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Short Communication

Spectral Properties Observations: a First Comparison of Bulgarian and Chilean Mountain Lakes

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Abstract

While Bulgaria has oligotrophic lakes in mountain zones with *Pinus mugus* shrubs associated with mountains with *Fagus* forests, northern Chilean Patagonia has numerous pristine lakes associated with *Nothofagus* forests. The present study consists of an optical properties description of mountain lakes from Bulgaria with Chilean mountain lakes (Huerquehue and Alerce Andino National Parks) with *Nothofagus* forest, in visible, close, and medium infrared wavelengths. The results revealed that Bulgarian lakes have different optical properties than Chilean lakes, in spite of the oligotrophy associated with surrounding vegetation and geological characteristics of both groups of studied sites.

Keywords: remote sensing, satellite images, lakes, oligotrophy

Introduction

The Rila mountains in Bulgaria have lakes located at 42°N. Their surrounding vegetation is characterized by *Pinus mugus* shrubs, above which lie the native coniferous and *Fagus* L. forest [1-2]. In contrast, Chilean north Patagonian lakes are located between 39-41°S, with *Nothofagus* forest as dominant genus [3-5]. Both groups of lakes are pristine, located in protected zones that are difficult to access due the surrounding mountains and forests [1-4]. In this scenario we first conducted a comparative study about zooplankton assemblages in both kinds of lakes, and in spite of the oligotrophy we found marked differences [4].

On the basis of studies using remote sensing techniques done for Chilean Patagonian lakes that are characterized by their access difficulties [5-7], it would be possible to do a comparative study of both groups of mountain lakes. The aim of the present study is to compare spectral properties data obtained on LANDSAT ETM+ in Bulgarian Rila mountains with lakes of Alerce Andino and Huerquehue National Parks typical of northern Patagonian mountain lakes, considering the geographical and ecological differences between the two regions [4].

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Material and Methods

Studied sites: Bulgarian Rila mountain lakes are oligotrophic in high altitude zones with *Pinus mugus* shrubs above the native coniferous and *Fagus* L. forest [1-2]. Their origin is volcanic and glacial at high altitudes, and low human intervention [1-2].

Huerquehue National Park (39°S, Chile) lakes (Toro, Triangulo, Verde, and Tinquilco) are oligotrophic with glacial origin. These are associated with native *Nothofagus* Blume forest, particularly *N. antarctica* (G. Forst.) Oerst., *N. pumilio* (Poepp. et Endl.) Krasser, and *N. dombeyi* (Mirb.) Oerst. At altitudes greater than 1,000 m a.s.l., these species coexist with *Araucaria araucana* (Molina) K. Koch, between 38-39ºS [3-5].

Alerce Andino National Park (39°S, Chile) lakes (Chaiquenes, Sargazo, and Triangulo) are oligotrophic with glacial origin and these are associated with *Nothofagus* forests that coexist with *Fitzroya cupressoides* forest [4-5].

The remote sensing procedures in this step used a LANDSAT/ETM+ image obtained from 15 July 2012 from Rila mountain lakes [1-2] and lakes of Huerquehue and Alerce Andino National Parks, Chile, dated from 15 February 2012 [1-2, 4-5] (Table 1) provided by the Land Processess Distributed Active Archive Center (LP DAAC) of the U.S. Geological Survey (*http://LPDAAC.usgs.gov*). The bands of visible, near, and mid-infrarred were calibrated radiometrically to spectral irradiance and then to reflectance with atmospheric correction being applied (Table 2). Reflectance was applied as principal correspondence analysis for obtaining the grouping for sampled sites. This statistical analysis was applied using Analyze-it software based on the methodology used for Patagonian lakes [6-8].

Results

The results revealed that Bulgarian lakes are different from Chilean lakes in B1, B2, and B3 reflectance (Table 1), and for Bulgarian lakes the most different in reflectance are Bliznaka, Braveka, and Dolnoto. These differences would be associated with surrounding vegetation, and the origins of both groups of studied lakes.

The correlation analysis (Pearson correlation test) revealed direct significant correlations between B1 with B2 ($R = 0.499$; $p<0.05$), B2 with B3 ($R = 0.834$; $p<0.01$), B4 with B5 ($R = 0.725$; $p<0.01$), and B4 with B6 ($R = 0.772$; $p<0.01$) (Table 2), whereas significant

Table 1. Geographical locations, maximum depths (Z_{max}), and reflectance properties (B1, B2, B3, B4, B5, and B6) for studied lakes.

Bulgarian lakes [1, 2]										
	Geographical location	Z_{max} (m)	Altitude (m a.s.l.)	Surface (km^2)	B1	B2	B3	B4	B5	B6
Alekovo	42° 11'N; 23°34'E	14.5	1545	0.24	0.009137	0.009684	0.006862	0.017300	0.018221	0.017228
Babreka	42° 12'N; 23°18'E	28.0	2282	0.85	0.006970	0.004789	0.004609	0.020719	0.015184	0.008616
Bliznaka	42°12'N; 23°18'E	27.5	1143	0.91	0.006970	0.006984	0.006862	0.024139	0.012147	0.008616
Dolnoto	42° 09'N; 23°35'E	5.5	2368	0.11	0.006970	0.007236	0.002355	0.020719	0.015184	0.005745
Gorno Marichino	42°09'N; 23°35'E	10.8	2378	2.15	0.004803	0.012131	0.009116	0.027558	0.024294	0.011487
Karakashevo	42°10'N; 23°35'E	6.6	2391	0.26	0.006970	0.009684	0.009116	0.024139	0.024294	0.020099
Okoto	42°11'N; 23°18'E	37.5	2440	0.68	0.006970	0.012131	0.009116	0.030978	0.015184	0.011487
Ribnoto	42°11'N; 23°18'E	6.5	2184	0.35	0.013472	0.019473	0.011369	0.027558	0.021257	0.008616
Salzata	42°11'N; 23°18'E	4.5	2535	0.07	0.006970	0.017025	0.009116	0.034397	0.030368	0.017228
Trilistnika	42°11'N; 23°18'E	6.5	2216	0.02	0.009137	0.014578	0.011369	0.027558	0.021257	0.008616
Chilean lakes										
	Geographical location	Z_{max} (m)	Altitude (m)	Surface (km^2)	B1	B2	B3	B4	B5	B6
Tinquilco	39°10'S, 71°43'W	40.0	840	10.00	0.022201	0.016090	0.012502	0.007827	0.016396	0.003627
Toro	39°08'S; 71°42'W	No data	1254	No data	0.015221	0.011170	0.007998	0.004145	0.012137	0.002053
Verde	39°08'S; 71°42'W	No data	1240	No data	0.017063	0.012925	0.010691	0.004520	0.011340	0.002315
Chaiquenes	41°34'S; 72°32'W	No data	538	0.58	0.021168	0.015590	0.011889	0.006522	0.013080	0.005444
Sargazo	41°30'S; 72°36'W	No data	354	1.40	0.019510	0.014122	0.010763	0.005157	0.010244	0.003287
Triángulo	41°36'S; 72°38'W	No data	285	0.58	0.017038	0.012317	0.009000	0.004328	0.009226	0.003333

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

	B1	B2	B3	B4	B5
B6	**-0.688**	-0.102	-0.158	**0.725**	**0.772**
B5	**-0.547**	0.292	0.085	**0.762**	
B4	**-0.834**	-0.015	-0.207		
B3	**-0.607**	0.834			
B2	**0.499**				

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

	1	2
B1	0.520	-0.157
B2	0.178	-0.637
B3	0.261	-0.576
B4	-0.492	-0.182
B5	-0.409	-0.415
B6	-0.470	-0.182

inverse correlations were found between B1 with B3 (R = -0.607; p<0.05), B1 with B4 (R = 0.834; p<0.01), B1 with B5 (R = 0.547; p<0.05), and B1 with B6 (R = -0.688; p<0.05) (Table 2). PCA revealed that the main contributor variables for axis 1 were B1, B4, B5, and B6, whereas for the second axis the main variables where B2 and B3 (Table 3, Fig. 1). The PCA revealed that sites Alekovo, Babreka, Bliznaka, and Dolnoto have low B1, B2, and B3 reflectance values, and high B4, B5, and B6 reflectance values (Fig. 1), whereas Toro, Triangulo, and Verde have high B1, B2, and B3 reflectance values, and

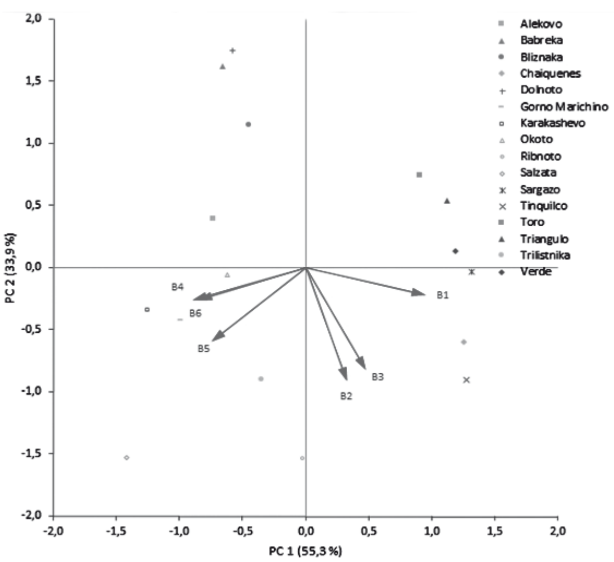

Fig 1. PCA analysis for variables considered in the present study.

low B4, B5, and B6 reflectance values (Fig. 1), whereas for Sargazo, Verde, and Chaiquenes we found B1, B2, and B3 high values, and B4, B5, and B6 low values (Fig. 1). Finally for Okoto, Karaschevo, Trilistnika, Ribnoto, Salzata, and Gorno Marichino we found high B4, B5, and B6 reflectance values, and low B1, B2, and B3 reflectance values (Fig. 1).

Discussion

The present study revealed differences in optical properties for Bulgarian and Chilean lakes. Both groups were markedly different probably due to geological and associated vegetation [1-2, 4]. Nevertheless, the marked differences for Bulgarian lakes would agree with the marked heterogeneity of the environments of these sites [1-2], which would be denoted using remote sensing techniques such as those observed for Patagonian lakes with marked environmental heterogeneity like that observed for Tagua Tagua and General Carrera lakes [6-8].

The environmental heterogeneity for Patagonian lakes has been described with details mainly of trophic status and associated basins [9-11], but recently we studied some optical properties associated with ecological implications due to the presence of associated glaciers with consequent changes in water coloration properties, light absorption, and changes in associated trophic webs [12-14], and these results would be associated with optical properties obtained from satellite images [6-8]. This scenario would have seen similar results if it had applied similar techniques for Bulgarian lakes that are characterized by their marked environmental heterogeneity, because these lakes have a mixture of volcanic and glacial origins and surrounding vegetation with *Pinus mugus* shrubs, associated with mountains and *Fagus* forests [1-2]. This scenario would probably have potential correlations between optical, chemical, and trophic status with consequent responses on plankton communities [15].

The presented results indicate that a potential correlation between environmental associations due to surrounding basins and optical properties might possibly be found. However, it would be necessary to carry out more intensive studies and obtain more data to confirm or discount the possibility of finding potential correlations and their variations in multiple spatial and temporal scales [16].

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