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Limnological characterization of freshwater systems of the Thomas Point Oasis (Admiralty Bay, King George Island, West Antarctica)

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Abstract

Hydrochemical research into the small, shallow water bodies and wetland areas around the Henryk Arctowski Polish Antarctic Station (King George Island) is presented. Concentrations of nitrite, nitrate, ammonium, and total nitrogen in these waters were determined, as were those of reactive and total phosphorous, inorganic carbon, organic carbon, total carbon, silicate, and chloride and sulfate ions. Conductivity and pH were also measured. Average concentrations ranged widely, e.g., total nitrogen 0.176−29.21 mg L^{-1}, total phosphorus 0.022−18.35 mg L^{-1}, total carbon 1.38−26.90 mg L^{-1}, Cl^- 30.17−850 mg L^{-1}, and SO_4^{2-} 2.11−236 mg L^{-1}. The trophic status was influenced by influxes of nitrogen and phosphorus from penguin rookeries. Selected water bodies supported 31 taxa of algae and 11 invertebrate taxa, with Euglenophyta dominating in waters with high concentrations of ammonium−nitrogen, whereas diatoms characterized Lake Wujka, with low ammonium concentrations. All water bodies studied had rotifers, but crustaceans were only represented in Lake Wujka.

Keywords: Antarctica; Freshwater bodies; Trophic status; Algae; Invertebrates

1. Introduction

The limnological characteristics of Antarctic lakes and smaller water bodies are strongly affected by their catchments, as well as by the presence of plant and animals, especially avifauna and mammals (Izaguirre et al., 1998; Vinocur and Unrein, 2000).

The polar regions contain many different kinds of water bodies, ranging from large, deep lakes to small, shallow depressions fed by snow and melting ice. For these and other reasons, these water bodies can differ in both salinity and nutrient concentrations, and range from freshwater to extremely saline and from ultra-oligotrophic to hypertrophic (Henshaw and Laybourn-Parry, 2002; Matsumoto et al., 1984, 1992; Vinocur and Unrein, 2000). With summer lasting just 2−4 months, deep lakes may develop permanent ice covers. Shallow lakes and seepages are more susceptible to changes in weather conditions, freezing from top to bottom in winter but warming to above 10 °C in

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summer. Such water bodies may dry out completely, especially in locations where precipitation is either limited or absent (Pociecha, 2008; Pociecha and Dumont, 2008; Toro et al., 2007).

Another feature of the lakes in Antarctica is their low primary productivity, even in water bodies with access to moderate concentrations of nutrients. Intensive phytoplankton development often accompanies winter thawing (Matsumoto et al., 1992; Toro et al., 2007). However, the negative influence of ultraviolet B (UV-B) radiation is presumed to be felt at various trophic levels. The spring temperature increases are sufficient to intensify autotrophic activity, because the period of exposure to harmful UV-B radiation at this stage is brief (Bothwell et al., 1994; Wulf et al., 2008).

Shallow water bodies, frequently present where ice is in retreat, are particularly important to the functioning of the terrestrial ecosystem. They have been shown to moderate 24 h temperature fluctuations in their vicinity, and to exert a more general restraining influence on the microclimate. They increase soil humidity, which can encourage floral and faunal development (Rakusa-Suszczewski, 2003). These phenomena are especially important in locations in which deglaciation has accelerated over the last few decades. Over the past four decades, a climatic warming trend has been observed in both the sub-Antarctic and the Antarctic Peninsula (Cook et al., 2005; Martianov and Rakusa-Suszczewski, 1990; Skvarca et al., 1998), and the consequences have included ongoing deglaciation and the appearance of new ice-free areas, both along the coast and inland (Birkenmajer, 2002). For example, during this period, deglaciation has increased the ice-free area on King George Island, South Shetlands, from 21 km^2 to 38 km^2 (Braun et al., 2001). Colonization of these areas depends not only on physical factors, like the wind-assisted dissemination of nutrients, plant and animal fragments, and seeds, but also on the availability of water (Janiec, 1999; Nędzarek and Rakusa-Suszczewski, 2007).

Such water bodies are characteristic of the geo-ecosystem of the western shore of Admiralty Bay, King George Island. The largest single ice-free area in the Bay's catchment is the so-called "Thomas Point Oasis", which covers around 5 km^2. The Oasis supports short watercourses, as well as shallow lakes and seepages, fed by glacial melt water and precipitation. The lakes covering the largest areas are on the lowest coastal terraces, whereas the higher lakes are smaller. The lakes remain completely frozen for around 8–10 months, except for the reservoir that provides drinking-water to the H. Arctowski Station, which has been banked with earth to increase its depth (3 m). Depending on the winter conditions, the ice cover varies between ca. 1.0 and 1.5 m thick, with liquid water present below this layer throughout the winter.

The aims of the present study were: (i) to assess the trophic status of the small bodies of freshwater making up the Thomas Point Oasis; (ii) to assess the organic load of these water bodies; (iii) to assess the taxonomic composition of the biota in selected water bodies; and (iv) to study the ecological role that such water bodies play in this ecosystem.

2. Materials and methods

This research formed part of the 28th and 29th Polish Antarctic Expeditions to the Henryk Arctowski Station on King George Island, West Antarctica. Samples were collected between December 2003 and March 2004 for biological research, and between December 2004 and March 2005 for hydrochemical research. The sampling sites, mapped in Fig. 1, are shallow lakes, small water bodies present in depressions, and wetland sites (Table 1).

The measurements made on nonfiltered water samples were total nitrogen (TN), total phosphorus (TP), inorganic carbon (IC), and total carbon (TC). Total organic phosphorus (TOP) was calculated as the difference between TP and the reactive phosphorus analyzed in the nonfiltered samples. Total organic nitrogen (TON) was calculated as the difference between TN and mineral nitrogen ($NO_2^- - N + NO_3^-$-N + NH_4^+-N) in nonfiltered samples. Colorimetric methods were applied, and absorbance measurements were made at the wavelengths recommended in Standard Methods for Examination of Water and Wastewater (1995), using a UV–VIS spectrophotometer Carl Zeiss SPEKOL-1100 (Analityk Jena AG, Jena, Germany). Conductivity was measured with a WTW LF 197 conductivity meter (Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany) and pH with an HI 9025 pH meter (Hanna Instruments Srl, Italy). Carbon analysis was performed using a TOC-V$_{CSN}$ total organic carbon analyzer from Shimadzu Corporation, Japan.

Samples for the measurement of dissolved reactive phosphorus (DRP), dissolved organic carbon (DOC), dissolved silica, dissolved nitrite-N, nitrate-N, and ammonium-N were filtered through rinsed, pre-combusted glass-fiber filters (Whatman GF/C) immediately after collection. The sum of the nitrogen from

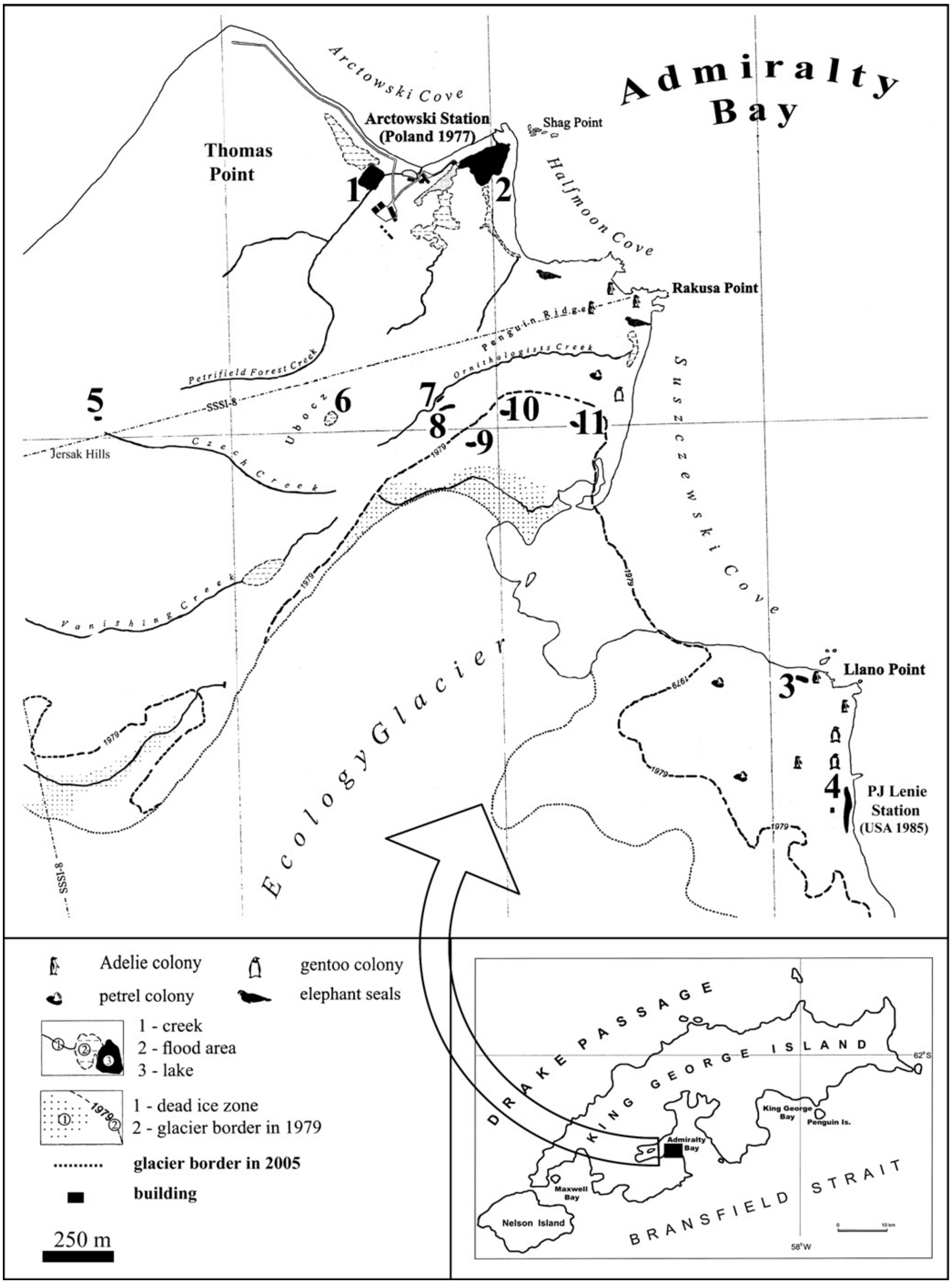

Fig. 1. Study area and locations of small water bodies (nos 1–5, 7–11) and seepage (no. 6) around the Henryk Arctowski Polish Antarctic Station.

dissolved nitrite, nitrate, and ammonium was used as the value for dissolved inorganic nitrogen (DIN).

The taxonomic compositions of the flora and fauna were studied in selected water bodies (nos. 2–4). The samples for qualitative investigations were collected from the entire water column of Lake Wujka (water body 2) and from the deepest part of water bodies 3 and 4. The samples were filtered through a plankton net of mesh size 35 μm and fixed in 4% formalin, before microscopic analysis (at 100–200× magnification) in a 0.5 mL chamber. The qualitative composition was investigated using a taxonomic key and

Table 1
Characteristics of the sampling sites investigated.

Sampling date	Name and number of water body	Sampled site description	Depth (m)	Area	Surrounding flora
21.01.2005 09.02.2005 18.02.2005 30.03.2005	1	Reservoir of drinking-water for the Arctowski station supplied by Petrifield Forest Creek; no influence of avifauna	3.0	0.4 ha	Limited numbers of sites of *Deschampsia antarctica* Desv. and *Poa annua* L.
	Lake Wujka 2	Small lake mainly fed by Moss Creek and water from catchment area; not directly impacted by avifauna from catchment area (Adelie penguin, *Pygoscelis adeliae*)	1.4	0.8 ha	*D. antarctica*, *P. annua,* and mosses
04.03.2005	Ipanema Beach Pond 3	Small pond located within a Gentoo penguin (*Pygoscelis papua*) colony	0.5	150 m^2	No plants
04.01.2005 03.02.2005 04.03.2005	Copa Hut Pond 4	Small pond located close to the American P.J. Lenie field camp; directly influenced by a Gentoo penguin colony	1.5	0.2 ha	*D. antarctica* and mosses
13.12.2004 15.01.2005 10.02.2005	5	In the Jersak Hills area at 180 m a.s.l; no influence of avifauna	0.6	170 m^2	No plants
	6	Seepage on the Ubocz Plateau 110 m a.s.l; located near nests of Antarctic skuas (*Catharacta antarctica*)	0.3	800 m^2	Mosses
	7	Located in the immediate vicinity of the right bank of Ornithologists Creek (at 50 m a.s.l.); no influence of avifauna	0.5	160 m^2	*D. antarctica* and mosses
	8	Located in the vicinity of the right bank of Ornithologists Creek (at 45 m a.s.l.); no influence of avifauna	0.5	460 m^2	*D. antarctica* and mosses
	9	Located 11 m a.s.l. in a postglacial moraine depression very close to the Ecology Glacier; no influence of avifauna	1.0	80 m^2	Occasional patches of *D. antarctica* and mosses
	10	Located 25 m a.s.l. in the postglacial moraine depression between the Ecology Glacier and the site of a colony of giant petrels (*Macronectes giganteus*)	1.0	120 m^2	*D. antarctica* and mosses
	11	Located 15 m a.s.l. in the postglacial moraine depression between the Ecology Glacier and the site of a colony of giant petrels (*Macronectes giganteus*)	0.7	180 m^2	*D. antarctica* and mosses

Table 2
Average concentrations of nitrogen and phosphorus forms in the water bodies studied at the Thomas Point Oasis.

Water body no.	N−NO$_2^-$	N−NO$_3^-$	N−NH$_4^+$	DIN	TON	TN	DRP	TOP	TP	N:P
	mg L^{-1}									
1	0.006 (0.003)[a]	0.057 (0.048)	0.026 (0.017)	0.089 (0.063)	0.072 (0.065)	0.176 (0.036)	0.032 (0.024)	0.024 (0.020)	0.066 (0.040)	5.87
2	0.013 (0.002)	0.769 (0.100)	0.086 (0.066)	0.867 (0.140)	0.745 (0.107)	1.645 (0.234)	0.103 (0.043)	0.067 (0.032)	0.177 (0.049)	18.57
3	0.003	0.082	8.27	8.36	18.47	29.21	6.02	10.552	18.35	3.07
4	0.051 (0.061)	2.33 (2.15)	8.09 (4.51)	10.47 (6.58)	4.65 (3.05)	18.32 (11.23)	3.38 (3.98)	2.089 (1.957)	6.541 (7.45)	6.84
5	0.001 (0.001)	0.034 (0.015)	0.010 (0.006)	0.044 (0.021)	0.237 (0.081)	0.295 (0.084)	0.009 (0.011)	0.010 (0.009)	0.022 (0.001)	10.89
6	0.001 (0.001)	0.120 (0.071)	0.016 (0.011)	0.138 (0.058)	0.236 (0.096)	0.393 (0.074)	0.009 (0.007)	0.016 (0.017)	0.032 (0.022)	32.62
7	0.001 (0.001)	0.061 (0.031)	0.045 (0.012)	0.106 (0.077)	0.281 (0.074)	0.415 (0.105)	0.030 (0.015)	0.028 (0.009)	0.065 (0.038)	7.81
8	0.001 (0.001)	0.065 (0.045)	0.009 (0.008)	0.075 (0.035)	0.294 (0.108)	0.379 (0.069)	0.016 (0.008)	0.014 (0.008)	0.034 (0.021)	10.20
9	0.001 (0.001)	0.055 (0.028)	0.019 (0.007)	0.075 (0.041)	0.197 (0.086)	0.288 (0.078)	0.016 (0.011)	0.015 (0.012)	0.037 (0.026)	10.20
10	0.001 (0.001)	0.038 (0.020)	0.015 (0.008)	0.054 (0.024)	0.273 (0.094)	0.335 (0.104)	0.005 (0.006)	0.015 (0.010)	0.023 (0.014)	23.88
11	0.001 (0.001)	0.040 (0.031)	0.011 (0.010)	0.052 (0.035)	0.281 (0.105)	0.342 (0.111)	0.006 (0.004)	0.017 (0.009)	0.039 (0.020)	19.17

[a] Standard deviation.

articles on freshwater algae and invertebrates (Dartnall, 1983; Dartnall and Hollowday, 1985; Lange-Bertalot and Kurt Krammer, 1987; Luścińska and Kyć, 1993).

The ordination of the water bodies was performed with principal components analysis (PCA) based on abiotic correlation matrix (StatSoft, 2008). PCA was performed using the mean values for each variable and each water body. The standardized values for the physical and chemical parameters were considered.

3. Results

3.1. Hydrochemistry

Our hydrochemical studies revealed marked differences in the concentrations of N, P, and mineral salts from one water body to another. These variables were also characterized by high fluctuations within each water body (high standard deviations [SD]; Tables 2 and 3).

The average concentrations of TN (0.176−29.21 mg L^{-1}) and TP (0.022−18.35 mg L^{-1}) fluctuated in the 11 water bodies studied (Table 2). The lowest concentration for a member of the nitrogen cycle was noted for nitrite-N (average concentrations ranged from 0.001 to 0.051 mg L^{-1}). The concentrations for these were: DIN 0.044−10.47 mg L^{-1}, NO_3^--N 0.034−2.33 mg L^{-1}, and NH_4^+-N 0.010−8.27 mg L^{-1}. DRP varied between 0.005 and 6.02 mg L^{-1}, whereas TOP varied between 0.010 and 10.55 mg L^{-1}. Conductivity varied between 109.2 and 3400 µS cm^{-1}, and pH between 6.80 and 8.78 (Table 3). The average concentrations of chloride ions (30.17−850 mg L^{-1}) and sulfate ions (2.11−236 mg L^{-1}) also ranged widely. The variation in the silica concentrations was smaller, with its concentrations in the range of 0.134−3.829 mg L^{-1}. The carbon concentrations in the water bodies studied were mostly low and the concentration range of TOC was 1.38−26.90 mg L^{-1}.

The dataset was subjected to multivariate analysis with PCA, as described above. The first two factors of the PCA based on the physical and chemical data accounted for 94.8% of the total variance. The first factor correlated positively with nutrients, and the second factor correlated positively with TC and DOC and negatively with conductivity and pH. Fig. 2 shows the ordination of the water bodies in relation to these axes. Two groups are clearly defined in this ordination. The mean values of the variables that explain the ordination of the water bodies in the two different groups are shown in Fig. 3.

Based on PCA (Fig. 2) and trophic level evaluations (Table 4), the studied water bodies were divided into two main groups. The first group (I) included water bodies with lower biogenic compound concentrations (water bodies 1 and 5−11), and the second group (II) included water bodies with high biogenic compound concentrations (water bodies 2−4).

3.1.1. Group I-lower concentrations of analyzed nutrients

Low concentrations of N and P characterized the drinking-water reservoir (water body 1) and the small water bodies located on the moraine between the Ecology Glacier and the breeding colonies of penguins and giant petrels, lying along the middle course of Ornithologists Creek, and located on the Ubocz Plateau or in the Jersak Hills (i.e., water bodies 5−11). The mean concentrations of DIN ranged from 0.089 mg L^{-1} (in the drinking-water reservoir) to 0.078 mg L^{-1} (in water

Table 3
Average values for the investigated forms of carbon (inorganic carbon, IC; dissolved organic carbon, DOC; and total carbon, TC), pH, conductivity, and concentrations of chloride and sulfate ions and silica in the water bodies studied in the Thomas Point Oasis.

Water body no.	IC	DOC	TC	pH	Conductivity	Cl^-	SO_4^{2-}	SiO_2
	mg L^{-1}				µS cm^{-1}	mg L^{-1}		
1	2.75 (0.23)[a]	0.68 (0.36)	3.57 (0.74)	7.81 (0.13)	165.6 (15.8)	41.94 (6.12)	8.91 (2.91)	1.718 (0.954)
2	3.60 (0.98)	1.91 (0.55)	5.91 (0.73)	7.95 (0.26)	665.0 (270.4)	162.64 (104.1)	63.06 (27.6)	2.123(2.77)
3	6.48	3.20	12.36	8.78	3400	850.0	236.0	3.820
4	12.42 (4.05)	11.53 (4.14)	26.90 (7.23)	7.72 (1.08)	1070.7 (471.1)	247.9 (162.3)	85.66 (54.7)	0.491 (0.233)
5	1.02 (0.13)	0.30 (0.21)	1.38 (0.87)	7.36 (0.15)	109.2 (10.1)	30.17 (7.1)	2.11 (1.01)	0.134 (0.101)
6	2.65(0.28)	1.94 (0.81)	5.21 (1.20)	7.04(0.20)	156.1 (25.5)	40.08(9.2)	3.09(1.12)	0.922 (0.307)
7	2.54 (0.75)	3.05 (0.97)	5.95 (1.32)	7.10 (0.11)	164.9 (30.6)	44.40 (6.6)	4.86 (0.86)	0.693 (0.452)
8	2.32 (0.34)	2.83 (1.11)	5.46 (0.87)	7.23 (0.22)	147.8 (12.3)	33.70 (9.0)	4.58 (0.93	0.756 (0.243)
9	1.15 (0.51)	1.02 (0.61)	2.34 (0.95)	8.02 (0.38)	253.0 (10.1)	46.10 (11.2)	7.55 (2.12)	0.809 (0.395)
10	1.98 (0.68)	1.94 (0.58)	4.21 (1.02)	6.80 (0.11)	197.4 (21.5)	53.20 (8.8)	6.62 (3.08)	0.944 (0.416)
11	1.81 (0.75)	1.16 (0.74)	3.24 (1.12)	7.44 (0.15)	173.8 (23.0)	40.80 (10.0)	5.14 (2.10)	0.219 (0.087)

[a] Standard deviation.

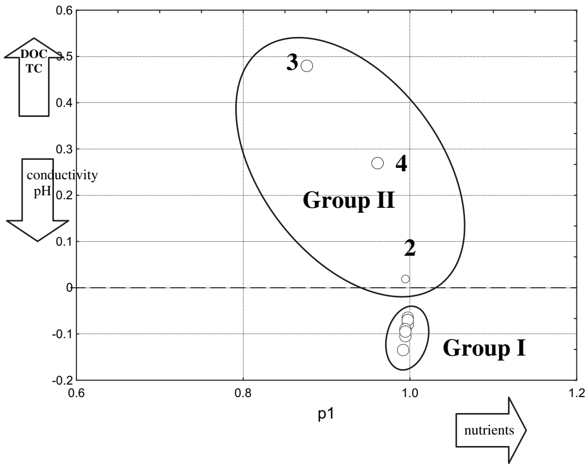

Fig. 2. Principal components analysis (PCA) of sampling sites based on the standardized physical and chemical parameters; plot of 11 water bodies according to their scores for factor 1 (p1) and factor 2 (p2) (group I, water bodies 1, 5–11; group II, water bodies 2–4).

bodies 5–11). Among the forms of mineral nitrogen assessed, nitrate-N prevailed over ammonium-N and nitrite-N in this group of water bodies (Table 2).

Concentrations of both organic and total N were lower in the drinking-water source and higher in water bodies 5–11; the mean concentrations of organic nitrogen were 0.072 and 0.257 mg L^{-1}, respectively, whereas those of total N were 0.176 and 0.350 mg L^{-1}, respectively.

The mean concentration of TP in water bodies 1 and 5–11 ranged from 0.022 to 0.065 mg L^{-1}, and the TP in water bodies 5–11 was lower on average (0.036 mg L^{-1}) than in the drinking-water reservoir (average 0.066 mg L^{-1}). Similar differences were also observed for DRP and TOP (Table 2).

The salinity of these water bodies was also limited, e.g., the mean values for conductivity ranged from 109.2 µS cm^{-1} in water body 5 to 253 µS cm^{-1} in water body 9. The concentrations of chloride and sulfate ions in these water bodies were also low (Table 3).

The average values for TC in the water bodies ranged from 3.57 mg L^{-1} (drinking-water reservoir) to 3.97 mg L^{-1} (average for water bodies 5–11). The drinking-water reservoir was characterized by higher IC concentrations and lower DOC concentrations compared with those of water bodies 5–11 (Table 3).

3.1.2. Group II-higher concentrations of analyzed nutrients

Higher N and P concentrations and high salinity were noted in water bodies 2–4 (Tables 2, 3). The TN concentrations in this group ranged from 1.645 to 29.21 mg L^{-1} and the TP concentrations ranged from 0.177 to 18.35 mg L^{-1} (Table 2).

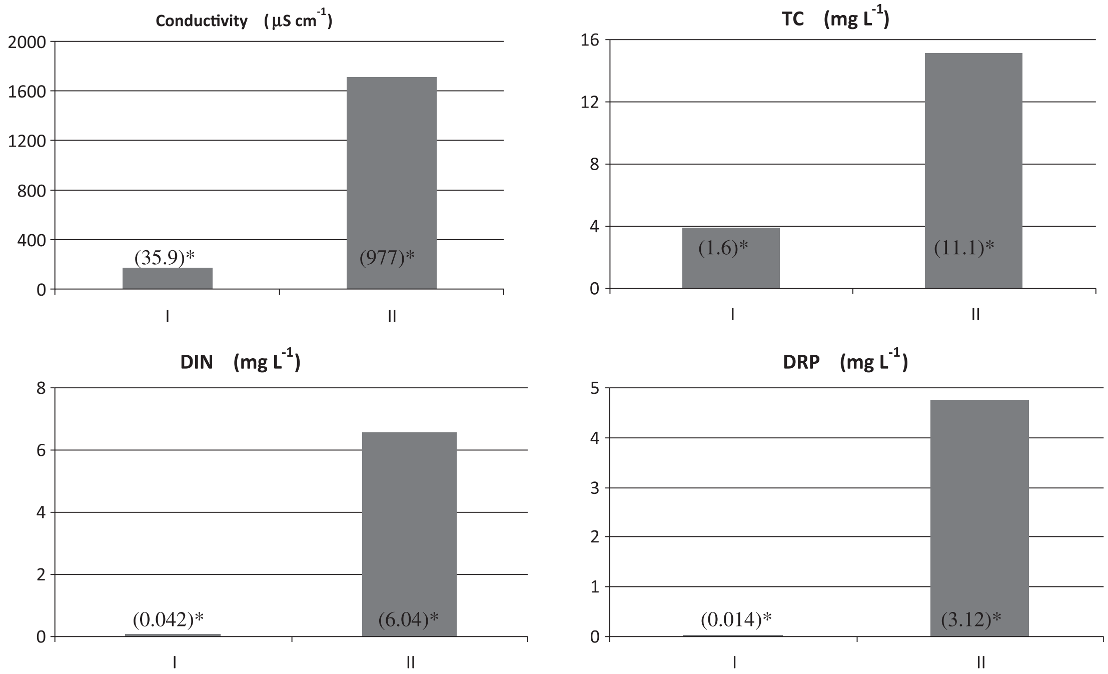

Fig. 3. Mean conductivity, total carbon (TC), dissolved inorganic nitrogen (DIN), and dissolved reactive phosphorus (DRP) for each PCA group (I and II) of water bodies. * Standard deviation.

Table 4
Trophic status of the studied water bodies on the basis of their total nitrogen (TN), total phosphorus (TP), and dissolved organic carbon (DOC); index concentrations are given in mg N, P, or C L^{-1}. **O**, oligotrophic (TN < 0.355; TP < 0.010; DOC 1–3); **M**, mesotrophic (TN 0.350–0.650; TP 0.010–0.030; DOC 2–4); **E**, eutrophic (TN 0.650–1.200; TP 0.030–0.100; DOC 3–34); **H**, hypertrophic (TN > 1.200; TP > 0.100; DOC 20–50). Concentration ranges for TN and TP by Nürnberg (1966) and concentration range for DOC by Thurman (1983).

Water body no.	TN	TP	DOC
1	O	E	O
2	H	H	O/M
3	H	H	E
4	H	H	E
5	O	M	O
6	M	E	O
7	M	E	O
8	M	E	O
9	O	E	O
10	O	M	O
11	O	E	O

Water body 2 had a very high mean concentration of nitrate-N and a rather low concentration of ammonium-N (0.769 and 0.086 mg L^{-1}, respectively). In contrast, water bodies 3 and 4 displayed the reverse trend, with 8.27 and 8.09 mg L^{-1}, respectively, from ammonium-N, and just 0.082 and 2.333 mg L^{-1}, respectively, from nitrate-N.

Low TP values characterized water body 2, whereas the TP concentrations in water bodies 3 and 4 were far higher (0.177, 18.35, and 6.54 mg L^{-1}, respectively).

Salinity values were also higher in water bodies 2–4 than in the other water bodies, e.g., the mean values for conductivity varied across a range from 665 to 3400 μS cm^{-1} (Table 3).

The average concentration of TC in this group of water bodies varied from 5.91 mg L^{-1} (water body 2) to 26.9 mg L^{-1} (water body 4). Water body 4 was also characterized by the highest DOC concentration (11.53 mg L^{-1}) among all the water bodies studied (Table 3).

3.2. The trophic state

A knowledge of the N and P concentrations in lakes is a prerequisite for their trophic classification. This classification system allows us to distinguish between the least fertile oligotrophic water bodies and their mesotrophic and eutrophic counterparts (Nürnberg, 1996; Smith et al., 1999). When nitrogen concentrations are considered, our data classify the drinking-water source (water body 1), together with water bodies 5 and 9–11, as oligotrophic, in contrast to the mesotrophic water bodies (6–8; Table 4).

In contrast, when P concentrations are used as the standard, the water bodies in our study are primarily eutrophic (water bodies 1, 6–9, and 11). Only water bodies 5 and 10 fall within the mesotrophic category in terms of their P concentrations. The remaining lakes (water bodies 2–4) have sufficient concentrations of TN and TP to be classified as hypertrophic.

Based on the classification of Thurman (1983), our DOC values suggest that the analyzed water bodies could be classified as oligotrophic (water bodies 1 and 5–11), at the boundary between oligotrophic and mesotrophic (water body 2), and eutrophic (water bodies 3 and 4; Table 4).

3.3. Taxonomic composition of the biota in selected water bodies

The taxonomic compositions of the flora and invertebrate fauna were determined in selected water bodies 2, 3, and 4. Taxonomic differences were observed, with the highest biodiversity recorded in water body 2, and more limited diversity found at the other two sites (Table 5).

A characteristic feature of the water bodies studied was the dominance of diatoms. Lake Wujka (water body 2) had the highest numbers of diatoms (17 species). In contrast, water bodies 3 and 4 were distinguished by the presence of *Euglena* spp. Lake Wujka (water body 2) was also characterized by the greatest faunal diversity (Table 5). An interesting discovery in Lake Wujka was the two crustacean species *Branchinecta gaini* Daday and *Boeckella poppei* Mrazek, which were absent from water bodies 3 and 4.

Rotifers were observed in water bodies 2 and 4. Other groups of invertebrates observed included protists, nematodes, and tardigrades (Table 5).

4. Discussion

This hydrochemical study revealed marked differences in the concentrations of N and P from one water body to another, allowing their assignment to different groups on the basis of their concentrations of biogenic elements. Similar observations were made by Vinocur and Unrein (2000) in water bodies on the Potter Peninsula and by Toro et al. (2007) in water bodies on the Byers Peninsula. The smaller Antarctic water bodies are strongly affected by their catchments, and each inflow of precipitation modifies their hydrochemical conditions (Izaguirre et al., 1998; Vinocur and Unrein, 2000).

Table 5
Flora and fauna of selected water bodies.

	Flora	Fauna
Water body 2 *Lake Wujka*	* Diatoms: *Achnanthes cf. helvetica* S. Wunsam, *Amphora pediculus* (Kützing) Grunow, *Caloneis* sp., *Chammaepinularia* sp., *Diadesmis tabelariaeformis* Lange-Bertalot & Wojtal, *Fragilaria capucina* Desm., *Gomphonema augustatum* Kiitz., *Hantzschia* sp., *Hippodonta hungarica* (Grunow) Lange-Bert., *Luticola mutica* (Kützing)*, L. muticopsis* (van Heurck), *Navicula gregaria* Donkin., *Nitzschia homburgensis* Lange-Bertalot, *Pinularia borealis* (Hust.) Krammer, *Planothidium delicatulum* (Kütz.) Round & Bukht., *Psammothidium pseudoinvestiens,* and *Staurosira construens* Ehr. * Filamentous algae from Conjugatophyceae: *Spirogyra* sp. and *Zygnema* sp. * Single filamentous: *Ulotrix* sp. * Cyanoprocariota: *Oscillatoria* sp.	* Nematodes * Tardigrads * Rotifers: *Cephalodella catellina* (O. F. Müller), *Lepadella patella* (O. F. Müller), *Epiphanes senta* (O. F. Müller), *Notholca squamula salina* Focke, Bdelloids n.d. * Copepods: *Boeckella poppei* Mrazek * Anostraca: *Branchinecta gaini* Daday
Water body 3 *Ipanema Beach* - pond (penguins present)	* Sparse diatoms from genera *Navicula* * Diatoms: *Fragilaria capucina* Desm., *Navicula mutica* Kütz., *Achnanthes* sp., *Pinnularia* sp. * Single filamentous: *Ulotrix* sp. * Euglena: *Euglena* sp. * Cyanoprocariota: *Oscillatoria* sp. * Algae from group Chrysophyceae: *Trochiscia rubra* Kol.	* Protists * Nematodes
Water body 4 *Copa Hut Pond* (penguins present)	* Diatoms: *Fragilaria ulna* (Nitzsch) Lange-Bertalot, *Navicula* sp., *Pinnularia* sp. * Filamentous algae from Conjugatophyceae: *Spirogyra* sp. * Filamentous algae from genus *Ulotrix* * Green algae: *Crucigenia* sp. * Euglena: *Euglena* sp. * Cyanoprocariota: *Jaaginema pseudogeminatum* (Schmid) Anagn & Kom, *Oscillatoria* sp.	* Protists * Nematodes * Rotifers: *Epiphanes senta* (O. F. Müller), *Cephalodella catellina* (O. F. Müller), *Lepadella patella* (O. F. Müller), *Resticula nyssa* Haring & Myers

The higher concentration of nitrate-N relative to that of ammonia-N in the water bodies studied may reflect nitrification, or else be linked to the nature of the immediate catchments (water bodies 6–10 are on ornithogenic soils). As Tatur (2002) made clear, the surface run-off infiltrating this kind of soil causes a prevalence of nitrate over ammonium. The marked differences in the organic nitrogen in these water bodies can be attributed to the presence or absence of colonies of breeding birds. The reservoir is supplied by Petrifield Forest Creek, whose basin is free of any influence of penguin rookeries, so the concentrations of biogenic elements are very low (Nędzarek, 2006). In contrast, water bodies 6–11 lie close to breeding colonies of either penguins or flying birds. Moreover, water bodies 6–10 are surrounded by the ornithogenic soils arising from the mineralization of guano and the phosphatization of clayey detritus. Tatur and Myrcha (1984) showed that these types of soils bind phosphorus compounds strongly and durably, a process that probably explains why the P concentrations are even lower in water bodies 6–10 than in the drinking-water reservoir (Table 2).

Precipitation is an important source of biogenic compounds (especially ammonium-N) for the part of the Thomas Point Oasis terrestrial ecosystem located further from the seabird colonies. As Nędzarek and Rakusa-Suszczewski (2007) demonstrated, precipitation enriched in N and P at the colonies passes further inland and hence enriches soils otherwise poor in nutrients. Rain samples collected at the center of a penguin colony had 0.221 mg L^{-1} ammonium-N on average, whereas rain falling in the Jersak Hills (where water body 5 is located) recorded a lower mean value of 0.071 mg L^{-1}, which was still three times the mean value for water bodies 5–11. The concentrations of reactive phosphorus in rain samples from the penguin colony were 0.096 mg L^{-1} compared with ca. 0.010 mg L^{-1} inland (Nędzarek and Rakusa-Suszczewski, 2007), which are slightly lower than those in water bodies 5–11.

One of the main sources of the mineral salts in these waters is precipitation. Nędzarek and Rakusa-Suszczewski (2007) reported a mean annual conductivity for the rainfall in this area of 290 μS cm^{-1}, compared with the highest average of 1613 μS cm^{-1} on the coastal terraces.

Very high concentrations of N and P were noted in water bodies 2–4. The features common to all these sites are their location on the least-elevated coastal terraces and the strong influence exerted by penguin colonies. Within this group of water bodies, the least productive was no. 2 and the most nutrient-rich was no. 3 (Table 2). These differences may again be attributable to the varying impacts of penguin rookeries. Water body 2 is fed by two streams that drain sites of Adélie penguin (*Pygoscelis adeliae*) colonies some 600 m away and include in their basins wet grasslands, with *Deschampsia antarctica* Desv. and mosses, and relict ornithogenic soils. In contrast, water body 3, located in the middle of a small Gentoo penguin (*Pygoscelis papua*) colony, receives the direct input of leachate from guano deposited on the surrounding land. Water body 4 is close to the U.S.A. P.J. Lenie field camp and its northern shore is at the center of a colony of Gentoo penguins. Land not directly affected by the rookery is overgrown with grass and moss.

Water body 2 reflects the inflow of water infiltrating relict ornithogenic soils, rich in nitrates (Tatur, 2002), and the process of nitrification (Toro et al., 2007). Conversely, the alimentation of water bodies 3 and 4 involves direct flow from penguin colonies. This runoff carries a heavy load of guano in suspension and some soluble nutrient components are also present in solution. Mineral nitrogen is dominated by ammonium, and the reactions of these waters are neutral or basic (Tatur, 2002). The same dependent relationships may account for the differences observed in the concentrations of phosphorus compounds in the three different water bodies. The basin drained by the streams that feed water body 2 has a capacity to accumulate phosphorus compounds (Tatur and Myrcha, 1984). This influence of a maritime ecosystem on freshwater water bodies and catchment areas via birds and marine mammals is a major source of the nitrogen and phosphorus enrichment of Antarctic lakes (Izaguirre et al., 2003; Toro et al., 2007; Vinocur and Unrein, 2000).

The salinity values were also higher in water bodies 2–4 than in the others bodies, varying across the conductivity range of 665–3400 μS cm^{-1} (Table 3). This situation is of course influenced by their shore-zone locations, plus their receipt of marine aerosols (Juchnowicz-Bierbasz, 1999; Nędzarek and Rakusa-Suszczewski, 2007; Pociecha, 2008; Pociecha and Dumont, 2008). As Pociecha (2008) showed for Lake Wujka (water body 2), the conductivity of the water can reach 37,600 μS cm^{-1} whereas the water temperature drops to −1 °C.

The trophic status of shallow water bodies depends on allochthonous matter and autochthonous productivity. A high trophic state is conditioned by the direct and indirect inflow of organic matter from breeding colonies of birds and marine mammals (Izaguirre et al., 1998; Toro et al., 2007; Vinocur and Unrein, 2000). In particular, water body 3 was enriched by penguin guano. In contrast, the water bodies of group I was not influenced by animals and exhibited oligotrophic characteristics, with low nutrient concentrations and profusely developed microbial mats (personal observations). This pattern was also observed in the lakes on Signy Island (Heywood, 1978) and a pond on Livingston Island (Davey, 1993), where the clear, nutrient-poor waters had well-developed, species-rich, perennial benthic microbial mats dominated by filamentous Cyanobacteria, diatoms, and chlorophytes. In the small pond on Livingston Island, the mat was not limited by nutrient availability, because both phosphorus and nitrogen were available in the overlying water and the N:P ratios in both the water and the mat indicated a roughly balanced supply (Davey, 1993). The N:P ratios in many of the analyzed water bodies were low (an atomic ratio of 20 is usually taken to indicate a balanced supply) (Heckey and Kilham, 1988) and if any nutrient was limiting, nitrogen was the most likely candidate. The high proportion of DON in the total nitrogen of these water bodies indicates possible nitrogen enrichment. Benthic mats covered a large area of the bottom and could be an important source of nitrogen enrichment, as occurs in other freshwater Antarctic ecosystems (Hawes and Brazier, 1991).

Climatic conditions in the Maritime Antarctic region are less extreme than those on the Antarctic continent. In this region, terrestrial aquatic ecosystems such as ponds, lakes, and other water bodies usually contain liquid water and become ice-free in summer. This allows the colonization of the Antarctic ecosystems by aquatic organisms (Camacho, 2006; Ochwanowski and Pociecha, 2005; Pociecha and Dumont, 2008; Toro et al., 2007).

The compositions of the microflora and fauna of the studied water bodies resemble those of other coastal lakes in Antarctica (Bayly et al., 2003; Izaguirre et al., 1998, 2003; Toro et al., 2007). The high densities of diatoms (6000 cells mL^{-1}; Ochwanowski and Pociecha,

2005) and large numbers of diatom species observed in Lake Wujka are characteristic of water bodies with high concentrations of silica and nitrate, which are both essential for diatom development (Wilk-Woźniak and Ligęza, 2003). The high diatom densities in Lake Wujka could also be associated with good water mixing and salinity. This observation was confirmed by Van de Vijver and Beyens (1999), who observed diatoms in circumneutral lakes with low chloride concentrations and in coastal pools with relatively high chloride levels.

In contrast to water body 2, *Euglena* spp. were prominent in water bodies 3 and 4, where the concentrations of ammonium-N were very high. Nitrogen in this form may be an important stimulatory factor for euglenophyte development. Bucka and Wilk-Wozniak (2007) showed that this group colonizes temporary fresh waters with high concentrations of organic substances and ammonium, and they may also occur in saline waters. Their presence also points to more-advanced eutrophication in water bodies 3 and 4 than in water body 2. Similar results showing a high concentration of nitrogen and the presence of *Euglena* species were reported by Vinocur and Unrein (2000) for a small water body (designated B) located inside Adélie and Gentoo penguins rookeries.

The observed taxonomic differences (highest biodiversity in water body 2 and more limited diversity at the other two sites) can be attributed to the effects of nearby penguin colonies. Differences in the microflora and fauna compositions of water bodies 3 and 4 compared with those of Lake Wujka (water body 2) probably reflect the direct impact of large numbers of Gentoo penguins on the former two sites.

It is interesting that the two crustacean species *B. gaini* Daday and *B. poppei* Mrazek were only observed in high densities in Lake Wujka. The summer densities of the two crustacean species reached 10 and 110 individuals per liter, respectively (Pociecha and Dumont, 2008). *B. gaini* is an unselective filter feeder, whose diet is determined by the food size it can handle. It collects benthic cyanobacteria, diatoms, protozoa, and rotifers, as well as fragments of the appendages of *B. poppei* and *B. gaini* itself (Björck et al., 1996; Paggi, 1996). *Boeckella* and *Branchinecta* may compete for food particles that are larger (*Fragilaria*) or smaller (bacteria). All these food particles were abundant in the water bodies investigated, although water bodies 3 and 4 sustained markedly lower species diversity, especially of diatoms. Food availability could be a factor underpinning the presence or absence of crustacean species. Because Gentoo penguins nest close by water bodies 3 and 4, the two kinds of crustaceans (both large and colorful) could have been consumed by them. However, we did not observe crustacean consumption by penguins in the field. *B. gaini* grows to 2.5 cm in length and is cream colored, whereas *B. poppei* grows to no more than 2 mm in length and is reddish.

The present study has shown that the freshwater flora and fauna in these lakes can be divided into two groups: one is characteristic of Lake Wujka (water body 2) and the second is characteristic of water bodies 3 and 4. It seems that some other physical, chemical, or biological features that were not addressed in this study could control the distributions of these organisms, which will be the focus of future studies.

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