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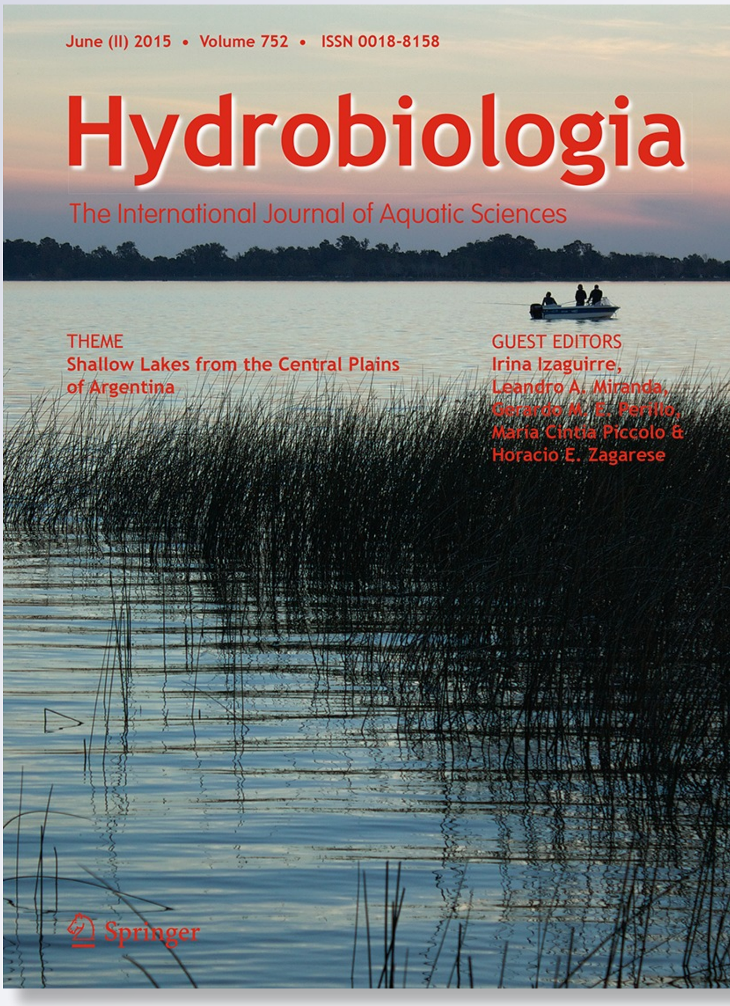

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ARGENTINE PAMPEAN SHALLOW LAKES

Impact of water salinity on *Odontesthes bonariensis* (Actinopterygii, Atherinopsidae) fisheries in Chasicó Lake (Argentina)

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Abstract *Odontesthes bonariensis* is an inland water fish from the *Pampas* region, valued due to the quality of its flesh and its attractiveness as a game fish. Chasicó Lake located in the south of the pampean region is appreciated by fishermen due to *O. bonariensis* abundance. However, in the last year, a reduction in their catches was recorded. In this work, it was analyzed the changes of *O. bonariensis* biomass in relation to climate change and salinity in Chasicó Lake from 1997 to 2013. From 2004 to 2013, when a dry period began, a reduction in lake area (68.1–47.4 km^2) and an increase in salinity (18.9–41.5 $g\ l^{-1}$) were observed. *O. bonariensis* catches showed a significant decrease in the same period as a result of salinity increments. Possibly, at high salinity, *O. bonariensis* may still develop but with an impaired reproduction and limited embryo and juvenile survival. In conclusion, after 2004, the fishery quality in Chasicó Lake showed a decreasing trend from the maximum registered in the *Pampas* lakes. This was in agreement with a marked decrease in the lake area which in turn increased water salinity up to levels close to the *O. bonariensis* tolerance limit.

Keywords Pampas region · Odontesthes bonariensis · Reproduction · Salinity

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Introduction

A typical water body in the *Pampas* region of *Argentina* is a relatively large (100+ha) permanent

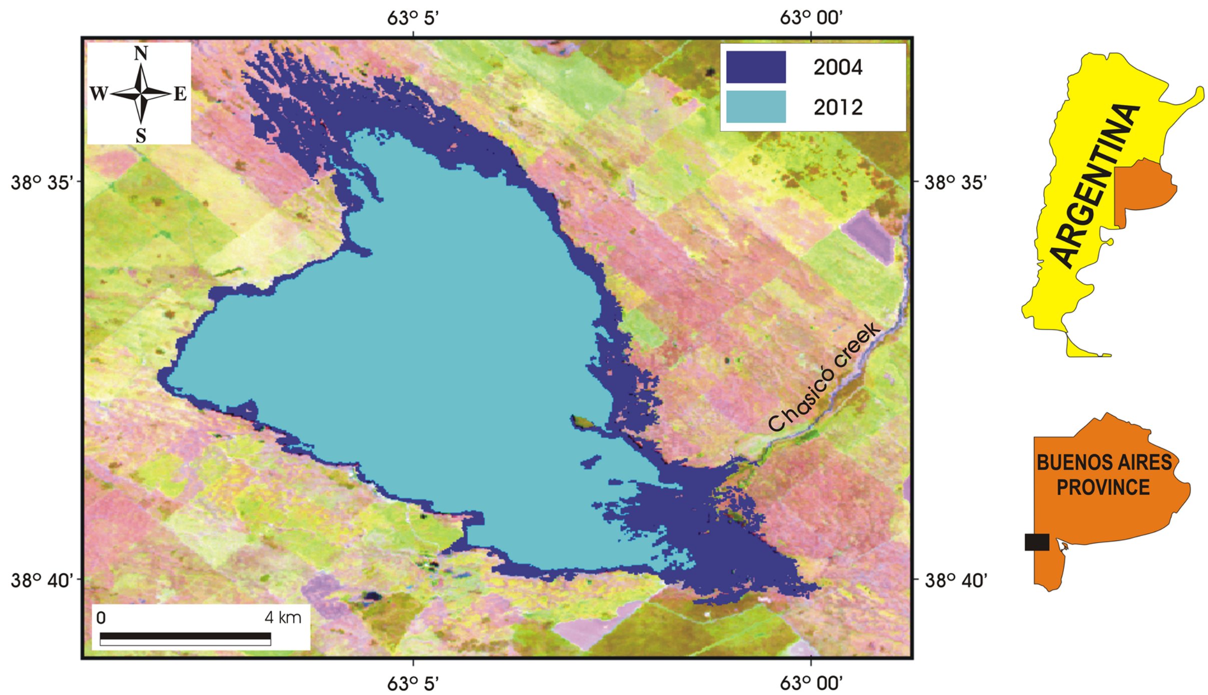

Fig. 1 Geographical location of Chasicó Lake in *Buenos Aires* Province, *Argentina*. Areal variation of the lake between 2004 and 2012

shallow lake without stable thermal stratification (Gómez et al., 2007; Torremorell et al., 2007), and can vary from eutrophic to hypertrophic presenting a highly variable hydrochemistry (Quirós et al., 2002). The mild climate of this region determines well-defined and contrasting seasons, with a wide thermal range. Moreover, a large seasonal rainfall with spatial and inter-annual variations define wet and dry periods that determine the volume of water in the lakes causing structural and functional changes in short periods of time (Coops et al., 2003). Due to their shallow depth, these lakes can be considered extremely sensitive to climatic variations (Jeppesen et al., 1998; Diovisalvi et al., 2010), being necessary to understand how the climate provokes hydrological changes that affect water bodies and associated biota (Adrian et al., 2009). In the last years, it was also demonstrated that the *Pampas* region is experiencing a large-scale change in climate, such as elevated temperatures, more abundant precipitations and increased frequency of floods and droughts events (Barros et al., 2006, 2008; Soria et al., 2008; Elisio et al., 2012).

Chasicó Lake is located in the south of the pampean region (38°37′S; 63°05′W) of the *Buenos Aires Province, Argentina* (Fig. 1). This endorheic lake has a geomorphologic tectonic-eolian origin with a maximum depth of 16 m and is topographically the lowest water body in South America (20 m below sea level). In 1963, Chasicó was a hyper-saline water body (100 g l^{-1}) with a surface area of around 3,100 ha and without fishes. For these reasons, it is not considered as a typical pampean water body (Volpedo & Fernández, 2013).

It is a closed system that receives water from the Chasicó creek and its tributaries (Fig. 1), and the recharge of the lake occurs by direct input from the precipitations, through the process of infiltration of groundwater and the contribution of surface runoff from a large watershed of 3,756 km^2 (Bonorino, 1991). The climate of the region in which the lake is located is temperate, with mean monthly temperatures between 14 and 20 °C and with maximum rainfalls in spring and autumn (Bohn et al., 2013). This saline lake experienced several flood episodes at the beginning of the 1980s, which were related to strong *El Niño* events (Lara, 2006), and underwent a rapid increase in surface area reaching 12,000 ha with a sharp decrease in the salinity with values around 20 g l^{-1} (Kopprio et al., 2010).

Although several species of Atheriniforms are commonly referred to as "pejerrey," this name is more often associated with *Odontesthes bonariensis* (Valenciennes, 1835), the largest member of the family Atherinopsidae. *O. bonariensis* is an inland water fish from the *Pampas* region and has a long history of domestic and international introductions, due to the high quality and market value of its flesh, as well as its attractiveness as a game fish (Somoza et al., 2008). Pejerrey is generally considered a freshwater species because of its natural habitat; however, preliminary evidence related to seed production in Japan suggested that stress situations and infectious diseases can be reduced by adding salt to the water (Murayama et al., 1977; Umezawa & Nomura, 1984; Strüssmann et al., 1996; Tsuzuki et al., 2001). The hypothesis of *O. bonariensis* having a marine origin could explain pejerrey tolerance of high salinity levels (Bamber & Henderson, 1988; Beheregaray & Levy, 2000). For example, *O. bonariensis* could live up to salinities close to 50 g l^{-1} in the saline lake of *Mar Chiquita* (Province of *Córdoba, Argentina*) but its fishery decreased drastically (Bucher & Etchegoin, 2006).

After the flood in 1980 of Chasicó Lake, it was suggested that pejerrey reached the lake through Chasicó creek (Fig. 1) finding appropriate salinities for hatching embryos and larval growth (Tsuzuki et al., 2000). In a few years, pejerrey fish biomass sharply increased with specimens reaching up to 50 cm of total length and up to 2 kg of total weight, with very high catch per unit effort (CPUE) values, being the maximum for *Buenos Aires* Province (Remes Lenicov et al., 1999).

In this context, the aim of this work was to analyze the changes of pejerrey biomass in relation with climate change and salinity in Chasicó Lake during the last 16 years.

Materials and methods

Chasicó Lake area variation was analyzed by satellite image processing using twelve LANDSAT 5 TM and 7 ETM+ satellite images scenes (226/087). They were selected according to data sampling (1997–2013) and availability of images lacking cloud cover. Digital image processing included geometric and atmospheric corrections. Chasicó Lake areas (km^2), through the studied period, were obtained by satellite image segmentation and vectorization. After that, they were introduced into Geographic Information System (GIS). Satellite images were provided by *Comisión Nacional de Actividades Espaciales* of *Argentina* (CONAE).

Annual rainfalls and mean temperatures (1999–2013) data belong to *Hilario Ascasubi* station (−39.37 S; −62.65 O) and were provided by *Instituto Nacional de Tecnología Agropecuaria* (INTA). Nonlinear regression was applied to assess the relationship between changes in water body area and salinity.

Fish from the lake were annually sampled from May 1997 to September 2013 using two net gangs, composed each by eight floating multifilament gill nets with a height of 1.3 m, differing in lengths (4.5; 7.4; 8.6; 13.4; 20.2; 30.2; 45.4; and 70.2 m), and mesh sizes (bar distance: 14, 19, 21, 25, 28, 32, 36, and 40 mm). Sampling was always carried out at night, and after each haul, all of the fish were measured (total length, TL, in mm) and weighed (total weight, W, in g). For all sampling dates, some animals were dissected in order to observe gonad condition macroscopically.

Water salinity was measured in each sampling date using an optical refractometer (Atago Co, Tokyo, Japan) to the nearest of 1 g l^{-1}.

Catch per unit of effort in number (CPUEn) and in total weight (CPUEw) was estimated by standardizing each haul to 12 h of fishing time for the entire set of gill nets. Changes in the CPUE values were analyzed throughout the sampling period. Linear and nonlinear regressions were performed to evaluate the existence of functional relationships between CPUE and salinity. In order to assess fish condition in relation with the standards for the species, the relative weight ($W_r = W/W_s \times 100$) was calculated following Colautti et al. (2006). $W =$ Total weight of the fish measured; $W_s =$ Standardized weight for a fish of the same size.

Results

A reduction of 30.4% of Chasicó Lake area was observed from 2004 to 2012 with values ranging from 68.1 to 47.4 km^2 (Fig. 1). In the case of water salinity, a sharp increase was recorded in the same period (18.9 to 41.5 g l^{-1}) showing a significant and strong nonlinear relationship with the lake area variation ($P < 0.05$; Fig. 2).

The decrease of the lake area appears to be more likely related to rainfall variations than with thermal

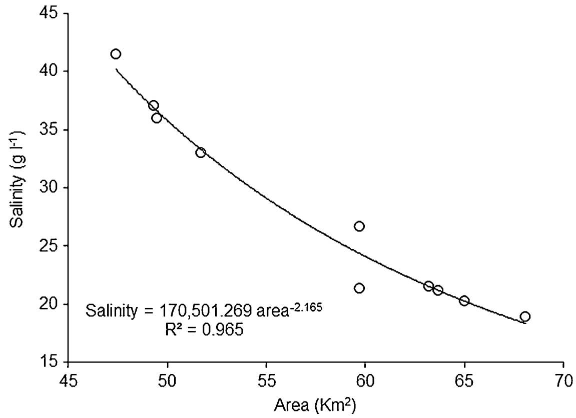

Fig. 2 Relationship observed between Chasicó Lake area (km^2) and water salinity ($g\ l^{-1}$) during the studied period

air temperatures which practically did not change during the period analyzed (Table 1).

The CPUE in kg (Fig. 3) and in number of fish caught (Fig. 4) showed a clear and significant decrease from 2004 to 2013 as function of salinity increments following a negative nonlinear model. The respective CPUE values ranged from 481.26 to 69.12 kg/net 12 h and from 1225.87 to 466 (individuals/net 12 h) (Table 2). The correlation between both CPUEs showed a direct relationship indicating that the biomass decreased due to a decline in the number of fish (Fig. 5), and also that the population structure did

Table 1 Annual rainfall and mean annual temperature in the region of Chasicó Lake

Year	Anual rainfall (mm)	Temperature °C (annual mean)
1999	467.6	14.93
2000	481.0	14.54
2001	634.8	15.03
2002	498.8	14.43
2003	373.9	15.14
2004	712.3	15.10
2005	307.2	13.35
2006	438.5	14.28
2007	316.3	14.36
2008	244.5	15.83
2009	297.9	15.83
2010	467.5	14.97
2011	505.2	15.38
2012	427.7	15.53
2013	315.9	14.45

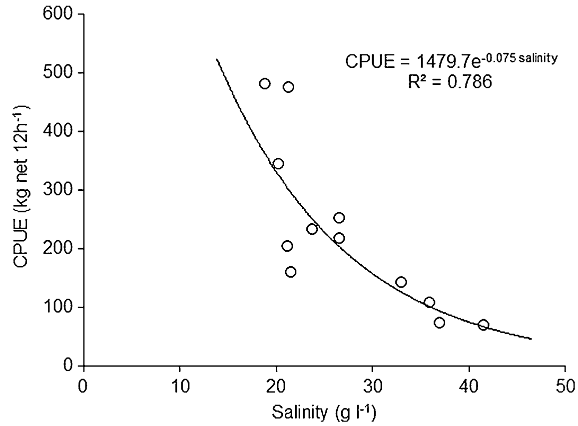

Fig. 3 Relationship observed between *O. bonariensis* catch per unit effort in kg CPUE (kg) and water salinity ($g\ l^{-1}$) during the studied period in Chasicó Lake

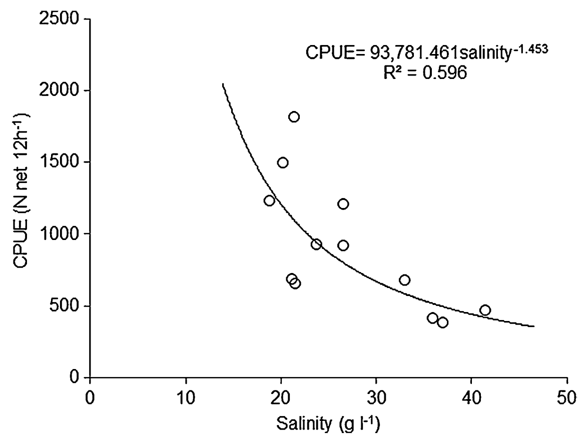

Fig. 4 Relationship observed between *O. bonariensis* catch per unit effort in number of fish CPUE (N) and water salinity ($g\ l^{-1}$) during the studied period in Chasicó Lake

not experiment significant changes. The exception is the data corresponding to 2004, when the catch was composed by larger and heavier fish coinciding with a maximum lake area, and a salinity value around 20 $g\ l^{-1}$ suggesting that these environmental conditions (at least for salinity) are the best for pejerrey development in Chasicó Lake. Relative weight values obtained showed that the pejerrey population in each sampling date was in good condition (Table 2; Fig. 6).

In all the catches, the dissected fish presented normal ovaries and testicles as shown in Figs. 7a, b, respectively. Furthermore, it was possible to obtain expressible milt easily in males caught in September 2013.

Table 2 Catch per unit effort at each sampling date expressed in kg and in number of fish (N) captured in 12 h by the entire gill net set

Date	CPUE (kg net 12 h^{-1})	CPUE (N net 12 h^{-1})	Wr	Wr (SD)
May 1997	216.95	917.10	97.67	7.46
June 1998	232.94	923.41	100.48	7.86
August 1999	474.31	1815.50	99.42	8.87
May 2001	251.89	1202.40	95.10	7.82
August 2004	481.26	1225.87	103.21	10.80
October 2006	343.40	1493.09	97.57	12.26
July 2007	203.62	686.66	99.15	11.71
October 2007	159.68	653.22	93.91	12.90
September 2011	142.82	677.84	96.22	9.23
June 2012	107.23	415.04	95.20	8.71
December 2012	72.85	383.10	96.59	9.82
September 2013	69.12	466.00	95.89	9.94

Wr relative fish weight, *SD* standard deviation

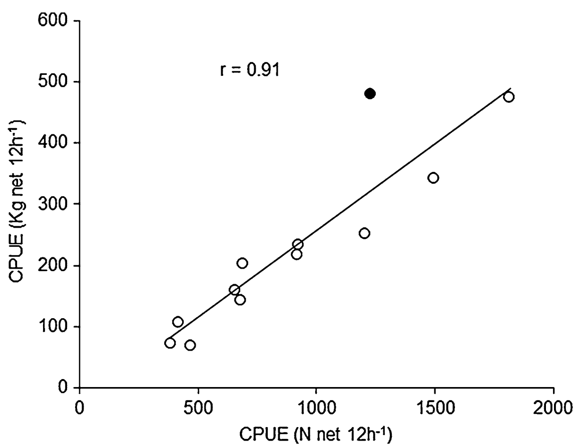

Fig. 5 Relationship between *O. bonariensis* CPUE (kg) and CPUE (N) during the studied period in in Chasicó Lake

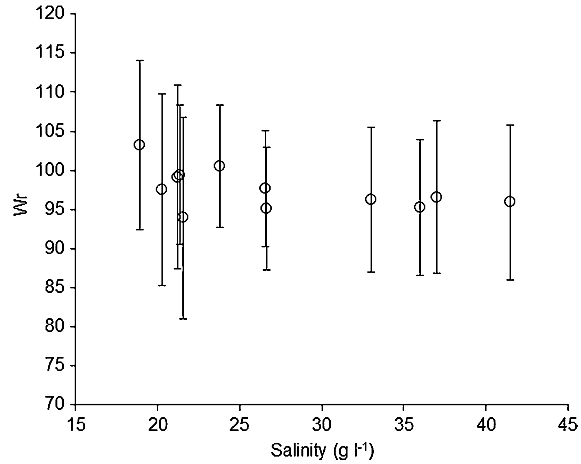

Fig. 6 Mean relative weight (Wr) for all the *O. bonariensis* capture for each sampling date in Chasicó Lake

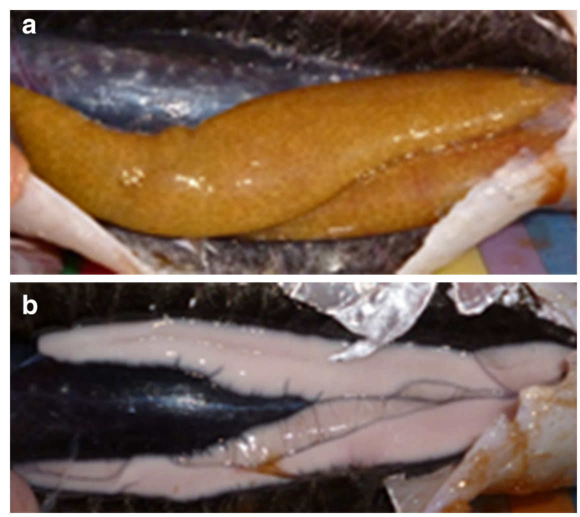

Fig. 7 External features of the ovary (**a**) and testis (**b**) from *O. bonariensis* captured on September of 2013 in Chasicó Lake

Discussion

As mentioned before, pampean lakes are very sensitive to climate changes (Torremorell et al., 2007; Diovisalvi et al., 2010), being dynamics ecosystems exposed to external and internal factors that force organisms to make necessary adjustments to adapt and avoid extinction (Padisák & Reynolds, 2003). In addition to changes that directly affect climate, rapid changes in land use in the Pampas region are important additional factors capable of influencing the biogeochemical cycles of aquatic systems, through alterations in sediment inputs and dissolved nutrients (Portela et al., 2009).

The clear relation between the decrease of Chasicó Lake area and the increase of water salinity from 2004 to date may be explained by changes in rainfall that influence the hydrological regime of Chasicó Creek. It was therefore suggested that the lake system recharge occurs primarily by rainfall. In wet periods, with heavy rains, water excesses are dumped into the lake through Chasicó Creek, meanwhile in dry periods, water supply is minimal. These processes directly affect the level of Chasicó Lake and the physicochemical characteristics of the water (Bonorino, 1991). The rainfall data showed that a wet period ended in 2004, when the maximum values of rainfall (712.3 mm), lake area (68.1 km^2), and minimum water salinity (18.9 g l^{-1}) were recorded. A dry period began with the lowest rainfall value in 2008 (244.5 mm) and a constant reduction of lake area and the concomitant increase in water salinity up to the present.

In general, it is estimated that some fish species can tolerate salinities up to 50 g l^{-1} to complete their reproductive cycle and may survive up to a salinity level of 60 g l^{-1}. This ability depends on proper acclimatization and decreases at low temperatures (Sardella et al., 2004, 2007). It has been observed that *O. bonariensis* can tolerate high salinities (50 g l^{-1}) but experiencing a drastic reduction in its population density (Bucher & Etchegoin, 2006). It has also been demonstrated that the survival of *O. bonariensis* embryos did not present any significant variation at salinities between 5 and 20 g l^{-1}, with higher hatching rate (Tsuzuki et al., 2000). More recently, similar experiments were carried out for the same species, but under higher salinity conditions (30 g l^{-1}) but in which all embryos died (Noguez Piedras et al., 2009). Besides, sperm motility suffered a drastic reduction at salinities greater than 15 g l^{-1} (Gárriz & Miranda, 2012). Furthermore, in other Atherinidae such as *Chirostoma estor*, embryos development was faster in freshwater and significantly reduced at higher salinities. This result may be related to inhibition of the activity of chorionase or mobility of the larvae at these conditions (Martínez-Palacios et al., 2004).

The drastic reduction of CPUE both in kg and fish numbers from 2004 to date seems to be directly related to the increase in water salinity. It is possible that at high salinity adult pejerrey may still develop in the lake, but with an impaired reproductive activity confined to less brackish water environments, particularly in the Chasicó creek. However, macroscopical observation of the gonads of some fish in every catch showed good conditions for both sexes. Even more in September of 2013 it was possible to obtain expressible milt from males. Thus, taking together all these observations into acount, it is possible to suggest that high salinity can directly affect pejerrey sperm motility, and the survival of eggs and small fish, promoting reductions in the fish reproductive success, which finally could cause the collapse of the fishery or even, the whole population. In support of this idea, it is important to mention that Tsuzuki et al. (2000) reported a reduction in pejerrey hatching rates, larvae survival and a significant mortality of 3–4 month juveniles kept at a salinity of 30 g l^{-1}.

In conclusion, since 2004 when a dry period began, the fishery quantity in Chasicó Lake showed a decreasing trend from the maximum registered in the pampean lakes to values almost seven times below. This correlated with a marked decrease in the lake area and the concomitant increase of water salinity from optimum values for pejerrey up to levels close to its tolerance limits.

As shown in this study, Chasicó Lake can be considered extremely sensitive to climatic variations. It is used to be a hyper-saline lake without fish, but after several floodings in the 1980's it turned into the best pejerrey fishery of Argentina for three decades. At present, the lake shows clear signals of reverting to its previous condition. As mentioned before, the pampean region is experiencing a large-scale climatic change such as elevated temperatures, more abundant precipitation and increased frequency of floods and droughts periods. Chasicó Lake case can be considered not only an example of such type of phenomenon, but also of how global change can affect natural resources and human economic activities.

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