―研究ノート―
Scientific Note

Summer Changes in the Vertical Distribution of Chlorophyll-*a* in Boeckella Lake (Hope Bay, Antarctic Peninsula)

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Boeckella 湖 (南極半島, ホープ湾) における 夏季のクロロフィル-*a* 鉛直分布変動

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要旨: Boeckella 湖における植物プランクトン由来のクロロフィル-*a* 鉛直分布を1992年及び1993年の夏季に調査した. 隣接するペンギンルッカリーからの有機物流入度合いの異なった二つの調査点を設け, 3水深から試料採取し比較検討した. クロロフィル-*a* 濃度は, 1993年の晩夏に湖氷が融解する期間において, 0.10 μl^{-1} 以下から 14.08 μl^{-1} まで変動した. 計測したリン酸態リン濃度は 14.77–970.46 μg PO_4-P l^{-1} で, 他の栄養塩負荷の大きな南極湖沼の値と匹敵するものであった. 二つの調査点間には, 電気伝導度, pH, リン酸塩濃度及びクロロフィル-*a* において顕著な差異が認められ, その湖における湖沼学的特長にペンギンルッカリーが多大な影響を及ぼしていることが推察された. これらの差異は特に氷で覆われている期間により大きくなっていた.

***Abstract*:** Vertical distribution of phytoplanktonic chlorophyll-*a* in Boeckella Lake was studied during summer periods in 1992 and 1993. Two opposite sites subjected to different organic matter inputs from the adjacent penguin rookeries were periodically sampled at three depths. Chlorophyll-*a* concentrations varied from less than 0.10 $\mu g\ l^{-1}$ during the ice thawing period, to 14.08 $\mu g\ l^{-1}$ during late summer 1993. Recorded phosphate values compare to data reported for other enriched Antarctic lakes (14.77–970.46 μg PO_4-P l^{-1}). Significant differences between both sampling sites were observed in relation to conductivity, pH, phosphate concentrations and chlorophyll-*a*, stressing the influence of the penguin rookeries on the limnological features of the lake. These differences were stronger during the ice cover period.

1. Introduction

This study is part of a research project supported by the National Antarctic Direction (Argentina) on taxonomy and ecology of freshwater algae from Hope Bay. In particular, between 1991 and 1993 the investigations have focused on the phytoplankton community of Boeckella Lake, since this is the main water body of Hope Bay and the source of drinking water for "Base Esperanza".

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The southern edge of the lake sets the limit of an extensive Adélie penguin rookery, which has increased during the last decades. In particular, a small colony located on this site increased from 40 to 277 nesting pairs between 1963 and 1985 (Myrcha *et al.*, 1987).

The first limnological report about nutrients inputs into Boeckella Lake was given in Izaguirre *et al.* (1993). Results of this work revealed that the lake receives a high phosphate load from the adjacent rookeries, which accounts for the high phytoplankton densities developing in summer. Observed differences between margins appeared to be partially due to this natural eutrophication.

The present study describes the temporal and vertical changes of chlorophyll-*a* and nutrients in the lake during two summers. For this purpose, samplings were conducted at different depths from two opposite sites of the lake subjected to different inputs of ornithogenic organic matter.

2. Study Site

Boeckella Lake, whose main morphometric features were given in Izaguirre *et al.* (1993), is situated on a fluvio-glacial depression about 500 m away from the sea. It is located on rocks of the triassic "Trinity Formation" (Myrcha *et al.*, 1987), which were once formerly occupied by rookeries, thus displaying relic phosphatic soils with a high C/N ratio (Tatur, 1989).

Retention time of the lake was estimated as varying from 2–3 days (ice thawing

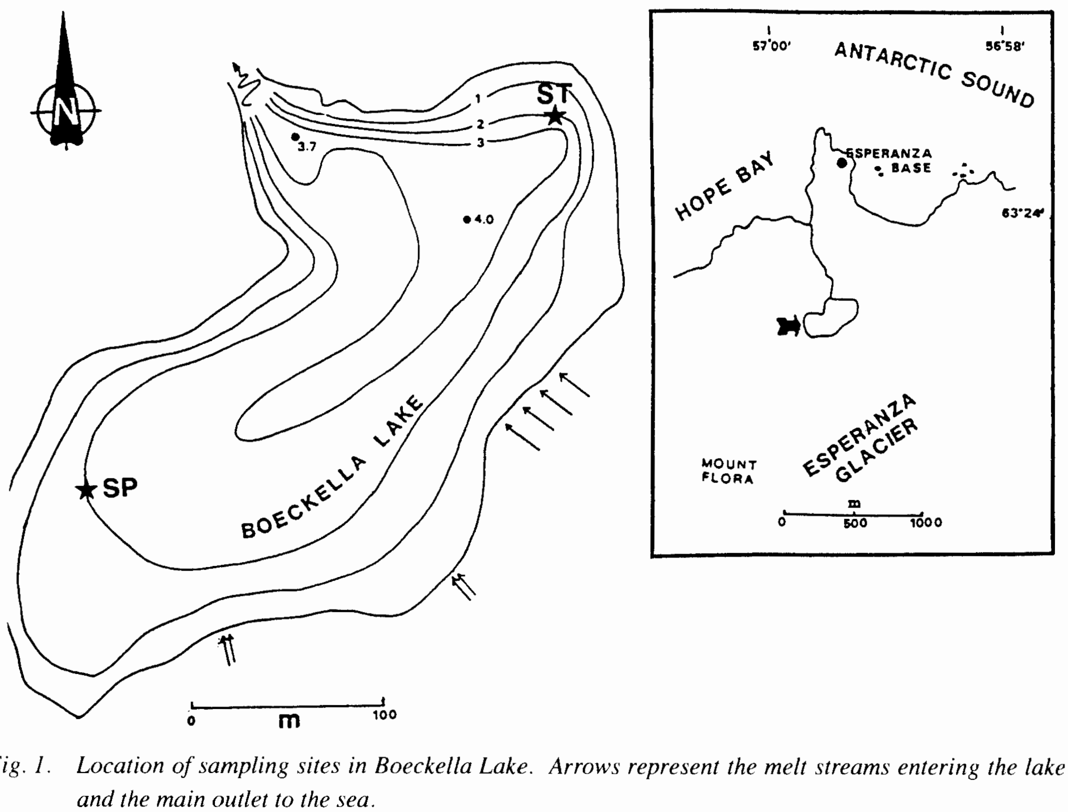

Fig. 1. Location of sampling sites in Boeckella Lake. Arrows represent the melt streams entering the lake and the main outlet to the sea.

period) to 15 days (low water period) on the basis of previous morphometric data of Boeckella Lake (DRAGO and PAIRA, 1987) and water discharge of its effluent (PIZARRO *et al.*, 1996).

At present, the lake receives a high amount of nutrients each summer from the big colony of Adélie-penguins of Hope Bay. According to our first observations, there are important differences between the margins of the lake, the site located at the base of the rookeries being the most eutrophic one. Two sampling sites were thus established in pelagial zones: ST (near Trinity British Station: "Trinity House") and SP (near the margin influenced by the rookeries), the positions of which are illustrated in Fig. 1.

3. Materials and Methods

Samplings were conducted periodically at the two preselected sites during summers of 1992 and 1993.

Water samples were taken from the surface, 1 m and 2 m (close to the bottom) depths using a peristaltic pump and placed in opaque containers during field manipulations. Water temperature, conductivity, pH and oxygen concentration were measured *in situ* with Luftman P300 and C400 combined electronic meters, and transparency with a Secchi disk.

At Esperanza Station, water samples were sequentially filtered through Whatman GF/F and 0.2 μm Nucleopore membrane filters for chlorophyll-*a* and nutrient analyses respectively. GF/F filters were frozen for 24 h in order to disrupt the algal membranes. Extraction into methanol was performed heating to boil for 2 min in a water bath. Chlorophyll-*a* concentrations were determined using a Beckman DU-65 spectrophotometer, and following SCOR-UNESCO (1966) equations.

Water samples for nutrient assessments were stored in PVC flasks and preserved frozen (–20°C) for two months until their analysis back in Buenos Aires. Dissolved reactive phosphorus (DRP) was determined following the Stannous Chloride method, while Nitrate and Nitrite concentrations were estimated using the Cadmium Reduction Method according APHA-AWWA-WPCF (1975).

A nonparametric Wilcoxon test (DANIEL, 1978) was used to establish the significance level of differences observed between sites in relation to some abiotic and biotic factors. Average values of the three depths were used for each factor.

4. Results and Discussion

4.1. Physical and chemical properties

During summers of 1992 and 1993, water temperature in Boeckella Lake varied between 0°C and 4.5°C (Fig. 2). Thermic stratification was evident from 13 January to 20 January 1992, when the lake was ice-covered. Opposite to what occurred during the summer of 1991 (IZAGUIRRE *et al.*, 1993), the lake surface remained free of ice until mid-March and water temperature remained above 0°C in 1992 and 1993. The highest value was recorded on 11 February 1993, after several sunny days and in coincidence with a low water level.

pH values ranged between 5.1 and 7.0, the highest ones being recorded during very

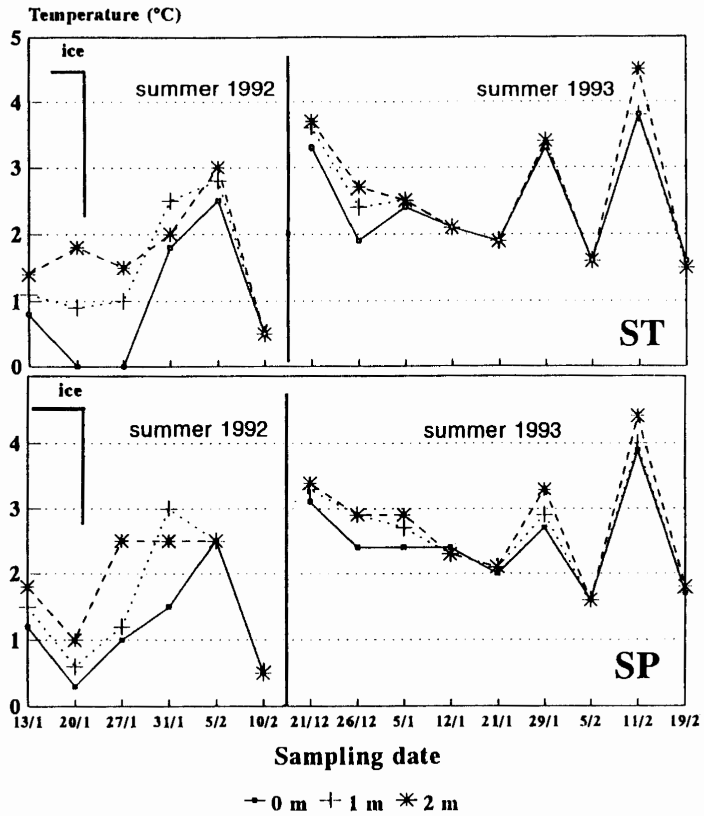

Fig. 2. Summer temperature variations at ST and SP for each studied depth.

sunny days. A high photosynthetic rate would probably account for this fact (Fig. 3a).

Dissolved oxygen concentrations were usually high (10–12.5 mg l^{-1}), and in some cases closes to saturation or super-saturation. This fact has also been observed in other Antarctic lakes (Torii *et al.*, 1988).

Conductivity was significantly higher in SP than in ST (Fig. 3b) according to the nonparametric Wilcoxon test ($P<0.004$). These results agree with the first observations reported for littoral sites of the lake (Izaguirre *et al.*, 1993). Also pH values were significantly higher in SP ($P<0.025$).

Transparency varied between 0.36 m (SP, 26/12/92) and 1.74 m (ST, 27/01/92). Highest values were registered when the lake was frozen and quiet, whereas the lowest ones are associated with the discharge peak of the melt streams that carry a great deal of sediments into the lake (Fig. 4). In general, transparency values were higher at the ST sampling site.

4.2. Nutrients

According to DRP values, which ranged between 14.77 and 970.46 μg PO_4-P l^{-1}, Boeckella Lake shows mesotrophic to very eutrophic conditions (Fig. 5). These high concentrations of phosphorus are due to the important inputs of organic matter from the adjacent penguin rookeries; the values were comparable to those registered for other Antarctic lakes receiving heavy biogenic nutrient loads (Hawes, 1990; Ellis-Evans,

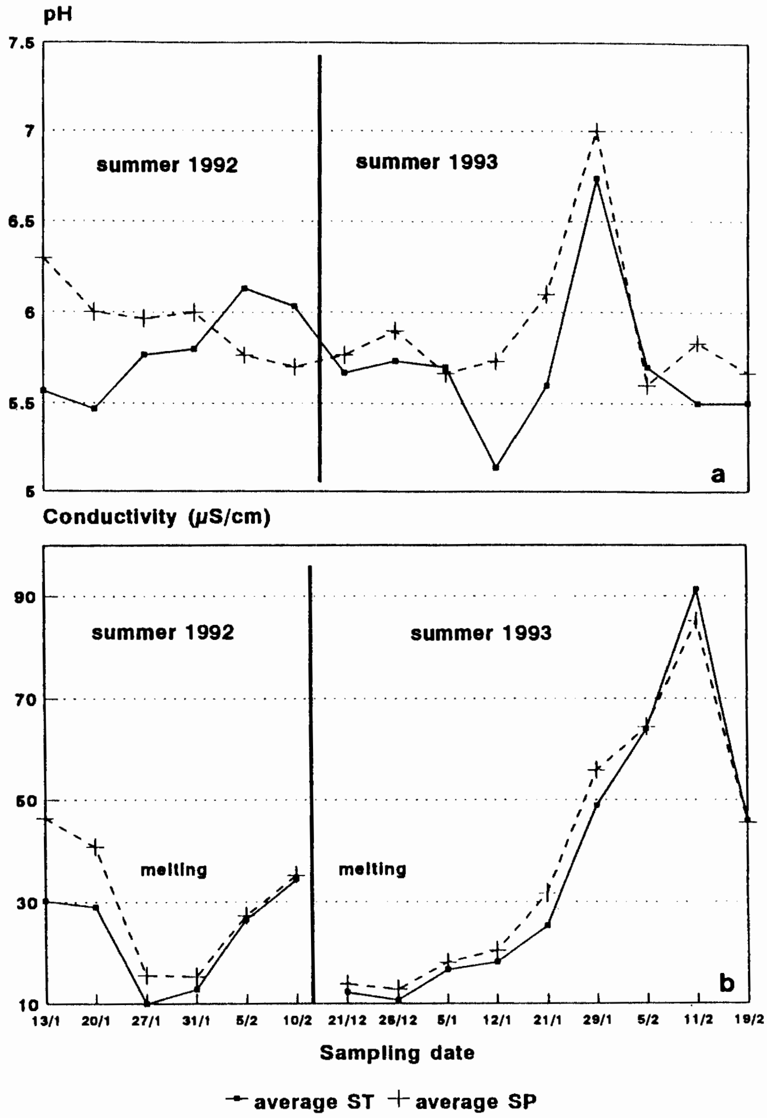

Fig. 3 a–b. Summer changes in pH and conductivity values at both sites. Average values of the three depths are plotted for each of them.

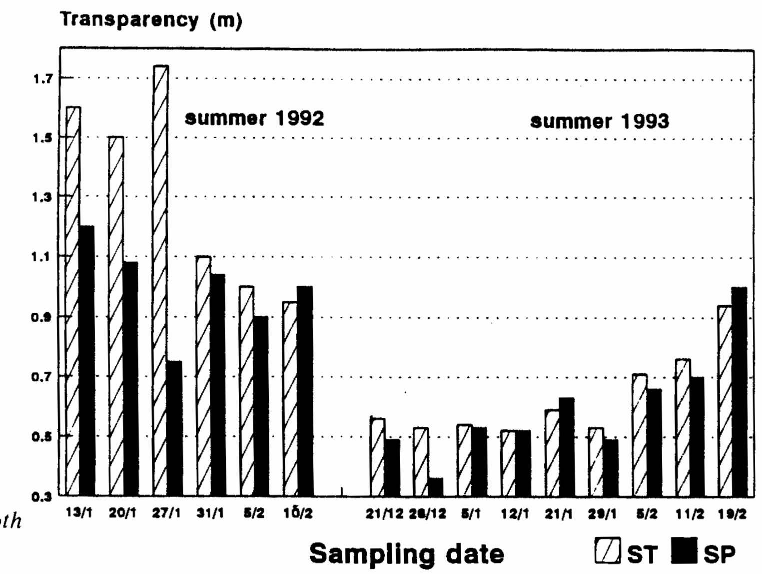

Fig. 4. Transparency values for both sites.

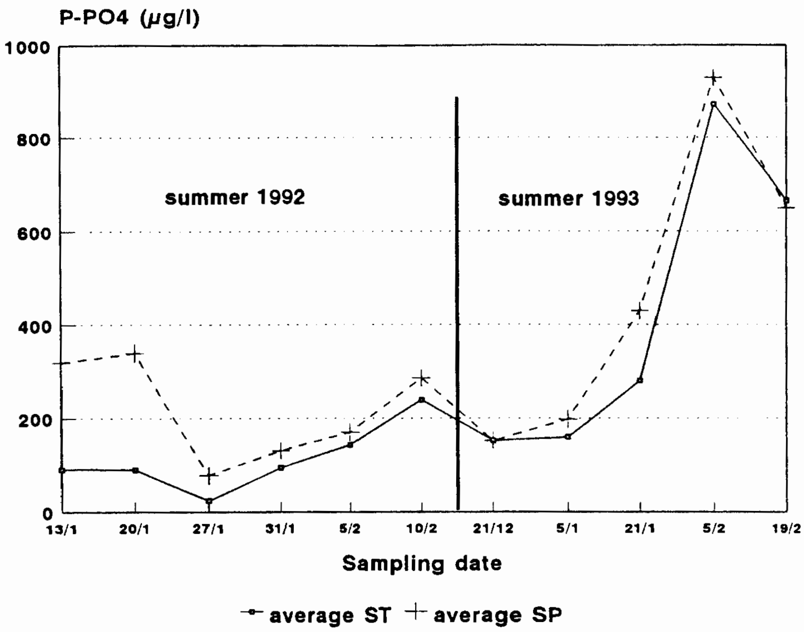

Fig. 5. *Dissolved phosphate values at ST and SP. Average values of the three depths are plotted for each of them.*

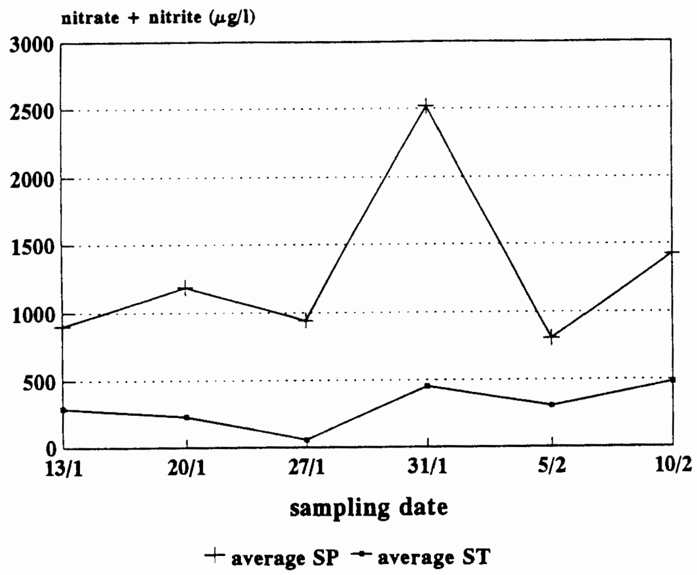

Fig. 6. *Nitrate + nitrite concentrations values at both sites. Average values of the three depths are plotted for each of them.*

1991). This fact is also supported by the results of the Wilcoxon test, which clearly show significant differences between ST and SP ($P<0.005$). These are more evident during the ice cover period, when mixing is minimum.

Nitrate and nitrite concentrations were measured only during the summer of 1992. Since concentrations of nitrite were very low in all samples, nitrogen is presented here as nitrate + nitrite (Fig. 6), ranging between 8.57 $\mu g N l^{-1}$ and 7157.42 $\mu g N l^{-1}$. This nutrient also showed significantly higher concentrations in SP (P<0.016).

Studies of the ornithogenic soils of Hope Bay showed that guano of the current soils contains high quantities of Mg-NH_4 phosphate and Ca phosphate, together with decomposed organic matter (Tatur, 1989). Relic phosphatic soils have also been preserved in the whole area between Buenos Aires glacier and Esperanza Station. Moreover, the same author found that microbiological decomposition of penguin excreta is much more rapid in Antarctic maritime areas than in continental ones. Thus, nutrient inputs to the lake from the rookeries are high and continuous during the growth season, and account for the above mentioned differences between sites.

4.3. Vertical chlorophyll-a changes

Profiles of chlorophyll-*a* concentrations during summers 1992 and 1993 are illustrated in Fig. 7. These were generally low and typical of oligotrophic lakes. Lowest values were recorded during maximum melt stream discharge owing to dilution. In

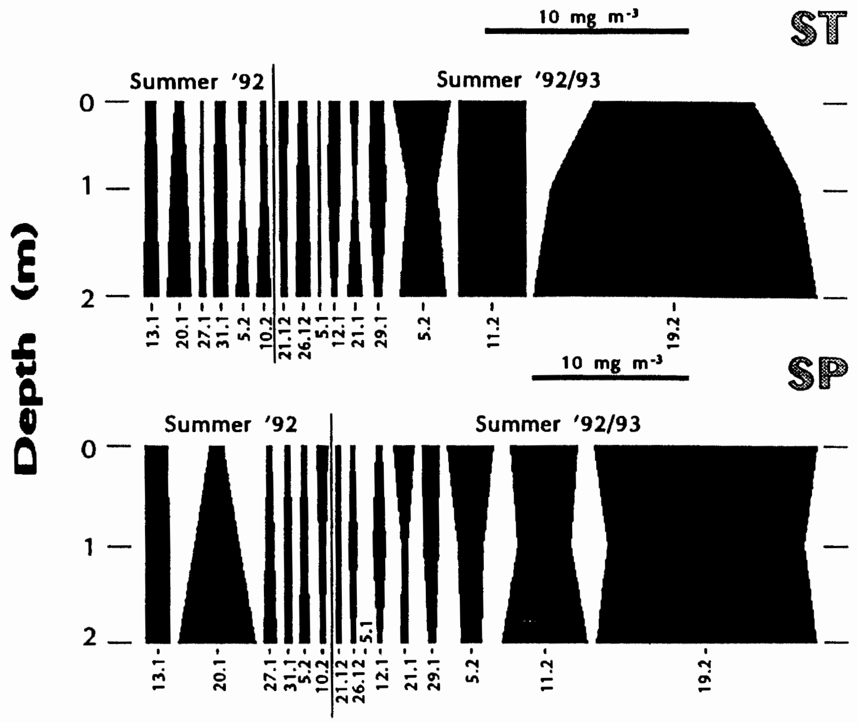

Fig. 7. Changes in chlorophyll-a (uncorrected for phaeopigments) profiles for ST and SP during summers 1992 and 1993.

particular, in early January 1993, a strong increase in both the lake level and the melt stream discharge resulted in undetectable chlorophyll-*a* concentrations. Nevertheless, when environmental contitions became favorable for algal growth, a rapid increase of chlorophyll-*a* took place. During the first two weeks of February 1993, no snowfall was resistered, and the highest values of water temperature (3.8–4.5°C) and concomitant low levels of both melt streams and lake were recorded. Under these unusual conditions, phytoplankton increased rapidly, giving rise to the chlorophyll-*a* peaks

Table 1. Comparisons between phytoplankton abundance and chlorophyll-a in Boeckella Lake (ST and SP sites).

	Algal density (ind. ml^{-1})		Chlorophyll-*a* ($\mu g l^{-1}$)	
	ST	SP	ST	SP
13/01/92	3672	15178	0.807	1.849
20/01/92	3296	31702	0.856	3.130
27/01/92	1680	3198	0.304	0.563
31/01/92	223	178	0.642	0.613
05/02/92	120	102	1.296	0.834
10/02/92	173	174	0.791	0.708
21/12/92	52	42	0.342	0.287
26/12/92	257	76	0.548	0.314
04/01/93	73	17	0.080	ND
12/01/93	110	20	0.437	0.466
20/01/93	77	36	0.383	0.740
29/01/93	136	126	0.603	0.847
03/02/93	654	1261	2.180	1.976
11/02/93	1581	2373	2.208	4.481
19/02/93	5069	6151	11.175	13.446

observed during mid-February (7.7–14.08 $\mu g l^{-1}$). These values compare to those recorded for other enriched mesotrophic Antarctic lakes (HAWES, 1985a, b; ELLIS-EVANS, 1991). This fact is also shown by the total phytoplankton densities (POSE, 1995). Table 1 displays comparisons between chlorophyll-*a* and phytoplankton abundance.

Even though an important phytoplankton peak was also recorded from 13 to 20 of January 1992 (mainly in SP), chlorophyll-*a* showed a relatively minor increase. This fact can be explained by the dominant group during this period (Chrysophyceae represented by *Ochromonas* sp.), which developed an under-ice bloom. As has been discussed by other authors, the species of this group can adapt to low-light, and have a diverse complement of photosynthetic pigments very similar to those of diatoms. In general, chl.-*a*/chl.-*c* ratios of diatoms and chrysophytes are lower than chl.-*a*/chl.*b* ratios of green algae (MARGALEF, 1983). Moreover, they are nutritionally opportunistic, being able to switch between autotrophic, heterotrophic and phagotrophic modes (SANDGREN, 1988).

According to many authors, phytoplankton in Antarctic lakes typically show a spring under-ice biomass increase. This can be, in some cases, much more rapid than the summer increase, and often chlorophyll-*a* reaches extremely high concentrations (HAWES, 1985). Although we could not measure chlorophyll-*a* changes during spring, our results show that on the two sampling dates of summer 1992, while the lake remained ice-covered, chlorophyll-*a* values were higher than those recorded at the beginning of the open water period.

Regarding the vertical distribution of chlorophyll-*a*, no definite pattern was detected. In general, the distribution was rather homogeneous during the high water level periods. A vertical stratification was evident on 20 January 1992 when chlorophyll-*a* concentration was low in the sub-ice zone, and increased toward the bottom. This observation coincides with that of HAWES (1990) for Signy Island lakes.

Comparison between sites using average chlorophyll-*a* data for each sampling date shows that its concentration is higher in SP (P<0.047 for Wilcoxon's nonparametric test). This result agrees with our first observations based on phytoplankton abundance (IZAGUIRRE *et al.*, 1993).

5. Conclusions

Boeckella Lake features are typical for a water body subjected to a natural eutrophication process. Nutrient inputs of the present and past neighboring penguin rookeries influence most of its physical, chemical and biological properties.

Strongest differences between the sampling site associated with the bird colony and the opposite one in terms of conductivity values, pH, nutrients and chlorophyll-*a* concentrations were recorded during the ice-cover period. Drastic changes in the lake chemistry take place during the melt stream discharge peak, mainly evidenced by a dramatic drop in chlorophyll-*a* concentrations. Nevertheless, the lake supports a high phytoplankton biomass during optimum conditions for algal growth, and under these conditions chlorophyll-*a* reaches high values typical of meso-eutrophic lakes.

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References

APHA-AWWA-WPCF (1975): Standard Methods for the Examination of Water and Waste-Water. Washington D. C., American Public Health Association, 1193 p.

DANIEL, W. N. (1978): Applied nonparametric statistics. Boston, Houhgton Nuffin Co., 503 p.

DRAGO, E. and PAIRA, A. (1987): Informe de la campaña antártica de verano 1986/87. Buenos Aires, Instituto Antártico Argentino.

ELLIS-EVANS, J. C. (1991): Numbers and activity of bacterio-and phytoplankton in contrasting maritime Antarctic lakes. Verh. Internat. Verein. Limnol., **24**, 1149–1155.

HAWES, I. (1985a): Light climate and phytoplankton photosynthesis in maritime Antarctic Lakes. Hydrobiologia, **123**, 69–79.

HAWES, I. (1985b): Factors controlling phytoplankton population in Maritime Antarctic lakes. Antarctic Nutrient Cycles and Food Webs, ed. by W. R. SIEGFRIED *et al.* Berlin, Springer, 245–252.

HAWES, I. (1990): Eutrophication and vegetation development in maritime Antarctic lakes. Antarctic Ecosystems: Ecological Change and Conservation, ed. by K. R. KERRY and G. HEMPEL. Proceeding of 5 th SCAR Symposium on Antarctic Biology. Berlin, Springer, 83–90.

IZAGUIRRE, I., MATALONI, G., VINOCUR, A. and TELL, G. (1993): Temporal and spatial variations of phytoplankton from Boeckella Lake (Hope Bay, Antarctic Peninsula). Antarct. Sci., **5**, 137–141.

MARGALEF, R. (1983): Limnología. Omega, Barcelona, 1010 p.

MYRCHA, A., TATUR, A. and DEL VALLE, R. (1987): Numbers of Adélie penguins breeding at Hope Bay and Seymour Island rookeries (West Antarctica) in 1985. Pol. Polar Res., **8**, 411–422.

PIZARRO, H., IZAGUIRRE, I. and TELL, G. (1996): Epilithic algae from a freshwater stream of Hope Bay, Antarctica. Antarct. Sci. (in press).

POSE, M. (1995): Análisis temporal y espacial del fitoplancton del lago Boeckella (Bahía Esperanza, Psula. Antártica). Seminario Licenciatura en Cs. Biol., Universidad de Buenos Aires, Argentina.

SANDGREN, C. D., ed. (1988): The ecology of Chrysophyte flagellates: their growth and perennation strategies as freshwater phytoplankton. Cambridge, Cambridge Univ. Press, 9–104.

SCOR-UNESCO Working Group 17 (1966): Determination of photosynthetic pigments in seawater. Monographs on Oceanographic Methodology, **1**. Paris, UNESCO.

TATUR, A. (1989): Ornithogenic soils of the maritime Antarctic. Pol. Polar Res., **10**, 481–532.

TORII, T., MATSUMOTO, G. I. and NAKAYA, S. (1988): The chemical characteristics of Antarctic lakes and ponds, with special emphasis on the distribution of nutrients. Polarforschung, **58**, 219–230.

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