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Short Communication

First Observations of *Boeckella michaelseni* Mrázek 1901 in and Optical Properties of a Central Patagonian Lake

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Abstract

The Patagonian lakes have a glacial origin and some of these are associated with glaciers that generate specific optical properties, such as water colorations due to glacier sediments. These lakes also are oligotrophic with a low crustacean zooplankton species number. The aim of the present study was to analyze potential associations between optical properties and zooplankton communities in General Carrera Lake (46°S). The results revealed inverse associations in reflectance of bands 1, 5, and 7 of LANDSAT TM+ with calanoid copepodites, between band 7 with conductivity, and band 7 with *B. michaelseni* abundance. Also, we observed direct associations between bands 1-5 with total dissolved solids, meaning that this zooplankton assemblage is similar to north Patagonian oligotrophic lakes. These results would agree with a few reports for other similar Patagonian lakes of glacial origins as reported for Argentinean and Chilean Patagonia. Nevertheless, more studies are necessary for finding potential associations between limnological characters and optical properties.

Keywords: glacier, optical properties, reflectance, zooplankton

Introduction

The Patagonian lakes located in southern Argentina and Chile (38-51°S) are of glacial origin [1-4], and some of these lakes are associated with ice fields in their surrounding basins that generate specific characteristics in landscapes such as those observed in Grey Lake in Torres del Paine National Park [5], or water colorations specifics for each lake, for example greenish bays in General Carrera or Todos los Santos lakes [1, 6]. Also, the Patagonian lakes are characterized by their marked oligotrophy (2.1-0.4 μg/L Chlorophyll a) [1, 5] generated as a consequence of low crustacean zooplankton species richness and the predominance of calanoids copepods of *Boeckella* and *Tumeodiaptomus* genera [1].

In this scenario, the low photosynthetic activity of phytoplankton can be enhanced by the presence of glacial sediments that generate an additional light limitation due to the low penetration abilities of photosynthetically active

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light [1]. In this scenario the optical properties of water bodies would be related to zooplankton communities such as those observed preliminarily for lakes General Carrera [6] and Tagua Tagua [4]. General Carrera is a binational lake that is shared with Argentina, where it is called as Buenos Aires lake [6]. It has glacial and volcanic influence on its northern shore, whereas the southern part has no glacial influences [2, 3] and is markedly oligotrophic [6]. The aim of the present study is do a study of zooplankton assemblage in terms of zooplankton abundances in General Carrera Lake and its potential association with optical properties using remote sensing techniques.

Material and Methods

Study Site

General Carrera Lake lies within a hydrological region in Central Patagonia located between 41-47°S, where lakes are shared between Argentina and Chile. In addition to General Carrera/Buenos Aires (410 m maximum depth, 1892 km^2 surface), the area also includes Cochrane/Pueyrredon (460 m maximum depth, 325 km^2 surface) and O'Higgins/San Martin (836 m maximum depth, 1013 km^2 surface), plus numerous other lakes and rivers in a mountainous zone with difficult access due to the mountains, and strong winds that can interfere with sampling work (Fig. 1).

Sampling Procedures

Seven sampling sites were georeferenced using a Garmintemperature GPS, pH, total dissolved solids, and conductivity that was measured in situ using a Hanna sensor. Zooplankton samples were taken using vertical hauls of 15 m with plankton net of 20 cm diameter and 100 µm mesh size. Zooplankton specimens were fixed in absolute ethanol and they were identified by microscoping analysis based on specialized literature [7, 8] and quantified in a laboratory using all specimens in samples [4, 6]. The site was visited on 2 February 2013.

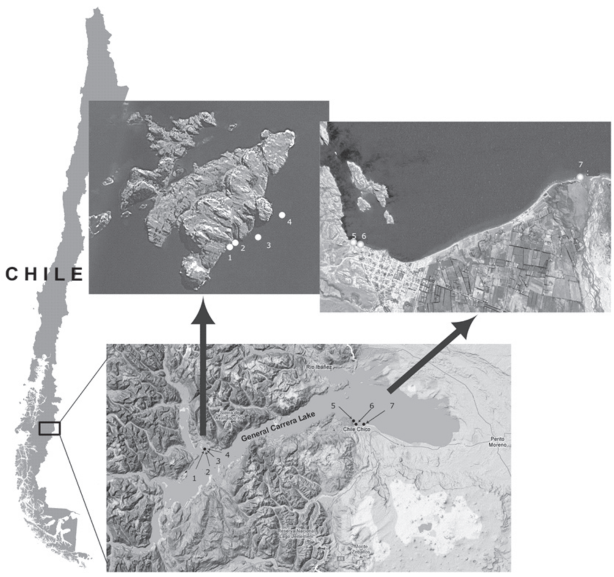

Fig. 1. Satellite image of General Carrera Lake with sampled sites.

Remote Sensing Procedures

This step used a LANDSAT/ETM+ image obtained in April 2013 (Fig. 1) provided by the Land Processes Distributed Active Archive Center (LP DAAC) of the U.S. Geological Survey (*LPDAAC.usgs.gov*). The bands of visible, near, and mid-infrared were calibrated radiometrically to spectral irradiance and then to reflectance with atmospheric correction being applied (Table 1).

Data Analysis

Reflectance and zooplankton abundances were applied as principal correspondence analysis for obtaining the grouping for sampled sites; in this analysis a Pearson correlation analysis was considered. This statistical analysis was applied using Xlstat 11.0 software (www.addinsoft.com).

Results

The results revealed low abundances of adults (0.019-0.001 ind/L) and copepodites (0.116-0.005 ind/L) of *Boeckella michaelseni* Mrázek, 1901, and other crustacean species there were not found in sampled sites; adult individuals were absent in sites 4-7 (Table 1). Site 7 shows high reflectance in all bands, whereas site 5 shows low reflectance in all bands and the site 6 shows low reflectance in B2-B5 and B7 (Table 1). Total dissolved solids, conductivity, and temperature were relatively low and with neutral pH (Table 1).

The correlation analysis (Pearson correlation test) revealed direct significant correlations between B1 with B2 (R^2 = 0.871, $p < 0.01$), B1 with B3 (R^2 = 0.758, $p < 0.01$), B1 with B4 (R^2 = 0.822, $p < 0.01$), B1 with B5 (R^2 = 0.935, $p < 0.01$), B1 with B7 (R^2 = 0.624, $p < 0.05$), and B1 with total dissolved solids (R^2 = 0.524, $p < 0.05$); B2 with B3 (R^2 = 0.977, $p < 0.01$), B2 with B4 (R^2 = 0.993, $p < 0.01$), B2 with B5 (R^2 = 0.935, $p < 0.01$), and B2 with total dissolved solids (R^2 = 0.807, $p < 0.01$); B3 with B4 (R^2 = 0.994, $p < 0.01$), B3 with B5 (R^2 = 0.857, $p < 0.01$), and B3 with total dissolved solids (R^2 = 0.888, $p < 0.01$); B4 with B5 (R^2 = 0.905, $p < 0.01$) and B4 with total dissolved solids (R^2 = 0.849, $p < 0.01$); B5 with B7 (R^2 = 0.612, $p < 0.05$) and B5 with total dissolved solids (R^2 = 0.554, $p < 0.05$); and calanoid copepodites with temperature (R^2 = 0.540, $p < 0.05$) and calanoid copepodites with conductivity (R^2 = 0.565, $p < 0.05$) (Table 2). Whereas we found inverse significant correlations between B1 with calanoid copepodites

Table 1. Geographical location, reflectance, and zooplankton composition (in ind/L) for seven studied sites.

	1	2	3	4	5	6	7
Geographical location	46°36.78S	46°36.74S	46°36.73S	46°36.59S	46°32.08S	46°32.14S	46°31.47S
	72°35.40W	72°35.37W	72°35.15W	72°34.94W	71°44.07W	71°43.96W	71°40.49W
B1	0.048	0.048	0.052	0.044	0.017	0.024	0.081
B2	0.027	0.020	0.024	0.020	0.008	0.008	0.115
B3	0.002	0.001	0.001	0.001	0.002	0.003	0.101
B4	0.004	0.004	0.004	0.004	0.003	0.003	0.017
B5	0.004	0.004	0.004	0.004	0.003	0.002	0.007
B7	0.002	0.002	0.001	0.002	0.001	0.001	0.002
Boeckella michaelseni Mrázek, 1901	0.019	0.002	0.001	0.000	0.000	0.000	0.000
Calanoids copepodites	0.000	0.032	0.064	0.014	0.049	0.116	0.005
Temperature (ºC)	14.9	13.5	13.1	12.8	17.0	17.5	14.7
pH	10.20	8.41	8.50	8.88	10.08	9.98	9.43
Total dissolved solids (mg/L)	0.01	0.01	0.01	0.01	0.01	0.02	0.03
Conductivity (mS/cm)	0.01	0.03	0.04	0.03	0.04	0.04	0.04

(R^2 = 0.601, $p < 0.05$), B1 with temperature (R^2 = 0.584, $p < 0.05$), B5 with calanoid copepodites (R^2 = 0.711, $p < 0.01$), B7 with calanoid copepodites (R^2 = 0.832, $p < 0.01$), B7 with conductivity (R^2 = 0.600, $p < 0.05$), and *B. michaelseni* with conductivity (R^2 = 0.921, $p < 0.01$) (Table 2).

The PCA revealed that the main contributor variables for axis 1 were B1, B3, B4, and B5, whereas for the second axis the main variables where B7, calanoid copepodites, *B. michaelseni,* temperature, total dissolved solids, and conductivity (Fig. 2). The PCA revealed that sites 1, 2, and 3 had high *B. michaelseni* abundance and high reflectance in band 7 and low reflectance in bands 1-5, temperature, pH, conductivity, and total dissolved solids, whereas site 7 had low *B. michaelseni* and calanoid copepodites abundance, and low reflectance, temperature, pH, conductivity, and total dissolved solids (Fig. 2). Sites 5 and 6, however, had high calanoid copepodites abundance, and high pH, temperature, conductivity, total dissolved solids, and low reflectance. Finally, site 4 had

Table 2. Correlation matrix for variables considered in the present study (values in bold denotes significant correlation; $p < 0.05$).

	B1	B2	B3	B4	B5	B7	B. michaelseni	Calanoids cop.	Temperature	pH	Total disolved solids
Conductivity	-0.084	0.150	0.284	0.232	0.000	**-0.600**	**-0.921**	**0.565**	0.236	-0.219	0.407
Total disolved solids	**0.524**	**0.807**	**0.888**	**0.849**	**0.554**	0.113	-0.283	0.031	0.289	0.216	
pH	-0.384	-0.038	0.060	-0.015	-0.250	-0.203	0.414	0.091	0.822		
Temperature	**-0.584**	-0.175	-0.001	-0.107	-0.463	-0.544	-0.026	**0.540**			
Calanoids cop.	**-0.601**	-0.493	-0.367	-0.435	**-0.711**	**-0.832**	-0.436				
B. michaelseni	0.083	-0.076	-0.194	-0.161	0.000	0.373					
B7	**0.624**	0.459	0.345	0.413	**0.612**						
B5	**0.935**	**0.935**	**0.857**	**0.905**							
B4	**0.822**	**0.993**	**0.994**								
B3	**0.758**	**0.977**									
B2	**0.871**										

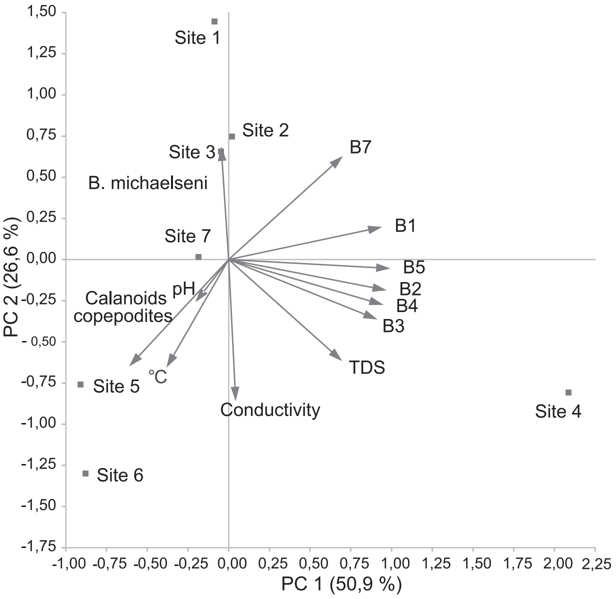

Fig 2. PCA analysis for variables considered in the present study.

high calanoid abundance, reflectance, conductivity, total dissolved solids, pH, and temperature (Fig. 2).

Discussion

The results described above agree with results obtained for other lakes of glacial origin, for example lakes Sarmiento and Del Toro in Torres del Paine National Park [9], and General Carrera Lake [7], where the markedly abundant calanoid species *B. gracilipes* Daday, 1901 and/or *B. michaelseni* are associated with low abundance of cyclopoid copepods and cladoceran *N. chilensis*. Similar results were observed for other glacial oligotrophic lakes in the park, such as Nordsdenkjold and Grey, where the zooplankton communities consist of only two species (*B. michaelseni* and *Tropocyclops prasinus* (Fischer, 1860) [10]. This situation differs from another Patagonian lake with glacial influence, Todos los Santos Lake, which has four species [1]. The relation between optical properties and zooplankton community composition has been reported for similar Patagonian lakes such as Tagua Tagua [4] and General Carrera [6].

Zooplankton communities can be affected by glacial influence. In marine environments zooplankton mortality, mainly associated with the chemical properties of the ice, has been found in areas close to ice fields [11, 12]. For Patagonian lakes the glacial influence is water turbidity due to glacier sediments and dissolved organic matter, which prevents light penetration into the water column [13, 14], with the consequences in photosynthesis activity that involve the biogeochemical process of nutrient input from phytoplankton that are grazed by zooplankton, such as was observed in Argentinean Patagonian lakes [14]. This would make it similar to some lakes with glacial influence in the national park, where only two species are found [1, 10], and General Carrera [6]. For General Carrera the low zooplankton species richness was found in sites with glacial sediments in comparison with sites without glacial sediments, which would agree with the present study if we consider that sites 1-4 are in a zone with glacial influence that generates the characteristic greenish coloration [6]. This scenario could probably have potential correlations between optical, chemical, and trophic status with consequent responses from plankton communities [15].

The results presented indicate that a potential correlation between zooplankton assemblages and optical properties might possibly be found; however, it would be necessary to carry out more intensive studies and obtain more data to be able to confirm or discount the possibility of finding potential correlations and their variation at multiple spatial and temporal scales [16].

Table 3. PCA contribution percentage of variables for axis 1 and 2.

Variable	Axis 1	Axis 2
B1	**0.385**	0.079
B2	**0.395**	-0.120
B3	**0.370**	-0.215
B4	**0.386**	-0.169
B5	**0.401**	0.033
B7	0.263	**0.350**
Calanoids cop.	-0.005	**0.405**
B. michaelseni	-0.265	**-0.361**
Temperature	-0.160	-0.322
pH	-0.080	-0.095
Total disolved solids	0.274	**-0.349**
Conductivity	0.002	**-0.499**

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