

The relationship between light attenuation, chlorophyll *a* and total suspended solids in a Southern Andes glacial lake

Beatriz Modenutti, Gonzalo Pérez, Esteban Balseiro and Claudia Queimaliños

Introduction

The light climate of oligotrophic lakes is normally characterised by high transparency, leading to deep euphotic zones. However, inputs of allochthonous particles to oligotrophic lakes can affect vertical light attenuation, and, consequently, influence phytoplankton communities. Glacial lakes frequently receive inputs of finely ground rock particles of glacial origin; thus, upper glacial lakes often have a grey or whitish appearance. In contrast, the lower lakes in a series of glacial lakes can be blue because all particles have settled out of the water column.

Several oligotrophic lakes in the Southern Andes receive inputs of glacial flour. In particular, Mascardi Lake has a marked gradient in glacial inputs with opaque, whitish waters in its western arm, and very transparent waters in its eastern arm. This condition also varies seasonally since the summer ice melt

results in higher solids concentrations during January and February, while during the winter minimum solids concentrations are observed (IRIONDO 1974). In this study, we will analyse temperature, suspended solids and chlorophyll *a* (Chl *a*) and light distributions along the lake gradient in a summer sampling.

Study site

Lake Mascardi ($41^{\circ} 15' - 41^{\circ} 25' S$; $71^{\circ} 28' - 71^{\circ} 39' W$) has a V-shape with a western arm (Brazo Tronador, $z_{\max} = 118$ m) and an eastern arm (Brazo Catedral, $z_{\max} = 218$ m) (Fig. 1), and a total surface area of 39.2 km^2 . The origin of the lake is glacial (IRIONDO 1974), with a deep basin and sharp margins. Climate is temperate with westerly winds dominating. The northern-most end of Brazo Tronador receives the Upper Río Manso River. This river begins at the largest glacier (Manso Glacier) from Tronador

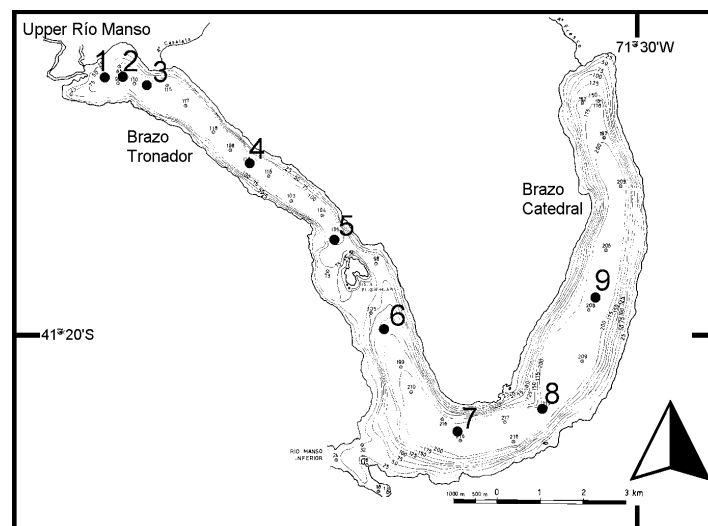


Fig. 1. Mascardi Lake and sampling stations.

Mountain (3554 m a.s.l.). During the warm months the glacier discharges large amounts of glacial flour and, therefore, streams draining this glacier are classified as white-waters (CHILLRUD et al. 1994). This feature leads to important differences between both arms of the lake, since Brazo Tronador has a high load of suspended glacial flour, while Brazo Catedral does not receive glacial flour.

Methods

Nine sampling stations were established along the two arms (Fig. 1). From December 1997 to April 1998 monthly sampling was conducted. Vertical profiles (0–60 m) of temperature, light (Photosynthetically Active Radiation, PAR) penetration, and chlorophyll *a* by in situ natural fluorescence were measured with a submersible radiometer (PUV500B). In addition, at stations 1, 3, 5, 7 and 9, 10 L of water were sampled at 0 and 20 m depth with a Schindler–Patalas trap for total suspended solids (TSS) and chlorophyll *a* determinations. Water was transported in darkness to the laboratory immediately

after sampling. TSS was determined according to APHA (1985), and Chl *a* was extracted in 90% ethanol according to NUSCH (1980).

Extinction coefficients for each sampling station were calculated by regressing natural log-transformed light irradiance against depth. In several cases, multiple linear segments were observed in the data. Consequently, partial vertical extinction coefficients were estimated for each of these linear segments.

Results and discussion

The vertical temperature profiles reflect thermal stratification in the whole lake, with a thermocline at approximately 20 m (Fig. 2). In contrast to temperature, light penetration varied greatly along the lake. Light extinction coefficients decreased steadily from Stations 1 to 9, indicating an increase in transparency towards Brazo Catedral (Fig. 2). A more detailed analysis showed that at stations 1 to 4, and some-

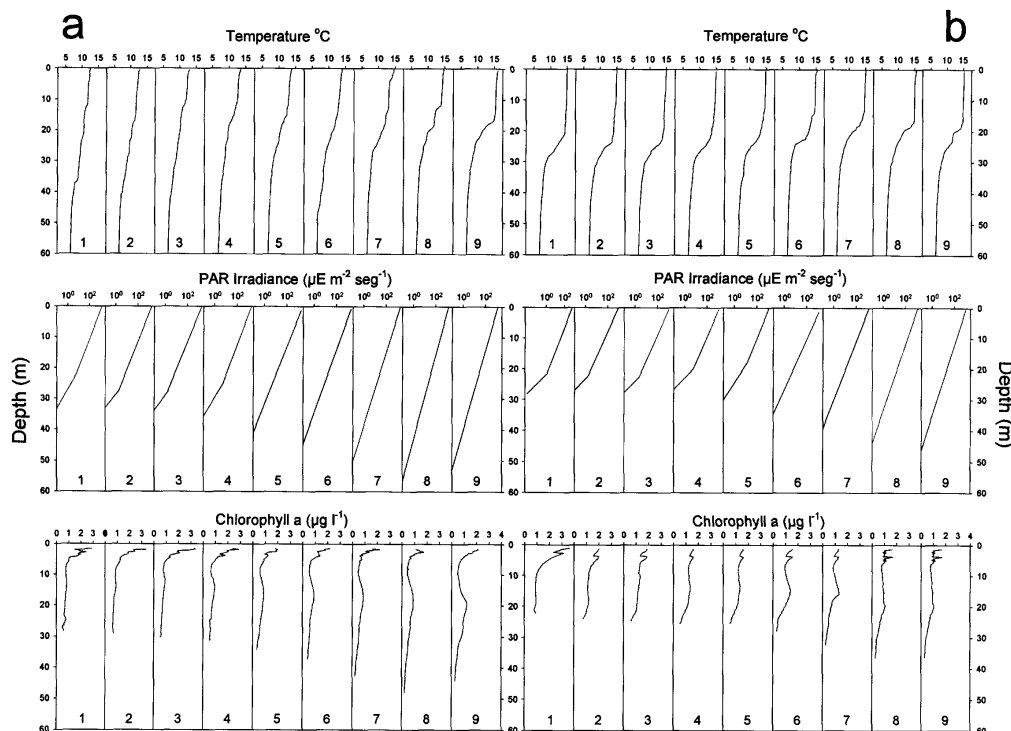


Fig. 2. Vertical profiles in two sampling occasions (February and March, 1998) in the nine sampling stations of Mascardi Lake, a: temperature; b: light (PAR) attenuation; c: chlorophyll *a* concentrations (in situ natural fluorescence).

times at 5, two distinctive layers with different light absorption properties (different K_d) existed. An upper layer (0–20 m) with moderate light absorption ($K_d = 0.24 \text{ m}^{-1}$) and a deep level where the K_d increases to 0.67 m^{-1} at station 2 (Fig. 2) could be delimited. From stations 6 to 9, a steady decrease in the K_d values (reaching a minimum of 0.16 m^{-1}) was observed and no differential optical layers were observed. The variation in the vertical attenuation of light was obviously related to total suspended solid concentration because we observed a strong statistical relationship between K_d and TSS concentrations ($P < 0.001$) (Fig. 3). The observed TSS values showed an increase from the surface to 20 m depth. The maximum difference was observed in Station 1, situated 1 km from the mouth of the Upper Manso River; in this case TSS concentrations varied from 1.35 mg L^{-1} at the surface to 2.50 mg L^{-1} at 20 m depth. This tributary brings a heavy load of glacial sediment which, together with a low temperature ($6 \text{ }^\circ\text{C}$), causes an increase in water density and consequently this inflowing water plunges (VALLVERDÚ et al. 1994). This feature causes the differences in the optical properties of the two layers detected in Brazo Tronador.

The maximum depth reached by the chlorophyll profiles, measured by natural fluorescence, showed an increase from 20–25 m (Brazo Tronador) to 40–45 m (Brazo Catedral). A maximum peak at approximately 15 m depth was detectable in station 6 deepening towards station 9 (Fig. 2). At stations 8 and 9 (Brazo Catedral) a distinctive deep chlorophyll maximum was observed and was situated below the upper limit of the metalimnion and near the level of 1% PAR (Fig. 2). A linear regression between the depth of chlorophyll maxima and K_d at each sampling station showed an increased relationship between these variables ($P < 0.001$) (Fig. 4). This result indicates that with an increase in transparency a deeper chlorophyll peak would be expected. This deep chlorophyll maxima has been noted in the open ocean and in other oligotrophic lakes (FALKOWSKI & RAVEN 1997). Chlorophyll con-

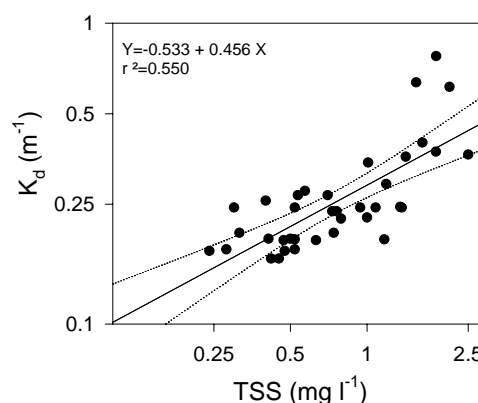


Fig. 3. Relationship between total suspended solid (TSS) concentrations and the extinction coefficients (K_d).

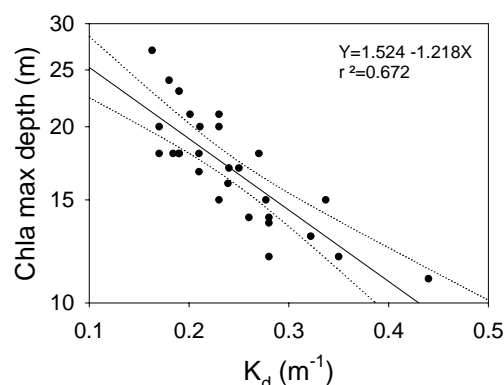


Fig. 4. Relationship between the depth of the chlorophyll maxima and the extinction coefficients (K_d).

centration ranged from less than $1 \mu\text{g L}^{-1}$ (in surface) up to $2 \mu\text{g L}^{-1}$ in the deepest layers (20 m). Since nutrient concentrations are very low in both arms (PEDROZO et al. 1993, MARKERT et al. 1997) the different chlorophyll vertical profiles result from the differential light climate along the lake. Therefore, the reduced light penetration may be linked to light control of phytoplankton standing crop. In shallow lakes, high non-algal solid concentrations (tripton) are primarily responsible for light limitation of primary production, as the mixing depth is significantly deeper than that of the

very shallow euphotic zone (PHILIPS et al. 1995). In the deep Mascardi Lake, the euphotic zone is included within the mixed layer in the Tronador arm, while in the Catedral arm the euphotic zone extends beyond the thermocline. The pronounced spatial differences in K_d , Chl a , and TSS in both arms illustrates how light attenuation by mineral particles can limit phytoplankton distribution in deep lakes.

Acknowledgements

This study was supported by UNC Grant and Foncyt PICT 01-00000-01194 and Fundación Antorchas A13218/1.

References

- AMERICAN PUBLIC HEALTH ASSOCIATION (APHA), 1985: *Standard methods for the examination of water, sewage, and wastewater*. 16th Ed. – American Public Health Association, Washington, D.C. 1134 pp
- CHILLRUD, S. N., PEDROZO, F. L., TEMPORETTI, P. F., PLANAS, F. H. & FROELICH, P. N., 1994: Chemical weathering of phosphate and germanium in glacial meltwater streams: Effects of subglacial pyrite oxidation. – *Limnol. Oceanogr.* **39**: 1130–1140.
- FALKOWSKI, P. G. & RAVEN, J. A., 1997: *Aquatic Photosynthesis*. – Blackwell Sciences, Massachusetts, 375 pp.
- IRIONDO, M., 1974: Modelo de sedimentación en el Lago Mascardi, Provincia de Río Negro. – *Rev. Asoc. Geol. Argent.* **29**: 349–358.
- MARKERT, B., PEDROZO, F., GELLER, W., FRIESE, K., KORHAMMER, S., BAFFICO, G., DIAZ, M. & WOLFL, S., 1997: A contribution to the study of the heavy-metal and nutritional element status of some lakes in the southern Andes of Patagonia (Argentina). – *Sci. Total Environ.* **206**: 1–15.
- NUSCH, E. A., 1980: Comparison of different methods for chlorophyll and phaeopigment determination. – *Arch. Hydrobiol. Beih. Ergebn. Limnol.* **14**: 14–36.
- PEDROZO, F., CHILLRUD, S., TEMPORETTI, P., & DIAZ, M., 1993: Chemical composition and nutrient limitation in rivers and lakes of northern Patagonian Andes (39.5°–42° S; 71° W) (Rep. Argentina). – *Verh. Internat. Verein. Limnol.* **25**: 205–214.
- PHILIPS, E. J., ALDRIDGE, F. J., SCHELSKE, C. L., & CRISMAN, T. L., 1995: Relationships between light availability, chlorophyll a , and tripton in a large, shallow subtropical lake. – *Limnol. Oceanogr.* **40**: 416–421.
- VALLVERDU, R. A., LUSKY, J. C. & DEL VALLE, R. A., 1994: Presentación preliminar de datos de sedimentación actual en el Lago Mascardi. – *3 Jornadas de Comunicaciones Antárticas IAA*. 117–125.

Authors' address:

B. MODENUTTI, G. PÉREZ, E. BALSEIRO, C. QUEIMALIÑOS, Laboratorio de Limnología, Centro Regional Universitario Bariloche, Unidad Postal Universidad, 8400 Bariloche, Argentina.
E-mail: bmode@crub.uncoma.edu.ar