Modern diatom assemblages in surface sediments from estuarine systems in the southeastern Buenos Aires Province, Argentina

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Abstract

Paleoecological reconstructions of Holocene sea-level changes in Argentinean coastal regions were based mainly on ecological data gathered from other regions, as there was a lack of information on modern estuarine diatom distributions. The aim of the present work was to assess the spatial variation of diatom assemblages in two representative estuaries of Argentina in order to gather ecological information for paleoecological reconstructions in the region. The two selected estuaries have different geomorphologic features and salinity regimes: Mar Chiquita Lagoon is shallow, which prevents the development of a stable salinity gradient as it occurs in the Quequén Grande River. Surface sediment samples were taken from selected stations representative of the environmental gradient from the inlet to the inner reaches of both estuaries. Cluster analysis defined three diatom zones at Mar Chiquita: marine/brackish assemblages dominate the inlet (zone I), where salinity, tidal range and current speed are higher. The brackish/freshwater tychoplankton *Staurosira construens* var. *venter* and *Staurosirella pinnata* dominate the inner lagoon (zone II), where environmental conditions are very variable and concentrations of suspended sediments are higher. Brackish/freshwater euryhaline diatoms dominate the headwaters (zone III). On the other hand, the Quequén Grande River was divided into three diatom zones: coastal taxa are distributed at the inlet (zone I), while the middle estuary (zone II) is dominated by brackish/freshwater euryhaline taxa. At the upper estuary region (zone III), freshwater diatoms dominate, and the halophobous *Nitzschia denticula* increased in abundance values. Diatom distributions were most closely related to the salinity gradient at Quequén Grande River than at Mar Chiquita Lagoon. Fossil data of a sequence from Mar Chiquita Lagoon (Las Gallinas Creek) were compared to the modern data set in order to search for analogies between fossil and modern diatom assemblages. DCA results showed that fossil diatom assemblages have modern counterparts. Most diatom assemblages of Las Gallinas Creek fall within Mar Chiquita zone III, representing a shallow brackish/freshwater environment, with low salinity fluctuations (∼1–9‰) and no tidal influence. Therefore, our modern diatom data provide useful analogs to interpret paleoenvironments in the region.

Introduction

Diatoms (Bacillariophyceae) are an important and often dominant component of benthic microalgal assemblages in estuarine and shallow coastal environments (Sullivan 1999). As diatoms respond quickly to environmental changes and reflect both physical and chemical characteristics of the

overlying water masses, they are particularly useful for paleoecological reconstructions (Cooper 1999; Jiang et al. 2001). Therefore, knowledge on the distribution, composition and diversity of present day diatom communities is a key issue to interpret fossil sequences.

Several studies using diatoms to reconstruct Holocene coastal changes have been published in Southern South America (Espinosa 1988, 1994, 1998, 2001; Espinosa et al. 2003; García-Rodríguez and Witkowski 2003; García-Rodríguez et al. 2004; Hassan et al. 2004). As there is no information about the ecology and distribution of benthic diatoms in estuaries of the Argentinean coast, except for a few taxonomic works where some references on ecological preferences are mentioned (Frenguelli 1935, 1938, 1939, 1941, 1945), paleoecological reconstructions were based on ecological data gathered from other regions (De Wolf 1982; Vos and De Wolf 1988; Denys 1991/1992).

This paper assessed the composition and spatial distribution of modern diatom assemblages in two estuaries from the Northeastern coast of Argentina. The aim of the present work is to gather quantitative ecological information that could be useful for diatom-based paleoecological reconstructions in the region. In order to assess the applicability of modern diatom data in the interpretation of fossil sequences, modern and fossil samples are compared by means of Detrended Correspondence Analysis (DCA).

Study area

Two estuaries in Buenos Aires province (northeastern coast of Argentina) were analyzed: Mar Chiquita Lagoon (37°40′ S; 57°20′ W) and Quequén Grande River (38°30′ S; 58°45′ W). Both environments were selected because of their different geomorphologic features and salinity regimes, being representative of the maximum estuarine variability along the Argentinean microtidal coast (0.6–1 m tidal range, Figure 1).

Mar Chiquita is a brackish water body with a surface area of 46 km^2 and a mean depth of 0.6 m (Isla and Gaido 2001). From a hydrological point of view, the lagoon can be divided into an innermost shallow zone, where the tidal effect is insignificant, and an estuarine zone subject to tidal

action (Isla et al. 1996; Reta et al. 2001; De Francesco and Isla 2003). Seasonal salinity changes are induced by rain and wind (Reta et al. 2001) that control water level changes within the lagoon, except for the estuarine zone (Fasano et al. 1982; Schwindt et al. 2004). Mar Chiquita sediments are mainly composed of sand and silt with high proportions of mollusc shells, except for Las Gallinas Creek delta. The shallowness of the main body of the lagoon induces sediment reworking (Fasano et al. 1982; see Figure 1). The geomorphology of the lagoon has changed since the building of the CELPA (Centro Experimental de Lanzamiento de Proyectiles Autopropulsados) bridge in 1967, located at the end of the estuarine zone (Figure 1) that induced sand-bank formation (Isla and Gaido 2001). The shallow depth and particular dynamics of the coastal lagoon prevent the development of a stable salinity gradient as it occurs in the Quequén Grande River. Nutrients and suspended sediment concentration are higher in the inner areas of the coastal lagoon than in the tidal channel, whereas salinity, current speed and depth show the opposite pattern (Schwindt et al. 2004).

The Quequén Grande River is carved into an undulated plain, related to the capture of several small basins upstream (Cortizo and Isla 2001). Mean depth is 2–3 m and width is 150–200 m. Most of the river runs on Pleistocene, partly cemented loess sediments. Due to the sediment characteristics, large portions of the river flows within a canyon whose walls may reach up to 12 m high (Perillo et al. 2005). Salinity is higher in winter and decreases significantly along the estuarine gradient (De Francesco and Isla 2003). The highest salinities (20–25‰) are found in the first 2–3 km of the inlet, but approximately 15 km upstream, salinity decreases to 1‰ (De Francesco and Isla 2003; Perillo et al. 2005).

Material and methods

Field and laboratory methods

Three replicates were taken from selected stations representative of the salinity gradient from the inlet to the inner reaches of both estuaries (10 sites at Mar Chiquita Lagoon and 12 sites at Quequén Grande River, Figure 1). Mar Chiquita site 9 is
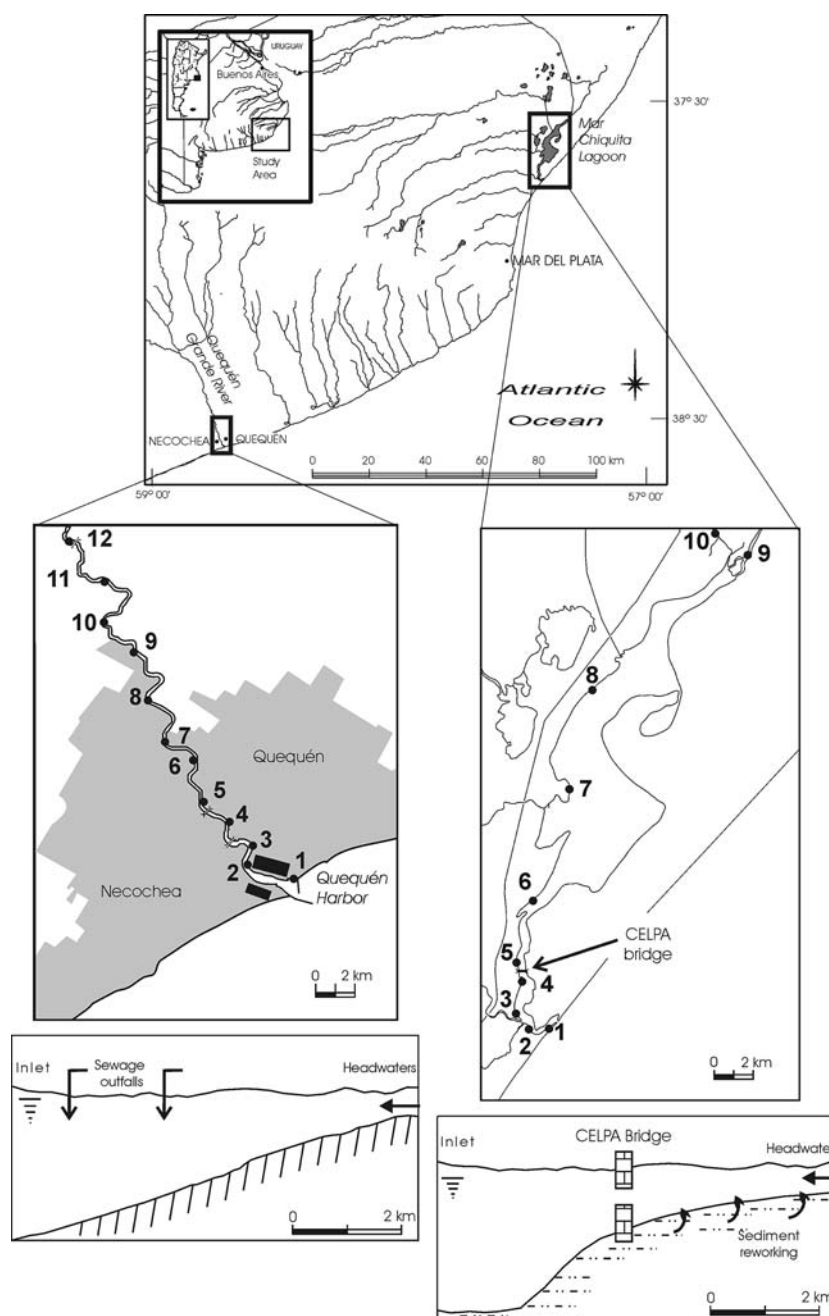
Figure 1. Location map of sampling sites and diagram of the transects in Quequén Grande River and Mar Chiquita Lagoon.

located at the Las Gallinas Creek, a shallow stream that flows into the headwaters of the Mar Chiquita Lagoon. Site 10 is a brackish, artificial channel located near the mouth of the Las Gallinas Creek. In each sampling station, salinity was measured once every three months from January through October 2004 with a Horiba-U10 water quality analyzer. Three replicate measurements were taken in each survey. Sampling stations, distances from the estuary mouth, sediment type, diatom concentration and mean salinities are given in Table 1.

Table 1. Sampling station, distance from estuary mouth, sediment type, diatom concentration and measured salinity (Mean ± SD) in the Mar Chiquita Lagoon (MCH) and Quequén Grande River (QG).

Sampling station	Distance from mouth (km)	Sediment type	Mean diatom concentration (valves gr-1 sediment)	Measured salinity (‰)
MCH 1	1.5	Silty sand with shells	913,703	15.6 ± 11.66
MCH 2	1.8	Sandy silt with shells	667,412	11.1 ± 11
MCH 3	2.3	Silt with shells	624,787	25.2 ± 5.81
MCH 4	3.3	Silt with shells	487,332	19.8 ± 10.25
MCH 5	3.5	Silt	346,245	21.4 ± 9.84
MCH 6	5.2	Coarse sand (shells)	949,086	17.3 ± 10.22
MCH 7	12	Sand with silt and shells	1,848,250	2 ± 1.58
MCH 8	17.4	Coarse sand (shells)	481,412	0.97 ± 0.22
MCH 9	27.8	Very fine sand	985,303	1.05 ± 0.45
MCH 10	30	Silt with shells	1,377,124	8.83 ± 4.39
QG 1	0	Very fine sand	8602	21.43 ± 4.62
QG 2	1.7	Silty sand	1,196,483	11.29 ± 1.01
QG 3	2.4	Silt	1,625,470	9.79 ± 1.21
QG 4	3.5	Silt	931,917	8.39 ± 1.13
QG 5	4.5	Silt	859,170	5.86 ± 1.59
QG 6	5.7	Silt	997,000	4.7 ± 1.17
QG 7	6.4	Silt	761,910	3.78 ± 1.12
QG 8	9	Sandy silt	1056,173	2.15 ± 0.95
QG 9	10.5	Sandy silt	817,883	0.7 ± 0.06
QG 10	12	Sandy silt with shells	317,883	0.74 ± 0.05
QG 11	15	Sandy silt	459,158	0.67 ± 0.06
QG 12	18	Silt	895,483	0.66 ± 0.06

Samples were collected from each sampling station by gaining access to the foreshore at low tide. Samples were taken with a 20 mm diameter × 100 mm length plastic tube. Most areas of the foreshore support a surface diatom flora and, since these diatoms are not part of the death assemblage, it is important that they are not included with the sediment sample (Juggins 1992). To avoid contamination with living individuals, the top 10 mm were removed from the core, and a 10 mm subsample was taken from the 'cleaned' surface. Samples were preserved with 4% formalin. Five grams of dry sediment were oxidised with hydrogen peroxide (10%) and hydrochloric acid (10%), washed 3 or 4 times with distilled water, and diluted to a total volume of 50 ml. After complete homogenization, a subsample of 20 μl was transferred to a coverslip and air-dried. Permanent drop slides were mounted with Canada Balsam and Naphrax®. On each slide at least 200 diatom valves were counted in random transects at 1000× magnification. Total diatom abundance (valves/gram of sediment dry) in each sample was calculated according to the aliquot method (Battarbee 1986).

Diatom species were identified according to Hustedt (1930, 1937–1938, 1959–1966), Germain (1981), Archibald (1983), Krammer and Lange-Bertalot (1986, 1988), Hartley (1996), Rumrich et al. (2000) and Lange-Bertalot (2001). Diatom species were characterized according to their salinity tolerances and life form following the ecological classifications of De Wolf (1982), Denys (1991/1992) and Vos and De Wolf (1988, 1993).

Data analysis

Constrained incremental sum of squares cluster analysis was performed on diatom percentages to define diatom zones in both estuaries using the computer program TILIA CONISS (Grimm 1991). An R-Mode Factor Analysis (extraction method: principal components, minimun eigenvalue: 0.01) followed by varimax normalized rotation was performed on the surface samples in order to define representative diatom assemblages

with the computer program Statistica 5.5 (Statsoft 1998).

Factor analysis is a powerful statistical technique that compresses the total information content of the multivariate data in terms of a few dimensions (factors) that are comprehensible (Kumru and Bakaç 2003). Principal component analysis (PCA), which was used in the present study, makes it possible for a few dimensions to account for most of the information in a large data set. PCA constitutes a purely mathematical solution, which is often devoid of biological meaning. The solution to this problem lies in the development of a suitable rotation, such as varimax rotation (Richman 1986) to determine loadings of the biological variables on the retained factors. Fossil samples were combined with the 66 modern surface samples by means of DCA (Detrended Correspondency Analysis) using the computer program TILIA (Grimm 1991).

Results

A total of 177 species were identified in both estuaries; 113 of them exhibited low relatively percentages (<2%). These rare taxa contributed little additional information to the statistical analysis, as their occurrence in a sample may have resulted from contamination by allochthonous inputs (Whiting and McIntire 1985). For statistical analysis, only the 64 species with frequencies ≥2% in at least one sample were considered (Figure 2).

Results of varimax factor scores and varimax component scores are listed in Tables 2 and 3. Only those species with factor loadings ≥0.7 were considered in factor analysis. The communalities of the taxa (the proportion of the variance of an element that is common to other elements in the set, see Kumru and Bakaç (2003)) associated with these factors were high (Tables 2 and 3). Details about variance, diatom content and ecological characteristics of all factors are listed in Table 4.

Mar Chiquita Lagoon

Seven factors explained 93% of the variance. Seven diatom assemblages were defined according to the factor analysis (Table 4A). Cluster analysis divided the transect into three diatom zones (Figure 3).

Zone I

Zone I was composed of the five sampling stations located within the tidal inlet (first 3.5 km). Salinity ranged between 1 and 35‰ in this zone (see Figure 3), which is dominated by polyhalobous and mesohalobous taxa, such as *Paralia sulcata* (Ehrenb.) Cleve (tychoplankton), *Opephora pacifica* (Grunow) Petit, *Dimeregramma minor* (Greg.) Ralfs, *Catenula adhaerens* (Meresch.) Meresch. and *Cocconeis scutellum* var. *parva* (Grunow) Cleve (epiphytes, Figure 3). Factor analysis identified factors 2, 4 and 6 as the principal components of this zone. These factors are grouping marine/brackish, periphytic and planktonic taxa (see Table 4A).

Zone II

This zone comprises the innermost shallow area of the lagoon without tidal influence, where salinity changes are mainly due to the effects of rain and wind, and with pronounced fluctuations of temperature and turbidity (Schwindt et al. 2004). This zone clusters stations 6, 7 and 8. Here, salinity values show a decreasing trend from the tidal inlet to the headwaters (Table 1). *Staurosira construens* var. *venter* (Ehrenb.) Hamilton and *Staurosirella pinnata* (Ehrenb.) Williams et Round (tychoplanktonic and oligohalobous indifferent) dominate this zone. They are accompanied by the benthic *Nitzschia* cf. *perminuta* (Grunow) Peragallo (oligohalobous indifferent) and the epiphytes and mesohalobous *Amphora coffeaeformis* (Agardh) Kütz. and *Planothidium delicatulum* (Kütz.) Burkht. & Round (Figure 3). Factor 6, characterized by periphytic and tychoplanktonic taxa from brackish/freshwater environments, is the principal component of this section (see Table 4A).

Zone III

Zone III clusters stations 9 and 10, located at streams flowing towards the inner lagoon (Figure 1). Station 9 is a freshwater environment while station 10 represents a small brackish channel with salinity fluctuations (~1–9‰, Table 1). Oligohalobous indifferent, oligohalobous halophilous and mesohalobous taxa dominate this zone. The most abundant species are *Staurosirella pinnata* (tychoplankton), *Cocconeis placentula* var. *euglypta* (Ehrenb.) Grunow (epiphyte), *Cyclotella meneghiniana* Kütz. (plankton) and the benthic *Hippodonta hungarica* (Grunow) Lange-Bert.,
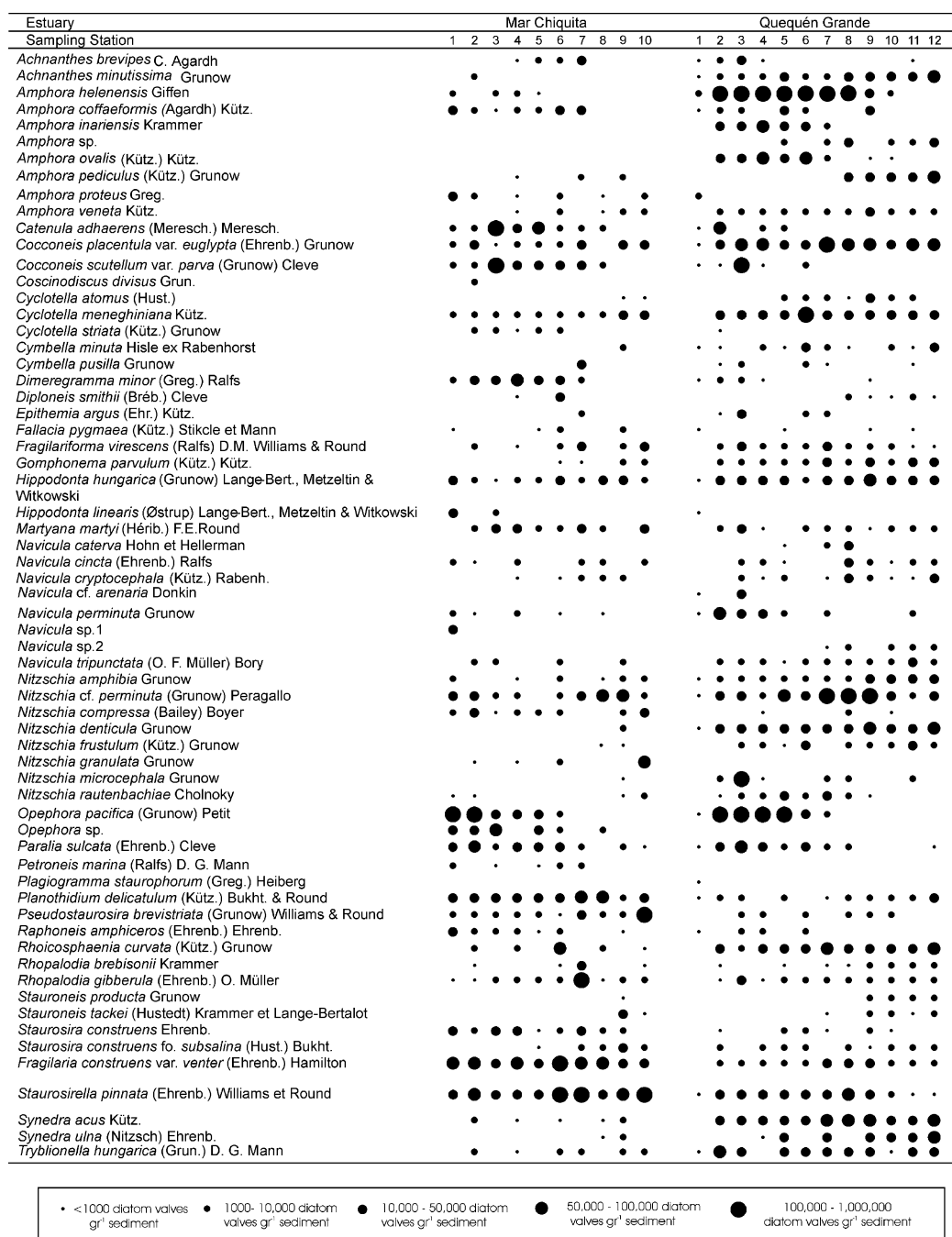
Estuary	Mar Chiquita	Quequén Grande
Sampling Station	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10 11 12

Achnanthes brevipes C. Agardh
Achnanthes minutissima Grunow
Amphora helenensis Giffen
Amphora coffaeformis (Agardh) Kütz.
Amphora inariensis Krammer
Amphora sp.
Amphora ovalis (Kütz.) Kütz.
Amphora pediculus (Kütz.) Grunow
Amphora proteus Greg.
Amphora veneta Kütz.
Catenula adhaerens (Meresch.) Meresch.
Cocconeis placentula var. euglypta (Ehrenb.) Grunow
Cocconeis scutellum var. parva (Grunow) Cleve
Coscinodiscus divisus Grun.
Cyclotella atomus (Hust.)
Cyclotella meneghiniana Kütz.
Cyclotella striata (Kütz.) Grunow
Cymbella minuta Hisle ex Rabenhorst
Cymbella pusilla Grunow
Dimeregramma minor (Greg.) Ralfs
Diploneis smithii (Bréb.) Cleve
Epithemia argus (Ehr.) Kütz.
Fallacia pygmaea (Kütz.) Stikcle et Mann
Fragilariforma virescens (Ralfs) D.M. Williams & Round
Gomphonema parvulum (Kütz.) Kütz.
Hippodonta hungarica (Grunow) Lange-Bert., Metzeltin & Witkowski
Hippodonta linearis (Østrup) Lange-Bert., Metzeltin & Witkowski
Martyana martyi (Hérib.) F.E.Round
Navicula caterva Hohn et Hellerman
Navicula cincta (Ehrenb.) Ralfs
Navicula cryptocephala (Kütz.) Rabenh.
Navicula cf. arenaria Donkin
Navicula perminuta Grunow
Navicula sp.1
Navicula sp.2
Navicula tripunctata (O. F. Müller) Bory
Nitzschia amphibia Grunow
Nitzschia cf. perminuta (Grunow) Peragallo
Nitzschia compressa (Bailey) Boyer
Nitzschia denticula Grunow
Nitzschia frustulum (Kütz.) Grunow
Nitzschia granulata Grunow
Nitzschia microcephala Grunow
Nitzschia rautenbachiae Cholnoky
Opephora pacifica (Grunow) Petit
Opephora sp.
Paralia sulcata (Ehrenb.) Cleve
Petroneis marina (Ralfs) D. G. Mann
Plagiogramma staurophorum (Greg.) Heiberg
Planothidium delicatulum (Kütz.) Bukht. & Round
Pseudostaurosira brevistriata (Grunow) Williams & Round
Raphoneis amphiceros (Ehrenb.) Ehrenb.
Rhoicosphaenia curvata (Kütz.) Grunow
Rhopalodia brebisonii Krammer
Rhopalodia gibberula (Ehrenb.) O. Müller
Stauroneis producta Grunow
Stauroneis tackei (Hustedt) Krammer et Lange-Bertalot
Staurosira construens Ehrenb.
Staurosira construens fo. subsalina (Hust.) Bukht.
Fragilaria construens var. venter (Ehrenb.) Hamilton
Staurosirella pinnata (Ehrenb.) Williams et Round
Synedra acus Kütz.
Synedra ulna (Nitzsch) Ehrenb.
Tryblionella hungarica (Grun.) D. G. Mann

• <1000 diatom valves gr¹ sediment	● 1000- 10,000 diatom valves gr¹ sediment	● 10,000 - 50,000 diatom valves gr¹ sediment	● 50,000 - 100,000 diatom valves gr¹ sediment	● 100,000 - 1,000,000 diatom valves gr¹ sediment

Figure 2. Concentration data of diatom samples from Mar Chiquita Lagoon and Quequén Grande River.

Metzeltin & Witkowski, *Navicula cincta* (Ehrenb.) Ralfs, *Nitzschia granulata* Grunow *and N. compressa* (Bailey) Boyer. Factors 1 and 3 defined this zone, by grouping the above mentioned brackish/ freshwater taxa (Table 4A).

Quequén Grande River

Seven factors explained 90.6% of the variance (Table 4B). Cluster analysis divided the transect into three diatom zones (Figure 4).

Table 2. Loading for varimax rotated factor matrix of seven-factor model from (A) Mar Chiquita Lagoon and (B) Quequén Grande River (C: communalities).

Species names	F1	F2	F3	F4	F5	F6	F7	C
(A)								
Amphora coffaeformis							− 0.94	0.99
Amphora helenensis		− 0.74						0.97
Amphora proteus		− 0.75						0.98
Cocconeis placentula var. *euglypta*	− 0.97							0.99
Cocconeis scutellum var. *parva*				− 0.71				0.82
Coscinodiscus divisus						− 0.92		0.92
Cyclotella meneghiniana	− 0.95							0.99
Dimeregramma minor				− 0.95				0.98
Diploneis smithii					− 0.98			0.98
Fragilariforma virescens			− 0.79					0.97
Hippodonta hungarica	− 0.83							0.99
Hippodonta linearis		− 0.95						0.99
Martyana martyi				− 0.97				0.99
Navicula cincta	− 0.96							0.99
Navicula sp. 1		− 0.98						0.99
Nitzschia granulata			− 0.96					0.99
Nitzschia cf. *perminuta*							− 0.85	0.99
Nitzschia compressa			− 0.94					0.99
Opephora pacifica		− 0.96						0.99
Paralia sulcata						− 0.91		0.97
Petroneis marina					− 0.95			0.99
Planothidium delicatulum							− 0.95	0.99
Pseudostaurosira brevistriata			− 0.94					0.99
Raphoneis amphiceros		− 0.91						0.99
Staurosira construens var. *construens*				− 0.88				0.97
Staurosira construens var. *subsalina*	− 0.91							0.99
Staurosira construens var. *venter*					− 0.95			0.99
Staurosirella pinnata			− 0.65					0.94
Eigenvalues	8.29	5.08	4.43	4.19	3.52	2.69	2.51	
Variance	25.11	15.39	13.44	12.69	10.67	8.16	7.61	
Cumulative variance	25.11	40.5	53.94	66.64	77.3	85.46	93.07	
(B)								
Achnanthes brevipes				− 0.96				0.99
Achnanthes minutissima	0.83							0.85
Amphora coffaeformis			−0.74					0.9
Amphora helenensis	−0.85							0.85
Amphora linearis		−0.84						0.95
Amphora pediculus	0.93							0.96
Amphora proteus			−0.97					0.98
Amphora proteus var. *oculata*			−0.97					0.98
Amphora veneta	0.87							0.99
Catenula adhaerens						-0.92		0.89
Cyclotella atomus					-0.7			0.94
Cymbella minuta					0.71			0.94
Epithemia argus				− 0.96				0.99
Fallacia pygmaea			− 0.98					0.99
Gomphonema parvulum	0.7							0.58
Hippodonta hungarica	0.9							0.99
Navicula cf. *arenaria*			− 0.7					0.99
Navicula caterva		− 0.96						0.99
Navicula cincta		− 0.94						0.97
Navicula cryptocephala		− 0.7						0.78
Navicula perminuta						− 0.87		0.93
Navicula sp. 2	0.86							0.99

Table 2. (Continued).

Species names	F1	F2	F3	F4	F5	F6	F7	C
Navicula tripunctata							− 0.82	0.85
Nitzschia amphibia	0.91							0.99
Nitzschia denticula	0.75							0.85
Nitzschia frustulum							− 0.85	0.97
Nitzschia microcephala				− 0.98				0.99
Opephora pacifica						− 0.78		0.89
Paralia sulcata				− 0.81				0.9
Plagiogramma staurophorum			− 0.97					0.98
Planothidium delicatulum	0.74							0.95
Rhopalodia brebisonii				− 0.99				0.99
Stauroneis producta	0.88							0.83
Stauroneis tackei		− 0.91						0.93
Staurosira construens var. *construens*		− 0.95						0.98
Staurosira construens var. *subsalina*	0.7							0.95
Staurosirella pinnata					− 0.72			0.95
Synedra ulna	0.7							0.76
Tryblionella hungarica						− 0.9		0.85
Eigenvalues	16.31	6.9	6.02	4.69	3.83	3.35	2.42	
Variance	33.98	14.37	12.5	9.77	7.98	6.98	5.05	
Cumulative variance	33.98	48.36	60.86	70.63	78.62	85.59	90.65	

Zone I

Only one sample (station 1) was taken in this area, located on the estuary mouth. Salinity values in this zone ranged between 15 and 27‰ (see Figure 4). Diatom assemblages are dominated by polyhalobous taxa: *Amphora proteus* Greg., *A. helenensis* Giffen, *Opephora pacifica* (epiphytes), *Fallacia pygmaea* (Kütz.) Stikcle et Mann and *Plagiogramma staurophorum* (Greg.) Heiberg (benthos, Figure 4). This zone is characterized by

Table 3. Scores for the seven-factor model in (A) Mar Chiquita coastal lagoon and (B) Quequén Grande river.

Site	F1	F2	F3	F4	F5	F6	F7
(A)							
1		− 2.79					
2						− 2.63	
3						1.12	
4				− 2.75			
5	0.71						
6					− 2.78		
7							
8							− 2.71
9		− 2.73					
10			− 2.73				
(B)							
1			− 3.01				
2						− 2.86	
3			− 3.12				
4							
5							
6						1.37	
7						0.78	
8		− 3.06					
9	1.11				− 2.38		
10	1.89						
11	0.91						− 2.84
12	1.22				2.02		1.16

Table 4. Factor descriptions of surface sediment samples from (A) Mar Chiquita Lagoon and (B) Quequén Grande River, with respect to their diatom content.

Factors	Variance (%)	Diatoms	Ecology
(A)			
F1	25.11	*Cocconeis placentula* var. *euglypta, Cyclotella meneghiniana, Hippodonta hungarica, Navicula cincta, Staurosira construens* var. *subsalina*	Brackish/freshwater periphyton and brackish/freshwater plankton
F2	15.39	*Amphora helenensis, A. proteus, Hippodonta linearis, Navicula* sp.1, *Opephora pacifica, Raphoneis amphiceros*	Marine/brackish benthos
F3	13.44	*Fragilariforma virescens, Nitzschia granulata, Nitzschia compressa, Pseudostaurosira brevistriata, Staurosirella pinnata*	Brackish/freshwater tychoplankton Brackish/freshwater epiphytes Marine/brackish epipelon Marine/brackish periphyton
F4	12.7	*Cocconeis scutellum* var. *parva, Dimeregramma minor, Martyana martyi, Staurosira construens* var. *construens*	
F5	10.67	*Diploneis smithii, Petroneis marina, Staurosira construens* var. *venter*	Marine/brackish benthos and Brackish/freshwater tychoplankton
F6	8.16	*Coscinodiscus divisus, Paralia sulcata*	Marine/brakish plankton
F7	7.6	*Amphora coffaeformis, Nitzschia* cf. *perminuta, Planothidium delicatulum*	Brackish/freshwater periphyton
(B)			
F1	33.9	*Achnanthes minutissima, Amphora pediculus, Amphora veneta, Staurosira construens* var. *subsalina, Hippodonta hungarica, Navicula* sp.2, *Nitzschia amphibia, N. denticula, Planothidium delicatulum, Stauroneis producta, Synedra ulna*	Freshwater periphyton
F2	14.37	*Amphora lineata, Staurosira construens* var. *construens, Navicula caterva, N. cincta, N. cryptocephala, Stauroneis tackei*	Brackish/freshwater benthos and Brackish/freshwater tychoplankton
F3	12.5	*Amphora coffaeformis, A. proteus, A. proteus* var. *oculata, Fallacia pygmaea, Navicula* cf. *arenaria, Plagiogramma staurophorum*	Marine/brackish periphyton
F4	9.77	*Achnanthes brevipes, Epithemia argus, Nitzschia microcephala, Paralia sulcata, Rhopalodia brebisonii*	Marine/brackish periphyton
F5	7.98	*Cyclotella atomus, Cymbella minuta, Staurosirella pinnata, Rhoicosphaenia curvata*	Brackish/freshwater periphyton and Brackish/freshwater tychoplankton
F6	6.98	*Amphora* cf. *helenensis, Catenula adhaerens, Navicula* cf. *perminuta, Tryblionella hungarica, Opephora pacifica*	Marine/Brackish benthos
F7	5.05	*Navicula tripunctata, Nitzschia frustulum*	Freshwater benthos
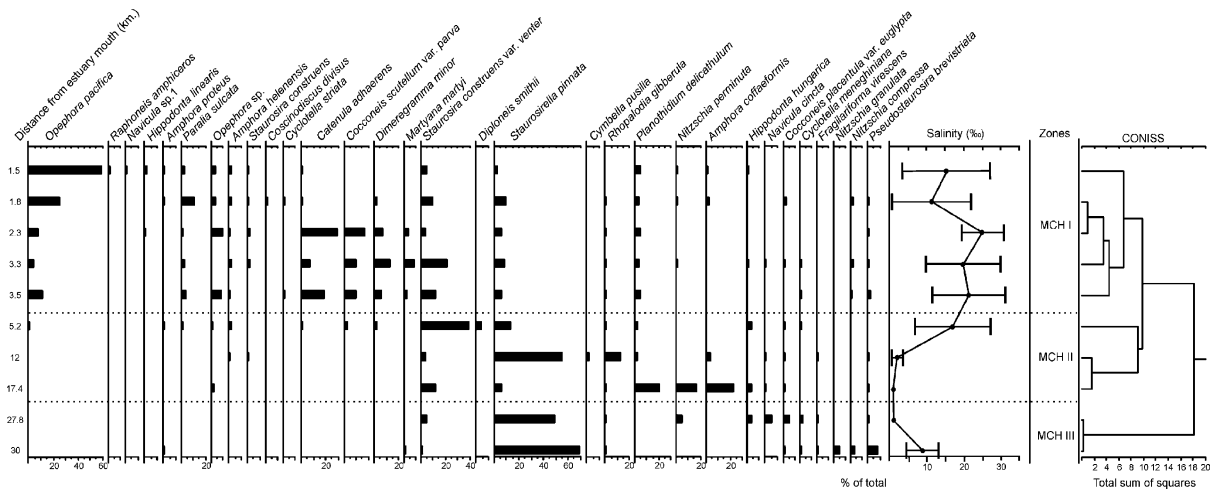
Figure 3. Relative frequency diagram of diatom composition at Mar Chiquita coastal lagoon.
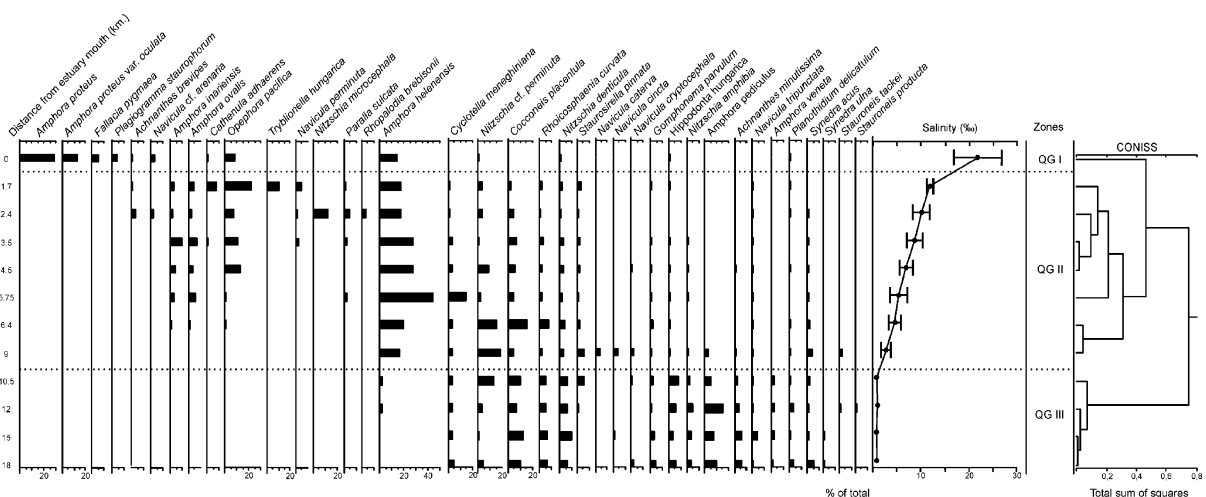
Figure 4. Relative frequency diagram of diatom composition at Quequén Grande River.

factor 3, which groups periphyton of marine/brackish affinities (Table 4B).

Zone II

Stations 2 through 8, located between 1.7 and 9 km from the estuary mouth, were clustered. This section represents a salinity gradient: salinity decreases from ∼ 11 ‰ in station 2, to ∼2 ‰ in station 8 (see Figure 4). It is characterized by the dominance of oligohalobous indifferent taxa, such as *Cocconeis placentula* var.*euglypta* and *Rhoicosphaenia curvata* (Kütz.) Grunow (epiphytes)

and mesohalobous/oligohalobous halophilous *Amphora helenensis* (epiphyte), *Cyclotella meneghiniana* (plankton) and *Nitzschia* cf. *perminuta* (benthos). This zone is characterized by factors 2, 4 and 6, which represents marine/brackish and brackish/freshwater environments (Table 4 B).

Zone III

Stations 9, 10, 11 and 12, located between 10.5 and 18 km from the estuary mouth were clustered. This is a zone of oligohaline waters, with salinities lower than 1 ‰ (Figure 4). It is dominated by the
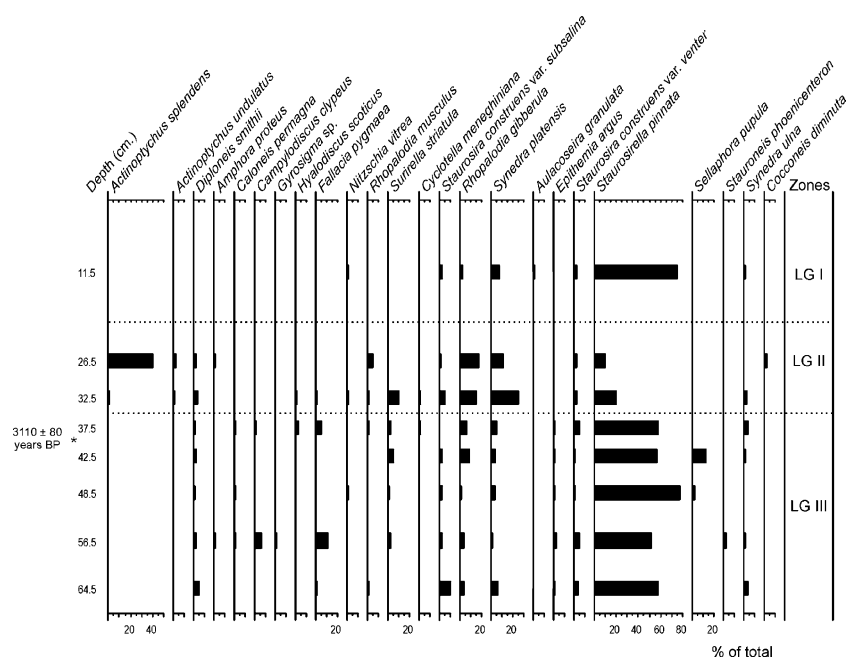
Figure 5. Relative frequency diagram of the Las Gallinas Creek (modified after Espinosa 1994).

oligohalobous indifferent *Cocconeis placentula* var. *euglypta*, *Gomphonema parvulum* (Kütz.) Kütz., *Rhoicosphaenia curvata* (epiphytes), *Amphora pediculus* (Kütz.) Grunow, *Hippodonta hungarica* (benthos) and *Nitzschia amphibia* Grunow (aerophilous).The halophobous and benthic *Nitzschia denticula* Grunow reaches a high abundance in this section. Factors 1, 5 and 7 characterized this zone, representing freshwater diatom assemblages (Table 4B).

DCA

The modern data set was compared with fossil data from a previously analyzed sequence located in the Mar Chiquita Lagoon (Figure 5, Espinosa 1994), in order to evaluate the applicability of the modern diatom assemblages in the interpretation of fossil sequences. The sequence is located ~5 km away from Mar Chiquita sampling station 9, at the right edge of the Las Gallinas Creek and was assigned to the late Holocene (3110 ± 80 years BP, Espinosa 1994).

Espinosa (1994) divided the Las Gallinas Creek sequence into three diatom zones by cluster analysis (Figure 5). From the base of the

sequence to ~35 cm (zone LG III) it was dominated by *Staurosirella pinnata* and *Staurosira construens* var. *venter* (oligohalobous indifferent) accompanied by *Fallacia pygmaea* and *Campylodiscus clypeus* (mesohalobous). Diatom assemblages preserved in zone LG II (35–23 cm) were dominated by the polyhalobous *Actinoptychus splendens*, the mesohalobous *Rhopalodia musculus* and the oligohalobous halophilous *R. gibberula*. The top of the sequence (zone LG I) was dominated by *S. pinnata* (75%), accompanied by *S. construens* var. *venter*, *S. construens* var. *subsalina* (oligohalobous halophilous), *Diploneis smithii* (polyhalobous) and *Aulacoseira granulata* (oligohalobous indifferent).

Results of DCA ordination are shown in Figure 6. Samples from Quequén Grande River (QG), Mar Chiquita Lagoon zones (MCHI, MCHII and MCHIII) and Las Gallinas Creek zones (LGI, LGII and LGIII) are plotted. Ordination of modern and fossil samples shows that zones I and III of Las Gallinas Creek have modern analogs in Mar Chiquita zone III. Similarity between fossil and modern diatom assemblages in these zones is due mainly to the dominance of *Staurosirella pinnata*. Las Gallinas Creek zone II has no analogs in the modern spectra.
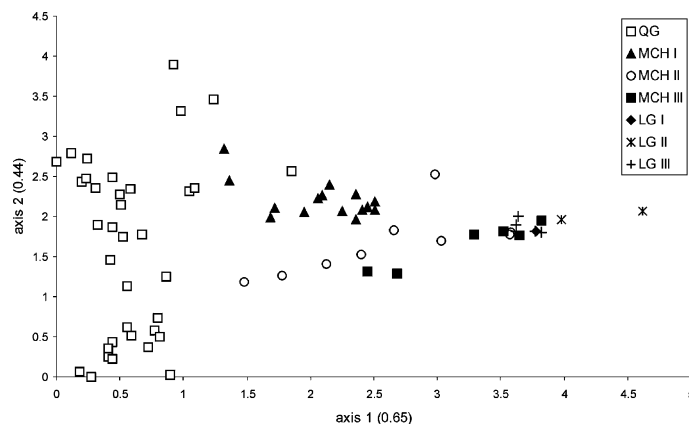
Figure 6. DCA of combined surface and fossil diatom samples (QG: Quequén Grande River, MCH: Mar Chiquita Lagoon, LG: Las Gallinas Creek).

Discussion

Most diatom species found in Mar Chiquita are euryhaline taxa. Dominance of euryhaline/brackish taxa has been observed in Brazilian coastal lagoons (e.g., Sylvestre et al. 2001). This pattern is characteristic of environments with fluctuating salinity regimes, where taxa are more selected according to their ability to adapt to changing salinity rather than to their salinity optima (Snoeijs 1999).

The spatial distribution of diatom assemblages in the Mar Chiquita Lagoon does not appear to be determined by their salinity optima, since we do not find a gradual replacement from marine to freshwater species along the longitudinal gradient. Mar Chiquita is characterized by great salinity changes. Previous work suggested that there is no correlation between diatom assemblages and salinity along the longitudinal gradient in changing environments, mostly because taxa distribution is affected by other environmental variables, such as salinity fluctuations, alkalinity, water temperature, light regime, nutrient concentrations, exposure to wave action and biotic interactions (Carpelan 1978; Snoeijs 1999; Sylvestre et al. 2001).

Different environmental factors may influence the diatom distributions observed in each zone of the lagoon. While marine/brackish assemblages dominate the inlet (zone I), where salinity, current speed and tidal range are higher (Reta et al. 2001; Schwindt et al. 2004), the brackish/freshwater tychoplanktonic *Staurosira construens* var. *venter* and *Staurosirella pinnata* dominate the inner lagoon (zone II). This distributional pattern may be a consequence of taphonomic processes rather than ecological attributes. Hassan et al. (2003) reported that over 70% of the diatom frustules found at the end of the estuarine channel consisted of empty frustules of tychoplanktonic taxa. Dominance of tide-transported marine planktonic and tychoplanckctonic diatoms is often found in sediments under tidal influence, where the conditions are unfavorable for the development of a benthic or epiphytic diatom population (Vos and De Wolf 1993). High concentrations of tychoplanktonic diatoms (probably allochthonous) found at Mar Chiquita zone II may be related to the obstacle of the CELPA bridge, which induces accumulation of suspended particles from the headwaters of the lagoon. Brackish/freshwater diatoms dominate in zone III, where there is no tidal influence and low salinity fluctuations, probably related to the evaporation-precipitation balance.

Diatom assemblages in the Quequén Grande River appear to be distributed according to the salinity gradient. Marine taxa, such as *Amphora proteus* and *Plagiogramma staurophorum*, are most abundant at the inlet (zone I). The middle estuary (zone II) is dominated by brackish/freshwater euryhaline species, such as *Amphora helenensis* and *Cocconeis placentula*. At the upper estuary (zone III), freshwater diatoms dominate, and the halophobous *Nitzschia denticula* increased in relative

proportion. This diatom zonation would be explained because of the quasi-stable salinity gradient present at Quequén Grande (De Francesco and Isla 2003). Similar diatom zonations were recorded in other estuaries with salinity gradients around the world (Moore and McIntire 1977; Ampsoker and McIntire 1978; Juggins 1992; Debenay et al. 2003). Since salinity is often a main environmental factor controlling the distribution of diatoms (Snoeijs 1994), their spatial distribution at Quequén Grande can be regarded as a simple relationship to salinity.

Paleoecological reconstructions based on autoecological classifications reflect the distributions of species groups with similar requirements. Most diatom-based paleoecological reconstructions in coastal systems lead to paleosalinity reconstructions (Denys and De Wolf 1999). Although salinity classes have broad ranges, some euryhaline or indifferent species do not fit within these boundaries, and are not very useful for indicating past salinity fluctuations (Vos and De Wolf 1993).

Many of the taxa recorded at Quequén Grande River have narrow salinity tolerances and are therefore useful for paleosalinity interpretations. On the other hand, most diatom taxa found in Mar Chiquita Lagoon are euryhaline taxa with broad distributions. Although these taxa do not offer accurate paleosalinity information, their dominance may be considered as an indicator of fluctuating salinity environments (coastal lagoons). More detailed work for assessing the relationship between diatom taxa distribution and other parameters, such as salinity fluctuation, nutrient concentration and sediment composition at Mar Chiquita, might lead to additional important ecological information applicable to paleoecological reconstructions.

DCA ordination of modern and fossil samples shows that zones I and III of Las Gallinas Creek have modern analogs. Both fossil zones fall within the Mar Chiquita zone III, and are characterized by the dominance of *Staurosirella pinnata*. This taxa was classified by Vos and De Wolf (1993) as brackish/freshwater tychoplankton, indicating a salinity range of 0–5‰. Comparison with modern environmental data corroborated that these zones represent shallow brackish/freshwater environments, with low salinity fluctuations (∼1–9‰) and no tidal influence. Both fossil levels were interpreted by Espinosa (1994) as brackish water

environments, and tidal channel conditions were proposed for LGIII based on the presence of silty clays and the dominance of tychoplankton. On the basis of modern data analysis, although brackish water conditions are suggested, no tidal influence can be proposed, since there is no similarity between fossil levels and modern assemblages from Mar Chiquita tidal inlet. This may be interpreted as a brackish lagoon environment with no tidal influence.

Conclusion

The distribution of diatom assemblages from the surface sediments at Mar Chiquita coastal lagoon and the Quequén Grande River, based on constrained cluster analysis, defined zones related to their geomorphological and hydrographical differences. The observed distribution of diatom assemblages in both estuaries was consistent with the salinity classifications proposed for other geographical regions. Our results suggest that the distribution of diatoms is related to the tolerances of marine and freshwater taxa at the Quequén Grande River, whereas at Mar Chiquita Lagoon, the taxa appear to be distributed according to their abilities to tolerate salinity changes. Comparison between fossil diatoms and the modern data set showed that this contribution provides useful analogs to interpret past environments in this region.

Council of Scientific and Technical Research of Argentina (CONICET).

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