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Late Quaternary molluscs from the northern San Matías Gulf (Northern Patagonia, Argentina), southwestern Atlantic: Faunistic changes and paleoenvironmental interpretation

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ABSTRACT

The Late Quaternary in the coastal area of South America is represented mostly by littoral ridges, cliffs and tidal plains, with associated remains of gastropods and bivalves currently used as paleoclimatic indicators. The aim of this study is to characterize the assemblages of molluscs (bivalves and gastropods) both Pleistocene (≥MIS 9, MIS 7, MIS 5e) and Holocene (MIS 1), from the northern San Matías Gulf (Northern Patagonia, Argentina) in the southwestern Atlantic Ocean, in order to assess whether faunal change occurred together with Late Quaternary climatic change. Twenty localities were studied, seven from different interglacial stages of the Pleistocene, six Holocene, and seven modern beaches, in which 42 species were recorded, 20 bivalves and 22 gastropods. Among bivalves, euryhaline, infaunal from sandy substrates, and filter feeders, prevail. *Amiantis purpurata* is the dominant species of the whole mollusc assemblage. Among gastropods, although also euryhaline, the epifaunal species of rocky and sandy substrates and carnivores prevail. On the basis of descriptive statistical analyses, Bray–Curtis and AC methods, the localities formed three groups according to ages (modern vs. Pleistocene and Holocene) and/or presence/abundance of species. 70% of the marine malacofauna of MIS 7 remains during MIS 5e, decreasing to 60% during MIS 1 and to 27% when compared to the modern beaches. The most notable changes in the distribution of the species were: *Tegula atra*, currently extinct in the Argentine Atlantic coast, but recorded in Pleistocene interglacials MIS 7 and MIS 5e; *Anomalocardia brasiliana*, which only appeared in MIS 5e, and *Mesodesma mactroides* in MIS 1. MIS 5e was likely the warmest stage within the period considered, followed by MIS 7, both with higher SST temperatures than the present ones, and since MIS 1, molluscs of temperate-cold lineages of the Magellan malacological province are recorded.

1. Introduction

The Quaternary is characterized by global climatic oscillations, with alternating glacial and interglacial periods, producing sea level fall and rise, respectively (e.g. Rohling et al., 2008). In coastal areas, transgressive–regressive events are recorded as erosive forms (e.g. paleocliffs, coastal terraces) and littoral deposits (e.g. littoral ridges, tidal planes, beaches), which for various reasons have been preserved from degradation processes, being important evidence of climate changes in recent geologic times (Shackleton, 1987).

The best studied interglacials worldwide, differentiated through marine isotopic stages (MIS), are MIS 11, MIS 9, MIS 7, MIS 5e, and MIS 1, which represent the warmest events during the Late Quaternary. The longest interglacial of the last 500 ka is MIS 11 (Berger and Loutre, 2002). It is characterized by oscillations of warm–cold climate (e.g. Bassinot et al., 1994; Tzedakis et al., 1997). From 425 ka to 390 ka there was a stable warming, whereas after360 ka an extremely cold climate began (Ashton et al., 2008). Some authors consider that during MIS 11 sea level reached approximately 6 m (e.g. Murray-Wallace, 2002; Bowen, 2003), and others 20 m a.s.l. (Hearty et al., 1999; Olson and Hearty, 2009). MIS 11 is considered analogous to the recent interglacial (e.g. Berger and Loutre, 2002; Bowen, 2010). MIS 9 comprised from ca. 330 to 310 ka, and sea

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level was 3 ± 3 m below the present one (Pedoja et al., 2011). In the Northern Hemisphere (NH) the highest sea levels are recorded between 334 ± 4 and 324 ± 3 ka, coincident with the maximum insolation of 333 ka (Stirling et al., 2001).

MIS 7 occurred from 230 to 190 ka (Pedoja et al., 2011) and, on the basis of isotopic data from some deep oceanic cores, sea level would have been below the present zero (Ortlieb, 1987; Shackleton, 1987), around −20 m (Dutton et al., 2009). MIS 5e occurred between 130 and 119 ka (Hearty et al., 2007) with a rise of the mean global surface temperatures at least 2 C° higher than today (Muhs and Kyser, 1987; Murray-Wallace and Belperio, 1991; Murray–Wallace et al., 2000; Rohling et al., 2008). Hearty et al. (2007) proposed that sea level at 120 ka was between 6 and 9 m a.s.l. For this interglacial, warm-water benthic marine molluscs are recorded worldwide, as well as changes in their geographic distribution (e.g. Muhs and Kyser, 1987; Lario et al., 1993; Muhs et al., 2002; Zazo et al., 2003; De Diego-Forbis et al., 2004; Zazo et al., 2010; Pereira Lopes and Simone, 2012).

MIS 1 is the most recent interglacial, defined for the last 11.7 ka, beginning with the end of the last glaciation (Walker et al., 2009). The mean temperature of the Earth surface during the Holocene oscillated between 14° and 15 °C, except for some short periods of abrupt cooling (deMenocal et al., 2000). The Holocene is characterized globally by the Climatic Optimum or *Hypsithermal* recorded mainly in the NH during the middle Holocene (8.7–7.8 ka). Evidence of a rise of the surface sea temperature and higher humidity have been recorded worldwide (e.g. Funder and Weidick, 1991; Salvigsen et al., 1991; Hjort et al., 1995; Rohling and De Rijk, 1999; Yuan et al., 2011) with some records in the Southern Hemisphere (SH; e.g. Aguirre, 1990, 1993, 2002; Cohen et al., 1992; Lutaenko, 1993). This event is reflected by changes in the composition, abundance, diversity and distribution of the benthic communities (e.g. Lutaenko, 1993; Parmesan, 2006) with the highest point around 6 ka. Since 4 ka the climatic conditions changed and a decrease of the oceanic surface temperature is probably coincident with a slight decrease of the sea level.

For South America, evidence of the last transgressive–regressive events has been recorded in Brazil (e.g. Caruso et al., 2000; Barreto et al., 2002), Uruguay (e.g. Goso Aguilar, 2006), Chile (e.g. Ota et al., 1995; Paskoff, R. 1999; Quezada et al., 2007), and Argentina (e.g. Feruglio, 1950; Angulo et al., 1978; Cionchi, 1987; Codignotto et al., 1988; Rutter et al., 1989, 1990; Codignotto and Aguirre, 1993; Isla, 1998; Schelmann, 1998; Isla et al., 2000; Rostami et al., 2000; Schellmann and Radtke, 2000, 2003; Weiler, 2000; Schnack et al., 2005; Bujalesky and Isla, 2006; Isla and Bujalesky, 2008; Fucks et al., 2009, 2010, 2012a,b; Pedoja et al., 2011).

In Argentina, Quaternary littoral deposits are represented along the whole littoral from the Río de la Plata (34°S) south to Tierra del Fuego (55°S) (Rostami et al., 2000; Schnack et al., 2005). Marine terraces, littoral ridges, paleocliffs, and paleobeaches can be observed along the Patagonian Argentinian coast. The age and altitude of these deposits are controversial (e.g. Feruglio, 1950; Rutter et al., 1989, 1990; Codignotto et al., 1992). Different heights may have been caused by subduction of the Nazca Plate and glacial isostasy (Rostami et al., 2000), and also as a consequence of an anomaly of the mantle convection (Pedoja et al., 2011). According to the ESR method (Electron Spin Resonance) most dates were interpreted as belonging to MIS 5e (Rutter et al., 1989, 1990), whereas the ages obtained through amino stratigraphy and U series suggest that they correspond to MIS 7 and older (e.g. Rostami et al., 2000; Schellmann and Radtke, 2000; Bujalesky et al., 2001; Pedoja et al., 2011).

Recently, Fucks et al. (2012b) recognized at least four transgressive–regressive marine events along the northern coast of San Matías Gulf, Río Negro Province (41°S); three of them assigned to the Pleistocene (MIS5e, MIS7 and an older one) and the fourth to the Holocene (MIS1). The Baliza San Matías and San Antonio formations (Angulo et al. 1978) would belong to the two last transgressive–regressive events of the Pleistocene: MIS 7 and MIS 5e, respectively (Fucks et al. 2012b). The malacofauna of these deposits is represented by benthic molluscs, mainly bivalves and gastropods, whose good preservation makes them useful as proxies of paleoclimates and paleoenvironmental record. Their systematic identification allows a correlation with environmental parameters such as temperature, salinity, and substrate. These parameters contribute to the interpretation of the paleoenvironment and paleocommunities through time.

The aim of this paper is to describe the malacological assemblages that characterize the different Quaternary marine deposits of the northern San Matías Gulf in order to evaluate whether faunistic changes occurred together with climatic changes during ≥MIS 9, MIS 7, MIS 5e, and MIS 1.

1.1. Study area

The study area comprises the northern coast of San Matías Gulf and extends from the vicinities of El Cóndor beach (41°02′S; 62°49′W) to Piedras Coloradas (40°51′S; 65°7′W) (Fig. 1). It is represented by paleobeaches and littoral ridges (gravel and sand deposits), and coastal plains and paleocliffs (cemented gravels) (Figs. 2 and 3).

Twenty localities were studied (Table 1), seven Pleistocene of different interglacial stages, six Holocene, and seven modern beaches. The illustrated material is housed in the Paleontological Collection of the Centro de Investigaciones Paleobiológicas de la Universidad Nacional de Córdoba, Argentina (CIPAL-CEGH-UNC).

Table 1
Description of sampled localities at northern Río Negro Province, Argentine.

Localities	Age	Coordinates (Lat–long)	Geomorphology	Altitude (m.a.s.l.)
1	Pleistocene (≥MIS 9)	40°39′53.13″S/65° 0′21.11″W	Beach ridge made of sandy and grave sediment with cemented by calcium carbonate	60
2	Pleistocene (MIS 7)	40°49′14.62″S/64°44′14.29″W	Coastal plains	2–1
3		40°51′45.77″S/65° 7′32.70″W	Coastal plains	2–1
4	Pleistocene (MIS 5e)	40°49′4.45″S/64°44′22.58″W	Beach ridge made of sandy and grave sediment with cemented by calcium carbonate	8
5		40°42′34.38″S/64°51′53.09″W	Littoral ridges	9
6		40°42′28.41″S/64°57′51.71″W	Beach ridge made of sandy and grave sediment with cemented by calcium carbonate	9
7		40°48′20.95″S/65° 4′35.72″W	Paleobeach	10
8	Holocene (MIS 1)	41°03′35.6″S/63°59′30.7″W	Beach	8–5
9		40°50′22.22″S/64°39′18.36″W	Beach	5
10		40°49′44.58″S/64°52′39.12″W	Microcliff	9–7

(*continued on next page*)

Table 1 (*continued*)

Localities	Age	Coordinates (Lat–long)	Geomorphology	Altitude (m.a.s.l.)
11		40°47′50.38″S/64°52′50.73″W	Cliff	9–5
12		40°47′09.9″S/64°50′52.2″W	Beach crests	9–5
13		40°47′6.23″S/64°50′55.26″W	Beach crests	9–5
14	Modern	41°02′52.4″S/62°49′17.5″W	Beach	0
15		40°49′13.83″S/64°44′20.94″W	Beach and coastal plains	0
16		40°49′16.86″S/64°44′9.32″W	Beach and coastal plains	0
17		40°47′44.12″S/64°52′38.57″W	Beach	0
18		40°49′50.58″S/64°52′46.47″W	Beach made of sandy and graves sediment (valves)	0
19		40°45′17.15″S/64°56′33.7″W	Beach	0
20		40°48′21.82″S/65° 4′35.62″W	Beach	0

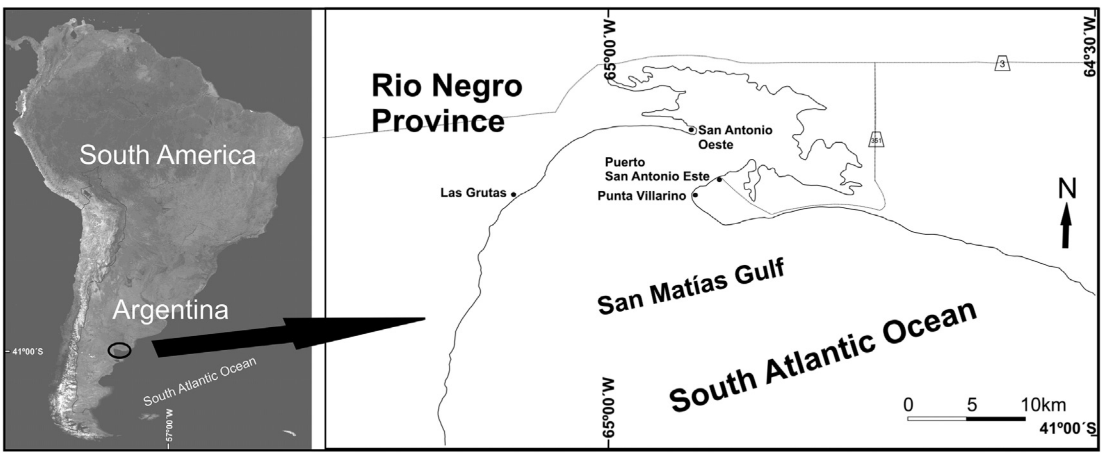

Fig. 1. Location map, showing the study area of San Matias Gulf in the Rio Negro Province, Argentina.

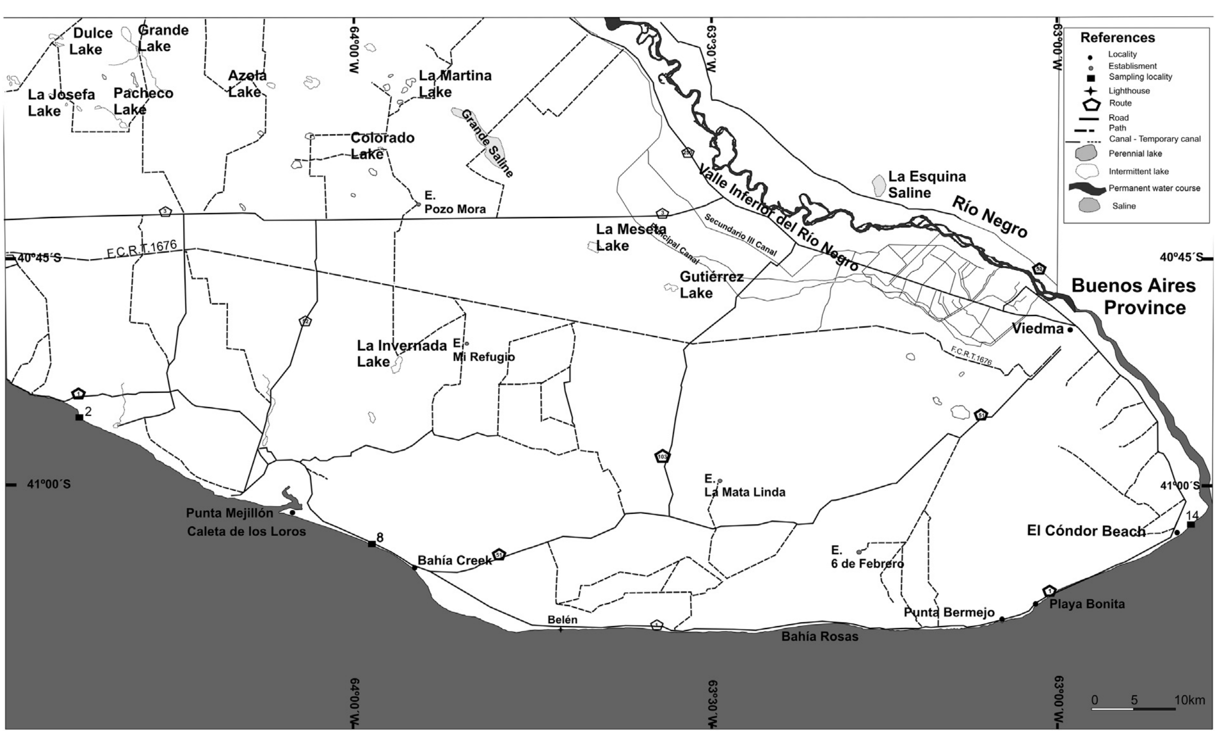

Fig. 2. Map showing the Pleistocene, Holocene and Modern sampling sites at northeastern Río Negro Province.

1.2. Geological background

The Quaternary marine deposits from the studied region were first described by Wichmann (1918), who assigned them to a Quaternary formation recognized near the coast of San Antonio Bay. Later, Feruglio (1950) reported these coastal deposits and their associated malacofauna. He recognized five marine terraces along the whole Patagonian coast according to their different altitudes. The deposits studied here are equivalent to Terrace VI (Comodoro Rivadavia) (Martínez et al., 2001a).

Angulo et al. (1978) separated the deposits located within San Antonio Bay into two stratigraphic units: Baliza San Matías (late Pleistocene) and San Antonio (Holocene) formations, on the basis of their morphology, degree of lithification and stratigraphic position. The San Antonio Formation yielded ^{14}C ages in mollusc shells between 40 and 28 ka, interpreted as retransported from older sediments.

Fidalgo et al. (1980) correlated the San Antonio and Baliza San Matías formations with the Pascua and Las Escobas formations of the northeastern bonaerensian region. Recent studies (Rutter et al., 1989, 1990; Fucks and Schnack, 2011; Fucks et al., 2012b) distinguished in the northern Río Negro at least four marine transgressive–regressive events, three Pleistocene and one (weakly-developed) Holocene level. Rutter et al. (1989, 1990) analyzed different Quaternary deposits including the area of San Antonio Oeste, and using amino acids and ESR obtained ages between 97–80 and 70–66 ka for the youngest Pleistocene deposits and ≥230 and ≥169 ka for the oldest ones. These ages confirm that the interglacials ≥MIS 9, MIS 7 and MIS 5e are those most probably represented in this area (Table 2).

1.2.1. Marine Quaternary deposits of northern San Matías Gulf

Along the northern San Matías Gulf, three Pleistocene–Holocene transgressive cycles were recognized, pertaining to ≥MIS 9, MIS 7, MIS 5e and MIS 1 (Fig. 4). According to Fucks et al. (2012b), the interglacial MIS 7 and MIS 5e deposits correspond to Baliza San Matías and San Antonio formations, respectively, and those of Holocene age have no designation (Fig. 4).

Furthermore, in the intertidal sectors, sands and gravels of a Pleistocene sea level are exposed and subject to erosion (Rutter et al., 1990). These coastal plains, best exposed in Baliza San Matías, and south of Las Grutas, are gently sloping towards the sea, several km long and 500–1000 m wide, visible during low tides. This transgressive–regressive event would correspond to MIS 7, whose height respect to the sea level would have been lower than MIS 5e (Ortlieb, 1987; Shackleton, 1987), and has been identified both south and east of the studied area (Gelós et al., 1988, 1993).

Other littoral forms representing old sea levels have been developed along the coast. From south of Las Grutas, a continuous ridge of lineations parallel or oblique to the coastline, relatively low (between 0.5 and 1 m) separated by depressions, is observed at up to 15 m a.s.l., representing MIS 5e (Fucks et al., 2012b). Finally, marine deposits, partially covered by dunes, assigned to MIS 1 have been described at 2–5 m a.s.l. In some sectors they cannot be recognized and are replaced by tidal plains.

1.3. Malacological background

Feruglio (1950) contributed largely to the knowledge of the marine Quaternary malacofauna of Patagonia, identifying and listing

Table 2
Absolute datings available from the study area.

Rio Negro province	Geological age (ESR and ^{14}C) Rutter et al. 1989, 1990; Fucks et al., 2012b	Localities	Fucks et al., 2012	Altitude (m.a.m.s.l.)
		Localities 1	≥MIS 9	60
	≥230 and ≥169	Caleta Falsa correlation with localities: south of Piedras Coloradas and west of Faro San Matías (Fucks et al., 2012b)	MIS 7	1–2
	230–208 ka	Baliza Camino	MIS 5e	9
	97.3–83 ka	Baliza San Matías	MIS 5e	8
	107–91 ka	La Rinconada	MIS 5e	10
	70.3–66.8 ka	Las Grutas	MIS 5e	10
	2.43 ka (^{14}C)	La Conchilla	MIS 1	1.50

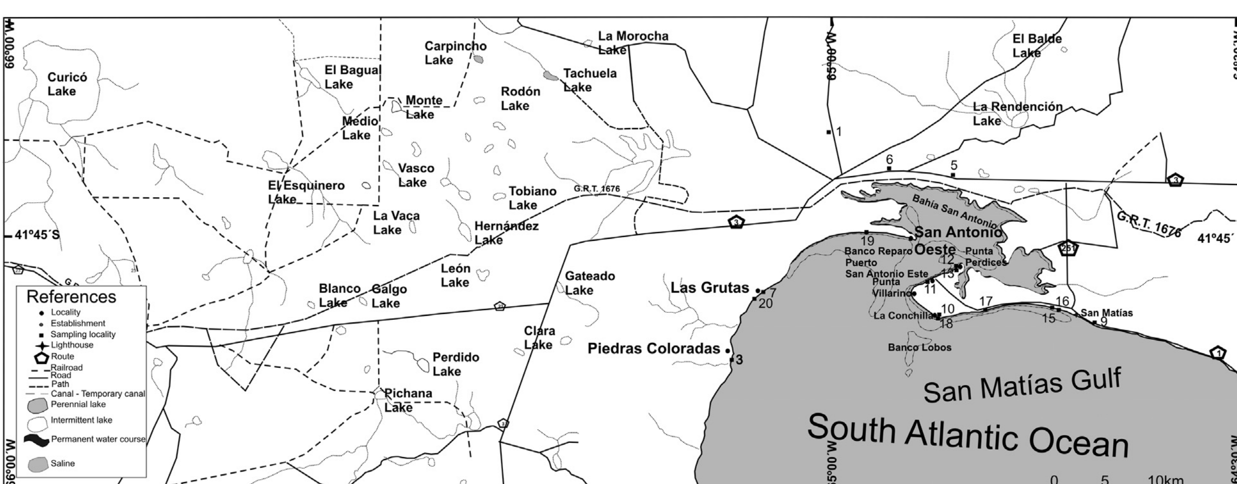

Fig. 3. Map showing the Pleistocene, Holocene and Modern sampling sites at northwestern Rio Negro Province.

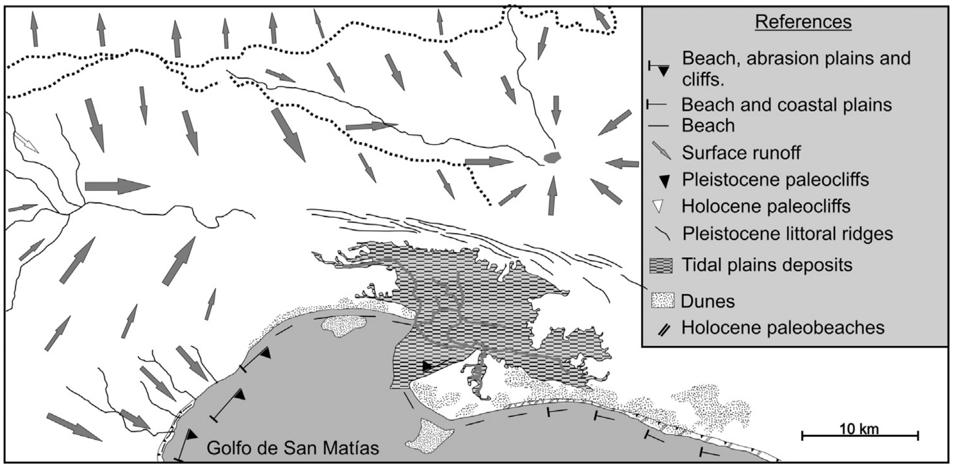

Fig. 4. Pleistocene and Holocene ridges of the northern region of San Matías Gulf (Fucks et al., 2012b).

gastropods and bivalves from the terraces of the Argentine Patagonia. Richards and Craig (1963) also contributed taxonomic information about Pleistocene molluscs of the Argentine platform. Later, several illustrated catalogs and specific works for the recognition of gastropods and bivalves of the Patagonian area were published (e.g. Castellanos, 1990, 1992; Ríos, 1994; Pastorino, 1991ab, 1994, 2000; Aguirre and Farinati, 2000; Forcelli, 2000; among others). Other works, focused on geomorphology and geochronology of the Quaternary deposits, also mentioned mollusc species for several localities including Las Grutas, La Rinconada, San Antonio Oeste and Baliza San Matías (i.e. Angulo et al., 1978; Gelós et al., 1988; Rutter et al., 1989, 1990; Fucks et al., 2012b). Other works centered on Pleistocene molluscs from different sectors of Patagonia Argentina include Pastorino (1991b, 1994, 2000), Aguirre (2003), Aguirre and Codignotto (1998), Aguirre et al. (2005, 2006, 2007, 2011), and, in Tierra del Fuego, that of Gordillo and Isla (2011).

2. Materials and methods

The samples of sediment and molluscs (1 dm^3) collected in the marine deposits were exposed to running water using three sieves of different mesh size 2.80, 1.40 and 0.080 mm. Then, a sequence of washing and drying on paper was followed. For those deposits in which the matrix was partially hardened, the samples were taken as blocks of 1 kg which were disintegrated with water to separate the molluscs, avoiding breakage of the material. Each specimen or biogenic fragment was identified and labeled. The identification of species was made with catalogs and systematic papers (e.g. Castellanos, 1990, 1992; Pastorino, 1994, 1999, 2002, 2005; Ríos, 1994; Guzmán et al., 1998; Forcelli, 2000; Clavijo et al., 2005; Penchaszadeh et al., 2007).

Absolute abundance of each species was calculated for each locality. Multivariate analyses (cluster analysis) were carried out with R software, version 2.15.0 (vegan package) (Oksanen, 2011) to analyse the degree of similarity between localities. UPGMA was used to group the faunal associations according to the Bray–Curtis Index. In addition, a second descriptive method, Correspondence Analysis (CA), was used to observe relationships between sites.

3. Results

3.1. Localities and taxa composition

3.1.1. Interglacial ≥MIS 9. locality 1

The Pleistocene deposit (40°39′S; 65°00′W) (Locality 1) found at 60 m a.s.l., is composed of clast-supported gravels cemented by calcium carbonate. This deposit is correlated with ≥MIS 9. The marine malacofauna is badly preserved, allowing identification only at genus level. The scarce fragments of shells belong to *Ostrea* sp. (Fig. 5).

3.1.2. Interglacial MIS 7. localities 2 and 3

Wide coastal plains are developed in the intertidal zone, discordantly underlain by Miocene marine sediments or volcanites.

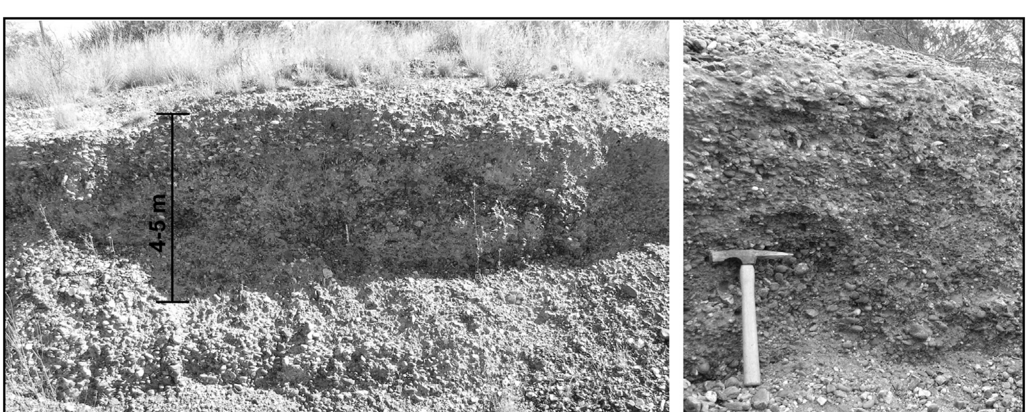

Fig. 5. Pleistocene outcrops (≥MIS 9) of gravels at 60 m height, with *Ostrea* sp. (Locality 1).

They are composed by sands and/or conglomerates, partially or completely lithified, forming beds 20–50 cm thick, varying from a gentle slope to 25–30° SE (Martínez et al., 2001a; Fucks et al., 2012b). The studied ones are those of west of Faro San Matías and south of Piedras Coloradas (Localities 2 and 3). Rutter et al. (1990) obtained ages >169 and 218 ka. They were correlated with the deposits of Caleta Falsa (Río Negro Province, Argentina) and assigned to MIS 7 (Fucks et al., 2012b) (Fig. 6).

3.1.3. Interglacial MIS 5e. Localities 4–7

An outstanding geomorphological feature of the area is the development of paleocliffs 1–3 m a.s.l. more or less continuous created by the Holocene transgression over the deposits of MIS 5e. As MIS 5e is the maximum transgression, the other substages of MIS 5, a, b and c, would not be represented in the northern coast of the gulf and would be below the present sea level. Consequently, we consider that all these deposits belong to MIS 5e.

At locality 4 west of Faro San Matías, this interglacial is represented by a littoral ridge 8 m a.s.l. composed of sand strata with gravels scarcely cemented, and remains of complete shells of the bivalves *Glycymeris longior* and *Amiantis purpurata* and the gastropod *Adelomelon brasiliana*.

Two other localities of San Matías Gulf (5 and 6) were analyzed. Locality 5, Baliza Camino, is a beach deposit 0.70 m thick of alternating fine beds of clast-supported gravels and sand with articulated and in life position fossils, mainly *Brachidontes rodriguezi*, a typical bivalve of intertidal hard substrates (Fig. 7).

In locality 6 (40°42′S; 64°57′W), MIS 5e is represented by a littoral ridge 1.30 m high at 9 m a.s.l. It is composed of sandy facies with shells settled in a concave-down orientation, and conglomerate facies. The most abundant marine fauna is represented by the bivalves *Aequipecten tehuelchus*, *G. longior* and *A. purpurata* (Fig. 8).

The most representative locality of MIS 5e is La Rinconada beach (Locality 7), at Las Grutas (1–1.5 m thick) (Fig. 9). Sandy sediments (Fig. 9Ca, c and e) alternate with fine gravels (Fig. 9C b and d), finely stratified and covered by brownish sands and silts with malacofauna (Fucks et al. 2012b). According to Rutter et al. (1990) the age of these deposits varies between 107 and 72 ka. Despite this calculated age, Rutter et al. (1989, 1990) and afterwards Fucks et al. (2012b) refer to this site as belonging to MIS 5e.

3.1.4. Interglacial MIS 1. localities 8–13

The marine deposits of MIS 1 are scarce and correspond to the withdrawal of the sea after the maximum transgression of the Middle Holocene (Favier Dubois et al., 2006). Because they reached 3–4 m a.s.l., the cliffs were not inundated by this transgressive–regressive event. They can be clearly seen at the low coasts or erosive areas. From the end of the cliffs at the north of Las Grutas, thin sand and fine pebble beds with shells can be seen below the dunes (Localities 8 and 9).

Locality 10, La Conchilla beach, is a microcliff 1.50 m thick with four different levels clearly dominated by *A. purpurata*. The first one is 0.70 m thick, clast-supported and fragmented shells (Fig. 10B a). The second level is 0.30 m thick of finer sand with isolated shells (Fig. 10B b). The third one is 0.10 m thick composed of sands with fragmented shells (Fig. 10B c), and the fourth level is 0.40 cm thick composed of finer sands with entire shells (Fig. 10B d). This deposit has one ^{14}C date that yielded an age of 2.43 ± 0.60 ka (LP: 2889).

Near the harbor of San Antonio Este (SAE; locality 11) deposits of MIS 1 are exposed along 200 m, 2 m thick, covered by 1–4 m of dunes (Fig. 11). The transgressive deposits are composed of two types of parallel strata, 10–15 cm thick with transitional contact. They have shells in chaotic position with entire and fragmented remains, generally concave-down with high proportions of pebbles. The finer-sediment strata are variable, although the deposit is always clast-supported.

Near Punta Perdices (Locality 12), there is a series of beach crests, of low relative height, 100 m wide and longer than 1 km, with remains of shells. The altitude varies 9–5 m between the highest and lowest crests (Fig. 12). There is a small quarry (Locality 13) 0.60–0.50 m thick of medium sands alternating with entire shells (Fig. 13).

3.1.5. Modern beaches. Localities 14–20

Modern beaches of the northern area of Río Negro Province are composed almost exclusively by entire and fragmented molluscs at the top and medium to fine sand at the low intertidal sectors, more than 100 m wide. The beaches at southern Baliza San Matías can be divided into two groups. Those in the north are 30–80 m wide, changing into the abrasion plain toward the sea, and to a sandy

Fig. 6. Coastal plain of the Interglacial MIS 7 south of Faro San Matías (Locality 2).

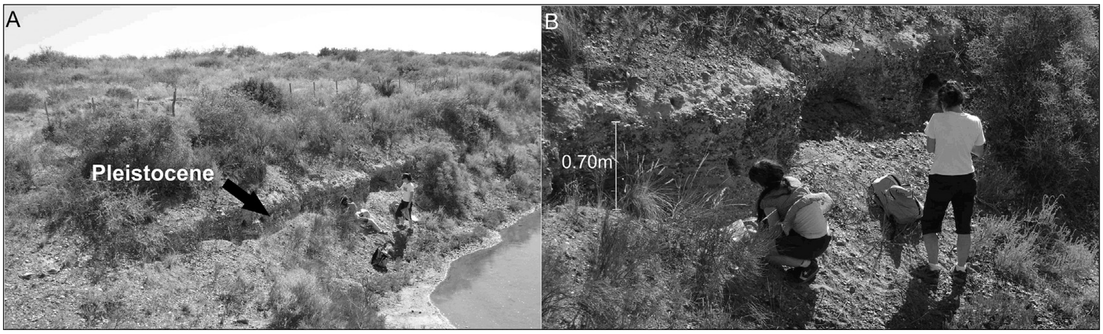

Fig. 7. A and B, Pleistocene outcrop of the Interglacial MIS 5e at Baliza Camino (Locality 5).

berm toward the continent that continues in a dune ridge with slopes between 7 and 10%. Those to the south are sandy to coarse gravelly sand, discontinuous, and smaller (Gelós et al. 1993).

The closest locality to the Buenos Aires – Río Negro provincial border is El Cóndor Beach (Locality 14) (41°02′S; 62°49′W), a fine-sand beach approximately 750 m wide. Among the marine malacofauna, the bivalves *Plicatula gibbosa* and *Ostrea puelchana* and the gastropod *Crepidula* sp. are abundant.

Localities 15 and 16, near Faro San Matías, are sandy open beaches, built on a coastal plain of MIS 7. The bivalves *A. purpurata*, *Retrotapes exalbidus* and *A. tehuelchus*, and the gastropod *Buccinanops cochlidium*, are recorded.

Locality 17 (40°47′S; 64°52′W), near the harbor of SAE, beaches are sandy with shells in great quantities. The bivalves *B. rodriguezi* and *Mytilus edulis platensis*, and the gastropods *Tegula patagonica* and *Crepidula* sp. are common.

The modern beach La Conchilla (Locality 18) (40°49′S; 64°52′W) is a wide sandy beach whose supra tidal zone is almost organogenic with large amounts of mollusc shells mostly of *A. purpurata* (Fig. 14).

The coast of Playa Villarino is formed mostly by *A. purpurata*. It is a fine sand beach with gentle slope, about 11 km long and up to 600 m wide. The beaches developed within the San Antonio Bay have higher slopes, about 15–20°, and are composed almost exclusively of fine and medium gravels and shells, with storm ridges newly formed (e.g. Morsán, 1997; Fucks et al., 2012b).

Locality 19 (40°45′S; 64°56′W), near San Antonio Oeste, is a fine sand beach 200–300 m wide formed by the bivalves *G. longior* and *B. rodriguezi*, and the gastropods *Bostrycapulus odites* and *Buccinanops globulosum*, among the most abundant species.

The modern beach of Las Grutas (Locality 20) (40°48′S; 65°4′W) is a sandy beach between the cliff and the coastal plain 60 to 20 m wide forming a wedge on the cliff. *G. longior* and *B. rodriguezi*, and *B. globulosum* and *Olivancillaria carcellesi* are among the most abundant bivalves and gastropods respectively (Fig. 15).

3.2. Ecological changes over time

A total of 42 species (20 bivalves and 22 gastropods) were recorded (Tables 3 and 4). Among them, five micromolluscs were identified; one bivalve: *Corbula lyoni*, and four gastropods: *Heleobia australis*, *Parvanachis isabellei*, *Olivella tehuelcha* and *Costoanachis sertulariarum*.

Table 3
Quaternary bivalves. Locality 1: Pleistocene (MIS 9), Localities 2–3: Pleistocene (MIS 7), Sites 4–7: Pleistocene (MIS 5e), Localities 8–13: Holocene (MIS 1), Localities 14–20: Modern.

Bivalvia	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Glycymerididae Newton, 1922																				
Glycymeris (G.) *longior* (Sowerby, 1832)			X	X	X	X	X					X	X	X	X	X			X	X
Mytilidae Rafinesque, 1815																				
Mytilus edulis platensis d'Orbigny, 1846							X				X	X		X		X	X			
Brachidontes (B.) *rodriguezi* (d'Orbigny, 1846)		X	X		X		X		X					X		X	X		X	X
Aulacomya atra (Molina,1782)												X								X
Pectinidae Rafinesque, 1815																				
Aequipecten tehuelchus (d'Orbigny, 1842)		X			X	X			X		X	X			X	X		X		
Plicatulidae Watson, 1930																				
Plicatula gibbosa Lamarck, 1801			X											X						
Ostreidae Rafinesque, 1815																				
Ostrea sp.	X																			
Ostreola equestris (Say, 1834)																	X		X	X
Ostrea puelchana d'Orbigny 1841						X	X		X		X	X	X	X	X	X	X		X	X
Cardiidae Lamarck, 1809																				
Trachycardium muricatum (Linné, 1758)							X					X			X					
Mactridae Lamarck, 1809																				
Mactra guidoi Signorelli & F. Scarabino, 2010			X																X	
Mesodesmatidae Gray, 1839																				
Mesodesma mactroides (Reeve, 1854)											X									
Veneridae Rafinesque, 1815																				
Tivela isabelleana (d'Orbigny, 1846)				X		X	X													
Anomalocardia brasiliana (Gmelin, 1791)					X															
Pitar (P.) *rostratus* (Philippi, 1844)				X		X	X													X
Amiantis purpurata (Lamarck, 1856)		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X

Table 3 (*continued*)

Bivalvia	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Retrotapes exalbidus (Dillwyn, 1817)								X							X					
Ameghinomya antiqua (King & Broderip, 1832)								X							X	X				
Hiatellidae Gray, 1824																				
Panopea abbreviata Valenciennes, 1839							X													
Corbulidae Lamarck, 1818																				
Corbula (*C.*) *lyoni* (Pilsbry, 1897)														X						
Thraciidae Stoliczka, 1870																				
Thracia similis Couthouy, 1839														X			X			

Table 4
Quaternary gastropods. Locality 1: Pleistocene (MIS 9), Localities 2–3: Pleistocene (MIS 7), Localities 4–7: Pleistocene (MIS 5e), Localities 8–13: Holocene (MIS 1), Localities 14–20: Modern.

Gastropods	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Nacellidae Thiele, 1891																				
Nacella (*P.*) *magallanica* (Gmelin, 1791)									X											
Fissurellidae Fleming, 1822																				
Fissurella radiosa radiosa Lesson, 1831												X								
Lucapinella henseli (Martens, 1900)														X						X
Calliostomatidae Thiele, 1924																				
Tegula (A.) *patagonica* (d'Orbigny, 1835)							X					X	X			X	X			
Tegula atra Lesson 1830		X	X				X													
Calyptraeidae Blainville, 1824																				
Bostrycapulus odites (Collin, 2005)			X		X				X			X		X	X	X	X	X	X	X
Crepidula sp.			X							X	X	X		X	X	X	X	X		
Crepidula dilatata Lamarck, 1822													X		X					X
Naticidae Forbes, 1828																				
Notocochlis isabelleana (Collin, 2005)																X				
Hydrobiidae Troschel, 1857																				
Heleobia australis (d'Orbigny, 1835)				X	X											X				
Muricidae da Costa, 1776																				
Trophon sp.																X	X	X		
Trophon patagonicus (d'Orbigny, 1839)		X					X					X							X	
Trophon geversianus (Pallas,1774)									X										X	
Volutidae Rafinesque, 1815																				
Adelomelon (P.) *brasiliana* (Lamarck, 1811)				X																
Odontocymbiola magallanica (Gmelin, 1791)									X				X		X					X
Olividae Latreille, 1825																				
Olivella (*O.*) *tehuelcha* (Dúclos, 1835)														X		X				X
Olivancillaria urceus (Röding, 1798)				X		X														
Olivancillaria carcellesi Klappenbach, 1965			X	X			X		X		X		X			X	X	X	X	X
Nassariidae Iredale, 1916																				
Buccinanops cochlidium (Dilwyn, 1817)				X					X		X	X	X		X		X			X
Buccinanops globulosum (Kiener, 1834)				X			X									X	X	X	X	X
Buccinanops uruguayensis (Pilsbry, 1897)											X									
Columbellidae Swaison, 1840																				
Parvanachis isabellei (d'Orbigny, 1839)																X				
Costoanachis sertulariarum (d'Orbigny, 1839)																X				
Siphonariidae Gray, 1840																				
Siphonaria lessoni Blainville, 1824							X		X			X				X	X			

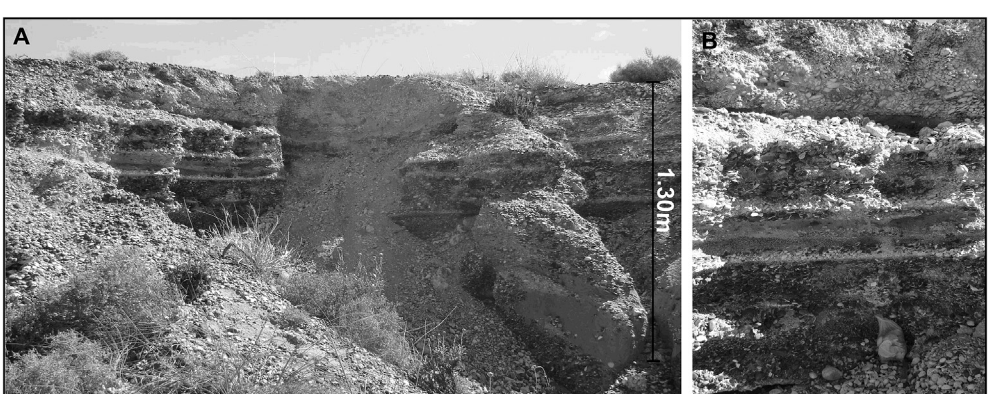

Fig. 8. Pleistocene outcrop (MIS 5e) (Locality 6).

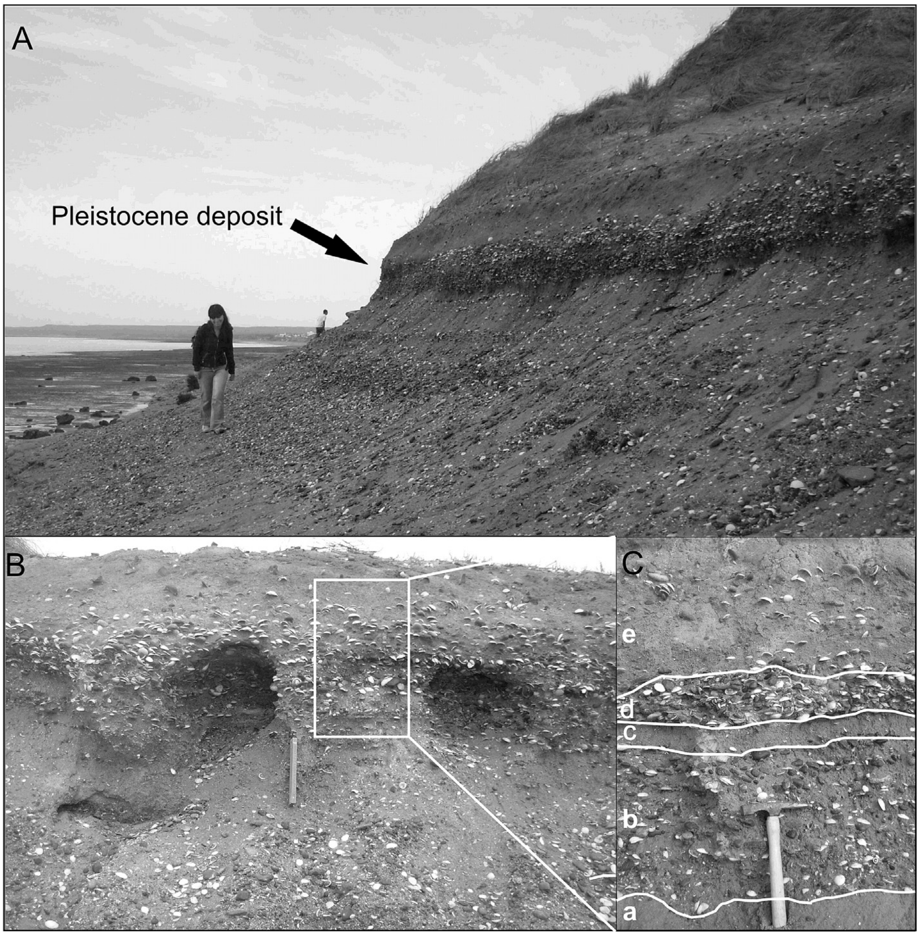

Fig. 9. A and B, Pleistocene outcrops (MIS 5e) at La Rinconada (Locality 7); C, detailed profile with sands (a, c, and e).

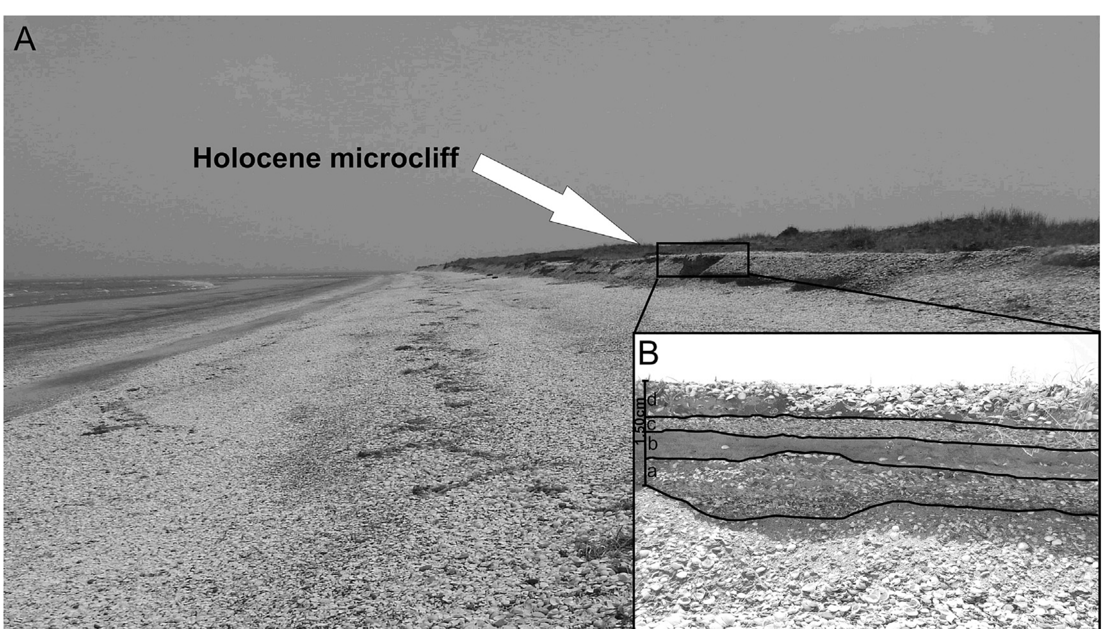

Fig. 10. A, Holocene microcliff at La Conchilla; B, Profile of the microcliff composed of levels with shells (Locality 10).

According to the paleoecological analysis, the malacofauna of MIS 7 is characterized by euryhaline bivalves, mostly infaunal and epifaunal, of sandy substrates with rocky and mixed ones, all filter feeders. In MIS 5e, bivalves are mostly euryhaline, with increases in proportion of euryhaline – polyhaline species. Most are infaunal, sandy substrate, carnivore species. From MIS 1 to the present, the ecological factors of the recorded species remain almost constant, regarding salinity, life mode, and substrate and trophic type (Fig. 16) (Table 5).

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

Bivalvia	Salinity	Life habit	Depth (m)	Substrate	Trophic type	Distribution area
Glycymeris (G.) *longior* (Sowerby, 1832)	E	I	10–75	S	Sf	10°S–42°S
Mytilus edulis platensis d'Orbigny, 1846	P-E	Ep	0–50	R	Sf	68°N–55.5°S
Brachidontes (B.) *rodriguezi* (d'Orbigny, 1846)	E	Ep	0–25	R	Sf	34°S–42°S
Aulacomya atra (Molina, 1782)	E	Ep	0–30	R	Sf	34°S–55.5°S
Aequipecten tehuelchus (d'Orbigny, 1842)	E	Ep	10–120	M	Sf	21°S–53°S
Plicatula gibbosa Lamarck, 1801	E	Ce	0–120	R	Sf	35.3°N–34°S*
Ostreola equestris (Say, 1834)	P-E	Ce	0–80	R	C	37°N–42°S
Ostrea puelchana d'Orbigny 1841	P-E	Ce	0–70	R	C	22°S–42°S
Trachycardium muricatum (Linné, 1758)	E	I	0–11	S	Sf	35°N–42°S
Mactra guidoi Signorelli &Scarabino	P-E	I	0–25	S	Sf	34°S–42°S
Mesodesma mactroides (Reeve, 1854)	E	I	0–20	S	Sf	23°S–41°S
Tivela isabelleana (d'Orbigny, 1846)	E	I	0–55	S	Sf	21°S–42°S
Anomalocardia brasiliana (Gmelin, 1791)	P-E	I	0.3–5	S	Sf	18°N–39°S*
Pitar (P.) *rostratus* (Philippi, 1844)	E	I	10–100	S	Sf	22°S–38.7°S*
Amiantis purpurata (Lamarck, 1856)	E	I	0–20	S	Sf	19°S–43°S
Retrotapes exalbidus (Dillwyn, 1817)	E	I	50–70	S	Sf	34°S–55.5°S
Ameghinomya antiqua (King & Broderip, 1832)	E	I	5–50	S	Sf	34°S–54°S
Panopea abbreviata Valenciennes, 1839	E	I	25–75	S	Sf	23°S–48°S
Corbula (C.) *lyoni* Pilsbry, 1897	E	I	11–67	S	Sf	19°S–43°S
Thracia similis Couthouy, 1839	E	I	50–86	S	Sf	22°S–42.58°S

In MIS 7, all gastropods are euryhaline and infaunal, mostly of rocky and sandy substrates, and carnivores, with increases of filter feeder and herbivore species. Since MIS 5e, most gastropods are euryhaline, with some oligohaline–polyhaline and mesohaline. All species are epifaunal, with increases of those associated with rocky substrates, and herbivore species. In MIS 1, gastropods are all euryhaline and epifaunal, with increases of those living on rocky substrates and carnivores. Today, most species are euryhaline, but with oligohaline–polyhaline–mesohaline taxa and infaunal species. There is an increase of sandy substrate and carnivore species (Fig. 17) (Table 6).

3.2.1. Pleistocene

A total of eleven species were recorded in MIS 7 (Localities 2 and 3) (five gastropods and six bivalves), very well preserved (Fig. 18). The most abundant were the herbivore gastropod *T. atra*, and the filter feeder infaunal bivalve *A. purpurata*.

In MIS 5e, represented by littoral ridges (Localities 4–7) at 8–10 m a.s.l., molluscs were more diverse than in MIS 7, with 22 species (11 gastropods and 11 bivalves). Among the most abundant were the bivalves *A. purpurata*, *G. longior* and *B. rodriguezi*, and the gastropods *H. australis*, *O. carcellesi* and *Olivancillaria urceus* (Figs. 19 and 20). The record of *A. brasiliana* is notable in Locality 5.

3.2.2. Holocene

Six localities were analyzed (8–13) and 23 species were recorded, (11 bivalves and 12 gastropods) (Figs. 21 and 22). The most abundant species are: *A. purpurata*, *O. puelchana* and *A. tehuelchus* (bivalves), and *B. cochlidium*, *Crepidula* sp. and *O. carcellesi* (gastropods). The record of the bivalve *Mesodesma mactroides* is outstanding, as a single specimen found along the northern San

Table 6
Ecological requirements and distribution of gastropods. Ep, epifaunal; I, infaunal; S, soft substrate; H, hard substrate; M, mixed substrate; Sf, suspension feeder; C, carnivore; D, detritivorous; He, herbivore; O, oligohaline (3–8‰); M, mesohaline (8–18‰); P, polyhaline (18–30‰); E, euryhaline (>30–35‰). * Distribution range extending to the Pacific.

Gasteropods	Salinity	Life habit	Depth	Substrate	Trophic type	Distribution area
Nacella (*P.*) *magallanica* (Gmelin, 1791)	E	Ep	0–200	R	He	38.5°S*–55.5°S
Fissurella radiosa radiosa Lesson, 1831	E	Ep	0	R	He	48°S–55°S
Lucapinella henseli (Martens, 1900)	E	Ep	0–55	R	He	23°S–53°S
Tegula (A.) *patagonica* (d'Orbigny, 1835)	E	Ep	0–57	R	He	23°S–54°S
Tegula atra Lesson 1830	E	Ep	0–9	R	He	38°S–55°S *
Calliostoma carcellesi Clench y Aguacho, 1940	E	Ep	0–60	S	He	40.37°S–41.67°S
Bostrycapulus odites (Collin, 2005)	E	Ep	0–46	R	Sf	25°S–45.8°S
Crepidula dilatata Lamarck, 1822	E	Ep	0–66	R	Sf	35°S–55.8°S
Notocochlis isabelleana (d'Orbigny, 1840)	E	I	0–113	S	C	22.4°S–42.58°S
Heleobia australis (d'Orbigny, 1835)	O, P, M	Ep	0–60	M	He	24°S–41°S
Trophon patagonicus (d'Orbigny, 1839)	E	Ep	0–55	R	C	32°S–40°S
Trophon geversianus (Pallas,1774)	E	Ep	0–586	R	C	36.42°S–54.98°S
Adelomelon (P.) *brasiliana* (Lamarck, 1811)	E	Ep	8–70	S	C	23°S–52°S
Odontocymbiola magallanica (Gmelin, 1791)	E	Ep	10–200	M	C	35°S–55.2°S
Olivella (O.) *tehuelcha* (Dúclos, 1835)	E	Ep	15–57	S	C	23.69°S–43°S

(continued on next page)

Table 6 (*continued*)

Gasteropods	Salinity	Life habit	Depth	Substrate	Trophic type	Distribution area
Olivancillaria urceus (Röding, 1798)	E	Ep	5–50	S	C	19°S–42°S
Olivancillaria carcellesi Klappenbach, 1965	E	Ep	0–22	S	C	23°S–42.5°S
Buccinanops uruguayensis (Pilsbry, 1897)	E	Ep	15–45	S	C	24°S–42°S
Buccinanops cochlidium (Dilwyn, 1817)	E	Ep	5–66	S	C	23°S–42.58°S
Buccinanops globulosus (Kiener, 1834)	E	Ep	0–6	S	C	35°S–46°S
Parvanachis isabellei (d'Orbigny, 1839)	E	Ep	10–65	S	C	30°S–54°S
Costoanachis sertulariarum (d'Orbigny, 1839)	E	Ec	0–20	S	C	35°N–54°S;
Siphonaria lessoni (Blainville, 1824)	E	Ep	0	R	He	32°S–55.22°S

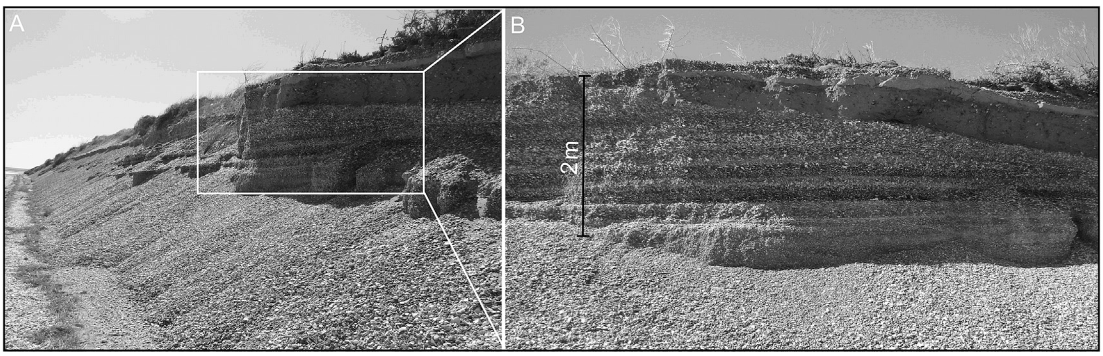

Fig. 11. A, B Holocene cliff near San Antonio Este harbor (Locality 11).

Matías Gulf. This species is recorded at present to southern Buenos Aires Province (Charó et al., 2013).

3.2.3. Modern beaches

Thirty one species (16 bivalves and 15 gastropods) were found in the six modern localities. Among them were *B. rodriguezi*, *G. longior* and *A. purpurata* (bivalves), and *Crepidula* sp., *B. globulosum*, *B. odites* and *O. carcellesi* (gastropods). The bivalves *Aulacomya atra, R. exalbidus*, *Ameghinomya antiqua* and the gastropods *Fisurella radiosa radiosa* and *Crepidula dilatata* are typical of the Río Negro beaches.

3.3. Malacological associations

3.3.1. Bray–Curtis method

According to the descriptive-statistical method of Bray–Curtis, there are three different associations (A, B and C) in the interglacials represented in the study area. Localities 1 and 8 are isolated. Association A is composed by two Pleistocene localities (2 and 6) with two bivalves *A. purpurata* and *A. tehuelchus*. Association B is composed by all the modern localities, with the gastropod *B. odites* and *Crepidula* sp.; among them, localities 16 and 17 are the most similar, having in common the abundance of *B. rodriguezi* (bivalvia). Group C is divided into subgroups C1 and C2. C1 belongs mostly to MIS 1, except for two localities of modern beaches 15 and 18. *O. puelchana* and *A. purpurata* are recorded in all localities. Localities 11 and 15 are the most similar to each other (Bray–Curtis index approximately 0.40), with abundance of *A. purpurata*, *A. tehuelchus* and *B. cochlidium*. Localities 10 and 18 are similar (Bray–Curtis index approximately 0.40), in location (La Conchilla, near Punta Villarino) and in abundance of *A. purpurata* and *Crepidula* sp. C2 belongs mostly to MIS 7 and MIS 5e characterized by the abundance of *G. longior*, *B. rodriguezi* and *O. carcellesi*. The modern localities 19 and 20 have a high diversity index and higher number of species, with abundance of species similar to localities of MIS 5e (localities 4, 5 and 7) and MIS 7 (locality 3) (Fig. 23).

Fig. 12. Holocene ridges at Punta Perdices (Locality 12).

3.3.2. Correspondence analysis (CA)

Three different associations (A, B, and C) are distinguished in all localities, except for three (localities 1, 14 and 20): Association A has *A. purpurata*, *R. exalbidus* and *A. antiqua*. Association B corresponds to Pleistocene localities of MIS 7 and MIS 5e and most of MIS 1. In all of these localities the bivalve *A. purpurata* is abundant. Association C corresponds to modern beaches with *A. purpurata* and the gastropods *B. odites* and *O. carcellesi*. Outlet localities, such as locality 1, belong to ≥MIS 9 with abundant *Ostrea* sp. Locality 14, El Cóndor beach, is characterized by the abundance of *P. gibbosa* and *Crepidula* sp. Locality 20, the southernmost beach, at Las Grutas, is characterized by *G. longior* and *B. globulosum* (Fig. 24).

4. Discussion

Marine bivalves and gastropods found in ≥MIS 9, MIS 7, MIS 5e, and MIS 1 in the study area differ in composition and abundance.

Fig. 13. Holocene quarry at Punta Perdices (Locality 13).

Fig. 14. Modern beach La Conchilla (Locality 18).

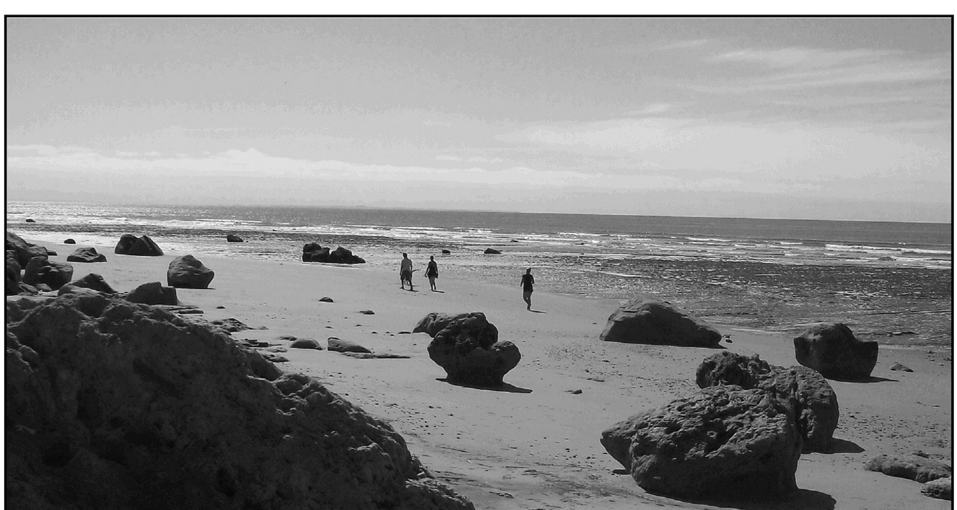

Fig. 15. Sandy beach of Las Grutas (Locality 20).

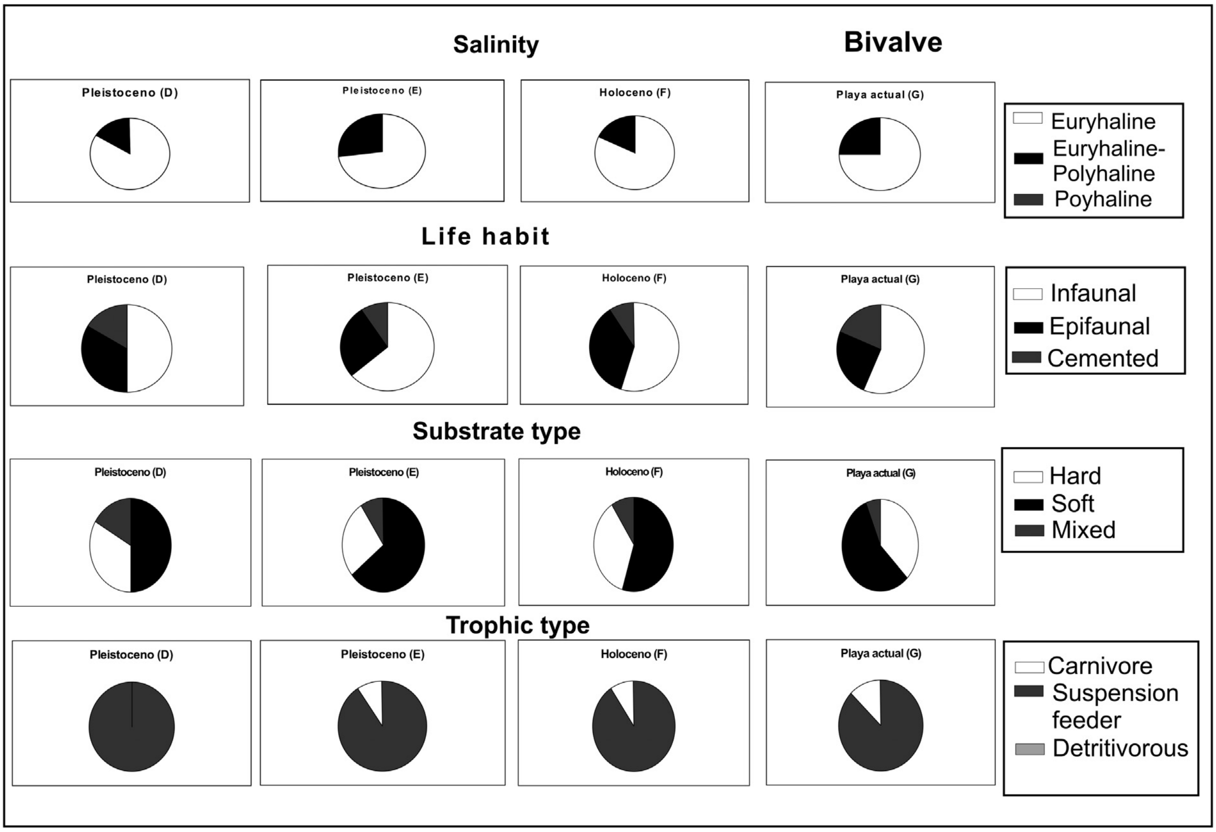

Fig. 16. Proportion of bivalves according to their substrate type, trophic type and life habit.

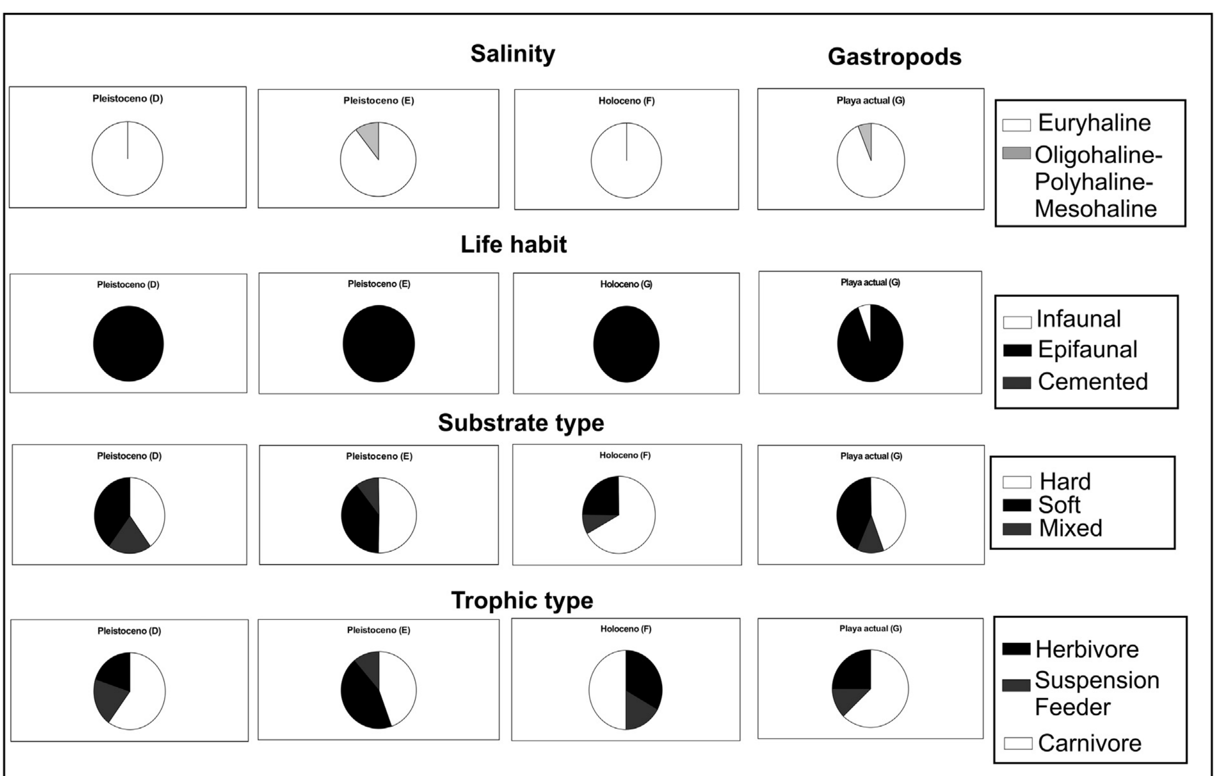

Fig. 17. Proportion of gastropods according to their substrate type, trophic type and life habit.

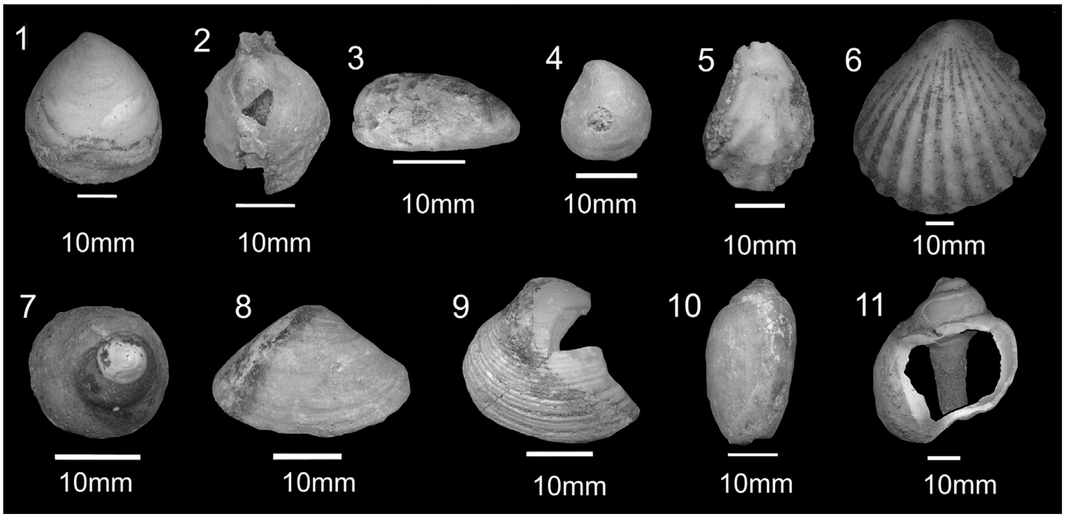

Fig. 18. Bivalvia and gastropod taxa from Quaternary marine deposits of Interglacial MIS 7 in northern Río Negro Province. 1, *Glycymeris* (G.) *longior* (Sowerby) (CEGH-UNC:25628, south of Piedras Coloradas); 2,*Crepidula* sp. (CEGH-UNC: 25638, south of Piedras Coloradas); 3, *Brachidontes* (B.) *rodriguezi* (d'Orbigny)(CEGH-UNC:25631, south of Piedras Coloradas); 4, *Bostrycapulus odites* (Collin)(CEGH-UNC:2563, south of Piedras Coloradas); 5, *Plicatula gibbosa* Lamarck (CEGH-UNC:25630, south of Piedras Coloradas); 6, *Aequipecten tehuelchus* (d'Orbigny)(CEGH-UNC:25627, south of Faro San Matías); 7,*Tegula atra* (Lesson) (CEGH-UNC: 25636, south of Piedras Coloradas); 8, *Mactra guidoi* Signorelli & Scarabino (CEGH-UNC:25632, south of Piedras Coloradas); 9, *Amiantis purpurata*; (Lamarck) (CEGH-UNC:25629, south of Piedras Coloradas); 10, *Olivancillaria carcellesi* Klappenbach (CEGH-UNC:25633, south of Piedras Coloradas); 11, *Trophon patagonicus* (d'Orbigny) (CEGH-UNC: 25635, south of Faro San Matías).

They are characterized, except for ≥MIS 9, by the abundance of *A. purpurata*. Of the malacofauna from MIS 7, 70% persists during MIS 5e, decreasing to 60% during MIS 1 and to 27% in modern beaches (Fig. 25).

Regarding the amount of warm/non-warm species represented in each period, except for ≥MIS 9, the record of warm species of bivalves is higher during MIS 5e with 27% and in modern beaches with 31% (Fig. 26). In gastropods, the highest proportion is in MIS 7 with 80% and MIS 5e with 60%, decreasing to 44% in modern beaches (Fig. 27).

4.1. Pleistocene species

Although Pleistocene species in general persist during the Holocene, some changes in proportions are evident in our data. In addition, the Pleistocene records of specific taxa including the gastropods *T. atra* and *H. australis* and the bivalve *A. brasiliana* require some explanation for different reasons.

4.1.1. *T. atra* (Lesson, 1830)

This gastropod is among the best preserved and abundant in MIS 7 and MIS 5e. Its most conspicuous morphologic characters are the thick trochoid or pyramidal shell formed by five turns, the last one wide and planar, the outer color varying from dark brownish violet to black and pearly interior (Guzmán et al., 1998). This species lives currently in intertidal to subtidal environments associated with rocky substrate, and over algae (e.i. Veliz and Vasquez, 2000; Palacios and Aldea, 2011). It is distributed in the Pacific from Pacasmayo (7°24′S, Peru) to the Magellan Strait (53°S, Chile) (e.g. Moreno, 2004; Rosenberg, 2009). There is no evidence of living

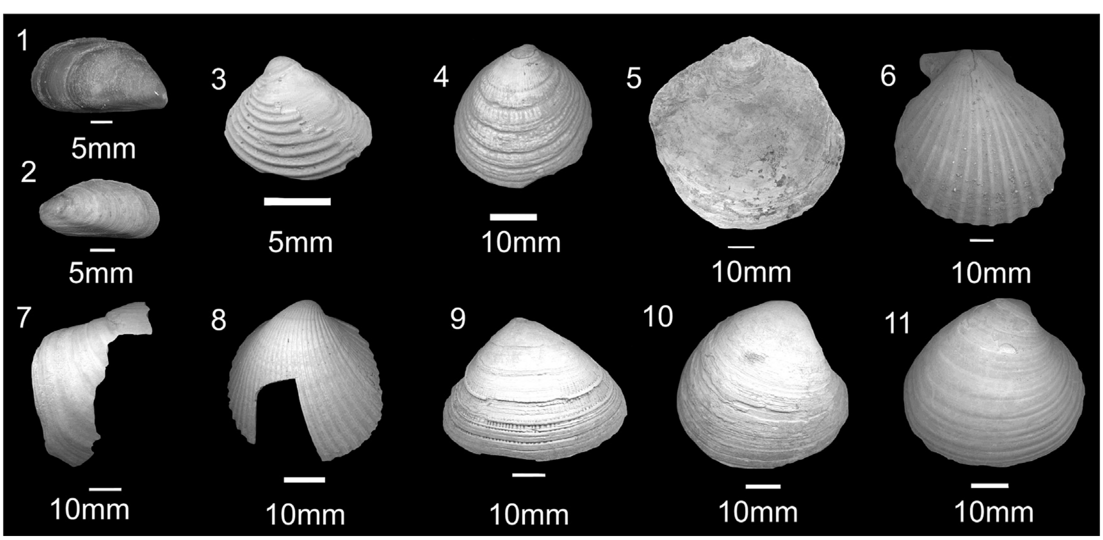

Fig. 19. Bivalvia taxa from Quaternary marine deposits of Interglacial MIS 5e in northern Río Negro Province. 1, *Mytilus edulis platensis* d'Orbigny (CEGH-UNC:25604, La Rinconada); 2, *Brachidontes* (B.) *rodriguezi* (d'Orbigny) (CEGH-UNC: 25601, La Rinconada); 3, *Anomalocardia brasiliana* (Gmelin) (CEGH-UNC:25609, Baliza Camino); 4, *Glycymeris* (*G.*) *longior* (Sowerby) (CEGH-UNC:25600, Baliza Camino); 5, *Ostrea puelchana* d'Orbigny (CEGH-UNC:25607, Bahía San Antonio); 6, *Aequipecten tehuelchus* (d'Orbigny)(CEGH-UNC:25606, Baliza Camino); 7, *Panopea abbreviata* Valenciennes (CEGH-UNC:25605, La Rinconada); 8, *Trachycardium muricatum* (Linné)(CEGH-UNC: 25602, La Rinconada); 9, *Tivela isabelleana* (d'Orbigny) (CEGH-UNC:25603, Bahía San Antonio); 10, *Pitar* (*P.*) *rostratus* (Philippi) (CEGh-UNC: 25598, Bahía San Antonio); 11, *Amiantis purpurata* d'Orbigny (CEGH-UNC:25599, Baliza Camino).

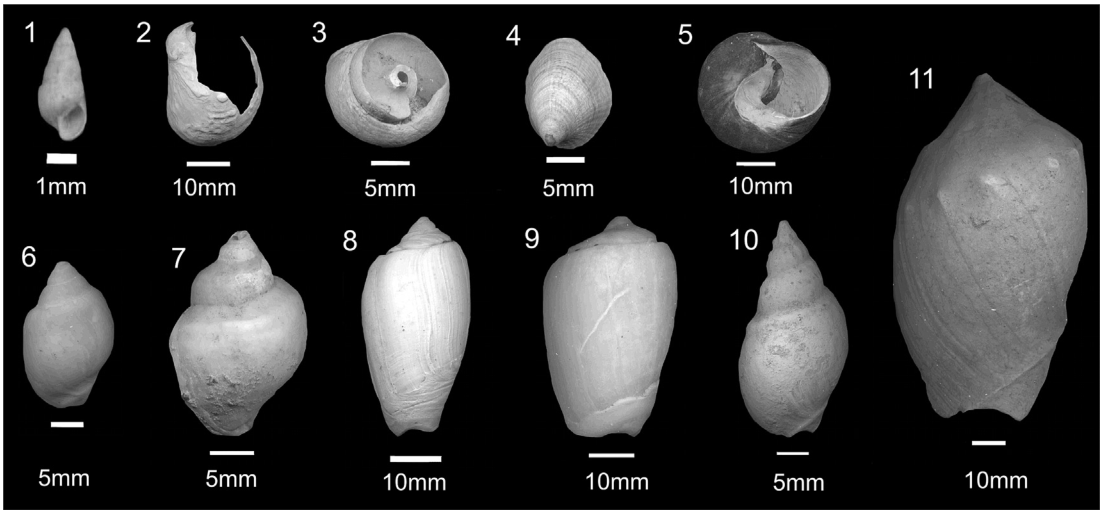

Fig. 20. Gastropod taxa from Quaternary marine deposits of Interglacial MIS 5e in northern Río Negro Province. 1, *Heleobia australis* (d'Orbigny)(CEGH-UNC:25619, Baliza Camino); 2, *Bostrycapulus odites* (Collin) (CEGH-UNC: 25621, Baliza Camino); 3, *Tegula patagonica* (d'Orbigny) (CEGH-UNC; 25614, Baliza Camino); 4, *Siphonaria lessoni* Blainville (CEGH-UNC:25624, La Rinconada); 5, *Tegula atra* (Lesson) (CEGH-UNC:25615, La Rinconada); 6, *Buccinanops globulosum* (Kiener) (CEGH-UNC:25616, Baliza Camino); 7, *Trophon patagonicus* (d'Orbigny)(CEGH-UNC:25617, La Rinconada); 8, *Olivancillaria carcellesi* Klappenbach (CEGH-UNC:25613, Baliza Camino); 9, *Olivancillaria urceus* (Röding)(CEGH-UNC:25618, Baliza Camino); 10, *Buccinanops cochlidium* (CEGH-UNC:25622, San Antonio Este); 11, *Adelomelon* (*P.*) *brasiliana* (Lamarck) (CEGH-UNC:25625, south of Faro San Matías).

specimens on the south Atlantic coasts, nor in the Holocene record (e.g. Gordillo, 1998; Pastorino, 2000; Aguirre et al. 2006). However, it is abundant in MIS7, decreasing in MIS 5e of the Atlantic coast, north of the Río Negro. Southward, *T. atra* appears in Pleistocene deposits of Chubut (Pastorino, 1991a, 1994, 2000; Aguirre, 2003; Aguirre et al. 2005), although it is not recorded in the Pleistocene–Holocene of Tierra del Fuego (Gordillo and Isla, 2011).

Along the Pacific coast, the genus *Tegula* appears in the fossil record in the Middle Miocene of California (USA), and the species *T. atra* is mentioned in the Pliocene of the Pacific coast of the SH (Hellberg, 1998). In Peru, several records have been reported from the Late Pleistocene of Región de San Juan-Lomas (northern coast) and Región de Chala (southern coast) (Ortlieb and Díaz, 1991), and the Holocene (MIS 1) of Santa province (9°S, northwestern end of the Ancash department). As living, *Tegula atra* is a typical species of Peru (Díaz and Ortlieb, 1993). In the Chilean coasts, *T. atra* is recorded in the late Pleistocene of Caleta Coloso, north and south of Antofagasta (northern Chile; Ortlieb et al., 1994), archaeological sites of the late Pleistocene and middle Holocene of Quebrada de Lazareto (south of Chile; Jackson et al., 2005), middle Holocene of the IV Region, Los Vilos (Méndez and Jackson, 2004), and Holocene of the Magellan Strait (Cárdenas and Gordillo, 2009). The record of this species in the San Matías Gulf, northern Patagonia, is probably due to more favorable temperatures for larval development in MIS7. In this regard, observations in living populations of the coast of Valdivia (Región de Los Ríos, Chile) demonstrated that the populations of *T. atra* are larger when the sea surface temperature is above 14 °C (Moreno, 2004). This author also pointed out that the larvae of this species are more abundant when the warm water front collides with the coastal zone, being a favorable micro climate for their development. On the other hand, Aguirre et al. (2011) characterize *T. atra* as a cold water gastropod and explain its disappearance from the Atlantic through oceanographic changes related to the influence of the Brazilian current or to the lower intensity of the Malvinas current after the Last Glacial Maximum. However, in the San Matías Gulf, in northern Patagonia, *T. atra* was found in Pleistocene sediments associated with other temperate to warm-water species including *A. purpurata* and *G. longior*, and along with two extinct warm water species, *Chama iudicai* and *Glycymeris sanmatiensis* (Pastorino, 1991b; Bayer and Gordillo, 2013). These discrepancies concerning the consideration of this species as a target species may be resolved on the basis of interdisciplinary studies, including environmental variables, genetics and the ecophysiological constraints of the living species, as well as a detailed analysis of the fossil record of the genus *Tegula* in South America.

4.1.2. *A. brasiliana (Gmelin, 1791)*

Marine benthic molluscs that indicate warm waters during MIS 5e are known in South America, as well as changes in their geographic distribution, both on the Pacific coast (e.g. Ortlieb et al., 1994) and the Atlantic coast (e.g. Chaar and Farinati, 1988; Martínez et al., 2001; Hearty, 2002; Muhs et al., 2002; Rojas and Urteaga, 2011). One is the bivalve *A. brasiliana*. It was recorded in Locality 5 in San Antonio Bay, representing one of the southernmost records of this species. This warm water species currently inhabits areas from French Antilles (18° N) to the Brazilian coasts (33° S). It is a surface infaunal and is able to tolerate large salinity ranges (e.g. Monti et al. 1991; Ríos, 1994; Arruda et al., 2009; Oliveira et al., 2011). Fossils have been previously found in Uruguay in MIS 5e (Nueva Palmira Formation; Martínez et al., 2001b), and MIS 1 (Villa Soriano Formation; Martínez et al., 2006). In Argentina, this species is not recorded in MIS 5e of northwestern Buenos Aires Province (Fucks et al., 2005, 2006), although it is present in marine deposits within the Pampean of Lomas de Zamora (34°46′S, central-east of Buenos Aires Province; Valentin, 1987).

4.1.3. *H. australis (d'Orbigny, 1835)*

This is another gastropod found in two MIS 5e localities. It is currently distributed from Río de Janeiro, Brazil (22° S) to northeast Argentine Patagonia (40° S) (e.g. Gaillard and Castellanos, 1976; Aguirre and Farinati, 2000; Carcedo and Fiori, 2012). It is first described for the Pleistocene of Río Negro, expanding its distribution for this period.

4.2. *Holocene*

Since MIS 1, the marine malacofauna of the study area varies both in abundance and composition, especially with the record of the bivalves *A. atra*, *R. exalbidus, Nacella magallanica*, and the gastropods *Fissurella radiosa radiosa* and *Crepidula dilatata*, all from temperate-cold environments of the Magellan Malacological

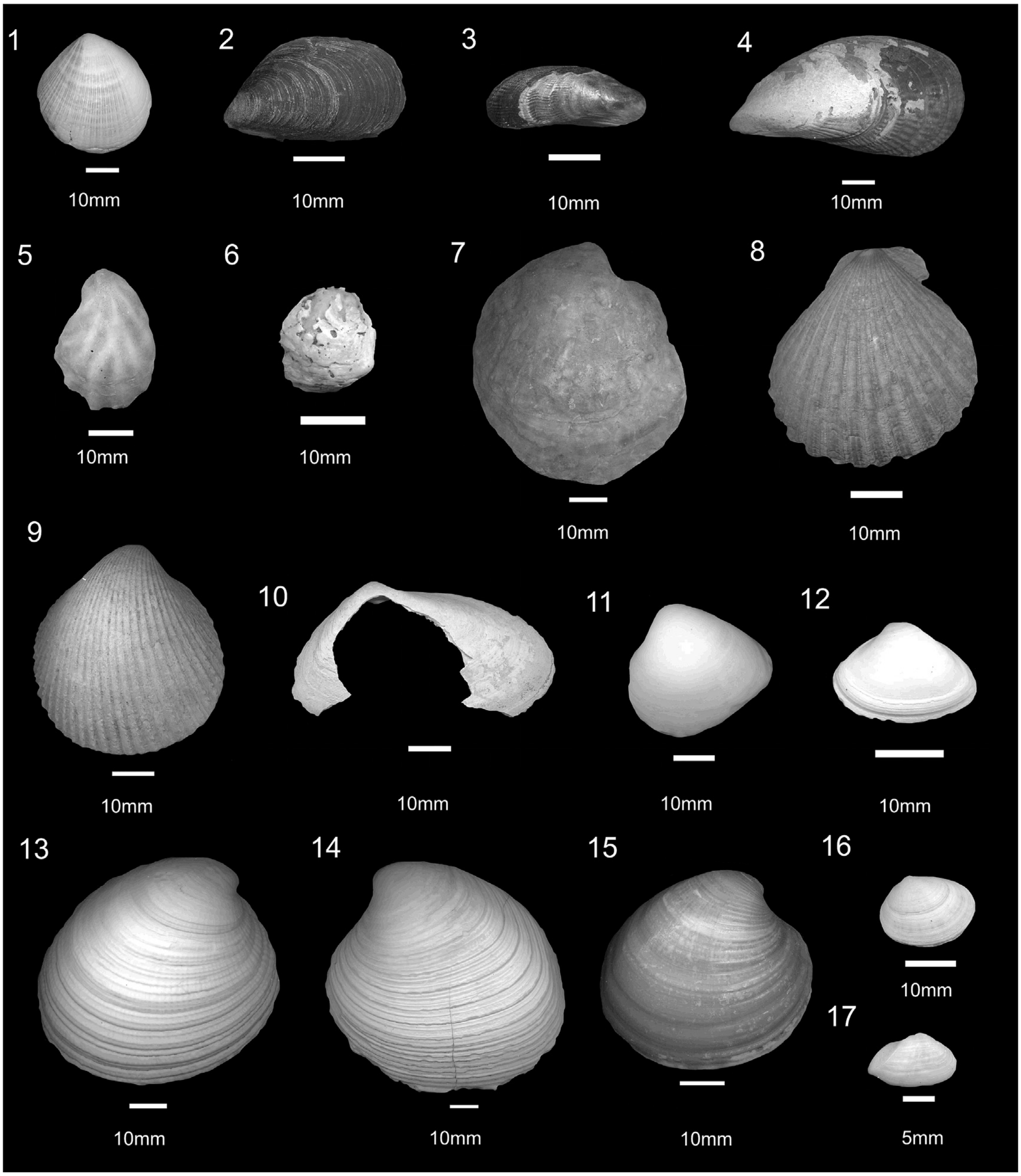

Fig. 21. Bivalvia taxa from Quaternary marine deposits of Interglacial MIS 1 in northern Río Negro Province. 1, *Glycymeris* (*G.*) *longior* (Sowerby) (CEGH-UNC: 25705, modern); 2, *Mytilus edulis platensis* d'Orbigny (CEGH-UNC: 25706, modern); 3, *Brachidontes* (*B.*) *rodriguezi* (d'Orbigny) (CEGH-UNC: 25707, modern); 4, *Aulacomya atra* (Molina) (CEGH-UNC: 25.708, modern); 5, *Plicatula gibbosa* Lamarck (CEGH-UNC: 25.710, modern); 6, *Ostreola equestris* (Say) (CEGH-UNC: 25.711, modern); 7, *Ostrea puelchana* d'Orbigny (CEGH-UNC: 25.712, Holocene); 8, *Aequipecten tehuelchus* (d'Orbigny) (CEGH-UNC: 25.709, Holocene); 9, *Trachycardium muricatum* (Linné) (CEGH-UNC: 25.713, Holocene); 10, *Mesodesma mactroides* (Reeve) (CEGH-UNC: 25.610, Holocene); 11, *Pitar* (*P.*) *rostratus* (Philippi) (CEGH-UNC: 25.715, modern); 12, *Mactra guidoi* Signorelli & Scarabino (CEGH-UNC:25.714, modern); 13, *Ameghinomya antiqua* (King & Broderip, 1832) (CEGH-UNC: 25718, Holocene); 14, *Retrotapes exalbidus* (Dillwyn) (CEGH-UNC: 25.717, Holocene); 15, *Amiantis purpurata* (Lamarck) (CEGH-UNC:25716, modern); 16, *Thracia similis* Couthouy (CEGH-UNC: 25.720, Holocene); 17, *Corbula* (*C.*) *Lyoni* Pilsbry (CEGH-UNC: 25.719, modern).

Province, to the south. In addition, the bivalve *M. mactroides*, currently located northward, is here recorded.

4.2.1. M. mactroides (Reeve, 1854)

This species lives today in sandy beaches exposed to waves, from Río de Janeiro (23°S, Brazil) to Jabalí Island (40° S, Buenos Aires Province, Argentina) (e.g. Ríos, 1994; Fiori and Morsan, 2004; Fiori and Defeo, 2006), associated with mild temperatures from the intertidal zone to shallow infralittoral (Bastida et al., 1991; Rosenberg, 2009). The southern limit was reported as Isla Jabalí (Fiori and Morsan, 2004; Charó et al., 2013), although other authors reported this species living in the Río Negro mouth (Bastida et al., 1991) or in Río Negro Province (41°S; e.g. Thompson and Sanchez de Bock, 2007). Its record in one of the Holocene ridges (Locality 27) near San Antonio Este harbor (40°47′S) suggests that this species would have reached these latitudes during the Holocene. Previous studies in modern populations demonstrated that the density of the population of *M. mactroides* decreases exponentially from middle to high temperatures. Another factor that seems to influence the population density of this species is the sediment type. Those beaches formed by fine-medium sand with gentle slopes, strong waves and high primary production are the best habitat for high densities of *M. mactroides* (e.g. Defeo and Scarabino, 1990; Fiori and Defeo, 2006). Likely, in Locality F27, the type of

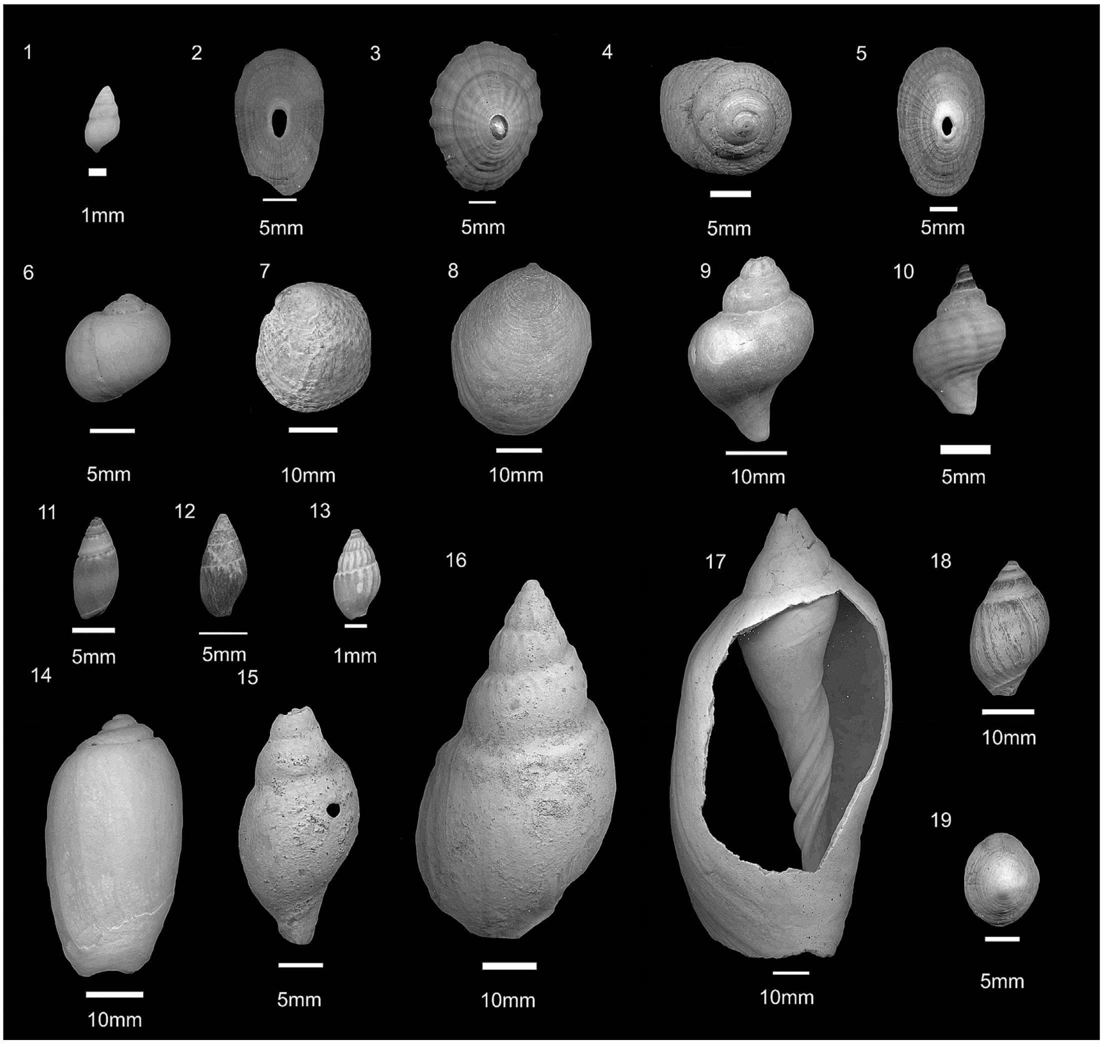

Fig. 22. Gastropod taxa from Quaternary marine deposits of Interglacial MIS 1 in northern Río Negro Province. 1, *Heleobia australis* (d'Orbigny) (CEGH-UNC: 25.723, modern); 2, *Lucapinella henseli* (Martens) (CEGH-UNC: 25689, modern); 3, *Nacella (P.) magallanica* (Gmelin) (CEGH- UNC: 25.688, Holocene); 4, *Tegula (A.) patagonica* (d'Orbigny) (CEGH-UNC: 25.690, Holocene); 5, *Fissurella radiosa radiosa* Lesson (CEGH-UNC: 25.687, Holocene); 6, *Notocochlis isabelleana* (d'Orbigny) (CEGH-UNC: 25.694, modern); 7, *Bostrycapulus odites* (Collin) (CEGH-UNC:25.691, modern); 8, *Crepidula dilatata* Lamarck (CEGH-UNC: 25.693, modern); 9, *Trophon patagonicus* (d'Orbigny) (CEGH-UNC: 25.695, modern); 10, *Trophon geversianus* (Pallas) (CEGH-UNC: 25.696, modern); 11, *Olivella (O.) tehuelcha* (Dúclos) (CEGH-UNC: 25.698, modern); 12, *Costoanachis sertulariarum* (d'Orbigny) (CEGH-UNC: 25.702, modern); 13, *Parvanachis isabellei* (d'Orbigny) (CEGH-UNC: 25.701, modern); 14, *Olivancillaria carcellesi* Klappenbach (CEGH-UNC: 25.699, Holocene); 15, *Buccinanops uruguayensis* (Pilsbry) (CEGH-UNC: 25.724, modern); 16, *Buccinanops cochlidium* (Dillwyn) (CEGH-UNC: 25.622, Holocene); 17, *Odontocymbiola magallanica* (Gmelin) (CEGH-UNC: 25.697, modern); 18, *Buccinanops globulosum* (Kiener) (CEGH-UNC: 25. 700, modern); 19, *Siphonaria lessoni* Blainville (CEGH-UNC: 25. 723, Holocene).

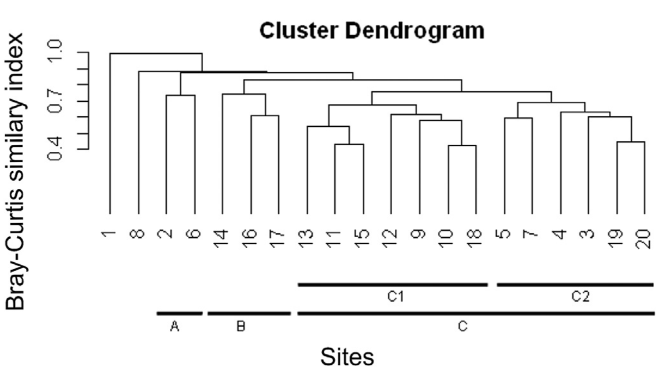

Fig. 23. Dendrogram of the localities based on Bray–Curtis index (Cluster analysis).

beach would have been the best determinant, being a favorable habitat for this species. Recent archaeo-malacofaunistic studies also pointed out that this bivalve is absent from Holocene shell-middens of the northern San Matías Gulf, although it was abundant in southern Buenos Aires Province (Zudimendi, 2007).

5. Conclusions

Late Quaternary interglacials ≥MIS 9, MIS 7, MIS 5e and MIS 1 are described for the northern area of San Matías Gulf through the study of 20 localities in which 42 species of molluscs were recovered (20 bivalves and 22 gastropods). Descriptive-statistical methods grouped the Quaternary malacofauna of Río Negro in three different groups separated by age (Pleistocene/Holocene and the present), and/or presence and abundance of certain species.

Regarding the faunal changes within the MIS 7 and the present, 70% of the malacofauna of MIS 7 remained during MIS 5e,

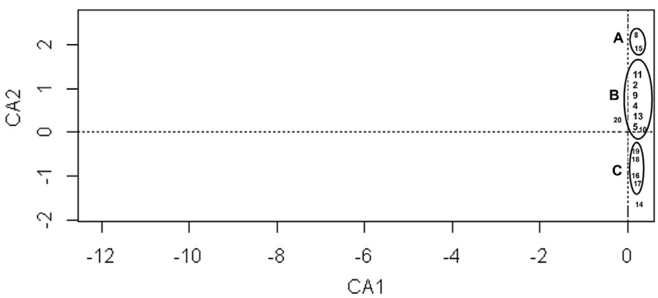

Fig. 24. Correspondence analysis of localities based on the abundance of taxa. Most sites are grouped in A, B and C group.

decreasing to 60% during MIS 1, and to 27% when compared to the modern beaches.

T. atra is among the most outstanding marine molluscs both in MIS 7 and MIS 5e, but this species no longer appears in MIS 1 and the present. Given its wide range of current distribution along the Pacific coast, and considering that along the Atlantic coast, particularly in northern Patagonia, Pleistocene *Tegula* appeared associated with warm-water elements, while further south this species appeared associated with cold water, it is necessary to re-evaluate whether this species can be treated as a climate indicator, given its wide versatility to live at a wide range of temperatures. The fact that this species has become extinct, at least regionally, is interpreted here in association with changes of environmental factors (i.e. sea surface temperature, sediments, salinity) during the last glaciation (110 ka–18 ka).

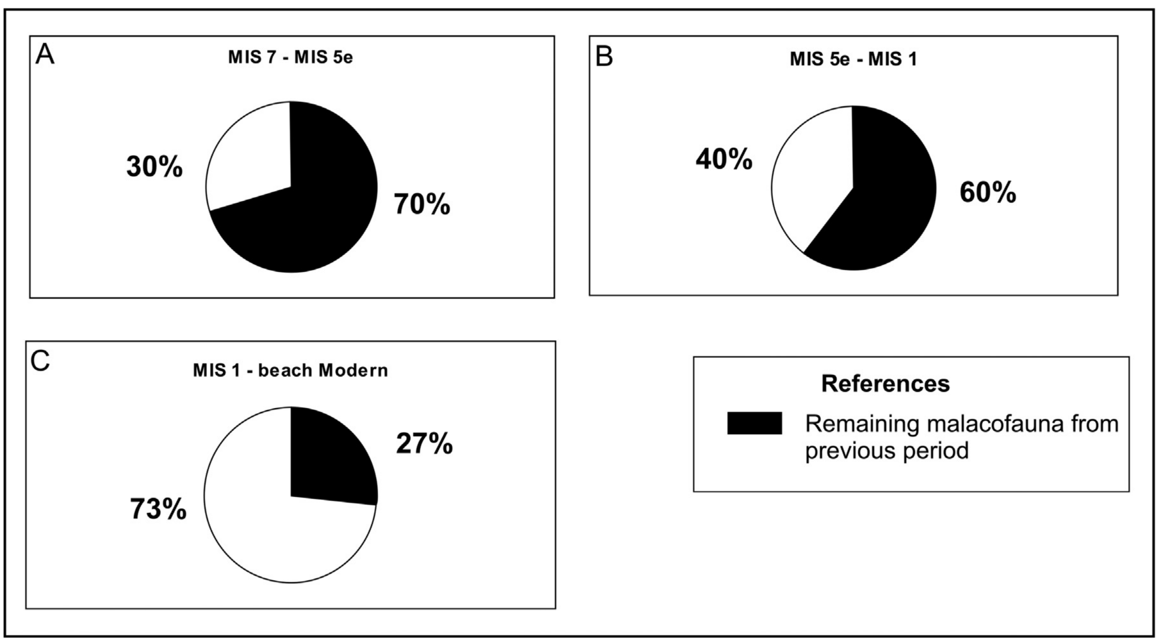

Fig. 25. Remaining fauna in a period with respect to the previous period. 70% of the fauna remains during MIS5e (A), decreasing up to 60% during the MIS1 (B), and decreasing up to 27% today.

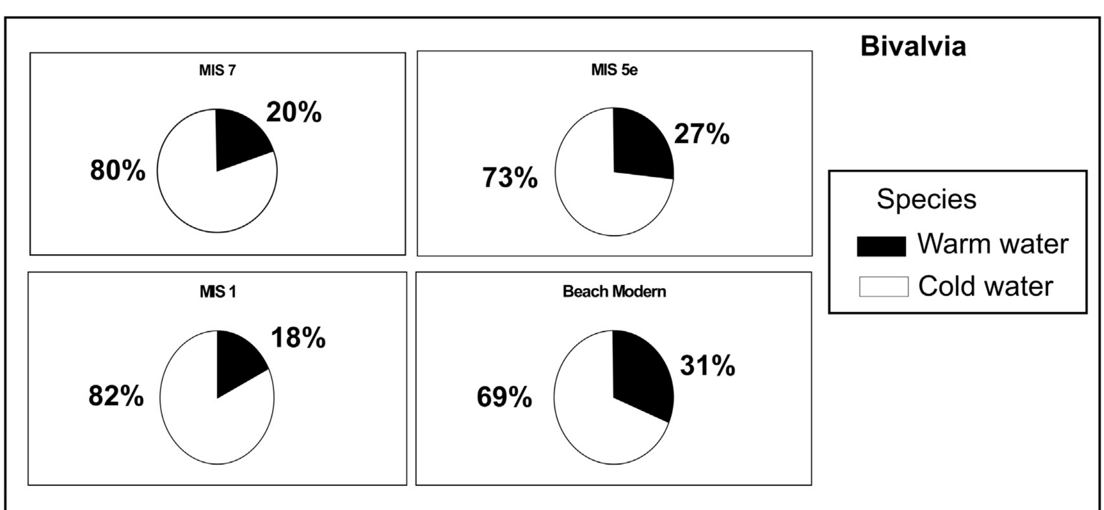

Fig. 26. Warm water vs. cold water bivalvia during the Quaternary.

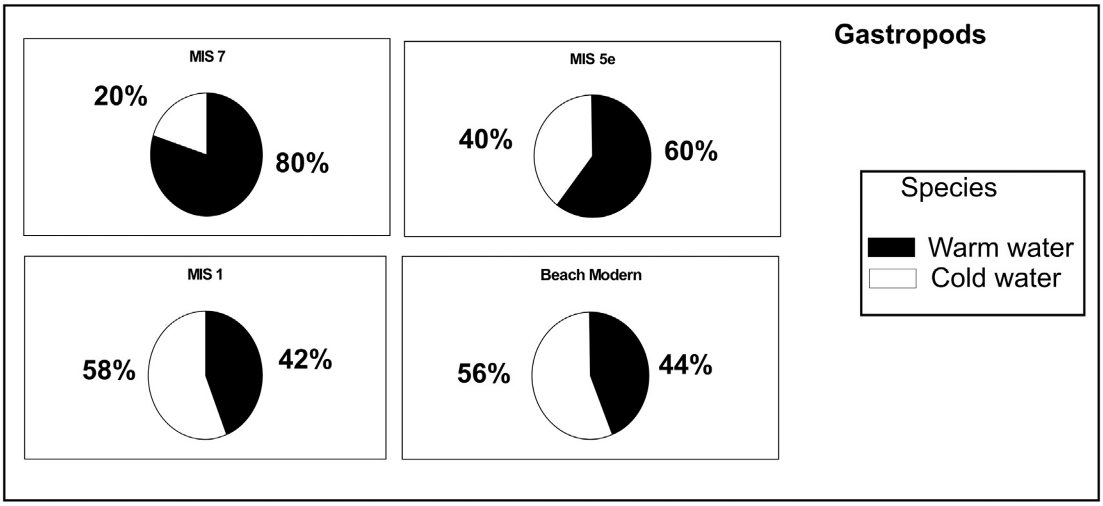

Fig. 27. Warm water vs. cold water gastropods during the Quaternary.

Another important record found in MIS 5e is the warm lineage bivalve *A. brasiliana*, which suggests that this interglacial was warmer than the present one. The gastropod *H. australis* is reported for the first time in the littoral ridges of MIS 5e and in modern beaches of the north of Río Negro.

M. mactroides was only recorded in MIS 1, with a single specimen. Its presence suggests fine-medium sand beaches with wave influence and mild temperature during the Holocene. Today, this species has been described only in southern Buenos Aires Province.

Temperate-cold taxa from the south including *A. atra, R. exalbidus*, *A. antiqua* (bivalvia) and *Fisurella radiosa radiosa* and *Crepidula dilatata* (gastropods) are added to the fossil record, mostly within MIS 1 continuing to the present, as they are recovered from the modern beaches of Río Negro Province.

The changes in the range of distribution of certain species as *A. brasiliana* and *M. mactroides*, which show latitudinal changes during the Holocene with respect to the present, and *T. atra*, which became extinct before the Holocene, could be responses to a combination of global climate events, correlated with other regions, and local changes affecting the sediment type and water circulation. These factors influence the development of different local benthic communities, with variations and changes in taxa composition and trophic groups.

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