Journal of South American Earth Sciences 98 (2020) 102468

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

journal homepage: www.elsevier.com/locate/jsames

Factors that control the seasonal dynamics of the shallow lakes in the Pampean region, Buenos Aires, Argentina

Maria Florencia Pisano[a,*], Gabriela D'Amico[b], Nicolas Ramos[c], Nicole Pommarés[c], Enrique Fucks[d]

[a] Centro de Estudios Integrales de la Dinámica Exógena, Argentina (CEIDE), Universidad Nacional de La Plata, Argentina (UNLP), Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina (CONICET), 64 street, N 3, 1900, La Plata, Argentina
[b] CEIDE-UNLP, Facultad de Humanidades y Ciencias de la Educación, Universidad Nacional de La Plata, Argentina, CONICET, 64 street, N 3, 1900, La Plata, Argentina
[c] CEIDE-UNLP, CONICET, 64 street, N 3, 1900, La Plata, Argentina
[d] CEIDE-UNLP, Instituto de Ambientes de Montaña y Zonas Áridas, Argentina (IAMRA), 64 street, N 3, 1900, La Plata, Argentina

ARTICLE INFO

Keywords:
Pampean shallow lakes
Salado River
Morphometry
Hydrochemistry
Anthropic intervention

ABSTRACT

Shallow lakes are distinctive aquatic ecosystems of the Pampean region. In this paper, climatic, morphometric and chemical-environmental aspects of six lacustrine bodies of the Salado River basin, Buenos Aires, are analyzed. The climatic variability of the region was estimated and linked to the behavior of each water body during the studied period (2017–2018); precipitations displayed deviations from the mean values, with periods of deficit in spring and summer, and excess in autumn. The analysis of satellite images showed a group of lakes with very low variation of the morphometric parameters because they have gates that keep the water level constant. On the contrary, those without anthropic intervention displayed a greater morphometric variability, since the water levels have been directly linked to local weather fluctuations. From a chemical-environmental perspective, changes were observed both at the regional ($p = 0.015$) and local ($p = 0.0014$) levels. Differences among sites cannot be characterized by a single variable but by a set of them. The dominant cation in the Pampean shallow lakes is the Na^+ coming from the contact of groundwater with loessic sediments. Lakes showed a particular anionic dominance that not following a seasonal but a particular pattern. These are mainly linked to the characteristics of the substrate (presence of marine sediments or gypsum deposits). The great vulnerability of these environments to global and regional climatic changes, anthropic modifications and a large number of shallow lakes in the area, allow finding different scenarios (geomorphological, ecological, hydrogeological, etc.) to assess their vulnerability and predict their behavior against future climate scenarios in an economically important area for Argentine.

1. Introduction

Shallow lakes are the most abundant lentic freshwater bodies at a global scale (Meerhoff and Jeppesen, 2009; Mayer and Pilson, 2017). Their maximum depth is 6 m, so light can potentially penetrate to the bottom. They are polymictic and have a littoral zone with rooted and submerged aquatic plants that cover 80% or more of the total area. Climate is among the main factors affecting the structure and functioning of these ecosystems. Directly or indirectly, it affects thermal regimes, changes the level and volume of water, nutrient cycle, and therefore their trophic state (Jeppesen, 1998; Coops et al., 2003; Scheffer and van Nes, 2007; Meerhoff and Jeppesen, 2009; Mayer and Pilson, 2017).

Shallow lakes are distributed in different regions of Argentina (South America), but mainly in the Pampean region, where they are known as “lagunas pampeanas”. These basins are mainly the result of wind deflation during the Quaternary. The alternation of dry periods, being deposition and wind erosion the dominant processes, and humid ones, associated with fluvio-lacustrine action and soil formation, modeled these basins to their current configuration and transformed deflation basins into true shallow lakes. These aquatic ecosystems are distinctive elements of the Pampean landscape and are intimately associated with regional economies (Diovisalvi et al., 2010). They are used as ecological, social and economic resources, either as reservoirs of freshwater, control and attenuation of floods, migratory birds key niches, aquaculture, commercial and sport fishing, tourism and leisure, among other activities.

In the Pampean region, shallow lakes can be permanent or

---

[*] Corresponding author.
E-mail addresses: fpisano@fcnym.unlp.edu.ar, florpisano23@gmail.com (M.F. Pisano), gdamico@fahce.unlp.edu.ar (G. D'Amico), nicolasramos@fcnym.unlp.edu.ar (N. Ramos), npommares@fcnym.unlp.edu.ar (N. Pommarés), efucks@fcnym.unlp.edu.ar (E. Fucks).

https://doi.org/10.1016/j.jsames.2019.102468
Received 13 September 2019; Received in revised form 12 December 2019; Accepted 12 December 2019
Available online 13 December 2019

temporary water bodies. Their average depth varies between 0.6 and 5.2 m. They have a non-defined thermal cycle or persistent stratification (Ringuelet, 1962; Quirós, 2004). Salinity and water time permanence are highly variable and depend mainly on local rainfall (Quirós et al., 2002; Quirós, 2005). The water recharge is produced by rainfall, natural tributaries contribution, artificial canals and shallow groundwater levels.

They are sensitive to the general and specific climatic variations of the region. During droughts, the water table decreases drying many shallow lakes; whereas, during humid periods, the phreatic levels rise, increasing the lake surface. Therefore, there is a direct relationship between precipitation/evaporation processes with the seasonal climatic cycles and typical drought and flood cycles of the Pampean region (Quirós et al., 2002) which determines the shallow lakes water.

Shallow lakes' physical and chemical characteristics are mainly conditioned by global and regional climate fluctuations. The objectives of this work are: to characterize and compare the seasonal limnological state of a set of Pampean shallow lakes and their morphometric behavior through the use of satellite images; and to analyze the observed changes in order to understand which are the natural or/and anthropic factors conditioning their performance.

2. Study area

The Pampean region is an extensive plain of more than 600,000 km^2 developed between 30°S and 38°S latitudes, in the center-east of Argentina. The study area is located in the Pampa Deprimida (Frenguelli, 1950), a gentle slope east-declining plain, in the order of 0.1 to 0.01%.

The Salado basin has an extension of 90,000 km^2, without considering the SW and NW artificially connected sectors, being the Salado river its main collector (Fig. 1). The sand and silt sediments of the "Pampean Aeolic System" (Iriondo and Kröhling, 1995) constitute both various morphologies and the water courses substrate throughout the basin. Mainly in the upper sector and, to a lesser extent, in the middle sector, there are numerous positive morphologies (longitudinal, parabolic and transverse silt dunes). However, part of this plain has no defined geoforms. In the middle and lower sectors, the depressions (constituting most of them shallow lakes) and lunettes that may or may not be present in their NE sector have been mainly developed by deflation. This situation suggests that the basin upper sector has been dominated by transport and sand accumulation processes, while in the lower sector deflation processes have prevailed.

Climatically, the region is characterized by a temperate-humid with marked thermal seasonality. The average annual temperature ranges between 14 °C and 17 °C, with values ranging from less than 5 °C in July and a maximum of 30 °C in January. The average relative humidity is 70%, with a dry (winter) and wet (summer) season. This region is not climate uniform (Diovisalvi et al., 2015) as the temperature decreases to the south. The mean annual rainfall is 900 mm. As indicated in the last update (2017) of the Comprehensive Master Plan for the Salado River Basin (Halcrow Consortium, 1999), rainfall has shown a marked increase in recent decades. In the 1960's, the values were close to 900 mm, while they reached 1000 mm in the 1990's. The occurrence of important floods in the years 1914, 1919, 1980, 1993, 1998, 2001, 2007, 2014 and 2015 is noteworthy, indicating that these events are becoming more frequent. As a result, the water table has risen considerably and without a natural outlet, the permanence of the water in the depressions, like the studied shallow lakes, can be very long.

Salado river flow changes in relation to climatic conditions, ranging from 1500 m^{3}s^{-1} during rainy periods, to 100 m^{3}s^{-1} during droughts (Quaíni et al., 2005). Along its course, the river associates with numerous shallow lakes and marshes that feed the river or receive its water, depending on the water course level. The scarce relief slope prevents the evacuation of important volumes of water, which may accumulate in a short time leading to the occurrence and persistence of waterlogging (Brandizi and Labraga, 2012). Anthropic action and many of the management plans have intensified this characteristic. Among

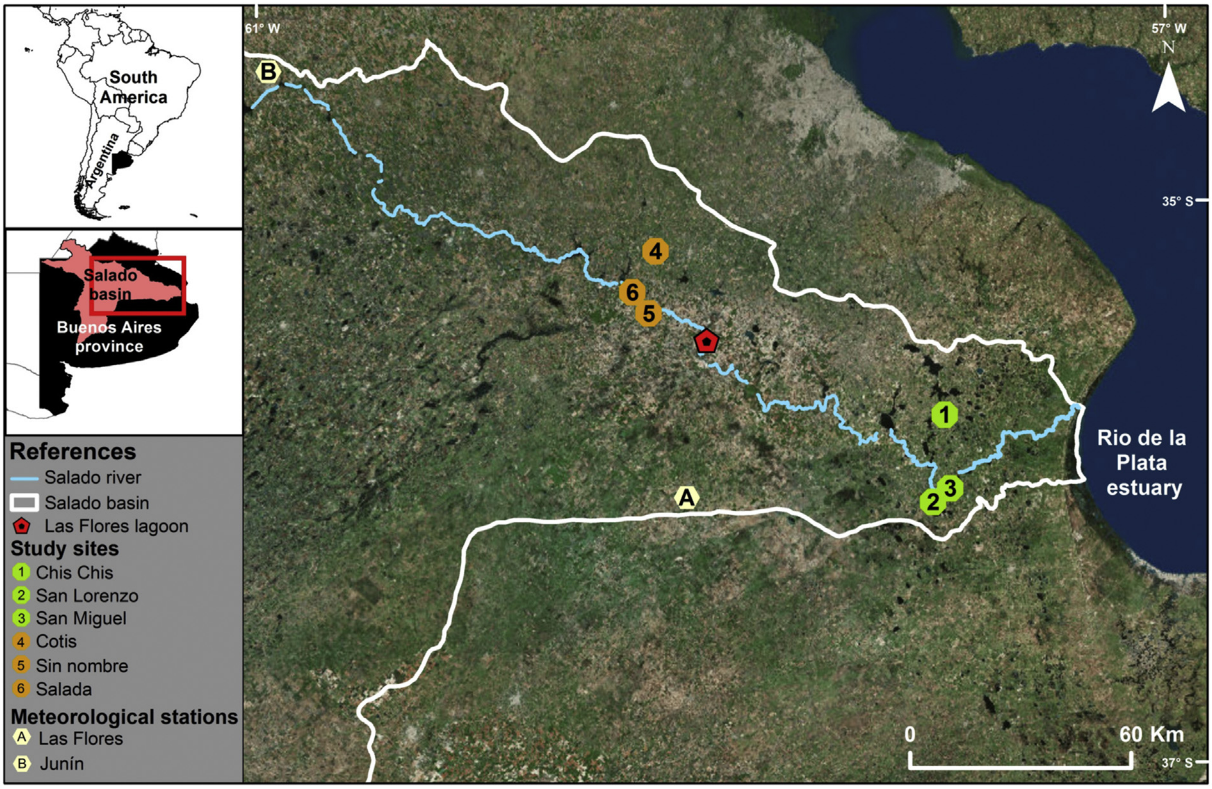

Fig. 1. General location of the studied area, shallow lakes and meteorological stations. Base image: Digital Globe, 2018. Salado River Vector: National Geographic Institute, Argentina. Salado Basin Vector: Government Secretary of Environment and Sustainable Development, Argentina.

Table 1
General location data and coding of the regional and local criteria used in the studied shallow lakes. Abbreviations: LS: low sector, MS = middle sector, Is = Isolated, Cn = Connected, Tr = Traversed.

Site	Shallow lake	Latitude	Longitude	Regional	Local
1	Chis Chis	35°45′19.34″S	57°56′31.59″W	LS	Is
2	San Lorenzo	36°4′30.53″S	58°1′0.12″W	LS	Cn
3	San Miguel	36°1′58.85″S	57°56′39.81″W	LS	Tr
4	Cotis	35°10′38.82″S	59°14′45.68″W	MS	Is
5	"Sin Nombre"	35°22′52.52″S	59°10′57.01″W	MS	Cn
6	Salada	35°18′34.43″S	59°20′15.81″W	MS	Tr

the most important transformations, there are the North-South routes and railroads tracing, perpendicular to the natural slope, which further block the weak runoff. Moreover, the canals, many of them illegal, derive the water to neighboring establishments that had not been affected in the past (Velázquez et al., 2014).

The rainfall variability directly affects the infiltration capacity, the nutrients and carbon availability, and the supply of ecosystem services, biomass and primary productivity, among others (Aliaga et al., 2016).

3. Materials and methods

Six shallow lakes (Table 1, Fig. 1) were sampled seasonally from November 2017 to September 2018. The sites were chosen according to regional and local geomorphological criteria. Regarding the first ones, their location was taken into account; therefore, three shallow lakes were selected from the middle sector (MS) of the Salado river basin, northwest of Las Flores lake, and three from the lower sector (LS) at its southeast.

To establish the local geomorphological criteria, the relationship between these shallow lakes and the Salado River was taken into account (Table 1). In this regard, we selected two isolated shallow lakes (Is), i.e., with no connection with the main course; two catalogued as connected (Cn), where a canal or stream links the lakes with the river; and two traversed ones (Tr), i.e., when the connection between both the lakes and the river is direct and hence, in flood periods, their limits cannot be clearly established, reversing this situation when normal flows are restored.

The Chis Chis shallow lake is part of the chained lakes system of the Salado Basin, located to the east of Buenos Aires province. Together with Vitel, Chascomús, Manantiales, Adela, del Burro, Tablilla and Barrancas, the lakes are interconnected through streams and canals that eventually flow into the Salado River. For this research, Chis Chis was considered as isolated, because it has no permanent relationship with the river. The single moment in which the system receives input from the river waters and the water flow is reverted, occurs during maximum flood events (Torremorell et al., 2007). This situation was not observed during the study period; therefore, the only possible link is water supply by draining the system itself and not the inverse. This enables us to regard this shallow lake as isolated, at least for the study period. On the other hand, the San Lorenzo lake (now called La Boca by local residents) is linked to the river course through the San Miguel creek; in 2014 a gate was built to maintain the water level constant during droughts periods.

3.1. Climate data

Precipitation and temperature data from Junín and Las Flores stations, near the study sites (Fig. 1), provided by the Servicio Meteorológico Nacional (2018), were analyzed. The Junín station is considered a reference for the characterization of the middle sector of the area, while the Las Flores station is used for the lower sector.

The data was evaluated on two-time scales. Initially, we worked with average monthly and annual values calculated for the 1987–2018 (30 years) period, in order to characterize the monthly general trends and compare the values with the specific ones for the studied period. Secondly, given that the sampling was seasonal, the specific climatic data (average seasonal values of maximum temperature and total precipitation) of the study period were grouped in the same way for each meteorological station.

3.2. Image processing

The Sentinel-2 A and B satellites, developed by the European Spatial Agency (ESA), own large advantages for land surface coverage identification, given their high spatial and temporal resolution, and the possibility of free image downloads.

Based on the shallow lake's location, twelve satellite images were selected within two areas of interest. The criterion was the proximity of the capture dates (December 15, 2017; January 8, 2018; April 24, 2018 and September 6, 2018) with the field samplings, as well as the absence or low cloud cover. For each specified date, three images of the 21HTB, 21HTA and 21HVA tiles were downloaded and a mosaic was compiled by date.

To perform the multitemporal analysis between dates, Top of Atmosphere (TOA) values were corrected to surface reflectance -Bottom of Atmosphere -BOA-, using the QGIS software Semi-Automatic Classification Plug-In.

For the hallow lakes bodies identification, the $\mathrm{AWEI_{nsh}}$ Index -Automated Water Extraction Index (nsh: no shadow)- was used (Feyisa et al., 2014). Mathematically, the AWEI formula is expressed as:

$$\mathbf{AWEI_{nsh}} = \mathbf{4} \times (\mathbf{Green–SWIR1}) - (\mathbf{0.25} \times \mathbf{NIR} + \mathbf{2.75} \times \mathbf{SWIR2})$$

Originally proposed for Landsat 5 images, AWEI manages to enhance the difference between land and water coverings in different environmental conditions (Jawak et al., 2015), through band differentiation, addition and application of different coefficients. According to the Sentinel 2 satellite bands, the AWEI nsh formula is translated as:

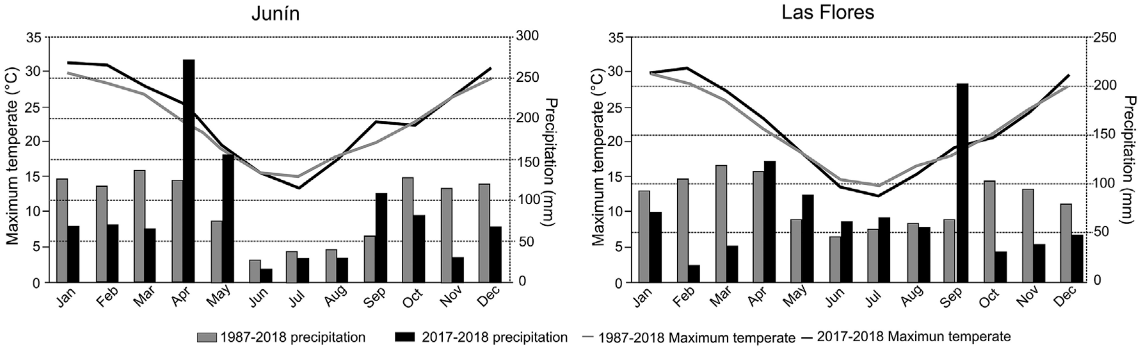

Fig. 2. Comparison between values of maximum temperature and average precipitations between 1987 and 2018 (in gray) and the period under study (November 2017 to October 2018, in black).

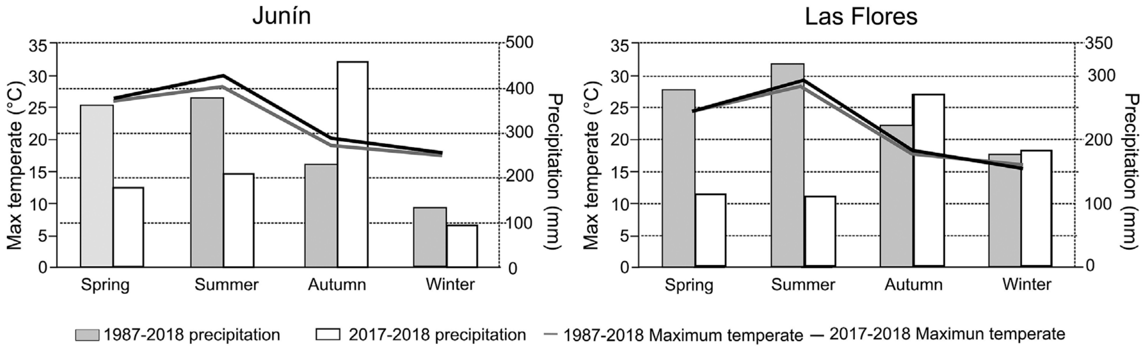

Fig. 3. Seasonal comparison between values of maximum temperature and average precipitations between the period 1987–2018 (in gray) and the period under study (November 2017 to October 2018, in black).

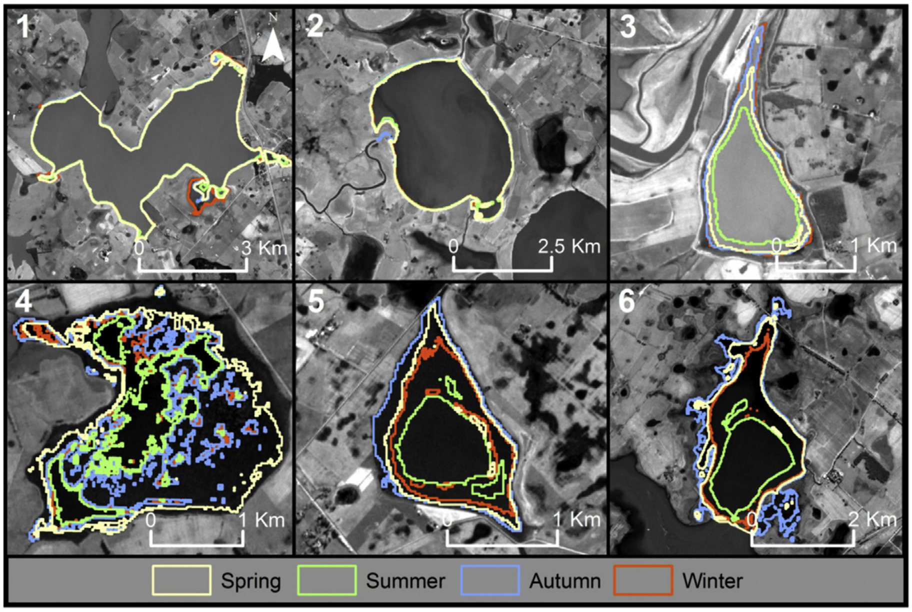

Fig. 4. Seasonal variations in the coastlines in shallow lakes. Base image: Sentinel 2 B.

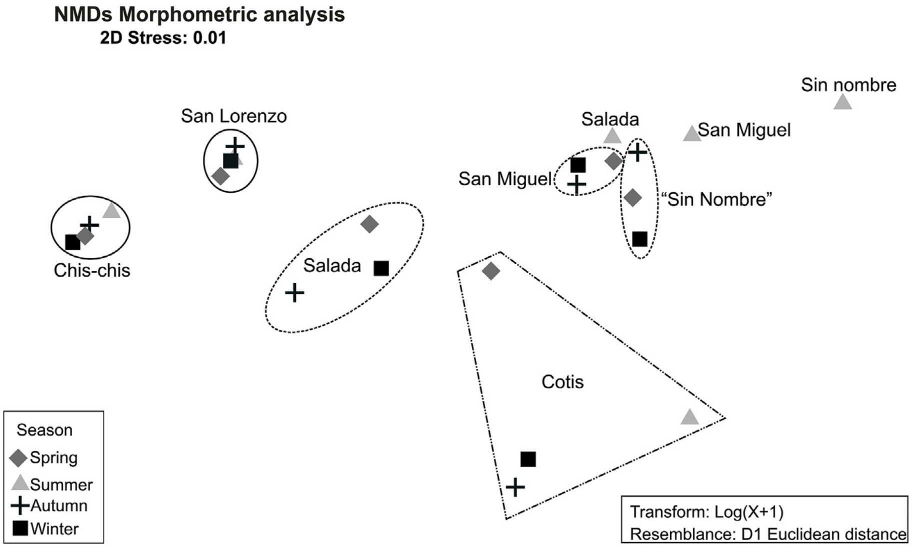

Fig. 5. Non-Metric Multidimensional Scaling (NMDs) considering seasonal variations of the morphometric parameters.

$$\mathbf{AWEI_{nsh}} = \mathbf{4} \times (\mathbf{B3{-}B11}) - (\mathbf{0.\ 25} \times \mathbf{B8} + \mathbf{2.\ 75} \times \mathbf{B12})$$

The index includes the red band (Band 3), the near-infrared band (Band 8), and the shortwave infrared bands (Bands 11 and 12). Water coverages develop a high reflectance in band 3, and to a lesser extent in

Table 2
Table of the morphometric parameters calculated seasonally. In summary are the **mean** values ± **standard deviation,** and **coefficient of variation (%).** Data are expressed in km except for the area in km^2. Abbreviations: TML = Total Maximum Length, TMW = Total Maximum Wide, SHD (Shoreline Development). For TML and TMW principal orientation are expressed between ().

Site	Station	Area	SHL	TML	TMW	SHD
Chis Chis	Spring	13.78	39.34	6.42 (n-s)	3.74 (n-s)	2.99
	Summer	13.32	33.64	6.34 (n-s)	3.58 (n-s)	2.60
	Autumm	13.76	37.19	6.43 (n-s)	3.79 (n-s)	2.83
	Winter	14.26	39.35	6.41 (n-s)	4.43 (n-s)	2.94
	Summary	**13.78** ± **0.38 (2.79)**	**39.35** ± **2.69 (7.2)**	**6.4** ± **0.04 (0.64)**	**3.88** ± **0.37 (9.63)**	**2.89** ± **0.17 (6.10)**
San Lorenzo	Spring	10.23	22.06	3.93 (nw-se)	3.33 (e-w)	1.94
	Summer	10.11	20.04	3.81 (nw-se)	3.20(e-w)	1.77
	Autumm	10.34	19.26	3.93 (nw-se)	3.14 (e-w)	1.69
	Winter	10.14	20.28	3.91 (nw-se)	3.25 (e-w)	1.80
	Summary	**10.21** ± **0.10 (1.01)**	**20.41** ± **1.18 (5.8)**	**3.89** ± **0.06 (1.47)**	**3.23** ± **0.08 (2.49)**	**1.80** ± **0.10 (5.89)**
San Miguel	Spring	1.63	8.8	2.36 (n-s)	1.25 (e-w)	1.78
	Summer	1.21	06.04	1.74 (n-s)	1.06 (e-w)	1.55
	Autumm	1.82	9.92	2.88 (n-s)	1.19 (e-w)	2.07
	Winter	1.87	9.8	2.89 (n-s)	1.33 (e-w)	1.87
	Summary	**1.63** ± **0.3 (18.38)**	**8.28** ± **1.67 (20.19)**	**2.47** ± **0.54 (22.07)**	**1.21** ± **0.11 (9.43)**	**1.82** ± **0.22 (11.96)**
Cotis	Spring	2.74	17.9	1.73 (n-s)	1.97 (e-w)	2.91
	Summer	0.42	14.08	1.55 (nw-se)	0.72 (e-w)	6.13
	Autumm	1.20	28.88	2.26 (nw-se)	1.41(e-w)	7.44
	Winter	1.20	25.88	2.28 (nw-se)	1.37 (e-w)	6.66
	Summary	**1.39** ± **0.97 (69.95)**	**21.48** ± **7.03 (32.71)**	**1.95** ± **0.37 (18.99)**	**1.37** ± **0.51 (37.38)**	**5.78** ± **1.98 (34.38)**
“Sin nombre”	Spring	1.27	8.86	2.17 (nw-se)	1.17 (e-w)	2.22
	Summer	0.48	3.42	0.80 (n-s)	0.86 (e-w)	1.39
	Autumm	1.51	7.38	2.20 (nw-se)	1.31 (e-w)	1.69
	Winter	1.3	10.8	1.66 (nw-se)	1.06 (e-w)	2.49
	Summary	**1.14** ± **0.45 (39.72)**	**7.43** ± **2.89 (38.94)**	**1.71** ± **0.65 (38.29)**	**1.10** ± **0.19 (17.34)**	**1.95** ± **0.49 (25.54)**
Salada	Spring	4.56	18.75	4.25 (n-s)	1.91 (e-w)	2.48
	Summer	1.83	7.94	2.02 (n-s)	1.46 (e-w)	1.65
	Autumm	5.58	28.33	4.29 (n-s)	2.10 (e-w)	3.38
	Winter	3.87	20.85	3.88 (n-s)	2.00 (nw-se)	2.99
	Summary	**3.96** ± **1.58 (40)**	**18.97** ± **8.42 (44.41)**	**3.61** ± **1.07 (29.65)**	**1.87** ± **0.28 (15.13)**	**2.63** ± **0.74 (28.4)**

band 8, while water reflectance is minimum in the rest.

Before index calculation, pixel resizing of bands 11 and 12 (20 m) is mandatory, in order to match bands 3 and 8 pixel sizes (10 m). This processing was automatically performed, together with the images correction. Subsequently, a binary image was created by selecting a soil/water coverage threshold, which was then vectorized allowing different measurements.

In order to obtain morphometric parameters, a different delimitation criterion for shallow lakes was established. National Geographic Institute (IGN) lake vectors allowed redefining those cases where the water body extension exceeded the limits during a period. Laguna Salada, not present in the IGN cartography, was delimited towards the SW side using the intersection of the shallow lake with the Salado River.

Morphometric characterization of the shallow lakes was carried out through image analysis and different parameter calculation (Dangavs, 1976), such as Total Maximum Length (TML), Total Maximum Wide (TMW), Shoreline Length (SHL), Area (A) and Shoreline Development (SHD), seasonally estimated for each lake. For TML and TMW calculation, the orientation of the measurements axis is also clarified; all the data is expressed in km, except for the surface data, indicated in km^2. Shoreline Development (SHD = P/2(π.A)½) measures the coastline irregularity degree. Contreras and Paira (2015) classify the lakes by their shape in: circular (SHD 1–1.14), subcircular (1.15–1.29), triangular (1.30–1.99), simple irregular (2–2.99), dendritic (3–3.99) and irregular complex (SHD > 4) attributing to them different origins.

3.3. Chemical and environmental data

During samplings, the water turbidity was evaluated using a Secchi disc, and electrical conductivity and pH were measured using a portable pH/Conductivity Lutron meter. Bottom sediment samples were gathered in order to know easily oxidizable carbon (OC) and organic matter concentration (OM). The Walkley-Black method was used to determine the OC, and the OM was estimated according to the following formula: OM (%) = 1.724 × C (%), both values are expressed in percentage. These analyses were carried out at the Edaphology Laboratory of the Facultad de Ciencias Agrarias y Forestales, Universidad Nacional de La Plata (FCAyF-UNLP).

In addition, 1000 ml plastic water containers were collected seasonally in each site to conduct chemical analyses. All samples were kept in an ice-cooled box and transferred to the laboratory within a few hours after sampling. For major ions analysis, standardized APHA methods (1998) were applied. The calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions were determined by titration of EDTA (Standard Methods M 3500-Ca D and M 3500-Mg E), chloride (Cl^-) by titration with the MOHR method (Standard Methods M 4500 Cl-B), carbonates ($CO_3{}^{2-}$) and bicarbonates ($HCO_3{}^-$) by titration with acid (Standard Methods M 2320 B), sodium (Na^+) and potassium (K^+) by flame photometry (Standard Methods M 3500-Na D and Standard Methods M 3500-K D) using a Crudo Caamaño equipment, Iono meter Alphanumeric model. The sulfates ($SO_4{}^{2-}$) were determined by turbidimetry using the spectrophotometric method (Standard Methods M 4500 SO42-E), and nitrates ($NO_3{}^-$) were determined by the selective ultraviolet spectrometric method (Standard Methods M 4500 NO3-B), in both cases by means of a UV–Visible spectrophotometry with a double beam Shimadzu UV-160A. Conductivity is expressed in μS/cm, and concentrations in mg/L. The measurements were made at the Geochemistry Laboratory (Geohydrology Sector) of the Centro de Investigaciones Geologicas (CIG, CONICET-UNLP), according to standardized methods of the APHA (American Public Health Association) by triplicate, expressing the final result the average value.

3.4. Data analysis

Non-parametric tests (Mann Whitney and Kruskal–Wallis) were used to inspect the difference between shallows lakes according to

Table 3
Summary with mean values ± deviation, minimum and maximum values and coefficient of variation (CV, %) of chemical and environmental parameters. Abbreviations: CO = Easily oxidizable carbon, MO = Organic matter, Cond = Conductivity, Hard = Hardness, Turb = Turbidity.

Site	Cotis			"Sin Nombre"			Salada		
	Media ± SD	Min-Max	CV %	Media ± SD	Min-Max	CV %	Media ± SD	Min-Max	CV %
CO	3.99 ± 3.06	2.08–7.52	76.6	5.37 ± 4.64	1.71–11.58	86.3	4.74 ± 1.53	2.96–6.7	32.3
MO	6.88 ± 5.28	3.58–12.97	76.7	9.27 ± 7.99	2.96–19.97	86.3	8.18 ± 2,64	5.11–11.56	32.3
pH	7.86 + -0.31	7.49–8.16	4.34	8.83 + 1.11	7.52–10.17	12.6	8.68 + 9.08	7.5–9.71	10.5
Cond	1678 + 1072	768–2860	63.9	3460 + 2010	1719–6360	58.1	6638 + 4005	3500–12120	60.3
CO_3^{-2}	10.85 ± 18.80	0–32.56	173.2	82.54 ± 111.3	0–235.4	134.8	86.36 ± 97.18	0–223.5	112.5
HCO_3^-	670.7 ± 449.6	339.5–1183	67	595.7 ± 178.9	351.7–780.1	30	600.4 ± 117.6	447.4–693.6	19.6
Cl^-	195.4 ± 124.3	80.67–327.5	63.6	501.3 ± 208.1	291.5–789.2	41.5	1379 ± 745.7	751.9–2255	54.1
SO_4^{-2}	46.46 ± 27.53	18.34–73.36	59.2	439.7 ± 661.3	79.03–1431	150.4	1619 ± 1684	179.7–3741	104
NO_3^-	14.65 ± 4.24	12.07–19.54	28.9	19.46 ± 10.64	10.93–34.41	54.7	15.48 ± 13.94	4.81–35.96	90.1
Ca^{+2}	34.09 ± 22.27	13.94–58	65.3	35.21 ± 18.29	18.81–61	51.9	94.53 ± 55.98	32.62–164.1	59.2
Na^+	334 ± 264.5	121–630	79.2	680 ± 448.2	320–1320	65.9	1338 ± 878.7	510–2540	65.7
Mg^{+2}	37.11 ± 5.93	30.45–41.82	15.9	51.61 ± 14.17	37.40–65.59	27.4	149.3 ± 70.79	79.85–241.7	47.4
K^+	58 ± 40.29	29–104	69.5	118 ± 115.6	33–286	98	125.3 ± 129.6	40–315	103.5
Hard	239.1 ± 77.66	161.7–317.1	32.5	302.5 ± 57.35	223.3–358.5	18.9	857.3 + 390.7	508.6–1417	45.6
Turb	31.33 ± 23.46	5–50	74.9	17 ± 7.16	10–25	42.15	28 ± 28.15	5–67	100.5

Site	Chis Chis			San Lorenzo			San Miguel		
	Media ± SD	Min-Max	CV %	Media ± SD	Min-Max	CV %	Media ± SD	Min-Max	CV %
CO	0.9 ± 1.08	0.17–2.46	119	0.32 ± 0.18	0.21–0.6	57.5	2.52 ± 0.78	1.88–3.56	31
MO	1.56 ± 1.85	0.32–4.23	118.7	0.56 ± 0.32	0.37–1.04	57.8	4.34 ± 1.35	3.24–6.14	31.03
pH	8.74 ± 0.68	7.97–9.43	7.8	8.37 ± 0.62	7.61–8.91	7.4	8.30 ± 0.39	7.73–8.59	4.7
Cond	1361 + 190.4	1125–1584	13.9	3023 + 585.2	2350–3640	19.4	6328 + 3091	4060–10880	48.8
CO_3^{-2}	33.49 ± 23.17	0–53.21	69.2	17 ± 23.59	0–50.2	138.8	16.84 ± 22.21	0–46.82	131.9
HCO_3^-	360.5 ± 37.92	332.5–415.5	10.5	304 ± 38.79	261.2–343	12.8	392.1 ± 100	292.5–489.1	25.5
Cl^-	234.1 ± 29.18	194.6–261.5	12.5	684.7 ± 128	535.5–794.2	18.7	1586 ± 758.8	946.9–2683	47.8
SO_4^{-2}	194.2 ± 207	50.42–95.2	106.6	301.2 ± 242.2	53.14–594.2	80.4	750.9 ± 1065	183.4–2347	141.8
NO_3^-	12.07 ± 1.87	9.99–13.68	15.5	11.43 ± 0.85	10.62–12.54	7.4	246.1 ± 467.2	7.99–946.9	189.9
Ca^{+2}	25.48 ± 7.3	17.66–35	28.6	64.11 ± 10.48	55–76.89	16.3	93.14 ± 35.65	64–143.4	38.3
Na^+	313.3 ± 40.84	253–340	13	530 ± 103.9	440–620	19.6	1263 ± 609.4	870–2170	48.3
Mg^{+2}	26.77 ± 1.79	25.21–8.76	6.7	74.81 ± 10.64	62.36–87.21	14.2	128.3 ± 58.36	72.76–209.3	45.5
K^+	46 ± 29.98	22–86	65.2	53.75 ± 35.14	29–104	65.4	117 ± 51.56	47–268	88.1
Hard	174.9 + 14.26	162.1–191.6	8,1	471.2 ± 51.83	394.1–503.6	11	766.4 ± 332.9	459.4–1230	43.4
Turb	19.75 ± 4.92	14–26	24.9	21.25 ± 4.57	16–27	21.5	13.50 + 5.74	10–22	42.5

regional and local geomorphological criteria.

In addition, a Permutational Multivariate Variance Analysis (PERMANOVA) was carried out to evaluate differences between the shallows lakes and the data set as a whole (chemical, environmental and sediment). The design used for the PERMANOVA consisted of two factors: 1) geomorphological, with three levels: isolated, connected and crossed and 2) geographical: with two levels: medium and low sector. Variables were standardized at a common scaleSubsequently, the dissimilarity matrix was constructed with the Euclidean distance considered appropriate for this multivariate analysis (Clarke and Warwick, 2001), α = 0.05 was considered and 4999 permutations were performed to obtain the p (perm) (Anderson et al., 2008). When the PERMANOVA showed significant differences, pair-wise comparisons and a Similarity Percentage analysis (SIMPER) were performed to identify the variables that explained the differences.

In addition, Non-Metric Multidimensional Scales (NMDS) were performed, which ordered the objects spatially, placing the most similar ones closer and allowing the multivariate pattern to be visualized. $<$ 0.1 values of STRESS (Standard Residuals Sum of Square) correspond to good orderings and values $<$ 0.2 give a potentially useful interpretation of the data (Clarke, 1993). The PERMANOVA and SIMPER analysis were carried out using the PRIMER 7 program, 7.0.13 version (PRIMER-e, free version) (Clarke and Gorley, 2006). NMDS analysis and graphs were performed with the vegan statistical pack (Oksanen et al., 2013) of the program R version 3.0.1. (R Core Team, 2013).

4. Results

4.1. Climate analysis

When comparing the precipitation data for the period 1987–2018 along to the average values between November 2017 and March 2018 (Fig. 2) a negative rainfall anomaly was detected. Anomalies showed positive between April–May, registered mainly in the Junín station (positive difference of 146 mm), and during September, with a maximum difference of 75 mm for Las Flores station. Although the monthly maximum temperature data (Fig. 2) showed a similar trend in both periods, during the 2017–2018 interval values were lower than the mean between June and August. In addition, positive anomalies were registered between January and April, and in September.

According to climatic seasons, precipitations assessment (Fig. 3) showed important rainfall deficits in spring and summer (negative anomalies) for the study period, while in autumn rainfall was higher than the average, mainly in Junín. Regarding temperatures, general traits in all seasons showed maximum temperature positive anomalies in the study period, being that of summer near +2 °C.

4.2. Morphometric analysis

The satellite images analysis (Fig. 4) showed seasonal changes in the lakes' water level and allowed the identification of shallow lakes groups (Fig. 5). Chis Chis and San Lorenzo, in which morphometric parameters remained uniform throughout the study (Fig. 5, greatest proximity of the points), showed the lowest variation for all the estimated variables (Table 2). Conversely, San Miguel, Salada, and "Sin Nombre" showed

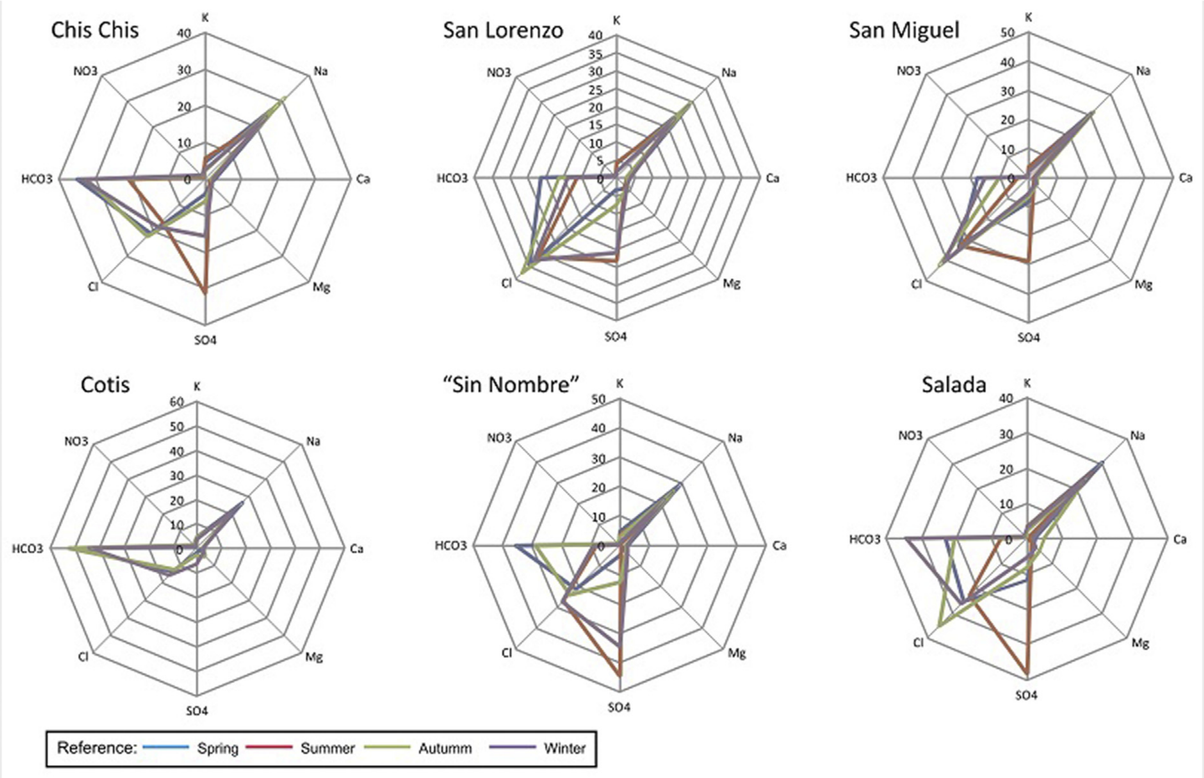

Fig. 6. Maucha plot showing characterization of major ions in shallow lakes; concentrations are expressed as percentage frequencies.

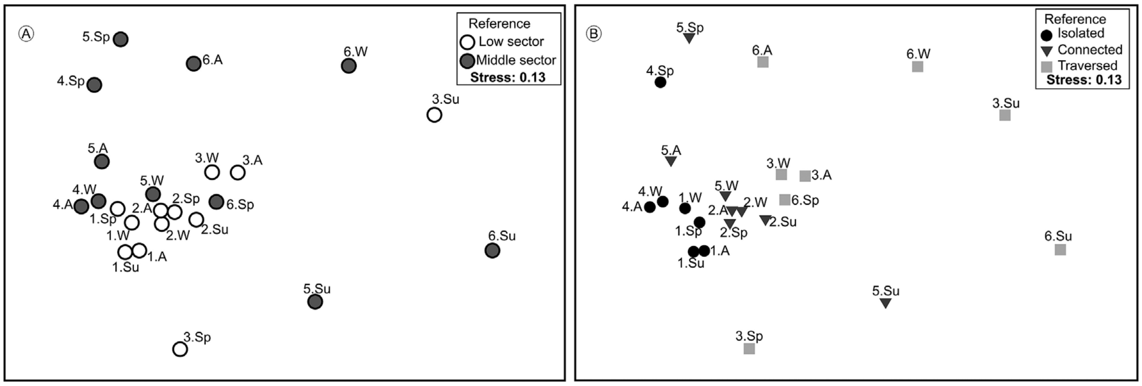

Fig. 7. Non-Metric Multidimensional Scaling (NMDs) considering seasonal variations of the chemical and environmental parameters at regional (A) and local (B) level.

morphometric stability throughout the studied period, except for summer when the bodies were significantly reduced. The variation was minimal in San Miguel, in which coefficients had values lower than 20%. The most variable parameters of Salada and “Sin Nombre” were the Shoreline Length (44.41% and 38.94% respectively) and maximum TML (29.65% and 38.29% respectively). Finally, Cotis underwent the largest changes (Fig. 5, the greatest dispersion of points), mainly in area and TMW values.

SHD values (Table 2) indicated that the lower sector shallow lakes maintained their shape throughout the year (coefficients of variation less than 11%). Chis Chis can be classified as simple irregular, while San Miguel was mostly triangular in shape. Conversely, those lakes located in the middle sector showed shape modifications (coefficients of variation greater than 25%). Cotis markedly reduced its size (area) during the summer. The images reflect the presence of isolated flooded sectors with extremely irregular edges, going from dendritic in spring to irregular complex in the rest of the seasons. This means that the Shoreline length values were probably overestimated, and in fact, they showed the highest SHD. Finally, the Salada shallow lake varied from triangular in spring to dendritic in summer and irregularly simple in autumn and winter, while “Sin Nombre” had a triangular shape in the first samplings and simple irregular in the last ones.

4.3. Hydrochemical analysis

The chemical and environmental data (Table 3, Fig. 6) enabled the studied sites to be characterized as follows. Chis Chis is distinguished for having an alkaline pH (7.97–9.43), low conductivity (it was the site with the lowest average value 1361 ± 190.4 μS/cm), and low hardness values. These three parameters showed low variation coefficients (less than 14%). Both the OM and the OC had the highest variation (118.7% and 119% respectively). Its waters were sodium-bicarbonate throughout the year, except for the summer where they were sodium-sulphate. San Lorenzo behaved as an alkaline shallow lake with an

Table 4
Permanova analysis results with Euclidean distances at regional and local level, and Pair Wise test results.

PERMANOVA analysis			
	Df	Pseudo-F	p(Perm)
Regional	1	2.75	**0.01**
Local	2	3.77	**0.001**
Regional*Local	2	0.71	0.71
Residuales	17		
Total	22		
Pair Wise test			
Groups		t	P(Perm)
Lower-Middle Sector		1.66	**0.021**
Isolated-Connected		1.18	0.23
Isolated-Traverserd		2.44	**0.003**
Connected-Traversed		1.71	**0.028**

average pH of 8.37, with soft to slightly hard water (394–503 mg/L) and slightly brackish (2350–3640 µS/cm), with sodium-chlorinated water, and had a marked increase in sulphate concentration during summer and winter.

San Miguel showed the lowest turbidity (13.50 ± 5.74) with brackish water (average conductivity 6328 ± 3091), reaching maximum values (10,880 µS/cm) during autumn. Its waters were sodium-chlorinated throughout the year, although during the summer chlorides and sulphates shared dominance. Cotis could not be sampled in summer since the water level dropped markedly and the access to the few sites with water was impossible. Its average pH was the lowest (7.86 ± 0.31). Conductivity and hardness values indicated that it was a soft freshwater shallow lake, classified as sodium-bicarbonate during the whole period.

“Sin Nombre” shallow lake was slightly brackish (3460 ± 2010 µS/cm) reaching maximum values in autumn. It had sodium-bicarbonated waters throughout the year, except for the summer when they were classified as sodium-sulphated. Finally, Salada conducted as an alkaline limnic body of hard to very hard and brackish water, with the highest conductivity (between 3500 and 12120 µS/cm) and hardness (508.6–1417 mg/L) values of the whole area. The Maucha diagram (Fig. 6) indicates that this was the most fluctuating site in terms of its anionic composition. In spring, a dominant anion was not registered (percentage abundances Bicarbonate = 23%, Chlorides = 25%). In summer, waters were sulphated, chlorinated in autumn and bicarbonated in winter.

Regional shallow lakes analysis showed changes at a chemical and environmental level ($p = 0.015$, Fig. 7b) (Table 4) between middle and lower sector groups. This was also observed at a local level ($p = 0.0014$, Fig. 7a) specifically between the isolated and traversed shallow lakes ($p = 0.003$), and between the connected and traversed ones ($p = 0.028$). In addition, the analysis showed no significant interaction between both factors ($p = 0.71$). When variables were compared individually and through the SIMPER analysis (Table 5), the differences between both sectors were observed in the OC, OM and HCO_3 values ($p = 0.0021$, $p = 0.0023$, $p = 0.0008$ respectively, Fig. 8). At a local geomorphological level, differences in conductivity and hardness ($p = 0.0002$, $p = 0.0001$) and in the values of Cl^-, SO_4^{-2}, Ca^{+2}, Na^+ and Mg^{+2} (Fig. 9) were observed. The Simper analysis showed that the environmental and chemical variables that reflected the differences among sites were particular between each analyzed pair (Table 5). It was not a single variable but a set of them that reflected these differences.

5. Discussion and conclusion

In recent decades, studies on the dynamics of the shallow lakes around the world have increased due to their ecological and economic importance (Carpenter et al., 1995). In the Pampean region, they are intimately associated with regional economies and they also play an important ecological and social role.

When evaluating the general behavior and the changes in the physical-chemical variables of different Pampean region shallow lakes, a multicausal limnological variability profile was found. Two groups can be recognized regarding morphometric development. San Miguel, Cotis, “Sin Nombre” and Salada lakes (Fig. 10) showed water level variations directly linked to local weather conditions, associated with a deficit or increase of precipitations. This situation is similar to what happens in other Pampean shallow lakes during dry and humid periods (Bohn et al., 2011). Conversely, in Chis Chis and San Lorenzo shape changes were imperceptible because both are intervened. Frequently, dams floodgates and embankments are built to retain water during rainfall deficit periods. But also artificial canals, which are built to speed up the fields drainage during floods, tend to alter the shallow lakes' water level.

When analyzing the shallow lakes' shape, triangular and simple irregular shapes were dominant. The origin of the triangular shapes is associated with unconfined floods or the presence of some type of bar (sand dune or a dam. Irregular shapes could arise by the confluence of basins or smaller lakes (Timms, 1992). In the case of the studied shallow lakes, the shape variation could be related to the characteristics of the different geomorphological environments where they are located. Those located in the middle sector have developed in an interdune environment, therefore during flood periods, the different water bodies connect with each other through irregular, wide and shallow depressions. On the other hand, those of the lower sector that were formed on loessic sediments are deeper than the middle sector lakes, and have well-defined edges, especially towards the E and NE margins, where the presence of lunettes contribute to confine the shoreline length more clearly and permanently.

Chemically, lentic systems are dominated by calcium and bicarbonate worldwide (Miretzky, 2011). Relations among cations are: $Ca^{+2} > Mg^{+2} > Na^+ > K^+$, and among anions are:

Table 5
SIMPER analysis on Euclidean distances for environmental and chemical variables, showing different percentages contribution (Contr%) to the differences found between the lower (LS) and middle (MS) sector and among isolated (Is), traversed (Tr) and connected (Co) lakes.

LS-MS	(Contr%)	Is-Co	(Contr%)	Is-Tr	(Contr%)	Co-Tr	(Contr%)
HCO_3^-	10.45	pH	17.14	Cl^-	10.85	NO_3^-	8.66
MO	10.42	CO_3^{-2}	11.53	Hardness	10.31	Mg^{+2}	8.33
CO	10.42	HCO_3^-	11.35	Mg^{+2}	10.22	Hardness	8.23
CO_3^{-2}	8.89	MO	9.63	Cond.	9.6	SO_4^{-2}	8.22
Turb.	8.46	CO	9.63	Ca^{+2}	9.22	Na^+	8.04
pH	8.41	Turb.	9.44	Na^+	9.02	Cl^-	7.99
NO_3^-	7.99	K^+	7.13	NO_3^-	8	Ca^{+2}	7.72
K^+	7.16			SO_4^{-2}	7.15	Cond.	7.53
						K^+	7.37

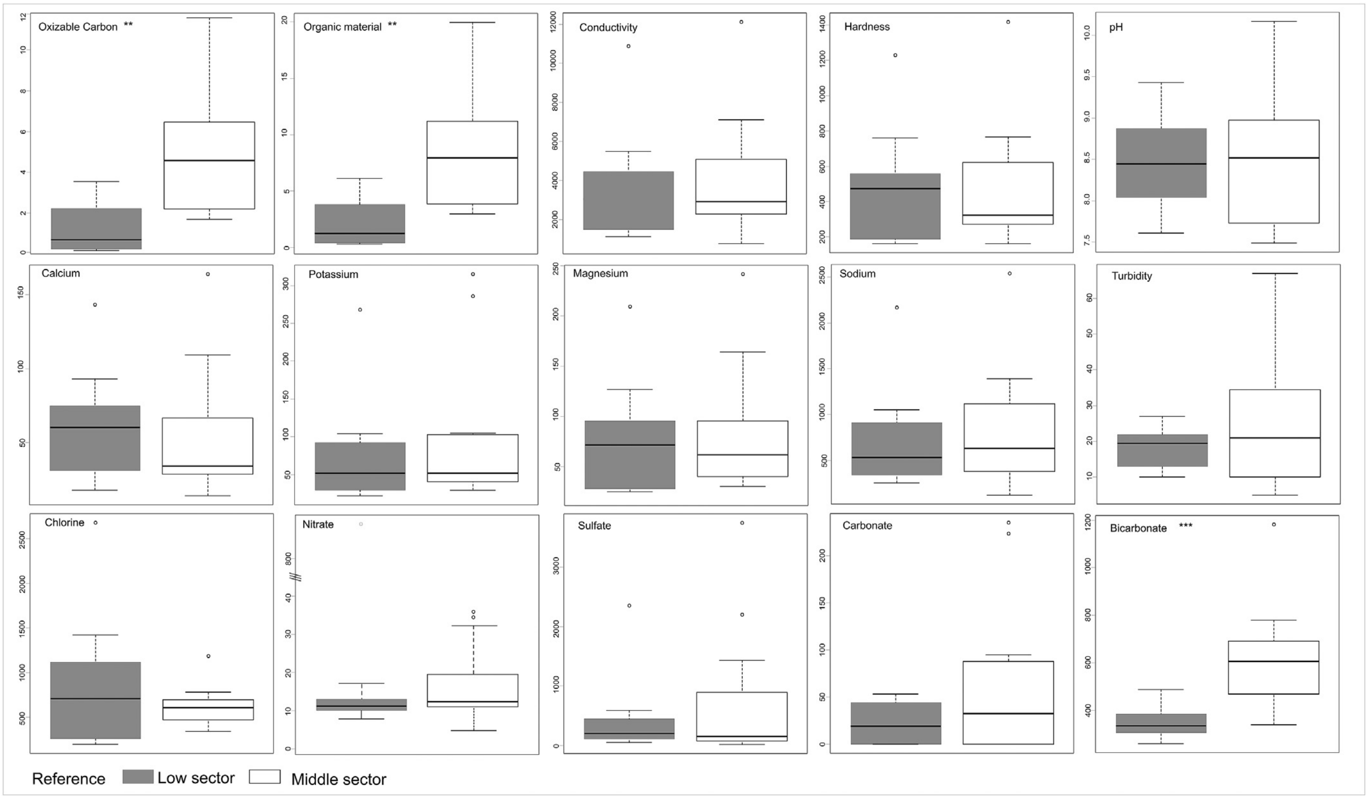

Fig. 8. Box plot showing enviromental-chemical variables among shallow lakes in Low sector (gry) and Middle sector (white). Values obtained with Mann Whitney test. Error bar means a 95% confidence interval. Signif. codes: '***' 0.001; '**' 0.01.

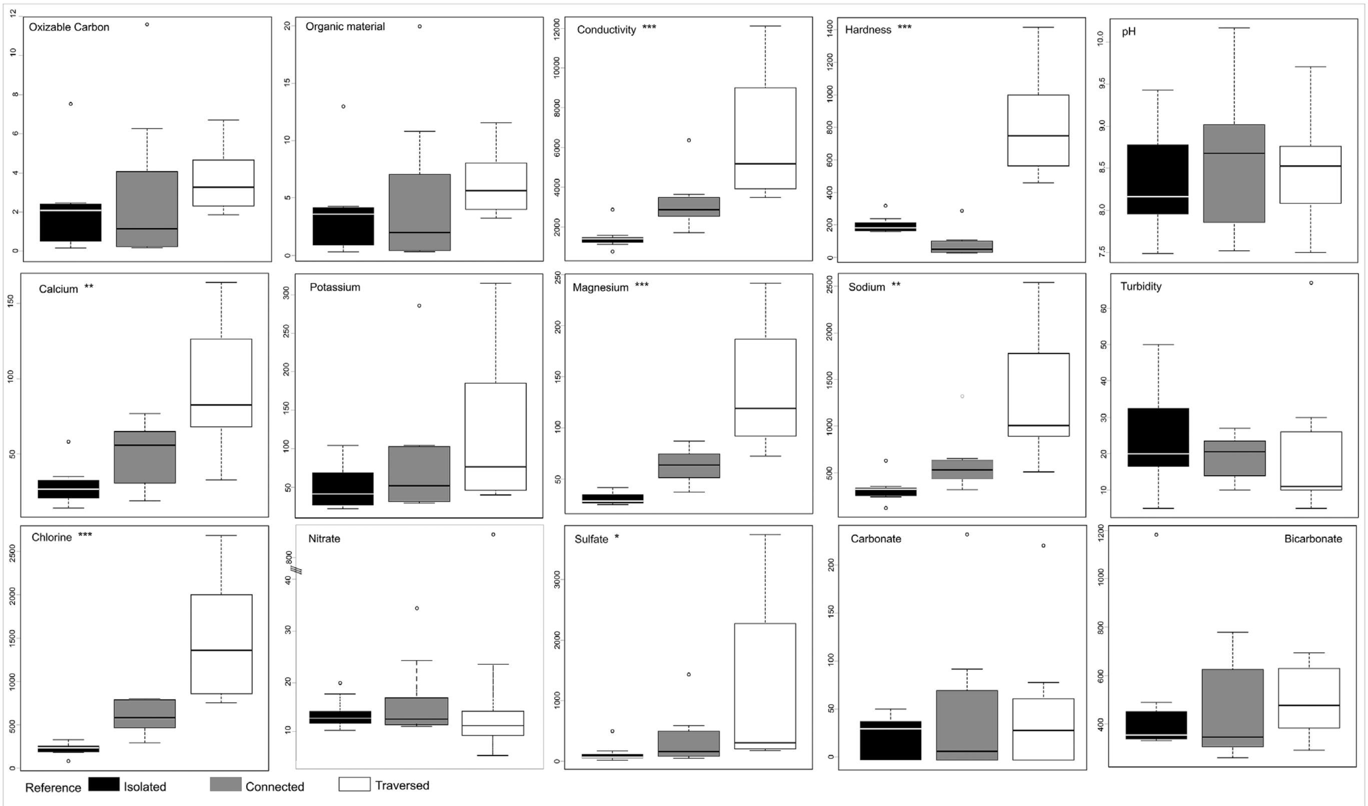

Fig. 9. Boxplot showing enviromental-chemical variables in Isolated (black), Connected (gray) and Traversed (white) shallow lakes. Values obtained with Kruskall-Wallis test. Error bar means a 95% confidence interval. Signif. codes: '***' 0.001; '**' 0.01.

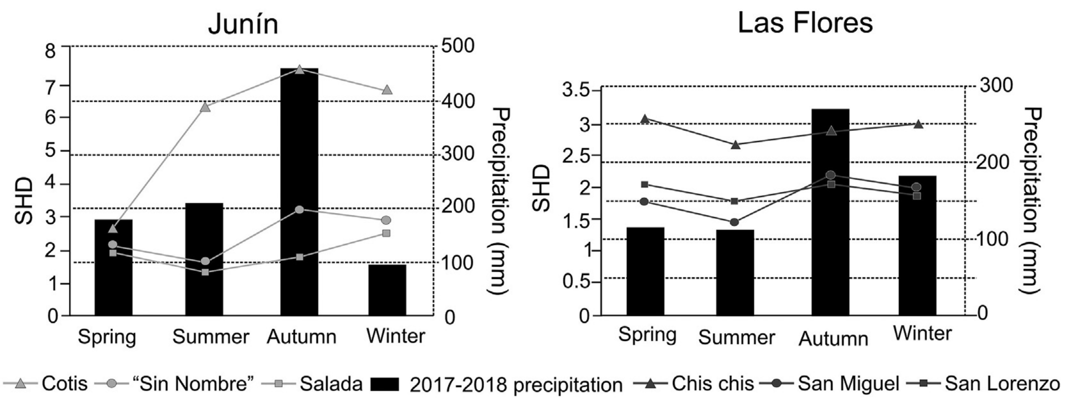

Fig. 10. Seasonal comparison between Shoreline Development (SHD) and average precipitations to the period November 2017 to October 2018.

HCO_3^- > SO_4^{-2} > Cl^-. Regarding Pampean shallow lakes, these relations are different: sodium is the dominant element among cations, while for anions the prevalence of bicarbonate can be replaced by chlorides or sulfates.

The studied lakes were Na^+ enriched. This agrees with the regional general cationic pattern and is caused by the groundwater and Pampean loessic sediments (Plio-Pleistocene) contact, where a cation exchange takes place: the Ca^{+2} of the water is replaced by the Na^+ of the clays that largely constitute the loess (Miretzky et al., 2000; Fernández Cirelli and Miretzky, 2004; Puntoriero et al., 2015) on which the shallow lakes were carved.

Different authors have proposed a general model for the anion composition of the Pampean lakes linked to climatic conditions and surface water and groundwater level fluctuations (Dangavs et al., 1996; Halcrow Consortium, 1999; Miretzky et al., 1999; Miretzky, 2011; Fernández Cirelli and Miretzky, 2004; Laprida and Valero-Garcés, 2009). During floods, when the groundwater level rises, bicarbonate is the dominant anion; while in periods of extreme water deficit or during summer, the conductivity increases as a result of the water body reduction, being Cl^- the main anion. This general seasonal pattern was not observed in the studied shallow lakes. The dominant anions, HCO_3^- (43%), Cl^- (35%), SO_4^{-2} (13%), remained stable in each lake during the study period.

Bicarbonated waters were found in Chis Chis, which was isolated, during the study period, from the Salado River and where the water levels did not vary during the sampling period. Nevertheless, Cotis and "Sin Nombre" lakes also had this characteristic, because of the water body reduction during the summer, but they were able to recover their water mirror after the intense autumn rains. We could also recognize that Chloride was the dominant anion in San Lorenzo and San Miguel lakes, located in the lower sector. Chloride is associated with lakes with oceanic connections or with the presence of marine evaporite deposits (Miretzky, 2011). Marine sediments corresponding to the Canal de Las Escobas Formation can be found in both areas, accumulated during the last marine transgression (MIS 1). Fucks et al. (2015) interpreted that the sea would have entered the area going upstream the Salado River and occupying the depressions or ancient shallow lakes near its course. The presence of these sediments has been confirmed in both sites during the field surveys and they can be found in different neighboring localities (Fucks et al., 2015; Ramos et al., 2019). The sulphate enriched water is explained by the gypsum dissolution, present both in the loessic and fluvio-lacustrine sediments of the area (Fernández Cirelli and Miretzky, 2004; Fucks et al., 2015). In some cases, it forms notorious rosettes by the union of small crystals. The presence of these rosettes has been corroborated in the San Miguel and Salada shallow lakes, and with a different development, in some lentic and lotic bodies of the study area (i.e. Dangavs and Blasi, 1992, 2002); this would explain the presence of sulfates in the water of some of the studied shallow lakes.

Therefore, the lower sector shallow lakes showed minimum variations in terms of the morphometric parameters during the studied period. This is due to the water retention works carried out in the Encadenadas system, to which Chis Chis belongs, and in San Lorenzo lake. In addition, these lakes have little variation in their chemical water composition; the presence of chlorinated-sodium waters in San Lorenzo and San Miguel lakes stands out, related to the Holocene marine sediments, which provide the chlorides that enrich the water. In Chis Chis, waters were mainly bicarbonate-sodium, which agrees with previous results obtained for other lakes in the Encadenadas system (Torremorell et al., 2007).

The middle sector shallow lakes, which do not have anthropic modifications, showed greater morphometric variations linked to rainfall during the sampling. The waters of Cotis and "Sin Nombre" were bicarbonate during the entire period, except for the summer when no water was registered in Cotis, and in "Sin Nombre" the sulfates were dominant. Finally, the Salada lake could not be characterized by a single major anions type.

The studied shallow lakes physical and chemical indicators are not only related to regional climatic variations but to the geomorphological environment, the surrounding sediments and the anthropic interventions which impede or facilitate the drainage, generating notable runoff changes and dissimilar responses from those naturally expected beyond the typical climatic variations of the region.

This study, which integrates climate, satellite images and environmental-chemical data analysis is a starting point for the systematic monitoring of these environments over longer periods of time, aiming to include different extreme climatic situations and suggesting their response over time. The creation of a quantitative database will enable the evaluation of shallow lakes environment vulnerability to human changes to future climate scenarios in this vitally economic area.

CRediT authorship contribution statement

Maria Florencia Pisano: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - original draft, Visualization, Funding acquisition. **Gabriela D'Amico:** Formal analysis, Writing - original draft, Visualization. **Nicolas Ramos:** Methodology, Investigation. **Nicole Pommarés:** Formal analysis, Investigation, Writing - original draft. **Enrique Fucks:** Investigation, Resources, Writing - original draft, Funding acquisition.

Acknowledgements

This research was founded by the Agencia Nacional de Promoción Científica y Tecnológica, Argentina (PICT2017-0491) and Universidad Nacional de La Plata (N800). We would like to thank Carlos Pedroli and Martín Villanueva for permitting the access to San Lorenzo and San Miguel shallow lakes.

References

Aliaga, V., Ferrelli, F., Alberdi Algañaraz, E., Bohn, V., Piccolo, M.C., 2016. Distribución y variabilidad de la precipitación en la Región Pampeana, Argentina; Universidad de La Rioja. Cuad. Investig. Geogr. 42 (1), 261–280.

Anderson, M.J., Gorley, R.N., Clarke, K.R., 2008. PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E, Plymouth, UK, pp. 218.

APHA, 1998. Standard Methods for the Examination of Water and Waste Water. American Public Health Association, pp. 874.

Bohn, V.Y., Perillo, G.M.E., Piccolo, M.C., 2011. Distribution and morphometry of shallow lakes in a temperate zone (Buenos Aires Province, Argentina). Limnética 30 (1), 89–102. https://doi.org/10.23818/limn.30.08.

Brandizi, L.D., Labraga, J.C., 2012. Calibración del modelo hidrológico SWAT en la cuenca del Río Salado, Provincia de Buenos Aires. In: XI Congreso de Meteorología, CONGREMET XI, Mendoza.

Carpenter, S.R., Chisholm, S.W., Krebs, C.J., Schindler, D.W., Wrigh, R.F., 1995. Ecosystem experiments. Science 269, 324–327.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 18, 117–143. https://doi.org/10.1111/j.1442-9993.

Clarke, K.R., Gorley, R.N., 2006. PRIMER V6: User manual/Tutorial. PRIMER-E Ltd, Plymouth.

Clarke, K.R., Warwick, R.M., 2001. Changes in Marine Communities: an Approach to Statistical Analyses and Interpretation, second ed. PRIMER-E, Plymouth, pp. 176.

Contreras, F., Paira, A., 2015. Comparación morfométrica entre lagunas de la planicie aluvial del río Paraná Medio y la Lomada Norte (Corrientes, Argentina). Cuad. Geogr. Rev. Colomb. Geogr. 24 (1), 61–71.

Coops, H., Beklioglu, M., Crisman, T.L., 2003. The role of water-level fluctuations in shallow lake ecosystems – workshop conclusions. Hydrobiologia 506–509 (1–3), 23–27. https://doi.org/10.1023/b:hydr.0000008595.14393.77.

Dangavs, N., 1976. Descripción sistemática de los parámetros morfométricos considerados en las lagunas pampásicas. Limnobios 1 (2), 35–59.

Dangavs, N., Blasi, A., 1992. Presencia de yeso en Lobos, Buenos Aires. Argent. Rev. Mus. La Plata, Sección Geol. 11, 17–32.

Dangavs, N., Blasi, A., 2002. Los depósitos de yeso intrasedimentario del arroyo El Siasgo, partidos de Monte y General Paz, provincia de Buenos Aires. Rev. Asoc. Geol. Argent. 57 (3), 315–327.

Dangavs, N.V., Blasi, A.M., Merlo, D.O., 1996. Geolimnología de la Laguna de Chacomús, provincia de Buenos Aires, Argentina. Rev. Mus. La Plata, Nueva Serie, Geol. 9, 167–195.

Diovisalvi, N., Berasain, G., Unrein, F., Colautti, D., Fermani, P., Llames, M.E., Torremorelli, A.M., Lagomarsino, L., Pérez, G., Escaray, R., Bustingorry, J., Ferraro, M., Zagarese, H.E., 2010. Chascomús: estructura y funcionamiento de una laguna pampeana turbia. Ecol. Austral 20, 115–127.

Diovisalvi, N., Bohn, V.Y., Piccolo, M.C., Perillo, G.M.E., Baigu, C., Zagarese, H.E., 2015. Shallow lakes from the central plains of Argentina: an overview and worldwide comparative analysis of their basic limnological features. Hydrobiologia 752 (1), 5–20. https://doi.org/10.1007/s10750-014-1946-x.

Fernández Cirelli, A., Miretzky, P., 2004. Ionic relations: a tool for studying hydrogeochemical processes in Pampean shallow lakes (Buenos Aires, Argentina). Quat. Int. 114, 113–121. https://doi.org/10.1016/S1040-6182(03)00046-6.

Feyisa, G.L., Meilby, H., Fensholt, R., Proud, S.R., 2014. Automated water extraction index: a new technique for Surface water mapping using landsat imagery. Remote Sens. Environ. 140, 23–35. https://doi.org/10.1016/j.rse.2013.08.029.

Frenguelli, J., 1950. Rasgos generales de la morfología y la geología de la provincia de Buenos Aires. Public. Lab. Ensayo Mater. Investig. Tecnol. (LEMIT), Serie 2 (33), 1–72.

Fucks, E., Pisano, M.F., Huarte, R.A., Di Lello, C.V., Mari, F., Carbonari, J.E., 2015. Stratigraphy of the fluvial deposits of the Salado river basin, Buenos Aires Province: lithology, chronology and paleoclimate. J. South Am. Earth Sci. 60, 129–139. https://doi.org/10.1016/j.jsames.2015.03.007.

Halcrow Consortium, 1999. Plan Maestro Integral Cuenca del Río Salado, Informe Final. Ministerio de Obras y Servicios Públicos de la Provincia de Buenos Aires. La Plata, Argentina. Disponible en: http://www.mosp.gba.gov.ar, Accessed date: 20 April 2019.

Instituto Geográfico Nacional (IGN). GIS-250 geographicaldatabase. Disponible en: http://www.ign.gob.ar/(Fecha de acceso: 20/02/2019).

Iriondo, M., Kröhling, D., 1995. El sistema eólico pampeano. Comun. Mus. Prov. Cienc. Nat. 5, 1–68.

Jawak, S.D., Kulkarni, K., Luis, A.J., 2015. A review on extraction of lakes from remotely sensed optical satellite data with a special focus on cryospheric lakes. Adv. Rem. Sens. 4, 196–213. https://doi.org/10.1016/j.aqpro.2015.02.018.

Jeppesen, E., 1998. The Ecology of Shallow Lakes – Trophic Interactions in the Pelagial. University of Copenhagen, Silkeborg, pp. 358.

Laprida, C., Valero-Garcés, B., 2009. Cambios ambientales de épocas históricas en la pampa bonaerense en base a ostrácodos: historia hidrológica de la laguna de Chascomús. Ameghiniana 46 (1), 95–111.

Mayer, T.D., Pilson, S.L., 2017. Interactions of water levels with water quality, endemic waterbirds, and invasive species in a shallow tropical pond. Hydrobiologia 829 (1), 77–93. https://doi.org/10.1007/s10750-017-3401-2.

Meerhoff, M., Jeppesen, E., 2009. Shallow lakes and ponds. In: Likens, G.E. (Ed.), Encyclopedia of Inland Waters. Elsevier, Oxford, pp. 645–655. https://doi.org/10.1016/b978-012370626-3.00041-7.

Miretzky, P., 2011. Procesos geoquímicos en la cuenca baja del río Salado. Facultad de Ciencia Exactas y Naturales, Universidad Nacional de Buenos Aires. Tesis, pp. 289.

Miretzky, P., Herrero, A., Galindo, G., Fernandez Cirelli, A., 1999. Caracterización de los recursos hídricos en la zona del Sistema de las lagunas Encadenadas de Chascomús, Provincia de Buenos Aires. Estudios preliminares. Rev. Geol. Apl. Ing. Ambient. 12, 85–100.

Miretzky, P., Conzonno, V., Fernández Cirelli, A., 2000. Hydrochemistry of Pampean ponds in the lower stream bed of Salado river drainage basin (Argentina). Environ. Geol. 39, 951–956.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Henry, M., Stevens, H., Wagner, H., 2013. Vegan: Community Ecology Package. R Package Version 2.0-8. Disponible en: http://CRAN.R-project.org/package5vegan.

Puntoriero, M.L., Fernández Cirelli, A., Volpedo, A.V., 2015. Geochemical mechanisms controlling the chemical composition of ground water and Surface water in the southwest of the Pampean plain (Argentina). J. Geochem. Explor. 150, 64–72. https://doi.org/10.1016/j.gexplo.2014.12.011.

QGIS Development Team, 2019. QGIS geographic information system. Open source geospatial foundation project. Disponible en: http://qgis.osgeo.org.

Quaíni, K., Gabellone, N., Ardohain, M., Solari, L., 2005. Muestreo intensivo de parámetros físico-químicos en dos sitios de la cuenca inferior del río Salado (provincia de Buenos Aires): estudio comparativo. Biol. Acuatica 22, 215–222.

Quirós, R., 2004. Sobre la morfología de las lagunas Pampeanas. Doc. Trabajo Área Sistemas Prod. Acuát. N° 3, 1–15.

Quirós, R., 2005. La ecología de las lagunas de las Pampas. Investigación y Ciencia. Madrid, España. pp. 13. www.produccionovina.com.ar/produccion_peces/piscicultura/11-ecologia_lagunas_pampas.pdf.

Quirós, R., Rosso, J.J., Rennella, A., Sosnovsky, A., Boveri, M., 2002. Estudio sobre el estado trófico de las lagunas pampeanas. Interciencia 27, 584–591.

R Core Team, 2013. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria Disponible en: http://www.R-project.org/.

Ramos, N.A., Carignano, A.P., Cusminsky, G.C., Fucks, E., 2019. Calcareous microfossils (Ostracoda and Foraminifera) from the Holocene (MIS 1) at the Salado basin (arroyo san Miguel site, pila, Buenos Aires province, Argentina). In: Cusminsky, G., Bernasconi, E., Concheyro, G. (Eds.), Advances in South American Micropaleontology. Springer, pp. 159–174.

Ringuelet, R.A., 1962. Ecología Acuática Continental. Editorial EUDEBA, Buenos Aires, pp. 138.

Scheffer, M., van Nes, E.H., 2007. Shallow lakes theory revisited: various alternative regimes driven by climate, nutrients, depth and lake size. Hydrobiologia 584, 455–466. https://doi.org/10.1007/s10750-007-0616-7.

Servicio Meteorológico Nacional, 2018. Ministerio de Defensa. Secretaría de Planeamiento. Datos estadísticos de temperaturas máximas y mínimas. Disponible en. www.smn.gob.ar, Accessed date: 20 April 2019.

Timms, B., 1992. Lake Geomorphology. Adelaide, Gleneagles Publishing, Australia.

Torremorell, A., Bustigorry, J., Escaray, R., Zagarese, H.E., 2007. Seasonal dynamics of a large, shallow lake, laguna Chascomús: the role of light limitation and other physical variables. Limnologica 37, 100–108. https://doi.org/10.1016/j.limno.2006.09.002.

Velázquez, G.A., Tisnés, A., Gómez, N.J., 2014. Región pampeana: geografía y bienestar según subregiones. Geograficando 10 (2), 1–25.