During austral summer 2006 (27.1.2006–18.1.2007), temperature was monitored in hourly intervals in seepages below Berry Hill using two dataloggers (Minikin T, EMS Brno, Czech

Republic). Both dataloggers were equipped with two sensors, measured values were finally averaged.

Results

A total of 57 diatom taxa (including species, varieties and forms) belonging to 17 genera has been identified in 22 samples. 46 taxa, which were recorded during semi-quantitative estimation, have been used in successive analysis. A list of observed diatom taxa with classes of their relative abundances according to Kelly (2000) is shown in Appendix 1. The most frequent species were *Nitzchia gracilis* Hantzsch (19% of all counted valves), *Fragliaria capucina* var. *rumpens* (Kűtzing) Lange-Bertalot (13%), *Eolimna jamesrossensis* Kopalová et al. (11%), *Luticola muticopsis* (Van Heurck) Mann (7%). *Luticola* was the most abundant and species-rich genus (10 species and 10% of all counted valves). Only a small part of valves belonged to the genera such as *Navicula* and *Muelleria*. The genera *Diadesmis*, *Eolimna*, *Hantzschia*, *Sauroneis* and *Nitzschia* dominated in seepages in contrast to the genus *Fragilaria*, which was represented only in stream samples. The genera *Luticola* was common in both habitats.

The highest number of species was recorded in the following samples collected in seepages: SP2 (27), sample 8 (21) and sample 15 (17). Stream samples were characterised by 12 genera. The highest number of taxa from stream habitat was observed in sample T8 (18 species). The lowest richness of species has been observed in the sample T4 (4 species). Overall, seepages represented more diverse habitat in comparison with streams. The correspondence analysis (CA) explored the relationships between diatom community composition and the type of habitat (Fig. 1). The ordination diagram shows only 16 taxa with best relationship to canonical axes. The analysis clearly separated both habitats according to their species composition. The first group contained all samples collected in seepages, whereas the second group included most stream samples. Sample 16 from Algal Creek was separated from both groups as a result of its different species composition. Species observed in seepages group were mainly *Diadesmis arcuata* (Heiden) Lange-Bertalot, *Eolimna jamesrossensis* Kopalová et al., *Hantzschia amphioxys* (Ehrenberg) Grunow, *Hantzschia abundans* Lange-Bertalot, *Luticola muticopsis* (Van Heurck) Mann, *Mayamaea atomus* var. *permitis* (Hustedt) Lange-Bertalot, *Nitzchia gracilis* Hantzsch, *Nitzschia homburgiensis* Lange-Bertalot, *Stauroneis latistauros* Van de Vijver & Lange-Bertalot. Following taxa was also rarely observed: *Luticola caubergsii* Van de Vijver, *Melosira varians* Agardh, *Muelleria regigeorgiensis* Van de Vijver & Spaulding manuscriptname, *Muelleria* *varipunctata* Spauling & J.P. Kociolek, Nitzschia acidoclinata Lange-Bertalot, *Nitzschia agnita* Hustedt, *Nitzschia palea* var. *debilis* (Kützing) Grunow, *Pinnularia australorabenhorstii* Van de Vijver, *Pinnularia divergens* var. *media* Krammer, *Pinnularia intermedia* (Lagerstedt) Cleve, *Pinnularia rabenhorstii* (Grunow) Krammer (not included in Appendix).

The year-round temperature measurement in seepages below Berry Hill in 2006–2007 showed high seasonal and daily fluctuations, which are characteristic for this habitat (Fig. 2). In austral summer, temperature rarely dropped below 0°C and varied mostly between 0°C and 20°C. The maximum temperature was recorded on 7th December 2006 (24.5°C). In winter, temperature was permanently below freezing point; the lowest temperature (–25,5°C) was measured on 24th August 2006. Basic physico-chemical characteristics of seepages below Berry Hill in 2004 and Tern Creek in 2006 are compared in Table 2.

Discussion

The construction of the Czech scientific station "J.G. Mendel" was completed in the Antarctic summer season (March 2006) on the northern coast of James Ross Island. Several biological, climatological and namely geological studies have been previously conducted in the deglaciated area of the island (e.g. Björck et al. 1996). However, detailed taxonomical and ecological research on cyanobacterial and algal microflora was started recently in the vicinity of the station (Komárek & Elster 2008, Komárek et al. 2008). Although many papers have dealt with diatom diversity in different localities in the Antarctic region (e.g., Van de Vijver & Beyens 1997, Sabbe et al. 2003, Cremer et al. 2004), the diatom flora from James Ross Island is still poorly known. Seepages frequently occur in broader surroundings of the station, and are frequently dominated by characteristic cyanobacterial assemblages, which form structured mats with specific morphotypes from the genera *Leptolyngbya*, *Geitlerinema* and *Phormidium*, Streams on James Ross Island are the result of melting of glaciers, snow fields and ice corns in moraine deposits. Their microflora is formed mainly by diatoms, filamentous cyanobacteria and green algae (*Klebsormidium*) (Komárek & Elster 2008). This study provided first results, which characterized in detail diatom communities in seepages and streams.

Similarly to cyanobacterial flora (Komárek et al. 2008), there was higher richness of diatom species in seepages when compared to streams. Although diatoms represent an important component of microflora in seepages of James Ross Island, diatom research has never been done there before. As far as streams are concerned, there is only one paper by Hawes & Brazier (1991) which considered mainly chemical and physical analysis of stream water but without emphasis on diatom composition. The species richness of diatom flora in Tern and Algal Creek is comparable with streams in Taylor valley (McMurdo Dry Valleys region, continental Antarctica) (Spaulding et al. 2009, Broady 1982). However, species composition in the two regions is different: some species abundant in James Ross island streams were not recorded in Taylor valley (e.g., *Fragilaria capucina* (Kűtzing) Lange-Bertalot, *Nitzschia gracilis* Hantzch, *Nitzschia homburgensis* Lange-Bertalot, *Nitzschia perminuta* (Grunow) Peragallo). On the contrary, we did not found *Nitzschia westii* West and West, which is common in both Taylor valley streams (Spaulding et al. 2009). These differences further indicate specific character of diatom flora in continental and maritime Antarctica with high degree of endemism, which was already suggested in previous studies (Sabbe et al. 2003, Esposito et al. 2008, Van de Vijver & Mataloni 2008). On the other hand, species diversity of the non-marine diatom flora in this study is not very high, when compared to sub-Antarctic islands, for example Iles Kerguelen (Van de Vijver et al. 2001). Many diatom species identified on Iles Kerguelen have never been found in our study. The number of taxa recorded during this survey (57) roughly corresponds to the richness of diatom flora on Livingston Island (South Shetland Archipelago, maritime Antarctica) (Van de Vijver & Beyens 1997). The most frequent *Luticola* taxa in James Ross Island, confirm the opinion of diatom communities in high productivity habitats.

Glacial streams were shown to have a poor algal flora in comparison with seepages, which can be the result of higher disturbance rates in this habitat. The turbidity is one of the main factors that affect the abundance and distribution of microflora in Antarctic streams (Hawes & Brazier 1991). Diatom communities in streams contained many aerophylic diatoms (e.g. *Hantzschia amphioxys* (Ehrenberg) Grunow, *Achnanthes coarctata* (Brébisson) Grunow, *Luticola cohni* (Hilse) Mann). These species are able to survive in both aquatic and terrestrial habitats. Aerophilic diatoms in streams were also found on Livingston Island (Zidarova 2007).

As far as biogeographical aspects are concerned, cosmopolitan species were present in seepages and streams of James Ross Island (*Hantzschia abundans* Lange-Bertalot, *Hantzschia amphioxys* (Ehrenberg) Grunow, *Luticola muticopsis* (Van Heurck) Mann, *Mayamaea atomus* (Kűtzing) Lange-Bertalot, *Navicula cincta* (Ehrenberg) Ralfs), but species characterized by a limited distribution were very important (e.g., *Luticola cohnii*, which is characteristic for continental Antarctica). This is in agreement with recent studies emphasising the high degree of endemism in Antarctic diatom flora (Van de Vijver et al. 2002, 2004, Fermani et al. 2007, Esposito et al. 2008). Moreover, some relatively abundant species in seepages of James Ross Island were previously identified as new to science (*Diadesmis inconspicua* Kopalová & Van de Vijver, *Eolimna jamesrossensis* Kopalová & Van de Vijver, *Luticola truncata* Kopalová & Van de Vijver) (Kopalová et al. 2009). The fourth newly described species, *Luticola austroatlantica* Van de Vijver et al., was also found in McMurdo Dry Valleys (Esposito et al.2008).

There is a hypothesis that taxonomic turnover increases with geographic distance (Verleyen et al. 2009). In addition, diatoms commonly show good relationships with chemical and physical variables, and represent thus good markers for environmental and paleo-ecological studies (Battarbee 2000, Passy 2007). In the past few years, detailed morphological investigations revealed a specific Antarctic diatom flora in many regions, e.g. South Georgia Island (Van de Vijver & Beyens 1996), King George Island (Schmidt et al. 1990, Heard Island (Van de Vijver et al. 2004, Van de Vijver et al. 2004), Marion Island (Van de Vijver & Gremmen 2006), Ile de la Possession (Van de Vijver & Beyens 1999, Van de Vijver & Beyens 2002, Van de Vijver et al. 2002,), Komárek & Komárek 2003), Iles Kerguelen (Van de Vijver et al. 1998, Van de Vijver et al. 2001, Cohu & Van de Vijver 2002, Gremmen et al. 2007) and continental Antarctica (Sabbe et al. 2003, Esposito et al. 2008).

The field research suggested that seepages represent a typical habitat of coastal polar region, characterized by relatively high productivity. The dominant components of polar wetlands are prokaryotic cyanobacteria and a wide spectrum of eukaryotic algae (Elster 2002). Generally, all species must be tolerant to high fluctuations of environmental conditions both during year and day. Streams on James Ross Island are usually characterized by a system of small and shallow furrows and seepages as shallow wetlands with the presence of liquid water during short austral summer. However, namely at the beginning and towards the end of the summer, water can freeze both in seepages and streams (Komárek & Elster 2008). The most stressful factors are desiccation-rehydratation and freeze-thaw cycles. These processes were tested in laboratory on cyanobacterial and algal strains collected in maritime and continental Antarctica (Šabacká & Elster 2006). Cyanobacteria from seepage habitats were shown to be less tolerant to freezing and desiccation than strains from other wetlands. Cyanobacteria from continental Antarctica were more tolerant to low sub-zero temperature in comparison with similar strains from maritime Antarctica which indicates adaptation to harsh conditions. Diatom strains were not included in this study, but they must be tolerant to freezing since they represent important component of microflora in Antarctic streams and seepages (Elster 2002, Zidarova 2007). In both habitats, temperature, nutrients and level of humidity fluctuate depending on local physical conditions and snow and ice cover in the winter time (Hawes & Brazier, 1991). However, the adaptation mechanisms in Antarctic diatoms are still poorly known, In future studies, it will be necessary to focus on seasonal colonisation strategy and dynamics of algal vegetation in seepages and streams.

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Table 1. List of sampling sites, together with their basic characteristics and GPS coordinates (where available).

Code	Date	Alt. m a.s.l.	GPS	Characteristics
B3	21.2.2004	231	S 63°48.848' W 57°50.007'	moss seepages in polygon soils
B4	21.2.2004	194	S 63°48.962' W 57°50.237'	snow brook similar to seepages
SP2	20.2.2004	56	S 63°48.200' W 57°50.772'	second seepage below Berry Hill
SP3	20.2.2004	52	S 63°48.173' W 57°50.592'	third seepage below Berry Hill
3	22.2.2007	~50	S 63°48.183' W 57°50.980'	first seepage below Berry Hill, grey-brown mat on stones
4	22.2.2007			first seepage below Berry Hill, black-grey mat on sand
5	22.2.2007			first seepage below Berry Hill, black mat
6	22.2.2007			first seepage below Berry Hill,brown-red mat
8	22.2.2007			first seepage below Berry Hill, green mat on stones
9	22.2.2007			first seepage below Berry Hill, *Klebsormidium*
10	22.2.2007			first seepage below Berry Hill, brown mat
13	22.2.2007			first seepage below Berry Hill, black mat
14	22.2.2007			first seepage below Berry Hill, brown mat on stones
15	22.2.2007			first seepage below Berry Hill, black mat
16	22.2.2007			Algal Creek, brown mat
17	22.2.2007			Tern Creek, red mat
T1	3.2.2006	~20	S 63°49.134' W 57°48.567'	Tern Creek, red and black mat, 20–40 m from estuary
T2	3.2.2006			Tern Creek, red and black mat, *Prasiola*, 200 m from estuary
T4	3.2.2006	27	S 63°49.225' W 57°48.981'	Tern Creek, red and black mat, green algae, 0.5 km from estuary
T6	3.2.2006	114	S 63°49.075' W 57°49.716'	Tern Creek, edge of a snowfield, 1200 m from estuary
T7	3.2.2006	184	S 63°48.984' W 57°50.149'	Tern Creek, red and brown mat, green algae, 1.6 km from estuary
T8	3.2.2006			Tern Creek, red mat, *Nostoc*, *Zygnema*, 1.8 km from estuary

Table 2. Basic physico-chemical characteristics of seepages below Berry Hill and Tern Creek. For site codes, see Tab. 1, codes Ta-Te represent samples from Tern Creek collected along its profile from estuary to source area on 10th February 2006.

Sample	pH	Cond. ($\mu S.cm^{-1}$)	Cl^- ($mg.l^{-1}$)	NH_4-N ($\mu g.l^{-1}$)	NO_2-N ($\mu g.l^{-1}$)	NO_3-N ($\mu g.l^{-1}$)	PO_4-P ($\mu g.l^{-1}$)	TN ($\mu g.l^{-1}$)	TP ($\mu g.l^{-1}$)	DW ($mg.l^{-1}$)
SP2	7.30	29	2.4	7.1	0	6.1	28.3	144.0	53.4	15.5
SP3	6.79	33	4.5	34.8	0	14.4	<10	291.5	50.8	6.2
Ta	9.25	256	33.7	9.2	0.9	4.3	16.2	171.3	38.6	7.4
Tb	9.17	256	33.6	13.4	0.5	5.5	22.2	134.2	38.5	3.6
Tc	9.22	182	29.4	9.2	1.0	119.4	21.8	275.2	35.0	9.7
Td	8.9	92	18.8	13.4	1.3	57.4	16.2	224.8	42.4	2.8
Te	8.25	36	5.3	13.4	1.0	35.8	24.3	154.3	42.7	37.8

Explanations: Cond. – conductivity; Cl^- –chlorides; NH_4–N ammonium nitrogen; NO_2–N nitrite nitrogen; NO_3–N – nitrate nitrogen; PO_4–P – phosphate phosphorus; TN; – total nitrogen; TP – total phosphorus; DW – dry weight.

Figure 1

CA ordination diagram based on species data. The samples are clearly separated according to the habitat type (streams – black circles, seepages – grey circles). Only 16 diatom taxa with best relationship to canonical axes are displayed. The first two axes explained 38.5% of variability. For sample codes, see Table 1, taxa codes in Appendix 1.

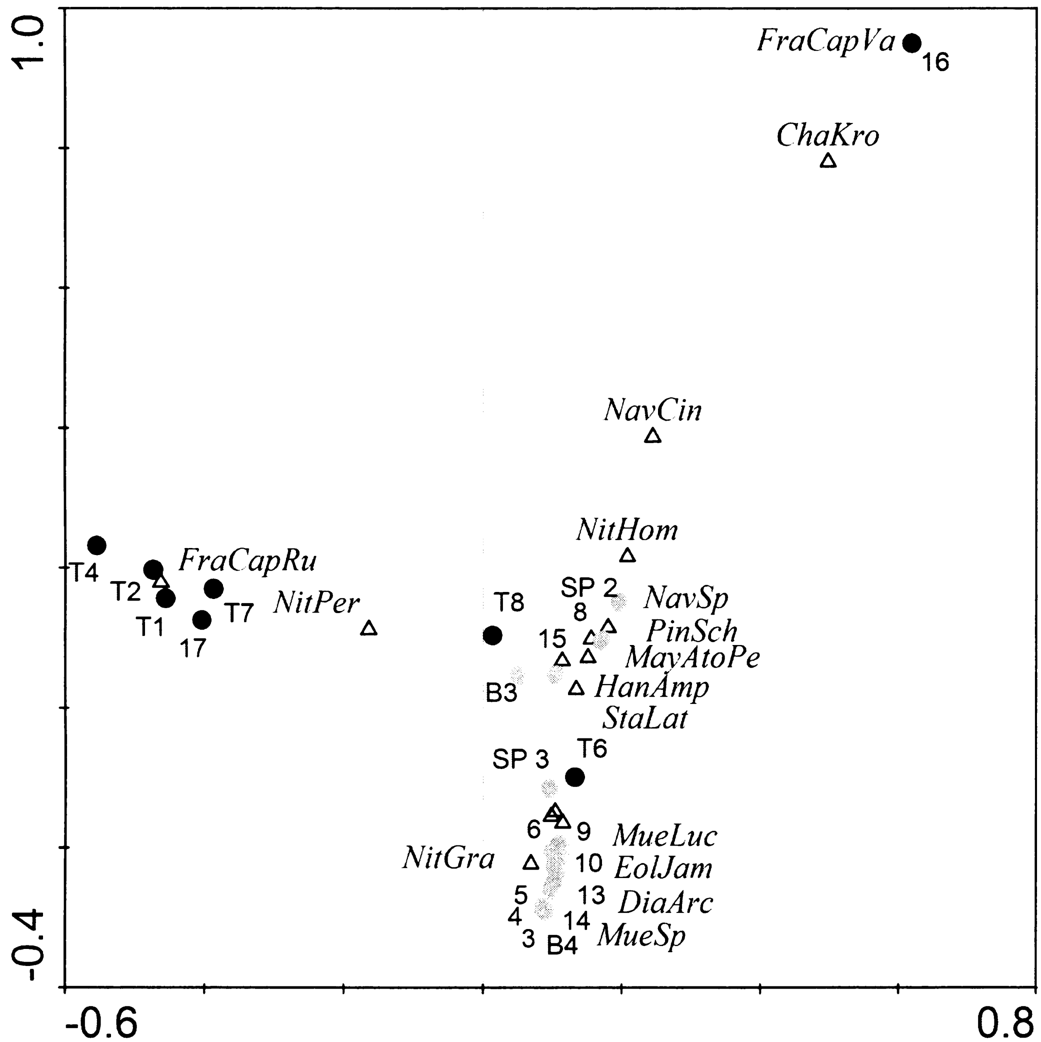
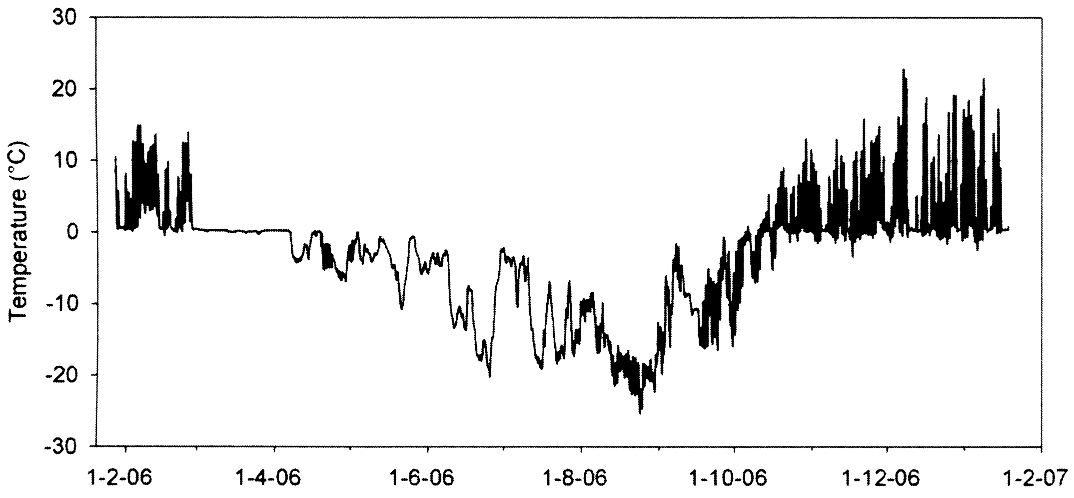


Figure 2

Annual change of temperature in seepages (northern slopes below Berry Hill) in 2006–2007.



APPENDIX 1. List of diatom taxa from seepages and streams on James Ross Island and their relative abundances.

SPECIES	ACRONYM	B3	B4	SP2	SP3	3	4	5	6	8	9	10	13	14	15	16	17	T1	T2	T4	T6	T7	T8
Achnanthes coarctata (Brébisson) Grunow	*AchCoa*	1	–	–	2	–	–	–	–	1	–	–	–	–	2	–	–	–	–	–	–	–	–
Achnanthes muelleri Carlson	*AchMue*	2	–	–	–	–	–	–	–	1	–	1	1	–	–	–	–	–	–	1	–	–	–
Achnanthes taylorensis Kellogg et al.	*AchTay*	2	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Brachysira minor (Krasske) Lange-Bertalot	*BraMin*	–	–	2	–	1	–	–	1	1	–	1	–	–	–	–	1	–	–	–	–	1	1
Chamaepinnularia krookiiformis (Krammer) Lange-Bertalot & Krammer	*ChaKro*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	1
Chamaepinnularia sp.	*ChaSP.*	–	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diadesmis arcuata (Heiden) Lange-Bertalot	*DiaArc*	–	2	2	–	2	1	4	4	1	1	–	2	1	–	1	–	–	–	–	–	–	2
Diadesmis comperei Le Cohu & Van de Vijver	*DiaCom*	–	–	3	–	–	–	–	–	4	2	–	–	1	–	–	–	–	–	–	–	–	–
Diadesmis inconspicua Kopalová et al.	*DiaInc*	2	2	–	–	–	–	–	1	–	–	1	–	–	2	–	–	–	–	–	1	–	–
Diadesmis ingeae Van de Vijver	*DiaIng*	1	–	3	–	–	1	1	2	–	–	–	–	–	–	–	–	–	–	–	1	–	1
Diadesmis sp.	*DiaSP.*	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Eolimna jamesrossensis Kopalová et al.	*EolJam*	–	–	–	4	4	2	4	4	1	–	4	4	4	–	4	5	–	–	–	5	3	2
Fragliaria capucina var. *rumpens* (Kützing) Lange-Bertalot	*FraCapRum*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	5	5	5	1	5	1
Fragilaria capucina var. *vaucheriae* (Kützing) Lange-Bertalot	*FraCapVau*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–	–	–	–	–	–	–
Hantzschia abundans Lange-Bertalot	*HanAbu*	2	–	2	–	–	–	1	2	4	–	1	2	1	3	–	–	–	–	–	–	–	–
Hantzschia amphioxys (Ehrenberg) Grunow	*HanAmp*	1	–	4	2	1	–	2	3	4	–	–	1	–	4	–	–	1	1	1	–	–	3
Hantzschia hyperborea (Grunow) Lange-Bertalot	*HanHyp*	1	2	–	–	1	–	1	–	–	–	1	1	–	1	–	–	1	2	–	–	–	1
Luticola australomutica Van de Vijver manuscriptname	*LutAus*	–	–	2	1	1	1	–	–	1	–	–	1	–	–	–	–	–	–	–	–	–	–
Luticola austroatlantica Kopalová et al.	*LutAat*	–	–	–	–	1	1	1	–	–	1	–	–	–	2	–	–	–	–	–	–	2	1
Luticola caubergsii Van de Vijver manuscriptname	*LutCau*	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Luticola cohnii (Hilse) Mann	*LutCoh*	2	–	1	1	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	1
Luticola gigamuticopsis Van de Vijver manuscriptname	*LutGig*	–	–	1	–	–	–	–	–	–	3	1	–	–	1	–	–	–	–	–	–	–	–
Luticola murrayi (West & West) Mann	*LutMur*	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Luticola muticopsis (Van Heurck) Mann	*LutMut*	5	1	4	3	4	–	2	3	4	1	2	4	2	4	2	3	2	4	5	3	2	4
Luticola sp.1	*LutSp1*	–	–	–	–	–	–	2	1	–	–	–	–	–	2	–	–	–	–	–	–	–	–
Luticola sp.2	*LutSp2*	–	–	2	–	–	–	2	2	–	–	–	–	–	4	–	–	1	1	–	2	1	–
Luticola truncata Kopalová et al.	*LutTrun*	–	–	2	–	2	–	2	2	–	–	–	–	–	–	–	–	–	–	–	–	1	2
Mayamaea atomus var. *atomus* (Kützing) Lange-Bertalot	*MayAtoAto*	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mayamaea atomus var. *permitis* (Hustedt) Lange-Bertalot	*MayAtoPer*	–	–	–	2	2	–	5	1	1	3	1	–	–	–	3	–	–	–	–	4	–	4
Muelleria luculenta Spaulding & Stoermer	*MueLuc*	–	2	1	2	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Muelleria sp.	*MueSp.*	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Navicula cincta (Ehrenberg) Ralfs	*NavCin*	1	–	1	–	–	–	–	–	1	–	–	–	–	–	2	–	1	–	–	–	–	–
Naviculadicta sp.	*NavSp.*	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Nitzchia gracilis Hantzsch	*NitGra*	–	5	–	3	5	5	4	4	–	5	5	4	4	2	–	4	4	2	–	1	–	1
Nitzschia homburgiensis Lange-Bertalot	*NitHom*	–	–	4	2	1	1	1	2	4	1	–	–	–	3	4	1	–	2	–	3	–	3

SPECIES	ACRONYM	B3	B4	SP 2	SP 3	3	4	5	6	8	9	10	13	14	15	16	17	T1	T2	T4	T6	T7	T8
Nitzschia perminuta (Grunow) Peragallo	*NitPer*	–	–	1	3	–	–	–	1	1	–	–	–	–	–	–	5	–	–	–	–	4	4
Orthoseira roeseana (Rabenhorst) O'Meara	*OrtRoe*	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pinnularia borealis var. *islandica* Krammer	*PinBorIsl*	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pinnularia borealis var. *lanceolata* Hustedt	*PinBorLan*	4	–	–	–	–	–	–	–	–	–	–	1	–	2	–	–	–	–	–	–	–	–
Pinnularia borealis var. *scalaris* (Ehrenberg) Rabenhorst	*PinBorSca*	3	–	–	–	–	–	–	–	1	–	–	–	–	2	–	–	–	–	–	–	–	–
Pinnularia schoenfelderi Krammer	*PinSch*	–	–	1	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	–	–	–
Psammothidium metakryophilum (Lange-Bertalot & Schmidt) Sabbe	*PsaMet*	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Stauroneis jarensis Lange-Bertalot et al.	*StaJar*	–	–	1	–	1	–	–	–	3	–	–	–	–	1	–	–	–	–	–	–	–	2
Stauroneis latistauros Van de Vijver & Lange-Bertalot	*StaLat*	–	–	2	2	–	–	1	1	5	–	1	1	–	–	–	–	–	1	–	1	–	1
Stauroneis pseudomuriella Van de Vijver & Lange-Bertalot	*StaPsm*	–	–	1	–	–	–	–	–	4	–	–	–	–	–	–	1	–	–	–	–	–	–
Stauroneis pseudoschimanskii Van de Vijver & Lange-Bertalot	*StaPss*	–	–	1	2	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Explanations: **1** – < 1%, **2** – ≥ 1 < 5%, **3** – ≥ 5 <10%, **4** – ≥ 10 <50%, **5** – ≥ 50% (classes of relative abundances according to Kelly, 2000). For site codes, see key in Table 1.

CHAPTER 2

Kopalová, K., Elster, J., Nedbalová, L. & Van de Vijver, B. 2009. Three new terrestrial diatom species from seepage areas on James Ross Island (Antarctic Peninsula region). *Diatom Research* 24(1): 113-122

CHAPTER 3

Esposito, R.M.M., Spaulding, S.A., McKnight, D.M., Van de Vijver, B., Kopalová, K., Lubinski, D., Hall, B. & Whittaker, T. 2008. Inland diatoms from the McMurdo Dry Valleys and James Ross Island, Antarctica. *Botany* 86: 1378–1392.

CHAPTER 4

Van de Vijver, B. & Kopalová, K. 2008. *Orthoseira gremmenii* sp. nov., a new aerophilic diatom from Gough Island (southern Atlantic Ocean). *Cryptogamie, Algologie* 29(2): 105-118

CONCLUSIONS

- The current study of diatom communities on James Ross Island (Antarctica) revealed higher richness of species in seepage areas when comparing with streams. Similar pattern which was already observed in cyanobacterial assemblages, can be the result of higher disturbance rates in the latter habitat.

- Diatom species composition differed significantly between seapages and streams. *Fragilaria capucina* (Kűtzing) Lange-Bertalot represented a typical stream species, which was not found in seepage area, where *Luticola* spp. together with *Eolimna jamesrossensis* Kopalová & Van de Vijver prevailed. *Nitzschia gracilis* Hantzch was abundant in both habitats.

- Annual course of temperature was recorded in seepages on James Ross Island showing high daily fluctuation during summer season. Comparison of basic physico-chemical parameters in both habitats study revealed higher pH and conductivity levels in streams.

- Altogether, 57 species belonging to 17 genera were recorded in seepages and streams of James Ross Island and three of them were described as species new for science (*Diadesmis inconspicua* Kopalová & Van de Vijver, *Luticola truncata* Kopalová & Van de Vijver and *Eolimna jamesrosssensis* Kopalová & Van de Vijver).

- *Luticola austroatlantica* Van de Vijver et al. was found on James Ross Island and McMurdo Dry Valleys. It was described as a new taxon together with three more species (*Luticola dolia* Spaulding & Esposito, *Luticola laeta* Spaulding & Esposito, *Muelleria supra* Spaulding & Esposito).

- *Orthoseira gremmenii* Van de Vijver & Kopalová was described from bryophyte mats in a seepage area on a small, volcanic, isolated Gough Island (southern Atlantic Ocean) as a component of its very specific non-marine diatom flora.

- Overall, this study represents a contribution to the knowledge of taxonomy, ecology and biogeography of diatoms in the Antarctic and sub-Antarctic region. The results further confirmed the unique character of Antarctic diatom flora with high proportion of species with limited distribution. Moreover, the presence of a habitat-specific flora on James Ross Island was demonstrated.