Late Pleistocene Diatoms of the Lower Basin from the Quequén Salado River, Argentina

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Abstract. Diatom assemblages from a site called Cueva del Tigre were studied. It is located in the lower basin of the Quequén Salado River, Buenos Aires province (38° 50′ 2.2″ S–60° 32′ 7.1″ W). The results are part of a project that includes sedimentologic, stratigraphic and palaeontologic aspects with the aim of reconstructing the environmental history of south-eastern Buenos Aires during the Late Cenozoic. The studied sedimentary succession is 1.90 m thick and has a tabular geometry with alternating levels of coarse sandstone and clayey siltstones. Diatom analysis of the 17 samples corresponding to four levels (N1, N2, N3 and N4) was performed using conventional techniques of taxonomic identification and treatment. A total of 74 diatom taxa were recognized and grouped according to salt tolerance and life form. Cluster analysis allowed dividing the sedimentary sequence into two diatom zones. The deposit begins with a freshwater/shallow lakes with associated vegetation (N1: 7 samples) dominated by *Cyclotella meneghiniana* Kützing 1844 (plankton) accompanied by the epiphytes *Cocconeis placentula* Ehrenberg 1838 and *Cymbella cistula* (Ehrenberg) Kirchner 1878. The overlapping levels: N2 (4 samples), N3 (3 samples) dated on 29,360 ± 670 years ^{14}C BP (33,128 cal. years BP) and N4 (3 samples) represent brackish conditions in a shallow pond, where benthic epipelic diatoms dominate: *Caloneis westii* (W.Smith) Hendey 1964, *Campylodiscus clypeus* Ehrenberg 1840 and *Surirella striatula* Turpin 1828. Today, these taxa live in temperate waters with salinities of 2–10‰. The comparison between fossil and modern samples through NMDS analysis showed that modern diatom assemblages from the Quequén Salado River are distinctly dissimilar to the Pleistocene assemblages under study, but they strongly correlate with diatom assemblages from Buenos Aires shallow lakes in agreement with the autoecological interpretation.

Keywords: Diatoms · Palaeoenvironments · Pleistocene · Argentina South America

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1 Introduction

The Marine Isotopic Stage 3 (MIS 3; ca. 56,000–25,000 ^{14}C years BP) was an interstadial period during the Pleistocene with relatively warmer conditions than today, where climatic conditions fluctuated over millennia scales (Rabassa and Ponce 2013). The updating and reinterpretation of diatom studies that cover this period in South America showed the need and importance of selecting new sites for high-resolution interdisciplinary studies in the region (Espinosa 2016).

In the south-eastern part of the Buenos Aires province, Argentina, in a region set between the Tandilia and Ventania ranges, rivers like Quequén Salado, Indio Rico and Las Mostazas modelled banks that have been the subject of many geological studies (Schillizzi et al. 2006; Isla et al. 2014). The first studies in the Quequén Salado River correspond to Frenguelli (1928, 1945), who assigned these deposits to the *Lujanense* (upper Pleistocene) and *Platense* (Holocene) stages. More recently, Aramayo et al. (2005) recognized deposits of Late Pleistocene and Holocene ages (between 16,000 and 4800 years BP) in the south-east coast of Buenos Aires province between the localities of Pehuen-Có and Monte Hermoso, ca. 50 km south-west from the Quequén Salado inlet. Schillizzi et al. (2006) analysed profiles near Oriente (12 km upstream) assigning Late Pleistocene and Holocene ages. Isla et al. (2014) described and discussed the Neogene records outcropping at the Irene village. Beilinson et al. (2015) studied the stratigraphy and sedimentology of more than 10 km of sea cliffs of Buenos Aires province where the main macromammals sites are found and concluded that during accumulation of the Middle to Late Pleistocene succession, glacio-eustasy and/or climate controlled the balance between generation of accommodation space and sediment supply. A geological model for the Quequén Salado river valley was proposed by Beilinson et al. (2017), a case of downcutting and headward erosion that explains the spatial distribution of facies and fossil taxa: the younger in the distal sector of the Quequén Salado middle basin and the older in the lower basin.

Several biological and sedimentologic proxy records preserved in Late Quaternary sequences constitute a valuable source of information for understanding the palaeoenvironmental changes that characterized the aquatic environments. Diatoms have been used as proxy indicators to reconstruct Late Quaternary environmental and climatic changes in every continent, being in continental aquatic ecosystems much more common than in marine or coastal studies (Mackay et al. 2003). Even so, the number of diatom-based Quaternary climatic reconstructions from marine and coastal environments is increasing in recent years (Romero 2010; Cermeño et al. 2013).

Diatoms have been widely employed to reconstruct changes in salinity, depth and trophic status related to Holocene sea level changes and shoreline position in Southern South America (e.g. Espinosa et al. 2003, 2012; Garcia Rodriguez et al. 2004; Fayó and Espinosa 2014; Dos Santos et al. 2016). However, despite the high potential of diatom records for environmental reconstructions, a limited number of detailed studies have been conducted for Pleistocene age deposits in South America (Espinosa 2016). Furthermore, few studies have focused on the interaction between climate variability and aquatic ecology (Mackay et al. 2012). This highlights the need for increased knowledge of environmental responses to changes in climate in aquatic ecosystems in the southern hemisphere that can be used as analogues for palaeoclimatic interpretations. The lack of long-term, continuous or near-continuous climate records, particularly those spanning through the Late Pleistocene, limits detailed understanding of the aquatic communities' responses to climatic changes.

2 Methods

2.1 Regional Setting

The Quequén Salado River (Fig. 1) is located in the south-eastern Pampean Region, reaching to the Atlantic Ocean as a mesotidal estuary (2–3 m tidal range) and flowing across the region known as the *Humid Pampas*. It has a mean discharge of 10.76 m^3/seg (max: 28.8 m^3/seg, min: 4.6 m^3/seg, Marini and Piccolo 2000). The zone has a temperate climate (annual mean temperature of 14 °C) and an annual mean rainfall of 800 mm (Marini and Piccolo 2004). The river runs along the hilly plain (also called "Undulated Pampa") between the Tandilia and Ventania ranges. It is characterized by the presence of riffles every 1 or 2 km in the middle and lower sections, while its channel can reach 15–20 m wide. The lower valley is oriented NNW–SSE and is flanked by cliffs of 8–15 m high. In the last 5 km, the river runs across a sandy barrier composed of vegetated dunes (Marini and Piccolo 2000). A site named Cueva del Tigre was studied. It is located 12 km from the outlet (38° 50′ 2.2″ S–60° 32′ 7.1″ W). The outcrop consists of two stratigraphic units (Fig. 2). The lower one, 1.90 m thick and tabular geometry, comprises sandstones, silty sandstones and mudstones. The upper one is presented as a carbonate lenticular body *tufa* with a maximum high of 2.60 m

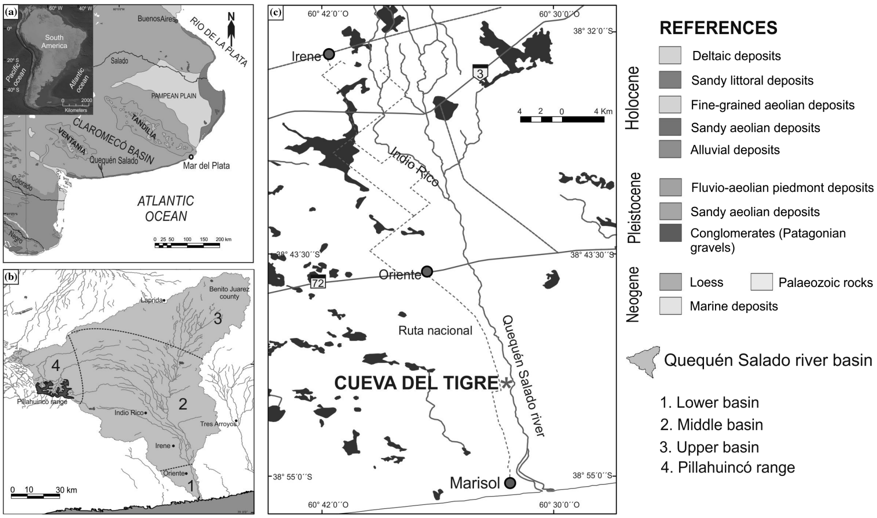

Fig. 1. Location map. **a** Geological map of the Buenos Aires province. **b** Quequén Salado River basin showing the upper, middle and lower reaches. **c** Cueva del Tigre sampling site. Modified from Beilinson et al. (2017)

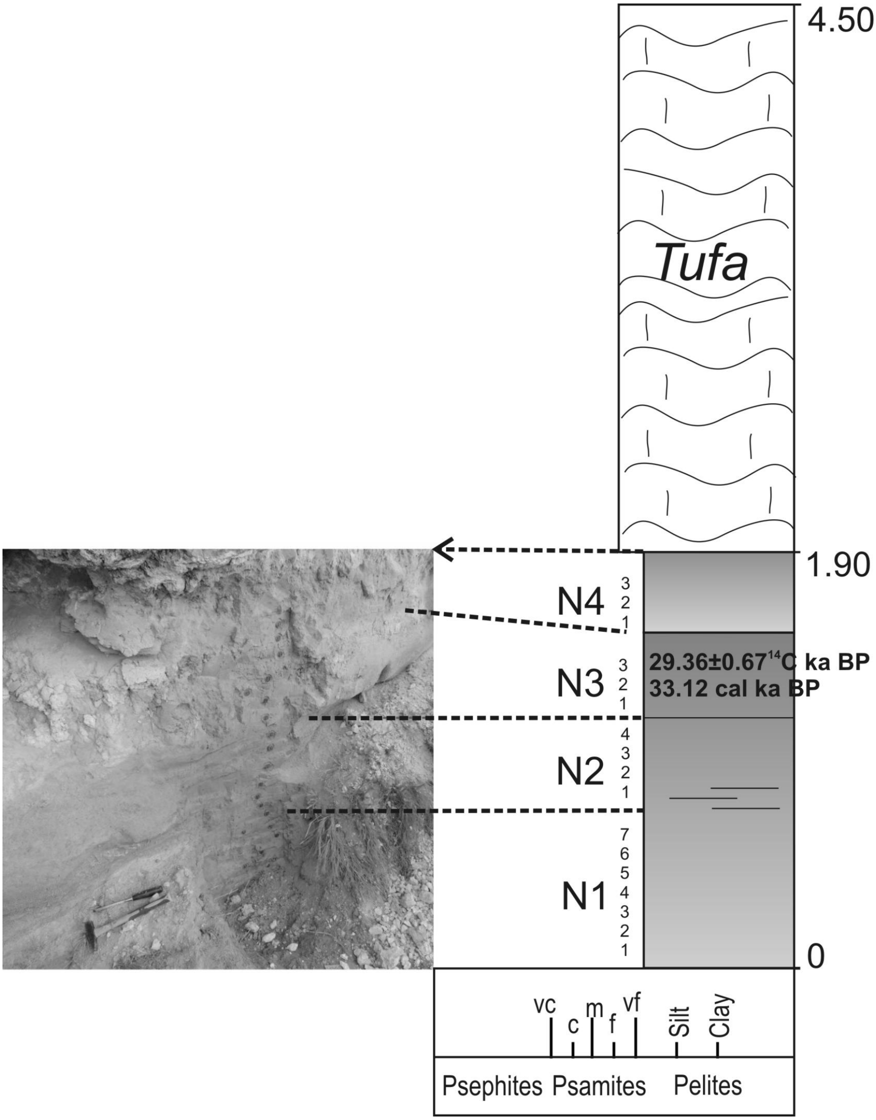

Fig. 2. Sedimentologic profile of the study site

and lateral extension of tens of metres. Its base is concave and irregular, showing an interdigitation with the non-calcareous deposits that underlie it.

Two different profiles were studied at the Cueva del Tigre site. Even though they are about 100 m from each other, correlation between them is easy to make. Taking into account the position of the levels within the Quequén Salado valley, it is observed that the tufa and diatom succession correspond to the lower terrace, and that the upstream profiles emerge at higher elevations, on the upper terrace of Quequén Salado River. Then, based on this geomorphological interpretation, the upstream profiles would be older than the levels with diatoms. Since the contact relationships between both units cannot be observed, it is difficult to discern if it is transitional or not, but there is definitely no faulting between both profiles.

Absolute chronological data for the Quequén Salado River basin is scarce. Mari et al. (2015) dated *Heleobia* sp. shells from sandy silt sediments corresponding to level 3 (N3) of the studied profile giving a radiocarbon age of 29,360 ± 670 years BP/33,128 years cal. BP (LP 3031).

2.2 Diatom Analysis

Diatoms were extracted from 17 sediment samples corresponding to four levels: N1, N2, N3 and N4 (Fig. 2). 5 g of dry sediment was oxidized with hydrogen peroxide (30%) and hydrochloric acid (10%) to remove organic matter and carbonates, washed four or five times with distilled water and diluted to a total volume of 100 ml. Diatom residues were mounted onto microscope slides using Naphrax®. On each slide at least 300 diatom valves were counted in random transects. All counts were performed under oil immersion (1000×), using a Zeiss light microscope equipped with phase contrast optics. The identification of species was based on the local and standard diatom taxonomic literature. Nomenclature and taxonomic authorities follow AlgaeBase (Guiry and Guiry 2018). Photographs of the diatom species were archived. The relative abundance of each species is presented as a proportion of the total frustule counts, and species representing less than 5% of the relative abundance were removed to increase the significance of the data. Ecological groups proposed by De Wolf (1982), Denys (1991/1992) and Vos and De Wolf (1988, 1993) were used to classify diatom taxa according to their salinity and habitat preferences. Diatom diagram and cluster analyses were performed using the TILIA and TILIAGRAPH software (Grimm 1991). The purpose of cluster analysis was to define diatom zones based on a stratigraphic constrained classification (minimum variance, Euclidean distance).

2.3 Comparison with the Modern Data set

Fossil assemblages are compared with a modern diatom data set for the region (Hassan et al. 2007, 2011) by means of *non-metric multidimensional scaling (NMDS)*. NMDS is a robust ordination technique for community analysis (Minchin 1987) and was used to create similarity matrixes. A numerical measure of the closeness between the similarities in the lower dimensional space is called stress. Stress values range from 0 to 1, with 0 indicating perfect fit and 1 indicating worst possible fit. NMDS based on Bray–Curtis similarity measure was performed with the program

PAST versus 1.81, (Hammer et al. 2008).

3 Results

3.1 Diatoms

Seventy-four diatom taxa were identified. Twenty-two taxa constituted >5% of the total assemblage in at least one sample (Fig. 3). Some photographs of the dominant diatom species are presented in Fig. 4. The observed pattern of taxon occurrence and a cluster analysis on this subset permitted to define two major diatom assemblage zones, described as follows:

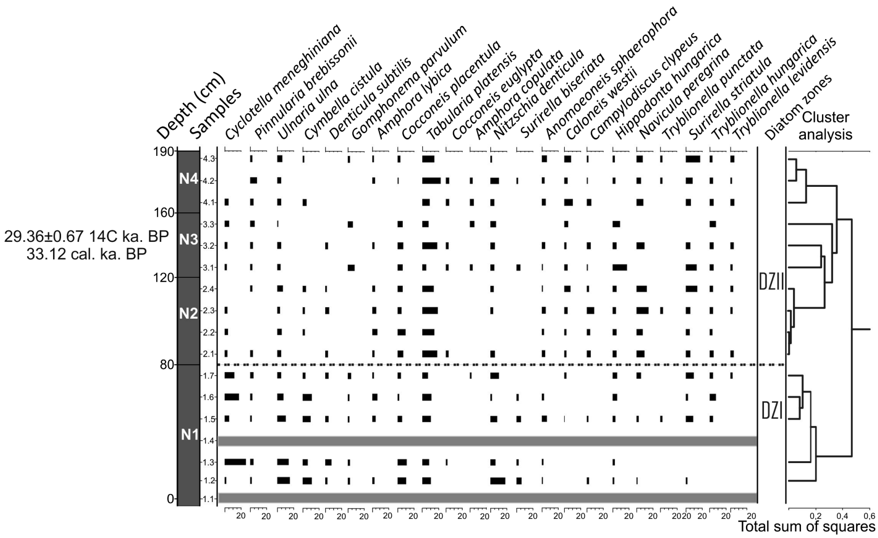

Fig. 3. Diatom diagram of Cueva del Tigre sequence. Grey shaded shows the barren levels (1.1 and 1.4)

Zone I (DZI; 0–80 cm) is characterized by the abundance of *C. meneghiniana* Kützing 1844 (plankton) accompanied by the epiphytes *Cocconeis placentula* Ehrenberg 1838, *Ulnaria ulna* (Nitzsch) Compère 2001, *Tabularia platensis* (Frenguelli) Sar and Sala 2009 and *Cymbella cistula* (Ehrenberg) O. Kirchner 1878. This assemblage is related to brackish/freshwater lagoons. Low, but sustained, abundances of benthic diatom species *Nitzschia denticula* Grunow 1880 and *Hippodonta hungarica* (Grunow) Lange-Bertalot, Metzeltin and Witkowski 1996 occur in this zone.

Zone II (DZII; 80–190 cm) is characterized by highly abundant, *T. platensis* (Frenguelli) Sar and Sala 2009. The increase of this brackish and epiphyte taxa defines the boundary between zones I and II in the same way as the appearance of the brackish, benthic and eutrophic taxa *Caloneis westii* (Smith) Hendey 1964, *Campylodiscus clypeus* Ehrenberg 1840, *Navicula peregrina* (Ehrenberg) Kützing 1844 and *Surirella striatula* Turpin 1828. Today, all of them live commonly in periodic water bodies or wet subaerial environments.

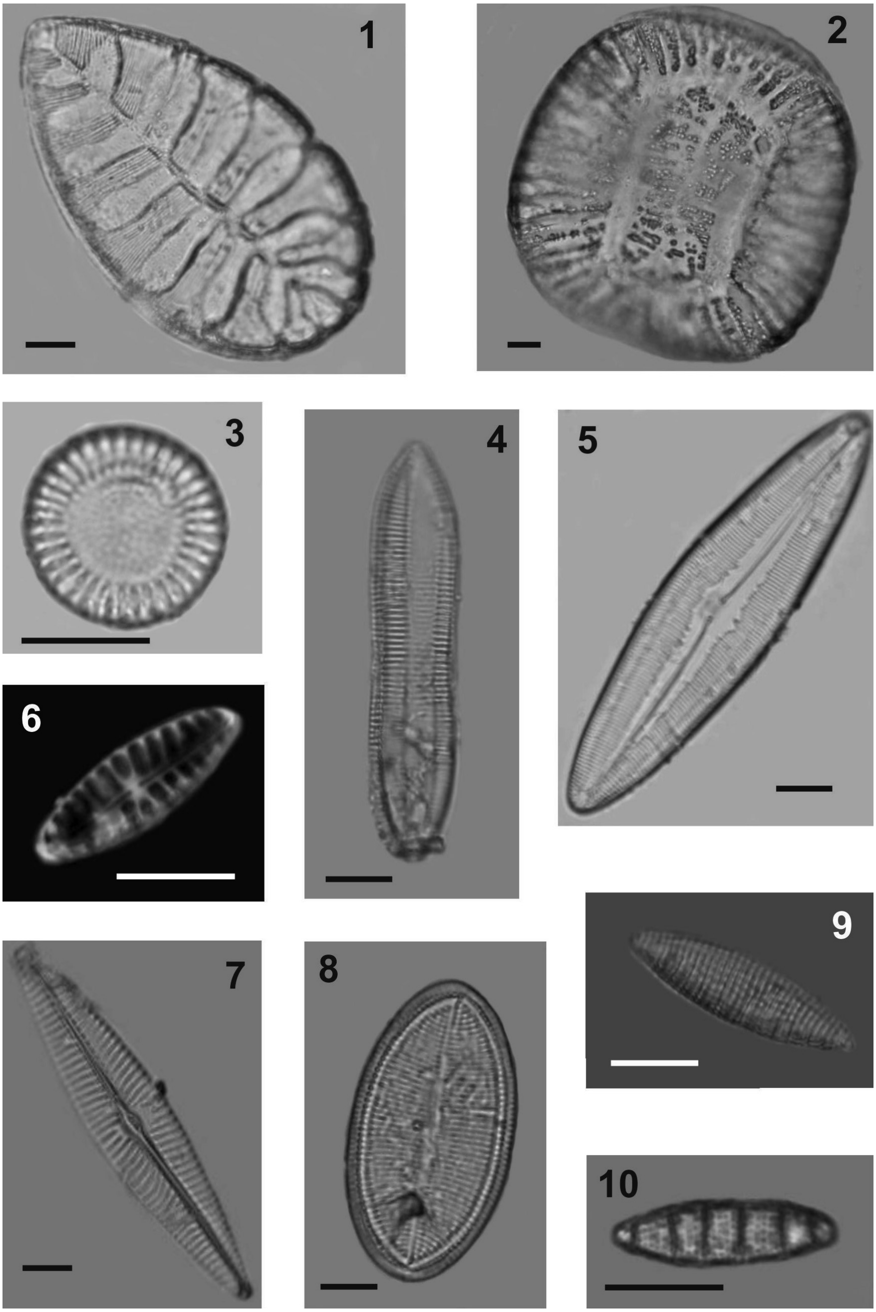

Fig. 4. Dominant diatom taxa from Cueva del Tigre sediment profile. Light microscope. **1** *Surirella striatula*; **2** *Campylodiscus clypeus*; **3** *Cyclotella meneghiniana*; **4** *Tryblionella hungarica*; **5** *Caloneis westii*; **6** *Hippodonta hungarica*; **7** *Navicula peregrina*; **8** *Cocconeis placentula*; **9** *Nitzschia denticula*; **10** *Denticula subtilis*. Scale bars = 10 µm

3.2 Non-Metric Multidimensional Scaling Analysis (NMDS)

NMDS arranged diatom samples in a specified dimensional space according to the rank order of their ecological similarities. The plot reveal differences in the structure of the assemblages. Samples showed a distributional pattern clearly related to their environment type. At first, NMDS analysis was performed between fossil samples from Cueva del Tigre profile and modern samples of the Quequén Salado River (Fig. 5a; Hassan et al. 2007) obtaining a stress value of 0.09. Figure 5b shows fossil samples (*N*) in the positive quadrant and modern samples (QS) on the negative quadrant. Quequén Salado River assemblages are distinctly dissimilar to the fossil assemblages from the Pleistocene succession under study.

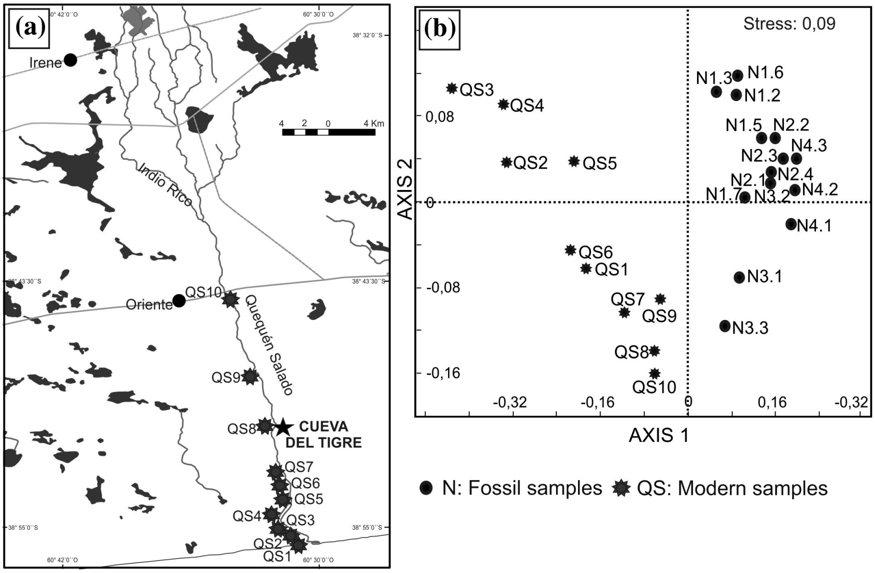

Fig. 5. **a** Modern sample sites along Quequén Salado River (Hassan et al. 2007). **b** NMDS analysis between Cueva del Tigre fossil samples (N) and modern samples (QS)

In order to find modern analogues that allow us to complete the characterization of the Pleistocene environments recorded at *Cueva del Tigre*, a second NMDS analysis was carried out between the fossil samples and the modern ones belonging to shallow lakes of the central zone of Argentina (Buenos Aires, La Pampa and Mendoza). Stress value obtained was 0.25. A total of 34 shallow ponds (most <2 m in depth) distributed across Central Argentina (Fig. 6a) were sampled by Hassan et al (2011). Most of them are thermally homogeneous and saturated with dissolved oxygen. Figure 6b shows that fossil assemblages belonging to Cueva del Tigre profile (*N*) remained together and close to modern samples of some shallow lakes from the Pampa Ecoregion (1, 5, 6 and 11: Buenos Aires). These samples were characterized by high percentages of organic matter (up to 85%), and pH ranges between 8.25 and 9.8 and annual precipitation of 800–1,000 mm (Hassan et al. 2011).

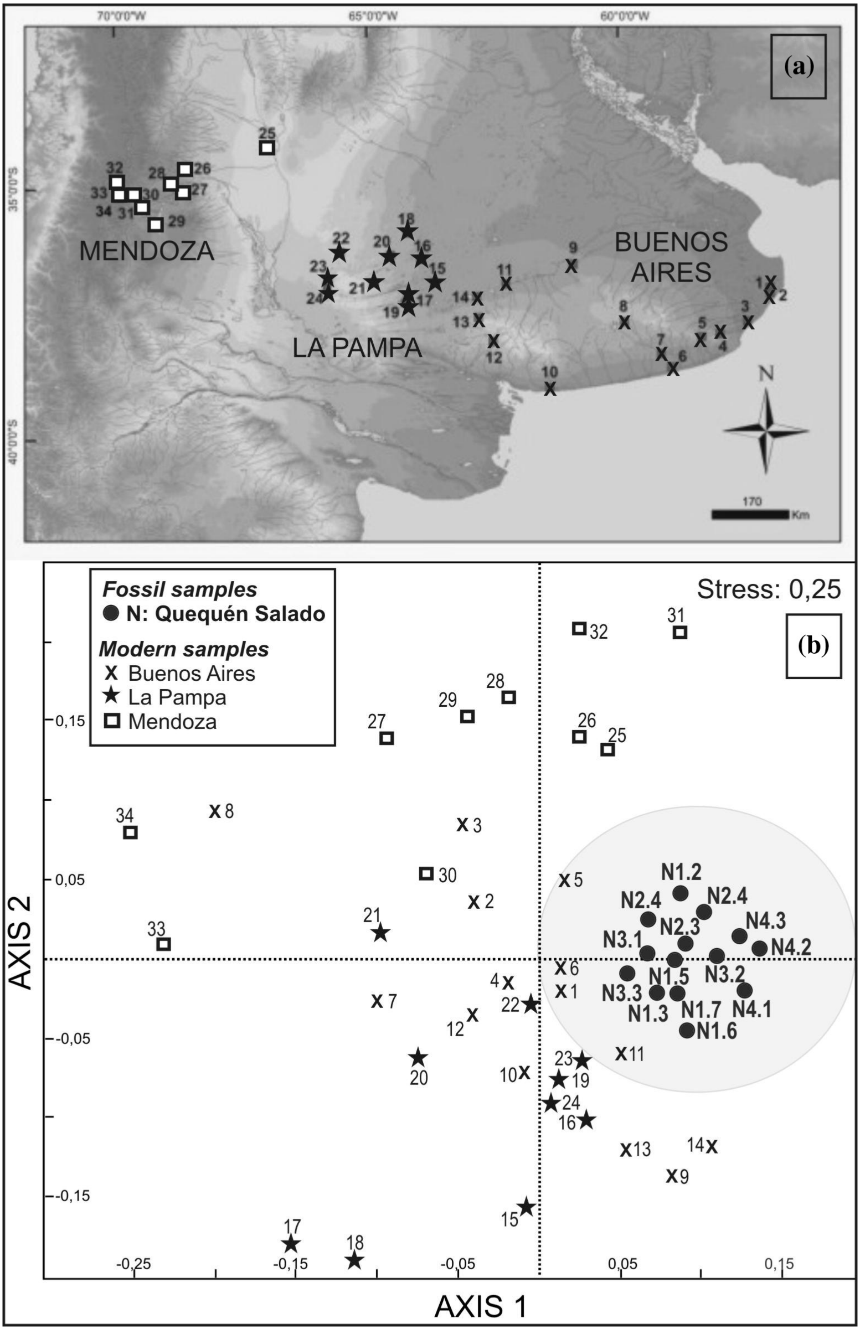

Fig. 6. **a** Modern sample sites from Central Argentina (Hassan et al. 2011). **b** NMDS analysis of modern and fossil samples (N)

4 Discussion and Final Remarks

The Quequén Salado River basin (Pampa region) was studied by means of stratigraphic, sedimentologic and palaeomagnetic approaches as well as palaeontologic analysis of vertebrate remains by Beilinson et al. (2017); Grill and Fernández (2016) analysed the palynomorphs content (spores, pollen and organic-walled marine microplankton) of two localities in the lower basin of the Quequén Salado River (Estancia Thomas Profile and QS1 Archaeological Site) to provide a palaeoenvironmental and palaeoclimatic reconstruction from the Late Pleistocene to the present. They inferred aeolian environments of extreme arid conditions during the late Pleistocene (ca. 16,000 years BP) shown by bad pollen preservation and scarce populations of ostracods and diatoms.

The diatom analysis from Cueva del Tigre succession provides new data about the palaeoenvironments of the lower basin of the Quequén Salado River ca. 30,000 years BP ago, during the Marine Isotopic Stage 3 (MIS 3). This sequence represents the second MIS 3 diatom record for Buenos Aires province: the other is a sedimentary succession located on the middle basin of the Luján River (Blasi et al. 2010). Although some Pleistocene records may have poor microfossil preservation (Grill and Fernández 2016), Cueva del Tigre profile contains well-preserved diatom frustules, but the abundance is not comparable with that found in other Holocene deposits from Buenos Aires (e.g. Espinosa et al. 2012). Both MIS 3 records from Buenos Aires province (Quequén Salado and Luján rivers) present important similarities on diatom content.

According to the cluster analysis of the diatom assemblages, it was possible to identify two zones in the evolution of the water body. The first zone (DZI) clustered seven samples of N1 (level 1). Diatom assemblages are dominated by the planktonic centric diatom *Cyclotella meneghiniana*. This species is common in swamps, shallow lakes and hot springs (Owen et al. 2004) and reflects a slightly deep freshwater/brackish environment. *C. meneghiniana* can live in different habitats, from freshwater to brackish (Tuchman et al. 1984; Hakansson and Chepurnov 1999 and is widely distributed in the modern diatom flora of the Pampean shallow lakes, dominating under alkaline (pH 8–10.5) and eutrophic conditions (Hassan et al. 2011). The accompanying flora is composed of the epiphytes *C. placentula*, *Ulnaria ulna* and *C. cistula.* All of them are freshwater taxa, but *C. placentula* is very tolerant to salinity and temperature changes, 0.2–30.4% and 4.7–33.5 °C, respectively (Trobajo Pujadas 2007), and is common in slow-flowing streams (Haworth 1976; Gasse 1986) and shallow lakes of Central Argentina (Hassan et al. 2011).

The diatom assemblage that characterizes DZII is composed by brackish taxa: the epiphyte *T. platensis* and the benthic and eutrophic *C. westii*, *C. clypeus, N. peregrina* and *S. striatula.* Today, all of them live commonly in periodic water bodies or wet subaerial environments.

In the Luján River basin, the lapse between 44,000 and 37,700 years B.P. is characterized by lacustrine deposits with abundant diatoms, where the planktonic and brackish *C. meneghiniana* dominate accompanied by the epiphytes *Epithemia adnata* and *C. placentula* (Blasi et al. 2010). This assemblage is very similar to DZI (the bearing level has not radiocarbon dates yet), and it is possible that a correlation exists between both levels with diatoms.

The relative abundance of the most dominant species within both assemblages (DZI and DZII) varies and might indicate differences in climatic conditions, mainly changes in water availability.

According to NMDS analysis, modern assemblages from the Quequén Salado River are distinctly dissimilar to the fossil assemblages from the Pleistocene succession of Cueva del Tigre. In this sense, most of the recorded diatom taxa in the fossil sediments are absent in the modern surface sediments of the river. Then, the environment at the time of the MIS 3 was different from the modern, with diatom assemblages that suggest fluctuations from a deep freshwater/brackish environment to shallow brackish water dominated by saline diatom taxa. Diatom analysis indicated that the interval would have had relatively humid and mild conditions in agreement with the regional patterns (Rabassa and Ponce 2013).

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