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Intertidal native and introduced barnacles in Brazil: distribution and abundance

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*The few records of introduced barnacles in Brazil are most commonly reported on artificial (anthropic) substrates. Here we examine the barnacle assemblage in the intertidal regions of rocky shores and natural reefs and build a data base for future monitoring and study for Brazil. We sampled 24 locations between 3 and 29°S latitude. While we found three introduced (*Amphibalanus reticulatus, Megabalanus coccopoma *and* A. amphitrite*) and three cryptogenic species (*M. tintinnabulum, A. improvisus *and* Newmanella radiata*), they were uncommon at all locations and only* M. coccopoma *was widespread south of 20°. Native species still predominated in all samples. Management strategies should focus on preventing future invasions on locations where species have not reached yet.*

Keywords: Cirripedia, latitudinal distribution, exotic species, bioinvasion, medium littoral, rocky shores, west South Atlantic, hard substrates

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INTRODUCTION

The rate of introduction of exotic species in marine and estuarine systems has been increasing exponentially for many years and consequently problems associated with their facile adaptation to new environments have also increased (Carlton & Geller, 1993; Cohen & Carlton, 1998; Ruiz *et al.*, 2000). Hard substrates (floats, docks, piers, retaining walls, buoys, etc.), especially those in estuaries and bays where hydrodynamics are limited, are most susceptible to the introduction of exotic species. At the same time, those introduced species are often unable to spread to surrounding coastal marine areas (Wasson *et al.*, 2005; Ruiz *et al.*, 2009), although there are exceptions. For example, in South Africa the exotic mussel *Mytilus galloprovincialis* (Lamarck, 1819) compete with native mussels (*Perna perna* (Linnaeus, 1758)—Branch & Steffani, 2004); the tunicate *Pyura praeputialis* (Heller, 1878), is displacing the native mussel *Perumytilus purpuratus* (Lamarck, 1819) in Chile (Castilla *et al.*, 2004); the mussel *Isognomon bicolor* (Adams, 1845) is abundant in Rio de Janeiro (Breves-Ramos *et al.*, 2010) and overtaking the area occupied by the mussel *Perna perna* that was introduced long ago (Souza *et al.*, 2004).

The lower invasibility of coastal marine areas compared to estuaries has been attributed to: (1) lower propagule pressure; (2) selection of estuarine specialists by the transport vector (ballast water); (3) limited establishment of viable populations because of the dispersal of larvae; and (4) stronger biotic resistance (Wasson *et al.*, 2005). Further, tidal regions often impose a filter due to the wide variation in environmental conditions that occur from low to high tide and which may limit invasibility of some species. Temperature variation during low tides which imposes metabolic costs has long been recognized as a limitation against the upper dispersal of many rocky shore species (Somero, 2002). Even tide pools suffer strong temperature variation and constitute a limiting factor for the establishment of some species (Klugh, 1924). Other sources of environment stress in intertidal zones are exposure to storm-generated waves and abrasion by floating debris, desiccation stress, reduced feeding opportunity and shortage of oxygen during low tides (Levinton, 2008). As a consequence, one would expect that the intertidal zone would be less invaded by exotic species than the subtidal zone in coastal marine areas but such comparison has not been done yet.

Crustaceans are among the most common invasive marine organisms (Carlton, 2011), perhaps because of being carried in the ballast of ocean-going vessels (Carlton & Geller, 1993; Ruiz *et al.*, 2000). In this group, barnacles are among the most frequently introduced crustaceans due to their habit of becoming fixed on a variety of substrates, especially in sea ports that have heavy ship traffic (Lewis *et al.*, 2005). Barnacles are also dominant inhabitants of the intertidal zone and some of the famous cases of barnacle introductions in this habitat include the invasion of coastal Argentina and artificial (human-made) substrates in Japan by *Balanus glandula* Darwin, 1854, native to the eastern Pacific Ocean. In both localities, *Balanus glandula* is dominating the intertidal zone and causing a decline in native species (Vallarino & Elias, 1997; Kado, 2003; Schwindt, 2007). *Austrominius modestus* (Darwin, 1854) is outcompeting the native *Semibalanus*

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balanoides (Linnaeus, 1767) (Crisp, 1958; Harms, 1999) apparently due to its tolerance of low salinity and cold waters (Harms, 1999; Lawson *et al.*, 2004). *Chthamalus proteus* Dando & Southward, 1980 was introduced more recently in Hawaii but, while considered to be established there, has not yet shown signs of becoming a problem (Southward *et al.*, 1998), but in some manipulative field experiments this species showed potential negative impacts such as decreasing the abundance of the native limpet *Siphonaria normalis* (Zabin & Altieri, 2007) and competing with other barnacles via substrate pre-emption, resulting in niche compression (Zabin, 2009).

Brazil is still in early stages of gathering information on invasions and invasive species in marine systems and therefore research is often centred on certain places and settings, rather than broader regional considerations, thus it is difficult to examine or describe broader trends. The first list of exotic marine species was published in 2009 and included the following barnacles in the suborder Balanomorpha: *Amphibalanus reticulatus* (Utinomi, 1967), *Megabalanus coccopoma* (Darwin, 1854) and *Striatobalanus amaryllis* (Darwin, 1854) (Lopes, 2009). A recent survey of intertidal and shallow water barnacles, on the north-eastern coast produced a checklist of 28 non-symbiont species and increased the number of exotic species (Farrapeira, 2010). The revision by Carlton *et al.* (2011) did not agree with some of the criteria used to classify exotic species in the Farrapeira (2010) study and considered six species as introduced on the Brazilian coast: the three already listed plus *Balanus trigonus* Darwin, 1854, *Amphibalanus amphritite* (Darwin, 1854), and *Amphibalanus subalbidus* (Henry, 1974). In addition to introduced species, cryptogenic species must be considered in bioinvasions to avoid underestimating the importance of species whose origins are still not well known (Carlton & Geller, 1993; Carlton, 1996). Due to the lack of surveys prior to the 1950s, many species of widespread barnacles in Brazil are considered cryptogenic (e.g. *A. eburneus* (Gould, 1841), *A. improvisus* (Darwin, 1854), *A. venustus* (Darwin, 1854) and *Megabalanus tintinnabulum* (Linnaeus, 1758)) (Farrapeira, 2010; Carlton *et al.*, 2011).

Since most previous surveys were done on artificial substrates, here we examine the issue of barnacle invasion in Brazil with the following objectives: (1) determine which species of barnacles have been introduced in the intertidal zones of rocky shores and reefs in Brazil; (2) estimate the abundance of those barnacles (as percentage cover); and (3) create a reference database for future studies of barnacle bioinvasions.

MATERIALS AND METHODS

Study area

The study was carried out in rocky intertidal zones and coastal reefs over a range of more than 25° latitude, including the States of Ceará (CE), Pernambuco (PE), Espírito Santo (ES) which belong to the Spalding *et al.* (2007) Tropical Southwestern Atlantic province, and São Paulo (SP), Paraná (PR), Santa Catarina (SC) and Rio Grande do Sul (RS) which belong to the Warm Temperate Southwestern Atlantic province (Figure 1). Three coastal locations were sampled in each state, with a minimum of 5 km between sampling points. Two places were sampled (north and south) in the State of São Paulo (Table 1).



Fig. 1. Map of Brazil showing the States and locations where we sampled. Each triangle indicates three sites (except Espírito Santo where north = 1 site and south = 2 sites). State abbreviations as in Table 1.

All the sites were at marine open coast and the substrate characteristics of each are shown in Table 1.

Sampling

Samples were collected between July and October 2010 during low spring tides by researchers of the South American Research Group on Coastal Ecosystems—SARCE. Part of this project is to examine and explain latitudinal species distribution patterns throughout coastal South America.

The intertidal zone was divided into horizontal strata following the zonation patterns exhibited by the organisms in each location. Thus, three strata were identified in the States of Paraná, São Paulo, Ceará and in Paraíso (PE), while two strata were recognizable in the remaining places. Ten quadrats were used per stratum, with the exception of Ilha do Mel and Guaratuba, where the rocky coasts were small and we sampled only five quadrats, and Ilha do Farol, where we sampled seven. Percentage cover was estimated for barnacles along with the amount of empty space using the point-intercept method. To estimate cover and empty space, a 0.25 m^2 quadrat was used, in which a grid was laid out with 100 points. At each point, barnacles (or empty space) was present or absent. In addition to quadrats, active searches were used to find barnacles. When found, the species and intertidal stratum in which it was found were noted.

Species were identified when possible in the field. When not possible, animals were fixed in alcohol and taken to the laboratory for later identification. Species were classified as native, introduced or cryptogenic following Carlton *et al.* (2011).

RESULTS

All species were identified in most of the locations, but in Espírito Santo and Ceará, this was not possible with two species in the genus *Chthamalus* (*C. bisinuatus* Pilsbry, 1916 and *C. proteus*). Therefore, both are referred to as *Chthamalus* spp.

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Table 1. List of sampling locations along the Brazilian coast.

Place, Municipality (State[1])	Coordinates	Nearest port	Substrate description
Flexeira, Trairi (CE)	3°13′02″S 39°15′57″W	Pecém (63 km)	Sandstone platform
Manguinhos, Trairi (CE)	3°13′23″S 39°14′56″W	Pecém (56 km)	Sandstone platform
Guajiru, Trairi (CE)	3°14′34″S 39°13′30″W	Pecém (60 km)	Sandstone platform
Enseada dos Corais, Cabo de Santo Agostinho (PE)	8°19′22″S 34°56′53″W	Recife (30 km)	Sandstone platform
Gaibú, Cabo de Santo Agostinho (PE)	8°20′14″S 34°56′58″W	Recife (32 km)	Sandstone platform
Paraíso, Cabo de Santo Agostinho (PE)	8°21′28″S 34°56′58″W	Recife (34 km)	Sandstone platform and granite boulders
Manguinhos, Serra (ES)	20°11′11″S 40°11′47″W	Vitória (12 km)	Granite and laterite platform
Ubú, Anchieta (ES)	20°48′27″S 40°35′27″W	Ubú (3 km)	Granite wall
Parati, Anchieta (ES)	20°48′34″S 40°36′38″W	Ubú (5 km)	Granite boulders
Itaguá, Ubatuba (SP)	23°27′04”S 45°02′43″W	São Sebastião (52 km)	Granite wall and boulders
Praia Grande, Ubatuba (SP)	23°28′01″S 45°03′35″W	São Sebastião (50 km)	Granite wall and boulders
Enseada, Ubatuba (SP)	23°29′59″S 45°05′03″W	São Sebastião (45 km)	Granite wall and boulders
Ilha Porchat, Baixada Santista (SP)	23°58′54″S 46°22′04″W	Santos (6 km)	Granite wall and boulders
Itaquitanduva, Baixada Santista (SP)	24°00′01″S 46°23′30″W	Santos (9 km)	Granite wall and boulders
Guaiuba, Baixada Santista (SP)	24°01′13″S 46°17′27″W	Santos (10 km)	Granite wall and boulders
Ilha do Mel, Paranaguá (PR)	25°34′23″S 48°19′12″W	Paranaguá (23 km)	Granite boulders
Ilha do Farol, Matinhos (PR)	25°51′00″S 48°32′11″W	Paranaguá (39 km)	Granite boulders
Guaratuba, Guaratuba (PR)	25°53′26″S 48°33′36″W	Paranaguá (44 km)	Granite and basalt boulders
Ponta do Papagaio, Palhoça (SC)	27°51′00″S 48°34′49″W	Imbituba (44 km)	Granite and basalt boulders
Praia de Cima, Palhoça (SC)	27°52′57″S 48°34′41″W	Imbituba (39 km)	Granite boulders
Pinheira, Palhoça (SC)	27°52′58″S 48°35′19″W	Imbituba (23 km)	Granite boulders
Morro do Farol, Torres (RS)	29°20′49″S 49°43′42″W	Laguna (>100 km)	Basalt platform
Guarita de Fora, Torres (RS)	29°21′06″S 49°43′51″W	Laguna (>100 km)	Basalt boulders
Guarita de Dentro, Torres (RS)	29°21′30″S 49°43′59″W	Laguna (>100 km)	Basalt boulders

[1] CE, Ceará; PE, Pernambuco; ES, Espírito Santo; SP, São Paulo; PR, Paraná; SC, Santa Catarina; RS, Rio Grande do Sul.

Table 2. Barnacle species and position (low (L), medium (M) or high (H)) in the intertidal zone along the Brazilian coast.

State	Location[1]	Native			Cryptogenic			Introduced		
		Cb[2]	*Cspp*	*Ts*	*Ai*	*Mt*	*Nr*	*Aa*	*Ar*	*Mc*
CE	FLE		MH							
	GUA									
	MAN		H					H		
PE	ENS	H		H						
	GAI	H		L						
	PAR	MH		HM				M		
ES	MAN		MH							
	PAR		MH	LM		MH*				MH*
	UBU		MH	LM		MH*	MH*			MH*
SP	ENS	MH		M						
	ITA	MH		LM						
	PGDE	MH		M						
	GUAI	MH		LMH		LM				
	IPOR	MH		M						
	ITAQ	MH		LMH						
PR	GUAR	MH		M						M*
	IFA	LMH		LM						
	IME	MH			M*			M	M*	M*
SC	PIN	MH		MH						LM
	POP	MH		MH						
	PCI	LMH		LM						LM
RS	GDE	LMH			LM*					LMH
	GFO	LMH			LM					LM
	MFA	MH								

[1] FLE, Flecheiras; GUA, Guajiru; MAN, Manguinhos; ENS, Enseada; GAI, Gaibú; PAR, Paraíso; MAN, Manguinhos; PAR, Parati; UBU, Ubú; ITA, Itaguá; PGDE, Praia Grande; GUAI, Guaiúba; IPOR, Ilha Porchat; ITAQ, Itaquitanduva; GUAR, Guaratuba; IFA, Ilha do Farol; IME, Ilha do Mel; PIN, Pinheira; POP, Ponta do Papagaio; PCI, Praia de Cima; GDE, Guarita de Dentro; GFO, Guarita de Fora; MFA, Morro do Farol; [2] *Cb*, *Chthamalus bisinuatus*; *Cspp*, *Chthamalus* spp.; *Ts*, *Tetraclita stalactifera*; *Ai*, *Amphibalanus improvisus*; *Mt*, *Megabalanus tintinnabulum*; *Nr*, *Newmanella radiatta*; *Aa*, *Amphibalanus amphitrite*; *Ar*, *Amphibalanus reticulatus*; *Mc*, *Megabalanus coccopoma*; *, locations where the species were only found by active search ouside the quadrats.

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Table 3. Percentage cover of the most common barnacle species and bare space along the Brazilian coast. Values correspond to the total cover of ten 1 m² quadrats in one of three sites in each state.

State	Intertidal zones	Chthamalus spp.		*Amphibalanus amphritite*		*Tetraclita stalactifera*		Bare space	
		Max	Min	Max	Min	Max	Min	Max	Min
Ceará	Low	0	0	0	0	0	0	57.4	26.5
	Mid	1.7	0	0	0	0	0	57.2	34.3
	High	12.4	0	7.1	0	0	0	53.2	32.2
Pernambuco	Low	0	0	0	0	0.5	0	27.7	11.9
	Mid	14.7	0	0.1	0	0	0	21	0
	High	58.6	24.8	0	0	0	0	20	15.6
Espírito Santo	Low	0	0	0	0	0.1	0	33.1	4.2
	High	39.9	17.7	0	0	3	0	32.6	17.2
São Paulo (U)*	Low	0	0	0	0	0.3	0	3.2	0.3
	Mid	1.7	1.1	0	0	16.3	4.2	66.1	36.3
	High	49.4	25.9	0	0	0	0	65.3	26.6
São Paulo (BS)*	Low	0	0	0	0	0.5	0	4.5	3
	Mid	5.9	1.7	0	0	18	2.2	34.3	25.3
	High	64.5	48.2	0	0	0.7	0	45.7	16.4
Paraná	Low	0.7	0	0	0	0.4	0	18	6.5
	Mid	17.5	9.2	1.2	0	2.6	0	12.4	6.2
	High	55.6	24.4	0	0	0	0	36	11.2
Santa Catarina	Low	0.6	0	0	0	1.5	0	7.7	3.4
	High	48.3	22	0	0	1.8	0.4	35.2	19.5
Rio Grande do Sul	Low	1.1	0	0	0	0	0	10.5	7.9
	High	54.7	34.3	0	0	0	0	52.7	74.3

*U, Ubatuba; BS, Baixada Santista.

Nine species of barnacles were found in the 24 sampled locations. Of these, three are native (*Chthamalus bisinuatus*, *Chthamalus proteus* and *Tetraclita stalactifera* (Lamarck, 1818)), three are introduced (*Amphibalanus amphitrite* (Darwin, 1854), *A. reticulatus* and *Megabalanus coccopoma*) and three are cryptogenic (*A. improvisus*, *M. tintinnabulum* (Linnaeus, 1758) and *Newmanella radiata* (Bruguière, 1789)).

Five species was the greatest richness found in two places, Ubú (Espírito Santo) and Ilha do Mel (Paraná). One species at Ubú (*M. coccopoma*) and three at Ilha do Mel (*M. coccopoma*, *A. amphitrite and A. reticulatus*) were introduced (Table 2). *Megabalanus coccopoma* was also found at Parati (Espírito Santo), Guaratuba (Paraná), Pinheira and Praia de Cima (Santa Catarina), Guarita de Fora and Guarita de Dentro (Rio Grande do Sul); *Amphibalanus amphitrite* was found at Manguinhos (Ceará) and Paraíso (Pernambuco) while *A. reticulatus* was only found at Ilha do Mel (Paraná; Table 2).

Among the cryptogenic species *Amphibalanus improvisus* was found at Ilha do Mel (Paraná), Guarita de Dentro and Guarita de Fora (Rio Grande do Sul); *M. tintinnabulum* at Parati and Ubú in Espirito Santo) and Guaiuba (São Paulo) and *N. radiata* only at Ubú (Espírito Santo; Table 2).

Some species were found only by active search (qualitative method) in certain localities: *A. improvisus* at Ilha do Mel and Guarita de Dentro; *A. reticulatus* at Ilha do Mel; *M. coccopoma* at Ilha do Mel, Guaratuba, Parati and Ubú; *M. tintinnabulum* at Parati and Ubú; *N. radiata* at Ubú (locations marked with * in Table 2).

The genus *Chthamalus* was found at all sites except Guajiru (Ceará), where no species of barnacle was found (Table 2). *Chthamalus bisinuatus* was usually the most abundant of the barnacles and in the upper intertidal stratum of the rocky shore in São Paulo (Table 3). *Tetraclita stalactifera*, also native, was found in all sampling sites in the States of Pernambuco, Santa Catarina and São Paulo, and in Parati and Ubú (Espírito Santo), Guaratuba and Ilha do Farol (Paraná). It was also found in all strata, but most abundantly in the mid-intertidal zone in Ubatuba, São Paulo (Table 3). It was found in neither Ceará nor Rio Grande do Sul (Table 2). *Megabalanus coccopoma* was only found in small numbers in the middle stratum in Paraná and the infralittoral of Santa Catarina and Rio Grande do Sul (all at less than 1%). *Amphibalanus amphitrite* was more abundant in the upper strata in Ceará (7.1%) (Table 3).

Usually the upper and middle strata had more available bare space (except in Ceará and Pernambuco), varying from 66.1% in São Paulo to 6.2% in Paraná. Ceará was different than the overall pattern, with equal available space in all three strata (Table 3).

DISCUSSION

The nine species of barnacles were evenly distributed between native, introduced and cryptogenic, which perhaps is not surprising for such an easily transported group of organisms. In contrast, the native *Chthamalus* spp. was always most abundant, while the introduced and cryptogenic species were always less common when present. *Chthamalus* spp. was expected to be most abundant considering that it is typical of hard rocky intertidal regions (especially the upper stratum) in Brazil (Young, 1993; Farrapeira, 2009, 2010; Masi *et al.*, 2009). It also has morphological adaptations for this situation of extreme exposure to drying, high temperatures and lack of food when exposed during low tides (Pannacciulli & Relini, 2000). In Rio Grande do Sul, Santa Catarina, Paraná, São Paulo and Pernambuco this genus was exclusively represented by the species *C. bisinuatus*, while in

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the remaining locations both *C. bisinuatus* and *C. proteus* may occur because we did not collect samples from those areas and field identification of this genus is very difficult.

While our methodology (which was used for other purposes) may underestimate the abundance of rare species (all species except *Chthamalus*), we still found three introduced (*Amphibalanus amphitrite, A. reticulatus* and *Megabalanus coccopoma*) and three cryptogenic species (*A. improvisus*, *M. tintinnabulum* and *Newmanella radiata*). But, we did not find *Striatobalanus amaryllis*, *Amphibalanus subalbidus* or *Balanus trigonus* that have already been recognized as introduced along the Brazilian coast (Farrapeira, 2009, 2010; Carlton *et al.*, 2011). While they may occur in the intertidal zone, they seem to be more restricted to the sublittoral.

Previously considered cryptogenic, *Amphibalanus amphitrite* (Neves *et al.*, 2007; Lopes, 2009; Farrapeira, 2010) may instead have been introduced to the western Atlantic after the Second World War (see review in Carlton *et al.,* 2011). That same review concluded that information is still lacking to determine the status of *M. tintinnabulum* and so its status remains cryptogenic. *Newmanella radiata* is a West Atlantic species found in the Gulf of Mexico (Gittings, 2009), Bahamas, Puerto Rico, Venezuela, Trinidad & Tobago (Ross, 1969) and along the Brazilian coast, from Pernambuco in the north to Santa Catarina in the south (Farrapeira, 2009). Since we do not have enough information about its origin and to know whether the Amazon delta is a natural barrier against dispersal, the species may be either native to its present distribution or the result of human transport across this barrier. Thus we decided to consider it cryptogenic, although previous publications considered it introduced in Brazil.

Amphibalanus reticulatus was only detected at Ilha do Mel by active search and this is the first report of the species on natural substrate in southern Brazil, even though it is one of the most common barnacles on artificial substrates in Paranaguá Bay (Rocha *et al.*, 2010). It seems to be a sublittoral species (Rigo, 2011) that can rarely recruit and survive in the intertidal, and its rarity prevents it from being sampled with the quadrat methodology. It may have arrived here through: (1) larvae liberated by adults that are encrusted on ship hulls that visited the Paranaguá Port; and (2) larvae liberated by adults already established on artificial substrates in the Port of Paranaguá or the Yacht Club of Paranaguá. This species has been found on artificial substrates in Rio Grande do Norte, Paraíba, Pernambuco and Rio de Janeiro and in natural settings in Maranhão, Pernambuco, Alagoas, Bahia, Rio de Janeiro and Paraná (Calado & Souza, 2003; Farrapeira, 2006, 2008, 2009, 2010; Ignacio *et al.*, 2010; Rocha *et al.*, 2010). It seems to be rare, while a recent introduction to Brazil, it is becoming more abundant than *A. amphitrite* in some places, and it has a greater growth rate than *A. improvisus* (Mayer-Pinto, 2004). Also, it is very similar to the native *Fistulobalanus citerosum* in Paranaguá Bay in respect to the high reproductive effort (>50,000 brooded larvae per individual), continuous liberation of larvae along the year, and minimum age for development of gonads (Rigo, 2011). This shows that it has adapted to local conditions (or already was) and its introduction in natural settings may have consequences for the local native barnacles and other animals in these places. In São Paulo, this species was seen on the sea turtle *Chelonia mydas* (Linnaeus, 1758) (Loreto & Bondioli, 2008), which indicates that its capacity for transport includes natural vectors as well. Thus, even though not (yet) abundant in our sampling locations, it is important that it be monitored to monitor its possible expansion to avoid damage to the native community.

Megabalanus coccopoma is more widespread, from Espírito Santo on the central coast to Rio Grande do Sul in the south. We did not find it in São Paulo but its known distribution does include São Paulo and Rio de Janeiro. In Rio de Janeiro it is more abundant than, and competes for space with, *M. tintinnabulum* where there is anthropic perturbation (Lacombe & Monteiro, 1974; Young, 1994, 1998; Ignacio *et al.*, 2010). In Pernambuco and Rio Grande do Norte it is still restricted to artificial substrates and as part of the encrusting fauna on boat and ship hulls (Silveira *et al.*, 2006; Farrapeira *et al.*, 2007).

Amphibalanus improvisus and *M. tintinnabulum* were already recorded at these locations and are widespread in coastal Brazil (Young, 1994). They are among the most abundant members of the encrusting community on hulls, which is the most likely method of dispersal (Farrapeira, 2010).

Ilha do Mel (Paraná) had the greatest barnacle species richness and consequently, also the greatest number of introduced species. This island is adjacent to the route for ship traffic to the Port of Paranaguá (23 km from the port, but much closer to the traffic lanes) which is the likely source of propagules (Cohen & Carlton, 1998; Breton, 2005). On the other hand, while the Baixada Santista (São Paulo) is only 6 km from the port of Santos and Manguinhos (Espírito Santo) only 12 km from the port of Vitória, neither had introduced species and both had lower richness than Paranaguá. Why this is so is unclear but might be because researchers only took samples from the quadrats and did not search all substrates in Santos. However, that is not true in Vitória, where all substrates were searched. So, while being near a port may favour introduction, it does not necessarily guarantee successful colonization. An alternative explanation is that processes following introduction such as physical or biological factors that facilitate or prevent the establishment of introduced species are more important at those locations (Wasson *et al.*, 2005).

The hypothesis that tropical regions have greater number of species interactions that reduce the success of species introductions (Sax, 2001) might explain the fewer number of species found to the north of Espírito Santo. However, the most tropical State in this study, Ceará, had more empty space and lower native species richness. This may have led to this area being more vulnerable to introductions if there is a positive correlation between species diversity and resistance to invasion as hypothesized (Stachowicz *et al.*, 1999; Naeem *et al.*, 2000). Greater resistance to invasion in more diverse communities is a consequence of more efficient occupation of space by the native species, which results in less space available for settling for larvae of exotics (Stachowicz *et al.*, 2002). If so, the absence of cryptogenic species and only one introduced species in Ceará may be due to: (1) methodological issues, since in this location researchers did not search actively for them outside the quadrats; or (2) other factors such as the lack of propagules or biotic resistance (Ruiz *et al.*, 2000; Wasson *et al.*, 2005).

While the three introduced species were found all along the coast of Brazil, their abundance was very low, except for *A. amphritite* in Manguinhos, Ceará. Native species were dominant in all sampling locations, which are similar to the pattern in coastal North America (Ruiz *et al.*, 2009). Most introduced species in Brazil are sublittoral and may be

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found along the lower limit of the intertidal region. One exception, *Amphibalanus amphitrite*, is commonly found in polluted regions of the lower to middle intertidal zones in estuaries and marinas (Lacombe & Monteiro, 1986; Young, 1994; Junqueira *et al.*, 2000; Breves-Ramos *et al.*, 2005; Farrapeira, 2006, 2009). Again, two types of explanation are possible: (1) pre-introduction processes are influencing the propagule availability; or (2) processes following introduction are preventing species establishment (Wasson *et al.*, 2005). Since most exotic species found are sublittoral, vectors (e.g. ship hulls, buoys and other floating substrates) which favour species that are unaccustomed to exposure to air might be more important than non-selective vectors (e.g. ballast water) for those species. Thus, the intertidal region may be somewhat protected from introductions due to transport selection for species that do not resist desiccation in the intertidal region. Further, only in Ceará the port is offshore and marine larvae would have direct access to open ocean substrates. All other ports are inside estuarine regions and larvae would have to leave the estuary to reach the sampling locations. Studies of the interactions of introduced barnacles with their environment or with the natural community are still lacking in Brazil and we do not have any evidence about processes following introductions (environment stress or biotic resistance) avoiding the establishment of exotics in the intertidal zone.

While *A. amphitrite* and *Balanus trigonus* arrived around 100 years ago, in the Americas most introductions occurred in the 1950s just after the Second World War (Carlton *et al.*, 2011). But, introductions in the intertidal zones could be even more recent, such as *Balanus glandula* in Argentina in the 1970s (Vallarino & Elias, 1997; Schwindt, 2007). The scarcity of barnacle studies in South America may explain why we do not see more introductions. Most studies are restricted to, usually submerged, artificial structures in ports and marinas.

While abundance of introduced and cryptogenic species in this study is apparently low (but, 65% of the total number of species), it is important that management focus on preventing future invasions, through assiduous attention to ballast water and ship hull incrustations, importation of allochthonous shellfish stocks for culture, and so forth. In addition to monitoring for introductions, the ecological impact and population dynamics of the species already introduced must be studied to determine the impact of introductions on native species and better understand processes that could avoid the establishment of exotics.

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