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Temporal variations on chlorophyll concentration in Riñihue lake (39° S, Patagonia, Chile) and its relation with satellite Landsat ETM+ spectral data.

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Abstract

The Chilean north Patagonian lakes formerly called "Araucanian lakes" (38oS-41° S), were described originally as oligotrophic, nevertheless since 1978, a transition from oligotrophy to mesotrophy has been reported in some bays due to human intervention, such as towns and industrial activities. The aim of the present study was to analyze the temporal variations between five years in a north Patagonian lake comparing chlorophyll concentration with spectral properties based on LANDSAT ETM+ sensor. The results revealed significant direct correlation between chlorophyll concentrations with B2, B3. B4, B5 and B7 reflection bands. The multiple regression analysis revealed a direct association between chlorophyll concentrations with B4, and inverse with B5. The obtained results agree with observations for other Chilean north Patagonian lakes about chlorophyll increase in determined bays with human intervention, and the use of remote sensing techniques would be an optimal tool for study changes.

Keywords: oligotrophy, mesotrophy, Patagonian lakes, remote sensing, spectral properties.

1. Introduction

The Chilean North Patagonian lakes formerly called "Araucanian lakes" (38-41° S) characterized originally by their marked oligotrophy (Campos 1984, Soto and Zúñiga, 1991, Soto, 2002). Nevertheless in the last two decades a transition from oligotrophy to mesotrophy has been reported (Woelfl et al. 2003), indeed to changes in their surrounding basins in some bays due to human intervention, specifically towns, agricultural and industrial activities with the consequent replacement of original native forest (Soto 2002). An example can be Riñihue lake that has reported a transition from oligotrophy to mesotrophy, from 1978 to 1998 (Woelfl et al., 2003), or Llanquihue lake with bays with a wide gradient of trophic status due human activities associated such as towns, agriculture or aquaculture activities (Soto 2002, De los Ríos-Escalante et al, 2017a). Also, according to the literature, the main regulator of phytoplankton activity in Chilean Patagonian lakes is the mixing depth; a marked inverse correlation exists between both parameters, consequently, the northern Patagonian lakes, due their low mixing depth are more exposed to increase their chlorophyll concentration due to nutrients inputs (Soto, 2002).

The literature reports the use of remote sensing techniques for limnological monitoring (Kondratyev and Filaratov, 1999), some of them are related with phytoplankton pigments monitoring specifically for avoid toxic algal blooms (Li *et al*. 2015, Lunetta *et al*. 2015, Oyama *et al*. 2015). There are very scarce reports about use of remote sensing techniques in Chilean lakes, the existing few studies are based on spectral properties in spatial gradient in glacial influenced lakes in Chilean Patagonia (De los Ríos-Escalante and Acevedo 2016a,b), where the gradient of glacial influence generate changes in water color with consequent changes in zooplankton composition. Also, the use of remote sensing techniques was reported for Chilean Patagonian mountain lakes with difficult access, as first descriptions of these water bodies (De los Ríos-Escalante *et al*., 2017b,c,d). The aim of the present study is to find correlations between chlorophyll concentrations and spectral properties in Riñihue Lake, because this lake was one of the most studied in Chile, considering its temporal variations in trophic status during three decades (Woelfl *et al*. 2003).

2. Material and methods

Data of Chlorophyll concentrations in Riñihue lake (Fig. 1), from May 2004 to October 2009, during the period corresponding to late winter to late summer, that corresponds to maximum chlorophyll concentrations (Wölfl, 1996; Table 1), were obtained from "Dirección General de Aguas" database (www.dga.cl). These sites corresponds to sampling point located at 39°48'53''S and 72°24'44' W (Figure 1). Satellite data was obtained from LANDSAT/ETM+ image dated between May 2004 to October 2009 (Table 1) provided by the Land Processess Distributed Active Archive Center (LP DAAC), U.S. Geological Survey (http://LPDAAC.usgs.gov). The bands of visible, near, and mid-infrared (Table 2) were calibrated radiometrically to spectral irradiance and then to reflectance with correction being applied (Table 1). All data analysis was applied using software "R" (R Development Core Team, 2009). At afirst step, data were analyzed by matrix correlation analysis using Hmisc R package, (Harrell, 2016) for determine the associations between studied variables. At a second step multiple regression analysis was applied considering chlorophyll concentration as dependent variable, whereas the spectral properties B1, B2, B3, B4, B5 and B7 reflectance bands were considered as independent variables. This statistical analysis was applied with the HSAUR R package (Everitt and Hothorn, 2016).

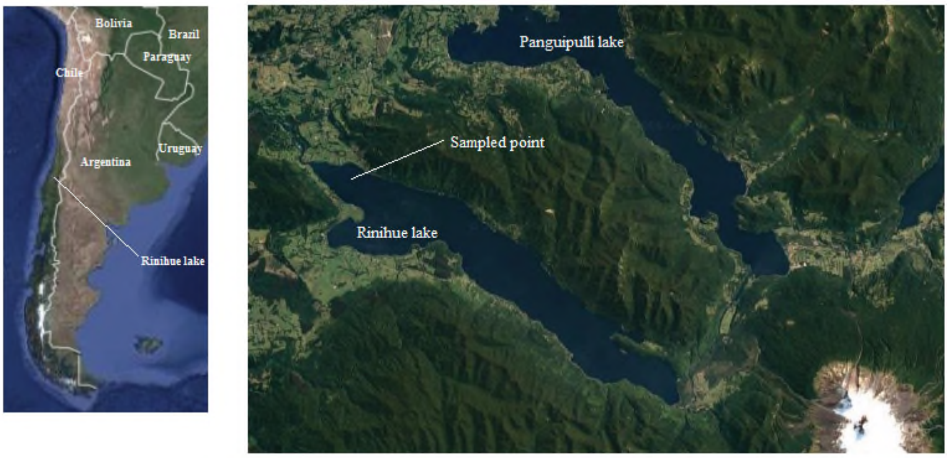

Figure 1: Map with studied site.

Table 1 : Chlorophyll "a" concentration ("Chl(a)", in mg/L), and reflectance in Landsat ETM+ bands, for sampled site in Riñihue Lake.

Sampling date	Chl(a)	Satellite date	B1	B2	B3
26-05-2004	1.10	13-05-2004	0.1040	0.0580	0.0310
11-02-2005	0.50	09-02-2005	0.0810	0.0475	0.0235
18-11-2005	0.40	08-11-2005	0.0775	0.0440	0.0220
09-08-2006	1.80	30-07-2006	0.1011	0.0587	0.0349
25-10-2006	0.60	26-10-2006	0.0777	0.0445	0.0226
26-05-2007	1.10	06-05-2007	0.1106	0.0611	0.0360
21-08-2007	3.40	18-08-2007	0.0918	0.0566	0.0339
20-11-2007	0.70	14-11-2007	0.0772	0.0424	0.0219
26-02-2008	0.50	26-02-2008	0.0829	0.0486	0.0287
23-08-2008	4.40	13-09-2008	0.1062	0.0703	0.0479
25-02-2009	0.36	28-02-2009	0.0793	0.0447	0.0252
03-06-2009	1.40	12-06-2009	0.1246	0.0721	0.0409
28-10-2009	0.70	11-11-2009	0.0789	0.0485	0.0275
26-05-2004	1.10	13-05-2004	0.0180	0.0008	0.0006
11-02-2005	0.50	09-02-2005	0.0177	0.0041	0.0024
18-11-2005	0.40	08-11-2005	0.0171	0.0020	0.0010
09-08-2006	1.80	30-07-2006	0.0235	0.0026	0.0026
25-10-2006	0.60	26-10-2006	0.0165	0.0022	0.0011
26-05-2007	1.10	06-05-2007	0.0212	0.0027	0.0020
21-08-2007	3.40	18-08-2007	0.0246	0.0029	0.0027
20-11-2007	0.70	14-11-2007	0.0164	0.0016	0.0011
26-02-2008	0.50	26-02-2008	0.0234	0.0064	0.0045
23-08-2008	4.40	13-09-2008	0.0531	0.0235	0.0159
25-02-2009	0.36	28-02-2009	0.0199	0.0031	0.0018
03-06-2009	1.40	12-06-2009	0.0235	0.0024	0.0015
28-10-2009	0.70	11-11-2009	0.0209	0.0034	0.0028

Table 2 : Technical characteristics of the Landsat7/ETM+ sensor

Band	Spectral Range [µm]	Wavelength Center [µm]	GSD [m]
1	0.450 – 0.515	0.479	30
2	0.525 – 0.605	0.561	30
3	0.630 – 0.690	0.661	30
4	0.775 – 0.900	0.835	30
5	1.550 – 1.750	1.650	30
7	2.090 – 2.350	2.208	30

3. Results

The results revealed low chlorophyll “a” concentrations that varied between 0.36 to 4.40 μg/L that would correspond to transition from oligotrophic to mesotrophic status, similar to the descriptions for Patagonian lakes (Table 1). There is not a regular trend of chlorophyll concentration variations during the sampled period (Table 1).

The correlation analysis revealed significant direct associations between chlorophyll “a” concentration with B2, B3, B4, B5, B7 reflectance, B1 with B3, B3 with B2, B4 with B2, B4 with B3, B5 with B3, B5 with B4, B7 with B3, B7 with B4, B7 with B5 (Tables 2 and 3).

Table 3: Correlation matrix for parameters considered in the present study (“p” values between brackets, “p” values lower than 0.05 denotes significant correlations).

	B1	**B2**	**B3**	**B4**	**B5**	**B7**
Chl(a)	0.48 (0.09) n.s	0.69 (< 0.01)*	0.80 (< 0.01)*	0.84 (< 0.01)*	0.70 (< 0.01)*	0.75 (< 0.01)*
	B1	0.95 (< 0.01)*	0.85 (< 0.01)*	0.41 (0.16) n.s	0.21 (0.49) n.s	0.24 (0.43) n.s
		B2	0.96 (< 0.01)*	0.65 (0.01)*	0.45 (0.11)n.s	0.49 (0.09) n.s
			B3	0.81 (< 0.01)*	0.63 (0.02)*	0.67 (0.01)*
				B4	0.96 (< 0.01)*	0.97 (< 0.01)*
					B7	0.71 (< 0.01)*

Multiple regression analysis yielded an inverse association between chlorophyll concentration and B5 reflectance, and direct association with B4 reflectance. The regression equation describing this association was:

$$Y = -3.4873 + 260.6268X_1 - 256.9269X_2$$

Where:
Y = chlorophyll concentration,
X_1 = B4 reflectance,

X_2 = B5 reflectance,
Multiple R-squared: 0.8333
Adjusted R-squared: 0.7999
F statistic: 24.99
P = 0.00012.

4. Discussion

The results denoted the oligomesotrophic status observed and predicted for Chilean northern Patagonian lakes during the last decade due changes in their surrounding basin (Soto, 2002, Woelfl *et al*. 2003, Woelfl 2007, De los Ríos-Escalante *et al*., 2011, in 2017d). It is a marked different situation in comparison to northern Patagonian lakes that are oligotrophic (Trochine *et al*. 2015, Modenutti *et al*. 2013). Rinihue lake was intensively studied between 1978 to 1998, period where it was reported marked nutrient inputs due changes in soil use in their surrounding basin, mainly in sampled point (Woelfl *et al*., 2003).

The use of remote sensing techniques in limnology of Chilean lakes have been a good predictive tool for determine the zooplankton community based in water column transparence (De los Ríos-Escalante and Acevedo, 2016a,b; De los Ríos-Escalante *et al*., 2013). These variations in water column transparence are a consequence of glacier melt inputs, that generate light limitation that would affect the phytoplankton activity necessary for sustain zooplankton communities such as been observed for Argentinean glacial Patagonian lakes (Laspoudamares *et al*, 2013, Hylander *et al*. 2011).

The use of remote sensing techniques has important applications for limnology, mainly in lakes with difficult access like in northern Patagonia with many mountain lakes, located in protected areas, where some few of them are accessible by long mountain paths (De los Ríos-Escalante *et al*. in press 2017b,c,d). Some of these lakes were exposed during the last decade to catastrophic events such as volcanic activity with consequences in their water composition, such as been observed in mountain lakes of Conguillio National Park. These changes can be detected using remote sensing techniques specifically LANDAT ETM+ images (De los Ríos-Escalante *et al*. 2017c). In this scenario, and if we considerate the literature descriptions about use of remote sensing applications to detect with phytoplankton pigments (Li et al. 2015, Lunetta *et al*. 2015, Oyama *et al*. 2015), the exposed results would agree with the literature descriptions.

The literature reports that studied site originally has mixotrophic ciliates in its original oligotrophic status, and these were gradually replaced by phytoplankton, specifically diatoms and chlorophytes due the nutrients inputs (Wölfl, 1995, Woelfl, 2007). In this scenario, if we considere the study of mixotrophic ciliates concentration and phytoplankton pigments concentrations independently, it would have probably more robust predictive models, that would explain also, all pelagic structure in Patagonian lakes. As conclusion the remote sensing applications for limnological studies of Chilean Patagonian lakes is auseful and robust technique that would have interesting applications for water monitoring procedures at temporal and spatial scales.

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