

RICHNESS AND PALAEO-ZOOGEOGRAPHICAL SIGNIFICANCE OF THE BENTHIC OSTRACODA (CRUSTACEA) FROM THE OCEANIC ISLAND OF TRINDADE AND ROCAS ATOLL, BRAZIL

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ABSTRACT – Twenty-one ostracode species from Trindade Island and 23 species from Rocas Atoll are herein recorded. The collective fauna shows low richness and low abundance compared with other oceanic islands. Nevertheless, the presence of tropical pandemic species such as *Kotarcythere inconspicua* (Brady) and *Triebelina sertata* Triebel, of the almost exclusively Pacific genus *Australimoosella*, the Atlanto-Caribbean taxa such as *Glyptobairdia coronata* (Brady) and *Caudites obliquecostatus* Bold, together with species typical of the Brazilian shelf, reveals a mixed fauna likely influenced by dispersal of shallow-water taxa between seamounts during Quaternary sea-level lowstands. In contrast to other oceanic islands, endemic ostracode taxa are apparently absent in these two islands. *Tenedocythere trinidadensis* sp. nov., a species also recorded on the Brazilian equatorial shelf, is described and illustrated.

Key words: oceanic island, ostracodes, Rocas Atoll, Trindade Island, zoogeography, paleozoogeography.

RESUMO – Foram registradas 21 espécies de ostracodes para a Ilha da Trindade e 23 para o Atol das Rocas. Ambas ostracofaunas mostram baixa riqueza e abundância de espécies quando comparadas com outras ilhas oceânicas. Contudo, a presença de espécies tropicais pandêmicas, como *Kotarcythere inconspicua* (Brady) e *Triebelina sertata* Triebel, do gênero *Australimoosella* que é quase exclusivo do Pacífico, e de táxons atlântico-caribenhos como *Glyptobairdia coronata* (Brady) e *Caudites obliquecostatus* Bold, juntamente com espécies típicas da plataforma brasileira, revela uma fauna mista provavelmente influenciada pela dispersão de táxons de águas rasas entre montes submarinos durante períodos de mar baixo ao longo do Quaternário. Contrastando com outras ilhas oceânicas, estas duas ilhas parecem não apresentar espécies endêmicas de ostracodes. *Tenedocythere trinidadensis* sp. nov., uma espécie também registrada na plataforma equatorial do Brasil, é aqui descrita e ilustrada.

Palavras-chave: ilhas oceânicas, ostracodes, Atol das Rocas, Ilha da Trindade, zoogeografia, paleozoogeografia.

INTRODUCTION

Physical isolation is conducive to allopatric speciation and thus responsible for generally high levels of endemism. One of the many causes of isolation is the imposition of barriers, such as seaways for terrestrial and freshwater organisms, or land masses for the marine taxa. The deep ocean, in turn, constitutes a barrier to the dispersal of benthic invertebrates with life cycles restricted to shallow waters on the continental shelf. In the case of oceanic islands, it is expected that areas consistently isolated over millions of years have higher levels of endemism than those with continual or intermittent shallow submarine connections with the mainland or other islands (Larwood & Whatley, 1993). Oceanic islands typically harbor low species richness and a high proportion of endemic reef fish and benthic species owing to their extreme isolation and relatively restricted shallow water zones (Whittaker & Fernandez-Palacios, 2007).

Benthic marine shallow water Ostracoda is a key group since it does not possess a planktotrophic larval stage and most marine species are not good swimmers.

Together with São Pedro and São Paulo Rocks, Fernando de Noronha Archipelago and Martin Vaz Island, the Rocas Atoll and Trindade constitute the set of Brazilian oceanic islands. In 2002 the Brazilian Environmental Bureau declared the Trindade Island a highly important area for the conservation of marine animal and plant life due to its unique tropical Atlantic oceanic setting. However, recent studies indicate that the marine biota of Trindade is the least known among the five Brazilian oceanic islands and archipelagos (Alves & Castro, 2006). Nevertheless, some studies have been undertaken in order to compile an inventory of the Trindade's biodiversity, for which mechanisms of conservation, protection, and management can be established. They have focused on both the flora (Joly, 1950; Pedrini, 1989; Nassar,

1994; Alves & Guimarães 1998; Yoneshigue-Valentin *et al.*, 2005; Villaça *et al.*, 2006) and fauna (Vannucci, 1950; Carvalho, 1950; Pinto, 1957; Lanzieri, 1966; Brito, 1971; Coelho, 1974; Breure & Coelho 1976; Tavares, 1999; Moraes *et al.*, 2006; Pinheiro *et al.*, 2009; Pereira-Filho *et al.*, 2011). Concerning the study of microfossils, with the exception of a brief report on foraminifers (Rodrigues, 1971) and a book chapter with preliminary data on ostracodes (Coimbra *et al.*, 2009), microfossils groups have not been studied at Trindade.

Because Rocas is the only atoll in the Southwest Atlantic, and it is also one of the smallest in the world, it was declared as a Marine Biological Reserve in 1979 and recognized as a UNESCO Worldwide Heritage Site, in 2001. Despite its importance, no micropalaeontological study has been carried out in the area with the exception of preliminary lists of foraminifers (Tinoco, 1965, 1972; Rossi *et al.*, 1996), foraminifers and bryozoans (Machado & Souza, 1994) and ostracodes (Coimbra *et al.*, 2009).

The present study constitutes the most comprehensive study of the benthic shallow marine ostracode species in the Brazilian oceanic Trindade Island and Rocas Atoll, and represents a contribution to the modern and palaeo-zoogeographic knowledge of this group. It is focused on the species richness of these two ostracode faunas and on unraveling the distributional history of their taxa.

The study of Quaternary and late Neogene ostracodes from oceanic islands and archipelagos dates back to the nineteenth century, however intense research on such faunas developed only in the 1970s. The first comprehensive study on this subject was undertaken at Clipperton Island in the tropical northeastern Pacific (Allison & Holden, 1971). Such studies have not been numerous and most deals with Pacific or Indo-Pacific regions, the best known being in the Solomon Islands, southwestern Pacific Ocean (Whatley & Titterton, 1981; Titterton & Whatley, 1988a,b, 2005, 2006a,b, 2007, 2008, 2009a,b, 2010); the Galapagos Islands, tropical southeastern Pacific (Pokorný, 1970, 1972; Bate *et al.*, 1981); in French Polynesia, tropical central Pacific (Hartmann, 1984); at some atolls and a few larger islands in Micronesia, western equatorial Pacific (Weissleder *et al.*, 1989); at Réunion Island, southern Indian Ocean (Whatley & Keeler, 1989); at Easter Island, southeastern Pacific Ocean (Whatley & Jones, 1999; Whatley, 2000; Whatley *et al.*, 2000); at Bermuda, western North Atlantic Ocean (Keyser & Schöning, 2000); at Marion/Prince Edward islands, sub-Antarctic Indian Ocean (Dingle, 2002, 2003); in the Cape Verde Archipelago, tropical eastern Atlantic Ocean (Wouters, 2003); in the Mariana Islands, western equatorial Pacific (Paulay *et al.*, 2003); at Pitcairn, Oeno and Henderson islands, southern Pacific (Whatley *et al.*, 2004); in the islands of New Caledonia, tropical southwestern Pacific (Maddocks, 2007); and a preliminary study in the São Pedro and São Paulo Archipelago, equatorial Atlantic (Antonietto *et al.*, 2012). These studies mostly focused on the taxonomy and zoogeography (some of them including migration strategies and endemism) of ostracodes.

STUDY AREAS

Trindade Island

Trindade Island is somewhat elliptical, 2.5 km wide, and is located in the South Atlantic Ocean (20°30'S, 29°18'W) around 1,170 km from the Brazilian coast, approximately at the same latitude as Vitória City, the capital of the Espírito Santo State (Figure 1). It is positioned on the Vitória-Trindade Alignment, which constitutes an E-W submarine volcanic chain with an inactive volcano lying at a depth of 5,500 m (Figure 2). The alignment extends east for 1,000 km from the seamount of Victoria, located near the southeast coast of Brazil, to the islands of Trindade and Martin Vaz. Volcanic activity spanned in time since the late Pliocene (~3.4 Ma) to the early Holocene, maintaining Trindade above the ocean surface (Almeida, 2002).

According to Thomaz Filho & Rodriguez (1999), the Vitória-Trindade Alignment developed as a result of multiple magmatic events as the South American Plate moved over a hot-spot during its separation from the African plate. Trindade Island corresponds to an emergent part of one of the volcanic edifices (Ferrari & Ricomini, 1999) with three peaks that rise to about 600 m above sea level. The island is surrounded by oceanic waters that reach 5,800 m depth. Most of the island consists of volcanic rocks apart from a small area with coastal sediments.

Rocas Atoll

Rocas Atoll has been described as a ring-like, semi-closed, elliptical reef, open at its western and southern limits, and is located 260 km east of Natal City and 145 km west of the Fernando de Noronha Archipelago (03°52'S, 33°9'W) (Figure 1).

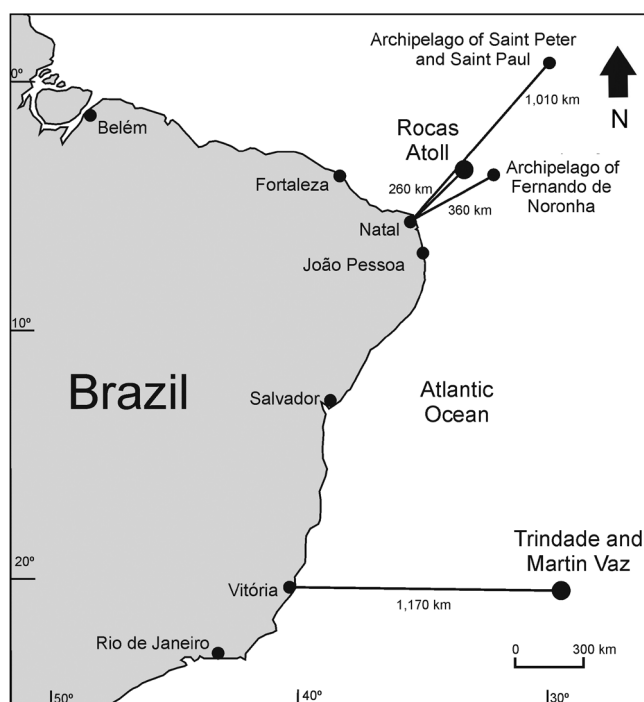


Figure 1. Location map of the Brazilian oceanic islands and archipelagos showing the distances to the nearest cities (modified from Almeida, 2006).

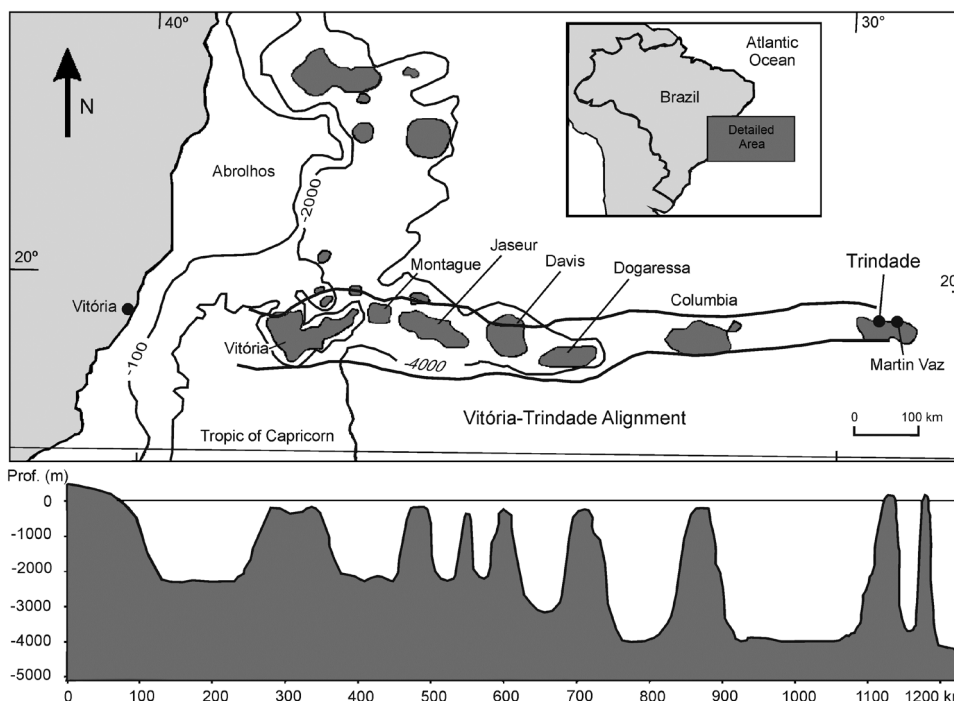


Figure 2. Geographical and bathymetrical map of the Vitória-Trindade Alignment and its seamounts (modified from Alves, 1998 and Almeida, 2006).

According to Almeida (1955, 2002, 2006), both the Fernando Noronha Archipelago and Rocas Atoll are part of a seamounts alignment developed along the Fernando de Noronha Fracture Zone of the meso-Atlantic Ridge (Figure 3). The volcanic rocks are covered by coralline algae, such as *Porolithon*, *Lithophyllum*, *Sporolithon* and *Lithoporella*, associated with vermetid gastropods and corals (*Siderastrea stellata* Verrill, 1868) and

an abundant species of the encrusting foraminifera *Homotrema rubrum* (Lamarck, 1816).

Oceanic circulation

The cool Benguela Current runs northward along the African coast, flowing then westward creating the South Equatorial Current (SEC), which crosses the Atlantic

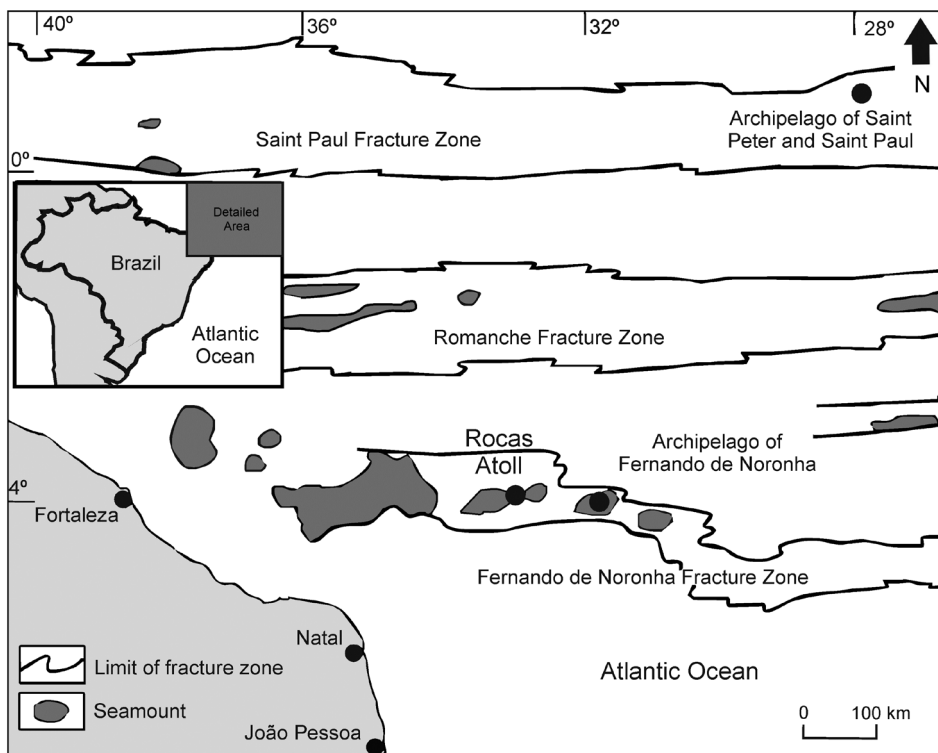


Figure 3. Map of the ocean area off the coast of NE Brazil, with some emphasis on the Fracture Zone of Fernando de Noronha and the Rocas Atoll (modified from Almeida, 2006).

parallel to the Equator. The SEC is a broad, westward flowing current that extends from the surface to a nominal depth of 100 m. Its northern boundary is usually near 4°N, while the southern boundary is usually found between 15-25°S, depending primarily on longitudinal location and the time of the year. It divides near to Brazilian coast (10-14°S) generating the North Brazil Current (= Guyana Current), which runs along the equatorial margin, and the Brazil Current, which runs southward (Peterson & Stramma, 1991) (Figure 4).

The region around Trindade Island is strongly influenced by the Brazil Current (salinity ~37‰; $T^{\circ} \sim 27^{\circ}\text{C}$; transparency up to 50 m depth), presents tropical climate and temperatures around 25.2°C on average (February 30.2°C, August 17.3°C) with intermittent influence of cold fronts from the South Pole. The southwest trade winds are dominant, and the average annual precipitation is low (Alves, 1998).

Rocas Atoll is bathed by SEC. The ESE dominant winds blow during 45% of the year. Between June and August (winter), SE winds are recorded in 35% of the days while the frequency of the E winds is 15% in the same period. Between December and April (summer), SE and E winds occur during 20% of the days. The wind speed ranges from six to 10 m/s on average during the year, but in the winter, speeds between 11 and 15 m/s are common. Speeds above 20 m/s have been recorded more frequently during the summer (Kikuchi, 2002).

The annual temperature varies between 17.5 and 35.8°C, with a monthly pluvial regime average of 860 mm; the average water temperature around the atoll is 27°C, the minimum is 25.5°C and maximum of 28°C (Kikuchi, 2002).

MATERIAL AND METHODS

Surface sample details were registered according to location, depth, and sediment type (Table 1). All samples from Trindade Island, with the exception of sample M0200, which was collected by I.I. Leipnitz in 1990, were hand collected by the biologists C.P. Machado, N.G. Drozinski and V.G. Ghilardi with the help of the Brazilian marine crew, at the beginning of the first decade of the 21st century. At Rocas Atoll, samples were hand collected by the Brazilian marine crew, in 1992, at various depths from three transects located on the western side of the atoll.

The samples were washed and prepared for study following standard procedures for calcareous microfossils. The material was provided as dry sediment and each sample was sieved into three size fractions: 0.250, 0.177 and 0.063 mm. All size fractions were thoroughly picked for Ostracoda, although the finest material was commonly barren. All photographs were taken at the Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México (UNAM).

The ostracodes examined in this study are held in the collections of the 'Museu de Paleontologia', Universidade Federal do Rio Grande do Sul (UFRGS), Section of Ostracoda. The type material is identified by the prefix MP-O. This paper follows the suprageneric classification of Ostracoda by Liebau (2005).

TAPHONOMY

The sampling techniques used in this study did not permit the distinction between living and sub-Recent ostracodes,

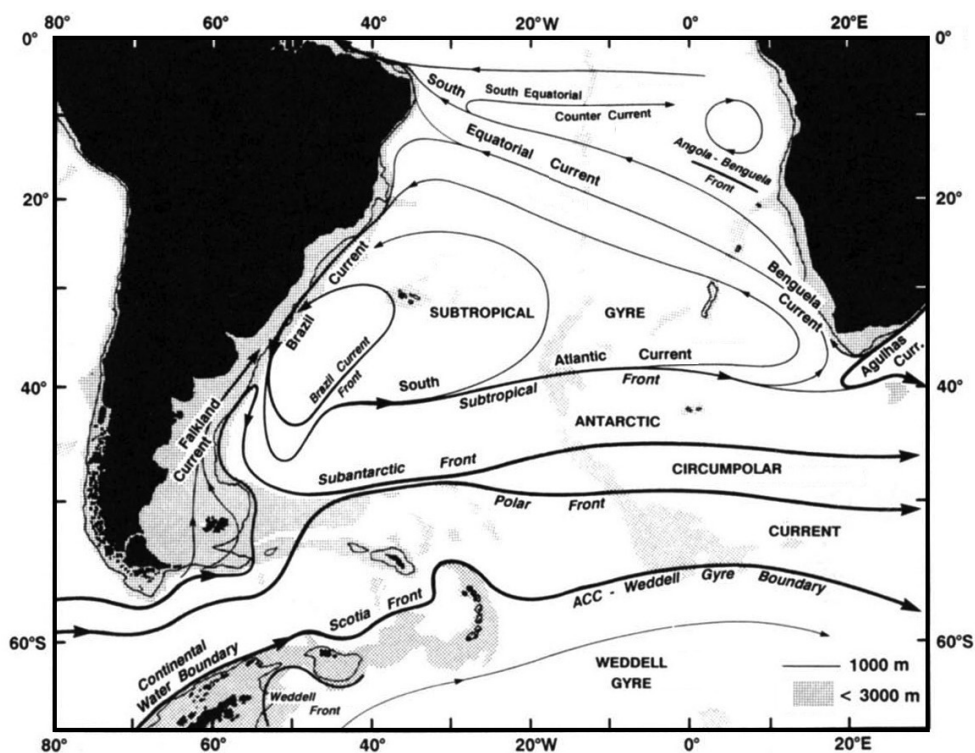


Figure 4. Surface circulation in the South Atlantic (modified from Peterson & Stramma, 1991).

Table 1. Number, location, depth, and sediment type of samples recovered from Trindade Island and Rocas Atoll, Brazil.

Sample	Locality	Coordinates	Depth (m)	Sediment
MO200	Trindade, just on face of Andradas Beach	20°30'33"S-29°16'22"W	20	fine to medium sand
MO201	Trindade. Parcel das Tartarugas Pool	20°31'13"S-29°17'59"W	1	very fine sand
MO202	Trindade. Crista do Galo Pool	20°29'13"S-29°20'16"W	1	very fine sand
MO203	Trindade. Calheta Beach	20°30'30"S-29°18'33"W	1	medium sand
MO204	Trindade. Calheta Beach	20°30'31"S-29°18'32"W	7	medium sand
MO205	Trindade. Calheta Beach	20°30'36"S-29°18'26"W	10	medium sand
MO206	Trindade. Calheta Beach	20°30'38"S-29°48'27"W	15	medium sand
MO207	Trindade. Andradas Beach	20°30'42"S-29°18'23"W	3	medium sand
MO208	Trindade. Andradas Beach	20°30'47"S-29°18'21"W	3	medium sand
MO209	Trindade. Tartarugas Beach	20°31'04"S-29°18'02"W	1	medium sand
MO210	Trindade. Túnel Beach	20°31'31"S-29°17'58"W	1	coarse sand
MO307	Rocas Atoll. Transect A	3°51'08.2"S-30°49'19.32"W	10	gravel
MO308	Rocas Atoll. Transect A	3°51'00"S-30°49'21.35"W	18	coarse sand
MO309	Rocas Atoll. Transect A	3°50'49.75"S-30°49'35.6"W	27	very coarse sand and gravel
MO310	Rocas Atoll. Transect B	3°52'17.29"S-30°49'39.7"W	10	gravel
MO311	Rocas Atoll. Transect B	3°52'24.91"S-30°49'39.7"W	20	coarse sand
MO312	Rocas Atoll. Transect B	3°52'33.05"S-30°49'48.8"W	30	gravel
MO313	Rocas Atoll. Transect C	3°51'32.82"S-30°49'39.7"W	10	coarse sand
MO314	Rocas Atoll. Transect C	3°51'32.82"S-30°49'50.3"W	20	coarse sand
MO315	Rocas Atoll. Transect C	3°51'32.82"S-30°50'05.1"W	27	coarse sand

since only empty carapaces and valves were obtained. Although the authors do not ignore the possibility of bias introduced by time-averaging in marine accumulations, they are unaware of studies on this topic done using marine benthic ostracodes. However, some analysis based on larger bivalve invertebrates, such as mollusks and brachiopods recovered from tropical and sub-tropical shallow-water samples of unconsolidated surficial deposits, has revealed that shells can range in age from modern to 4,000 yr B.P. (Kowalewski *et al.*, 1994, 1998, 2000, 2002). Carroll *et al.* (2003), in a study on empty shells and valves of the terebratulid *Bouchardia rosea* (Mawe, 1823) recovered from the inner shelf off São Paulo State, dated specimens from modern to 3,000 yr B.P. with a standard deviation of 690 years, and so concluded that time-averaging in such accumulations varied from hundreds to thousands of years. The estimates of time-averaging differed greatly among the study sites, with an age range of 370 years at the least time-averaged locality and over 3,200 years at the most time-averaged locality. Finally, Krause *et al.* (2010) dated 178 shells collected from two sites on a mixed carbonate-siliciclastic shelf off the coast of SE Brazil where the brachiopod *B. rosea* and the bivalve *Semele casali* Doello-Jurado, 1949 were dominant components of the local fauna. The material ranged in age from zero (not lived collected) to 8,118 yr B.P., but 83% of them were from the last 3,000 years.

Moreover, regarding the transport of dead shells and valves, biostratigraphic studies have demonstrated clearly that transport of macrobenthic shells (*e.g.* Carroll *et al.*, 2003 and references therein), or even microscopic tests of foraminifers (Be' & Hutson, 1977; Martin, 1999), is limited in marine environments, even in high-energy, shallow-water settings. Carroll *et al.* (2003) identified substantial lack of transport,

even by direct observations, as follows: "the brachiopod shells occur in patches and are found primarily in those areas where live specimens are present. They represent *in situ* accumulations produced by local populations, and not transported material."

According to the above discussion and on biostratigraphic inferences based on assemblages of Ostracoda performed by Van Morkhoven (1972), Whatley (1983), Brouwers (1988), Whatley & Boomer (1995) and Coimbra *et al.* (1999b), the present authors concluded that the analysis of the total fauna of dry bottom sediments recovered from the Trindade Island and Rocas Atoll, is an appropriate option to perform estimation of species richness and zoogeographical and palaeozoogeographical analysis. In fact, it also presents some advantages over the study of exclusively living faunas: (i) it offers good ecological interpretations due to the greater number of specimens available; (ii) it eliminates the possibility of fluctuations in the composition of the fauna which results, for example, from seasonal variability; (iii) it allows a more direct comparison between Recent and fossil assemblages.

FAUNAL ANALYSIS

Similarly to other Brazilian oceanic islands, these two study islands possess poorly diversified reef fish and benthic assemblages, possibly due to its isolation and small size in comparison to the mainland (Floeter *et al.*, 2008; Pereira-Filho *et al.*, 2011). The same statement is also true for the present study, where a relatively low richness and abundance of benthic ostracodes were registered. However, it differs from studies based on other zoological groups by the apparent

absence of endemic species. Samples M0203, M0204, M0209 and M0210 were barren for ostracodes but 21 species were recorded from the remaining samples. Due to the scarcity of adult specimens, five species were left in open nomenclature and at least two ones were identified only to Bairdiidae. With the exception of the three species of *Caudites*, the other genera recorded are monospecific.

The diversity and abundance of ostracodes at Rocas Atoll was also comparatively low and no endemic species were recovered so far. Samples MO310 and MO313 were barren. Twenty-five species were recorded from the remaining seven samples. Fifteen species were confidently identified and the remainder left in open nomenclature.

The number of valves and carapaces of each species in each sample are given in the Tables 2 and 3. Assemblages from both localities contain very common shallow water pandemic species, such as *Triebelina sertata* Triebel, 1948 and *Kotarocythere inconspicua* (Brady, 1880) as well as *Tenedocythere* ex gr. *transoceanica* (Teeter, 1975), which are considered to have originated in the Indo-Pacific Ocean, but are nowadays widely distributed in shallow tropical marine shelves, including part of the Brazilian shelf (Coimbra *et al.*, 1999b) and the Tamandaré Bay in northeastern Brazil (Coimbra *et al.*, 1992). On the other hand, *Keijia demissa* Teeter, 1975, *Neomonoceratina mediterranea* (Ruggieri, 1953) and *Kangarina abyssicola* (Müller, 1894), also well-known warm-water pandemic ostracodes with records on the Brazilian tropical shelf (Coimbra *et al.*, 1999b), are unexpectedly absent both from Trindade and Rocas.

Species largely considered to be typically Caribbean [*Glyptobairdia coronata* (Brady, 1870), *Caudites obliquecostatus* Bold, 1963, and *Radimella confragosa* (Edwards, 1944)] were recorded at one or both islands (Tables 2, 3). These taxa have all been reported previously in Brazil (Coimbra *et al.*, 1992, 1999b). *Paracytheridea tschoppi* Bold, 1946, a Miocene species that nowadays has a wide distribution in the Atlantic and is also present in the East and West Pacific oceans and in some oceanic islands, such as Clipperton, Solomon and Réunion, and *Hemicytherura bradyi* (Puri, 1960), a species reported since the upper Miocene in the Caribbean, Gulf of Mexico and Florida, were also recorded in the studied samples. They are also represented by few specimens in Holocene sediments from the equatorial shelf of Brazil as discussed by Coimbra *et al.* (1999a,b).

Among the other species recorded from Trindade, *Caudites exmouthensis* Hartmann 1978 and *Caudites seminudus* Whatley & Keeler, 1989, both assumed to have originated in the Indo-Pacific Ocean, are scarce and are also sparsely distributed in Holocene sediments from Tamandaré Bay, northeastern Brazil (Coimbra *et al.*, 1992). *Auradilus costatus* (Hu, 1979), described from the Pleistocene of Taiwan and with living populations in the Indian and Pacific oceans, is also present at Trindade Island and has been reported along the Brazilian equatorial and northeastern shelves and in Tamandaré and Sepetiba bays (Fauth & Coimbra, 1998; Coimbra *et al.*, 1999b).

A few carapaces (three) and valves (five) of *Australimoosella polypleuron* Coimbra *et al.*, 2004, whose genus is more diversified in the Pacific Ocean, were recovered from Trindade

Table 2. Occurrence and abundance of ostracode species recorded at Trindade Island. **Abbreviations:** c, carapace; v, valve.

Species	Samples						
	MO200	MO201	MO202	MO205	MO206	MO207	MO208
<i>Auradilus costatus</i>	1c, 2v						
<i>Australimoosella polypleuron</i>	3c, 5v						
Bairdiidae indet. 1	3v			1v	1v		
Bairdiidae indet. 2	2c, 8v	3v					
<i>Caudites exmouthensis</i>	1c, 1v						
<i>Caudites obliquecostatus</i>	1c	3v	4v				
<i>Caudites seminudus</i>	4c, 2v	7c, 21v	3c	4v		1v	4c
<i>Hemicytherura bradyi</i>		1v		1v		1v	1c
<i>Keijicyoidea</i> sp.	8c, 19v	1c, 6v				1v	2v
<i>Kotarocythere inconspicua</i>		2c, 1v		2c, 2v	2c		
<i>Loxococoncha bullata</i>	6c, 214v	6v	1v	2v			
<i>Macrocyprina</i> sp.	1c, 13v						
<i>Nanocoquimba labyrinthica</i>	5c						3c, 1v
<i>Paracypris</i> sp.				2c, 1v		1c	
<i>Paracytheridea tschoppi</i>	533v	14v	1v	4v	1v		3v
<i>Paranesidea parabipustulosa</i>	2c, 8v						
<i>Puriana variabilis</i>	4c, 8v						
<i>Sclerochilus</i> sp.		1c, 5v					
<i>Tenedocythere trindadensis</i>	78c, 93v	9v		1v, 4v	2v		1v
<i>Triebelina sertata</i>	20v	1v				1v	1v
<i>Xestoleberis</i> sp.	1c, 10v	1v	2v	21v			

Table 3. Occurrence and abundance of ostracode species recorded at Rocas Atoll. **Abbreviations:** c, carapace; v, valve.

Species	Samples						
	MO307	MO308	MO309	MO311	MO312	MO314	MO315
<i>Caudites seminudus</i>	1c		1v	2v			
<i>Caudites</i> sp.	5c, 6v		1c, 1v		1v		
<i>Cytherura</i> sp.				1v			
<i>Glyptobairdia coronata</i>	4v		1v			1v	2c, 2v
<i>Hemicytherura bradyi</i>			1v	1c, 8v			
<i>Keijcyoidea amazonica</i>	6v	1v	5v			1c, 1v	1c, 1v
<i>Kotarocythere inconspicua</i>			4v	7c, 8v			1c
<i>Loxoconcha</i> sp.	6v						
<i>Loxocorniculum tricoratum</i>	1c, 10v		12v	5v	4v		4c
<i>Macrocyprina</i> sp.		1v	2c, 1v	1v	1c, 2v		2v
<i>Neocaudites subimpressus</i>							1c
<i>Neonesidea</i> sp.1					6v	2v	
<i>Neonesidea?</i> spp.	13v,	3c, 2v,	11v	2v, 9v	2v	1c, 13v	5c, 15v
<i>Orionina bradyi</i>			1c		1c		
<i>Paracytheridea batei</i>	2v	1v	18v	2v	1v		
<i>Pellucistoma</i> sp.			3v				
<i>Puriana convoluta</i>	1c, 1v		4v	2v			1c
<i>Radimella confragosa</i>	1v	1c	2c, 1v				1c, 1v
<i>Tenedocythere</i> ex gr. <i>transoceanica</i>	20v		2c, 10v	5v	2v		1c, 1v
<i>Tenedocythere trinidadensis</i>	4c, 2v	1c	1c		1v	1c	1c, 1v
<i>Triebelina sertata</i>	2v		1v				2v, 1v
<i>Xestoleberis</i> spp.	1c, 6v	3v	8c, 38v	9c, 24v	3c, 3v	2c, 3v	5c, 2v

Island, constituting just the second record of this genus (and species) in the Atlantic Ocean; its extremely low abundance did not allow confident explanation of its presence. Coimbra *et al.* (2009) tentatively proposed that this genus, which has few species, migrated from an origin in the Australian region (see Hartmann, 1978) during the Quaternary. Nevertheless, the currently documented distribution of *Australimoosella* detracts from resolving an obvious migration route or mechanism. The same applies to the all species above mentioned whose origin is in the Indo-Pacific Ocean. A likely explanation is that these ostracodes arrived at these islands from the east (Indian and Pacific oceans) on floating algae, their holdfasts and attached sediments through a process of island hopping during times of low sea level. This hypothesis is reinforced by both the oceanic currents and wind flow pattern (see above Ocean circulation) in South Atlantic. Such a mechanism is discussed by Machado *et al.* (2005) in the study of the ecology and distribution of ostracodes in Rio de Janeiro inner shelf. Notwithstanding the wide distribution of many pandemic shallow marine ostracodes since the Neogene, some authors have inferred that recent human shipping has played an important role in the passive dispersal of these microcrustaceans (Witte & Van Harten, 1991).

In general, as above discussed, the ostracode assemblage recovered in the present study consists of species that have been most frequently reported on the equatorial and/or northeastern Brazilian shelves. However, *Nanocoquimba labyrinthica* Ramos, 1996 and *Loxoconcha bullata* Hartmann,

1956, two species recorded at Trindade Island, were previously known only from the southeast and southern Brazil (see Ramos, 1996; Coimbra *et al.* 2006, 2007).

TAXONOMY

The identity of a few species recovered in this study is unsolved, leaving some uncertainty regarding their distribution and biogeographic affinities. One such case is *Tenedocythere* ex gr. *transoceanica*, a relatively abundant species at Rocas Atoll. Although Teeter (1975) and Cronin (1988) regarded this widely dispersed ostracode as morphologically well-defined, Cronin (1988, pl. 1, figs. 1-8) illustrated a slightly but conspicuous morphological variability among specimens from different populations around the world. Additionally, the circumtropical species *Kotarocythere inconspicua* shows no geographical variations, but it is a polymorphic ostracode with morphotypes that may occur sympatrically. According to Witte & Van Harten (1991) it is a conspicuous species whose polymorphism has brought some confusion to systematics and zoo- and palaeozoogeography. Finally, *Auradilus costatus* (Hu, 1979), the only known species of this genus in waters beyond the Indian and Pacific oceans (Jellinek, 1995), was considered by Mostafawi *et al.* (2005) as a junior synonym of *Auradilus convolutus* (Brady, 1868), although in the opinion of the present authors they should be considered as distinct taxa.

Most species reported herein have been thoroughly described elsewhere; therefore, only a complete checklist is

provided in Appendix 1. Because of the scarcity of specimens, poor preservation, and/or presence of only juvenile valves or carapaces, it was not possible to identify some forms at specific level and, therefore, they are listed under open nomenclature. Further works in the two study sites might bring additional data to elucidate some taxonomic aspects still poorly understood on Brazilian island ostracode faunas.

Order PODOCOPIDA Sars, 1866
 Suborder CYTHEROCOPINA Gründel, 1967
 Infraorder NOMOCYTHERININA Liebau, 1991
 Superfamily TRACHYLEBERIDOIDEA Liebau, 2005
 Family HEMICYTHERIDAE Puri, 1953
 Subfamily THAEROCYTHERINAE Hazel, 1967

Tenedocythere Sissingh, 1972

Type species. *Cythere prava* Baird 1850. Holocene, Buzzards Bay, southeastern Massachusetts, USA.

Remarks. Although there is debate on the affinities of *Tenedocythere* with *Quadracythere* Hornibrook 1952, the latter lacks the well-developed ribs typical of the former. On the other hand, some authors (e.g. Titterton & Whatley, 2008) consider *Bosasella* Bonaduce 1985, *Neohornibrookella* Jellinek, 1993 and *Paraquadracythere* Jellinek, 1993 to be junior synonyms of *Tenedocythere*. However, we consider that the morphologies of these taxa require further investigation before their synonymy can be justified. Finally, the real taxonomic status and relationships among the problematic genera *Jugosocythereis* Puri, 1957 and *Quadracythere* and *Tenedocythere* was not resolved by Titterton & Whatley (2008), although *Jugosocythereis* possess some internal features that distinguish it from the other genera.

Tenedocythere trinidadensis sp. nov.
 (Figures 5A-L; Table 4)

1999b *Hermanites transoceanicus* Teeter. Coimbra, Pinto, Würdig & Carmo, p. 370, pl. 2, fig. 3.

[non] 1975 *Hermanites transoceanicus* Teeter, p. 450, figs. 11o-q, 12h.

2009 *Tenedocythere?* sp. Coimbra, Ghilardi, Casetta & Bergue, p. 136, fig. 5.1r.

Table 4. Morphometric data (mm) for *Tenedocythere trinidadensis* sp. nov.

Specimen	Length	Height	Width
MP-O-2402 Female LV	0.52	0.34	-
MP-O-2403 Female RV	0.50	0.31	-
MP-O-2404 Female C	0.50	0.34	0.29
MP-O-2405 Female LV	0.50	0.31	-
MP-O-2406 Female RV	0.52	0.34	-
MP-O-2407 Male? C	0.50	0.28	0.28
MP-O-2408 Female C	0.52	0.32	0.29
MP-O-2409 Female C	0.52	0.33	0.29
MP-O-2410 Female C	0.52	0.34	0.29

Type material. Holotype, MP-O-2402. Paratypes, MP-O-2403 to 2410. All type material is deposited in the collections of the 'Museu de Paleontologia', Universidade Federal do Rio Grande do Sul (UFRGS), Section of Ostracoda.

Type locality. Piscina Crista do Galo, 1 m water depth, sample MO200 (20°29'13"S-29°20'16"W). Very fine sand, Trindade Island, Brazil.

Additional material. Trindade Island: 78 carapaces and 110 valves; Rocas Atoll: three carapaces and 38 valves. See Tables 2 and 3.

Etymology. From the type locality, Trindade Island.

Diagnosis. Medium size. Surface with well-developed ornament of rounded to ovate fossae, somewhat subquadrate in dorsal, ventral and anterior regions. Ribs scarce and mainly oblique; ventro-lateral rib posteriorly alate. A well-defined wing-like process protrudes on the postero-dorsal margin. Eye tubercle conspicuous and crossed by the antero-marginal rib.

Description. Medium-size carapace. Sub-rectangular in lateral view; greatest height at the anterior cardinal angle; greatest width just after mid-length in the swelling area. Subcentrally, a smooth swelling slightly antero-ventral in position. Eye tubercle conspicuous. Dorsal margin straight and inclined towards the posterior where it is largely obscured by a lateral wing-like process. Anterior margin broadly and slightly asymmetrically rounded with a well-developed flange more visibly plicate in the ventral half. Posterior margin laterally compressed, concave above, sub-acute and truncated sub-ventrally with five to six, short, strong and commonly broken spines. Ventral margin straight with distinct antero-median concavity, partially hidden by a ventro-lateral alate rib. Surface covered with rounded to ovate fossae, somewhat subquadrate in dorsal, ventral and anterior regions. Sieve-type normal pores. An antero-marginal rib begins at the anterior cardinal angle, crosses the eye tubercle and runs parallel to the anterior margin being mid-ventrally very tenuous and ending in the antero-ventral margin. A somewhat blade-like dorsal rib runs parallel to the margin from the eye tubercle to the posterior cardinal angle where it forms a well-developed lateral wing-like process; ventral-lateral rib posteriorly alate. A rounded rib diverges from the dorsal rib, approximately at 1/3 from the posterior cardinal angle, and runs obliquely downwards passing above the subcentral weakly developed swelling and ending almost anterior to it. A second more delicate but conspicuous rib diverges from the antero-ventral margin and runs upward in a curved path and just anterior to the subcentral swelling abruptly recurves, crossing the swelling, and continues straight ending approximately at 1/4 before the posterior margin. Ornamentation less developed in RV than in LV. In dorsal view, carapace moderately inflated. Internally, RV hinge has a strong triangular anterior tooth and a deep post-adjacent socket with a medial smooth groove ending in an oval knob-like posterior tooth. Adductor muscle scar pattern consists of a slightly oblique row of four elongate scars with two frontal smaller and ovate scars, situated in the subcentral depression. In LV, muscle scars slightly obscured and situated in a more antero-ventral position. Radial pore canals straight, simple and numerous. Inner lamella broad,

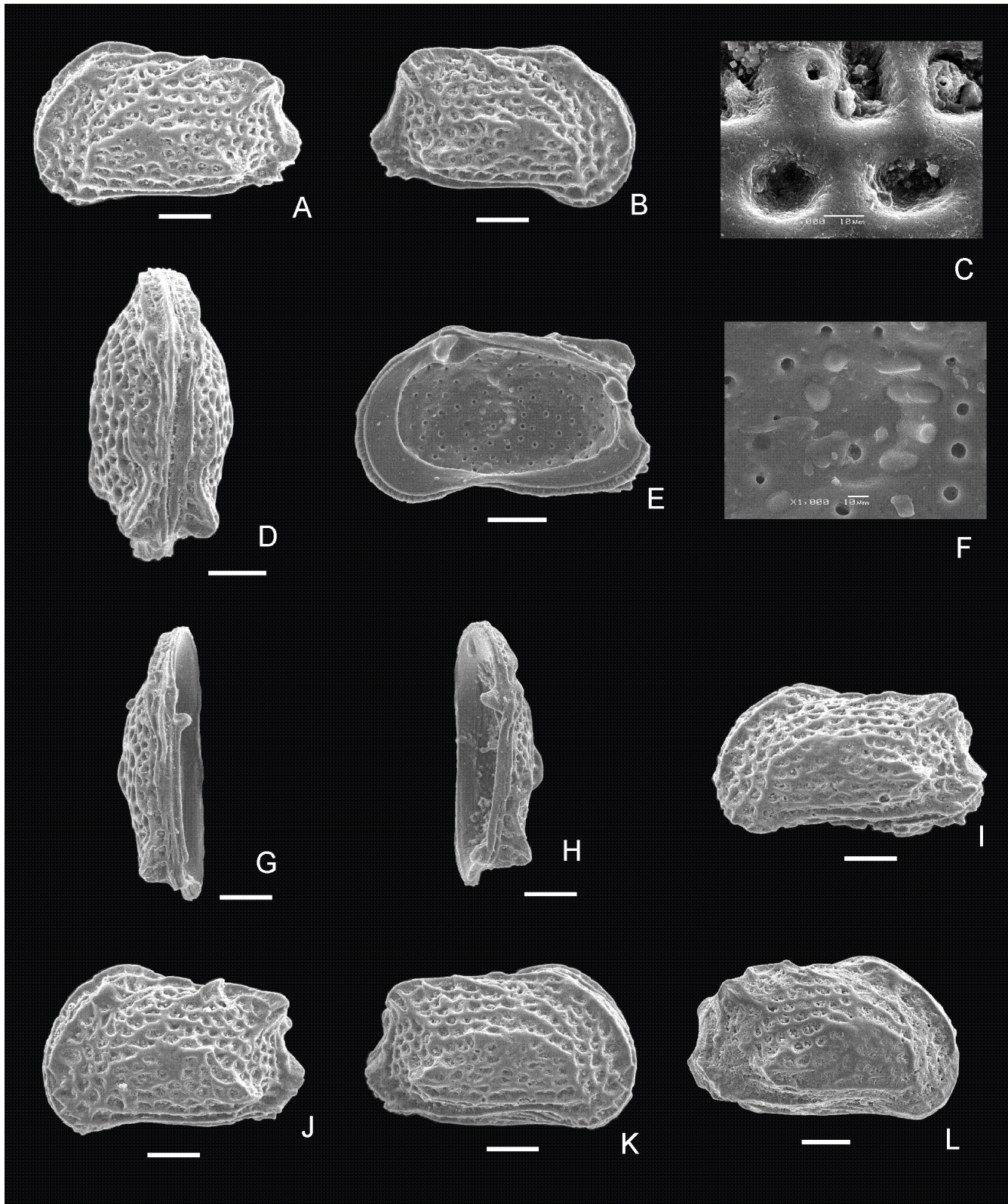


Figure 5. Specimens from Trindade Island, sample MO200. **A-L**, *Tenedocythere trindadensis* sp. nov. **A, C**, MP-O-2402, holotype, female left valve; **A**, external lateral view; **C**, detail of an intramural normal pore and a sieve-pore on solum. **B, E, F**, MP-O-2403, paratype, female right valve; **B**, external lateral view; **E**, internal lateral view; **F**, detail of the central muscle scars. **D**, MP-O-2404, paratype, female carapace, dorsal view. **G**, MP-O-2405, paratype, hinge of a female left valve, dorsal view. **H**, MP-O-2406, paratype, hinge of a female right valve, dorsal view. **I**, MP-O-2407, paratype, male? carapace, left lateral view. **J**, MP-O-2408, female carapace, left lateral view. Specimen showing second central low rib short and slightly sinuous. **K**, MP-O-2409, female carapace, right lateral view. Specimen showing second central low rib running long and straight before reaching the subcentral tubercle. **L**, MP-O-2410, paratype, female carapace, right lateral view, abraded specimen. Scale bars: A, B, D, G, H, J, K = 100 μ m; C, F = 10 μ m; E = 95 μ m; I, L = 90 μ m.

narrow ventrally and incurved, line of conrescence and inner margin coinciding throughout. Males more elongate than females and with few developed alar processes.

Geographical distribution. Besides its presence at Trindade Island and Rocas Atoll, this species was previously registered as *Hermanites transoceanicus* Teeter, 1975 based on a few specimens on the Brazilian equatorial shelf, but just to the southeast of the mouth of the Amazonas and Pará rivers (see Coimbra *et al.*, 1999b).

Remarks. This species was previously identified by Coimbra *et al.* (1999b) as *Hermanites transoceanicus* and by Coimbra *et al.* (2009) as *Tenedocythere?* sp. According to Whatley & Roberts (1995), Whatley *et al.* (2004) and Titterton & Whatley (2008), *H. transoceanicus* possesses internal and external morphological features that make it better assigned to *Tenedocythere*. However, based on the morphological variation expressed by this species, as shown in the zoo- and palaeozoogeographic study by Cronin (1988, pl. 1, figs. 1-8), and in the opinion of the present authors, assignment to *Tenedocythere ex gr. transoceanica* would be more appropriate. Nevertheless, the two main ribs that characterize the central surface ornamentation in *T. ex gr. transoceanica* and *T. trinidadensis* sp. nov. have markedly different orientation. For example, particularly in the first species, the upper rib is born at the wing-like projection extending antero-ventrally and crossing the subcentral tubercle, whereas in the new species the upper rib diverges from the dorsal rib at $\frac{1}{3}$ from the posterior cardinal angle and passes above the subcentral few developed swelling. The second lower rib is more weakly defined in *T. ex gr. transoceanica*, shorter and crosses the subcentral tubercle ventral and parallel to the upper rib, whereas in the species described herein the second rib is born at the antero-ventral margin, follows a curved path that runs upward and just in anterior to the subcentral swelling recurves, crossing the swelling, and continues straight, ending approximately at $\frac{1}{3}$ before reaching the posterior margin. *Tenedocythere trinidadensis* sp. nov. is also slightly smaller, possesses a different reticulation pattern, has less numerous and pronounced ribs and the posterior margin is less laterally compressed than in *T. ex gr. transoceanica*, which is also more angled sub-ventrally and less concave above. Some variations in adult specimens of the new species have been observed concerning the second central lower rib, which may be short and straight, long and somewhat sinuous or long and straight before reaching the subcentral tubercle.

DISCUSSION AND CONCLUDING REMARKS

The species richness and the abundance of ostracodes in both study areas are low and no endemic species have been recorded so far. Among the species left in open nomenclature it is possible that some might be endemic. However, additional material is necessary to confirm the identity of these species.

This apparent lack of endemism is significant because, when compared with other oceanic islands, some of them isolated for hundreds of kilometres (*e.g.* Cape Verde Archipelago, Clipperton Island, Eastern Island, Galapagos

Islands, Marion/Prince Eduard Islands, Réunion Island), the Trindade Island and Rocas Atoll are components of two chains of seamounts associated with the Trindade-Vitória Alignment (Figure 2) and the Fernando de Noronha Fracture Zone (Figure 3), respectively. About 21 ka BP the last glacial event (= LGM) reached its maximum leaving the summits of some seamounts in a shallower position or even partially emerged, creating shallow water environments in oceanic regions. After the deglacial, it was only about between 19-7 ka BP that the sea level rose to the nowadays marks (about 130 m higher). Therefore, migration routes linking those areas to the Brazilian shelf during sea-level lowstands may explain the relatively cosmopolitan aspect of the faunas.

The present authors interpret the low abundance of ostracodes at Rocas Atoll to be a consequence of the predominantly coarse to very coarse sediments and a narrow shelf around the atoll, which probably do not allow the establishing of a rich and abundant benthic fauna. On the other hand, this hypothesis could be not true for Trindade Island, where medium sand dominates the samples. As discussed above in 'Faunal analysis', marine biodiversity of Trindade is considered one of the poorest among tropical islands in the world, and then the relative low species richness for ostracodes is simply a pattern followed also by other benthic groups previously studied in the area. The explanation for this low diversity, however, could not be fully explained by the available data and are beyond the objectives of the present study.

Furthermore, two species particularly dominate the Trindade samples: *Paracytheridea tschoppi* Bold, 1946 and *Loxococoncha bullata* Hartmann, 1956. The first is also very abundant in the Brazilian equatorial shelf and occurs sporadically along the northeastern Brazilian shelf (Purper & Ornellas, 1987), whereas *L. bullata* has been recorded in southeastern and southern Brazil where it can withstand some changes in salinity and temperature and dwell not only bottom sediments, but *Sargassum* mats (see Coimbra & Bergue, 2003; Coimbra *et al.*, 2007). According to the species recovered in these two study areas, it seems that interchange between the equatorial and northeast Brazilian shelves and the seamounts was probably more effective at Rocas Atoll, which is much closer to the Brazilian coast than Trindade Island.

Pandemic species and those considered to be typical Caribbean inhabitants and some others that are characteristic of the Brazilian shelf are present at the study sites. A few species have experienced long passive spread (coming from the Indian and Pacific oceans) during times of low sea level in the Quaternary. *Australimoosela polypleuron* and *Tenedocythere trinidadensis* sp. nov. have their centres of abundance at Trindade Island. *Australimoosela* is a well-known Pacific ostracode genus whereas *A. polypleuron* is unique to the Atlantic Ocean. In a study along the Brazilian equatorial shelf, Coimbra *et al.* (2004) analyzed 339 samples and reported this species only in seven (~ 60 specimens in total), all of them localized to the SW of the mouth of the Amazon River. Thus, the five specimens of *A. polypleuron* recovered from Trindade are not so few since just 11 samples

were investigated. On the other hand, *T. trinidadensis* sp. nov. possesses a rather high abundance at Trindade contrasting with less than 20 specimens recorded along the entire Brazilian equatorial shelf. This species is also rare at Rocas Atoll. It is quite possible that these species originated on Trindade Island and only recently dispersed to the continental shelf and then to the Rocas Atoll.

It is also important to note that some well-known circumtropical shallow-water ostracodes are absent in both sites, such as *Neomonoceratina mediterranea* (Ruggieri, 1953), *Keijia demissa* (Brady, 1868) and *Kangarina abyssicola* (Mueller, 1894). The first two have an Indo-Pacific origin and the last is of Tethyan origin, all of them having experienced a long period of evolutionary stasis and geographical dispersal. Despite being pandemic, these three species are normally a minor component in the ostracode faunas where they occur, a phenomenon also present in the Brazilian equatorial shelf (see Coimbra *et al.*, 1999b). It is, therefore, possible that their absence in Trindade and Rocas is not real, but due their small populations and to the relative paucity of sampling. However, further sampling is required to test this hypothesis.

The ostracode faunas of the South Atlantic Trindade Island and Rocas Atoll are markedly less rich than those of the Pacific and Indo-Pacific tropical oceanic islands regardless of the context of sampling. Even when compared with the relatively small and largely isolated Marion/Prince Edward islands (46°54'S, 37°44'E), in the southern Indian Ocean (~6° of latitude south of the Sub-Tropical Convergence), the faunas studied herein are much more impoverished. This is also true when one compares the shelf benthic ostracode fauna of the Atlantic Ocean with those of the Indo-Pacific and SW Pacific oceans, since these two last areas have been reported as centres of evolutionary radiation for several marine invertebrate groups including Ostracoda (see Whatley 1987, Coimbra *et al.* 1999b).

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Appendix 1. Ostracode species examined in this study.

Family Bairdiidae Sars, 1888
 Genus *Glyptobairdia* Stephenson, 1946
Glyptobairdia coronata (Brady, 1870)
 Genus *Neonesidea* Maddocks, 1969
Neonesidea sp. 1
Neonesidea? spp.
 Genus *Paranesidea* Maddocks, 1969
Paranesidea parabipustulosa Coimbra & Carreño, 2002
 Genus *Triebelina* Bold, 1946
Triebelina sertata Triebel, 1948
 Bairdiidae indet. 1
 Bairdiidae indet. 2
 Family Candonidae Kaufmann, 1900
 Genus *Paracypris* Sars, 1866
Paracypris sp.
 Family Cytherellidae Sars, 1866
 Genus *Keijcyoidea* Malz, 1981
Keijcyoidea amazonica Bergue & Coimbra, 2002
Keijcyoidea sp.
 Family Cytheruridae Müller, 1894
 Genus *Cytherura* Sars, 1866
Cytherura sp.
 Genus *Hemicytherura* Elofson, 1941
Hemicytherura bradyi (Puri, 1960) emend. Coimbra, Carreño & Michelli, 1999
 Genus *Paracytheridea* Müller, 1894
Paracytheridea batei Purper & Ornellas, 1987
Paracytheridea tschoppi Bold, 1946
 Family Hemicytheridae Puri, 1953
 Genus *Auradilus* Jellinek, 1995
Auradilus costatus (Hu, 1979)
 Genus *Caudites* Coryell & Fields, 1937
Caudites exmouthensis Hartmann, 1978
Caudites obliquecostatus Bold, 1963
Caudites seminudus Whatley & Keeler, 1989
Caudites sp.
 Genus *Nanocoquimba* Ohmert, 1968
Nanocoquimba labyrinthica Ramos, 1996
 Genus *Orionina* Puri, 1953
Orionina bradyi Bold, 1963
 Genus *Radimella* Pokorný, 1969
Radimella confragosa (Edwards, 1944)
 Genus *Tenedocythere* Sissing, 1972
Tenedocythere ex gr. *transoceanica* (Teeter, 1975)
Tenedocythere trinidadensis sp. nov.
 Family Loxoconchidae Sars, 1925
 Genus *Loxoconcha* Sars, 1866
Loxoconcha bullata Hartmann, 1956
Loxoconcha sp.
Loxocorniculum tricoratum Krutak, 1971
 Family Macrocyprididae Müller, 1912
 Genus *Macrocyprina* Triebel, 1960
Macrocyprina sp.
 Family Paradoxostomatidae Brady & Norman, 1889
 Genus *Pellucistoma* Coryell & Fields, 1937
Pellucistoma sp.
 Family Pectocytheridae Hanai, 1957
 Genus *Kotoracythere* Ishizaki, 1966
Kotoracythere inconspicua (Brady, 1880)
 Family Trachyleberididae Sylvester-Bradley, 1948
 Genus *Australimoosella* Hartmann, 1978
Australimoosella polypleuron Coimbra, Ramos, Whatley & Bergue, 2004
 Genus *Puriana* Coryell & Fields, 1953
Puriana variabilis Chukewiski & Purper, 1985
Puriana convoluta Teeter, 1975
 Family Xestoleberididae Sars, 1928
 Genus *Xestoleberis* Sars, 1866
Xestoleberis sp. 1
Xestoleberis sp. 2
Xestoleberis sp. 3
 Family Paradoxostomatidae Brady & Norman, 1889
 Genus *Sclerochilus* Sars, 1866
Sclerochilus sp.