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Initial Limnology of Laguna Pozo Verde, Costa Rica: Bathymetry, Water, Sediments, and Diatoms

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ABSTRACT. Introduction: Costa Rica has hundreds of lakes, many of which have never been scientifically studied. **Objective:** To carry out a first, basic limnological study of Laguna Pozo Verde in Juan Castro Blanco National Park, Costa Rica (~1935m elevation), to provide baseline data for studying future changes. **Methods:** We measured water depths and temperatures, and Secchi depth; analyzed surface sediments; and examined maps and satellite imagery. **Results:** Though described by some as formed by volcanic processes, Laguna Pozo Verde likely formed in a landslide, which occur frequently in this rainy area on the steep south slope of the inactive Porvenir Volcano. Our soundings showed a maximum depth of 9,25m near the center of the lake. The water was moderately transparent (Secchi depth 2,6m), with circumneutral pH, and temperatures from 15,9–18,1°C, with weak stratification at 0,5m. Surface sediments contained 27% organic matter, and had C/N ratios and stable carbon isotope values consistent with lacustrine algae and C_3 plants; *Surirella angusta* composed over 90% of the diatoms. **Conclusion:** The lake is significantly shallower than reported, and surface sediments have a diatom assemblage unique among 88 lakes examined in Costs Rica.

Keywords: Lake formation, bathymetry, water temperatures, lacustrine sediments, diatoms.

RESUMEN. "Limnología inicial de Laguna Pozo Verde, Costa Rica: Batimetría, agua, sedimentos y diatomeas." **Introducción:** Costa Rica tiene cientos de lagos, muchos nunca estudiados científicamente. **Objetivo:** Conocer la limnología de Laguna Pozo Verde en el Parque Nacional Juan Castro Blanco, Costa Rica (~1935m de elevación), como referencia para estudiar futuros cambios. **Métodos:** Medimos la profundidad y temperatura del agua y la profundidad de Secchi; analizamos sedimentos superficiales; y examinamos mapas e imágenes satelitales. **Resultados:** Aunque algunos la describen como formado por procesos volcánicos, es probable que Laguna Pozo Verde se haya formado en un deslizamiento de tierra, algo común en esta zona lluviosa de la empinada ladera sur del Volcán Porvenir (inactivo). Hallamos una profundidad máxima de 9,25m cerca del centro. El agua era moderadamente transparente (profundidad de Secchi 2,6m), con un pH cercano a neutral y temperaturas de 15,9-18,1°C, y una débil estratificación a 0,5m. Los sedimentos superficiales contenían un 27% de materia orgánica y tenían cocientes C/N y valores de isótopos de carbono estables, coherentes con algas lacustres y plantas C_3; más del 90% de las diatomeas eran *Surirella angusta*. **Conclusión:** La laguna es significativamente más somera de lo informado y los sedimentos superficiales albergan una combinación de diatomeas única entre los 88 lagos examinados en Costa Rica.

Palabras clave: Formación de lagos, batimetría, temperatura del agua, sedimentos lacustres, diatomeas.

Costa Rica has hundreds of natural lakes, of diverse characteristics and modes of formation, which have been studied by national and international researchers for over seven decades (Umaña et al., 1999; Horn & Haberyan, 2016). Nonetheless, many lakes remain undescribed. Lakes are vulnerable to shifts in physical, chemical, and biological properties resulting from natural and human drivers including climate change, the introduction of non-native species, deforestation, and air and water pollution (Dodds & Whiles, 2019). Studying the limnology of lakes in Costa Rica and the sediments now accumulating in them provides baseline data for studying future changes in lake conditions. These studies also support reconstructions of limnological and environmental changes over past centuries and millennia based on the analysis of evidence preserved in sediment cores (Horn, 2007).

In July 2019, we carried out a first, basic limnological survey of Laguna Pozo Verde (Fig. 1), a small lake within Juan Castro Blanco National Park in central Costa Rica (10.2623 N, 84.3558 W), in a sector of the park owned and administered by the Coopelesca electric cooperative. We have found no mention of this lake or its limnology in the scientific literature or in government surveys of lakes and wetlands in Costa Rica (Córdoba et al., 1998; Coto et al., 2005; Proyecto Humedales de SINAC-PNUD-GEF, 2018). At the time we visited, a Coopelesca sign at the edge of the lake stated the elevation of the lake to be 1850m, and the depth 15m. The sign did not mention the origin of the lake, but web pages developed by Coopelesca and other sources have described the lake as being of volcanic origin.

For our survey of Laguna Pozo Verde, we measured lake depths along transects on 20 July 2019, using a MarCum LX-i digital handheld sonar unit set to measure depths to the nearest 0,1ft (~3cm). We measured the elevation of the lake using a handheld Trimble Juno 3B GPS unit. From a central sampling location, we measured water temperatures using a YSI 55 probe, and Secchi disk depth, between 11:28 and 11:45am on 21 July 2019. We collected water samples for chemical analyses, but erred by collecting insufficient volume, and we have no water data. We collected a coarse pH measurement using pH paper. We used a LaMotte dredge to collect a sample of surface sediment from near the center of the lake.

In the lab, we used a Munsell book to manually determine the color of the sediments, and loss-on-ignition at 550°C to estimate organic content (Dean, 1974). We measured stable carbon and nitrogen isotope ratios along with carbon and nitrogen elemental content on a Costech 4010 elemental analyzer interfaced with a Thermo Delta V Plus stable isotope mass spectrometer. The nitrogen contents and isotope ratios were analyzed on unacidified samples, and the carbon contents and isotope ratios were analyzed on samples acidified by fumigation in concentrated HCl. The values reported are means of two duplicate samples. Diatom samples were prepared by nitric acid digestion, rinsing, drying on coverslips, and mounting in Naphrax (Haberyan & Horn, 2023). We used our depth soundings and a spline function in ArcGIS to produce a bathymetric map with lake depths reported in cm, and measured lake area in ArcGIS. To characterize the setting and explore the possible mode of formation of the lake, we examined maps and Google Earth imagery. We did not have access to historical aerial photographs for this study, but recommend this additional source of information for future studies.

Fig. 1. Laguna Pozo Verde in July 2019: looking northwest across the lake from near the southeastern shore. S. Horn.

Our depth soundings and bathymetric map (Fig. 2) show that Laguna Pozo Verde is steep-sided, with a maximum depth of 925cm in the north central part of the basin. The lake does not have the flat bottom often found in lakes occupying volcanic craters. We calculated the area of the lake to be 0,55ha. We measured an elevation of 1935m for the lake at the shoreline closest to the access trail. Our measurement is consistent with the elevation of 1934m provided by Google Earth for the same location, and with the 1:50,000-scale topographic map of the area (Instituto Geográfico Nacional, 1966), which shows the lake to be located between the elevation contours of 1920 and 1940m.

Laguna Pozo Verde is located on the steep southern slope of Porvenir volcano, about 1km SSE of the summit. The lake lies on or near the southern end of an NNW-trending fault that cuts the eastern summit area of the volcano, and near or along a second fault running E–W near the lake, as mapped by Alvarado and Carr (1993). These authors described shallow earthquake swarms and associated landslides in their study published 30 years ago. Satellite imagery accessed with Google Earth Pro in 2023 shows multiple recent landslides that have occurred since that study. On July 23, 2023, an enormous landslide, with a detachment area estimated to be at least 200 ha, occurred near Laguna Pozo Verde during an interval of heavy rain (Coto, 2023; Delgado, 2023). By comparing an aerial image in a screen capture from TVN Noticias with an image in Google Earth, we calculated that the western edge of this slide came within 100m of the lake. Based on the geomorphic instability of the region and the high annual rainfall of ca. 4000mm (based on map in Coen, 1983), we suggest that Laguna Pozo Verde may have formed from a landslide, rather than from volcanic activity as popularly described.

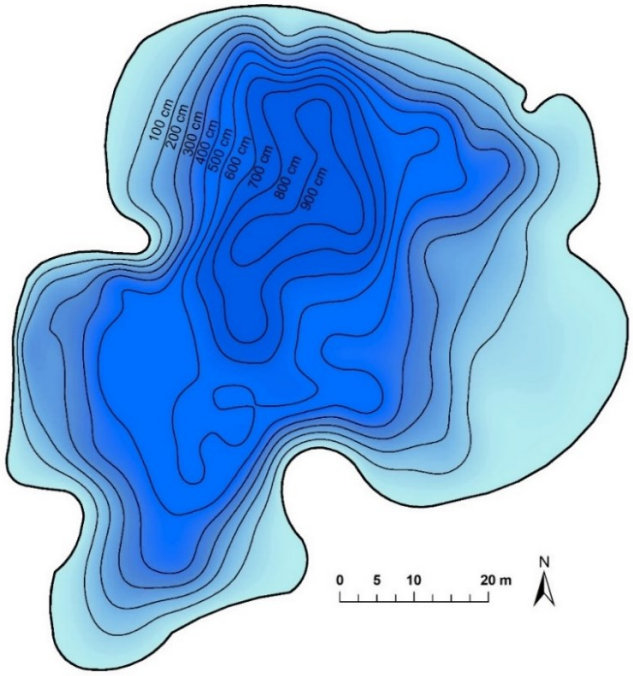

Fig. 2. Bathymetry of Laguna Pozo Verde

We measured a Secchi disk depth of 2,6m, indicating moderate transparency, and a mildly acidic pH of 6–7. Our temperature sounding showed water temperatures of 15,9–18,1°C, with weak stratification at 0,5m. Repeat measurements would be necessary to characterize the mixing of the lake; our single observation and the depth of the lake indicate that it may stratify periodically.

The surface sediments collected with a dredge are dark greyish brown in color (Munsell 2.5Y 3/2). Loss-on-ignition analysis gave an estimated organic content of 27% by dry mass, very close to the mean value (26,8%) for surface sediments from a set of 57 Costa Rican lakes presented by Horn et al. (2018). The low carbon isotope ratio and atomic C/N data (Table 1) indicate that lacustrine algae and plants using the C_3 photosynthetic pathway are the main contributors to the sedimentary organic matter pool in the lake (Meyers & Teranes, 2001). The diatom assemblage is highly unique. The assemblage is dominated by *Surirella angusta* (Fig. 3), which comprises 91% of the diatom flora, along with *Encyonema gracile* (5%), *Eunotia minor* (3%), and *Encyonema silesiacum* (1%). The diatom *Surirella angusta* was not found in diatom analyses at 87 other lakes in Costa Rica (Horn & Haberyan, 2023).

TABLE 1

Geochemical characteristics of the sediments of Laguna Pozo Verde

Parameter	Value
%C	5,64
%N	0,67
$\delta^{13}C$	-28,05
$\delta^{15}N$	-0,76
C/N mass ratio*	8,36
C/N atomic ratio[2]	9,76

*C/N ratios calculated using values for %C and %N with more decimals than shown in table. The C/N atomic ratio is the C/N mass ratio multiplied by 1.167, which is the ratio of atomic weights of nitrogen and carbon (Meyers & Teranes, 2001). Both C/N ratios are used in publications, so both are provided to facilitate comparisons.

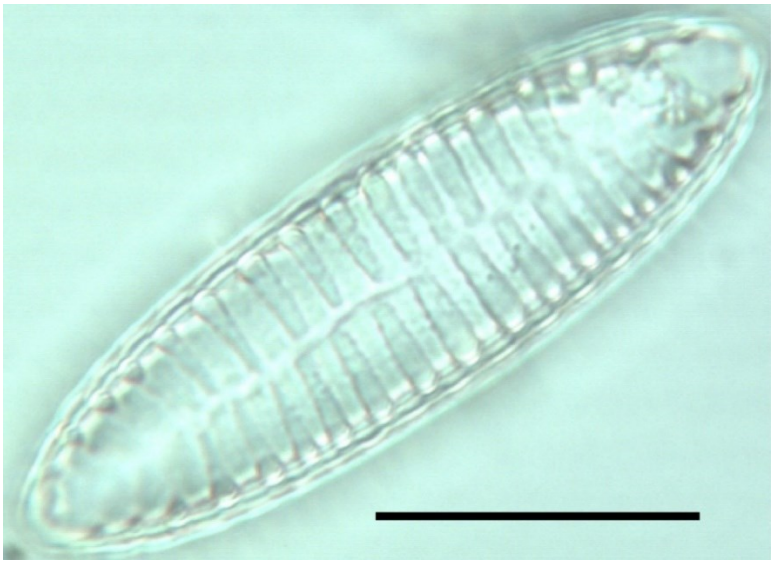

Fig. 3. The diatom *Surirella angusta.* Scale bar: 20 micrometers. K. Haberyan

To our knowledge, this is the first published report on Laguna Pozo Verde. Our results show that the that the lake is considerably shallower than reported on the sign next to the lake, but is located about 85m higher in elevation than reported. The modern sediments of the lake contain a unique diatom assemblage. We recommend further study of the lake, including sampling of water, phytoplankton, and zooplankton, and measurements of limnological properties at different times of the year. We also recommend studies of the geomorphological evolution of the lake and region. Our interpretation is that the lake formed from a landslide, rather than volcanic processes, but more detailed studies are needed. How the July 2023 event may have affected the lake and how this and other landslides could affect the lake in the future are questions that we hope to see addressed in future studies.

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ETHICAL, CONFLICT OF INTEREST AND FINANCIAL STATEMENTS

The authors declare that they have fully complied with all pertinent ethical and legal requirements, both during the study and in the production of the manuscript; that there are no conflicts of interest of any kind; that all financial sources are fully and clearly stated in the acknowledgements section; and that they fully agree with the final edited version of the article. A signed document has been filed in the journal archives.

The statement of each author's contribution to the manuscript is as follows: S.P.H., E.N.J., and M.M.H.: Study design. S.P.H., E.N.J., M.M.H., and T.F.: collection of field data and samples. S.P.H., K.A.H., and C.S.L.: Laboratory analyses and data interpretation. S.P.H.: manuscript preparation. E.N.J.: bathymetric map and ArcGIS analyses. All co-authors: editing and final approval of the manuscript.

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