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# First characterization of Easter Island inland waters using remote sensing techniques

**Patricio De los Ríos Escalante[1,2,*], Eliana Ibáñez[1], Patricio Acevedo[3,4], Manuel Castro[5]**

1- Laboratorio de Ecología Aplicada y Biodiversidad, Escuela de Ciencias Ambientales, Facultad de Recursos Naturales, Universidad Católica de Temuco, Casilla 15-D, Temuco, Chile.

2- Núcleo de Estudios Ambientales, UC Temuco.

3- Universidad de La Frontera, Departamento de Ciencias Físicas, Casilla 54-D, Temuco, Chile.

4- Center for Optics and Photonics, Universidad de Concepción, Casilla 4012, Concepción, Chile.

5- Laboratorio de Teledetección Satelital, Departamento de Ciencias Físicas, Facultad de Ingeniería y Ciencias, Universidad de La Frontera, Casilla 54-D, Temuco, Chile.

* Author for correspondence, email: prios@uct.cl

## Abstract

Easter Island is the farthest human-inhabited site from a continent, and due to this condition studies on it are very scarce and restricted to basic field descriptions of its coastal marine and terrestrial ecosystems. The aim of the present study is to complete a first description of Easter Island's inland waters using remote sensing techniques, specifically the GVMI index. The results revealed monthly fluctuations in water body and wet soil surface that are due mainly to rainy seasons. These results provide an interesting first step for other limnological studies in Easter Island and other sites with access problems.

Keywords: remote sensing, GVMI index, Easter Island.

## Introduction

Easter Island, located in the mid-subtropical Pacific Ocean, is the farthest human-inhabited site from any continent. The island has endemic species, as well as Asia-Pacific and South American species (Fernandez et al., 2014). In terms of hydrologic conditions, it has two crater lakes (Rano Kau and Rano Raraku) and some ephemeral pools that are present during rainy periods (Niemeyer & Cereceda, 1984; Dummont & Martens 1996). The first faunal descriptions were of aquatic insects (Campos & Peña, 1973; Dummont & Verschuren, 1991), rotifers (Segers & Dummont, 1993) and crustaceans (Dummont & Martens, 1996). Regarding fish species, the presence of introduced *Gambusia affinis* was reported in the mid-19th century (Baird & Girard, 1853; Magliulo-Cepriano et al., 2003; De los Ríos-Escalante, 2010). The widespread presence of crustacean species for Easter Island that probably were human introduced were described more recently (De los Ríos-Escalante & Ibáñez, 2015). In spite of these reports, there are no limnological descriptions for Easter Island, and in this context, if we consider its geographical isolation, it would be possible to do a first study using remote sensing techniques as an exploratory approach (Kondratyev & Filatov, 1999; Verpoorter et al., 2012; 2014). In this context, remote sensing techniques have been used for first observations of mountain lakes in Chilean Patagonia (De los Ríos-Escalante et al., 2013; 2016, 2017; De los Ríos-Escalante

& Acevedo, 2016a,b). The aim of the present study is to do a first ecological limnology analysis of Easter Island water bodies using remote sensing techniques, considering the access difficulties of these water bodies.

## Material and Methods

Study site: Easter Island was visited between 19th and 24th September 2014, when it was sampled at three sites: Rano Kau and Rano Raraku crater lakes, located in the homonymous volcanoes and Rano Aroi plain, in a high plain with ephemeral pools and streams, (Table 1, Fig. 1). These sites are the main inland water bodies of Easter Island (Dummont & Martens, 1996; Canyellas-Bolta et al., 2014; De los Ríos-Escalante & Ibáñez, 2015). Rano Kau lake has a surface area of 0.11 $km^2$ and is 2-3 m deep (Canyellas-Bolta et al., 2014), whereas Rano Raraku lake has a surface of 0.09 $km^2$ and is 3 m deep (Dummont et al., 1998), and Rano Aroi is a high plain with approximately a flooding zone of 0.13 $km^2$ (Margalef et al., 2013). Each site was georeferenced using a Garmin GPS, and we also measured in situ water conductivity and total dissolved solids with a HANNA sensor.

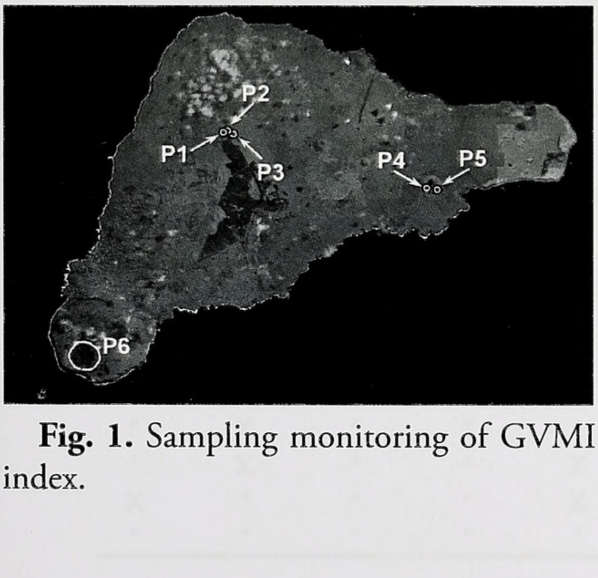


**Fig. 1.** Sampling monitoring of GVMI index.

Satellite information and wet index: the satellite information corresponding to ten images (Table 1), of the multispectral Operational Land Imager (OLI) sensor of LandSat-8 satellite. In the processing of the images a radiometric correction and reflectance calibration were applied, with atmospheric adjustment using software ENVI, with Flash, one of the standard MODTRAN model atmospheres and the 2-Band K-T (Kaufman & Tanre, 1992) aerosol retrieval method. After image calibration, we used the spectral index Global Vegetation Moisture Index (GVMI) for wet study (Ceccato et al., 2002; Sow et al., 2013). The GVMI was calculated from equation 1:

$$[1]\ GVMI = \frac{(\rho_{nir} + 0.1) - (\rho_{swir} + 0.02)}{(\rho_{nir} + 0.1) + (\rho_{swir} + 0.02)}$$

where $\rho_{nir}$ and $\rho_{swir}$ are the reflectance in close infrared bands (NIR 850-878 nm) and medium infrared (SWIR: 1556-1651 nm). The NIR and SWIR bands spatial resolution of the OLI sensor is 30 m.

Ceccato et al. (2002), define the GVMI based on an EWT (leaf equivalent water thickness), by adjusting spectral reflectance in the close and medium infrared. The index provides primarily phenological and water information, given its high sensitivity to the change of moisture content in vegetation (Sánchez, 2002; Ceccato et al., 2002; Sánchez & Chuvieco, 2000; Yang et al., 1997), whereas SWIR sensitivity is due to water presence. According to the results obtained from SWIR and NIR, it is possible to use both as effective tools to remove the vegetation influence (Ceccato et al., 2002).

Satellite monitoring: the GVMI index considered six sites where P1, P2 and P3 are located in the Rano Aroi plain, P4 and P5 are located in the surrounding of the Rano

Raraku volcano, and P6 is located inside the Rano Kau volcano. The GVMI index values correspond to mean values of areas not covered by water inside the crater (Fig. 1 and Table 1).

## Results and Discussion

The results revealed that all sites have low conductivity, low total dissolved solids values and relatively neutral pH (Table 1). All sites have high levels of the GVMI index during the southern autumn and winter (April to August). The Rano Kau volcano site has a low GVMI index because it is a permanent lake with much surrounding vegetation, and with many submersed macrophytes that form a kind of vegetation island, whereas the Rano Raraku crater lagoon has intermediate values because it is a permanent lake with low littoral vegetation (Fig. 2, Table 3). A different situation was observed for the Rano Aroi sites: high GVMI index values with marked differences in seasons, with markedly low values in the southern spring-summer (September to March, Figure 2, Table 3) and high values in June, due to the rain increase in autumn (Niemeyer & Cereceda, 1984). These results agree with field observations in September 2014 (De los Ríos-Escalante & Ibáñez, 2015).

Table 1. Geographical location, altitude (m a.s.l.) total dissolved solids (mg/L), and conductivity (dS/cm), for studied sites.

| | Rano Aroi 1 | Rano Aroi 2 | Rano Aroi 3 | Rano Raraku | Rano Kau |
|---|---|---|---|---|---|
| Nomenclature at map (see fig. 1). | P1 | P2 | P3 | P4-P5 | P6 |
| Geographical location | 27° 06' 02.5'' S 109° 22' 24.3'' W | 27° 06' 01.5'' S 109° 22' 21.5'' W | 27° 06' 06.0'' S 109° 22' 13.0'' W | 27° 07' 23.8'' S 109° 17' 26.0'' W | 27° 08' 08.4'' S 109° 26' 37.9'' W |
| Altitude | 420 | 402 | 380 | 90 | 23 |
| TDS | 0.02 | 0.01 | 0.02 | 0.45 | 0.05 |
| Conductivity | 0.04 | 0.01 | 0.04 | 1.17 | 0.11 |

Table 2: Satellite images used in this study. The (*) corresponds to a condition free of clouds.

| Date D-M-Y | P1 | P2 | P3 | P4 | P5 | P6 |
|---|---|---|---|---|---|---|
| 16th February 2014 | * | * | * | * | * | * |
| 05th April 2014 | X | * | * | * | * | * |
| 07th May 2014 | * | * | * | * | * | * |
| 24th June 2014 | * | * | * | X | X | X |
| 26th July 2014 | * | * | * | X | X | * |
| 27th August 2014 | * | * | * | X | * | X |
| 28th September 2014 | * | * | * | * | X | * |
| 14th October 2014. | * | X | * | * | X | * |
| 15th November 2014 | X | X | * | * | * | X |
| 17th December 2014 | * | * | * | * | * | * |

Table 3: Results of GVMI index for the studied sites in Easter Island.

| Date | P1 | P2 | P3 | P4 | P5 | P6 |
|---|---|---|---|---|---|---|
| 16th February 2014 | 0.22 | 0.18 | 0.25 | 0.13 | 0.24 | 0.06 |
| 05th April 2014 | No data | 0.20 | 0.31 | 0.30 | 0.34 | 0.05 |
| 07th May 2014 | 0.28 | 0.21 | 0.32 | 0.31 | 0.33 | 0.08 |
| 24th June 2014 | 0.33 | 0.35 | 0.39 | No data | No data | No data |
| 26th July 2014 | 0.22 | 0.28 | 0.19 | No data | No data | 0.12 |
| 27th August 2014 | 0.19 | 0.22 | 0.19 | No data | 0.24 | No data |
| 28th September 2014 | 0.12 | 0.18 | 0.12 | 0.18 | No data | 0.02 |
| 14th October 2014 | 0.11 | No data | 0.11 | 0.17 | No data | 0.05 |
| 15th November 2014 | No data | No data | 0.11 | 0.15 | 0.22 | No data |
| 17th December 2014 | 0.12 | 0.14 | 0.17 | 0.14 | 0.27 | 0.01 |

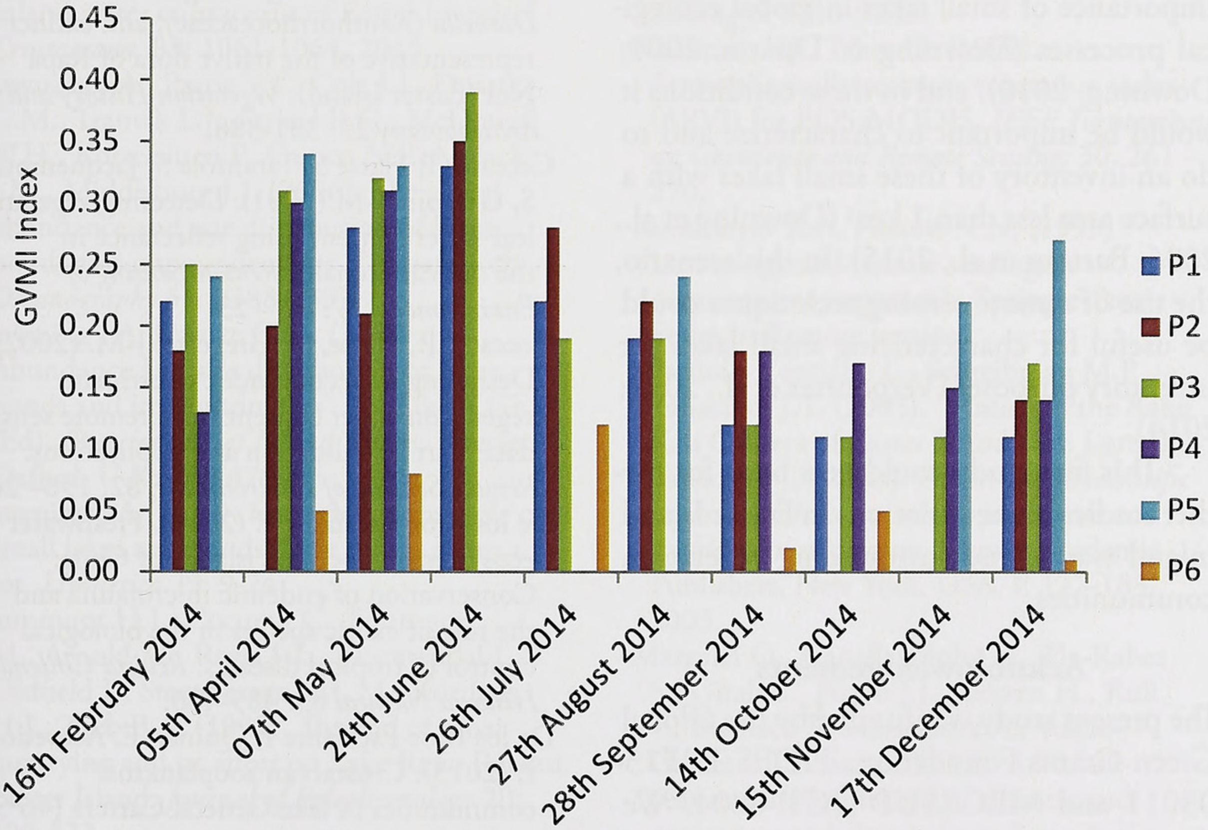


Fig. 2. GVMI index results during 2014 at six points considered in the present study.

The results would indicate that it is possible to use the GVMI index to study variations in wetlands or ecotones conformed by littoral vegetation or submerged macrophytes in shallow lakes (Nagler et al., 2013; Jarihani et al., 2014; Brooks et al., 2015; Giardino et al., 2015). From this viewpoint, these remote sensing techniques would be an important tool for basic exploration in inland waters with access problems (Mathews, 2011; Palmer et al., 2015). Moreover, if we integrated these findings, it would be possible to study variations in littoral vegetation over temporal intervals (Pérez-Luque et al., 2015).

The current literature mentions the importance of small lakes in global ecological processes (Downing & Duarte, 2009; Downing, 2010), and in these conditions it would be important to characterize and to do an inventory of these small lakes with a surface area less than 1 $km^2$ (Downing et al., 2006; Bartout et al., 2015). In this scenario, the use of remote sensing techniques could be useful for characterizing small lakes for inventory purposes (Verpoorter et al., 2012; 2014).

This first study could be a basis for further studies of the variations in Easter Island inland waters and surrounding vegetation communities.

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