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*Short Communication*

# Spectral Property Observations in Lakes Surrounding a Chilean Volcano

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**Abstract**

Northern Chilean Patagonia has numerous pristine lakes associated with *Nothofagus* and *Araucaria araucana* forests. The present study consists of a study of optical properties in visible, close, and medium infrared wavelengths in mountain lakes surrounding Llaima Volcano – lakes that have associated *Nothofagus* and *Araucaria araucana* native forests with volcanic origins. The results revealed high reflectance values in Arcoiris Lagoon that has volcanic stones in its bottom, whereas the other lakes and lagoons have low reflectance values. These differences in spite of oligotrophy would be associated with surrounding vegetation and geological characteristics of studied sites.

**Keywords**: remote sensing, satellite images, lakes, oligotrophy

## Introduction

The mountain lakes of the Chilean Araucanian Andes (38-39ºS) are oligotrophic, of glacial or volcanic origin. They 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 [1-3]. Some of these lakes have marked volcanic influence because there are active volcanos, such as Llaima, that can expulse their ashes to the surrounding landscapes, consequently affecting inland water bodies [4-5]. Ash from other distant volcanoes also can affect the study area, such as Cordón Caulle [6]. The aim of the present study is to compare spectral properties data obtained from LANDSAT ETM+ in lakes surrounding Llaima Volcano, specifically Icalma and Galletué lakes, and lagoons located within Conguillio National Park (Conguillio, Verde, Arcoiris, and Captrén). Lakes Galletué and Icalma have similar characteristics in depth and surface, whereas the lagoons in Conguillío National Park are small and shallow. From these lagoons Verde and Arcoiris are the lowest [2], with Verde having volcanic material and Arcoiris having submerged vegetation.

Remote sensing allows us to measure reflectance value in oceans, lakes, and rivers using the measurement of reflected light [7-9]. For wavelengths from infrared the

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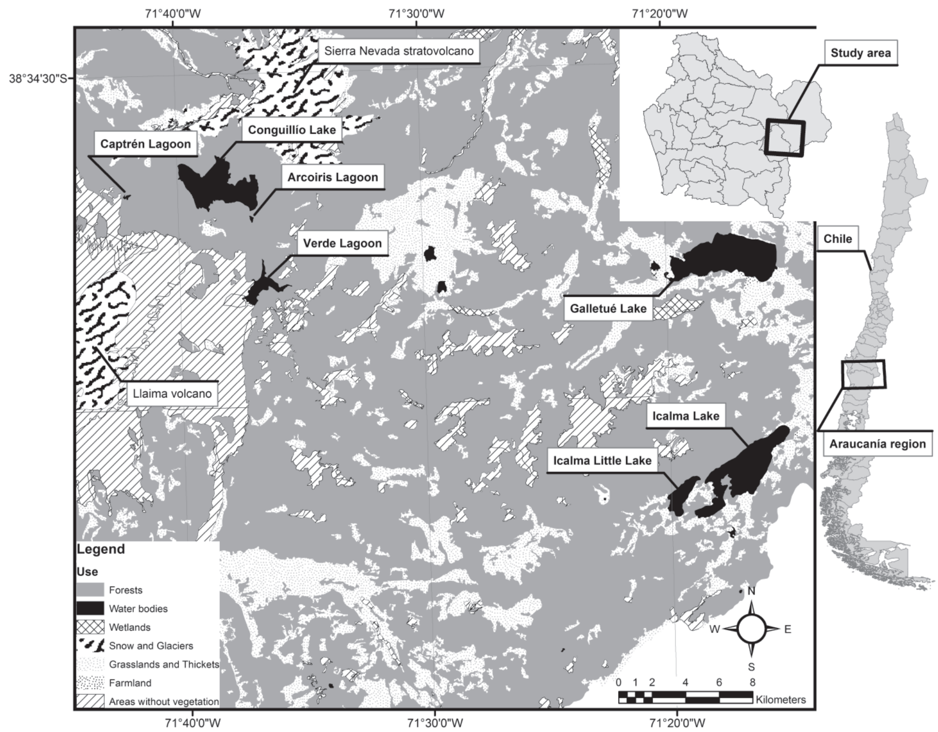


Fig. 1. Study area: North Patagonian Chile (from Native Forest Census – CONAF 2013).

measurements correspond exclusively to water surface, whereas in visible wavelengths these are related to water volume due to more light penetrating into water for these wavelengths for meters of penetration [10-12].

## Material and Methods

### Remote Sensing Procedures

In this step a LANDSAT/ETM+ image is used to obtain dated lakes of Icalma and Galletué and lagoons located within Chile's Conguillio National Park (Fig. 1 and Table 1). This image is dated 12 January 2012 and is provided by the Land Processess Distributed Active Archive Center (LP DAAC) of the U.S. Geological Survey (*LPDAAC.usgs.gov*). The scene corresponds to path/row 233/087, Landsat series. Additionally, two other Landsat/ETM+ images were used, dated from 6 January 2010 and 9 January 2011.

The spectral and spatial characteristics of the ETM+ sensor are presented in Fig. 2 and Table 2. The bands of visible, near, and mid-infrared were calibrated radiometrically to spectral radiance and then to reflectance with atmospheric correction being applied (Table 3). Data analysis: 2012 reflectance was applied to principal correspondence analysis to obtain the grouping for sampled sites. This statistical analysis was applied using Analyse-it software based on the methodology used for Patagonian lakes [13].

Table 1. Geographical locations and areas of studied lakes.

| Lake | Location | Surface area ($km^2$) |
|---|---|---|
| Arcoiris | 38° 40' S; 71° 37´W | 0.036 |
| Captrén | 38° 38' S; 71° 42' W | 0.080 |
| Conguillío | 38° 40' S; 71° 37' W | 8.422 |
| Galletué | 38° 40' S; 71° 15' W | 12.366 |
| Icalma | 38° 40' S; 71° 15' W | 9.940 |
| Icalma Chica | 38° 40' S; 71° 15' W | 2.031 |
| Verde | 38° 40' S; 71° 37' W | 1.861 |

## Results and Discussion

Correlation analysis (Pearson correlation test) to 2012 data revealed direct significant correlations between B1

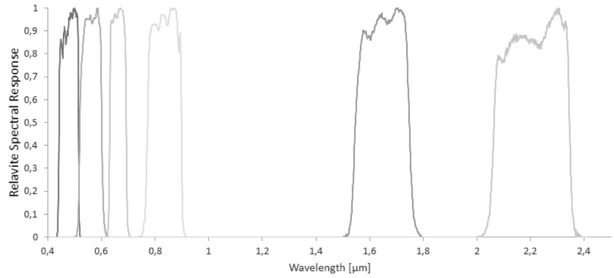


Fig. 2. Relative spectral response, sensor ETM+/Landsat-7.

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

| Band | Spectral range (μm) | Wavelength center (μm) | GSD (m) |
|---|---|---|---|
| PAN | 0.520-0.900 | 0.720 | 15 |
| 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 |
| 6 | 10.40-12.50 | 11.450 | 60 |
| 7 | 2.090-2.350 | 2.208 | 30 |

with B2 ($R2 = 0.991$, $p<0.05$), B1 with B3 ($R2 = 0.932$, $p<0.05$), B1 with B4 ($R2 = 0.790$, $p<0.05$), B2 with B3 ($R2 = 0.955$, $p<0.05$), B2 with B4 ($R2 = 0.797$, $p<0.05$), B2 with B5 ($R2 = 0.755$, $p<0.05$), B3 with B4 ($R2 = 0.852$, $p<0.05$), B3 with B5 ($R2 = 0.814$, $p<0.05$), B3 with B7 ($R2 = 0.794$, $p < 0.05$), B4 with B5 ($R2 = 0.995$, $p<0.05$), B4 with B7 ($R2 = 0.994$, $p<0.05$), and B5 with B7 ($R2 = 0.995$, $p<0.05$) (Table 4). PCA revealed that all variables contributed to axis 1, whereas B1, B2, and B3 made a positive contribution to axis 2 while B4, B5, and B7 made a negative contribution to axis 2 (Table 5, Fig. 3). This may be due to the different light penetration in water of visible (bands 1, 2, 3) and infrared wavelengths (bands 4, 5, 7).

The results of PCA revealed that Verde Lagoon – and partially Conguillio Lagoon and Icalma Lake – have high reflectance for B1, B2, and B3, and low reflectance for B4, B5, and B7, whereas Arcoiris, Icalma Chica, and Captrén lagoons and Galletué Lake (Fig. 1) have low reflectance for B1, B2, and B3 and high reflectance for B4, B5, and B7.

The present study revealed differences in optical properties for studied lakes that could be denoted using remote sensing techniques such as were observed for Patagonian lakes with marked environmental heterogeneity such as was observed for lakes Tagua Tagua and General Carrera [13-15].

Table 4. Correlation matrix for variables considered in the present study (values in bold denote significant correlation; $p<0.05$).

| | B1 | B2 | B3 | B4 | B5 |
|---|---|---|---|---|---|
| B6 | 0.749 | 0.751 | **0.794** | **0.994** | **0.995** |
| B5 | 0.750 | **0.755** | **0.814** | **0.995** | |
| B4 | **0.790** | **0.797** | **0.852** | | |
| B3 | **0.932** | **0.955** | | | |
| B2 | **0.991** | | | | |

The environmental heterogeneity for Patagonian lakes has been described in details mainly regarding trophic status and associated basins [16-18], but recently was studied using 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 [19-21], and these results would be associated with optical properties obtained from satellite images [13-15].

All of the studied sites are associated with the volcanic activity of Cordón Caulle and Llaima volcanoes. The Caulle Cordon began in the middle of 2011 with sustained emissions of volcanic ash until early 2012. This ash often covered the area of Conguillio National Park and surrounding zones. Llaima Volcano had weak eruptive activity in early 2012. The ash plumes of both volcanoes affect all surrounding ecosystems for studied sites [20]. Also, the sites included in Conguillio National Park feature the geological characteristic of having many volcanic stones along their bottoms, such as was observed for Verde and Arcoiris lagoons [5]. Also, in Arcoiris Lagoon the high infrared reflectance values are related to the presence of high quantities of submerged vegetation. In this scenario, there is potential correlation between optical, chemical, and trophic status with a consequent response regarding the biological characteristics of the ecosystem [13-15, 22].

Table 3. Reflectance for studied lakes (2010-12).

| | B1 (%) | | | B2 (%) | | | B3 (%) | | | B4 (%) | | | B5 (%) | | | B7 (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake | 2010 | 2011 | 2012 | 2010 | 2011 | 2012 | 2010 | 2011 | 2012 | 2010 | 2011 | 2012 | 2010 | 2011 | 2012 | 2010 | 2011 | 2012 |
| Arcoiris | 2.79 | 2.96 | 2.71 | 3.21 | 3.03 | 2.29 | 3.73 | 3.45 | 2.46 | 6.54 | 6.02 | 2.78 | 5.18 | 5.38 | 4.04 | 4.53 | 5.84 | 4.13 |
| Captrén | 3.24 | 2.82 | 1.75 | 3.48 | 2.99 | 1.38 | 3.12 | 2.65 | 1.31 | 4.27 | 3.80 | 0.74 | 3.23 | 2.65 | 1.32 | 2.71 | 2.33 | 0.20 |
| Conguillío | 3.02 | 2.86 | 2.13 | 2.72 | 2.47 | 1.62 | 2.14 | 2.15 | 1.26 | 2.39 | 2.25 | 0.62 | 2.27 | 2.03 | 1.01 | 2.21 | 1.98 | 0.13 |
| Galletué | 2.12 | 2.59 | 1.62 | 1.98 | 2.43 | 1.25 | 2.14 | 2.43 | 0.93 | 2.04 | 2.58 | 0.57 | 2.27 | 2.42 | 0.88 | 2.21 | 2.28 | 0.12 |
| Icalma | 2.12 | 2.63 | 2.01 | 1.98 | 2.41 | 1.64 | 2.14 | 2.43 | 1.18 | 2.04 | 2.60 | 0.63 | 2.27 | 2.46 | 1.06 | 2.21 | 2.28 | 0.21 |
| Icalma Chica | 1.90 | 2.65 | 1.82 | 1.98 | 2.56 | 1.44 | 1.91 | 2.53 | 1.10 | 1.69 | 2.75 | 0.63 | 1.95 | 2.58 | 1.15 | 2.21 | 2.36 | 0.22 |
| Verde | 3.02 | 3.79 | 2.39 | 2.96 | 3.58 | 2.03 | 2.59 | 2.87 | 2.02 | 2.74 | 2.91 | 0.86 | 2.58 | 2.58 | 1.16 | 2.51 | 2.47 | 0.21 |

Table 5. PCA contribution percentages of variables for axis 1 and 2.

| | 1 | 2 |
|---|---|---|
| B1 | 0.401 | 0.458 |
| B2 | 0.403 | 0.460 |
| B3 | 0.411 | 0.303 |
| B4 | 0.418 | -0.342 |
| B5 | 0.409 | -0.423 |
| B6 | 0.407 | -0.437 |

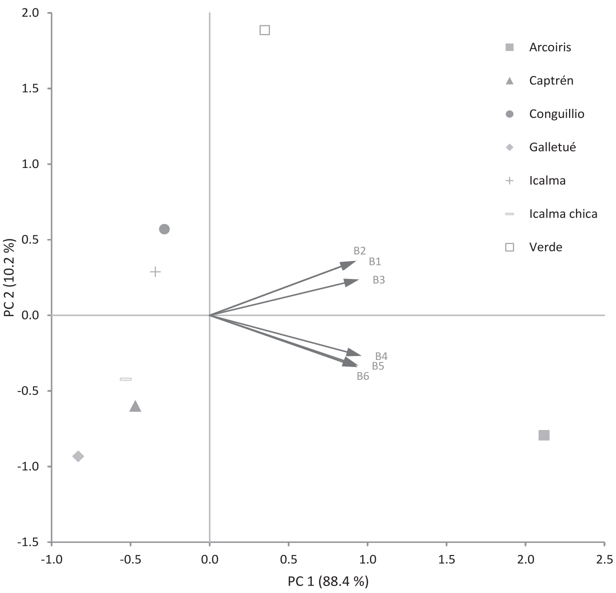


Fig. 3. PCA analysis for variables considered in the present study.

## Conclusion

It is possible to use satellite reflectance data to monitor the chemical and trophic status of lakes and lagoons. This information detects not exclusively differences related to physical features of the lakes, and also recognizes changes of water reflectance generated by ash fall from volcanic plumes. For example, for Arcoiris, Captrén, and Verde in three analyzed data (Table 2), their infrared reflectance values were permanently higher in comparison to other lakes and lagoons, which is due to their low surface and depth. Also, the reflectance value of lakes and lagoons showed a strong decrease in 2012, corresponding to the effect of volcanic ash fall from the Caulle cordon eruption and Llaima volcano eruption.

The results presented indicate a potential correlation between environmental associations due to surrounding basins and that optical properties might possibly be found [23]; 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 [24].

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