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Optical properties and light penetration in a deep, naturally acidic, iron rich lake: Lago Caviahue (Patagonia, Argentina)

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ABSTRACT

The optical properties and light climate in the deep and extremely acid Lake Caviahue have been studied in order to better understand its characteristics and the possible influence upon the phytoplankton community. The absorption coefficients for the dissolved fraction were maximal in the ultraviolet (UV) region and the water absorption spectra showed a shoulder around 300 nm, which was attributed to the concentration of Fe(III). No radiation was detected in the water column below 360 nm. The depth of the 1% incident radiation was dependent of wavelength, showing its maximum of 13.3 m at 565 nm, compared to 1.7 m and 4.8 m at 400 nm and 700 nm, respectively. Phytoplankton biomass was low and showed an almost constant profile with depth despite the relative darkness of the water column. Optical climate of Lake Caviahue is not typical of high elevation lakes but is more similar to low elevation shallow lakes of the Andean region. The chemical composition of the water, mainly Fe oxidation state and concentration, is the responsible for the high attenuation of the UV radiation (UVR). Living organisms are protected of UVR because Lake Caviahue waters are a shield against UV-B.

Introduction

The quantity and quality of light within an aquatic ecosystem is a very important physical variable with profound implications on the biological communities. For example, a direct effect of this variable is the depth distribution, abundance and primary production of photoautotrophs in the water column, while an indirect effect is the bacterioplankton enhanced production as a consequence of the photobleaching of dissolved organic matter (DOM) (Lindell et al., 1996; De Lange et al., 2003; Engelhaupt et al., 2003).

The underwater light field is affected by the properties of the incoming irradiance and those of the aquatic medium. The spectral dimension of light in a water body can be studied by examining optical properties of water which can be classified as: inherent properties, that depend on the nature and composition of particles and dissolved substances in the medium (e.g. absorption coefficient, scattering coefficient, etc.) and apparent properties, that depend on the medium and on the geometrical structure of light (e.g. the angular distribution of the underwater radiation) (Maritorena and Guillocheau, 1996; Van Duin et al., 2001; Kirk, 2011).

In order to characterize the radiation within an aquatic system the apparent optical property, diffuse attenuation coefficient (K_d) is calculated based on the measurement of the downward irradiance flux at different depths (Kirk, 2011). The attenuation coefficient will vary spatially and temporally with the chemical and physical characteristic of the medium. Besides the water itself, dissolved and particulate matter in the water play a role in the attenuation of ultraviolet (UV) and photosynthetically active radiation (PAR) (Morris et al., 1995; Bracchini et al., 2004). Light attenuation in most fresh waters is dominated by organic chromophores or algal biomass. Chromophoric DOM (CDOM) absorption decreases exponentially with decreasing wavelength. Therefore the short wavelength visible and UV radiation (UVR) is most highly attenuated (Kirk, 2011). Understanding the depth profile of solar UVR and its underwater spectral composition is essential, for example, when evaluating exposure to harmful doses of UVR to aquatic organisms in their habitats (Huovinen et al., 2003). Alpine lakes (lentic ecosystems located above tree line) and organisms inhabiting them have been cited to be more sensitive to increased UVR as a consequence of their elevation and their low content of DOM (e.g. Sommaruga, 2001; Vinebrooke and Leavitt, 2005).

Strongly acidic aquatic environments (pH < 4) originate either naturally (volcanic springs, peat bogs, natural acid rock drainage) or through anthropogenic activities (acid mine drainage, acidification of lakes and ponds) (Geller et al., 1998). Both situations can lead to similar results: water with low pH often accompanied by high metal concentrations (particularly iron). Iron-rich lakes of natural origin are few and in consequence less studied than human acidified lakes. Lessmann et al. (2000) reported that the light environment in acidic lakes is different than in normal lakes because attenuation of wavelengths <600 nm is enhanced due to the Fe(III)

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in the water. Koschorreck and Tittel (2002) studied benthic photosynthesis in an acid mine lake with high iron content and stated that iron-rich waters create an unusual spectral profile, but did not show the profile. Gómez et al. (2007) found that the presence of high concentrations of soluble ferric iron in Río Tinto river (Spain) protects acidophilic algae from UV radiation in the 200–315 nm range.

In the present study, absorption coefficients (inherent optical properties) of acid Lake Caviahue were investigated, and spectral attenuation coefficients (apparent optical properties) were determined in order to know the underwater optical climate present in the lake. The aim of the study was to arrive at a more detailed understanding of the light climate in a high elevation, deep, naturally acidic, iron-rich lake and its possible effects on the biomass of the phytoplankton community.

Materials and methods

Study area

Lake Caviahue is located at 1600 m a.s.l. in the Copahue-Caviahue Provincial Park (37°53′ S; 71°02′ W), in the Andean area of Neuquén Province, Patagonia, Argentina. The lake has two arms (North and South), an area of 9.2 km^2, and a maximum depth of 93 m. It is naturally acidified by the acidic waters of the Upper Agrio River (pH < 2) (Pedrozo et al., 2001; Baffico et al., 2004; Varekamp, 2008), one of the main inflows of the lake, as a consequence of the close location of the river sources to the crater of the active Copahue Volcano (2965 m a.s.l.). The water of the lake has a pH < 3, high concentrations of sulphate (SO_4^{2-}), iron (Fe), and aluminium (Al) (Pedrozo et al., 2001; Gammons et al., 2005; Varekamp, 2008), and low dissolved organic carbon (DOC) concentrations (0.2–1.6 mg/l, Beamud et al., 2010). Thermal, chemical, and biological characteristics of the lake have been described previously in detail (Pedrozo et al., 2001, 2002; Beamud et al., 2007, 2010; Varekamp, 2003, 2008). The phytoplankton community has very low diversity and is dominated by *Keratococcus raphidioides* (Hansgirg) Pascher (Chlorophyta) accounting for >90% of the total biomass (Pedrozo et al., 2001; Beamud et al., 2007). The zooplankton community is dominated by the rotifer *Philodina* sp. (Pedrozo et al., 2001).

The vegetation on the basin of the lake is mainly composed of herbaceous steppes with important percentage of naked soil (between 20 and 60%) below 2000 m a.s.l., and light forest of *Araucaria araucana* trees until 1800 m a.s.l. (Martin et al., 1988). Above 2000 m a.s.l. there are no vegetation on the basin of the lake.

Field methods

The lake was sampled during the warm season in different years (2000, 2004, 2005, 2007–2011). Samples were obtained at a central sampling point located at the deepest part of the North Arm (93 m). Water samples were obtained with a Van Dorn bottle at different depths in order to measure optical properties of the water and the phytoplankton biomass. Sampling depths were selected as 0 (first 20 cm of the water column), 2, 5, 10, 20, 30, 50 and 80 m. The samples were transferred to acid-washed polypropylene containers which were kept in darkness and immediately taken to the laboratory. Vertical profiles of downward irradiance for the UV range (290–400 nm, 1 nm resolution) and the visible range (400–750 nm, 1 nm resolution) were measured using a spectroradiometer (USB2000, Ocean Optics; grating #2, UV2/OFLV-4 detector, L2 lens, 25 μm slit) during the 2009 sampling campaign. UV measurements were made at 0, 10, 20, 40, 60 and 100 cm depth, while visible measurements were made at 0, 0.1, 0.2, 0.5, 1, 2, 3 and 4 m depth. The equipment was calibrated against tungsten and mercury reference lamps following the procedure defined by the manufacturer, in order to give measurements in irradiance units. The spectral vertical attenuation coefficient for downward irradiance ($K_{d,\lambda}$) was obtained from the slope of the linear regression of the natural logarithm of measured irradiance versus depth. Since the distance to the depth where the irradiance falls below the detection limit was very short, only a few centimetres at UV, the estimates of K_d at these wavelengths are less precise, or in some cases could not be determined.

Laboratory methods

For the determination of the optical properties, lake water was filtered with a 0.22 μm membrane (GE nylon syringe filters) to remove the particulate fraction. The filters were not tested for potential CDOM release. Absorbance (190–1100 nm, every 1 nm) of the dissolved fraction was measured with a UV-visible spectrophotometer (Hewlett Packard 8453) in a 1 cm quartz cuvette, using filtered deionized distilled water as a blank. Absorbance at 750 nm was assumed to be zero and was subtracted from each spectrum to correct for offsets due to instrument baseline drift, temperature, scattering and refractive effects. Absorbance units were converted to absorption coefficients (ad) for the dissolved fraction of lake water as $ad = 2.303A(\lambda)/l$, where A is absorbance, λ is wavelength (nm) and l is the optical path length (m).

Total Fe concentrations were determined in the filtered 0 m depth water sample by total reflection X-ray fluorescence spectroscopy (detection limit of 1 μg/l; 2000, 2004 and 2005 sampling campaigns) or with commercial test kits (detection limit of 0.02 mg/l, FerroVer Method 8008, HACH Company, USA; 2007–2011 sampling campaigns). Samples were diluted with distilled water to provide Fe concentrations within the analytical range of the test.

Phytoplankton biomass was estimated by measurement of chlorophyll *a* concentrations. The water samples from each depth were filtered on glass fibre filters (Whatman GF/F) and kept frozen at −20 °C until extraction in 90% acetone and spectrophotometric measurements (APHA, 1992).

Results

Absorption coefficients for the dissolved fraction of Lake Caviahue water showed high values in the UV region and lower values

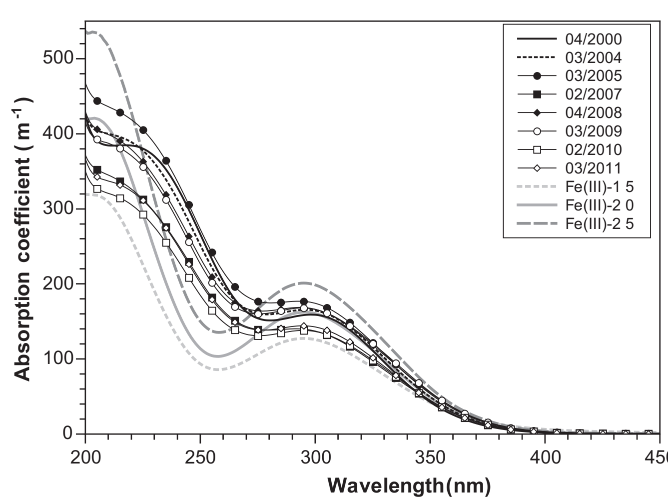

Fig. 1. Absorption coefficients for the dissolved fraction of Lake Caviahue water at 0 m depth in different sampling years. Three different concentrations of $FeCl_3$ dissolved in distilled water (15, 20 and 25 mg Fe(III)/l) are shown for comparison.