Comparative analysis of temperature courses in Antarctic lakes of different morphology: Study from James Ross Island, Antarctica

Peter Váczi[1], Miloš Barták[1*], Linda Nedbalová[2,4], Josef Elster[3,4]

[1]*Laboratory of Photosynthetic Processes, Section of Plant Physiology, Department of Experimental Biology, Masaryk University, Kamenice 5, 62500 Brno, Czech Republic*
[2]*Department of Ecology, Faculty of Science, Charles University, Viničná 7, 128 44 Praha 2, Czech Republic*
[3]*Centre for Polar Ecology, Faculty of Science, University of South Bohemia, Branišovská 31, 37005 České Budějovice, Czech Republic*
[4]*Institute of Botany, Academy of Sciences of the Czech Republic, Dukelská 135, 379 82, Třeboň, Czech Republic*

Abstract
Monitoring of physical properties of terrestrial lakes belongs to one of key research activities performed by Czech scientists at James Ross Island. Throughout 2011, water temperature was measured and recorded by dataloggers in 1 h interval in two Antarctic lakes of different size and morphology. The first lake is a large shallow one located in a depression of sedimentary rock (Lachman Lake 1) at the altitude of 10 m a.s.l. Lake Dulanek, the second one, is typical small-area water body located on stony glacier surface at the altitude of 220 m a.s.l. Dulanek Lake, thanks to higher altitude, remained frozen for longer period (274 d) of austral winter than Lachman Lake 1 (205 d). Presence of thick snow cover over Dulanek lake during winter period, however, caused higher values of winter minimal temperature (-17.5°C) than those recorded for Lachman lake 1 (several periods below -20.0°C). Mean annual temperature reached -4.6°C and -5.2°C for Lake Dulanek, and Lachman Lake 1, respectively. Shorter summer season accompanied by lower water temperature in Lake Dulanek however, did not bring unfovourable conditions for growth and reproduction of autotrophic organisms. Biomass of autotrophic organisms found in Lake Dulanek was quite high.

Key words: water temperature, length of winter season, freezing, snow depth

Introduction

In the Antarctica, freshwater lakes represent important ecosystems to study long-term trends in regional climate, their effects on physical and chemical properties of water environment as well as their microbiological communities (Gibson et al. 2006, Lyons et al. 2006). Water temperature is an important factor that influences the development of algae and cyanobacteria that form the autotrophic component of Antarctic lakes (Matsumoto et al. 1984). In long-term studies per-

Received March 22, 2012, *accepted* May 14, 2012.
[*]Corresponding author: mbartak@sci.muni.cz
Acknowledgement: The authors acknowledge the possibility to use J. G. Mendel station infrastructure during the Czech Antarctic Expedition (Jan. – March 2012).

formed in the Antarctica, temperature profiles in Antarctic lakes have been often measured together with other environmental factors, *e.g.* Heywood Lake, Signy Island (Butler 1999). It is well documented that an increase in water temperature is accompanied by increased carbon fixation by the phytoplankton, as well as lipid and polysaccharides content (Hawes 1990). Similar conclusion was made also from the studies carried out in subantarctic lakes – Marion Island (Robarts et al. 1991).

At the James Ross Island, a long term research of lake ecosystems with an emphasis on the diversity and ecology of cyanobacteria and algae has started in 2006. A total of 36 lakes in the northern deglaciated part of the island were sampled, and their origin, geomorphological, hydrological, physical, chemical and biological characteristics, including diversity and ecology of cyanobacteria and algae were examined (Nedbalová et al. 2009, Nedbalová et al. submitted). In these studies, the lake ecosystems of James Ross Island have been divided to the following types: A) stable shallow lakes of higher-lying levelled surface, B) shallow coastal lakes, C) stable lakes in old moraines, D) small unstable lakes in young moraines, E) stable deep cirque lakes, and F) kettle lakes. The set of lakes represents a unique collection of diverse ecosystem because they are located in the transitional zone between maritime and continental Antarctica (*see e.g.* Bednarek-Ochyra et al. 2000). These lakes thus play an important role as a marker of climate change in this part of the Antarctica, because a substantial air temperature increase is reported over last decades. This warming trend is well documented at the islands located both at the Western (maritime, Turner et al. 2005) and Eastern (continental, Skvarca et de Angelis 2003) side of the Antarctic Peninsula. During the first years after the completion of the Mendel station, the phycological research at the James Ross Island was focused on basic floristic and ecological survey of the area. The main types of habitats with dominant cyanobacterial assemblages were analyzed, including several lakes (Komárek et Elster 2008). A detailed study of the diversity and ecological distribution of cyanobacteria was done by Komárek et al. (2008) and Strunecký et al. (2012), and revealed the presence of 75 morphotypes with the majority of them connected to special habitats and forming distinct populations and ecologically delimited communities. A majority of the studied taxa did not correspond to known species from other regions, and only a small number of morphospecies (maximum 20%) was recognized to be distributed outside the Antarctica. The study of Strunecký et al. (2012) also have shown that several endemic species probably occur at James Ross for quite long period of time (from time when Gondwava broke down) and survive here several glaciations. The study also suggested a transitional character of the cyanobacterial microflora that reflects the geographic position of the area. Recently, three new heterocytous species were described from James Ross Island lakes (Komárek et al. 2012).

A similar pattern was confirmed during the ongoing study of the diatom flora. Well-developed diatom assemblages with more than 100 taxa were found in lake samples with the dominance of species, which are considered as endemic for the Antarctica. Moreover, several new diatom species were also described (Zidarova et al. 2009, van de Vijver et al. 2010, Kopalová et al. 2011). To conclude, there is growing evidence that James Ross Island lakes host specific autotrophic communities, which could be significantly influenced by the current environmental changes in the Antarctic region (Quayle et al. 2002).

Material and methods

Description of lakes

For this study, two lakes of contrasting size, origin, and location were selected in order to distinguish differences in their annual courses of water temperature. The first one is a large shallow lake located in a depression of sedimentary rock (Lachman Lake 1), while the other one is typical small-area water body located on stony glacier surface (Dulanek Lake).

The Lachman Lake 1 is located in the northeastern part of the Ulu Peninsula, Northern part of James Ross Island, at the altitude of 10m a.s.l. It is a typical shallow water body with summer-season water depth up to 0.5 m. The lake is located only 100 m from the coastal line of Herbert Sound (Fig. 1) and has an area of 30 000 m^2. During austral summer season, Lachman Lake 1 is ice free and supplied by melt water from neighbouring snow fields. Other sources of water supply are numerous seepages and two small shallow pools in a close vicinity, situated between Lachman Lakes 1 and 2. The lake has a muddy-stony littoral. The lake bottom is formed by a thick muddy layer that originates mostly from a high input of cretaceous sediments. Rich cyanobacterial populations and communi-ties develop regularly in the lake and surrounding wet habitats during summer season (Nedbalová et al. 2009).

The Dulanek Lake is a small-area pool located close to Panorama Pass at the altitude of 220 m a.s.l. about 2 000 m from coastal line. The area and depth of the pool vary slightly between years, however, average values are 25 m^2 and 0.8 m, respectively. In spite of the fact that, due to neighbouring rock walls of the Lachman Crags mesa, the pool is sunlit directly only for limited period of daytime (typically until 15:30 local time), Dulanek Lake is rich in cyanobacterial mats. Since 2009, measurements of dissolved oxygen con-centration have been carried out there during summer season (Váczi et Barták 2011).

Temperature measurements

In Lachman Lake 1, water temperature was measured by a Minikin-Ti datalogger with in-built temperature sensor (Environ-mental Monitoring Systems, Czech Re-public). The datalogger was placed on the bottom of the lake into the depth of about 0.3 m in January 2009. Value of water temperature has been recorded in 1h interval since that time continuously. In this study, only yearly data from 2011 are presented. In the Dulanek Lake, a data-logger equipped with temperature sensors was established in January 2011 to characterize water profile. The system consisted of a datalogger (Environmental Monitoring Systems, Czech Republic) and four temperature sensors (Pt-100) set in 30, 40, 60 and 80 cm from the bottom of the lake. Courses of the water temperature profile have been recorded in 30 min. interval. Additionally, yearly temperature data measured at the height of 5 cm above stony surface of the neighbourhood of the pool was recorded.

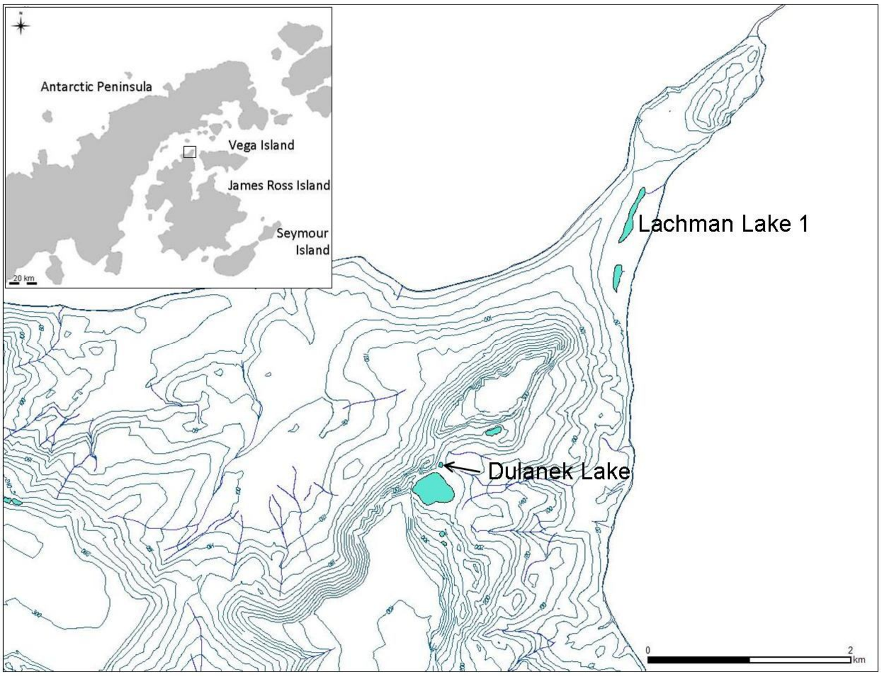

Fig. 1. Geographical location of James Ross Island and the two lakes involved into the study: Lachman Lake 1, and Lake Dulanek. Modified from the Czech Geological Survey map (2009) – *see* References - Other sources.

Results

The annual courses of water temperature in Lachman Lake 1 and Dulanek Lake are shown in Fig. 2. In the Lachman Lake 1, temperature showed a clear annual course, varying from minimum of -23.1°C recorded on August, 13th to maximum of 18.8°C recorded on December, 26th. The annual average temperature was -5.2°C. During the Antarctic summer period, from the beginning of January till the first decade of March, the water temperature varied from -0.5 to 15.6°C and the average was 3.8°C, however, temperature below zero occurred only occasionally during early morning hours. Within this period, daily courses of water temperature were apparent showing daily maxima ranging from 5 to 15°C and minima close to zero. Nedbalová et al. (submitted) reported similar values in January - February 2009 with a maximum of 18.2°C. In the period from March 7th to March 24th, water temperatures remained under zero for the whole day. In the following period (March 24th to April 16th), water temperature showed a decreasing trend due to decreasing air temperature. During winter period (from the end of March till the first decade of October), the average temperature decreased to -11.9°C (mean value). Within winter period, several minima reaching the values from -15 to -20°C were recorded, however, only two periods of minima below -20°C. were recorded The first one was reached at the beginning of August (absolute minimum on August 3th), the other one on August 16th, respectively.

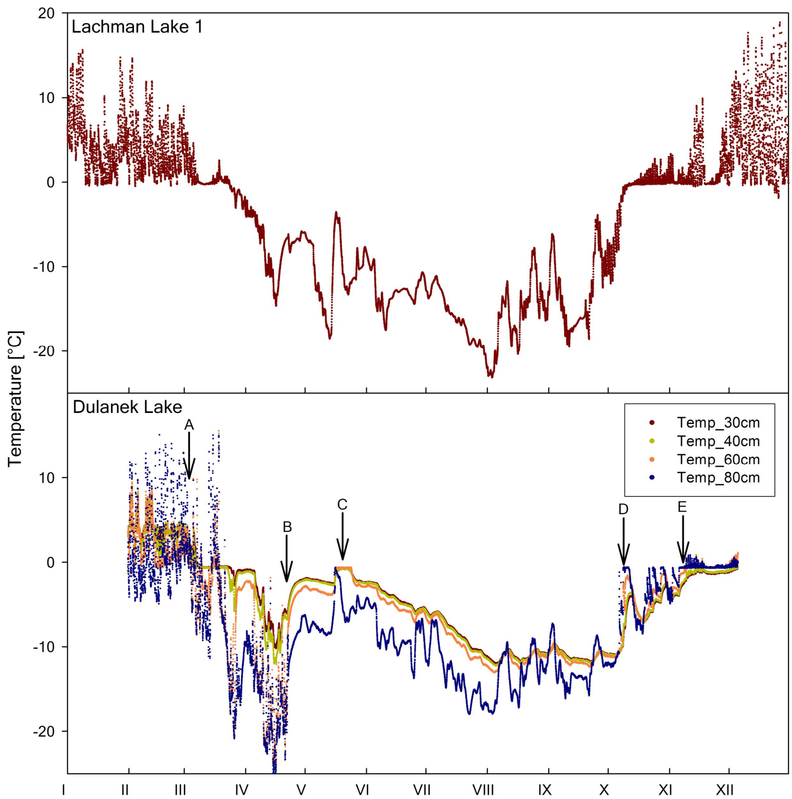

Fig. 2. Yearly courses of water temperature recorded in Lachman Lake 1 at the depth of 0.3 m (above), and Lake Dulanek (below) at different depths. The sensors were installed 30, 40, 60, and 80 cm above bottom. The uppermost one (Temp_80) remained above water level for the whole year 2011. The lowest two (Temp_30, and Temp_40) remained within water columns for the whole year. A, B, C, D, E denote important events - *see* Results.

Both minima were reached during the periods with extremely low air temperatures (Barták, unpublished data). Last part of this period was typical by fast increase in temperature to the values close to zero. In early summer period, *i.e.* from the second decade of October till the end of December, an average temperature was 2.7°C. The period was typical by clearly distinguished daily courses of temperature ranging from close to zero temperature (or even below) to the values of 10-15°C. However, during the second half of December, several maxima higher than 15°C occurred. These maxima were higher than those recorded in this period in 2009 and 2010, respectively (Nedbalová, unpublished data). This clearly indicated the loss of water by evaporation that happened most likely in the second week of December 2011. The lake dried out and datalogger and sensor was exposed to air temperature. Dark color of naked lake bottom absorbed more solar radiation energy than under a 0.3 m thick water column which resulted in higher values of temperature recorded in this period. The absence of water column was documented in 2012, when the crew of Czech Antarctic expedition arrived to the James Ross Island (*see* Figs. 3, 4).

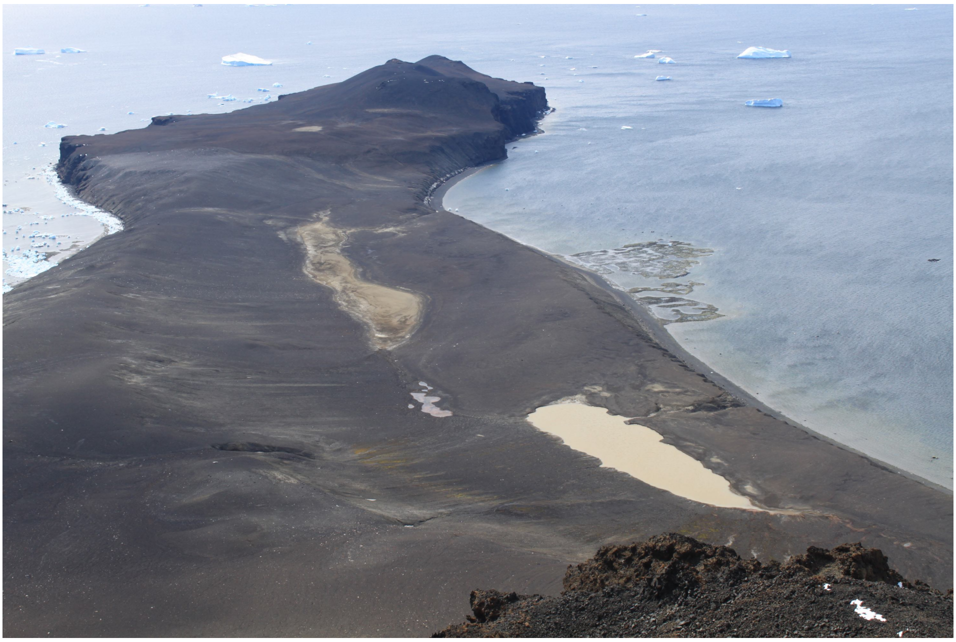

Fig. 3. General view on Lachman Lake 1 (dried-out) and Lachman Lake 2 taken on February 7th, 2012. Photo Miloš Barták.

Fig. 4. Dried bottom of Lachman Lake 1 with a Minikin datalogger (February 2012). Rich microbial mats are clearly visible. Photo Miloš Barták.

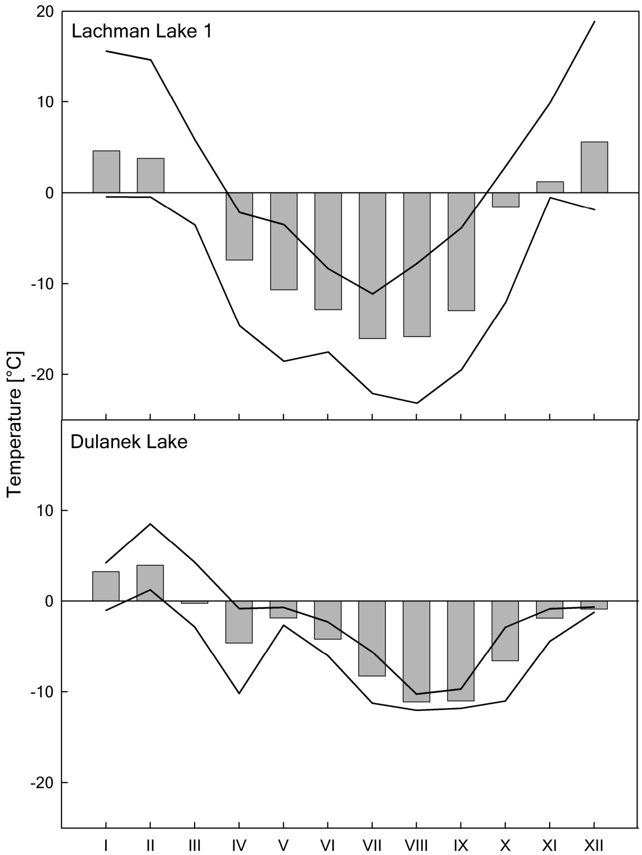

Fig. 5. Monthly mean water temperature (colums), mothly maxima (upper line) and minima (lower line) for Lachman Lake 1 and Lake Dulanek.

In spite of higher altitude of the Dulanek Lake, summer–season water temperatures lasted for longer period than in Lake Lachman 1 (January to end of February 2011 for Lake Dulanek). However, daily maxima were much lower in Dulanek Lake than in Lake Lachman 1. They ranged between 4 and 10°C in Lake Dulanek while they reached 5-15°C in Lake Lachman 1. Since water temperature was measured at several depths in Lake Dulanek, more detailed analysis of water temperature regime and weather condition events might be done. From data follows, that there was a gradual decrease in water level of at least 10 cm in the period of January - March 2011, because the sensor Temp_60cm (*see* Fig. 2) that had been located within water column at the depth of 5 cm (January 28th) appeared above water level on March 7th, 2012. Since that time, the sensor has been exposed to air temperature that fluctuated more intensively than the temperature recorded by the sensors permanently located in frozen water column (*see* Fig. 2-A). On April 22nd, frozen Lake Dulanek was covered by about 10-15 cm thick snow layer. This was documented by the increase in temperature recorded by the sensor Temp_60cm (60 cm above bottom, *see* Fig. 2-B). At the same time, the sensor Temp_80cm (80 cm above bottom) was exposed to air and followed much lower air temperature course. The snow cover lasted until thawing period that started at the first decade of November. Annual average temperature was -4.6°C for Lake Dulanek which is by about 1°C higher than in Lachman Lake 1. Absolute temperature minima of ice in fully-frozen Lake Dulanek were, however, higher (-17.5 °C) than in Lachman Lake 1. This was caused by much thicker snow cover over Lake Dulanek than Lachman lake 1 that lasted for majority of wither season and prevented from direct effects of cold air masses (*see* also Discussion). An episodic increase of temperature to the values close to zero was apparent during May for several consecutive days (May 16-24th, *see* Fig. 2-C). At the end of winter period, the first sign of temperature rise towards 0 °C appeared on October 10th (*see* Fig. 2–D), followed by several similar situations recorded between October 10th-November 11th. From the first decade of November, the sensors Temp_80 cm and Temp_60cm, located 80 and 60 cm above Lake Dulanek bottom, were snow-free and recorded diurnals of air temperature while the lower-located sensors still recorded melting ice temperature. From the temperature courses, it might be expected that Lake Dulanek was completely melt not earlier than on December 5th.

Discussion

The annual courses of water temperature varied between the two lakes significantly (*see* Figs. 2 and 5). Due to altitude-related differences in air temperature and the duration of snow cover, Lake Dulanek had much longer winter period with frozen water column at temperature below 0°C. This caused decrease in the length of summer season with favourable conditions for growth and reproduction of both autotrophic and heterotrophic organisms. Biomass of autotrophic organisms found in Lake Dulanek is, however, quite high (Váczi et Barták 2009), when compared to Lachman Lake 1 and seems not be affected by a shorter summer season. This idea could also be supported by the measurements of photosynthetic activity of autotrophic algae and cyanobacteria by oxygen electrode. Data on concentrations of dissolved oxygen (Váczi et Barták 2009, Barták - unpublished data) gathered during 2009-2012 summer seasons at the James Ross Island proved that there is only minor difference between Lake Dulanek (9.8-15.3 mg O_2 l^{-1}) and Lachman Lake 2 (10.8-14.3 mg O_2 l^{-1}), a similarly-sized and located lake as Lachman Lake 1.

Annual temperature means reached for Lachman Lake 1 and for Lake Dulanek, respectively, were well comparable to earlier observations of Nedbalová, Elster who reported annual mean of -4.8^{o}C for Lachman Lake 1 for 2010 (not yet published). Butler (1999) reported that typical lake of Maritime Antarctica should exhibit low water temperature not exceeding 6^{o}C. Recently, the region along the Antarctic Peninsula has been subjected to the consequences of climate warming. Antarctic lake ecosystems are believed to respond quite rapidly to long-term increase in air temperature. Alterations may include prolongation of the period during which melt water is available, increased nutrient input, longer period without ice, increased wind-induced mixing of lake water, increased primary production and higher carbon fluxes into lake bodies (Lyons et al. 2006). Freezing dynamics in particular has been demonstrated as a very important factor structuring chemistry and biological communities of Antarctic shallow lakes

(Hawes et al. 2011). In Signy Island lakes, extremely fast ecosystem changes were already reported, which appeared to be directly linked to reductions in snow and ice cover. For these reasons, long-term studies of Antarctic lake ecosystems are unavoidable for predictions of their likely responses to variation of future climate. At James Ross Island, monitoring of yearly courses of lake temperature will continue together with short-term measurements of oxygen concentration.

References

BEDNAREK-OCHYRA, H., VÁŇA, J., OCHYRA, R. and LEWIS SMITH, R.I. (2000): The liverwort flora of Antarctica. Polish Academy of Science, Institute of Botany, Krakow. 236 p.

BUTLER, H. (1999): Seasonal dynamics of the planktonic microbial community in a maritime Antarctic lake undergoing eutrophication. *Journal of Plankton Research*, 21: 2393-2419.

GIBSON, J.A.E, WILMOTE, A., TATON, A., VAN DE VIJVER, B., BEYENS, L. and DARTNALL, H.J.G. (2006): Biogeographic trends in Antarcic lake communities. *In*: D.M. Bergstroem, P. Convey, E. Huiskes (Eds.): Trends in Antarctic Terrestrial and Limnetic Ecosystems. Antarctica as Global Indicator. Springer, Germany, p. 71-99.

HAWES, I. (1990) The effects of light and temperature on photosynthate partitioning in Antarctic freshwater phytoplankton. *Journal of Plankton Research*, 12: 513–518.

HAWES, I., SAFI, I., SORREL, B., WEBSTER-BROWN, J.G., BROWN, K.L. and ARSCOTT, D. (2011): Summer–winter transitions in Antarctic ponds I: The physical environment. *Antarctic Science*, 23: 235–242.

KOMÁREK, J., ELSTER, J. (2008): Ecological background of cyanobacterial assemblages of the northern part of James Ross Island, Antarctica. *Polish Polar Research*, 29: 17–32.

KOMÁREK, J., ELSTER, J. and KOMÁREK, O. (2008): Diversity of the cyanobacterial microflora of the northern part of James Ross Island, NW Weddell Sea, Antarctica. *Polar Biology*, 31: 853–865.

KOMÁREK, J., NEDBALOVÁ, L. and HAUER, T. (2012): Phylogenetic position and taxonomy of three heterocytous cyanobacteria dominating the littoral of deglaciated lakes, James Ross Island, Antarctica. *Polar Biology*, 35: 759–774.

KOPALOVÁ K., NEDBALOVÁ, L., DE HAAN, M. and VAN DE VIJVER (2011): Description of five new species of the diatom genus *Luticola* (Bacillariophyta, Diadesmidaceae) found in lakes of James Ross Island (Maritime Antarctic Region). *Phytotaxa*, 27: 44-60.

LYONS. W.B., LAYBOURN-PARRY, J., WELCH, K.A. and PRISCU, J.C. (2006): Antarctic lake systems and Climate Change. *In*: D.M. Bergstroem, P. Convey, E. Huiskes (Eds.): Trends in Antarctic Terrestrial and Limnetic Ecosystems. Antarctica as Global Indicator. Springer, Germany, pp. 273-295.

MATSUMOTO, G., TORII, T. and HANYA, T. (1984): Vertical distribution of organic constituents in an Antarctic lake: Lake Vanda. *Hydrobiologia*, 111: 119-126.

NEDBALOVÁ, L., ELSTER, J., KOMÁREK, J. and NÝVLT, D. (2009): Lake ecosystems of James Ross Island: short characteristics. *In*: M. Barták, J. Hájek, P. Váczi (eds.): *Structure and Function of Antarctic Terrestrial Ecosystems*. *Book of Abstracts and Contributed Papers*. 22.–23. October 2009, Brno, Czech Republic, pp. 33–34.

NEDBALOVÁ, L. NÝVLT, D., KOPÁČEK, J., ŠOBR, M. and ELSTER, J. (*submitted*): Freshwater lakes of Ulu Peninsula (James Ross Island, NE Antarctic Peninsula): Origin, geomorphology and physico-chemical limnology. *Antarctic Science*, *submitted*.

SKVARCA, P., DE ANGELIS, H. (2003): Impact assessment of regional climate warming on glaciers and ice shelves of the northerneastern Antarctic Peninsula. *In:* E. Domack, A. Leventes, A. Burnett, R. Bindschadler, R. Convey, M. Kirby (eds.): *Antarctic Peninsula Climate Variability*. *Historical and Paleoenvironmental Perspectives*. *Antarctic Research Series*, 79: 69-78.

STRUNECKÝ, O., ELSTER, J. and KOMÁREK, J. 2012: Molecular clock evidence for survival of Antarctic cyanobacteria (Oscillatoriales, *Phormidium autumnale*) from Paleozoic times. *FEMS Microbial Ecology* (*accepted*).

QUAYLE, W.C, PECK, L.S., PEAT, H., ELLIS-EVANS, J.C. and HARRIGAN, P.R. (2002): Extreme responses to climate change in Antarctic lakes. *Science*, 295: 645.

RICHARD, D., ROBARTS, R.D., LYNNE M., SEPHTON, L.M. and WICKS, R.J. (1991): Labile dissolved organic carbon and water temperature as regulators of heterotrophic bacterial activity and production in the lakes of Sub-Antarctic Marion Island. *Polar Biology*, 11: 403-413.

TURNER, J., COLWELL, S. R., MARSHALL, G. J., LACHLAN-COPE, T. A., CARLETON, A. M., JONES, P. D, LAGUN, V., REID, P. A. and IAGOVKINA, S. (2005): Antarctic climate change during the last 50 years. *International Journal of Climatology*, 25: 279-294.

VÁCZI, P., BARTÁK, M. (2009): Variability of oxygen content in different lakes of the James Ross Island as dependent on actual weather conditions. *In*: M. Barták, J. Hájek & P. Váczi (eds.): *Structure and Function of Antarctic Terrestrial Ecosystems*. *Book of Abstracts and Contributed Papers.* 22.–23. October 2009, Brno, Czech Republic, p. 35-37.

VÁCZI, P., BARTÁK, M. (2011): Summer season variability of dissolved oxygen concentration in Antarctic lakes rich in cyanobacterial mats. *Czech Polar Reports*, 1: 42-48.

VAN DE VIJVER, B., STERKEN, M., VYVERMAN, W., MATALONI, G., NEDBALOVÁ, L., KOPALOVÁ, K., ELSTER, J., VERLEYEN, E. and SABBE, K. (2010): Four new non-marine diatom taxa from the Subantarctic and Antarctic regions. *Diatom research*, 25: 431–443.

ZIDAROVA, R., VAN DE VIJVER, B., MATALONI, G., KOPALOVÁ, K. and NEDBALOVÁ, L. (2009): Four new freshwater diatom species from Antarctica. *Cryptogamie Algologie*, 30: 295–310.

Other sources

Czech Geological Survey. 2009. James Ross Island - Northern Part. Topographic map 1 : 25 000. First edition. Praha, Czech Geological Survey. ISBN 978-80-7075-734-5.