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Paleoenvironmental interpretation of late Quaternary molluscan assemblages from southern South America: A taphonomic comparison between the Strait of Magellan and the Beagle Channel

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ABSTRACT. This study analyzes the Holocene molluscan assemblage in raised marine terraces along the coasts of the Strait of Magellan and the Beagle Channel. A total of 33 gastropods and 12 bivalves were identified. They constitute the first mollusk listing for deposits in the Strait of Magellan. Taphonomic analysis suggests a high energy environment with epifaunal elements in the Strait of Magellan and a low energy environment with the predominance of infaunal elements in the Beagle Channel. All the collected species are living taxa suggesting that postglacial climatic variations were not enough to alter the composition of the communities since at least 6,000 yr BP in the southern Chile-Argentina region.

Keywords: Late Quaternary, Mollusks, Paleocology, Taphonomy, Strait of Magellan, Beagle Channel, Chile, Argentina.

RESUMEN. Interpretación paleoambiental de ensambles de moluscos del Cuaternario tardío del sur de América del Sur: una comparación tafonómica entre el Estrecho de Magallanes y el Canal Beagle. Este trabajo analiza los ensambles de moluscos del Holoceno de las terrazas marinas presentes a lo largo de las costas del Estrecho de Magallanes y del Canal Beagle. Un total de 33 especies de gastrópodos y 12 de bivalvos fueron identificados. Ellos constituyen un primer listado de moluscos para los depósitos del Estrecho de Magallanes. El análisis tafonómico sugiere un ambiente de alta energía con elementos epifaunales en el Estrecho de Magallanes y un ambiente de baja energía con el predominio de elementos infaunales para el Canal Beagle. Todas las especies colectadas son taxa vivientes, lo que sugiere que las variaciones climáticas postglaciales no fueron suficientes para alterar la composición de las comunidades desde al menos 6.000 años AP en el extremo austral de Chile-Argentina.

Palabras claves: Cuaternario tardío, Moluscos, Paleocología, Tafonomía, Estrecho de Magallanes, Canal Beagle, Chile, Argentina.

1. Introduction

The southern tip of South America, Tierra del Fuego, experienced the combined effects of glaciations, changes in the sea level and interrupted connectivity between the Atlantic and the Pacific Ocean. Given that this area lies between both oceans, it is a critical region for the evaluation of paleoenvironmental changes and the interpretation of faunal distributions in the Magellan Region (Gordillo *et al.*, 2008). Previous research in the Strait of Magellan and the Beagle Channel revealed that marine events during the Pleistocene and Holocene are represented by marine terraces with altitudinal differences resulting from glacio-isostatic effects and the neotectonic uplift which occurred after the Last Glacial Maximum (LGM) (Brambati *et al.*, 1998; Rabassa *et al.*, 2000).

Quaternary marine deposits containing mainly mollusks are extensively distributed along the coasts of the Strait of Magellan and the Beagle Channel (Rabassa *et al.*, 1986; Gordillo *et al.*, 1992; Brambati *et al.*, 1998). Previous studies along the southern Tierra del Fuego coastline show that mollusks are a key to reconstruct Holocene paleocommunities (Gordillo, 1999) and to evaluate changes in faunal composition after the LGM (Gordillo *et al.*, 2005). Interspecies variations existing in the fossil record are the result of a combination of life habits, intrinsic shell properties and habitat. In this way, taphonomic analyses may constitute a powerful tool for paleoenvironmental analyses of Quaternary marine deposits (Brandt, 1989; Nielsen and Funder, 2003).

The objective of this study is to compare the Holocene molluscan assemblages located along the Strait of Magellan and the Beagle Channel coastlines by means of taxonomic, paleoecologic and taphonomic analyses.

2. Materials and Methods

2.1. Study area

The coastal area examined in this study consists of 11 localities, with a total of 14 marine terraces along the Strait of Magellan and the Beagle Channel (Fig. 1, Table 1).

Strait of Magellan. The Strait of Magellan separates Patagonia from Tierra del Fuego. It was repeatedly

occupied by outlet glaciers of an expanded southern Andean ice cap during successive Pleistocene glaciations (Porter *et al.*, 1992; Kilian *et al.*, 2007). Today, the strait is dominated by an indented rocky shoreline and characterized by semi-diurnal and heterogeneous tides with mean amplitudes ranging from 1.2 m on the west coast to 9 m in the Atlantic inlet of the east coast (Andrade, 1991).

Brambati *et al.* (1998) recognized four orders of marine terraces: I, II, III and IV order; with their age estimations based on radiometric dating of fossil macrofauna. The selected localities for paleontological samples correspond to five sites previously dated by Brambati *et al.* (1998): Bahía Porvenir (BP), Puerto del Hambre (PH), Punta Palo (PP), Punta Zeger (PZ) and Seno Otway (SO) (Table 1). **Beagle Channel.** The Beagle Channel is located in the seismically active tectonic area of the Fuegian Andes and was covered during the Last Glacial Maximum. This channel is a glacial Andean valley, occupied by the sea since 8,000 yr BP (Rabassa *et al.*, 1986). It extends for 180 km long in a W-E trend linking the Atlantic and Pacific oceans along the southern coast of Tierra del Fuego. The northern Beagle Channel is characterized by a Holocene terrace system with at least 3 orders of terraces at 10-8 m, 6-4 m and 3-1.5 m (Gordillo *et al.*, 1992). Today, the Beagle Channel, is dominated by an indented, rocky shoreline, with pocket gravel beaches. Tides are semi-diurnal with mean amplitudes of one meter (e.g., 1.1 m at Ushuaia) (Gordillo *et al.*, 1992). The selected study localities for paleontological samples correspond to sites previously dated (Table 1): Alakush (AK), Bahía Brown (BB, two levels), Harberton (HA), Isla Gable (IG), Lago Roca (LR) and Ushuaia (US).

2.2. Material studied

2.2.1. Taxa composition and paleoecology

Fossil mollusks were collected from selected terraces in the Strait of Magellan and the Beagle Channel. Three samples of 10 dm³ bulk of sediment and biologic material were obtained from each terrace; samples were sieved in the field using 1 mm and 0.05 mm sieves to reduce volume. All specimens were sorted, counted and identified to the species level in the laboratory. Taxonomic and paleoecologic aspects of the mollusks were studied and examined. The autoecological characterization of the fossil

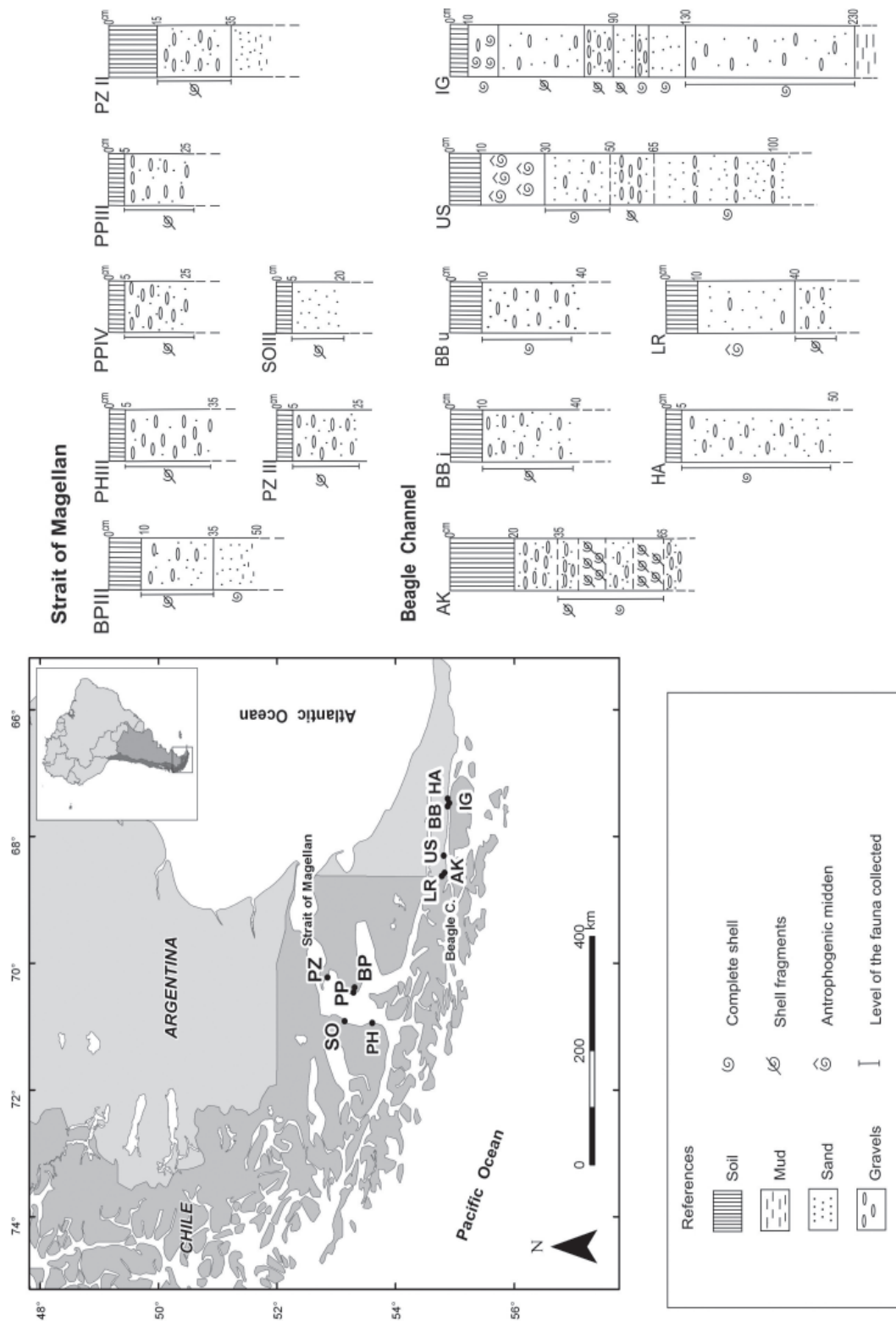


FIG. 1. Map of the localities sampled and stratigraphic profiles from Strait of Magellan and Beagle Channel. **BP**: Bahía Porvenir; **PH**: Puerto del Hambre; **PP**: Punta Palo; **PZ**: Punta Zeger; **SO**: Seno Otway; **AK**: Alakush; **BB**: Bahía Brown; **HA**: Harberton; **IG**: Isla Gable; **LR**: Lago Roca; **US**: Ushuaia.

TABLE 1. GEOGRAPHIC CHARACTERIZATION OF THE STRAIT OF MAGELLAN AND THE BEAGLE CHANNEL.

Localities	Sampling site code	Coordinates	Years BP	Elevation (m a.s.l.)	Characteristics of the sampling sites	References
Bahía Porvenir	BPIII	53°18'S, 70°22'W	4,000-5,000	2.0	This bay is located near the city of Porvenir, in Tierra del Fuego. The substrate corresponds to sand and gravel.	
Puerto del Hambre	PHIII	53°36'S, 70°55'W	4,000-5,000	1.5	This bay is located about 50 km south of Punta Arenas. The rocky coast of the mainland, constituted by southeast-trending bedrock ridges formed by gravel.	
Punta Palo	PPIII	53°17'S, 70°27'W	4,000-5,000	2.3	This site is located in Segunda Angostura, in Tierra del Fuego.	
	PPIV		1,000-2,000	1.2	Both deposits, III and IV order, are constituted mainly by gravel.	(1)
Punta Zeger	PZII	52°54'S, 70°16'W	6,190±65	5.0	This site is located in Tierra del Fuego and reveals intermediate raised shorelines, with gravelly and sandy deposits.	
	PZIII		4,000-5,000	2.0	Occurs close to the second order terrace, and shows coarse sand and gravel substrate.	
Seno Otway	SOIII	53°08'S, 70°54'W	4,000-5,000	2.3	It is a large inland sound occupying a rather narrow belt that runs parallel to the current coast. It is constituted by a sandy substrate.	
Alakush	AK	54°50'S, 68°34'W	4,440±120 AC-937	5.0	This site is a raised beach located in an area (the so-called Cormoranes Archipelago) that is also disconnected from the open sea at present. It is formed by a series of low, rounded bedrock hills, surrounded by interconnected depressions filled with freshwater.	(2)
Bahía Brown	BBu	54°53'S, 67°31'W	2,970±70 Pa 1010	4.0	This bay is located about 50 km east of Ushuaia.	(3)
	BBI		985±135 Pa 1011	2.6		(3)
Harborton	HA	54°53'S, 67°24'W	2,770±50 Pa 1009	2.3	This deposit is located 9 km west of Estancia Harborton, lying on an ancient inter-drumlin channel.	(3)
Isla Gable	IG	55°55'S, 67°30'W	4,790±100 AECV-648c	5.0	This 9 km long-island is located 70 km east of Ushuaia and divides the Beagle Channel into two branches forming its narrowest part.	(4)
Lago Roca	LR	54°48'S, 68°36'W	5,920±90 AC-1060	6.4	Although in the recent past this lake was part of a marine archipelago, at present it is a freshwater lake disconnected from the open sea.	(5)
Ushuaia	US	54°00'S, 68°16'W	5,160±130 AECV-876c	8.0	This is a small embayment open to the east and protected from the sea by the Ushuaia Peninsula.	(6)

References: (1) Brambatti *et al.*, 1998; (2) Figueroa and Mengoni, 1986; (3) Gordillo *et al.*, 1992; (4) Gordillo, 1991; (5) Rabassa *et al.*, 1986; (6) Gordillo, 1990.

taxa and their patterns of distribution (*i.e.*, substratum, depth and mode of life, nature of locomotion and feeding) were derived from comparison with the ecology of their current living counterparts. The identification and taxonomic status are based on Soot-Ryen (1959), Castellanos and Landoni (1988, 1993), Linse (1999), Valdovinos (1999), Reid and Osorio (2000), Osorio and Reid (2004). Specimens were deposited at the Centro de Investigaciones Paleobiológicas (CIPAL), Universidad Nacional de Córdoba, Argentina.

2.2.2. Taphonomic analyses

Taphons. Five filter feeder bivalve species were chosen for taphonomic analysis: *Mytilus edulis chilensis* (Hupé, 1854), *Perumytilus purpuratus* (Lamarck, 1819), *Aulacomya atra* (Molina, 1782), *Tawera gayi* (Hupé, 1854) and *Retrotapes exalbidus* (Dillwyn, 1817). This selection was based on the high abundance of these taxa, their ecological requirements and the distributional ranges that have been compiled and are common to both regions, thereby facilitating comparisons (Table 2).

Taphonomic attributes. Each specimen was characterized based on the main taphonomic features to reconstruct paleoenvironment conditions.

Type of valve (right, left): A significant concentration of one valve type indicates uneven hydrodynamic properties such as beaches or areas with tidal influence (Parsons and Brett, 1991).

Disarticulation of bivalves: Articulated shells are associated with rapid burial or transport capacity (Parsons and Brett, 1991).

Shell fragmentation: Breakage of skeletons is usually related to exposure to high energy environments resulting from wave action, tides or winds (Zuschin and Stanton, 2001).

Abrasion: The abrasion degree is associated to environmental energy, time of exposure and particle size of abrasive agents (Parson and Brett, 1991).

Biotic interactions: This refers to different interactions with other organisms that remain in the shell, such as encrusted shells, borings, tunnels and drill holes made by predatory gastropods (Farinati *et al.*, 2006).

Twelve marines terraces were considered for taphonomic analyses BPIII, PHIII, PPIII, PPIV, PZII, PZIII, AK, BBu, HA, IG, LR and US. Seno Otway (SOIII) and Bahía Brown (BBI) show a low species richness and there is no record of the bivalves

selected for taphonomic analyses. Therefore these sites are considered only for analyses of composition and species richness (Table 3).

3. Results

3.1. Taxa composition and paleoecology

A total of 2,727 specimens of mollusks were collected. The whole faunal content is composed of 45 mollusk species, 12 species of bivalves and 33 gastropods (Table 2).

The Magellan Strait has the highest species richness with a total of 43 species, while the deposits of the Beagle Channel have 22 species. Nineteen of the species are present in both areas: *Fissurella radiosa*, *Nacella deurata*, *Nacella magellanica*, *Margarella violacea*, *Crepidatella dilatata*, *Calyptraea pileolus*, *Trophon geversianus*, *Xymenopsis muriciformis*, *Acanthina monodon*, *Pareuthria plumbea*, *Siphonaria lessoni*, *Aulacomya atra*, *Mytilus edulis chilensis*, *Perumytilus purpuratus*, *Mulinia edulis*, *Prothotaca antiqua*, *Retrotapes exalbidus*, *Tawera gayi* and *Hiatella solida* (Table 2, Figure 2A). The sites with the greatest diversity are PHIII and PZIII, with 29 and 23 species respectively in the Strait of Magellan, and in the Beagle Channel the greater richness occurs in LR, with 16 species and HA with 14 (Figure 2B).

Of the 2,133 specimens collected in the Strait of Magellan, 70% are gastropods; while in the Beagle Channel, 68% of the 594 specimens are bivalves. Organisms from the intertidal and subtidal zones are dominant in both areas. Hard substrate and epybissate species dominate in the Strait of Magellan, while the Beagle Channel is dominated by species showing preference for soft substrate and an infaunal mode of life (Table 2). Many gastropods are phytophagous (60%), followed by carnivores (36%) with a minor proportion of filter feeders whereas all bivalves studied are filter feeders (Table 2).

3.2 Taphonomic analysis

Strait of Magellan terraces. Marine terraces located in this area are mainly composed of epifaunal elements, characterized by poorly preserved shell remains. There is a difference in the left/right proportion of valves in all sites, which suggests transport.

TABLE 2. SPECIES COMPOSITION BY STUDY SITE AND ECOLOGICAL REQUIREMENTS OF GASTROPODA AND BIVALVIA.

CLASS Family	GASTROPODA	Species	Sampling sites	Zonation			Substrate			Trophic level		
				SUPR	INTER	SUB	HARD	SOFT	PHYTO	FILT	CARN	
Fissurellidae		<i>Fissurella picta</i> (Gmelin, 1791)	PHA, PHIII, PPA, PPIV, PZA, PZII, SOA, SOIII	x	x	x	x			x		
		<i>Fissurella radiosa</i> (Lesson, 1831)	PHA, PHIII, PPA, PPIV, PZA, PZIII, SOA, SOIII	x		x	x			x		
		<i>Fissurella oriens</i> (Sowerby, 1835)	PHA, PHIII, PPIV, PZIII, SOA, SOIII	x		x	x			x		
		<i>Puncturella conica</i> (d'Orbigny, 1841)	PHA, PHIII, PPIII		x	x	x			x		
		<i>Nacella (Patinigera) delicatissima</i> (Strebel, 1907)	PHA, PHIII		x	x	x			x		
Nacellidae		<i>Nacella (Patinigera) deaurata</i> (Gmelin, 1791)	PHA, PHIII, PPA, PPIII, PPIV, PZA, PZII, PZIII, SOA	x	x	x	x			x		
		<i>Nacella (Patinigera) magellanica</i> (Gmelin, 1791)	PHA, PHIII, PPA, PPIII, PPIV, PZA, PZII, PZIII, SOA	x		x	x			x		
		<i>Nacella (Nacella) mytilina</i> (Helbling, 1779)	BPA, PHA, PHIII, PPA, PZA, PZII		x	x	x			x		
		<i>Lotia ceciliiana</i> (d'Orbigny, 1841)	PHA, PHIII, PPA, PPIII, SOA		x		x			x		
Acmeidae		<i>Margarella violacea</i> (King and Broderip, 1832)	PHA, PHIII, PPIII	x	x	x	x		x	x		
		<i>Photinula</i> sp	PZA		x		x			x		
Trochidae		<i>Tegula atra</i> (Lesson, 1830)	BPIII, PPA, PPIV, SOA		x	x	x			x		
		<i>Homalopoma cunninghami</i> (Smith, 1881)	PHA, PHIII, SOA		x	x	x			x		
		<i>Crepidatella dilatata</i> (Lamarck, 1822)	PHA, PHIII, PPA, PPIII, PPIV, PZA, PZIII, SOIII, SOA			x	x				x	
		<i>Calyptraea decipiens</i> (Philippi, 1845)	PPIII, PPIV, PZIII, SOA		x			x		x		
		<i>Calyptraea costellata</i> (Philippi, 1845)	PZA, PZII		x			x		x		
Naticidae		<i>Falsilunatia soluta</i> (Gould, 1847)	BPIII, PHA, PHIII, PPIII, PPIV, PZII, PZIII, SOA			x	x			x		
		<i>Argobuccinum magellanicus</i> (Röding, 1798)	PZII								x	
Ranelidae		<i>Epitonium magellanicum</i> (Philippi, 1845)	PHA, PZII		x	x	x			x		
Eptoniidae		<i>Eumetula pulla</i> (Philippi, 1845)	PHA, PHIII, PPIII, PZII, PZIII, SOA		x	x	x			x		
		<i>Trophon geversianus</i> (Pallas, 1774)	BPA, BPIII, PHA, PPA, PPIII, PPIV, PZA, PZII, PZIII, SOA, AK, BBI, BBu, HA, IG, LR, US		x	x	x			x		x

Table 2 (continued).

CLASS Family	Species	Samplig sites	Zonation			Substrate			Trophic level		
			SUPR	INTER	SUB	HARD	SOFT	PHYTO	FILT	CARN	CARN
GASTROPODA											
	<i>Xymenopsis muriciformis</i> (King and Broderip, 1832)	BP III, PH III, PPIII, PPIV, PZII, PZIII, SOII, AK, HA, IG, LR, US		x	x	x					x
	<i>Acanthina monodon</i> (Lamarck, 1816)	PH III, PPIII, PPIV, PZIII, HA		x	x	x	x				x
	<i>Metreuthria martensi</i> (Strebel, 1905)	PH III			x	?		?			
	<i>Pareuthria plumbea</i> (Philippi, 1848)	BP III, PH III, PPIII, PPIV, PZII, PZIII, AK, HA, IG, LR, US		x	x	x					x
Volutidae	<i>Pareuthria powelli</i> (Cernohorsky, 1977)	PH III, PPIII		x	x	x					x
	<i>Adelomelon ancilla</i> (Lightfoot, 1786)	BP III, PPIII, PPIV, PZII, PZIII		x			x				x
	Volutidae indet.	PPIII, PZII, PZIII		x			x				x
Siphonariidae	<i>Siphonaria lessoni</i> (Blainville, 1824)	BP III, PH III, PPIV, PZII, PZIII, SOIII, HA		x	x	x	x		x		
	<i>Kerguelenella lateralis</i> (Gould, 1846)	BP III, PH III, PPIV, PZII, PZIII		x		x			x		
BIVALVIA											
	<i>Aulacomya atra</i> (Molina, 1782)*	PH III, PPIII, PPIV, PZIII, BBu, IG, HA, US		x	x	x					x
	<i>Mytilus edulis chilensis</i> (Hupé, 1854)*	BP III, PH III, PPIII, PPIV, PZII, PZIII, AK, BBu, HA, IG, LR, US		x	x	x					x
	<i>Perumytilus purpuratus</i> (Lamarck, 1819)*	PH III, PPIII, PPIV, PZIII, HA, IG, LR	x	x	x	x					x
	<i>Zygochlamys patagonica</i> (King and Broderip, 1832)	LR			x	x	x				x
	<i>Cyclocardia</i> sp.	PPIII, PPIV, PZIII			x		x				x
	<i>Mulinia edulis</i> (King and Broderip, 1832)	SOIII, AK, BBu, IG, LR			x	x					x
	<i>Gaimardia trapesina</i> (Lamarck, 1819)	PH III, PPIII		x	x		x				x
	<i>Prothotaca antiqua</i> [synonym= <i>Venus antiqua</i>] (King and Broderip, 1832)	PPIII, PPIV, PZIII, SOIII, AK, IG, LR			x		x				x
	<i>Retrotapes exalbidus</i> (Chemnitz, 1795)*	BP III, PH III, PPIV, PZII, PZIII, AK, BBu, BBI, HA, IG, LR, US			x		x				x
Hiatellidae	<i>Pitar rostrata</i> (Philippi, 1844)	BP III			x		x				x
	<i>Tawera gayi</i> (Hupé, 1854)*	PH III, PPIII, PPIV, PZIII, AK, BBu, BBI, HA, IG, LR, US			x		x				x
	<i>Hiatella solida</i> (Sowerby, 1834)	PH III, PPIV, PZII, PZIII, HA, LR, US		x	x	x	x				x

BP: Bahía Porvenir; PH: Puerto del Hambre; PP: Punta Palo; PZ: Punta Zeger; SO: Seno Otway; AK: Alakush; BB: Bahía Brown; HA: Harborton; IG: Isla Gable; LR: Lago Roca; US: Ushuaia. CARN: Carnivorous; FILT: Filter Feeding; INTER: Intertidal; PHYTO: Phytophagous; SUB: Sublittoral; SUPR: Supralittoral; *: Species Selected For Taphonomic Analyses.

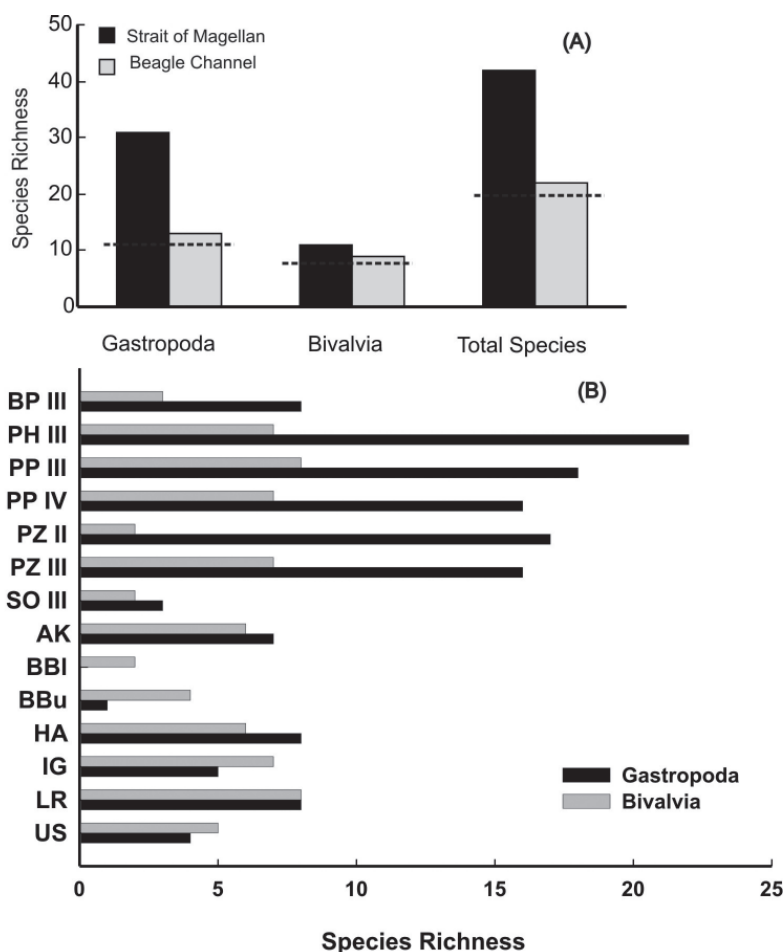


FIG. 2. Number of species collected in the Strait of Magellan and the Beagle Channel. **A.** Comparison between the Strait of Magellan and the Beagle Channel. The dotted line indicates the number of species shared between both areas; **B.** Species richness by each marine terrace **BP:** Bahía Porvenir; **PH:** Puerto del Hambre; **PP:** Punta Palo; **PZ:** Punta Zeger; **SO:** Seno Otway; **AK:** Alakush; **BB:** Bahía Brown; **HA:** Harberton; **IG:** Isla Gable; **LR:** Lago Roca; **US:** Ushuaia.

All mytilids (*A. atra*, *P. purpuratus* and *M. edulis chilensis*) analyzed were disarticulated, with highly fragmented and abraded valves (Table 3). Most venerids (*T. gayi* and *R. exalbidus*) were disarticulated, with moderate fragmentation and abrasion; the exceptions are PZII, PZIII terraces and BP site, where a few articulated specimens were collected. These infaunal species show traces of bioerosion on the valve surface, such as borings attributed to gastropod predators like Naticidae and Muricidae.

Beagle Channel terraces. Marine terraces located in this channel contain mainly infaunal bivalves. Most of these species are disarticulated and there is a moderate degree of fragmentation and abrasion

throughout the different locations. However, few articulated specimens of *T. gayi* collected on the AK, BB and HA terraces exhibit good preservation, moderate fragmentation and moderate or no abrasion in the valves. *Tawera gayi* and *R. exalbidus* show different levels of bioerosion (high, moderate and scarce). Although there are differences in the type of valves (left/right) among sites, deposits of AK, HA, LR and US have at least one species with an equal number of right and left valves. In the LR, all species have the same number of opposite valves. In addition, the attributes of fragmentation, abrasion and biotic interaction indicate good preservation and minimal transport.

TABLE 3. TAPHONOMIC ATTRIBUTES OF SELECTED BIVALVE SPECIES ANALYZED FROM DIFFERENT ENVIRONMENTS OF THE COASTAL AREA/A.

	Magellan Strait				Beagle Channel				LR	US	
	BP III	PH III	PP III	PP IV	PZ II	PZ III	AK	BBu			HA
a) <i>Aulacomya atra</i>											
Type of valve	-	-	$n_{KV} > n_{LV}$	$n_{KV} > n_{LV}$	-	$n_{KV} < n_{LV}$	-	-	$n_{KV} = n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} < n_{LV}$
Desarticulation	-	-	High	High	-	High	-	-	High	High	High
Fragmentation	-	-	High	None	-	Moderate	-	-	None	None	Moderate
Abrasion	-	-	High	Moderate	-	High	-	-	Moderate	None	Moderate
Biotic interactions	-	-	None	Scarce	-	None	-	-	Scarce	None	None
b) <i>Mytilus chilensis</i>											
Type of valve	$n_{KV} > n_{LV}$	$n_{KV} < n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} < n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} < n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} > n_{LV}$
Desarticulation	High	High	High	High	High	High	High	High	High	High	High
Fragmentation	High	High	Moderate	Moderate	Moderate	Moderate	None	High	Moderate	None	Moderate
Abrasion	High	High	High	High	None	High	Scarce	None	Scarce	Moderate	Scarce
Biotic interactions	None	Scarce	Scarce	Scarce	Scarce	Scarce	None	None	Scarce	None	None
c) <i>Perumytilus purpuratus</i>											
Type of valve	-	$n_{KV} > n_{LV}$	$n_{KV} < n_{LV}$	$n_{KV} < n_{LV}$	-	$n_{KV} > n_{LV}$	-	-	$n_{KV} < n_{LV}$	$n_{KV} = n_{LV}$	-
Desarticulation	-	High	High	High	-	High	-	-	High	High	-
Fragmentation	-	Moderate	Moderate	Moderate	-	Moderate	-	-	High	Moderate	-
Abrasion	-	High	High	High	-	High	-	-	High	Moderate	-
Biotic interactions	-	None	Scarce	None	-	Scarce	-	-	None	None	-
d) <i>Tawera gayi</i>											
Type of valve	-	$n_{KV} > n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} < n_{LV}$	-	$n_{KV} > n_{LV}$	$n_{KV} = n_{LV}$	$n_{KV} < n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} = n_{LV}$	$n_{KV} > n_{LV}$
Desarticulation	-	High	High	High	-	High	Moderate	Moderate	High	High	High
Fragmentation	-	High	Moderate	High	-	Moderate	High	Moderate	Moderate	Moderate	High
Abrasion	-	High	High	High	-	High	None	Moderate	Moderate	None	Moderate
Biotic interactions	-	High	Moderate	High	-	Scarce	None	Moderate	High	Scarce	None
e) <i>Retrotapes exalbidus</i>											
Type of valve	$n_{KV} > n_{LV}$	-	$n_{KV} = n_{LV}$	$n_{KV} = n_{LV}$	$n_{KV} > n_{LV}$	$n_{KV} < n_{LV}$	$n_{KV} > n_{LV}$	-	$n_{KV} < n_{LV}$	$n_{KV} = n_{LV}$	$n_{KV} = n_{LV}$
Desarticulation	High	-	High	High	High	High	High	-	High	High	High
Fragmentation	Moderate	-	None	None	Moderate	High	High	-	High	High	High
Abrasion	High	-	High	High	High	High	None	-	Moderate	Moderate	Moderate
Biotic interactions	High	-	Scarce	Scarce	Scarce	Scarce	None	-	High	Scarce	None

4. Discussion

4.1. Taxa composition and paleoecology

Of a total of 45 species cited in this work, 42 are in the deposits of the Strait of Magellan and only 22 in the Beagle Channel, which implied greater richness in the Strait of Magellan. However, previous studies of Gordillo (1999) and Gordillo *et al.* (1992, 2005) on deposits which also include other sites along the Beagle Channel indicate a total of 79 species for this channel, with Gastropoda (47 species) more diverse than Bivalvia (32 species). The species richness reported in these previous studies challenges a conclusion of greater diversity in the Strait of Magellan. Works by Porter *et al.* (1984) and Di Geronimo and Rosso (1996) only mention some Holocene paleontological mollusks and therefore provide a preliminary list for the Strait of Magellan deposits. In terms of relative abundance, the bivalves are the most representative, agreeing with the works mentioned above.

Differences in composition and paleoecology between the Strait of Magellan and the Beagle Channel are closely related to environmental factors such as substrate type, salinity and temperature (Fürsich and Flessa, 1987). Thus, changes in these factors may produce changes in the marine biota.

Global events, such as the climatic optimum, caused paleoenvironmental and geomorphologic changes in littoral zones that led to changes in assemblages of mollusks (Lutaenko, 1993; Camus, 2001). For instance, for the Argentinian coastlines, Aguirre *et al.* (2005, 2006) described the shift of warm water mollusks to higher latitudes on Bonariensis coasts (south Atlantic) during the climatic optimum linked with a rise in the oceanic temperature and salinity. The effect of this period is still an open debate for southern Patagonia, although changes in sea level in Tierra del Fuego (Porter *et al.*, 1984; Rabassa *et al.*, 1986), as well as changes in moisture and temperature (Pendall *et al.*, 2001; Kilian *et al.*, 2007) have been documented. Results suggest that there are no changes in the species composition since 6,000 years BP, which agrees with a previous work of Gordillo (1999) of deposits in the Beagle Channel. Likewise, all species analyzed in this work show a distribution that agrees with current references (Linse, 1999; Valdovinos, 1999; Osorio and Reid, 2004).

Although the diversity and stability of the communities have a close relationship to climatic variability (Walther *et al.*, 2002), many taxa can tolerate small climate fluctuations or experience variations at the population level with morphometric and body size changes and relative abundance, thus showing an adaptation to different environments (Stahl, 1996; Roy *et al.*, 2001). For instance, Gordillo (1992) found morphometric differences between modern and fossil specimens of *Tawera gayi* from the Beagle Channel. Likewise, size and shape of *Hiatella solida* shells are potentially related to many associated parameters including the primary influences of the substratum and temperature (Gordillo, 1995).

4.2. Taphonomic aspects

Environmental energy plays an important role in determining fossil preservation. For instance, fragile shells may remain intact in quiet waters for a long time prior to burial, and the damage they show is often of a nonmechanical nature (*e.g.*, corrosion, bioerosion). High fragmentation and abrasion tends to occur in zones with high sedimentation rates indicative of high energy environments (Brett and Baird, 1986).

According to taphonomic analyses, two types of environment exist on the coasts of Tierra del Fuego, one of high energy in the Strait of Magellan terraces and the other of low to moderate energy in the Beagle Channel. In the Strait of Magellan, the epifauna shows high fragmentation and abrasion, thus implying that they were subject to long exposure on the sea bottom before burial, and was affected by biotic and abiotic factors. It is also possible that these taxa experienced shell transport in abrasive sediment due to currents in a high-energy setting such as a foreshore environment, and/or multiple reworking episodes (Speyer and Brett, 1991). In the Beagle Channel, fossil assemblages have moderate fragmentation and abrasion, indicating a low to moderate energy environment with dominance of soft bottoms as sand or small gravel, especially in the LR where the preservation suggests minimal transport and/or a minor influence of postmortem processes on the valves.

Despite the type of environment and external factors such as temperature, salinity and substrate, it is necessary to consider intrinsic factors such as

biology, mode of life and mineralogy of the studied organisms to describe and interpret the processes that affect fossilization and the postmortem process (Lazo, 2004; Zuschin and Stanton, 2001). Epifaunal elements are thicker or have structures as byssus that give resistance and stability to organisms in conditions of high energy, but the long exposure to waves produced more fragmentation and abrasion of the shells, which creates a disadvantage in the preservation (e.g., *Mytilus*) (Zuschin and Stanton, 2001). Alternatively, the infaunal species support the results of other taphonomic works that describe the advantages of using infaunal bivalves, because they have a fast burial rate and the preservation is better than epifaunal organisms (Aguirre and Farinati, 1999; Nielsen and Funder, 2003). In this work, venerids show a good preservation in both zones of Tierra del Fuego and although abrasion and fragmentation in the deposits is moderate, this can be attributed to high bioerosion of their valves caused mainly by boring gastropods and/or encrusting elements on the surface of the shell (Zuschin and Stanton, 2001). In this regard, results show a relationship between the bioerosion level and the fragmentation in the deposits of the Strait of Magellan, i.e., deposits with high bioerosion also show high fragmentation. Nonetheless, in Alakush and Ushuaia (Beagle Channel) this relationship does not exist and the high fragmentation of venerids could be associated to different postmortem processes.

Other relevant factors related to preservation are the distribution of trophic and life habit groups. According to Gordillo and Aitken (2000), and to this study in the Strait of Magellan and Beagle Channel, the infaunal suspension feeders (bivalves) exhibit a high preservation potential, while carnivores and infaunal deposit feeders are a minor proportion of the Quaternary marine fossil records.

5. Conclusions

All fossil species collected in both zones correspond to mollusks occurring on modern beaches, which suggest that postglacial climatic changes were not enough to produce variations in the composition of the benthic communities or the environmental conditions since at least 6,000 yr BP in Tierra del Fuego. The qualitative differences between the faunistic elements of both regions, however, could be the result of different types of habitat. The local

ecological variations are caused by the occurrence of two substrate types that exist in the region: epifaunal elements associated to hard or rocky bottoms (Strait of Magellan) and infaunal elements associated to sandy bottoms (Beagle Channel).

The taphonomic attributes of five bivalve species, well represented in the Holocene littoral deposits of Tierra del Fuego, are useful indicators of paleoenvironmental conditions. In particular, venerids show a higher preservation potential than mytilids, and their infaunal life cycle and their fast burial rate makes them more reliable to use in further taphonomic analyses.

Integration of taxonomic, ecologic and taphonomic analyses do not show any significant change, either in the molluscan composition or in the energy conditions of both areas since 6,000 years BP. Future research needs to consider stable isotopes ($\delta^{13}\text{C}$ y $\delta^{18}\text{O}$) and morphometric analyses of the valves to evaluate changes in paleotemperature and other paleoenvironmental conditions during the Holocene, and their potential effects at the species level.

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