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Charo López-Blanco: investigation, formal analysis, methodology, writing-review& Editing; **Gloria Alejandra Rodríguez-Abaunza:** investigation, formal analysis, methodology, writing-review & Editing; **Carina Seitz:** investigation, formal analysis, methodology, writing-review & Editing; **Laura Pérez:** investigation, formal analysis, methodology, writing-review & Editing; **Carolina Cuña-Rodríguez:** investigation, formal analysis, methodology, writing-review & Editing; **Sonia L. Fontana:** funding acquisition, conceptualization, review, validation, supervision.

A 700-year multiproxy reconstruction on the Argentinian Pampas inferred from the sediments of Laguna Blanca Grande

*Charo López-Blanco[1,2], Gloria Alejandra Rodríguez-Abaunza[3,4,5], Carina Seitz[6], Laura Perez[7], Carolina Cuña-Rodriguez[8], Sonia L. Fontana[9,10]

[1] Escuela Politécnica Nacional, Facultad de Ingeniería Civil y Ambiental, Quito, Ecuador.

[2] Animal Ecology and Systematics, Justus Liebig University Giessen, Heinrich-Buff-Ring 26 (IFZ) D-35392 Giessen, Germany.

[3] Grupo de Investigación Biología para la Conservación. Universidad Pedagógica y Tecnológica de Colombia. Avenida Central del Norte 39-115, Tunja, Colombia.

[4] Posgrado en Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México. Av. Ciudad Universitaria 3000, C.P. 04510, Coyoacán, Ciudad de México, México

[5] Smithsonian Tropical Research Institute, Balboa–Ancón 0843–03092, Panamá, Panamá

[6]Universidad Nacional del Sur (UNS). Instituto Argentino de Oceanografía (UNS-CONICET), Bahía Blanca, Argentina.

[7]Centro Universitario Regional del Este (CURE), Universidad de la República, Rocha-Uruguay.

[8]Centro de Investigaciones en Ciencias de la Tierra (CICTERRA-CONICET), F.C.E.F. y N., Universidad Nacional de Córdoba, Córdoba, Argentina.

[9]Cátedra de Palinología, Facultad de Ciencias Naturales y Museo, UNLP, Calle 64 n°3, 1900 La Plata, Argentina

[10]Faculty of Resource Management, HAWK University of Applied Sciences and Arts. Büsgenweg 1a 37077 Göttingen, Germany

*Corresponding author: charo.lopezblanco@gmail.com

ABSTRACT

The Pampean region is a crucial area to obtain sensitive paleoclimatic lacustrine archives due to the presence of shallow environments in a territory non impacted by humans until the last centuries. In this study, we provide a paleoecological reconstruction for the last ca. 700 years based on a multiproxy lacustrine record from Laguna Blanca Grande, in Olavarría (Buenos Aires, Argentina). Our inferences, which were based on sedimentary properties, diatom, cladoceran and ostracod assemblages, offered interesting information about hydroclimatic variability and nutrient increase. Changes in relative abundances on diatoms, specifically on *Aulacoseira granulata* and *Aulacoseira granulata* var. *angustissima* and fragilariods, were used to infer shifts in nutrient conditions. The remainder proxies together indicated small lake level changes. Reconstructed hydroclimatic conditions in Laguna Blanca Grande are consistent with previous paleoecological inferences indicating a humid phase around ca. AD 1450 and progressive drier conditions ca. AD 1530-1900. A flood gate construction and an increase of nutrients in the lake revealed a higher human pressure due to population increase and land-use changes during the last century. Further studies on taxonomy and autecology of microcrustaceans are needed to effectively unlock the information contained in biological proxies from Sudamerican records.

Keywords: nutrient enrichment, hydroclimatic reconstruction, lake level changes, diatoms, cladocerans, ostracods.

1. Introduction

The Pampean plains are fertile and vast lowlands that cover more than 750,000 km^2, which include some regions in Argentina, Uruguay, and the southernmost states of Brazil (Politis, 2008; Viglizzo et al., 2001; Zarate, 2003). The interannual rainfall variability in this region is related to the sea surface temperature over the western South Atlantic, the intensity and position of the South Atlantic Convergence Zone (SACZ) and the South American summer monsoon (SASM) (Barros et al., 2000; Garreaud et al., 2009), which explains the migration of moisture and precipitation patterns in subtropical plains producing rainy conditions during the austral summer. In addition to the intrannual variability, the region is strongly influenced by interannual phenomena such as the El Niño Southern Oscillation (ENSO). As a result of these different modes of climatic variability, the Pampean lakes have shown important lakes level changes during the Holocene, as demonstrated in Laguna Mar Chiquita (Cuña-Rodriguez, 2018; Coianiz et al., 2014; Piovano et al., 2014; 2009; 2004; 2002), Lagunas Encadenadas del Oeste de Buenos Aires (Córdoba, 2012; 2014), Lake Nahuel Rucá (Stutz et al., 2010), Lake Lonkoy (Stutz et al., 2012), Lake La Barrancosa (Plastani et al., 2019), Lake Adela (Dangavs and Mormeneo, 2012), Laguna del Monte (Dangavs and Pierrard, 2013), Lake La Brava (Irurzun et al., 2014; Laprida et al., 2014) and Lake Melincué (Guerra et al., 2015; 2017) (Fig. 1). Despite the existence of some paleohydrological reconstructions, multiproxy inferences in the southern Pampas (classification according to Iriondo, 1994) are still needed to provide additional information on the timing and relationship of local hydrovariability with large-scale climatic events (Guerra et al., 2017; Lüning et al., 2019). Moreover, understanding the interaction of past climatic changes with limnological features is also crucial to face future challenges such as the synergic effect of climate warming and eutrophication on local/endemic biodiversity (Kopprio et al., 2010). This is particularly meaningful when taking into account the socioeconomical implications and ecosystem services of these lakes, considering that they play an important role as reservoirs of endemic biodiversity, flood control, recreation, tourism and climate change mitigation (Iwan et al., 2017).

In this study we used a lacustrine record based on diatoms, cladocerans and ostracods from Laguna Blanca Grande (Buenos Aires, Argentina) to provide new paleoecological information from southern Pampas (Fig. 1) and also to help to understand the temporal-spatial features of hydrological changes and the role of human activities in the last centuries. We hyphotesize that this sequence may contain a relatively good signal of past natural conditions and climate variability since this region was not highly impacted by humans for a longtime. Documentary and historical sources (*e.g.*, Djenderedjian, 2012; Mayo, 2000; Pedrotta et al., 2012) indicated that only sparse native populations inhabit La Pampa until the end of the 19th century. Migration and farming conversion did not take place until the beginning of the 20th century. Hydroclimatic variability as well as the recent human impact might have been recorded in our sediment record.

2. Site Description

The Argentinian Pampean region comprises an extensive plain (~500,000 km^2) covering the center-east of the country. The geological setting is characterized by loess-like deposits covered by Quaternary aeolian sediments, composed of massive to poorly stratified sandy silt, partially reworked by fluvial action and with common carbonate accumulations of unknown origin (Muhs, 2013; Rubio et al., 2019; Zarate, 2003; Zarate and Tripaldi, 2012). The climate of southern Pampas is subtropical semiarid, characterized by mean annual temperature of 14.4ºC, with mean values of 2ºC in the coldest months (June-July) and 29ºC in the warmest (August). Mean annual rainfall is about 901 mm (mean values 1988-2010, National Meteorological Service from the Olavarría meteorological station). The geomorphology of this region -low slope and absence of geographical features- allows the development of wetlands and shallow lakes in the most depressed areas of the plain. Most of the lakes are small (< 500 ha), shallow (~ 4 m), eutrophic and polymictic (i.e., without thermal stratification) (Geraldi et al., 2011; Laprida, 2008; Quirós and Drago, 1999).

Laguna Blanca Grande (Fig. 1; 36°29'12, 99"S, 60°53'45,91"W) is located between Olavarría and San Carlos de Bolívar, Buenos Aires Province, Argentina. It is an almost round lake with a 450 ha basin, an average depth of 80 cm and a maximum of 180 cm. It receives water from the Brandsen Creek, in a permanent regime, and from three temporary watercourses. Water flows from the lake into the Arroyo Las Flores, where there is a sluicegate to regulate the level. This gate was probably built around the 1950s in a context of water management actions around Lagunas Encadenadas del Oeste to prevent the impacts of floods and droughts in the region (Monachesi and Albaladejo, 1997).

Lake shows alkaline waters (pH= 8.7) and total nitrogen values ca. 81.3 mg/l (Hassan, 2011). Conductivity is ca. 0.6 mS/cm and hardness is ca. 227 mg/l (Hassan et al., 2011). The order of major ion concentration is HCO_{3-} >> SO_4^{2-} > Cl^- and Na^+ >> Mg^{++} > K^+ > Ca^{++} (Colautti and Remes-Lenicov, 2003). Modern diatom assemblage is composed of *Aulacoseira granulata, Staurosira longirostris, Cyclotella menenghiniana, Hippodonta hungarica, Pseudostaurosira brevistriata* (Hassan et al., 2011; Hassan and

De Francesco, 2018). Zooplankton is composed of the rotifers *Keratella tropica*, *Notholca* sp., *Asplanchna girodi* and *Polyarthra vulgaris*, the cladocerans *Bosmina* sp. and *Macrotix laticornis* and the copepod *Notodiaptumus incompositus*. This is the main source of food of the Argentinian silverside (*Odontesthes bonariensis*), which also inhabits this lake (Colautti and Remes-Lenicov, 2003). Today, recreational fishing and tourism are some of the main activities around the lake. However, at regional scale, Olavarría has a diversified economy with important contribution of agriculture, stockbreeding and industry related to mining activities (Olavarría, 2010).

3. Materials and methods

3.1. Coring, sampling and chronology

Sediment cores were recovered with a Livingston piston corer from the deepest part of the lake (0.6 m) in December 2013. Two parallel and overlapping cores (LBG-A and LBG-B) were taken from the lake at a distance of 3 m from one another. Core LBG-A was 77 cm in length while core LBG-B was 102.5 cm in length. Core LBG-A extended from the mud-water interface to a depth of 77 cm. After the correlation of the cores, it was decided not to analyze the upper part of the core LBG-B, from the mud-water interface to 37.5cm, and perform the analysis only from 37.5 cm to the bottom of the core (65 cm length). This strategy ensured an overlap of ca. 40 cm between the two cores. Sediment cores were wrapped in plastic film, placed in PVC tubes and stored in a cool room at 4ºC until further processing. Core description was carried out following the methodology described in Schnurrenberger et al. (2003) and the Munsell color chart (Munsell Colour Company, 1975). The stratigraphic column was build using the lithological patterns suggested by the US Geological Survey (2006). Color and main physical properties such as composition, structure, or degree of humification were the initial basis to establish a correlation between both cores. Then, the correlation was confirmed by analytical measurements and biological proxies. Based on this correlation, four bulk sediment samples along the whole length of the composite record were selected for AMS ^{14}C analysis at the CHRONO Center laboratory at Queen's University Belfast, UK. Radiocarbon dates were calibrated using the ShCal13 database (Hogg et al., 2013) and the 95.4% distribution (2s probability interval) was considered to build the age-depth model.

As one of the samples did not accomplish the principle of superposition, an age-depth Bayesian statistic model was built using only three samples. The age-depth model was built using the package Bacon (Blaauw and Christen, 2011) in R 3.4.2 software (R Development Core Team, 2019). The curve was adjusted with a Gaussian model and included the starting condition that the surface was -63 as a ± 0 cal. years BP. Using these settings, over 7,000 iterations were run using a Markov chain Monte Carlo (MCMC) method to estimate the unknown parameters in the age-depth model. Although carbonate accumulations of variable morphology and genesis are common in the loess sequences (Muhs, 2007), Fontana (2007) showed that reservoir effect was negligible in a Pampean shallow lake in the same geological setting. Therefore, no correction for reservoir effect was applied in the model.

3.2. Analytical and biological methods

Volumetric subsamples of 1 cm^3 were taken at 5 cm intervals for organic matter, granulometry and biological analysis (diatoms, cladocerans and ostracods). For granulometric analysis, samples were dispersed in distilled water after organic matter and carbonates were dissolved with H_2O_2 and HCl, respectively, and analyzed by laser diffraction (Mastersizer Malvern, 2000). The samples with granulometry > 250 µm were sieved. Results were integrated into the GRADISTAT V 4.0 program (Blott and Pye, 2001). The granulometric analysis was performed at the Marine Geology Laboratory at the Instituto Argentino de Oceanografía, Argentina. Organic matter was determined by weight loss on ignition (LOI) at 550 °C for four hours. Subsequently, the CO_2 mass evolved from carbonate was determined by LOI at 950°C for two hours, and the carbonate content was calculated by multiplying the weight loss by 1.36 (Heiri and Lotter, 2001). LOI analysis was carried out at the Centro de Investigaciones en Ciencias de la Tierra (CICTERRA - CONICET - UNC).

For diatom and chrysophyte cyst analysis, samples were treated with sodium pyrophosphate ($Na_2P_2O_7$) to deflocculate the sediment and to remove the clays. Then, 15 mL of HCl (35%) were added to wet samples to remove carbonates. Finally, samples were heated to a water bath for 2 hours with H_2O_2 to remove organic matter (Metzeltin and García-Rodríguez, 2003). They were washed with distilled water successively until reaching a neutral pH in between the three treatments mentioned above. Once cleaned, permanent slides were made using an Entellan® (refractive Index: 1.54) mounting medium. At least 400 diatoms valves per sample were identified in an optical microscope at 1250× magnifications with oil immersion. Relative abundances of taxa (included chrysophyte cysts) were calculated by dividing the number of valves and cysts from each species by the total count on each slide/sample. These analyses were carried out at the Geoscience laboratory from CURE-Rocha, Uruguay. Diatom species were identified using the appropriate keys (Frenguelli, 1941; Gómez and Bauer, 2000; Hasle and Syvertsen, 1997; Krammer and Lange-Bertalot, 1991a, 1991b, 1988, 1986; Metzeltin et al., 2005; Metzeltin and García-Rodríguez, 2003; Theriot et al., 1992). Ecological information on diatom taxa preferences was extracted from Denys (1991); Theriot et al. (1992), Van Dam et al. (1994), Gómez and Bauer (2000a), Kociolek and Spaulding (2003), Rühland et al. (2003). Hassan et al. (2009) and Solak et al. (2012).

For cladoceran analysis, 1 cm^3 of sample was heated and stirred in 10% potassium hydroxide (KOH) for 30 min. Then, the sediment samples were sieved through a 40 μm mesh, following the procedure described by Szeroczyńska and Sarmaja-Korjonen (2007). The sieve residue was carefully transferred to a beaker. One tablet of *Lycopodium* spores was placed on a watch glass and a few drops of 10% HCl were added to dissolve the tablet. Afterward, the solution was poured off into the beaker and mixed well. Then, the sample was transferred into a test tube and centrifuged for 10 min at 3500 rpm. After centrifugation, the water was discarded, and a small quantity of ethanol was added and mixed. A slide was placed on a hot plate and liquefied glycerol jelly with some safranine drops were added. Then, a few drops of sample with ethanol was added and spread over the coverslip area. Finally, a coverslip was placed on the slide and pressed gently. Samples were identified under a LOMO/LUMAN fluorescence microscope at 20-100× magnification. Cladoceran identifications and ecological characteristics were obtained from the literature on south American cladocerans and from López-Blanco and Sinev, (2016), Paggi (1998a), (1995) and Smirnov (1971). This analysis was performed at the Escuela Politécnica Nacional, Ecuador.

Sample preparation for ostracod analysis was carried out using the methodology proposed by Holmes (2001) and Danielopol et al. (2002). Samples were washed and sieved through a 63 μm mesh. The freeze-cooling technique was used for sample disintegration in fine-grained sediment, by adding sodium hexametaphosphate before freezing. Then, samples were dried at room temperature for 12 hours, and the valves were picked out with a fine brush on a Nikon stereoscope (SMZ645) at 50× magnification. Identifications were based on taxonomic keys and specialized diagnosis (D'Ambrosio et al., 2015; Laprida, 2006; Ramón-Mercau et al., 2014). Absolute abundances were calculated from the number of adult valves of each species in 10 mL of sample. Additionally, charophyte oogonia, fish remains, gastropods and testate amoebae were also identified. Ostracod analysis was carried out at the GIBPC laboratory from Universidad Pedagógica y Tecnológica de Colombia.

Stratigraphic diagrams showing the relative abundances of each proxy were performed using the *Psimpoll* 4.27 software (Bennett, 2009). The broken stick model was applied to determine the number of significant stratigraphic zones (Bennett, 1996). Major zones were identified using the optimal division information content for ostracods and the binary splitting by sums-of-squares for cladocerans and diatoms. Before performing the zonation analyses, ostracod data were transformed using square root to stabilize the variances and increase the importance of rare species. Diatom data were log (x+1) transformed to give less weight to dominant and/or abundant taxa. Only the most abundant species were used for diatom analysis; those whose abundance was greater than 2% in at least 3 samples and considering that the percentage removed was less than 10% of the total abundance of each sample (Karst and Smol, 2000).

Detrended correspondence analysis (DCA) were applied to diatom data to estimate the degree of species turnover (Hill and Gauch, 1980). DCA has yielded good results for diatom analysis, allowing interpretation of records with different temporal scales and environmental gradients (*e.g.*, Correa-Metrio et al., 2014; Hassan et al., 2012). The meaning of DCA axis 1 was inferred in terms of *a priori* knowledge of their distribution in modern environmental gradients (Bicudo et al., 2016; Hassan et al., 2009). Then, the axis scores DCA1 was plotted stratigraphically to provide a simplified picture of changes through time. DCA analysis was performed using "*vegan*" package (Oksanen et al., 2019) in software R 3.6.3 (R Development Core Team, 2020).

4. Results

4.1. Sedimentology and physical characteristics

Physical properties and sedimentology analysis in cores LBG-A and LBG-B resulted in an overlap of ca. 40 cm. 66.5 cm in core LBG-A overlapped with 27.5 cm in core LBG-B, producing a composite sequence of 104 cm. This composite record was composed of dark-brownish sandy silt sediments with an increasing proportion of sand from top to the bottom part of the core. Eleven facies and six sedimentary units were distinguished, their colors varied from brown (10 YR 4/3) to dark brown (10 YR 4/29) (Table 1; Fig. 2). The mean values of organic matter throughout the first 75 cm of the sediment core were ca. 7% with a decreasing trend toward the top. A sharp shifting was observed ca. 75 cm (contact zone of Facies 8 and 9), where the organic matter content decreased towards the bottom of the core. Carbonate content was low, with mean values around 0.05% and increasing values in Unit 1.

4.2. Age-depth model

The chronological model based on three ^{14}C radiocarbon dates (Fig. 3) yields an average sedimentation rate (SR) of 1.47 mm/yr for Laguna Blanca Grande sediment core. However, the model showed distinct sedimentation rates depending on the age (Fig. 3). From 99.5 to 40 cm, the SR was relatively higher but it slowed down from 40 cm to the top of the sediment core.

4.3. Diatoms

A total of 55 diatom taxa representing 34 genera were identified in the Laguna Blanca Grande sediment core. The most representative taxa belonged to seven genera (*Aulacoseira*, *Cyclotella*, *Thalassiosira*, *Nitzschia*, *Amphora*, *Staurosira*, and *Surirella*). *Aulacoseira granulata* (Ehrenberg) Simonsen and *Aulacoseira granulata* var. *angustissima* (O.Müller) Simonsen dominated the sediment record (Fig. 4). Other abundant species were also *Aulacoseira ambigua* (Grunow) Simonsen, *Aulacoseira muzzanensis* (Meister) Krammer and *Cyclotella meneghiniana* (Kützing). Zonation analysis indicated the presence of four zones (DT-1, DT-2, DT-3 and DT-4). DT-1 zone (99.5-72 cm) was characterized by higher relative abundances of *A. granulata* and *C. meneghiniana*. In DT-2 (72-25 cm), the percentages of *A. granulata* decreased although they were still high. The two upper zones (DT-3 and DT-4; 24-10 cm and 9-0 cm, respectively) were associated with a relative increase of *A. granulata* var. *angustissima* in detriment of *A. granulata*. Besides, in the uppermost zone (DT-4), *Staurosira longirostris* (Frenguelli) Metzeltin, Lange-Bertalot & García-Rodríguez, *Staurosira construens* Ehrenberg and *Surirella rorata* Frenguelli increased their relative abundances.

DCA axes 1 and 2 of diatom samples were 1.52 and 1.16 standard deviations (SD) of species turnover in length. A. *granulata* var. *angustissima, S. longirostris* and *S. construens* had the highest scores on DCA Axis 1, while A. *granulata* and *A. muzzanensis* and chrysophytes, were associated with the lowest scores (Fig. 4).

4.4. Cladocera

A total of six Cladocera taxa were identified in Laguna Blanca Grande (Fig. 5); *Bosmina* Baird, 1846, which usually prefers pelagic environments and five littoral taxa *Chydorus sphaericus*-group, *Leydigia* sp. Kurz, 1875, small *Alona* sp., *Alona* cf. *affinis* (Leydig, 1860) and *Pleuroxus* Baird, 1843 (Fig. 5). *Bosmina* was the dominant taxa throughout the sediment core with relative values ca. 70 - 90%. In the CL-1 zone (99.5 - 75 cm), *Bosmina* showed its maximum relative abundances. CL-2 (75-10 cm) zone was marked by higher relative abundances of *Chydorus sphaericus-group,* which together with the benthic *Leydigia* had a more continuous presence throughout the zone. However, both groups of cladocerans showed several changes along the whole zone, especially around 32 cm, where *Chydorus* increased at the expense of *Bosmina*. CL-3 (10 - 0 cm) was characterized by higher values of *Bosmina* and decreasing values of the benthic species.

4.5. Ostracods

Four species of ostracods were recorded in the Laguna Blanca Grande sediment record (Fig. 6): *Limnocythere cusminskyae* Ramón-Mercau, 2014, *Cyprideis salebrosa* Bold, 1963, *Heterocypris incongruens* Ramdohr, 1808 and *Ilyocypris ramirezi* Cusminsky and Whatley, 1996. The number of individuals per sample never exceeds 400 and the maximum abundance was 40 ind /mL (Fig. 6). *Limnocythere cusminskyae* and *H. incongruens* were the main taxa of the assemblage. *L. cusminskyae* dominated over 90% of the assemblages and represented 85% of individuals throughout the core. In fact, six out of the 23 samples contained monospecific populations of *L. cusminskyae,* which were dominated by females. *Ilyocypris ramirezi* was only found in two samples, while only juvenile valves from *C. salebrosa* were found in five depths. The preservation of the valves throughout the composite sequence was heterogeneous, with both well preserved and broken specimens.

OST-1 (104 -75 cm) was characterized by the presence of gastropods, fish scales, charophytes, *L. cusminskyae* (< 25 ind/mL), *H. incongruens* and juveniles from *C. salebrosa*). In OST-2 (75 - 63 cm) and OST-4 (51 - 39 cm), ostracods were absent. The top of OST-3 (63-51cm) was mainly composed of articulated shells of *L. cusminskyae* (< 40 ind/mL) with some valves of *H. incongruens.* In OST-5 (39 - 7 cm), gastropod remains, fish scales and testate amoebae were recorded, while ostracods were again abundant (< 30 ind/mL). *Limnocythere cusminskyae* was the dominant species, representing 85% of the assemblage, followed by *H. incongruens* (13%), while *I. ramirezi* and *C. salebrosa* represented the remaining 2%. In OST-6 (7 - 0 cm), ostracods were less abundant than in the previous zone. Only specimens of *L. cusminskyae* with ruptured and disarticulated valves together with testate amoebae and fish remains were recovered (Fig. 6).

5. Discussion

The biological assemblage in Laguna Blanca Grande is typical of shallow, eutrophic and alkaline freshwater systems from the Pampean region (Hassan, 2011; Laprida, 2006; Paggi, 1998b; Plastani et al., 2019; Smol, 1985). Biological proxies coupled with sediment properties' changes suggested a shift in nutrients and hydroclimatic conditions during the last centuries. Diatom assemblage was marked by high relative abundances of *A. granulata*, which is replaced by the variety *angustissima* in the upper part of the record. Given the different ecological preferences of these varieties for nutrient conditions (Bicudo et al., 2016; Kilham and Kilham, 1975; Stoermer et al., 1985; Turkia, 1999), this is interpreted as changes in trophic state. Bicudo et al. (2016) and Turkia and Lepisto (1999) found that *A. granulata* has a lower weighted average optimum for nitrogen and phosphorous than the variety *angustissima*. Moreover, the increase of *A. granulata* var. *angustissim*a in our sequence also occurs together with an increase of *C. meneghiniana*, which is favored by high organic and turbid waters with limited light penetration (Hassan, 2013). These inferred changes in nutrient conditions are further evidenced by the DCA axis 1, which reflected the turnover of *A. granulata* by the variety *angustissima* in the upper part of the record and showed negative scores dominating before 1750 AD (Fig. 6). This inferred change in nutrient availability was not followed by an increase in organic matter, as shown in Figure 2. In many lakes, a large fraction of organic matter is decomposed under conditions high concentrations of oxygen and resuspension of sediments generated by wind (Meyers and Ishiwatari, 1995). These conditions are more frequent in polymictic lakes, like Pampean lakes, where the entire water column is mixed over the year or even daily. Mixing would produce an oxic environment at the bottom, increasing the rates of decomposition of organic matter by microorganisms in the upper part of the record. Furthermore, the nutrient increase might have triggered the observed shift in species composition but not a biovolume increase, as also noted in other paleoecological studies (e.g. López-Blanco et al., 2011).

However, the remaining biological and sedimentological proxies did not register a distinct change in the nutrient state, but they may indicate small oscillations in lake levels. The interpretation of cladoceran assemblages has limitations derived from the restricted knowledge of taxonomical and autecological characteristics in this part of the world. The assemblages showed the dominance of *Bosmina* sp., which generally has pelagic preferences. Regarding nutrient availability, *Bosmina* has eurioic preferences since it has been recorded both in oligotrophic (López-Blanco et al., 2020, 2011) and eutrophic environments (George, 1974; Lotter et al., 1998; Solis et al., 2018). The main components of the cladoceran littoral-benthic community might have been favored either under lower lake levels and/or under an increase in the trophic conditions. *C. sphaericus* and *Alona* are ubiquitous taxa with a great capacity for colonization, they can benefit from both nutrient enrichment and shallower conditions (Alonso, 1996; Smirnov, 1971). However, when plotting planktonic/benthonic ratio from cladoceran assemblages and comparing with ostracods, sedimentological data and other regional reconstructions, all together were concordant with small changes in hydrovariability (Fig. 7). Ostracods show a response to conductivity changes and thus, to small lake level changes. Four zones (OST-1, 3, 5 and 6) were characterized by the dominance of *L. cusminskyae*, which is highly tolerant to alkaline conditions and oligohaline waters

(Laprida, 2006; Marquez et al., 2016) and suggest a higher solute concentration at shallower levels. These biozones were intercalated by OST-2 and OST-4, where the absence of ostracods may indicate unstable conditions for ostracod colonization.

At the bottom of the sediment core (99.5 - 72 cm; ca. AD 1335-1472**)** (DT-1; CL-1; OST-1), less eutrophic conditions are inferred by higher values of *A.granulata.* The sediment here was composed of dark brown sandy coarse silt (Unit 1), poor in organic matter. The highest proportion of sand fraction in this unit, as well as the highest sedimentation rate, suggest important fluvial input that might have increased the lake level. The dark brown color associated with low organic matter content indicates relatively strong reducing conditions and a deposition in a perennial lacustrine environment (Wu and Li, 2004). The highest sedimentation rate calculated from the age-depth model in this section (Fig. 3) and the higher values of *Bosmina* and *A. granulata*, which was also related to high river flow conditions (Hötzel and Croome, 1996; Nogueira, 2000; Wang et al., 2009), are also compatible with considerable sediment input due to the high water inflow in Laguna Blanca Grande. Higher lake level reconstructed in the lower LIA (ca. AD 1270-1340) in Laguna Blanca Grande agrees well with the idea of a more humid phase inferred from Botuverá Cave (Bernal et al., 2016; Fig. 7) and with more humid conditions during the preceding period, the Medieval Climatic Anomaly (ca. AD 900-1300) (Cioccale, 1999; Iriondo and Kröhling, 1995). At the regional scale, this inference is concordant with the high-level stands described in Lagunas Encadenadas del Oeste (Laprida et al., 2009), Laguna Mar Chiquita (Coianiz et al., 2014; Piovano et al., 2002) and Lake Melincué (Guerra et al., 2015) (Fig. 7).

From ca. 72 – 9 cm (ca. AD 1472-1930) (DT-2) decreasing proportions of *A. granulata* in favor of *A.granulata* var. *angustissima* indicated variable conditions in terms of nutrient enrichment. Documentary sources show that indigenous societies were already present in the Pampean region 1000 years ago (Mazzanti, 2003). However, most of the native inhabitants were small and nomadic groups of hunter-gatherers and the population situated southern to Rio Salado was very scarce until the eighteenth century (Aldazabal, 2002). In AD 1828, historical documents situated the military fort of Blanca Grande during the “Previous Seasons to the Desert Conquest” very close to the lake for a very short time (Crivelli, 2013). Before Laguna Blanca is already mentioned in some historical documents from AD 1770-1790 (Floury-Dagorn, 2013), but there is historical and documentary evidence of the presence of sparse native population whose main activity was stockbreeding (Pedrotta et al., 2012). This period of variable nutrient enrichment was probably combined with small lake level oscillations with a tendency towards shallower conditions at the end of this period. Laminated dark brown silty fine sand (Unit 2) that changes to black sandy silt highly bioturbated with higher organic matter content (Unit 3) suggests a deposition by suspension in a low energy environment, which is concordant with the absence of ostracods (OST-4, OST-2) and with higher *Bosmina* abundances at relatively higher levels. The decrease in sand content indicates limited fluvial input in comparison with the previous period, which is supported by a lower SD in the chronological model (Fig. 3). The fine clastic lamination could respond to variations in the water and sediment inputs into the lake. In Unit 5, the sediment was composed of dark brown sandy coarse silt with iron mottles indicating intermittent oxidized conditions, which suggests that they were mainly deposited on a very shallow lake with high mixed conditions or temporary subaerial exposure. Ostracods also showed the highest total values and a more continuous presence, supporting the idea of decreasing lake levels. In particular, *L. cusminskyae* dominated the assemblage, which, together with *H. incrongruens*, might also indicate oscillations in lake levels and subsequent conductivity variations (Kihn et al., 2017; Laprida and Valero-Garcés, 2009; Marquez et al., 2016). Lake level fluctuations with a progressive reduction of level from 1340 AD to 1900 AD are ascribed to drier conditions and frequent extreme events registered in the Pampean region during the LIA (Córdoba, 2012; Córdoba et al., 2014; Guerra et al., 2017; Laprida et al., 2009; Piovano et al., 2009).

Nutrient enrichment is inferred in the upper part of the sediment record (from 9 cm; AD 1925) by higher relative abundances of the diatoms *A.granulata* var. *angustissima* and by the establishment of *S. longirostris* and *S. construens* (Dixit et al., 1992). Hassan et al. (2014) also interpreted a shift from *Aulacoseira* spp. by fragilariod taxa as a nutrient increase caused by the development of intensive farming activities. The Pampean Region experienced large scale deforestation since the end of the 19th century due to agriculture and railroad construction, which favored soil degradation (Dussart et al., 2011; Melo, 2004). Locally, colonists from Russia and Germany were established in Olavarría from AD 1878 within a national strategy to inhabit the

Pampean region. Intensification of the farming activities to obtain wheat, potatoes, corn and vegetables transformed the original landscape (Pedrotta et al., 2012).

In the uppermost part of the sequence (7.5cm; from ca. 1940), higher and relatively steady values of lake level with episodes of high energy are inferred. The sedimentary properties of Unit 6 and by the presence of disarticulated ostracod valves indicated events of higher mechanical disturbance. However, this inference in our record did not agree with regional reconstructions, which .recognized changes in hydrovariability. A regional increase of precipitation in AD 1940 was detected in instrumental records (Garreaud, 2009; Guerra et al., 2017; Pasquini et al., 2006). Similar hydroclimatic tendencies were also recognized in different paleolimnological records from the Pampean plain (Córdoba et al., 2014; Fontana, 2005; Laprida and Valero-Garcés, 2009; Piovano et al., 2009; Stutz et al., 2014). However, at a local scale, intensive periods of flooding and droughts in the western part of the Buenos Aires province led to agriculture losses and hydrological works (Monachesi and Albaladejo, 1997). The sluice gate construction in the 1950s might have effectively controlled lake levels in Laguna Blanca Grande and might be the origin of Unit 6 and the disarticulated valves of ostracods.

Although our paleoecological reconstruction agrees well with previous inferences, historical documents and instrumental records, the timing of the reconstruction in the upper part of the record (from the last ^{14}C date to the top of the core) should be considered with caution because the age control points here are sparse. A higher number of independent ^{14}C tie points or a ^{210}Pb-^{137}Cs chronology in the upper part of the sediment would provide a more accurate chronology for the recent human impact.

6. Conclusions

Overall and despite the low resolution of this sedimentary record, our paper contributes to increasing the spatial resolution in the Pampean plain in terms of both humidity and nutrient enrichment, as well as to understand the role and trends of natural variability versus anthropogenic impact in the last centuries. Human activities started in this region around ca. AD 1800 with the official foundation of the first towns (Pedrotta et al., 2012) but anthropogenic impacts were not evident until the twentieth century, when agricultural expansion (Monachesi and Albaladejo, 1997) led to nutrient enrichment and the establishment of a new diatom assemblage dominated by *A. granulata* var. angustissima and by fragilariod taxa. The main periods of hydrological variability, notably the humid phase (ca. AD 1450) and progressive drier conditions mirror previous reconstructions in the region. Recent alterations of the hydrological cycle (ca. AD 1950) are consistent with further anthropogenic impacts in Laguna Blanca Grande, already shown by the nutrient enrichment. High-resolution studies would improve our understanding of complex climatic patterns operating in this zone. However, further studies on taxonomy and autecology are needed to refine the paleoecological interpretations based on biological proxies and to effectively unlock the information contained in its sediment records.

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References

Aldazabal, V., 2002. La ocupación humana en el secotr centro oriental de la Pampa Deprimida. Universidad de Buenos Aires (Argentina).

Alonso, M., 1996. Crustacea Branchiopoda. Volumen 7. Fauna Ibérica.

Barros, V., Gonzalez, M., Liebmann, B., Camilloni, I., 2000. Influence of the South Atlantic convergence zone and South Atlantic Sea surface temperature on interannual summer rainfall variability in Southeastern South America. Theor. Appl. Climatol. 67, 123–133. doi:10.1007/s007040070002

Bennett, K., 2009. Psimpoll 4.27: C program for plotting pollen diagrams and analyzing pollen data.

Bennett, K.D., 1996. Determination of the number of zones. New Phytol. 132, 155–170.

Bernal, J.P., Cruz, F.W., Stríkis, N.M., Wang, X., Deininger, M., Catunda, M.C.A., Ortega-Obregón, C., Cheng, H., Edwards, R.L., Auler, A.S., 2016. High-resolution Holocene South American monsoon history recorded by a speleothem from Botuverá Cave, Brazil. Earth Planet. Sci. Lett. 450, 186–196. doi:10.1016/j.epsl.2016.06.008

Bicudo, P., Tremarin, P., Almeida, S., Zorzal- Almeida, S., Wengrat, S., Faustino, L., Costa, E., Bartozek, A., Rocha, C., 2016. Ecology and distribution of Aulacoseira species (Bacillariophyta) in tropical reservoirs from Brazil. Diatom Res. 31, 199–

215.

Blaauw, M., Christen, J.A., 2011. Flexible paleoclimate age-depth models using an autoregressive gamma process. Bayesian Anal. 6, 457–474. doi:10.1214/11-BA618

Blott, S.J., Pye, K., 2001. Gradistat: A grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surf. Process. Landforms 26, 1237–1248. doi:10.1002/esp.261

Cioccale, M.A., 1999. Climatic fluctuations in the central region of Argentina in the last 1000 years. Quat. Int. 62, 35–47. doi:10.1016/S1040-6182(99)00021-X

Coianiz, L., Ariztegui, D., Piovano, E.L., Lami, A., Guilizzoni, P., Gerli, S., Waldmann, N., 2014. Environmental change in subtropical South America for the last two millennia as shown by lacustrine pigments. J. Paleolimnol. 53, 233–250. doi:10.1007/s10933-014-9822-2

Colautti, D., Remes-Lenicov, M., 2003. Laguna Blanca Grande, Partido de Olavarría. Informe técnico nº 54.

Córdoba, F., 2012. El registro climático del Holoceno tardío en latitudes medias del SE de Sudamérica: limnogeología de las Lagunas Encadenadas del Oeste, Argentina. PhD Thesis. Universidad Nacional de Córdoba.

Córdoba, F.E., Guerra, L., Rodríguez, C.C., Piovano, E.L., Sylvestre, F., 2014. A Paleolimmological perspective of recent hidroclimate variability in the Central Argentina: From the Little Ice Age to the 21th century. Lat. Am. J. Sedimentol. Basin Anal. 21, 139–163.

Correa-Metrio, A., Dechnik, Y., Lozano-García, S., Caballero, M., 2014. Detrended correspondence analysis: A useful tool to quantify ecological changes from fossil data sets. Bol. la Soc. Geol. Mex. 66, 135–143. doi:10.18268/BSGM2014v66n1a10

Crivelli, E., 2013. Pactando con el enemigo: la doble frontera de Buenos Aires con las tribus hostiles en el período colonial. Tefros 11, 1–58.

D’Ambrosio, D.S., Díaz, A.R., García, A., Claps, M.C., 2015. First description of the soft part anatomy of Ilyocypris ramirezi Cusminsky & Whatley (Crustacea, Ostracoda) from Argentina, South America. Zootaxa 3957, 59–68.

doi:10.11646/zootaxa.3957.1.4

Dangavs, N., Mormeneo, M., 2012. Geolimnología y paleolimnología de la laguna Adela, Chascomús, provincia de Buenos Aires, Argentina. Rev. del Mus. La Plata, Sección Geol. 13 1–26.

Dangavs, N. V., Pierrard, L.R., 2013. Paleolimnología de la laguna del monte, San miguel del Monte, provincia de Buenos Aires. Rev. la Asoc. Geol. Argentina 70, 128–143.

Danielopol, D.L., Ito, E., Wansard, G., Kamiya, T., Cronin, T.M., Baltanás, A., 2002. Techniques for collection and study of ostracoda. Geophys. Monogr. Ser. 131, 65–97. doi:10.1029/131GM04

Denys, L., 1991. A check-list of the diatoms in the Holocene deposits of the western Belgian coastal plain with a survey of their apparent ecological requirements. I. Introduction, ecological code, and complete list. Brussels.

Dixit, S., Smol, J., Kingston, J., Charles, D., 1992. Diatoms: powerful indicators of environmental change. Environ. Sci. Technol. 19, 22–23.

Djenderedjian, J., 2012. Gringos en las Pampas: inmigrantes y colonos en el campo argentino. Penguin Random House Grupo Editorial Argentina.

Dussart, E., Chirino, C., Morici, E., Peinetti, R., 2011. Reconstrucción del paisaje del caldenal pampeano en los últimos 250 años. Quebracho Rev. Ciencias For. 19, 54–65.

Floury-Dagorn, G., 2013. La frontière du sud-ouest en Argentine jusqu'en 1890: d'une incomplète conquête à la conquête achevée. Université Rennes.

Fontana, S.L., 2007. Radiocarbon chronologies of Holocene lacustrine sediments from the southern coast of Buenos Aires Province, Argentina. Radiocarbon 49, 103–119. doi:10.1017/S003382220004193X

Fontana, S.L., 2005. Holocene vegetation history and palaeoenvironmental conditions on the temperate Atlantic coast of Argentina, as inferred from multi-proxy lacustrine records. J. Paleolimnol. 34, 445–469. doi:10.1007/s10933-005-5792-8

Frenguelli, J., 1941. Diatomeas del Río de la Plata. Rev. del Mus. la Plata. Sección

Botánica 3, 213–334.

Garreaud, R.D., 2009. The Andes climate and weather. Adv. Geosci. 22, 3–11. doi:10.5194/adgeo-22-3-2009

Garreaud, R.D., Vuille, M., Compagnucci, R., Marengo, J., 2009. Present-day South American climate. Palaeogeogr. Palaeoclimatol. Palaeoecol. 281, 180195. doi:10.1016/j.palaeo.2007.10.032

George, D.G., 1974. Dispersion Patterns in the Zooplankton Populations of a Eutrophic Reservoir. J. Anim. Ecol. 43, 537–551. doi:10.2307/3382

Geraldi, A.M., Píccolo, M.C., Perillo, G.M.E., 2011. Lagunas bonaerenses en el paisaje pampeano. Cienc. Hoy 21, 16–22.

Gómez, N., Bauer, D., 2000. Diversidad fitoplanctónica en la franja costera Sur del Río de la Plata. Biol. Acuática 19, 7–26.

Guerra, L., Piovano, E.L., Córdoba, F.E., Sylvestre, F., Damatto, S., 2015. The hydrological and environmental evolution of shallow Lake Melincué, central Argentinean Pampas, during the last millennium. J. Hydrol. 529, 570–583. doi:10.1016/j.jhydrol.2015.01.002

Guerra, L., Piovano, E.L., Córdoba, F.E., Tachikawa, K., Rostek, F., Garcia, M., Bard, E., Sylvestre, F., 2017. Climate change evidences from the end of the Little Ice Age to the Current Warm Period registered by Melincué Lake (Northern Pampas, Argentina). Quat. Int. 438, 160–174. doi:10.1016/j.quaint.2016.06.033

Hasle, G.R., Syvertsen, E.E., 1997. Chapter 2 – Marine Diatoms, in: Identifying Marine Phytoplankton. doi:10.1016/B978-012693018-4/50004-5

Hassan, G., Tietze, E., Cristini, P.A., DE Francesco, C., 2014. Differential preservation of freshwater diatoms and mollusks in Late Holocene sediments: paleoenvironmental implications. Palaios 29, 612–623. doi:10.2110/palo.2014.016

Hassan, G., Tietze, E., De Francesco, C., 2009. Modern diatom assemblages in surface sediments from shallow lakes and streams in southern Pampas (Argentina): palaeoenvironmental implications. Aquat. Sci. 71, 1015–1621.

Hassan, G.S., 2013. Diatom-based reconstruction of middle to late Holocene paleoenvironments in Lake Lonkoy, southern Pampas, Argentina. Diatom Res. 28, 473–486. doi:10.1080/0269249X.2013.851118

Hassan, G.S., 2011. Paleoecological significance of diatoms in Argentinean estuaries: What do they tell us about the environment?, in: Diatoms: Ecology and Life Cycle.

Hassan, G.S., De Francesco, C.G., 2018. Preservation of Cyclotella meneghiniana Kützing (Bacillariophyceae) Along a Continental Salinity Gradient: Implications for Diatom-Based Paleoenvironmental Reconstructions. Ameghiniana. doi:10.5710/AMGH.20.11.2017.3144

Hassan, G.S., De Francesco, C.G., Peretti, V., 2012. Distribution of diatoms and mollusks in shallow lakes from the semiarid Pampa region, Argentina: Their relative paleoenvironmental significance. J. Arid Environ. 78, 65–72. doi:10.1016/j.jaridenv.2011.11.002

Hassan, G.S., Tietze, E., De Francesco, C.G., Cristini, P.A., 2011. Problems and potentialities of using diatoms as paleoclimatic indicators in Central Argentina, in: Diatoms: Ecology and Life Cycle.

Heiri, O., Lotter, A., 2001. Loss on Ignition as a Method for Estimating Organic and Carbonate Content in Sediments : Reproducibility and Comparability of Results. J. Paleolimnol. 21, 101–110. doi:10.1023/A

Hill, M.O., Gauch, H.G., 1980. Detrended correspondence analysis: An improved ordination technique. Vegetatio 42, 47–58. doi:10.1007/BF00048870

Hogg, A.G., Hua, Q., Blackwell, P.G., Niu, M., Buck, C.E., Guilderson, T.P., Heaton, T.J., Palmer, J.G., Reimer, P.J., Reimer, R.W., Turney, C.S.M., Zimmerman, S.R.H., 2013. SHCal13 Southern Hemisphere Calibration, 0–50,000 Years cal BP. Radiocarbon 55, 1889–1903. doi:10.2458/azu_js_rc.55.16783

Hötzel, G., Croome, R., 1996. Population dynamics of Aulacoseira granulata (EHR.) SIMONSON (Bacillariophyceae, Centrales), the dominant alga in the Murray River, Australia. Arch. fur Hydrobiol. 136, 191–215.

Iriondo, M., 1994. Los climas cuaternarios de la región pampeana. Comun. del Mus. Prov. Ciencias Nat. Florentino Ameghino 4, 1–48.

Iriondo, M., Kröhling, D., 1995. El Sistema Eólico Pampeano, in: Comunicaciones Del

Museo Provincial de Ciencias Naturales 'Florentino Ameghino.' pp. 1–68.

Irurzun, M.A., Gogorza, C.S.G., Sinito, A.M., Chaparro, M.A.E., Prieto, A.R., Laprida, C., Lirio, J.M., Navas, A.M., Nuñez, H., 2014. A high-resolution palaeoclimate record for the last 4800 years from lake la Brava, SE pampas plains, Argentina. Geofis. Int. 53, 365–383. doi:10.1016/S0016-7169(14)70072-8

Iwan, A., Guerrero, E.M., Romanelli, A., Bocanegra, E., 2017. Valoración económica de los servicios ecosistémicos de una Laguna del sudeste bonaerense (Argentina). Investig. Geográficas 68, 173–189. doi:10.14198/ingeo2017.68.10

Karst, T.L., Smol, J.P., 2000. Paleolimnological evidence of limnetic nutrient concentration equilibrium in a shallow, macrophyte-dominated lake. Aquat. Sci. doi:10.1007/s000270050073

Kihn, R.G., Crespo, F., Pall, J.L., 2017. Ostrácodos de lagos someros de la región central de Argentina: Implicaciones paleolimnológicas. Rev. Bras. Paleontol. doi:10.4072/rbp.2017.3.08

Kilham, S.S., Kilham, P., 1975. Melosira granulata (Ehr.) Ralfs: morphology and ecology of a cosmopolitan freshwater diatom. Verhandlungen des Int. Verein Limnol. 19, 2716–2721. doi:10.1080/03680770.1974.11896368

Kociolek, J.P., Spaulding, S.A., 2003. Eunotioid and Asymmetrical Naviculoid Diatoms, in: Freshwater Algae of North America: Ecology and Classification. doi:10.1016/B978-012741550-5/50019-2

Kopprio, G.A., Freije, R.H., Strüssmann, C.A., Kattner, G., Hoffmeyer, M.S., Popovich, C.A., Lara, R.J., 2010. Vulnerability of pejerrey Odontesthes bonariensis populations to climate change in pampean lakes of Argentina. J. Fish Biol. 77, 1856–1866. doi:10.1111/j.1095-8649.2010.02750.x

Krammer, K., Lange-Bertalot, H., 1991a. Bacillariophyceae. 4. Teil: Achnanthaceae, Kritische Ergänzungenzu Navicula (Lineolatae) und Gomphonema, Gesamtliteraturverzeichnis Teil 1-4. Gustav Fischer Verlag, Jena, Germany.

Krammer, K., Lange-Bertalot, H., 1991b. Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. Gustav Fischer Verlag, Jena, Germany.

Krammer, K., Lange-Bertalot, H., 1988. Bacillariophyceae. 2. Teil: Bacillariaceae, Ephitemiaceae, Surirellaceae. VEB Gustav Fischer Verlag, Jena, Germany.

Krammer, K., Lange-Bertalot, H., 1986. Bacillariophyceae. 1.Teil: Naviculaceae. VEB Gustav Fischer Verlag, Jena, Germany.

Laprida, C., 2008. Cambios ambientales de épocas históricas en la pampa bonaerense en base a ostrácodos : historia hidrológica de la laguna de Chascomús. Ameghiniana 46, 95–111.

Laprida, C., 2006. Ostrácodos recientes de la llanura pampeana, Buenos Aires, Argentina: Ecología e implicancias paleolimnológicas. Ameghiniana 43, 181–204.

Laprida, C., Orgeira, M.J., García Chapori, N., 2009. El registro de la pequeña edad de hielo en lagunas pampeanas. Rev. la Asoc. Geol. Argentina 65, 603–611.

Laprida, C., Valero-Garcés, B.L., 2009. Cambios ambientales de épocas históricas en la pampa bonaerense en base a ostrácodos: historia hidrológica de la laguna de Chascomús. Ameghiniana 46, 95–111.

López-Blanco, C., Miracle, M.R., Vicente, E., 2011. Cladoceran assemblages in a karstic lake as indicators of hydrological alterations. Hydrobiologia 676, 249–261. doi:10.1007/s10750-011-0876-0

López-Blanco, C., Sinev, A.Y., 2016. Cladocera biodiversity in La Tembladera Lake (Ecuador): a palaeolimnological approach. Crustaceana 89, 1611–1637. doi:10.1163/15685403-00003605

López-Blanco, C., Tasevska, O., Kostoski, G., Wagner, B., Wilke, T., 2020. Ancient civilizations already had an impact on cladoceran assemblages in Europe’s oldest lake. Palaeogeogr. Palaeoclimatol. Palaeoecol. 552, 109734.

Lotter, A.F., Birks, H.J.B., Hofmann, W., Marchetto, A., Lotter, F., Birks, H.J.B., Hofmann, W., Marchetto, A., 1998. Modern diatom, cladocera, chironomid, and chrysophyte cyst assemblages as quantitative indicators for the reconstruction of past environmental conditions in the Alps. II. Nutrients. J. Paleolimnol. 19, 1998. doi:10.1023/A:1007994206432

Lüning, S., Gałka, M., Bamonte, F.P., Rodríguez, F.G., Vahrenholt, F., 2019. The Medieval Climate Anomaly in South America. Quat. Int. 508, 70–87. doi:10.1016/j.quaint.2018.10.041

Marquez, M., Ferrero, L., Cusminsky, G.C., 2016. Holocene palaeoenvironmental evolution of the Pampa coastal plain (Argentina) based on calcareous microfossils. Rev. Bras. Paleontol. 19, 25–40. doi:10.4072/rbp.2016.1.03

Mayo, C., 2000. Vivir en la Frontera. Collección Historías Americanas.

Mazzanti, D., 2003. Territorialidad y sociedades indígenas durante los últimos 1000 años, in: 5° Jornadas de Sociedades Indígenas Pampeanas (Mar Del Plata). Mar del Plata, pp. 6–11.

Melo, W., 2004. Génesis del estuario de Bahía Blanca: Relación morfodinámica y temporal con su cuenca hidrográfica. Universidad Nacional del Sur.

Metzeltin, D., García-Rodríguez, F., 2003. Las Diatomeas Uruguayas. Montevideo.

Metzeltin, D., Lange-Bertalot, H., García-Rodríguez, F., 2005. Diatoms of Uruguay - Taxonomy, Biogeography, Diversity, in: Lange-Bertalot, H., Gantner Verlag, A.R.G. (Eds.), Iconographia Diatomologica. Königstein, Germany, p. 737.

Meyers, P.A., Ishiwatari, R., 1995. Organic Matter Accumulation Records in Lake Sediments, in: Physics and Chemistry of Lakes. Springer-Verlag, Berlin, pp. 279–328.

Monachesi, A., Albaladejo, C., 1997. La gestion concertée de l’eau dans un bassin versant pampéen. Apprendre l’hydraulique et la démocratie. Natures Sci. Soc. 5, 24–38. doi:10.1016/S1240-1307(97)81523-3

Muhs, D.R., 2007. PALEOSOLS AND WIND-BLOWN SEDIMENTS/Overview. Encycl. Quat. Sci. 2075–2086. doi:10.1016/B0-44-452747-8/00378-1

Munsell Colour Company, 1975. Munsell Soil Colour Charts. Geoderma.

Nogueira, M.G., 2000. Phytoplankton composition, dominance and abundance as indicators of environmental compartmentalization in Jurumirim Reservoir (Paranapanema River), Sao Paulo, Brazil. Hydrobiologia 431, 115–128. doi:10.1023/A:1003769408757

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O’Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., Wagner, H., 2019. vegan: Community Ecology Package. R package version 2.5-2. Cran R.

Olavarría, 2010. Objetivos de desarrollo del milenio. Informe diagnóstico y meta para 2015.

Paggi, J., 1998a. Cladocera (Anomopoda and Ctenopoda), in: S, M.J.& C. (Ed.), Biodiversidad de Artropodos Argentinos: Una Perspectiva Biotaxonomica. Ediciones Sur, pp. 507-518 pp.

Paggi, J., 1998b. ‘Cladocera’ (Anomopoda y Ctenopoda), in: Sur, E. (Ed.), Biodiversidad de Artrópodos Argentinos, Una Perspectiva Biotaxonómica. Ediciones Sur, La Plata, pp. 507–518.

Paggi, J., 1995. Crustacea Cladocera, in: Ecosistemas de Aguas Continentales. Metodología Para Su Estudio. Ediciones Sur, pp. 909–951.

Pasquini, A.I., Lecomte, K.L., Piovano, E.L., Depetris, P.J., 2006. Recent rainfall and runoff variability in central Argentina. Quat. Int. 158, 127–139. doi:10.1016/j.quaint.2006.05.021

Pedrotta, V., Lanteri, S., Duguine, L., 2012. En busca de la tierra prometida. Modelos de colonización estatal en la frontera sur bonaerense durante el siglo XIX. Nuevo mundo mundos nuevos. doi:10.4000/nuevomundo.64168

Piovano, E., Ariztegui, D., Moreiras, S., 2002. Recent environmental changes in Laguna Mar Chiquita (central Argentina): A sedimentary model for a highly variable saline lake. Sedimentology 49, 1371–1384.

Piovano, E.L., Ariztegui, D., Córdoba, F., Cioccale, M., Sylvestre, F., 2009. Hydrological Variability in South America Below the Tropic of Capricorn (Pampas and Patagonia, Argentina) During the Last 13.0 Ka, in: Past Climate Variability in South America and Surrounding Regions. pp. 323–351. doi:10.1007/978-90-481-2672-9_14

Plastani, M., Laprida, C., Montes de Oca, F., Massaferro, J., Panarello, H., Ramón Mercau, J., Lami, A., 2019. Recent environmental changes inferred from sediments in a shallow lake of the Argentinian pampas. Journal of Paleolimnology. J. Paleolimnol. 61, :37-52.

Politis, G., 2008. The Pampas and Campos of South America, in: The Handbook of

South American Archaeology. pp. 235–260. doi:10.1007/978-0-387-74907-5_14

Quirós, R., Drago, E., 1999. The environmental state of Argentinean lakes: An overview. Lakes Reserv. Res. Manag. 22, 1987–2006. doi:10.1046/j.1440-1770.1999.00076.x

Ramón-Mercau, J., Plastani, M.S., Laprida, C., 2014. A review of the genus Limnocythere (Podocopida: Limnocytheridae) in the Pampean region (Argentina), with the description of a new species, Limnocythere cusminskyae sp. nov. Zootaxa 3821, 26–36. doi:10.11646/zootaxa.3821.1.2

Rühland, K.M., Smol, J.P., Pienitz, R., 2003. Ecology and spatial distributions of surface-sediment diatoms from 77 lakes in the subarctic Canadian treeline region. Can. J. Bot. 81, 57–73. doi:10.1139/b03-005

Smirnov, N., 1971. Fauna U.R.S.S. Part I, Vol. 2: Cladoceran Fauna of the World — Chydoridae.

Smol, J.P., 1985. The ratio of diatom frustules to chrysophycean statospores: A useful paleolimnological index. Hydrobiologia 123, 199–208. doi:10.1007/BF00034378

Solak, C.N., Dayioğlu, H., Barinova, S., Ács, É., 2012. Diversity and ecology of diatoms from Felent creek (Sakarya river basin), Turkey. Turk. J. Botany 36, 191–203. doi:10.3906/bot-1102-16

Solis, M., Pawlik-Skowrońska, B., Adamczuk, M., Kalinowska, R., 2018. Dynamics of small-sized Cladocera and their algal diet in lake with toxic cyanobacterial water blooms. Ann. Limnol. 54. doi:10.1051/limn/2018001

Stoermer, E.F., Wolin, J.A., Schelske, C.L., Conley, D.J., 1985. Variations in Melosira islandica valve morphology in Lake Ontario sediments related to eutrophication and silica depletion. Limnol. Oceanogr. 30, 414–418. doi:10.4319/lo.1985.30.2.0414

Stutz, S., Borel, C.M., Fontana, S.L., del Puerto, L., Inda, H., García-Rodriguez, F., Tonello, M.S., 2010. Late Holocene climate and environment of the SE Pampa grasslands, Argentina, inferred from biological indicators in shallow, freshwater Lake Nahuel Rucá. J. Paleolimnol. 44, 761–775. doi:10.1007/s10933-010-9450-4

Stutz, S., Borel, C.M., Fontana, S.L., Tonello, M.S., 2012. Holocene changes in trophic states of shallow lakes from the Pampa plain of Argentina. Holocene 22, 1263–1270. doi:10.1177/0959683612446667

Stutz, S., Tonello, M.S., Sagrario, M.D.L.Á.G., Navarro, D., Fontana, S.L., 2014. Historia ambiental de los lagos someros de la llanura Pampeana (Argentina) desde el Holoceno medio: Inferencias paleoclimáticas. Lat. Am. J. Sedimentol. Basin Anal.

Szeroczyńska, K., Sarmaja-Korjonen, K., 2007. Atlas of subfossil cladocera from central and northern Europe. Friends of the Lower Vistula Society.

Theriot, E., Herbarium, D., Round, F.E., Crawford, R.M., Mann, D.G., 1992. The Diatoms. Biology and Morphology of the Genera. Syst. Biol. 41. doi:10.2307/2992511

Turkia, J., 1999. Size variations of planktonic Aulacoseira Thwaites (Diatomae) in water and in sediment from Finnish lakes of varying trophic state. J. Plankton Res. 21, 757–770. doi:10.1093/plankt/21.4.757

Van Dam, H., Mertens, A., Sinkeldam, J., 1994. A coded checklist and ecological indicator values of freshwater diatoms from The Netherlands. Netherlands J. Aquat. Ecol. 28, 117–133. doi:10.1007/BF02334251

Viglizzo, E.F., Lértora, F., Pordomingo, A.J., Bernardos, J.N., Roberto, Z.E., Del Valle, H., 2001. Ecological lessons and applications from one century of low external-input farming in the pampas of Argentina. Agric. Ecosyst. Environ. 83, 65–81. doi:10.1016/S0167-8809(00)00155-9

Wang, C., Li, X., Lai, Z., Tan, X., Pang, S., Yang, W., 2009. Seasonal variations of Aulacoseira granulata population abundance in the Pearl River Estuary. Estuar. Coast. Shelf Sci. 85, 585–592. doi:10.1016/j.ecss.2009.09.031

Wu, Y., Li, S., 2004. Significance of lake sediment color for short time scale climate variation. Adv. Earth Sci. 19, 789–792.

Zarate, M.A., 2003. Loess of southern South America. Quat. Sci. Rev. 22, 1987–2003. doi:10.1016/S0277-3791(03)00165-3

Zárate, M.A., Tripaldi, A., 2012. The aeolian system of central Argentina. Aeolian Res. 3, 401–417. doi:10.1016/j.aeolia.2011.08.002

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Tables

Table **1**. Lithological description and facies characterization of the composite core LBG

Facies	DEPTH (cm)	DESCRIPTION	SEDIMENTARY UNITS
Facies 1	0-7	Massive, very fine sandy coarse silt, dark brown color, saturated in water, rich in organic matter, abundant plant macro remains.	Unit 6
Facies 2	7-11	Very fine sandy very coarse silt, brown color, with massive structure. It has diffuse planar contact with the underlying unit..	
Facies 3	11-25.5	Massive, very fine sandy coarse silt, dark brown, with iron mottles, It has indistinct contact with the underlying unit	Unit 5
Facies 4	25.5-26	Very fine sandy very coarse silt, dark grayish brown color, with massive structure. It has indistinct contact with the underlying unit	Unit 4
Facies 5	26-31.5	very fine sandy coarse silt, dark brown color, with massive structure. It has indistinct contact with the underlying unit	
Facies 6	31.5-52	Very fine sandy very coarse silt, brown color, with massive structure. It has indistinct contact with the underlying unit	
Facies 7	52-67.5	Very fine sandy very coarse silt, black color, with high bioturbation. It has a diffuse planar contact with the overlaying unit.	Unit 3
Facies 8	67.5-75.0	Very coarse-silty fine sand, lightly laminated, with thin light brown sandy (1-2 mm) laminae interbeed in dark-organic bed, very dark brown color. It has a planar sharp contact with the overlaying unit.	Unit 2
Facies 9	75.0-81.5	Very fine sandy very coarse silt. Presence of root remains, and light bioturbation, very dark brown color. It has a planar sharp contact with the overlaying unit.	Unit 1
Facies 10	81.5-93	Very fine sandy very coarse silt with a higher proportion of silt than the overlying unit, brown-black color. It has a planar sharp contact with the overlaying unit.	
Facies 11	93-104	Very fine sandy very coarse silt, black color. It has a diffuse planar contact with the overlaying unit	

Figure captions

Figure 1. Location map of the study site. A) Location of the study site in South America, showing the location of the main paleolimnological studies in the region: 1) La Brava (Irurzun et al. 2014); 2) Lakes Nahuel Rucá and 3) Lonkoy (Stutz et al., 2010, 2012); 4) Lake La Barrancosa (Plastani et al. 2018); 5) Lagunas Encadenadas del Oeste (Córdoba et al. 2012); 6) Lake Adela (Dangavs & Mormeneo, 2012); 7) Laguna del Monte (Dangavs & Pierrad (2013); 8) Lake Melincué (Guerra et al. 2015) and 9) Laguna Mar Chiquita B) Photograph of the lake and C) Satellite image of the lake showing the inlets and outlets.

Figure 2. Correlation and physical properties of the Laguna Blanca Grande sediment cores. From left to right: cross-correlation between LBG-A and LBG-B, dark red rectangles show the depth of radiocarbon samples; sedimentary facies; lithology; lithological description; granulometry; organic matter (LOI), carbonate content and sedimentary units of the resulting composite core LBG**.**

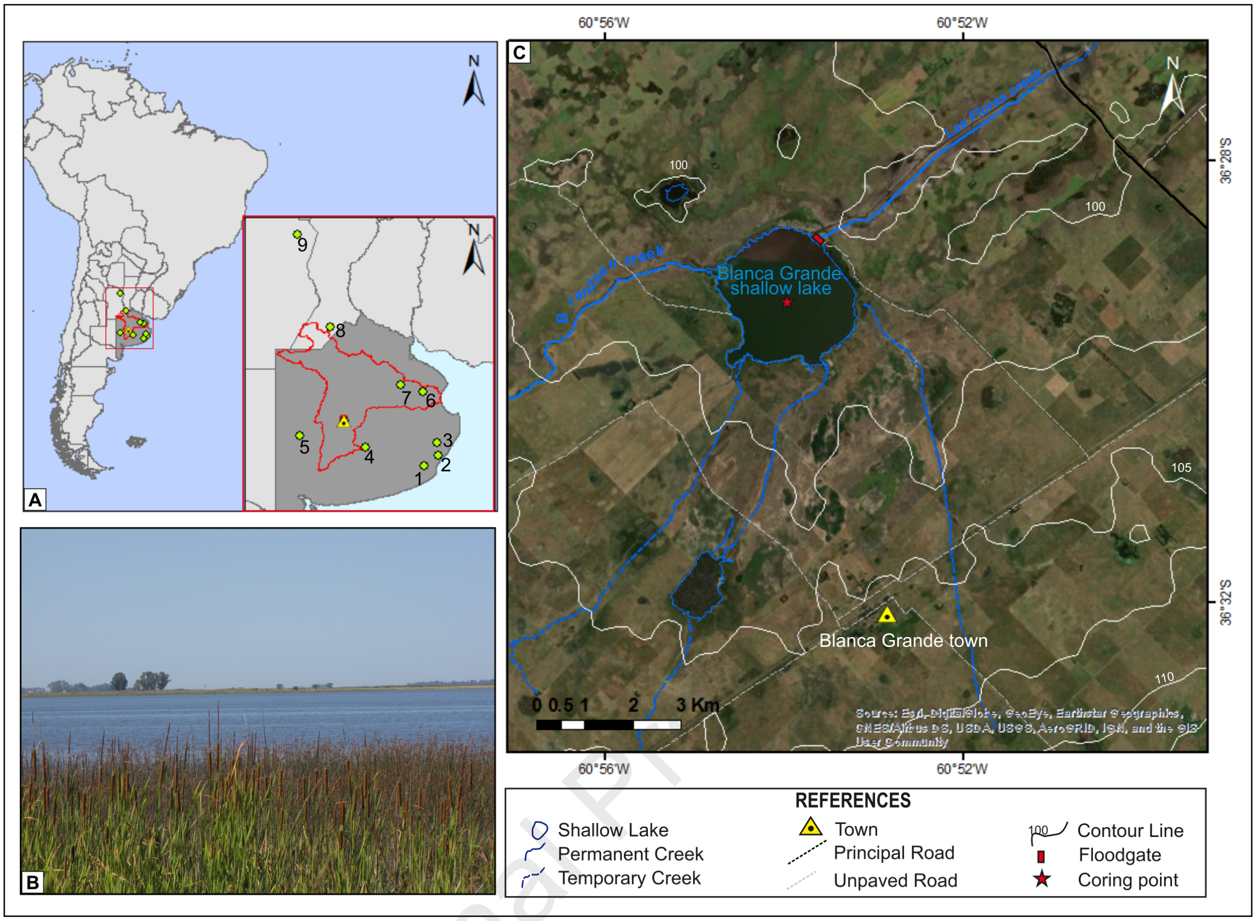
Figure 3. Chronological model for Laguna Blanca Grande sequence based on three AMS ^{14}C dates. The upper panel shows a table with the radiocarbon dates on Laguna Blanca Grande analyzed at 14CHRONO Centre for Climate, the Environment, and Chronology School of Geography, Archaeology, and Palaeoecology at the Queen's University Belfast (UBA code). Calibrated dates showed in the table were obtained in OxCal applying the ShCal13 calibration curve. Material dated: bulk sediment. The sample not used in the model is indicated in red. In the bottom panel, the Bayesian age model showing the calibrated ^{14}C dates (transparent blue) and the age-depth model (darker greys indicate more likely calendar ages; grey stippled lines show 95% confidence intervals; red curve shows single 'best' model based on the weighted mean age for each depth) (Blaauw and Christen, 2011).

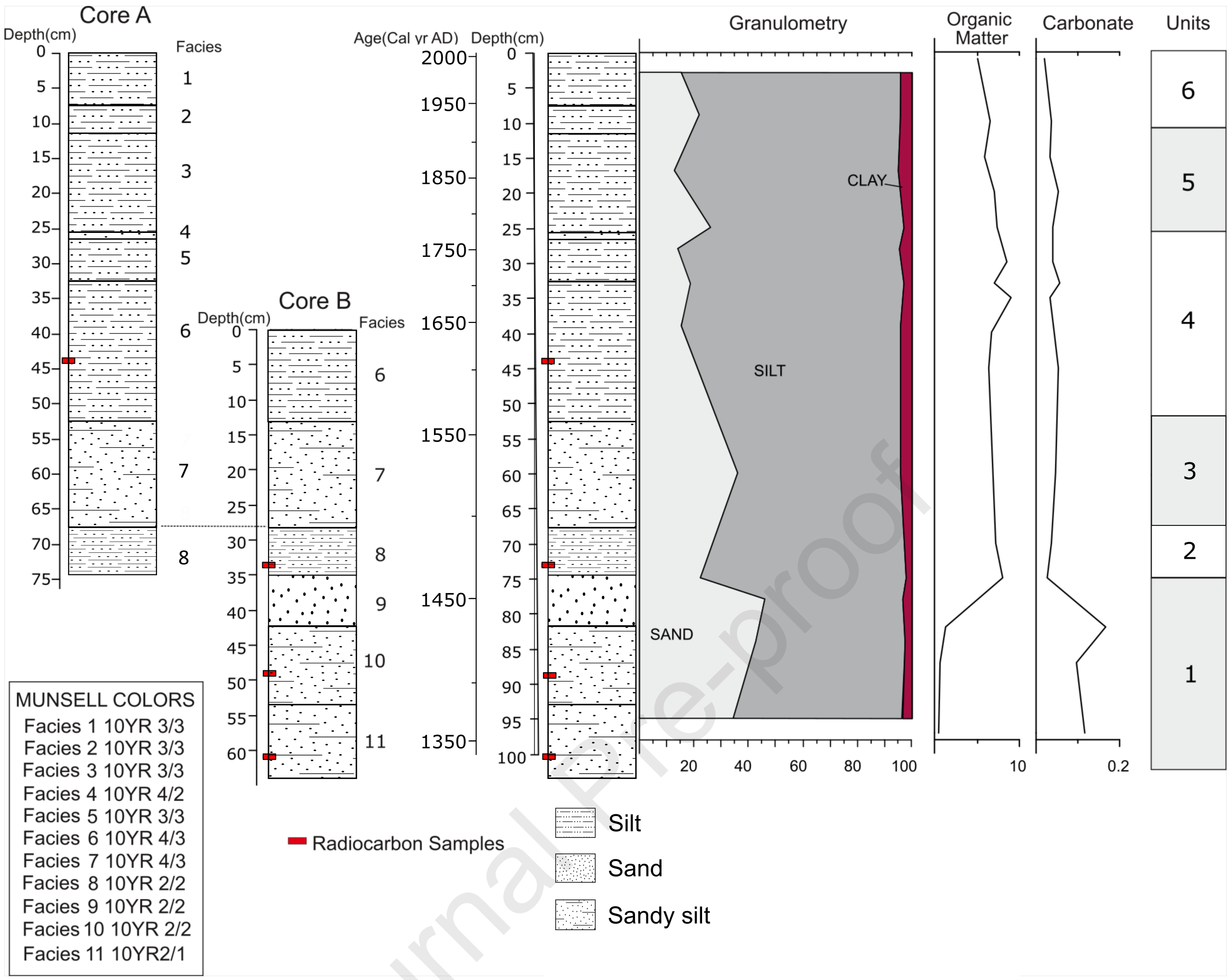
Figure 4. In the upper panel, the relative abundance of diatom species and Crysophyte cysts in LBG sediment core. Diatom zones (DT1-4) are based on the indicated cluster constrained analysis. In the bottom panel, a DCA ordination of (black circles), showing presenting the ecological space occupied by samples (red diamonds).

Figure 5. Relative abundance of the cladocerans in Laguna Blanca Grande sediment core. Cladocera zones (CL1-3) are based on the indicated cluster constrained analysis

Figure 6. Absolute abundance of ostracods in Laguna Blanca Grande sediment core. *Only juveniles were recorded. Zonation was defined using optimal division information content after applying a square-root transformation on the data set.

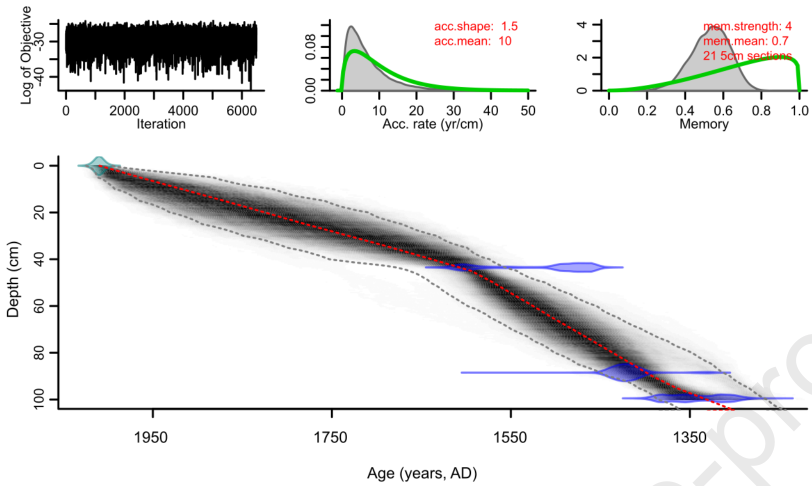
Figure 7. Comparison of proxies from the Laguna Blanca Grande sequence and selected local and regional palaeoclimate reconstructions in South America and the Pampean region. In the upper panel regional and Pampean reconstructions. In the lower panel compilation of the biological and sedimentological proxies together with historical/documentary data of anthropogenic activities in Laguna Blanca Grande. From upper to lower part of this panel: *Bosmina* sp. (%), ostracod biozones, sedimentary units, sedimentation rate, loadings from diatom DCA axis 1, paleoecological inferences about hydroclimatic variability/nutrient enrichment and historical data of land occupation and uses.

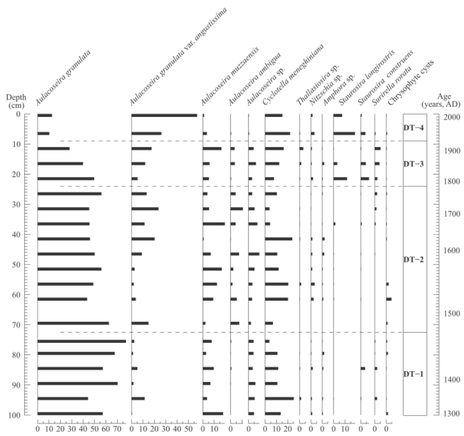

A
B
C
N
9
8
7
6
5
4
3
2
1
60°56'W
60°52'W
36°28'S
36°32'S
100
105
110
Las Flores creek
B. Grande creek
Blanca Grande shallow lake
Blanca Grande town
0 0.5 1 2 3 Km
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
REFERENCES
Shallow Lake
Permanent Creek
Temporary Creek
Town
Principal Road
Unpaved Road
Contour Line
Floodgate
Coring point

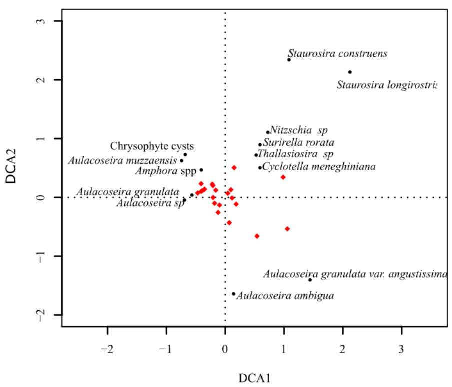


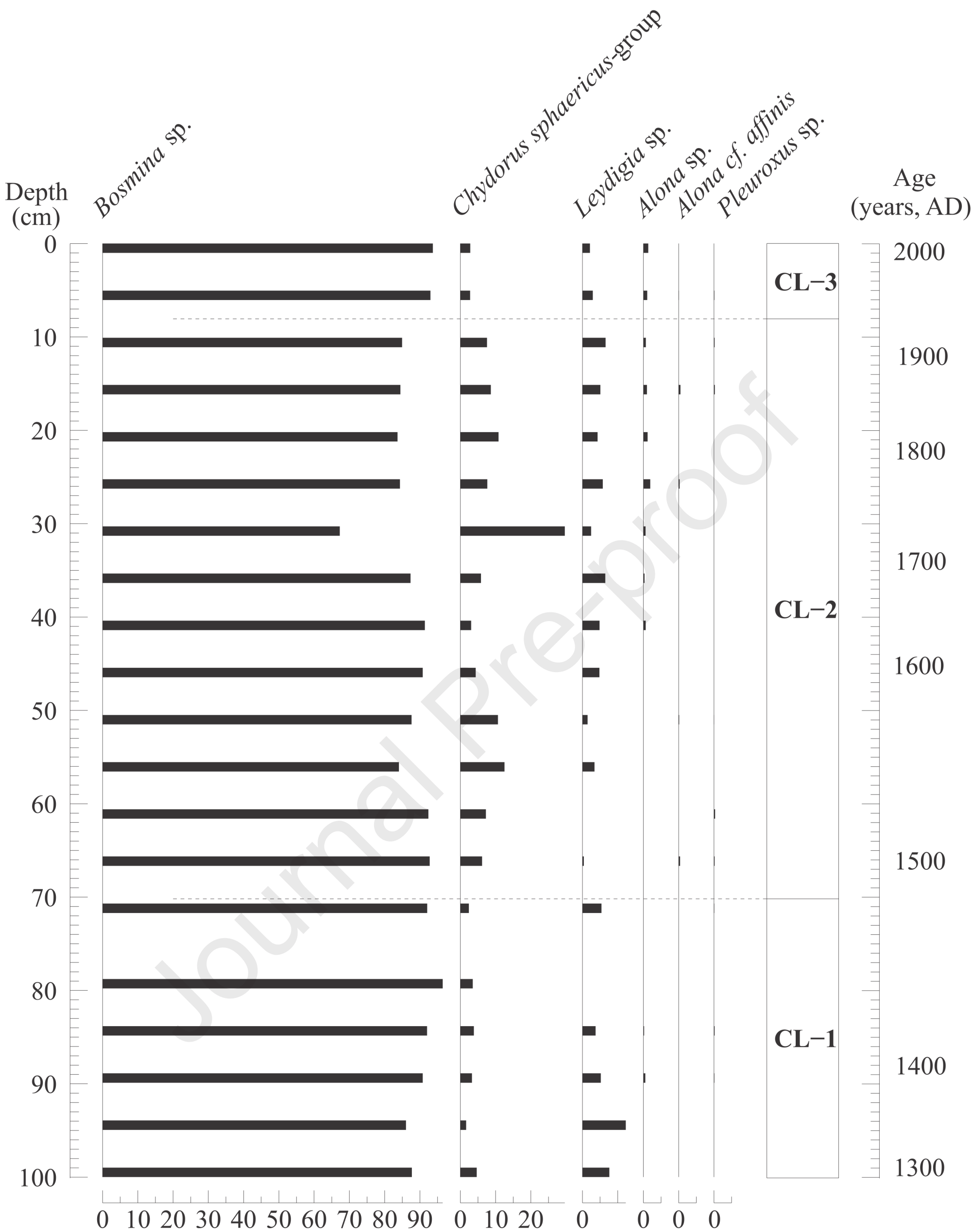
Core A
Depth(cm)
Facies
Core B
Depth(cm)
Facies
Age(Cal yr AD)
Depth(cm)
Granulometry
Organic Matter
Carbonate
Units
CLAY
SILT
SAND
MUNSELL COLORS
Facies 1 10YR 3/3
Facies 2 10YR 3/3
Facies 3 10YR 3/3
Facies 4 10YR 4/2
Facies 5 10YR 3/3
Facies 6 10YR 4/3
Facies 7 10YR 4/3
Facies 8 10YR 2/2
Facies 9 10YR 2/2
Facies 10 10YR 2/2
Facies 11 10YR2/1
Radiocarbon Samples
Silt
Sand
Sandy silt

Composite core depth (cm)	Depth LBG-A (cm)	Depth LBG-B (cm)	Lab code	^{14}C AMS age (yr BP)
43.25	43-43.5		UBA-30901	425±27
72.5		33-34	UBA-30902	1004±33
88.5		49-50	UBA-39237	549±29
99.5		60-61	UBA-23301	682±32

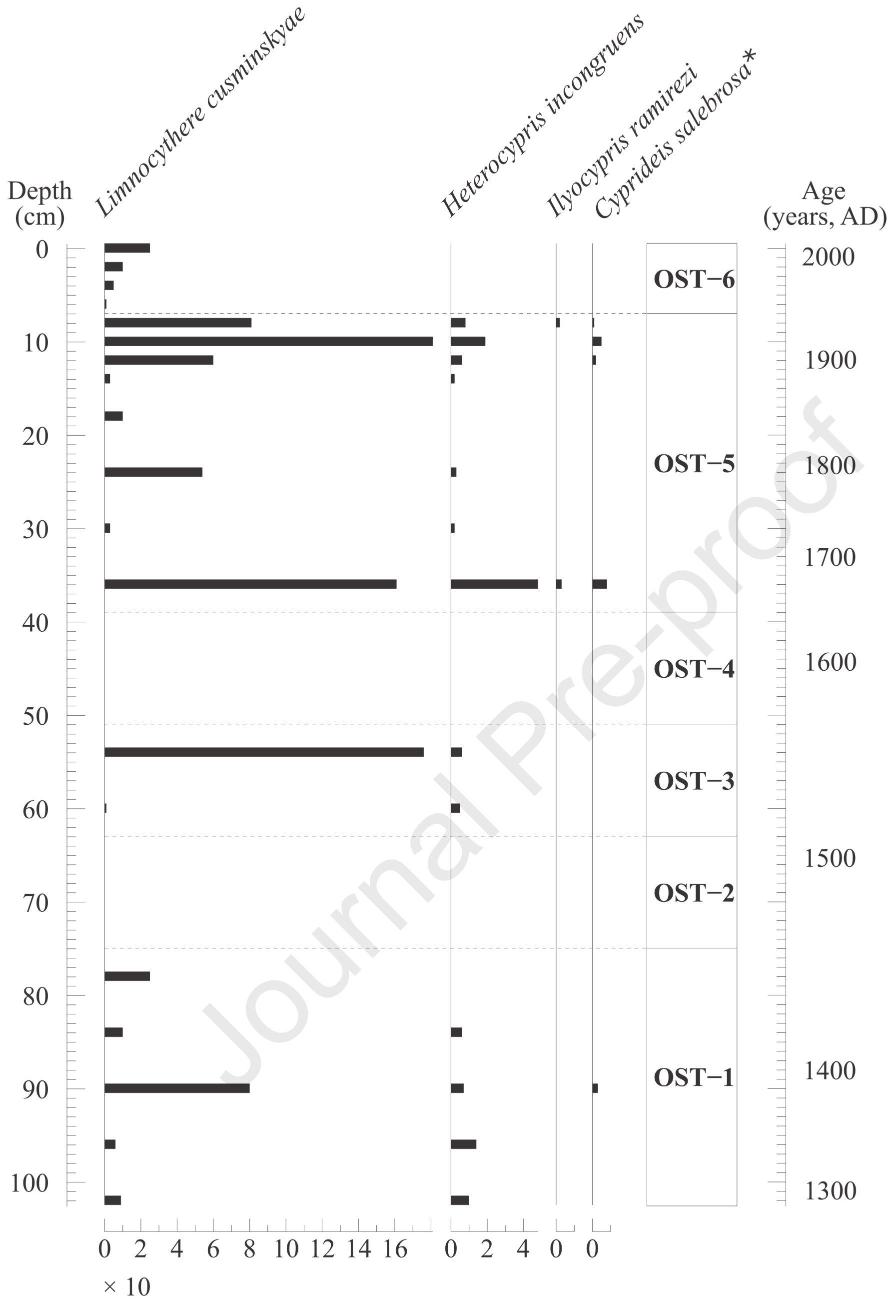



Depth (cm)
Age (years, AD)
Aulacoseira granulata
Aulacoseira granulata var. angustissima
Aulacoseira muzzaensis
Aulacoseira ambigua
Aulacoseira sp.
Cyclotella meneghiniana
Thallasiosira sp.
Nitzschia sp.
Amphora sp.
Staurosira longirostris
Staurosira construens
Surirella rorata
Chrysophyte cysts
DT−4
DT−3
DT−2
DT−1

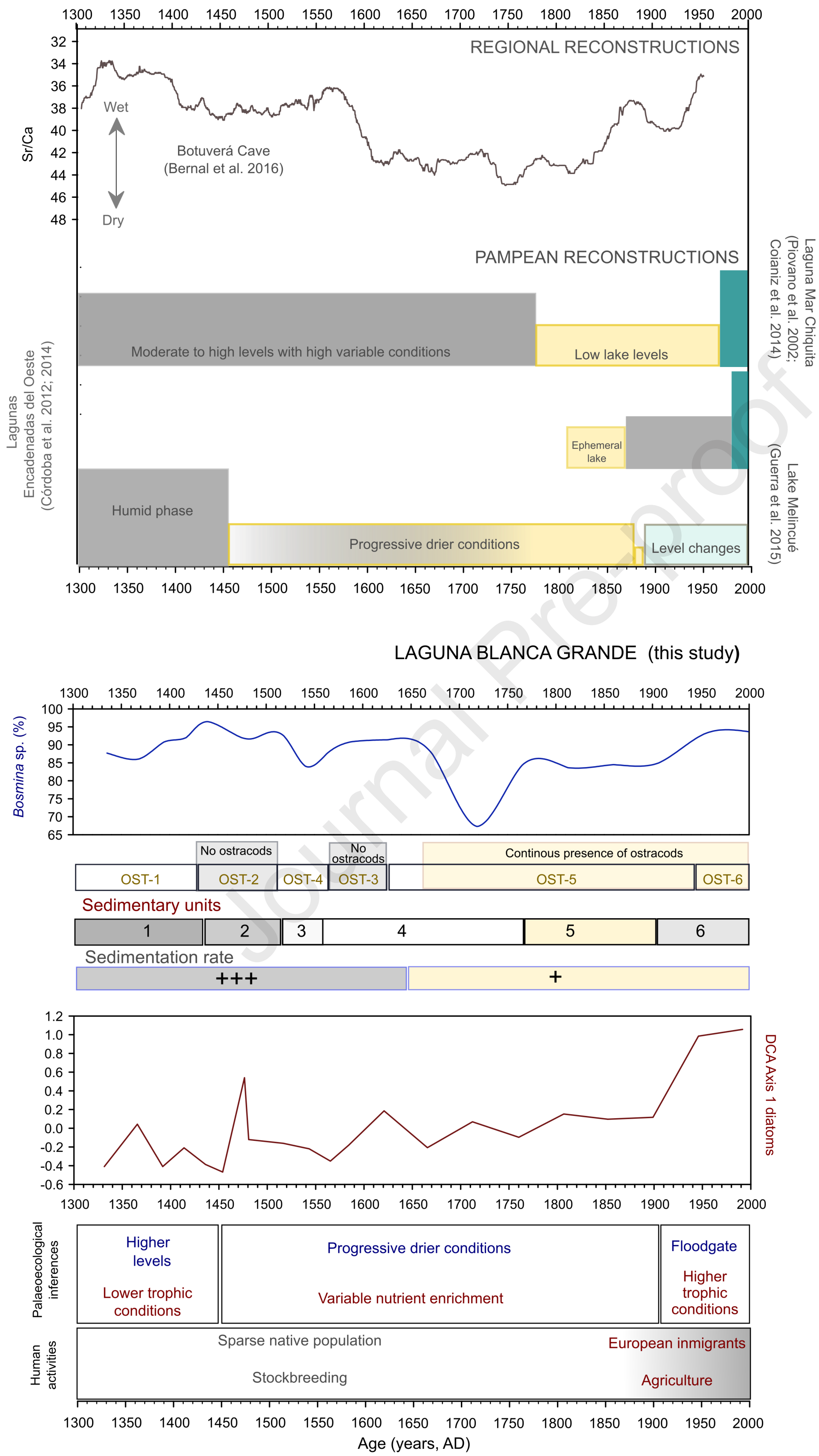

DCA2
DCA1
Staurosira construens
Staurosira longirostris
Nitzschia sp
Surirella rorata
Thallasiosira sp
Cyclotella meneghiniana
Chrysophyte cysts
Aulacoseira muzzaensis
Amphora spp
Aulacoseira granulata
Aulacoseira sp
Aulacoseira granulata var. angustissima
Aulacoseira ambigua



Depth (cm)
Bosmina sp.
Chydorus sphaericus-group
Leydigia sp.
Alona sp.
Alona cf. affinis
Pleuroxus sp.
Age (years, AD)
0
10
20
30
40
50
60
70
80
90
100
CL−3
CL−2
CL−1
2000
1900
1800
1700
1600
1500
1400
1300
0 10 20 30 40 50 60 70 80 90
0 10 20
0
0
0
0



Depth (cm)
Limnocythere cusminskyae
Heterocypris incongruens
Ilyocypris ramirezi
Cyprideis salebrosa*
Age (years, AD)
0
10
20
30
40
50
60
70
80
90
100
OST−6
OST−5
OST−4
OST−3
OST−2
OST−1
2000
1900
1800
1700
1600
1500
1400
1300
0 2 4 6 8 10 12 14 16
× 10
0 2 4
0
0


REGIONAL RECONSTRUCTIONS
Sr/Ca
Wet
Dry
Botuverá Cave
(Bernal et al. 2016)
PAMPEAN RECONSTRUCTIONS
Laguna Mar Chiquita
(Piovano et al. 2002;
Coianiz et al. 2014)
Moderate to high levels with high variable conditions
Low lake levels
Lagunas
Encadenadas del Oeste
(Córdoba et al. 2012; 2014)
Ephemeral lake
Humid phase
Progressive drier conditions
Level changes
Lake Melincué
(Guerra et al. 2015)
LAGUNA BLANCA GRANDE (this study)
Bosmina sp. (%)
No ostracods
No ostracods
Continous presence of ostracods
OST-1
OST-2
OST-4
OST-3
OST-5
OST-6
Sedimentary units
1
2
3
4
5
6
Sedimentation rate
+++
+
DCA Axis 1 diatoms
Palaeoecological inferences
Higher levels
Lower trophic conditions
Progressive drier conditions
Variable nutrient enrichment
Floodgate
Higher trophic conditions
Human activities
Sparse native population
Stockbreeding
European inmigrants
Agriculture
Age (years, AD)

HIGHLIGHTS

- Lakes in the Pampean region contain important archives of past environments.
- Sediment properties and biological proxies were analysed in a 700-years record.
- Lakes level changes mirror past hydroclimatic variability.
- Anthropogenic activities induced a nutrient increase in the last century.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: