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Late Pleistocene–Recent marine malacological assemblages of the Colorado River delta (south of Buenos Aires Province): Paleoecology and paleoclimatology

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ABSTRACT

The most recent Quaternary marine transgressions are well represented along the South Atlantic coast. In the Colorado River delta (39°15′S–39°55′S), south of Buenos Aires Province these deposits are mostly littoral ridges and tidal plains with abundant fossil marine fauna. Seventeen localities were analyzed (five Pleistocene, seven Holocene and five modern ones) representing the Interglacials ≥ MIS 9, MIS 5e and MIS 1. A total of 51 species were recorded (29 bivalves and 22 gastropods), together with nine micromolluscs. MIS 1 and the modern coast (37 and 42 species respectively) are the richest ones in species, unlike MIS 5e and MIS 9 (18 and 2 species respectively). In ≥MIS 9, the most abundant species is *Pitar rostratus*. MIS 5e and MIS 1 have in common the presence and abundance of the gastropod *Heleobia australis* and the bivalve *Tagelus plebeius*, as typical fauna of low energy environments, being the bivalve *Glycymeris longior* and the gastropods *Bostrycapulus odites* and *Buccinanops globulosus* common species in both kinds of marine deposits. Approximately 90% of bivalves and 75-71% of gastropods of the marine fauna are recorded from MIS 5e to the present. According to the different descriptive analyses (Bray–Curtis Index and AC) the molluscan fauna was grouped in two and five assemblages respectively, defined by age, type of deposit, and presence and/or abundance of species. Marine species represented in the area of the Colorado River delta vary in abundance among the interglacials but not in faunal composition. One of the possible causes would be the global climatic changes (e.g., rise of sea surface temperature SST) and the heterogeneity of habitats that would have conditioned the development of the different faunal assemblages during the Quaternary.

1. Introduction

During Quaternary transgressions, large areas of Buenos Aires and the north Patagonian coast of Argentina were affected by processes of accumulation and erosion generated by the different sea-level oscillations. Contemporary authors studied these deposits from geological, geomorphological and paleontological approaches, knowing their chronology in many cases through numerical ages; in the Buenos Aires Province (e.g. Feruglio, 1950; Fidalgo et al., 1973; Weiler, 1984, 1988; González et al., 1988; Violante and Parker, 1992; Codignotto and Aguirre, 1993; Isla et al., 2000; Weiler, 2000; Cavallotto, 2002; Cavallotto et al., 2004, 2005; Schnack et al., 2005; Fucks et al., 2010, 2012a) and in the Patagonian coast (e.g. Angulo et al., 1978, 1981; Cionchi, 1987; Rutter et al., 1989, 1990; Rostami et al., 2000; Schellmann and Radtke, 2000; Pedoja et al., 2011; Fucks et al., 2012b). Different authors studied fossil marine molluscs, especially bivalves and gastropods in Quaternary deposits of South America (e.g., Martin and Suguio, 1992; Díaz and Ortlieb, 1993; Ortlieb et al., 1994, 1996; Guzmán et al., 1995, 2001; Martínez et al., 1997, 2001, 2006; Maasch et al., 2001; Ragainia et al., 2002; Jones et al., 2010; Rojas and Urteaga, 2011) and particularly in Argentina (e.g., Farinati, 1978, 1985, 1994; Aguirre and Whatley, 1995; Gordillo, 1998, 1999; Aguirre and Farinati, 1999; Pastorino, 2000; Aguirre, 2003; Aguirre et al., 2005, 2006, 2007; Gordillo et al., 2005, 2008; Gordillo, 2009; Cárdenas and Gordillo, 2009; Rabassa et al., 2009; Charó et al., 2013a,b; 2014) achieving paleoecological, paleoenvironmental, and paleobiographic reconstructions for the Quaternary.

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In the northeast area of the Buenos Aires Province, marine deposits belonging to MIS 1 were the most studied and most malacological studies have focused mainly on this period. The fossil content (valves and shells of molluscs) found in marine deposits of MIS 5e is generally much cemented (Aguirre and Fucks, 2004), difficulting malacological studies. In the southern Buenos Aires Province, recent studies in the area of Anegada Bay (39° S) and San Blas Bay (40° S) described Pleistocene marine deposits of MIS 5e, analyzing the marine fauna of molluscs (bivalves and gastropods) from a paleoecological and paleoenvironmental approach (Charó et al., 2013a,b). Both investigations indicate warmer conditions in MIS 5e, bconsistent with evidence elsewhere (e.g., Murray-Wallace and Belperio, 1991; Mc Culloch and Esat, 2000; Murray-Wallace et al., 2000; Rohling et al., 2008) pointing to sea surface temperatures (SST) about 2 C° warmer than today.

In the Colorado River delta, south of Buenos Aires Province, marine deposits were studied from a geological and geochronological view (e.g., Alberó et al., 1980; Codignotto and Weiler, 1980; González and Weiler, 1983; Weiler, 1984). The interglacials represented are ≥ MIS 9, MIS 5e and MIS 1 which mostly correspond to paleocliffs, littoral ridges, and tidal plains (Weiler, 1984; Fucks et al., 2012a). The marine fauna associated with these deposits has been briefly mentioned previously (Weiler, 1984, 2000) but it has not been studied, especially the bivalves and gastropods, as “paleoclimatic proxies”. The main objective of this paper is to describe the different faunal assemblages of bivalves and gastropods and to study paleoecologic and paleoclimatic issues of the Colorado River delta during the Quaternary, particularly of ≥ MIS 9, MIS 5e and MIS 1.

2. Study area and geology

The area of the Colorado River delta extends from Verde Peninsula (39° 20′ S, 62° 4′ W) to Otero Island (39° 55′ S, 62° 08′ W) in southern Buenos Aires Province, Argentina (Fig. 1 and Table 1). The Colorado River runs from the Andes to the Atlantic Ocean, forming the boundary between Patagonia in the south and the sandy Pampa to the north (Spalletti and Isla, 2003). This river is the most important in the region while others have very little flow or become active in times of flood.

The delta of the Colorado River is a prograding body, composed of large number of active and abandoned channels, such as from N to S: the Colorado Nuevo, Colorado and Colorado Viejo. Deltaic plains of the Colorado River area comprise both the area of recent outlet channels (Colorado Viejo and Colorado Nuevo), and the “old deltas” known today as Caleta Brighman, Verde Peninsula, Verde Bay and Falsa Bay (Isla and Bértola, 2003). Verde Bay is an area in which the main factor to mobilize the material is the tidal current and the currents produced by the waves. In the center of the island there is a sequence of old sandy beach ridges that continue to the outlet of the Colorado Viejo and disappear toward the continent. These beach ridges are bordered by old tidal plains to the north and west.

Islands such as Puerto, Conejos, Word and Ariadna, and sandy banks are distributed within the bay. Among them, Verde Peninsula stands out, a true island during syzygy tides or severe storms (Weiler, 1984).

In the area between the Colorado and Negro rivers, south of Buenos Aires Province (39° 30′ S - 41° 02′ S), there are marine deposits assigned to the oldest interglacials because of their geomorphological, altimetric and cementation similarity (Fucks et al., 2012a). Among them, there are deposits assigned to ≥ MIS 9 which are scarce, thin, and isolated on the continent (Fucks and Schnack, 2011; Fucks et al., 2012a).

According to González et al. (1988) the marine deposits of the Sangamon (?; Late Pleistocene) are represented in the area of the Colorado River delta by paleocliffs associated with coast lines no more than 10 m height. The terminal area of the delta is formed by the marine deposits of the MIS 1 ingression, which are beach ridges of intertidal environments (Fucks et al., 2012a). Weiler (1984) described between Verde Bay and Laberinto Point old tidal plains between 5 and 2.5 m height, which are crossed by numerous tidal channels, functional today (Fig. 2 and Table 2).

3. Materials and methods

Seventeen localities were analyzed in the area of the Colorado River delta (five Pleistocene, seven Holocene and five modern ones) representing ≥ MIS 9, MIS 5e and MIS 1 (Fig. 3). The analysis of each site was made through volumetric samples of 1 dm^3 and in a quadrant 1 m × 1 m along transects perpendicular to the coast line in modern beaches. These deposits (1 dm^3) were separated using three sieves of different mesh size. Each fraction of biogenic content was identified and labeled.

The identification of species was made with catalogs and specific systematic papers (e.g., Castellanos, 1990, 1992; Aguirre, 1993a,b; Pastorino, 1993, 1999, 2002, 2005, 2009; Ríos, 1994; Guzmán et al., 1998; Aguirre and Farinati, 2000; Simone et al., 2000; Penchaszadeh et al., 2002, 2007; Clavijo et al., 2005; Collin, 2005; Signorelli, 2010; Pimenta et al., 2011; Pisano et al., 2013).

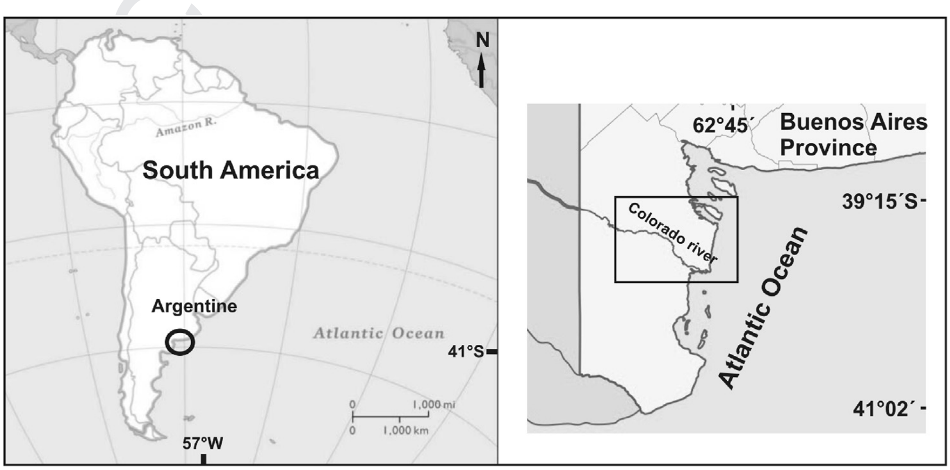

Fig. 1. Location map of the Colorado River delta, south of Buenos Aires province, Argentina.

Table 1
Description of sampled localities in the delta rio Colorado area.

delta río Colorado area	Age	Sites	Coordinates (Lat-Long)	Abundance	Shannon Index (H′)	Species richness (S)
	Pleistocene (≥MIS 9)	1	39°48′13.60″S; 62°39′56.19″W	12	1.24	4
	Pleistocene (MIS 5e)	2	39°47′10.55″S; 62°29′22.04″W	70	1.06	5
		3	39°47′16.66″S; 62°28′4.39″W	12	1.24	4
		4	39°47′10.55″S; 62°29′22.04″W	292	2.25	17
		5	39°52′0.65″S; 62°22′52.95″W	86	1.14	5
	Holocene	6	39°17′39.94″S; 62°11′12.81″W	1008	0.10	4
		7	39°21′37.47″S;62° 5′9.44″W	32	1.12	6
		8	39°28′11″S; 62°19′ 04″W	226	0.58	9
		9	39°34′23.04″S; 62°12′19.55″W	264	2.12	20
		10	39°35′45.89″S; 62°10′27.18″W	54	2.20	14
		11	39°51′29.78″S; 62°22′35.76″W	1018	0.44	11
		12	39°52′19.09″S; 62°20′54.94″W	218	2.40	19
	Modern	13	39°23′5.10″S; 62° 0′48.70″W	660	2.72	30
		14	39°35′17.69″S; 62° 5′59.84″W	256	1.21	4
		15	39°35′18.05″S; 62° 5′57.93″W	128	2.32	27
		16	39°35′18.46″S; 62° 5′54.47″W	140	2.81	23
		17	39°36′08.6″S; 62°06′12″W	68	1.94	10

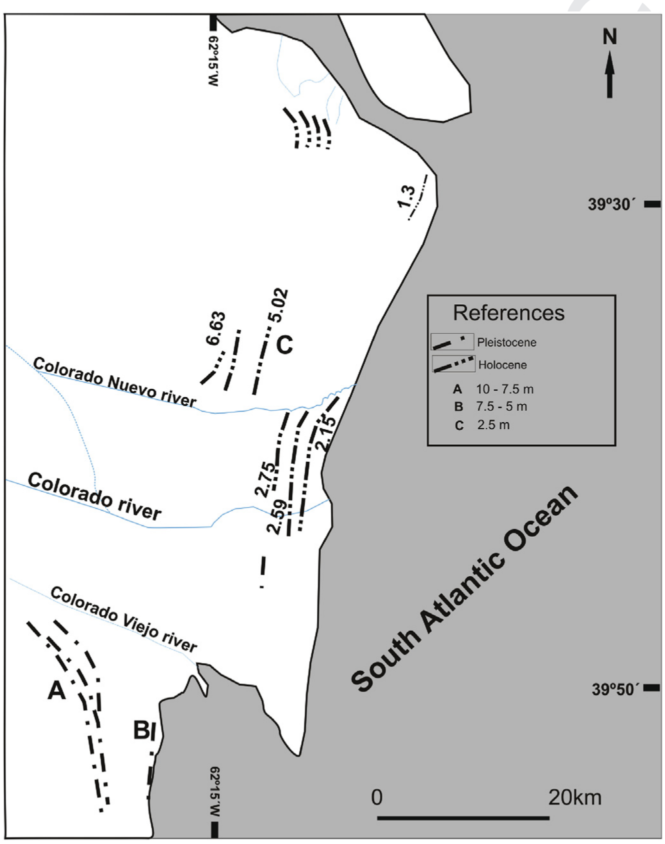

Fig. 2. Location of the Pleistocene and Holocene ridges in the area of the Colorado River delta (Weiler, 1984).

For each locality, the absolute abundance of each species was calculated. Abundance histograms were made for each site in different interglacials.

Two indices were used to study the biodiversity of the faunistic assemblages: Shannon index (H′), calculated with the program R version 2.15.0 (package "Biodiversity R"; Kindt and Coe, 2005), and richness of each sample (total number of species) (Pla, 2006). The similarity degree of the sites was analyzed with multivariate analyses (cluster analyses) of program R (vegan package) (Oksanen, 2011) through the Bray–Curtis Index, UPGMA method. This index is used to estimate similarity among species composition in each site. To enhance discrimination among them, we used correspondence analysis (CA), a statistical descriptive method that analyzes the relationships among sites. Both analyses grouped different faunal assemblages.

In order to arrive at paleoenvironmental conclusions focused on paleoecology of the different species, we built tables according to salinity range, life mode, depth, substrate, trophic type and area of distribution. These tables were made on the basis of ecological data of modern representatives of the different species, and following general bibliographic sources (e.g., Bastida et al., 1992; Lasta et al., 1998; Morris and Rosenberg, 2005; Penchaszadeh et al., 2007; Balech and Ehrich, 2008) or specific papers (e.g. Morsán, 1997; Iribarne et al., 1998; Ciocco, 2000; Collin, 2005; Cumplido, 2009). Afterwards, the ecological parameters of gastropods and bivalves of each analyzed area were compared through histograms.

The presence of warm water species and species that today are displaced toward lower latitudes were also used as source of paleoenvironmental information, in this case, as indicators of warmer conditions (e.g., Valentine, 1955, 1958; Beu, 1974; Aguirre, 1993b; Aguirre and Farinati, 1999, 2000). The illustrated material is housed in the Paleoinvertebrate Collection of the Museo de La Plata, Argentina (MLP-UNLP).

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Table 2
Absolute datings available from the study area.

Region	Coordinates (Lat-Long)	^{14}C method	Interglacial	Altitude (m.a.m.s.l.)	Cites
Delta del rio Colorado area	Verde Peninsula	2.170 ± 86 ka	MIS 1	3	Alberó et al. 1980
	Punta Laberinto área	5.7 ± 0.11–1.24 ± 0.08 ka	MIS 1	5	Weiler, 1984
	Colorado Chico river área	6.93 ± 0.13–0.407 ± 0.10 ka	MIS 1	5–2.5	Codignotto and Weiler, 1980; Alberó et al. 1980 and Weiler, 1984
	39 28′S; 62 19′O	–	MIS 5e	8	Fucks et al., 2012a
	39 47′S; 62 22′O	–	MIS 5e	5	Fucks et al., 2012a
	39 51′S; 62 22′O (Site 11)	3.69 ± 0.10 ka (LP 2480)	MIS 1	3	Charó et al., 2014
	Colorado Viejo river área	3.74 ± 0.09; 2.79 ± 0.90	MIS 1	5–3	Weiler, 1984

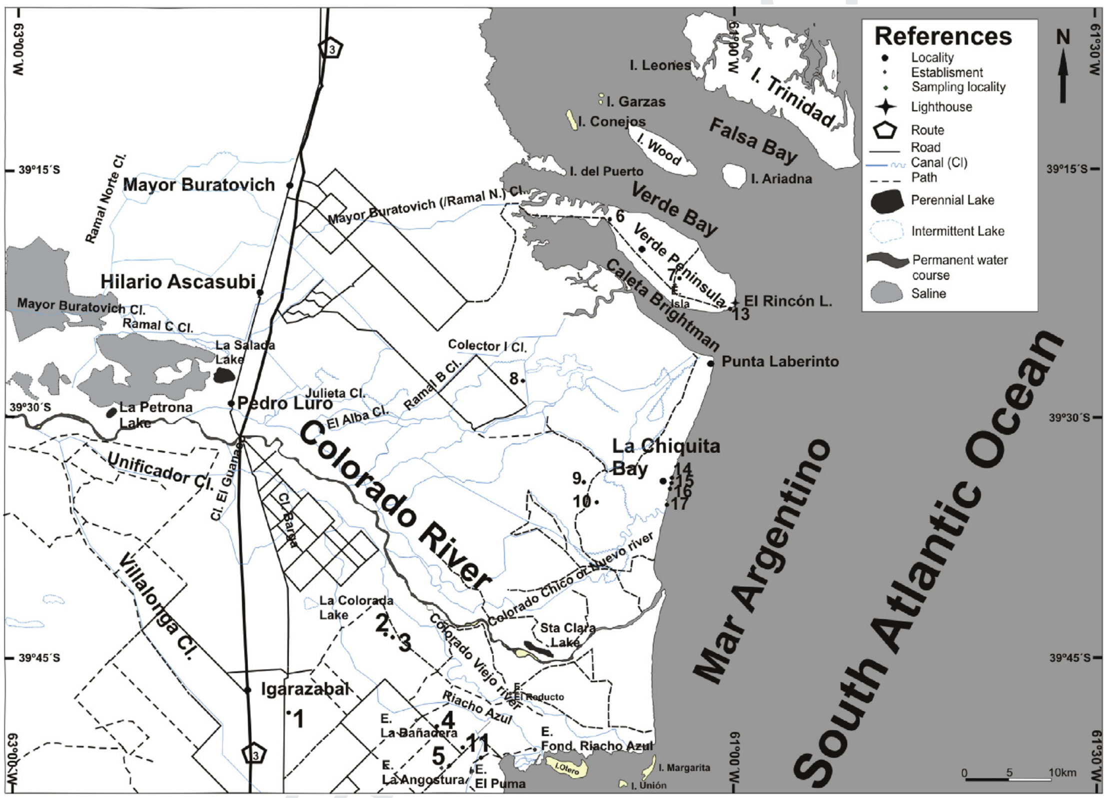

Fig. 3. Location of the studied sites of ≥MIS 9, MIS 5e and MIS 1.

4. Results

4.1. Pleistocene deposits (≥MIS 9) in the region of the Colorado River delta

Site 1 is near the locality of Villalonga, at a height of 16 m. It is a beach ridge made of gravel and cemented by calcium carbonate. The age is assigned on the basis of similarity of geomorphological features with other marine deposits south of this area (Fucks et al., 2012a,b; Charó et al., 2013a). It has little fossiliferous content with *Pitar rostratus* and *Corbula patagonica* (bivalves), and *Buccinanops* and *Crepidula* (gastropods) (Fig. 4).

4.2. Pleistocene deposits (MIS 5e) in the region of the Colorado River delta

Site 2 is a beach ridge at a height of 6 m. It is composed of 2 m of brownish silty sands covered by grayish brown clayey silts with scattered clasts, spherical and flattened, and upholstered with calcrete with mollusc remains. The recorded species are *Glycymeris longior, Tagelus plebeius* (bivalves) and *Heleobia australis*, *Tegula patagonica* and *Buccinanops globulosus* (gastropods).

Sites 3 and 5 form littoral ridges made of sandy sediments at a height of about 6 m. Among the most abundant molluscs are

Fig. 4. Pleistocene outcrop (≥MIS 9) of Colorado River delta.

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Glycymeris longior and *Buccinanops globulosus* Site 4 is a paleochannel 10 m above sea level. This deposit is composed of sandy silt sediments. Among the recorded species are *Tagelus plebeius*, *Corbula patagonica*, *Pitar rostratus*, and *Heleobia australis*.

4.3. Holocene marine deposits in the region of the Colorado River delta

Verde Peninsula is a geomorphological feature generated from the Holocene marine transgression where relict and modern tidal plains, active and stabilized dunes, coastal barriers, and beaches can be identified. Two Holocene sites were analyzed (Sites 6 and 7) the latter with an age of 2.17 ± 0.86 ka ^{14}C (Alberó et al. 1980). These are tidal plain deposits at a height of 4 m above sea level. Among the most abundant marine molluscs are *Amiantis purpurata* (bivalve) and *Heleobia australis*. The southern sector is characterized by the recent formation of a N–S barrier about 3.5 km from the dune line, generating a wide sandy tidal plain, mostly affected by littoral processes during storms and by the wind (Fucks et al., 2012a).

In the vicinity of the mouth of the Colorado Nuevo River, marine sediments are exposed continuously along 26 km of coastline. Sites 8, 9 and 12 are tidal plain deposits at a height of about 5–2 m above sea level. These deposits show 2 m high cliffs, composed of silty clayey sediments, grayish brown, homogeneous, covered in some sectors by eolian sediments. Transitionally overlying are grayish brown sandy sediments, laminated, with a minimum thickness of 0.50 m. These sediments bear a large amount of marine molluscs, mostly *Tagelus plebeius*, *Corbula patagonica*, *Pitar rostratus*, *Heleobia australis* and *Buccinanops globulosus*, often articulated and in life position (Fig. 5).

Site 10 is a tidal plain deposit, some 23 km away from the present coast line. It is an exposure at a height of 4–5 m represented by 2.5 m of clayey sand, brown, homogeneous with small clasts and bivalves and gastropods. Among them, the bivalves *Amiantis purpurata* and *Mesodesma mactroides* are abundant (Fig. 6).

Site 11 is a 1.40 m thick recent channel deposit at a height of 3 m, with high density of *Tagelus plebeius* and *Heleobia australis*. Three levels (A, B and C) were recognized as part of a shallow environment. Level A, is 0.10 m of fine gravel, matrix supported; level B is 0.60 m of clayey fine sand, homogeneous, dark brown with scattered valves and *Tagelus plebeius* in life position and articulated, covered by a level 0.50 m thick of a green brownish sediment; level C is a pedogenized sand 0.20 m thick. One ^{14}C date was performed in level B, which yielded an age of 3.69 ± 0.10 ka (LP 2480) (Fig. 7).

4.4. Modern beaches in the area of the Colorado River delta

The area between Punta Laberinto and vicinities of the Colorado Viejo River has a wide sandy beach which narrows towards the south, in a stretch of 45 km and a width that ranges from 2 km in Punta Laberinto to 500 m near the Colorado Viejo River (Weiler, 1984). Site 13 is the beach of Verde Peninsula is a sandy beach with a large amount of marine molluscs, most of the valves and shells are fragmented. Among the most abundant molluscs are *Adelomelon brasiliana* and *Zidona dufresnei* (gastropods) (Fig. 8).

The most outstanding beach of the area is La Chiquita Beach at Verde Bay, in front of Wood Island (sites 14–16). It is a wide sandy beach characterized by a frontal dune about 4 m high. In the berm near the shoreline, accumulations of valves of *Amiantis purpurata* and *Cyrtopleura lanceolata* (bivalves) are common (Fig. 9).

The coast of the east sector of the Colorado River delta is represented by a wide sandy beach (site 17), limited toward the continent by a dune body partially vegetated. Among the most abundant marine molluscs are the bivalves *Ostrea puelchana*, *Pitar rostratus* and *Amiantis purpurata*. In some sectors, as the vicinity of the mouths of the Colorado Chico or Colorado Nuevo rivers, partial erosion phenomena have been observed (Codignotto and Weiler, 1980) (Fig. 10).

4.5. Faunistic composition

In the area of the Colorado River delta, 17 sites (five Pleistocene, seven Holocene and five modern) were analyzed and a total of 51 species was recorded (29 bivalves and 22 gastropods) (N = 2.237 both valves and shells) (Figs. 11 and 12). Among them, nine micromolluscs were recorded: *Nucula nucleus*, *Ennucula grayi*, *Carditamera plata*, *Corbula patagonica* and *Corbula lyoni* (bivalves) and *Heleobia australis*, *Parvanachis isabellei*, *Olivella tehuelcha*, and *Turbonilla argentina* (gastropods) (Tables 3 and 4).

The oldest Pleistocene (Site 1) is characterized by the presence of *Pitar rostratus* and *Corbula patagonica* and two gastropod genera *Crepidula* and *Buccinanops*. The Pleistocene deposits of MIS 5e (Site 2–5) are represented mostly by littoral ridges of high energy, except for Site 4. A total of 18 species was recorded (12 bivalves and 6 gastropods). The abundance of *Glycymeris longior*, *Pitar rostratus*, *Tegula patagonica*, *Bostrycapulus odites* and *Buccinanops globulosus* is notable, and also *Tagelus plebeius* and *Heleobia australis* were recorded.

The marine deposits of MIS 1 recorded a total of 37 species (17 bivalves and 20 gastropods), mostly represented by tidal plains except for sites 7 and 10. *Corbula patagonica* and *Heleobia australis* are the most abundant, as well as *Pitar rostratus* and *Buccinanops globulosus*. *Tagelus plebeius* is abundant in sites 11 and 12. Site 11 is particularly notable by the presence of the microgastropod *Turbonilla argentina* (<10 mm). Sites 7 and 10 represent littoral ridges, in which *Amiantis purpurata* is recorded, and the abundance of *Mesodesma mactroides* is notable only in Site 10. Both deposits are

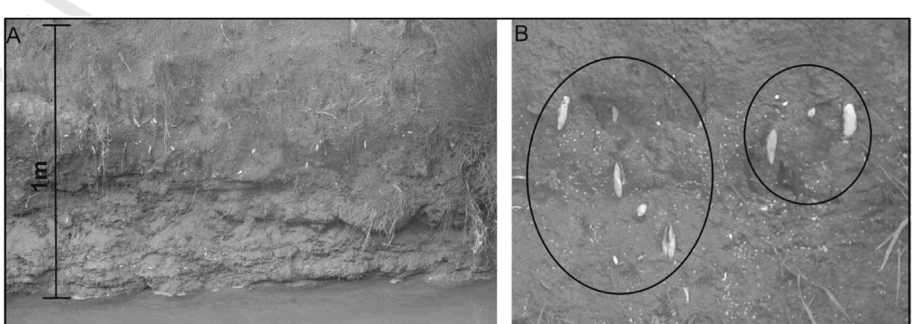

Fig. 5. A, Holocene marine deposits near the mouth of the Colorado River (Site 8); B, *Tagelus plebeius* articulates in Site 8.

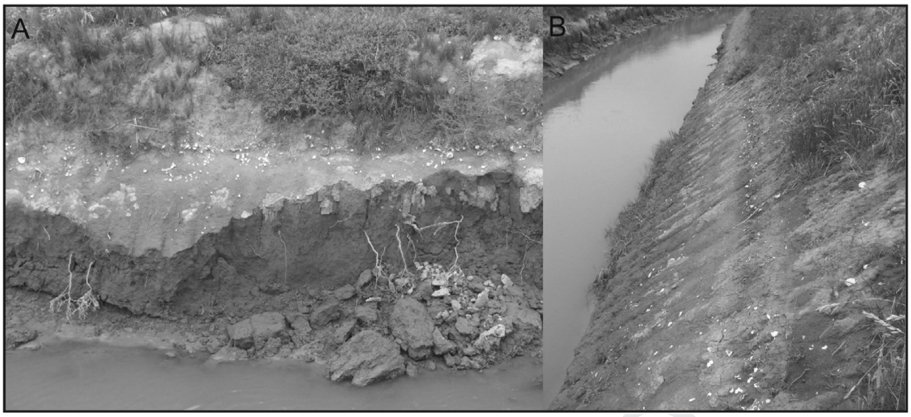

Fig. 6. A, B Holocene marine deposit of the Colorado River delta (Site 10).

Fig. 7. Holocene marine deposit with *Tagelus plebeius* in life position (Site 11).

distinctive for the presence of *Tagelus plebeius* and *Heleobia australis*.

In modern sand beaches, a total of 42 species was recorded (26 bivalves and 16 gastropods). The abundance of the bivalves *Ostreola equestris*, *Ostrea puelchana*, *Raeta plicatella*, *Mesodesma mactroides*, *Solen tehuelchus*, *Cyrtopleura lanceolata* and *Barnea lamellosa* is notable, as well as the association *Pitar rostratus* and *Amiantis purpurata*, and *Heleobia australis*, *Crepidula*, and *Notocochlis isabelleana* among the gastropods (Figs. 13 and 14).

The highest values of Shannon Index (H') are those of the modern sites (1.94–2.72), and the lowest are those of MIS 1 ($H'1 = 0.10$, $H'3 = 0.58$ and $H'6 = 0.44$). The highest values of richness are those of modern sites ($S\ 13 = 30$, $S\ 15 = 27$) and the lowest ones are those of S1, S3, and S6 with 4.

9 % of the bivalve species of MIS 5e are recorded in MIS 1, and 89.5% of them are still living today (Fig. 15). 75% of the gastropod species of MIS 5e are recorded in MIS 1, and 71.4% of them are still living today (Fig. 16).

4.5.1. Paleoecology

According to the faunal composition, both in bivalves and gastropods, marine species prevail over estuarine ones (e.g. *Heleobia australis*) (Tables 5 and 6).

In the oldest Pleistocene of $\geq$ MIS 9 all the bivalve species are euryhaline, infaunal, of sandy substrate, and filter feeders. Among gastropods, all the species are euryhaline, epifaunal, of sandy or rocky substrates, and filter feeders or carnivorous. In the Pleistocene deposits of MIS 5e most bivalves are euryhaline and polyhaline-euryhaline, infaunal with epifauna species, and cemented. They inhabited sandy substrates, and also rocky substrates. They are filter feeders, but some species are detritivorous and carnivorous. Euryhaline species increase in MIS 1, as well as cemented and detritivorous species increase respect to MIS 5e. Today there is an increase of rocky substrate species.

During Interglacial MIS 5e, most gastropod species were euryhaline, increasing the oligohaline-polyhaline-mesohaline species. All species were epifaunal, of sandy and rocky substrates, appearing those of mixed substrates. Most species were carnivorous, but also some herbivorous and filter feeder species are recorded. During

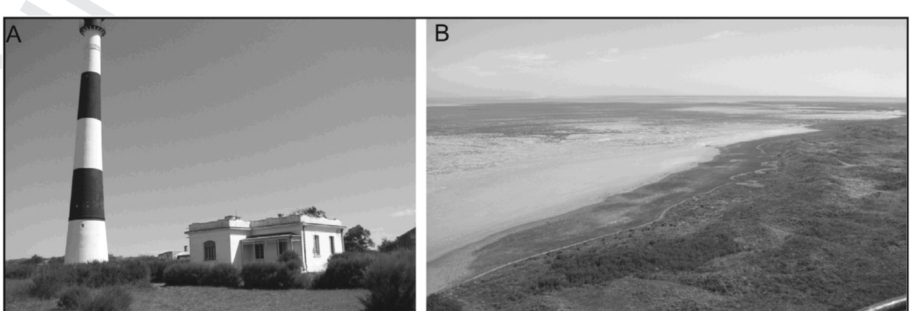

Fig. 8. A, San Antonio Lighthouse (Verde Península); B, Landscape view of the beach of Verde Peninsula (Site 13).

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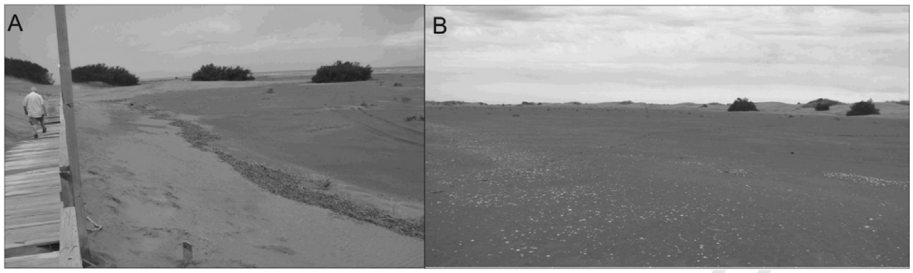

Fig. 9. Sandy beaches of La Chiquita Beach (Site 14).

Fig. 10. Beach near the mouth of the Colorado River (Site 17).

MIS 1, the ectoparasite and infaunal species appeared, with increases of carnivorous and species of sandy substrates. In modern beaches there are no records of ectoparasite species, and mixed sediment and herbivorous species increase (Fig. 17).

4.5.2. Warm water species

Concerning the amount of warm water bivalve and gastropod species represented in each interglacial, from ≥ MIS 9 to MIS 5e, 50% of the species are warm water ones. From MIS 1 to today, they increased by 10% (Fig. 18).

4.6. Malacological assemblages

4.6.1. Cluster analysis

According to the Bray–Curtis index, the marine malacofauna of the area of the Colorado River delta is divided into two major groups. Group A corresponds to the malacological association mostly of modern sites, and Group B to Pleistocene and Holocene sites. Group A is divided into two subgroups: A1) malacological association of beach sites with abundance of *Crepidula* and presence of bivalves such as *Mesodesma mactroides*, *Cyrtopleura lanceolata* and *Solen tehuelchus*; and A2) malacological associations mostly of beaches except for three sites (1, 7, and 8) with abundance of *Pitar rostratus* and *Amiantis purpurata*. Sites 1, 7, and 10 correspond to beach ridges with abundant malacological remains, similar to those found in modern beaches. Sites 7 and 10 (MIS 1) resemble each other by the abundance of *Amiantis purpurata*.

Group B is subdivided into three subgroups: B1) malacological association of MIS 5e represented by littoral ridges; B2) malacological association of MIS 1 represented by tidal plains with abundant *Heleobia australis*; B3) malacological associations of two sites of MIS 5e (sites 2 and 4) and two sites of MIS 1 (sites 9 and 12). Sites 4 and 12 are very similar, because of the presence and abundance of *Tagelus plebeius*, *Pitar rostratus*, *Corbula patagonica* and *Heleobia australis* (Fig. 19).

4.6.2. Correspondence analysis

According to the Correspondence analysis (CA), five malacological associations are distinguished. A) malacological association of MIS 5e (sites 3 and 5) which correspond to littoral ridges with presence of *Glycymeris longior*. B) malacological association of two bivalves *Pitar rostratus* and *Amiantis purpurata* with presence of the bivalves *Corbula patagonica*, *Lyonsia alvarezii* and *Diplodonta vilardeboana*, and the gastropods *Crepidula argentina*, *Urosalpinx rushi*, *Tegula patagonica*, *Bostrycapulus odites*, *Buccinanops globulosus*, and *Buccinanops cochlidium*. C) malacological associations of littoral ridges of sands and clasts with presence of the bivalves *Ostrea*, *Ostreola equestris, Brachidontes rodriguezii* and *Mactra guidoi* and the gastropod *Buccinanops uruguayensis*. D) malacological association of MIS 1 (sites 6, 8 and 11) corresponding to tidal plains with abundance of *Heleobia australis*. Site 8 is characterized by the particular presence of two micromolluscs: *Parvanachis isabellei* and *Turbonilla argentina*. E) malacological association that corresponds to modern sandy beaches (sites 15 and 16) close to each other composed of *Mesodesma mactroides*, *Cyrtopleura lanceolata*, *Barnea lamellosa* and *Raeta plicatella* (bivalves). Site 15 is outstanding by the presence of the bivalve *Atrina seminuda* and the gastropod *Epitonium striatum* (Fig. 20).

5. Discussion

The geographic distribution of marine gastropods and bivalves are related to the orography of the coast, the salinity, temperature, type of substrates and ocean currents. The circulation of the Southwestern Atlantic is mainly influenced by two currents: the warm Brazil Current and the cold Malvinas Current. The Brazil

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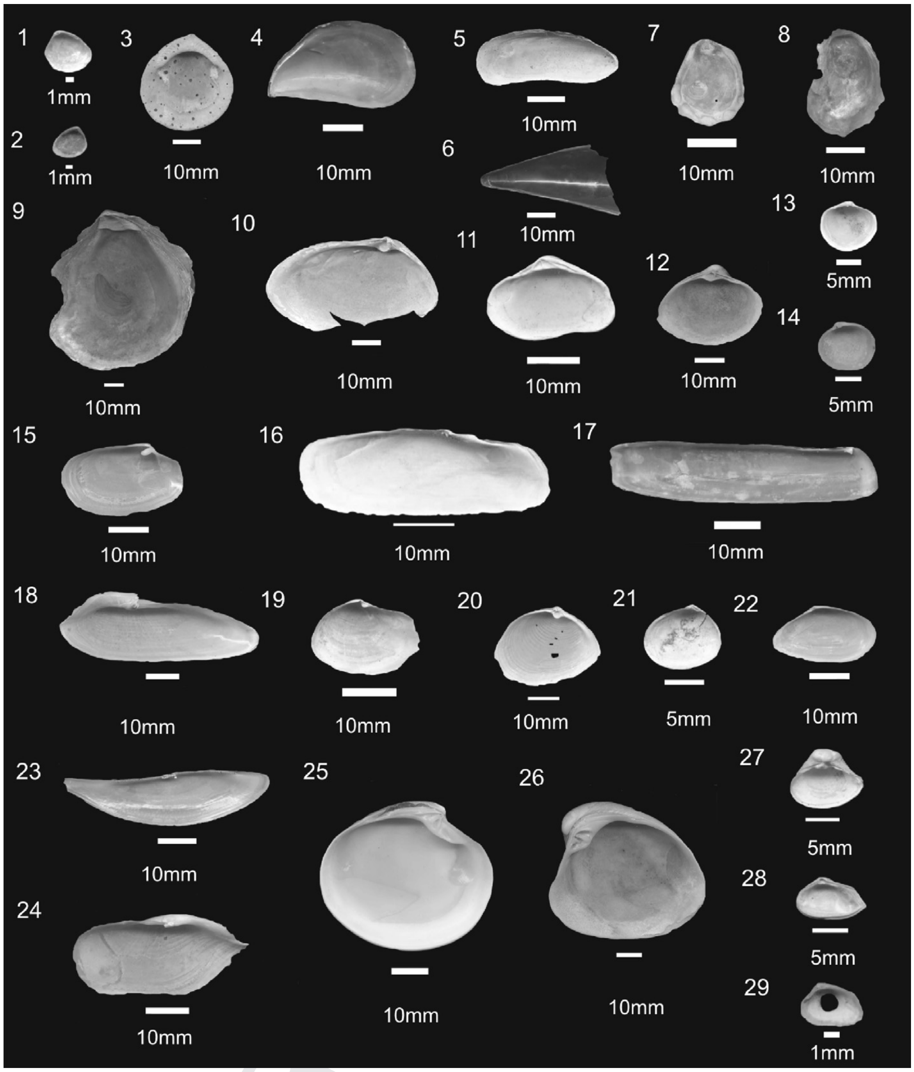

Fig. 11. Bivalve species typical of Quaternary marine deposits the area of the Colorado River delta.1, *Nucula (N.) nucleus* (MLP: 34.416, modern); 2, *Ennucula grayi* (MLP: 34.407, Holocene); 3, *Glycymeris (G.) longior* (MLP: 34.409,modern); 4, *Mytilus edulis platensis* (MLP: 34.415, modern); 5, *Brachidontes rodriguezii* (MLP: 34.401, Holocene); 6, *Atrina seminuda* (MLP:34.399, modern); 7, *Plicatula gibbosa* (MLP: 34.422, modern); 8, *Ostreola equestris* (MLP: 34.448, Holocene); 9, *Ostrea puelchana* (MLP: 34.419, modern); 10, *Mesodesma mactroides* (MLP: 34.414, modern); 11,*Mactra guidoi* (MLP:34.412, Holocene); 12, *Mactra isabelleana* (MLP: 34.413, Holocene); 13, *Diplodonta (D.) patagonica* (MLP: 34.406, modern); 14, *Diplodonta (F.) vilardeboana* (MLP: 34.408, modern); 15, *Periploma ovatum* (MLP: 34.420, modern); 16, *Tagelus (T.) plebeius* (MLP: 34.425, Pleistocene); 17, *Solen tehuelchus* (MLP: 34.424, modern); 18, *Cyrtopleura (S.) lanceolata* (MLP: 34.404, modern); 19, *Lyonsia (L.) alvarezii* (MLP: 34.410, Pleistocene); 20, *Raeta (R.) plicatella* (MLP: 34.423, modern); 21, *Abra (A.) aequalis* (MLP: 34.395, Pleistocene); 22, *Macoma (P.) uruguayensis* (MLP: 34.411, modern); 23, *Adrana electa* (MLP 34.398, actual); 24,*Barnea lamellosa* (MLP: 34.400, modern); 25, *Amiantis purpurata* (MLP: 34.397, modern); 26, *Pitar (P.) rostratus* (MLP: 34.421, modern); 27, *Corbula (C.) patagonica* (MLP: 34.405, Holocene); 28, *Corbula (C.) lyoni* (MLP: 34.403, modern); 29, *Carditamera plata* (MLP: 34.402, modern).

Current transports warm subtropical water ranging between 18 and 24 °C with salinities between 34.5 and 36%, and northwards the temperature is between 24 and 30 °C and salinity >36%.

The Brazil Current heads south along the coast of Brazil and Uruguay between 9° S and 38° S and is generally restricted to the first 600 m of the water column. At the Río de la Plata (38° S, Buenos Aires Province) this current begins to separate from the continental shelf at about 12° S, being completely separated at 36° S, and continues to flow south out of the Brazilian and Uruguayan continental shelf until it reaches 38° S and converges with the Malvinas Current.

The Malvinas Current is a branch of the Circumpolar Current and is divided into two branches: the western branch of cold water and low salinity, due to the contribution of inland water, flows northward along the continental shelf of Argentina until the edge of the continental shelf of Uruguay in front of the Río de la Plata. The eastern branch surrounds the Malvinas Islands and also flows northward, but contouring the edge of the continental shelf, running from south to north the South Atlantic from an approximate latitude of 55° S and up to the area between 39° and 36° S (e.g., Barré et al., 2006; Balech and Ehrich, 2008).

The contact of the two currents generates a large region of dynamic characteristics, both spatial and temporal, and mixtures of subtropical with sub-Antarctic waters. This area of confluence, called the Transition zone, is located between 30° and 46°S, from which the currents flow in opposite directions (Piola and Matano, 2001).

The marine mollusc assemblages of Buenos Aires Province are characterized by the frequency of warm and warm – temperate species, belonging to the Argentine Malacological Province. It extends from 28° 28′ S to 42°–43° S and is considered as an ecotone between the Magellan Malacological Province and Brazilian

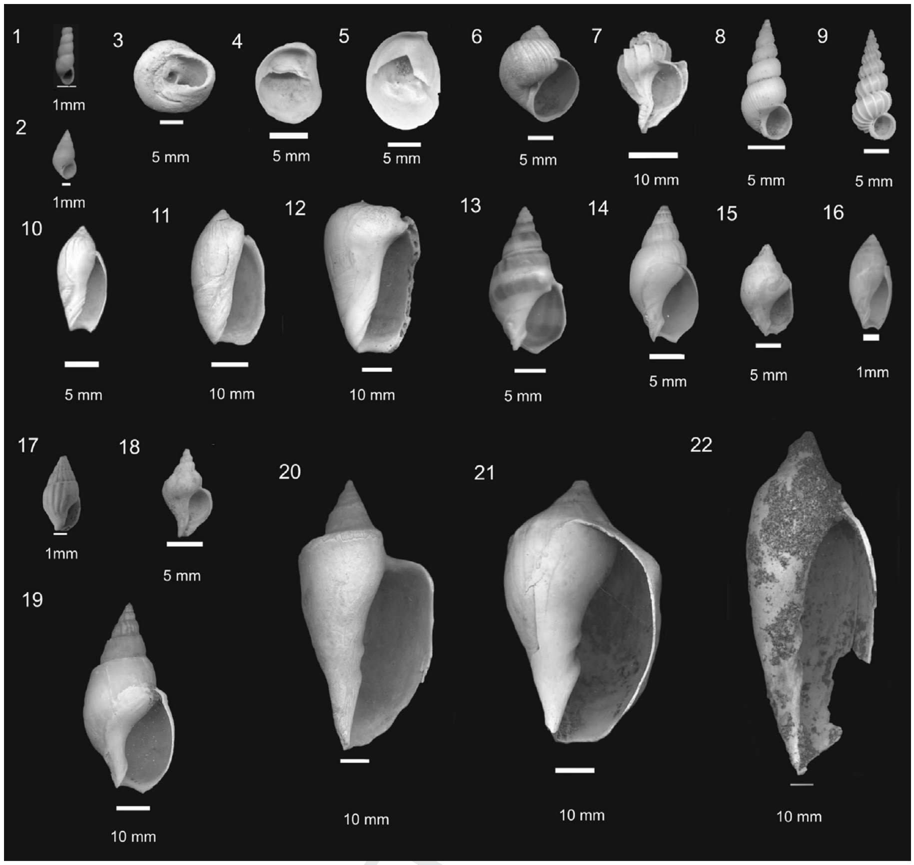

Fig. 12. Gatropods species typical of Quaternary marine deposits of the area of the Colorado River delta.1, *Turbonilla argentina* (MLP: 33.781, Holocene); 2, *Heleobia australis* (MLP: 34.387, modern); 3, *Tegula (A.) patagonica* (MLP: 34.392, Holocene); 4, *Bostrycapulus odites* (MLP: 34.392, Pleistocene); 5, *Crepidula argentina* (MLP: 34.384, modern); 6, *Notocochlis isabelleana* (MLP: 34.388, Holocene); 7, *Trophon patagonicus* (MLP: 34.393, Holocene); 8, *Epitenium striatellum* (MLP: 34.393, modern); 9, *Epitenium georgettinum* (MLP: 34.386, modern); 10, *Olivancillaria uretai* (MLP: 34.390, Holocene); 11, *Olivancillaria carcellesi* (MLP: 34.389, Holocene); 12, *Olivancillaria urceus* (MLP: 34,418, Holocene); 13, *Buccinanops monilifer* (MLP: 34.382, Holocene); 14, *Buccinanops uruguayensis* (MLP: 34.428, modern); 15, *Buccinanops globulosus* (MLP: 34.381, Holocene); 16, *Olivella (O.) tehuelcha* (MLP: 34.391, Holocene); 17, *Parvanachis isabellei* (MLP: 34.428, modern); 18, *Urosalpinx cala* (MLP:34.447, Holocene); 19, *Buccinanops cochlidium* (MLP: 34.380, modern); 20, *Zidona dufresnei* (MLP: 34.384, Holocene); 21, *Adelomelon (P.) brasiliana* (MLP: 34.378, Holocene); 22, *Odontocymbiola magallánica* (MLP: 34.417, Holocene).

Malacological Province with the presence of cold water species (Martínez and del Río, 2002).

The area of the delta of the Colorado River (39° S), is located in the transition zone of the warm Brazil Current and the cold Malvinas Current, but when compared to the coastal area of Uruguay (33°52′O) this latter is influenced by the Brazil Current (Scarabino, 1977). The Uruguayan Pleistocene deposit (Nueva Palmira Formation, 31–34 ka; Martínez et al., 2001) in Nueva Palmira (33° 52′ S), are related to the study area in 44.4% of the molluscan fauna. The species are mostly polyhaline-euhaline and euhaline, and of rocky and sandy substrate. This Pleistocene deposit is characterized by the presence of two warm-water species (*Anomalocardia brasiliana* and *Nioche subrostrata*), currently displaced towards lower latitudes, not found in the delta area. The Holocene deposits (Villa Soriano Formation, 6.8–1.8 ka; Martínez et al., 2001) are richer in species than in the study area (65 vs. 37 species respectively) and have a similarity of 54.05% with the Holocene marine malacofauna present in the delta area. Most species of the study area are euhaline, infaunal, and of sandy substrates. The higher percentage in species similarity between the two areas and the existence of warm water species in Villa Soriano Formation (*Anomalocardia brasiliana*, *Marshallora nigrocincta*, *Nioche subrostrata*, *Bulla striata* and *Miralda* sp.) currently displaced further north may be due to warmer waters and the displacement of the saline front of the estuary of the Río de la Plata during the Holocene (Martínez et al., 2001).

In southern Gualeguaychú (southern Entre Ríos province, 33° 1′S; 58° 31′W), the Pleistocene deposits (26.6–33 ka, minimum age; Guida and González, 1984) are considered by geographical vicinity to be similar in age to the Uruguayan Pleistocene deposits (Martínez and del Río, 2005). The Pleistocene faunal assemblages in southern Entre Ríos are characterized by low species richness (5 species), 11.1% agreeing with the study area, with the presence of *Tagelus plebeius* and *Heleobia australis* in both areas. The Holocene deposits (5.6–6 ka; Guida and González, 1984), are limited to three species in common (8.1% similarity). The difference between the two areas is the existence of the estuarine species *Erodona mactroides*, indicating brackish waters during the Holocene in Uruguay.

In the northeastern Buenos Aires Province (34°56′–36°S), La Plata – Samborombon Bay area, Aguirre (1990) indicated higher abundance and diversity of gastropods and bivalves in MIS 1 deposits with respect to MIS 5e. The Pleistocene marine deposits are restricted and discontinuous along the Buenos Aires coastline and interbedded or lying over Pampean sediments, and represented by different facies (Schnack et al., 2005). These deposits are assigned to the Puente de Pascua Formation (6–8 m, MIS 5e; Fucks et al., 2006), and show 44.4% similarity with higher specific richness than the study area (25 species vs. 18 species respectively). Species are mostly euryhaline, filter feeders, of sandy substrates, and epifaunal bivalves and infaunal gastropods (Aguirre and Fucks, 2004).

Table 3
Bivalves from the Quaternary marine deposits of delta río Colorado area.

Bivalves	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Nucula (N.) *nucleus* (Nn)				x					x		x	x	x				
Ennucula grayi (Eg)									x								
Adrana electa (Ael)																x	
Glycymeris (G.) *longior* (Gl)		x	x	x	x							x		x	x	x	x
Mytilus edulis platensis (Me)										x			x		x		x
Brachidontes (B.) *rodriguezii* (Br)				x				x	x		x	x	x			x	
Atrina seminuda (Ats)															x		
Plicatula gibbosa (Pg)																x	
Ostrea (Os)									x				x				
Ostreola equestris (Oe)									x			x	x		x	x	
Ostrea puelchana (Op)				x					x				x	x	x	x	x
Diplodonta (D.) *patagonica* (Dp)				x						x							
Diplodonta (F.) *vilardeboana* (Dv)													x				
Carditamera plata (Cpl)						x					x	x	x		x		
Mactra (Ms)															x		
Mactra isabelleana (Mi)													x				
Mactra guidoi (Mg)									x				x			x	
Raeta (R.) *plicatella* (Rp)				x						x			x		x	x	x
Mesodesma mactroides (Mm)										x			x		x	x	
Solen tehuelchus (St)													x		x	x	
Macoma (P.) *uruguayensis* (Mu)								x								x	
Abra (A.) *aequalis* (Aa)				x				x							x		
Tagelus (T.) *plebeius* (Tp)		x		x				x			x	x	x			x	
Pitar (P.) *rostratus* (Pr)	x			x	x	x	x	x	x	x	x	x		x	x	x	x
Amiantis purpurata (Ap)							x		x	x		x	x	x	x	x	x
Corbula (C.) *patagonica* (Cp)	x			x				x	x	x	x	x			x		
Corbula (C.) *lyoni* (Cl)																x	
Cyrtopleura (S.) *lanceolata* (Cyl)													x		x	x	x
Barnea lamellosa (Bl)															x	x	
Lyonsia (L.)*alvarezii* (La)				x													
Periploma ovatum (Po)																x	

Unlike in the study area, the marine malacofauna of MIS 1 (Cerro La Gloria Member of the Las Escobas Formation, 7.5–2 ka; Figini et al., 1984) correspond to the present Interglacial in warmer conditions (Fidalgo et al., 1973; Tonni and Fidalgo, 1978). It has 64.9% similarity with the marine malacofauna of the study area, with most species being euryhaline, infaunal and of sandy substrates. The difference between both faunas is the abundance of *Mactra isabelleana* in the Las Escobas Formation, and the representation of species found today in lower latitudes such as *Anomalocardia*, *Urosalpinx*, and *Noetia* (Aguirre, 1990). Other marine deposits characterize northwest Buenos Aires Province. Those of the Mar Chiquita Formation (4–3 ka; Schnack et al., 1980, 1982), coincide 51.3% with the marine malacofauna of the study area, with *Heleobia australis* being dominant (Aguirre, 1990). In both areas, species are mostly euryhaline, with brackish species, infaunal bivalves and epifaunal gastropods. Those of sandy and rocky substrate are

Table 4
Gastropods from the Quaternary marine deposits of delta río Colorado area.

Gastropods	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Tegula (A.) *patagonica* (Tpat)		x		x	x				x		x		x				
Bostrycapulus odites (Bo)			x	x	x			x	x		x	x	x		x		x
Crepidula (Cs)	x						x						x		x	x	
Crepidula argentina (Ca)												x					x
Notocochlis isabelleana (Ni)										x		x			x	x	
Heleobia australis (Ha)		x		x		x	x	x	x		x	x	x		x		
Epitonium (E.) *georgettinum* (Ege)												x	x		x		
Epitenium striatellum (Est)															x		
Trophon patagonicus (Tpg)									x				x				
Urosalpinx cala (Uc)												x					
Zidona dufresnei (Zd)							x		x				x				
Adelomelon (P.) *brasiliana* (Ab)										x			x		x	x	x
Odontocymbiola magallánica (Om)			x						x								
Olivella (O.) *tehuelcha* (Oteh)									x	x			x		x		
Olivancillaria urceus (Ou)							x										
Olivancillaria carcellesi (Oc)									x			x			x		
Olivancillaria uretai (Otai)										x			x				
Buccinanops (Bs)	x														x		
Buccinanops monilifer (Bm)										x			x			x	
Buccinanops cochlidium (Bc)				x					x	x		x	x		x		
Buccinanops globulosus (Bg)		x	x	x	x	x		x	x			x	x				
Buccinanops uruguayensis (Bu)										x		x					
Parvanachis isabellei (Pi)											x						
Turbonilla argentina (Ta)											x						

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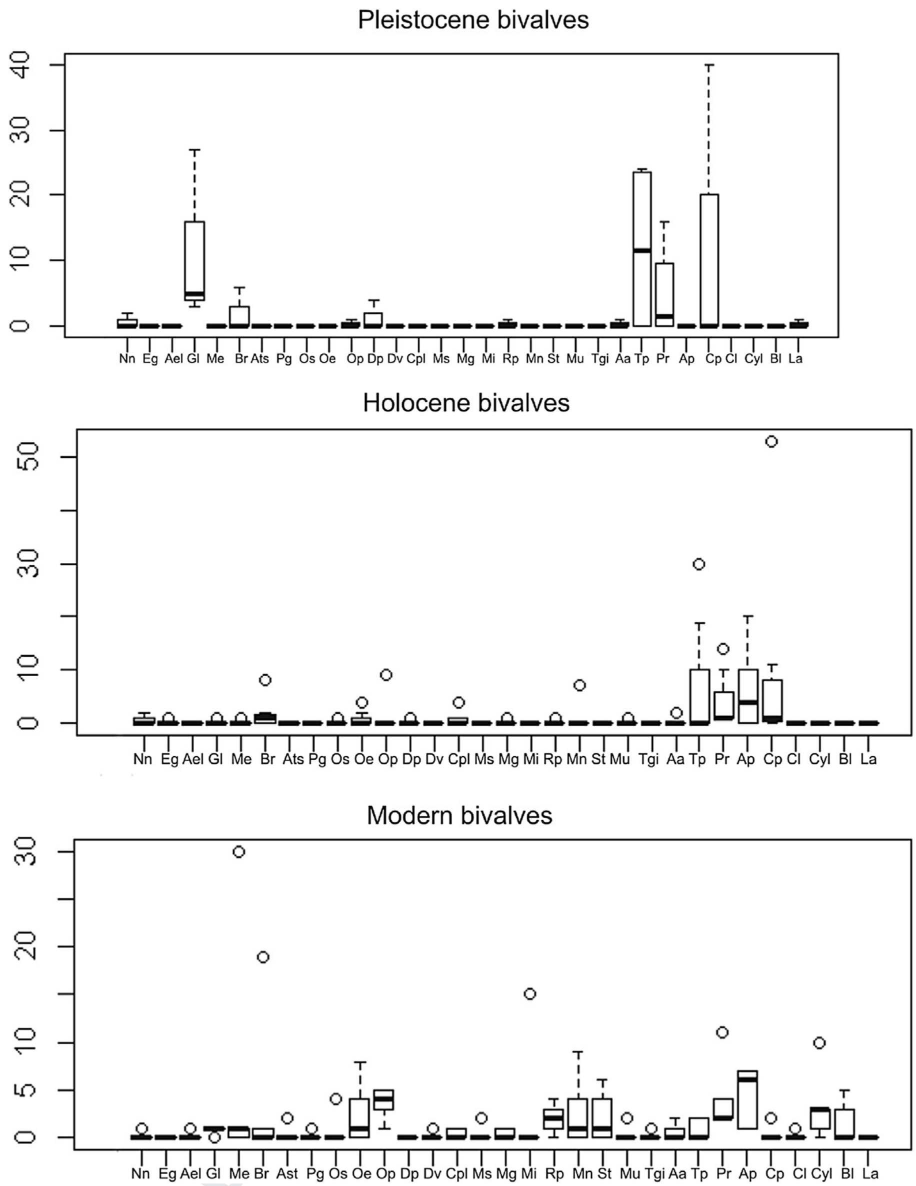

Fig. 13. Relative abundances of Quaternary bivalves of the area of the Colorado River delta (See Table 3).

dominant, and their feeding habits vary: filter feeders, detritivores and carnivores. Bivalves and gastropods that characterize the Mar Chiquita Formation are much more varied in the type of substrate, and of higher salinity than those of the Las Escobas Formation.

In the area of Bahía Blanca (38° 43′ S, south Buenos Aires Province), Pleistocene deposits (35.5–25 ka, minimum age; González, 1984), are characterized by the presence of two warm water species (*Crassostrea rhizophorae* and *Anomalocardia brasiliana*) (Chaar and Farinati, 1988), exclusive to the Pleistocene (Chaar et al., 1992), and only one of them is represented in the MIS 5e of the delta area. The Holocene deposits (7.4–1.4, MIS 1; Spagnuolo, 2005), correlated with the ridges of the Las Escobas Formation (Schnack et al., 2005), coincide 91.1% with the malacofauna of the study area (Farinati, 1985). In the Holocene deposits of Bahía Blanca, *Erodona mactroides*, *Tagelus plebeius* and *Heleobia australis* are dominant, the two latter being present and abundant in the Colorado River delta, indicating a lower salinity gradient.

5.1. *Southern Buenos Aires Province*

In the Colorado River delta, Interglacial ≥ MIS 9 is represented by species that continue in MIS 5e and MIS 1. This is also seen in the south of the study area, where at Anegada Bay (39° S), Charó et al. (2014) report marine deposits at 18 m height of Interglacial ≥ MIS 9 (Fucks et al., 2012b), with the most represented marine fauna being *Glycymeris longior*, *Zidona dufresnei* and *Buccinanops cochlidium*, recorded in this area today. In the area of San Blas Bay (40°S) the same fauna of Anegada Bay is recorded (Charó et al., 2013a, 2014) with *Pitar rostratus* and *Olivancillaria urceus*. In the northeast of the Buenos Aires Province (35°–36°S), deposits of this interglacial have not been preserved (Aguirre and Fucks, 2004). None of the studied deposits yielded warm water marine fauna which are displaced currently to lower latitudes (Charó et al., 2014).

In the south of the study area, at Anegada Bay, Charó (2014) recorded a larger amount of bivalves and gastropod species in MIS 5e with respect to MIS 1, the most abundant species in both

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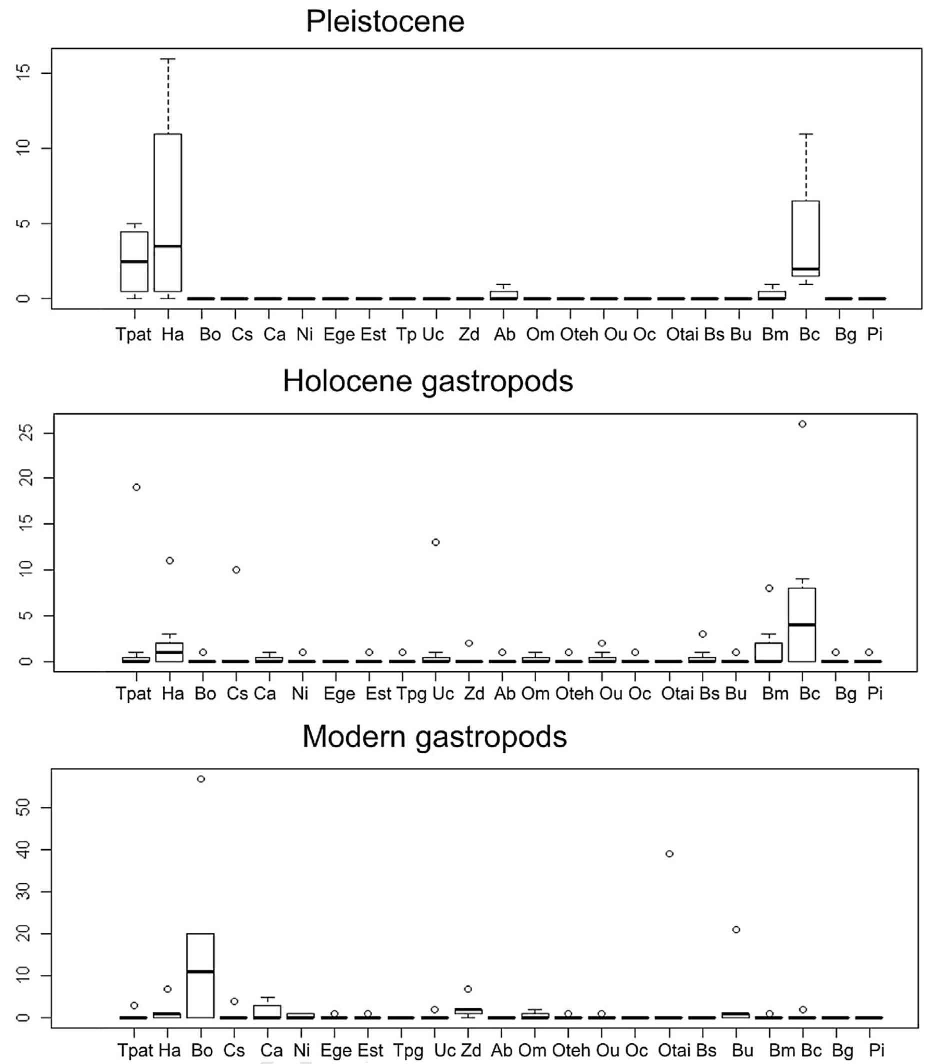

Fig. 14. Relatives abundances of Quaternary gastropods of the area of the Colorado River delta (See Table 4).

interglacials. In the Pleistocene ridges (38.5 and 28.7 ka; Weiler, 1993) assigned to the Last Interglacial (Weiler, 1993, 2000; Fucks et al., 2012a) there is a similarity of 66.6% with the study area. The appearance of *Crassostrea rhizophorae* in MIS 5e is noteworthy, as a bivalve of Caribbean lineage that currently lives at lower latitudes. In Holocene ridges associated with the postglacial transgression (Weiler, 1988, 1993) that vary between 5.9 and 3.6 ka (Charó et al., 2013a), the marine malacofauna has 75.7% similarity, with the presence of *Tagelus plebeius* and *Corbula patagonica*, which are among the most abundant species of low energy environments, coinciding with the Holocene deposits of the Colorado River delta.

In the area of San Blas Bay, the lowest indices of diversity and richness are those of the deposits of MIS 1 compared with those of MIS 5e (Charó et al., 2013a). The molluscan fauna of the Pleistocene

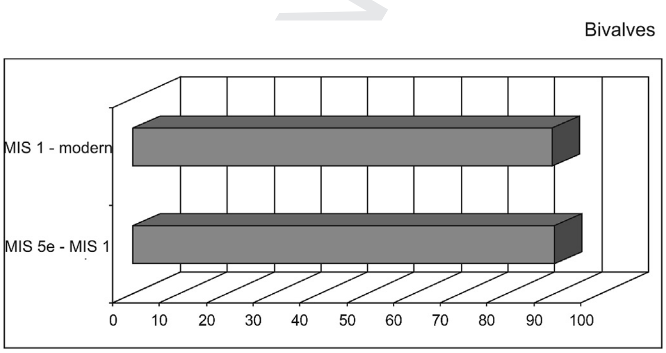

Fig. 15. Comparison of the relative abundances in percentages of bivalves in the different studied interglacials.

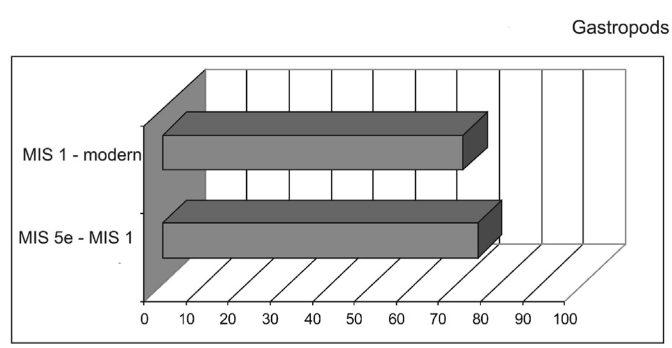

Fig. 16. Comparison of the relative abundances in percentages of gastropods in the different studied interglacials.

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Table 5
Ecological requirements and distribution of bivalves: Ep = epifaunal, I = infaunal, Ce = cemented; H = hard, S = soft; C = carnivorous, D = detritivorous, H = herbivore; Sf = suspension feeder; O = oligohaline (3–8 ‰), M = mesohaline (8–18 ‰), P = polyhaline (18–30 ‰), E = euhaline (>30–35 ‰). *Taxa found in the studied area.

Bivalves	Salinity	Life habit	Depth (m)	Substrate	Trophic type	Distribution area
Nucula (N.) nucleus	E	I	0–200	S	D	23°S–53.5°S
Ennucula grayi	E	I	5–1850	S	D	22.93°S–55.5°S
Adrana electa	E	I	20–75	S	D	22.93°S–39°S*
Glycymeris (G.) longior	E	I	10–75	S	Sf	10°S–42°S
Mytilus edulis platensis	P-E	Ep	0–50	H	Sf	68°N - 55.5°S
Brachidontes (B.) rodriguezii	P-E	Ep	0–25	H	Sf	34°S–42°S
Atrina seminuda	P-E	Ce	0–3	H	Sf	35°N–35°S*
Plicatula gibbosa	E	Ce	0–120	H	Sf	35.3°N–34°S*
Ostreola equestris	P-E	Ce	0–80	H	C	37°N–42°S
Ostrea puelchana	P-E	Ce	0–70	H	C	22°S–42°S
Diplodonta (D.) patagonica	E	I	36–102	S	Sf	21°S–42.58°S
Diplodonta (F.) vilardeboana	E	I	25–77	S	Sf	21°S–42°S
Carditamera plata	E	I	17–70	S	Sf	23°S–39°S*
Mactra guidoi	P-E	I	0–25	S	Sf	34°S–42°S
Mactra isabelleana	P-E	I	0–25	S	Sf	23°S–42°S
Raeta (R.) *plicatella*	P-E	I	0–11	S	Sf	39°N–41°S
Mesodesma mactroides	E	I	0–20	S	Sf	23°S–41°S
Solen tehuelchus	E	I	10–18	S	Sf	23°S–39°S*
Macoma (P.) uruguayensis	E	I	18–70	S	D	29°S–39°S*
Abra (A.) *aequalis*	E	I	0–50	S	D	35°N–23°S*
Tagelus (T.) plebeius	P	I	0–10	S	Sf	42°N–54°S
Pitar (P.) rostratus	E	I	10–100	S	Sf	22°S–38.7°S*
Amiantis purpurata	E	I	0–20	S	Sf	19°S–43°S
Corbula (C.) patagonica	E	I	15–90	S	Sf	23°S–43°S
Corbula (C.) lyoni	E	I	11–67	S	Sf	19°S–43°S
Cyrtopleura (S.) lanceolata	E	I	10–27	S	F	6°S–42°S
Barnea lamellosa	E	I	15–150	R	F	34°S–43°S
Lyonsia (L.)*alvarezii*	E	I	50–86	S	F	38.3°S–41°S
Periploma ovatum	E	I	?	S	F	35°S–40.5°S

deposits (30.7–28.9 ka; Trebino, 1987; Weiler, 2000) correlated with the Last Interglacial (Charó et al., 2013a), coincide 66.6% with those of the study area. Species are mostly euryhaline, epifaunal gastropods, and infaunal bivalves, of rocky and sandy substrates. Those of Holocene deposits (5.3–2.1 ka; Trebino, 1987) coincide with 83.8% similarity, most euryhaline, epifaunal, and of rocky and sandy substrates. In both areas located at the south of the Colorado River delta, warm water marine malacofauna is recorded for MIS 5e (*Crassostrea rhizophorae*), but not for MIS 1, as occurs in the area of Bahía Blanca (Chaar and Farinati, 1988).

During MIS 5e, changes of the geographic distribution of warm water marine molluscs are recorded (e.g., Muhs et al., 2002; Zazo et al., 2003, 2010; Aguirre et al., 2005). Some authors (e.g., Aguirre, 1993; Martínez et al., 2001) explain the high SST during MIS 5e by the southward displacement of the warm Brazil current. In the area of the Colorado River delta, MIS 5e and MIS 1 have in common the presence and abundance of *Heleobia australis* and *Tagelus plebeius*, typical species of low energy environments, and the record of *Glycymeris longior*, *Bostrycapulus odites* and *Buccinanops globulosus* in both deposits.

Table 6
Ecological requirements and distribution of gastropods: Ep = epifaunal, I = infaunal, Ce = cemented; H = hard, S = soft, M = mixed; C = carnivorous, D = detritivorous, H = herbivore; Sf = suspension feeder; O = oligohaline (3–8 ‰), M = mesohaline (8–18 ‰), P = polyhaline (18–30 ‰), E = euhaline (>30–35 ‰).

Gastropods	Salinity	Life habit	Depth (m)	Substrate	Trophic type	Distribution area
Tegula (A.) patagonica	E	Ep	0–57	H	He	23°S–54°S
Bostrycapulus odites	E	Ep	0–46	H	Sf	25°S–45.8°S
Notocochlis isabelleana	E	I	0–113	S	C	22.4°S–42.58°S
Heleobia australis	O, P, M	Ep	0–60	M	He	24°S–41°S
Epitonium (E.) georgettinum	E	Ep	0–101	M	He	23.37°S–44.27°S
Epitenium striatellum	E	Ep	30	M	He	23°S–41°S
Trophon patagonicus	E	Ep	0–50	H	C	32°S- 40°S
Urosalpinx cala	E	Ep	28–28	H	C	32°S–41°S
Zidona dufresnei	E	Ep	10–90	S	C	23°S–42°S
Adelomelon (P.) brasiliana	E	Ep	0–250	S	C	23°S–52°S
Odontocymbiola magallanica	E	Ep	10–200	M	C	35°S–55.2°S
Olivella (O.) tehuelcha	E	Ep	15–57	S	C	23.69°S–43°S
Olivancillaria urceus	E	Ep	5–50	S	C	19°S–42°S
Olivancillaria carcellesi	E	Ep	0–22	S	C	23°S–42.5°S
Olivancillaria uretai	E	Ep	0–30	S	C	23°S–40.6°S
Buccinanops monilifer	E	Ep	0–50	S	C	35°N–42°S
Buccinanops cochlidium	E	Ep	5–66	S	C	23°S–42.58°S
Buccinanops globulosus	E	Ep	0–6	S	C	35°S–46°S
Buccinanops uruguayensis	E	Ep	15–45	S	C	24°S–42°S
Parvanachis isabellei	E	Ep	10–65	S	C	30°S–54°S
Turbonilla argentina	E	Ec	18–57	S	C	35°S–41°S

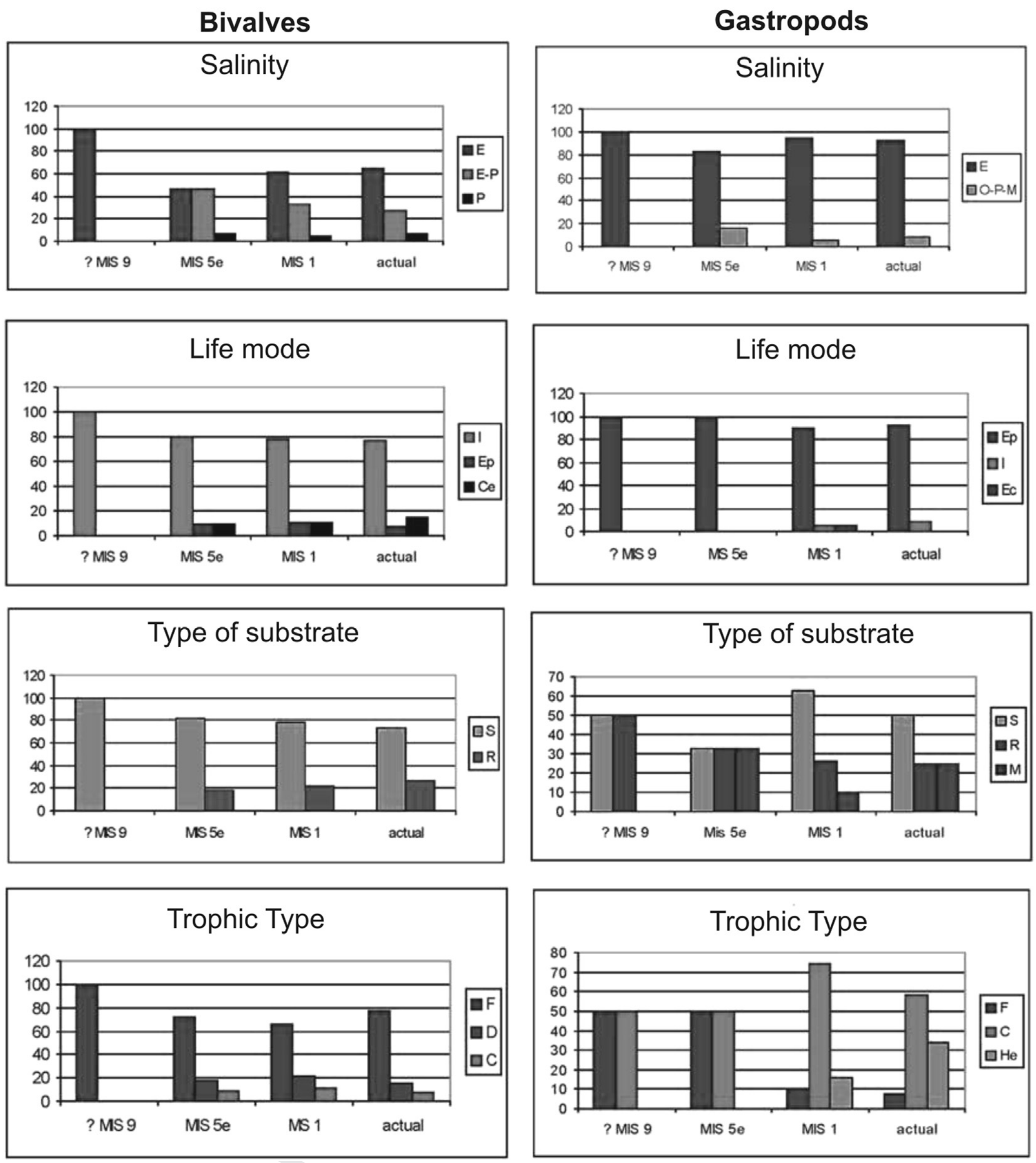

Fig. 17. Proportion of bivalves and gastropods according to salinity, life mode, type of substrate and trophic type.

In general, MIS 1 in Buenos Aires Province is represented by two types of deposits: tidal plains and littoral ridges. Tidal plains of the south of the Province of Buenos Aires are related to the development of the Colorado River and with the coeval geomorphological development related to island and tidal plains formation that affected the Colorado River, Anegada Bay and northern San Blas Bay. In the study area, as well as in Bahía Blanca area (Farinati et al., 1992), Anegada Bay (Charó et al., 2013b) and north of San Blas Bay (Charó et al., 2013a) the best represented bivalve in low energy marine deposits is *Tagelus plebeius*. The modern malacofauna of the study area records a higher richness index of species in MIS 1 respect to MIS 5e and ≥ MIS 9.

5.2. Northern Rio Negro Province

The fauna of marine bivalves and gastropods found in this area in the different interglacials differs in composition and abundance of species from those of the northern region of the San Matías Gulf (41° S). The Pleistocene deposits of northern Patagonia (Baliza San Matías Formation, 10–8 m, 107 and 72 ka) are correlated with Interglacial MIS 5e (Rutter et al., 1989, 1990; Fucks et al., 2012b; Charó et al., 2014), and coincide 55.5% with the molluscan fauna of the study area. Among the most abundant bivalves of northern Patagonia are *Amiantis purpurata*, *Glycymeris longior* and *Brachidontes rodriguezii*, and among gastropods; *Olivancillaria carcellesi* and *Olivancillaria urceus*. The most abundant species in the Colorado River delta are the bivalves *Glycymeris longior* and *Tagelus plebeius*, and the gastropods *Heleobia australis*, *Tegula patagonica* and *Buccinanops cochlidium*. The record of marine molluscs of low energy environments (e.g., *Heleobia australis*) is related to the geomorphological features of the area. Concerning the composition, northern Patagonia is characterized by *Anomalocardia brasiliana* and *Tegula atra*, the latter currently extinct in the Argentinean coasts (Charó et al., 2014). Since MIS 1 (San Antonio Formation, 2.43 ka; Charó et al., 2014), bivalves and gastropods changed in composition with respect to the MIS 5e, recording species such as *Aulacomya atra*, *Retrotapes exalbidus*, *Ameghinomya antiqua*, and the gastropods *Nacella magallanica* and *Fissurella*

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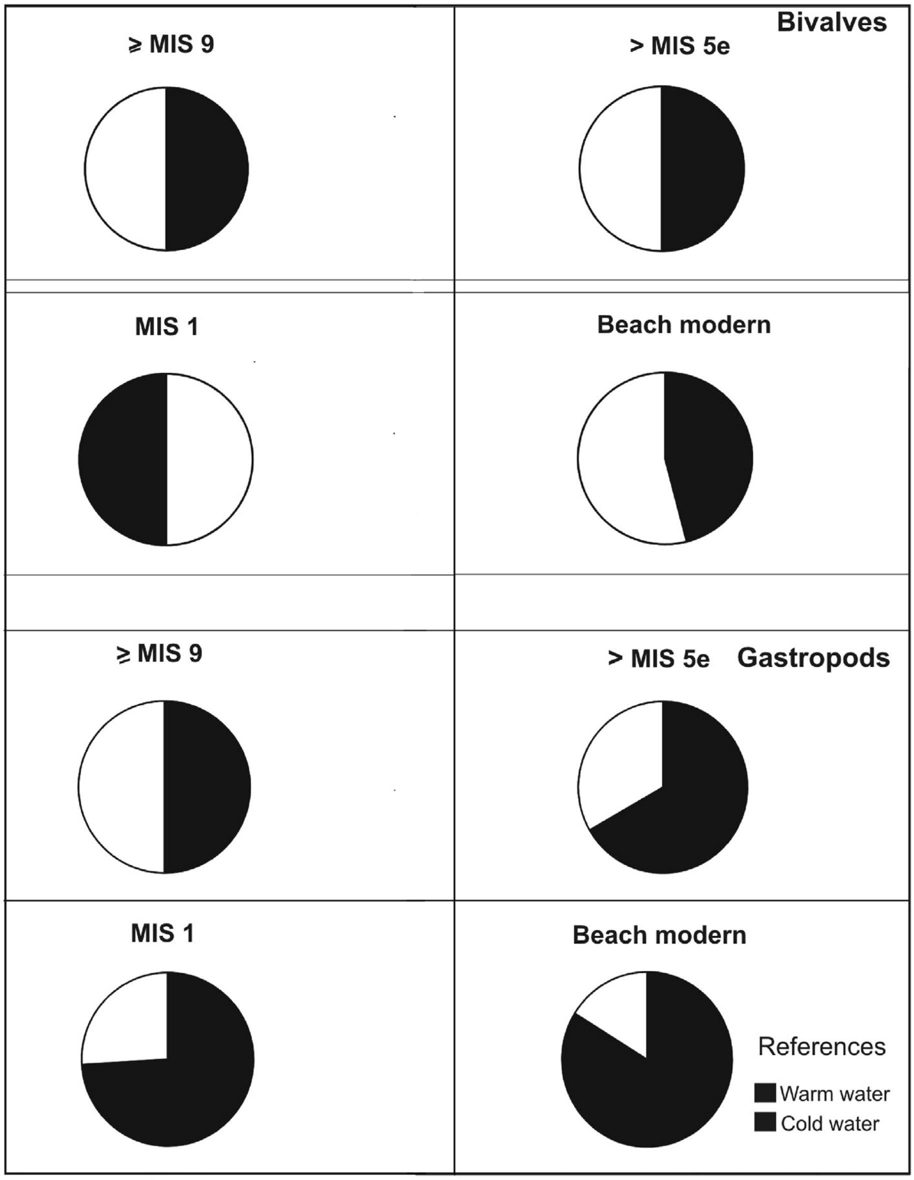

Fig. 18. Proportion of bivalves and gastropods of warm water and cold during the Quaternary.

radiosa radiosa typical of temperate-cold and cold waters of the Magellan Province. These are different from those bivalves and gastropods found in the area of the Colorado River delta, recording a similarity of 32.4% with those of the area of the Colorado River delta. Among the modern fauna, the record of bivalves such as *Ameghinomya antiqua*, *Retrotapes exalbidus* and *Aulacomya atra*, and gastropods such as *Crepidula dilatata* in the beaches north of the San Matías Gulf, differ greatly from the most common bivalves of

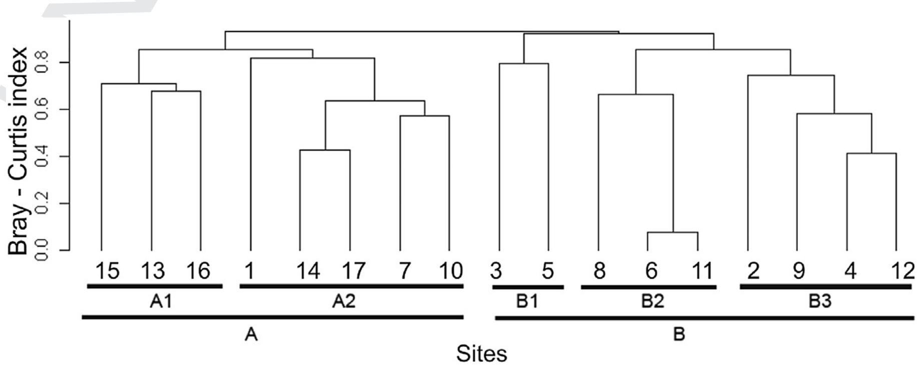

Fig. 19. Dendrogram of the studied sites based on the Bray–Curtis index.

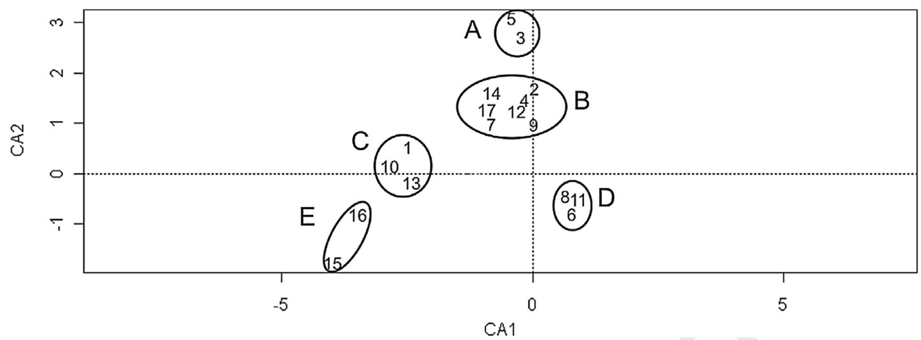

Fig. 20. Correspondence analysis (CA) based on the abundance of species. All sites form five groups A–E.

the south of the Buenos Aires Province such as *Cyrtopleura lanceolata*, *Barnea lamellosa*, *Solen tehuelchus* and *Mesodesma mactroides*. Despite these differences, they have 25 species in common (11 bivalves and 14 gastropods) of the total marine malacofauna, among them: *Amiantis purpurata*, *Glycymeris longior* and *Brachidontes rodriguezii*; and *Tegula patagonica*, *Bostrycapulus odites*, *Buccinanops cochlidium* and *Buccinanops globulosus* (Charó, 2014; Charó et al., 2014). The Negro River area is considered an "ecotone" influenced by the area of San Matías Gulf, which explains the presence of cold-water species and species in common with the Province of Buenos Aires.

5.3. Southern Patagonia

The malacological assemblages of southern Argentinean Patagonia have currently higher percentage of typical cold-water species, belonging to the Magellan Malacological Province, which is related since post-Miocene times to the cold Malvinas Current (del Rio, 2004). The Magellan Malacological Province extends along the Atlantic Ocean south of 42–55° S, comprising the Fuegian archipelago, Malvinas Islands and the Burdwood Bank, extending into the Pacific Ocean to southern Chile (44° S; Bastida et al., 2007).

During the Holocene, the proportion of bivalves and gastropods of the Colorado River delta is higher than in Península Valdez (42° 31′ S, Province of Chubut) (37 species vs. 28 species) with 13.5% similarity with the study area in two sites: Isla de los Pájaros and Punta Pardelas (Pastorino, 1989). In Isla de Los Pájaros (42° 25′ S) there are two Holocene ridges (Terrace VI or Comodoro Rivadavia terrace, F. San Miguel) (Feruglio, 1950; Haller, 1982) with four species in common with the study area (*Mytilus edulis platensis*, *Notochoclis isabelleana*, *Buccinanops globulosus* and *Olivella tehuelcha*; Pastorino, 1989). Most species are euryhaline, of sandy substrate and carnivores, and belong to the Magellan Malacological Province (Pastorino, 2000). In Punta Pardelas (42° 36′ S), the Holocene marine malacofauna (Terrace VI or Comodoro Rivadavia Terrace; Pastorino, 1989, 2000) coincides in three species with the study area (*Notochoclis isabelleana*, *Odontocymbiola magallanica* and *Ostrea puelchana*). Both sites have in common the presence of *Aulacomya atra*, *Ameghynomia antiqua*, and *Hiatella arctica*, among the most important, which are not recorded in the area of the Colorado River delta.

The proportion of Quaternary bivalves and gastropods is higher in the area of the Colorado River delta than in the area of Bahía Vera – Camarones (44.2° S–45° S) (51 species vs. 41 species). In the Pleistocene deposits 135–92 ka (Terrace V of Feruglio, MIS 5e?a?c?; Rostami et al., 2000) 22.2% of the marine malacofauna of the study area are shared with the latter area. All species are euryhaline, mostly epifaunal, both of rocky and sandy substrates, and filter feeders. Most of these species persisted since the Pleistocene, except for *Pitar rostratus*, *Brachidontes rodriguezii* and *Tegula patagonica* which are today displaced farther north, and *Tegula atra* which is extinct in the Atlantic Ocean (Aguirre et al., 2011; Charó et al., 2014). Feruglio (1950) recorded the bivalves *Corbula patagonica*, *Diplodonta vilardeboana* and *Mactra cf. patagonica* (Aguirre et al., 2007) in Pleistocene deposits of the area of Vera Bay – Camarones (Terrace III, 400 ka, MIS 11), which are today displaced to lower latitudes, and inhabiting the area of the delta, suggesting warmer waters in MIS 11 than today (Ortlieb et al., 1996). Holocene deposits (Terrace VI of Feruglio, 8–2.5 ka, MIS 1; Codignotto et al., 1988, 1993; Schellmann and Radtke, 2000; Rostami et al., 2000) have 18.9% similarity, with all the species epifaunal, mostly euryhaline, of rocky substrate and filter feeders.

In the area of Bustamante Bay – Caleta Malaspina (44.9°–45.3° S), the Pleistocene marine malacofauna coincides 33.3% with that of the study area (Feruglio, 1933, 1950; Cionchi, 1987; Aguirre et al., 2005). The species *Olivella tehuelcha*, *Trophon patagonicus*, *Pitar rostratus*, *Mactra isabellei* and *Mactra guidoi* coincide with the malacofauna of the delta area and are recorded in Pleistocene ridges as well (Terrace IV?, 211–227 ka and Terrace V of Feruglio, 155–98 ka; Rutter et al., 1989, 1990; Schellmann and Radtke, 2000) of the Bustamante area, but live today in lower latitudes (Feruglio, 1933, 1950; Aguirre et al., 2005). In the Holocene ridges (Terrace VI of Feruglio) (2.0 ka; 2.8 ka; 5.3–6.7 ka; Codignotto, 1983; Schellmann and Radtke, 1997, 2000) the similarity is only 16.21%, with typical cold-water species of the Magellan Malacological Province being recorded in higher abundance (Aguirre et al., 2005).

In the San Jorge Gulf (45°–47° S), Aguirre (2003) reported a total of 27 molluscs (12 bivalves and 15 gastropods). In the Pleistocene deposits (Terrace V of Feruglio, 39–25 ka, minimum ages; Codignotto, 1983; Rutter et al., 1990; Schellmann and Radtke, 1997) correlated with the Pascua Formation (MIS 5e) in Samborombón Bay (Aguirre, 2003), the similarity of the marine malacofauna with the study area is 11.1%, with species of Group II (*Bostrycapulus odites* and *Buccinanops globulosus*) which are typically tropical, subtropical or warm water species of the Argentinean Malacological Province. The Holocene deposits of Solano Bay, Rada Tilly and Langara Bay (Terrace V of Feruglio; 2–6.4; 5.2; 5 ka respectively; Codignotto et al., 1988, 1990; Shellmann and Radtke, 1997) correlated with the Las Escobas Formation in Samborombon Bay (Aguirre, 2003), coincide 8.1% with the fauna of the study area, with predominance of species of the Argentinean Malacological Province, indicators of slightly warmer waters during the Pleistocene and Holocene with respect to the current marine malacofauna of the area. In Tierra del Fuego, Porvenir Bay (53° 18′ S), the only species recorded in common with the study area is the bivalve *Pitar rostratus*, today displaced to lower latitudes, found in a single Holocene deposit (4–5 ka, MIS 1; Cárdenas and Gordillo, 2009).

6. Conclusions

The littoral deposits of the area of the Colorado River delta correspond to paleocliffs, littoral ridges, and tidal plains with associated marine malacofauna. Since MIS 9, euryhaline species typical of high energy environments of rocky and sandy substrates are dominant. In MIS 5e, species of quiet and brackish waters and sandy substrate increase, with *Tagelus plebeius* and *Heleobia australis* being more common, with higher diversity of species. At local scales, there are no significant changes in the taxonomic composition, but there are changes in abundance of the species among different interglacials. At regional scale, shifts of species toward lower latitudes are recorded along the coast of the South Atlantic (ej. *Crassostrea rhizophorae*, *Anomalocardia brasiliana*) as well as extinct species (ej. *Tegula atra*). The causes of the presence of different local and regional malacofaunal associations could be attributed to global climate changes (e.g., changes in STT, salinity, etc.) and the heterogeneity of sub-environments in the study area during the Quaternary.

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