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INTRA-REGIONAL TRANSPORTATION OF A TUGBOAT FOULING COMMUNITY BETWEEN THE PORTS OF RECIFE AND NATAL, NORTHEAST BRAZIL*

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ABSTRACT

This study aimed to identify the incrusting and sedentary animals associated with the hull of a tugboat active in the ports of Pernambuco and later loaned to the port of Natal, Rio Grande do Norte. Thus, areas with dense biofouling were scraped and the species then classified in terms of their bioinvasive status for the Brazilian coast. Six were native to Brazil, two were cryptogenic and 16 nonindigenous; nine of the latter were classified as established (*Musculus lateralis, Sphenia fragilis*, *Balanus trigonus*, *Biflustra savartii*, *Botrylloides nigrum*, *Didemnum psammatodes*, *Herdmania pallida*, *Microscosmus exasperatus*, and *Symplegma rubra*) and three as invasive (*Mytilopsis leucophaeta*, *Amphibalanus reticulatus*, and *Striatobalanus amaryllis*). The presence of *M. leucophaeata*, *Amphibalanus eburneus* and *A. reticulatus* on the boat's hull propitiated their introduction onto the Natal coast. The occurrence of a great number of tunicate species in Natal reflected the port area's benthic diversity and facilitated the inclusion of two bivalves – *Musculus lateralis* and *Sphenia fragilis* – found in their siphons and in the interstices between colonies or individuals, respectively. The results show the role of biofouling on boat hulls in the introduction of nonindigenous species and that the port of Recife acts as a source of some species.

RESUMO

Este trabalho objetivou identificar os animais incrustantes e sedentários associados ao casco de um rebocador que atuava nos Portos de Pernambuco e foi cedido para o Porto de Natal, Rio Grande do Norte. Áreas com densa bioincrustação foram raspadas e as espécies foram posteriormente classificadas em relação ao *status* de bioinvasão no litoral brasileiro. Dentre as espécies identificadas, seis eram nativas do Brasil, duas criptogênicas e 16 exóticas. Destas, oito foram classificadas como estabelecidas (*Musculus lateralis, Sphenia fragilis, Balanus trigonus, Biflustra savartii, Botrylloides nigrum, Didemnum psammatodes, Herdmania pallida, Microscosmus exasperatus, Symplegma rubra*) e três como invasoras (*Mytilopsis leucophaeta, Amphibalanus reticulatus* e *Striatobalanus amaryllis*). A presença de *M. leucophaeata, Amphibalanus eburneus* e *A. reticulatus* no casco da embarcação, propiciou sua introdução na costa de Natal. A ocorrência de grande número de espécies de tunicados em Natal refletiu a biodiversidade bêntica da área portuária e facilitou a inclusão de dois bivalves, *Musculus lateralis* e *Sphenia fragilis*, encontrados em seus sifões e nos interstícios entre colônias ou indivíduos, respectivamente. Os dados obtidos indicam que a incrustação em cascos de embarcações tem um papel preponderante na introdução de espécies exóticas, e que o Porto do Recife atuou como fonte de algumas destas espécies.

Descriptors: Bioinvasion, Vessels hulls, Fouling community, Harbor area, Nonindigenous species.
Descritores: Bioinvasão; Casco de embarcação, Comunidade incrustante; Área portuária, Espécie exótica.

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INTRODUCTION

Larval dispersal in marine currents is often considered an active means of dispersal for most marine benthic species since some larvae are known to demonstrate specific active behavior that enhances the probability of their being either transported by currents or retained in certain regions (SHANKS, 1995). In spite of this, other factors have influenced the dispersal of several species all over the world. For coastal ecosystems, transportation by ships has been an important means of species introduction in many regions (ALLEN, 1953; COHEN and CARLTON, 1995; HEWITT et al., 2009).

Although transportation on slow moving wooden-hulled ships is certainly the most ancient vector (CARLTON and HODDER, 1995), the ballast water of cargo ships is presently considered the main cause of transportation and release of planktonic organisms. This water carries between ports organisms that range from bacteria and protists to larvae of benthic invertebrates and fish (CARLTON, 1985; CARLTON and GELLER, 1993; COUTTS et al., 2007; DAVID et al., 2007). However, with the regulatory policies and practices of developed countries regarding the prohibition of the use of organotin compounds as biocides in antifouling boat hull paints (CHAMP, 2000), the biofouling of ship hulls and oil platforms is once again being considered a contributor to the introduction of nonindigenous organisms into marine environments (GOLLASCH, 2002).

According to Godwin (2003), ocean-going vessels can be thought of as biological islands for species that dwell in harbors and estuaries around the world. Fofonoff et al. (2000) highlighted that vessels provide protected recesses that can be occupied by both sessile and mobile fauna, and enclosed spaces that hold water in which a wide range of organisms from plankton to fish can become entrained.

In Brazil, several taxonomic studies have suggested the possibility of the introduction of species transported by shipping, but few show such pathway marine and estuarine areas (DePAULA and CREED, 2004; FERREIRA et al., 2006; SILVEIRA et al., 2006; FARRAPEIRA et al., 2007; NEVES et al, 2007).

In the harbor area of Natal, Rio Grande do Norte state, Northeast Brazil, a tugboat named Scorpius H2G which had previously been active in the ports of Recife and Suape, Pernambuco State, was transferred to Natal in May 2007. The hull was completely covered by the fouling community after a two-year period without maintenance; thus, it included the original community of the state of Pernambuco augmented by that acquired in the new port. The aims of this study were to identify the sessile and sedentary macro-organisms found on the hull of this vessel and ascertain the status of these species in relation to their distribution along the Brazilian coast.

MATERIAL AND METHODS

During the study, the Scorpius H2G tugboat was in service for four months in the harbor area of Natal (Rio Grande do Norte, northeastern Brazil), located on the estuary of the Potengi River (Fig. 1). This estuary extends for about 30 km with a width that ranges between 400 and 600 m. It is bordered by three cities with a total population of over 1,000,000 inhabitants; Natal alone discharges more than 60% of its untreated sewage sludge directly into the river (SILVA et al., 2006).

According to the port of Natal´s tide table, taken from the Brazilian Hydrographic and Navigation Directory (Diretoria de Hidrografia e Navegação – DHN), the harbor area has a semi-diurnal prevailing tide and an annual average high tide of 2.30 m at syzygy and 1.60 m at neap tide. Nair and Sankarankutty (1988) differentiated three well defined periods, in accordance with annual variations in salinity: the first from March to June, with lower salinity values (27 to 30 at high tide); the second from July to October, with intermediate salinity (33 to 35) and the third from November to February, with higher salinity than that of the open sea (36 to 37).

The sampling of the fouled vessel (18 m in length) moored in the estuarine area of the port of Natal was undertaken during low tide on August 3, 2007. Details of the maintenance of the vessel (such as how long the vessel had been moored in Natal and when it was last dry-docked and antifouled) were obtained from the crew and confirmed by the port authority.

The survey method was not quantitative, it was intended simply to determine the presence or absence of the species and identify them. Thus, two sampling areas were chosen after a qualitative analysis of the entire hull based on the density of sessile organisms. Both sampling sites were located in the areas corresponding to the narrow intertidal zone (about 25 cm in width and emerging above the water line) and the low sublittoral zone (up to 50 cm below the water line). They were classified as more visually representative of their biodiversity and presented dense biofouling. The macrofauna was scraped with a spatula and hammer into plastic bags, duly fixed with 4% formalin, and labeled. The invertebrates were separated into groups in the laboratory and identified with the aid of stereoscopic and optical microscopes, in accordance with the relevant bibliography.

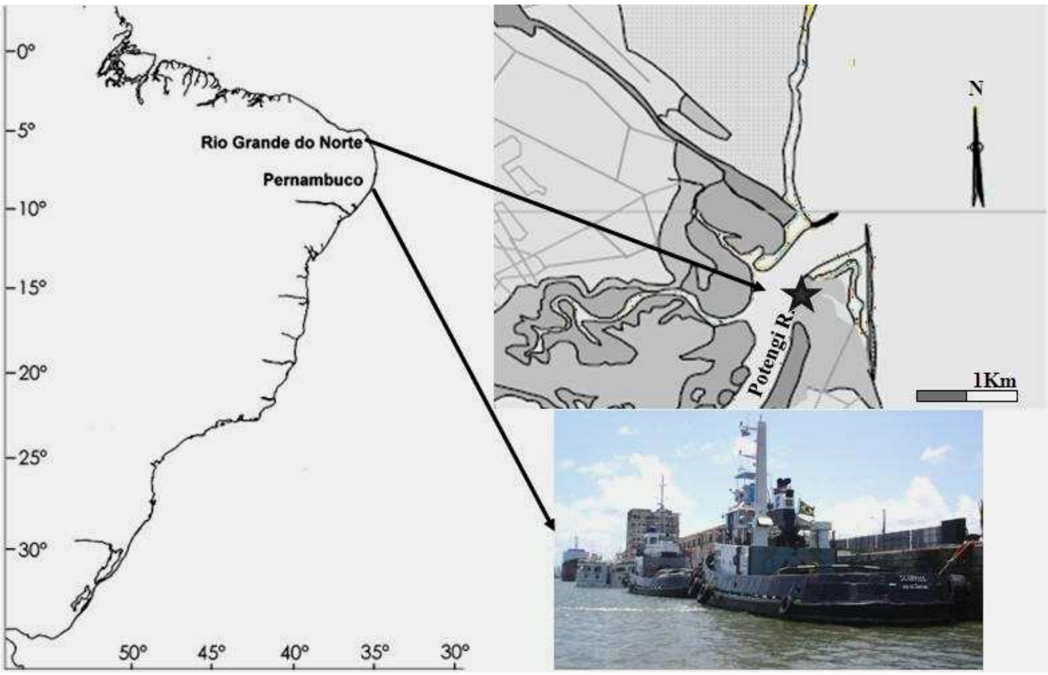

Fig. 1. Sites of Scorpius H2G tugboat operation. Natal City map, highlighting the location of Port of Natal (5º44'50"S and 35º12'34"W). Photo of the tugboat, below, taken at the Port of Recife in 2006.

To determine numerical representation, species were classified according to the number of specimens found (individuals and colonies): rare (1 to 10), common (11-30), and abundant (more than 30). The biological material collected when the tugboat was still active in Recife, Pernambuco, the data on which had been published by Farrapeira et al. (2007), was also reviewed.

The sessile and sedentary species were also classified in accordance with a terminology adapted from Carlton (1996) and Clarke et al. (2003): "Native" (N) – endemic for the Brazilian/ western Atlantic littoral; "Cryptogenic" (C) – widely distributed throughout the oceans and preferentially circumtropical, but of uncertain origin (i.e., the author does not indicate the geographical location where a type specimen was originally found) and not yet classified as native or introduced from any specific region; and "Nonindigenous" (NI) – typically from areas outside the limits of the Brazilian littoral whose presence in that area is explained as due to human mediation, often across natural barriers and/or vast distances. The source regions of each species introduced into Northeastern Brazil were based on literature.

The nonindigenous species were also classified on the basis of their bioecological behavior: "Nonindigenous Established" (NI-E) – had already been reproducing itself successfully for several generations in the region, yet without significant numerical representation; and "Nonindigenous Invasive" (NI-I) – in addition to having established itself in the region, had expanded its distribution into other places and competed with or replaced other species in a given ecological niche and become an ecological and/or economic nuisance. The criteria of the WWF (2009) were used to classify the species in this last category. Thus, to be considered harmful and invasive a species had usually to display at least one of the following characteristics in its new range: (i) displaces local native species by competing directly for food, space or light; (ii) substantially disrupts the local food web, sea floor or river habitat; (iii) enjoys prolific reproduction, recruitment, growth and survival due to its 'escape' from the natural predators, grazers, parasites or pathogens that control it in its native range; (iv) causes nuisance fouling to boats, ships, fishing gear, aquaculture equipment, industrial cooling water systems, jetty piles, etc, and (v) has noxious or pathogenic effects that cause fish mortality, disrupt aquaculture operations and/or directly threaten public health.

In order to apply this terminology, the data obtained from the harbor area was compared to all available published lists of species from the marine and estuarine environments of Brazil and other countries. In the case of species with widespread geographical distribution, the type locality and/or original distribution was verified from its initial description, and fossil records were also considered when available. The data retrieved was assembled into a combined database containing taxa, classification on bioinvasion status, comparative sampling data of Recife and Natal harbors, and geographical distribution. To indicate the species´ northward and southward limits, a generalist reference list was used indicating overall geographical distribution, which was complemented with an actual reference to expansion.

RESULTS

According to the crew members of the Scorpius H2G tugboat, the hull had not been scraped for approximately two years (which included the period when the boat was still operating in the Recife harbor area) and had been moored in the port of Natal for three months (since May 2007).

Twenty-six benthic species were found on the vessel's hull, including two species of unidentified polychaetes of the Sabellaridae and Serpulidae, eight species of bivalves, one species of bryozoan, seven species of barnacles, and eight ascidian species (Table 1, Fig. 2). The community settled in the narrow band of the hull located in the intertidal region was represented mainly by the striped barnacle *Amphibalanus amphitrite* (Darwin, 1854) and the ivory barnacle *A. eburneus* (Gould, 1841) (both classified as rare; most specimens were dead), as well as by the oysters *Crassostrea brasiliana* (Lamarck, 1819) and *C. rhizophorae* (Guilding, 1828) and some specimens of the mussel *Mytella charruana* (d'Orbigny, 1846). Twenty-two specimens (six adults in reproduction and the rest were younger) of the false dark mussel *Mytilopsis leucophaeta* (Conrad, 1831) were found in the borderline area between the intertidal and truly sublittoral zones (Fig. 2). Additionally, some serpulid epibionts were found on these invertebrates, the encrusting bryozoan *Biflustra savartii* (Audouin, 1826) and the crested oyster *Ostrea equestris* (Say, 1834), all settled on the barnacles' shells. The scorched mussel *Brachidontes exustus* (Linnaeus, 1758) was usually found in the crevices among barnacle and oyster shells.

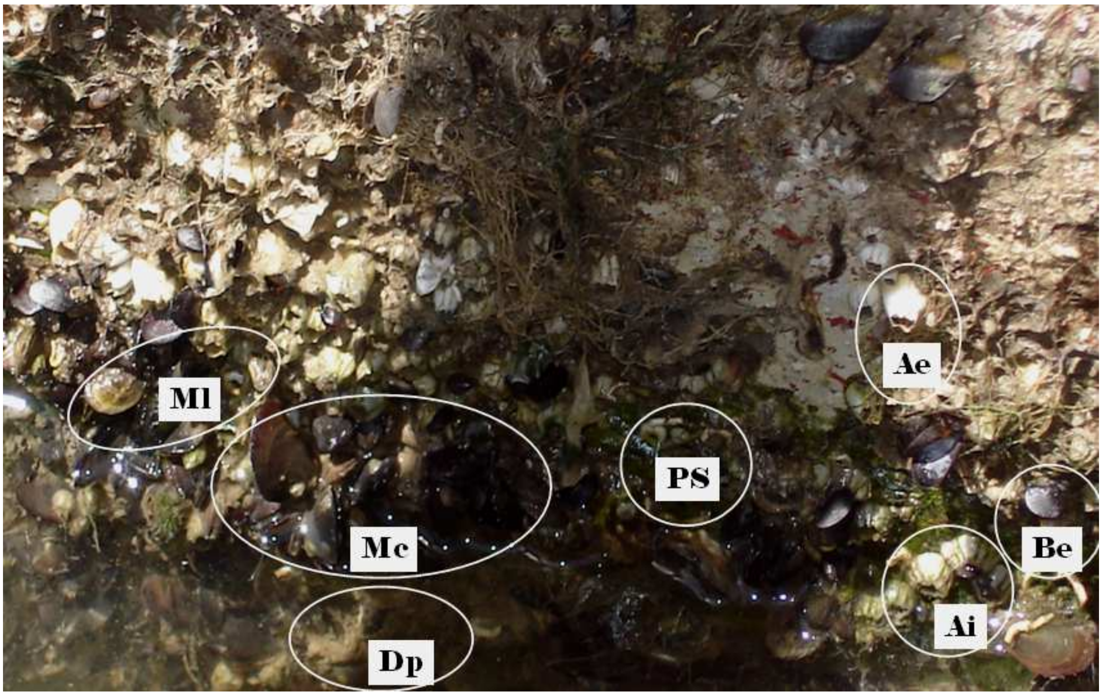

Fig. 2. Fouling community on the hull of the Scorpius H2G tugboat in Port of Natal, Northeast of Brazil, showing two delimited zones of organisms. Ae = *Amphibalanus eburneus*; Ai = *A. improvisus*; Be = *Brachidontes exustus*; Dp = *Didemnum psammatodes*; Mc = *Mytella charruana*; Ml = *Mytilopsis leucophaeta*; PS = Polychaeta Serpulidae.

Below the water line, the charru mussel (*Mytella charruana*) was fairly abundant on the hull and numerically dominant in the primary space. Many compound ascidians such as *Botrylloides nigrum* Herdman, 1886, *Botryllus* cf. *primigenus* Oka, 1928, and *Symplegma rubra* Monniot, 1972 overgrew great part of the surrounding epifauna, including mussel shells and their abundant epibiont species, the European barnacle *Amphibalanus improvisus* (Darwin, 1854). The solitary sea squirts *Herdmania pallida* (Heller, 1878) and *Microscosmus exasperatus* Heller, 1878 were abundant in the crevices among the shells, in empty barnacle shells, and on the rare barnacles *A. reticulatus* (Utinomi, 1967) and *Striatobalanus amaryllis* (Darwin, 1854) (only one immature specimen); *M. exasperatus* formed dense monospecific stands in some areas. Empty tubes of unidentified sabellid and serpulid worms were also abundant on the hull.

Another interesting fact about this sublittoral community was the association between the bivalves *Musculus lateralis* (Say, 1822) and *Sphenia fragilis* (H. & A. Adams, 1854) and the ascidians. The lateral mussel (*M. lateralis*) was found occupying the siphons of *Herdmania pallida* ascidians and also embedded in the tunic of the compound ascidian *Didemnum* sp., the tunic had wrapped around the mussels and formed a cavity. The other associated species, *Sphenia fragilis*, was found living primarily in the crevices among compound and solitary ascidians and also among barnacles and mussel shells; in this last case it was found on the accumulated associated sediment.

The list reporting the species when this vessel was active in Recife included ten species. With the exception of *Megabalanus tintinnabulum*, the fouling community found in the vessel when moored in the Natal harbor area was represented by the same community that had been found in Recife plus an additional 16 species: an unidentified Sabellariidae polychaete, the bivalves *Crassostrea brasiliana, Ostrea equestris, Musculus lateralis*, and *Sphenia fragilis*, the barnacles *Balanus trigonus*, and *Striatobalanus amaryllis*, the bryozoan *Biflustra* savartii, and eight ascidians (Table 1).

In relation to the bioinvasion status, six native species were identified: the bivalves *Brachidontes exustus, Crassostrea brasiliana, C. rhizophorae, Mytella charruana*, and *Ostrea equestris,* as well as the ivory barnacle (*Amphibalanus eburneus*). Among these, only *Crassostrea brasiliana* is endemic to Brazil, while the other species occur mainly (or at least) in the western Atlantic. There were two cryptogenic species, *Amphibalanus amphitrite* and *A. improvisus.* The remaining species were classified as nonindigenous, of which three were invasive: the false dark mussel (*Mytilopsis leucophaeta*) and barnacles *Amphibalanus reticulatus* and *Striatobalanus amaryllis*. Regarding the established species, some have old records of introduction for the Brazilian coast without significant numerical representation - as the bivalves *Musculus lateralis* and *Sphenia fragilis,* the striped acorn barnacle *Balanus trigonus,* the bryozoan *Biflustra savartii,* and the ascidians *Botrylloides nigrum*, *Didemnum psammatodes*, *Herdmania pallida*, *Microscosmus exasperatus*, and *Symplegma rubra* (Table 1).

Table 1. Benthic species found in the hull of Scorpius H2G tugboat in the Port of Natal, Rio Grande do Norte, Brazil, with indication of bioinvasion status (St) (C= cryptogenic, NI-E= nonindigenous established; NI-I= nonindigenous invader, N= native), their quantities representation (R= rare, CO= common, and A= abundant; # = specimens in reproductive stage), geographical distribution, and reports as shipborne (References numbers).

Species	St	Recife 2006	Natal 2007	Geographical distribution	Reports on ships' hull
Polychaeta					
unidentified Sabellariidae			CO	-	
unidentified Serpulidae		CO	A	-	
Bivalvia					
Brachidontes exustus	N	CO	CO	Amphi-Atlantic (Rios, 1994); Eastern Atlantic- introduced: Ireland (Minchin, 2007); Brazil: AP to RS (Rios, 1994), RA and FN (Gomes et al., 2006)	(8)
*Crassostrea brasiliana**	N	-	X	Western Atlantic (Lapègue et al., 2002); Brazil: SP to PR (Lapègue et al., 2002);	

Table 1. Continuation

Species	St	Recife 2006	Natal 2007	Geographical distribution	Reports on ships' hull
Crassostrea rhizophorae	N	A	A	Western Atlantic (Lapègue et al., 2002); Eastern Atlantic- introduced: France (Goulletquer et al., 2002); Brazil: AP - RS (Rios, 1994)	(8)
Musculus lateralis	NI-E	-	A#	Western Atlantic (Rios, 1994); Brazil: CE (Barreira et al., 2005); PE to SC (Rios, 1994)	
Mytella charruana	N	A	A#	Amphi-American (Rios, 1994); Brazil: AP - RS (Rios, 1994)	(8, 15)
Mytilopsis leucophaeta	NI-I	A	CO#	Western Atlantic (Abbott, 1974); Eastern Atlantic (Verween et al., 2007); Black Sea (Therriault et al. 2004); Brazil: PE (Souza et al., 2005)	(6, 7, 8, 12, 14)
*Ostrea equestris***	N	-	R	Western Atlantic (Shilts et al., 2007); Brazil: AP to RS (Rios, 1994)	(8)
Sphenia fragilis	NI-E	-	A#	Amphi-American: Western Atlantic (Rios, 1994); eastern Pacific: Panama (Reimer, 1976); Brazil: PA (Beasley et al., 2005); CE to SC (Rios, 1994)	
Cirripedia					
Amphibalanus amphitrite	C	R	CO	Cosmopolitan (Young, 1998); Brazil: AP to RS (Young, 1998)	(1, 2, 5, 8, 9, 10, 11, 16, 18, 21, 22)
Amphibalanus eburneus	N	R	R	Cosmopolitan (Young, 1998); Brazil: PE to SC (Cangussu et al., 2007)	(3, 4, 5, 8, 11, 19, 22)
Amphibalanus improvisus	C	A	A#	Cosmopolitan (Young, 1998); Brazil: CE to RS (Young, 1998)	(3, 5, 6, 7, 8, 9, 11, 12, 15, 16, 18, 19, 21)
Amphibalanus reticulatus	NI-I	R	R	Circuntropical (Young, 1998); Brazil- introduced: PE (Farrapeira-Assunção, 1990) to SC (Cangussu et al., 2007)	(8, 9, 10, 11, 15)
Balanus trigonus	NI-E	-	R	Cosmopolitan (Young, 1998); Brazil: AP to RS (Young, 1998)	(2, 4, 8, 9, 11, 16, 18, 21)
Megabalanus tintinnabulum		R	-	Cosmopolitan (Young, 1998); Brazil: PI to RS, and FN (Young, 1998)	(5, 8, 9, 11, 16)
Striatobalanus amaryllis	NI-I	-	R	Cosmopolitan; Southwestern Atlantic- introduced: Brazil (Young, 1998); Brazil: PI (Young, 1989) to PR (Neves et al., 2007)	(5, 8, 11)
Bryozoa					
Biflustra savartii	NI-E		R	Cosmopolitan (Winston, 1982); Brazil: BA (Kelmo et al, 2004); ES to PR (Vieira et al., 2008)	(9)
Ascidiacea					
Botrylloides nigrum	NI-E	-	A#	Cosmopolitan (Rodrigues et al., 1998); Brazil: PE (Lotufo, 2002) to SC (Rodrigues, 1962)	-
Botryllus cf. *primigenus*	-	-	A	-	-
Didemnum psammatodes		-	A#	Cosmopolitan (Rodrigues et al., 1998); Brazil: CE (Lotufo, 2002) to SP (Rodrigues et al., 1998)	-

Table 1. Continuation

Species	St	Recife 2006	Natal 2007	Geographical distribution	Reports on ships' hull
Didemnum sp.	-	-	A	-	-
Herdmania pallida	EE	-	R#	Cosmopolitan (Kott, 2002); Brazil: AL (Lotufo, 2002) to SP (Rodrigues et al., 1998)	-
Microscosmus exasperatus	EE	-	A	Cosmopolitan (Rodrigues et al., 1998); Brazil: PE (Millar, 1977) to SC (Van Name, 1945); and FN (Millar, 1977)	(9, 20)
Symplegma rubra	EE	-	CO	Cosmopolitan (Monniot C., 2002); Brazil: PB (Gama et al., 2006); BA to SC (Rocha et al., 2009)	(9, 13)
Pyuridae		-	R	-	-

Acronyms for the alphabetic names of the states: AL- Alagoas; AP- Amapá; BA- Bahia; CE- Ceará; ES- Espírito Santo; PA- Pará; PB- Paraíba; PE- Pernambuco; PI- Piauí; PR- Paraná; RS- Rio Grande do Sul; SC- Santa Catarina; and insular environments: FN- Fernando de Noronha Archipelago and RA- Rocas Atoll.

1- Allen (1953); 2- Bishop, 1947; 3- Bishop, 1951; 4- Cardigos et al., 2006; 5- Darwin, 1854; 6- Davidson et al., 2008a; 7- Davidson et al., 2008b; 8- Farrapeira et al., 2007; 9- Ferreira et al., 2006; 10- Godwin, 2003; 11- Gollasch, 2002; 12- Gollasch and Nehring, 2006; 13- Goodbody, 1993; 14- Nehring, 2006; 15- Neves et al., 2007; 16- Otani et al., 2007; 17- Rocha et al., 2009; 18- Skerman, 1960; 19- Streftaris et al., 2005; 20- Zibrowius, 2002; 21- Zvyagintsev, 2000; 22- Zvyagintsev, 2003.

* References reanalyzed after the biochemical DNA study of the Brazilian *Crassostrea* species done by Lapègue et al. (2002)

** used the generic name reassigned according Shilts et al. (2007), but considering it yet a distinct species, not synonymized with *Ostrea stentina*, Payradeau, 1826, and not including *O. aupouria* Dinamani & Beu, 1981.

Discussion

The sessile community found on the Scorpius H2G tugboat when it was moored in the Natal harbor area was represented by the same community found on the vessel in Recife in addition to other fouling species that might be present in the region and were probably recruited on the hull there. It should be highlighted that the following five species had extended their geographical range northward to Rio Grande do Norte state: *Mytilopsis leucophaeta*, *Amphibalanus eburneus*, *A. reticulatus*, *Botrylloides nigrum*, and *Microscosmus exasperatus*, all previously recorded in Pernambuco State (ROCHA & KREMER, 2005; SOUZA et al., 2005; FARRAPEIRA, 2008). Formerly, *Symplegma rubra*'s record was for the state of Paraíba (GAMA et al., 2006), *Herdmania pallida*'s for Alagoas state (LOTUFO, 2002), and *Biflustra savartii*'s for Pernambuco state (FARRAPEIRA et al., 2009b). Finding *Musculus lateralis and Striatobalanus amaryllis* in the state of Rio Grande do Norte was expected and closed a geographical hiatus in their distribution. On the Brazilian littoral, *M. lateralis* has been recorded in Ceará State (BARREIRA et al., 2005) and from Pernambuco to Santa Catarina States (RIOS, 1994). *S. amaryllis* was first reported in Brazilian waters on the coast of the state of Piauí (YOUNG, 1989) and is also found from Pernambuco to Santa Catarina states (FARRAPEIRA, 2008).

Since the identification of the oyster *Crassostrea brasiliana* is still controversial even after allozyme studies (IGNACIO et al., 2000; LAPÈGUE et al., 2002; VARELA et al., 2007), taxonomic classification has followed Lapègue et al. (2002), confirming the morphological identification when compared to specimens from the state of Paraná. Thus, the distribution of *C. brasiliana* after genetic reassignment was enlarged, now extending from the state of São Paulo to Rio Grande do Norte.

The presence of the false dark mussel *Mytilopsis leucophaeta*, including breeding and young specimens, in Natal is noteworthy. This species is native to the Gulf of Mexico, but is actually widespread on both sides of the Atlantic Ocean and Mediterranean. Records of it cover the coast from New York (CASTAGNA and CHANLEY, 1973) to the Gulf of Mexico (MARELLI and GRAY, 1983), from the North and Baltic Seas (GOLLASCH and NEHRING, 2006) to France (VERWEEN et al. 2005) and include the Mediterranean coast of Spain (ESCOT et al., 2003) and Ukraine (Therriault et al., 2004). It was introduced in 2004 in the estuarine area of Recife and the most plausible hypothesis for their occurrence and regional dispersion suggests accidental introduction through ballast water and/or vessel hull fouling (SOUZA et al, 2005, FARRAPEIRA, 2006). Farrapeira et al. (2007) then found it on 12 vessels in the harbor area of the city, including the vessel later examined in Natal for this study. This pathway of introduction, through settlement on vessel hulls, was thought by Gollasch and Nehring (2006) and Nehring (2006), both in the North Sea, and observed by Davidson et al. (2008a), who followed the fouling community settled on two vessels before and after being towed from the Pacific (California) to the Atlantic Ocean (Texas). Its appearance in Rio Grande do Norte State may be seen as a secondary introduction on the Brazilian littoral, mediated by a human-associated transport mechanism, in accordance with the concept of Minchin et al. (2009).

There are two important stages which together constitute the introduction of a nonindigenous species: specimen arrival and establishment. Arrival is defined as the process by which individuals are transported from a source using a dispersal pathway to a destination where they are introduced and attempt to establish themselves. The establishment or maintenance of viable populations is defined by the presence of successfully reproducing individuals within the species' ecological range, a fact that is only possible if production and survival of propagules is first assured (CARLTON, 1996; VERMEIJ, 1996; REISE et al., 2006). The finding of breeding adults of *Mytilopsis leucophaeta* and juvenile specimens settled on the hull investigated indicates that this species had spawned and colonized the harbor area of Natal; thus, in accordance with Cohen´s revised concept (2004), it has established a naturally reproducing population. In fact, it would only be necessary for the tugboat to have been in the harbor area once at a moment when the adults present on the hull had been in the reproductive stage to introduce this species in Natal. Apte et al. (2000) recorded a spawning of *Mytilus galloprovincialis* in Pearl Harbor, Hawaii, on the hull of a naval vessel two hours after arrival and suggested this had led to a local settlement.

In this sense, comparisons with a species' performance in its native region and in other recipient regions are particularly elucidating (GROSHOLZ and RUIZ, 1996). Whether or not introduced species can establish themselves and proliferate in their new environment depends on a variety of factors – not only suitable physical-chemical conditions such as temperature, salinity, light and oxygen, but also biological interactions with the members of the recipient community (VERMEIJ, 1991). The likelihood of an introduced organism becoming established in the new environment depend both on the characteristics of the species (its intrinsic properties) and the environment (the circumstances) into which it is introduced. The greater the similarity that exists between the native and the new environment, the more likely it is that a species should become established in the latter (WIJSMAN & SMAAL, 2006). The bioecological behavior of *Mytilopsis leucophaeta,* for example, is considered eurybiotic, mainly brackish (NEHRING, 2006) and highly euryhaline; it normally occurs in waters that range from fresh to those whose salinity exceeds 20, while its temperature tolerance varies from 5 to 30ºC for adults and from 10 to 30ºC for larvae (VERWEEN et al, 2007). In Recife's mesohaline Pina Basin it is submitted to salinities that range from 10 to 30 (low and high tide, respectively) (SOUZA et al., 2005).

According to data given in the literature, *M. leucophaeta* may be classified as nonindigenous invasive in several locations, mainly in the Northeastern Atlantic, where it has become a serious biofouling organism having an economic impact in the water-cooling systems of water-dependent industries, as reported by Verween et al. (2007) in Antwerp, Belgium, where it had caused major problems, and Laine et al. (2006) in the Gulf of Finland, Baltic Sea. The densest assemblages recorded by these latter authors covered stones and boulders up to 100%, at 1 to 3 m depth, with population densities up to 28,000 individuals/m². The species´ ecological and economic incidence is comparable to that of another dreissenid, the zebra mussel *Dreissena polymorpha* (Pallas, 1771), although the problems caused by *M. leucophaeta* seem less severe (ESCOT et al., 2003). Regarding the fact that it is much more tolerant to chlorination than *D. polymorpha*, Verween et al. (2006) believed that *M. leucophaeta* has the ability to become a major fouling problem once established.

In Brazil the species has been found, since 2004, only in Recife (SOUZA et al., 2005, FARRAPEIRA et al., 2009a) and Freitas et al. (2009) concluded that it is well established in the estuarine area of Recife, being numerically dominant on hard substrata and forming dense zones in the middle intertidal region, where it competes for space with the native charru mussel *Mytella charruana*.

Comparing the data of this environment, as recorded by Farrapeira-Assunção (1991), it may be seen that nowadays *M. leucophaeta* occupies the space previously used by the native mussel, practically limiting the distribution of this latter to sublittoral muddy bottoms (FREITAS et al., 2009). Souza et al. (2009) held open interviews with experienced mussel gatherers of this estuarine area, and nearly 65% of whom believed that the introduction of this species, locally known as the "white mussel", had been detrimental to their interests, because of its lack of economic value and also because its presence had led to a decrease in the population of the charru mussel. Besides, they also had difficulty in processing the material collected, because it took them a long time to separate the two species. Having said which and in the light of the fact that the ecological conditions of the estuarine area of Natal are favorable to the proliferation of *M. leucophaeta*, which can become a dominant species in the intertidal community, as happened in Recife, the establishment of this species in this new area should be monitored.

The occurrence of eight ascidian species was the most striking change in the fouling community if the findings for the harbor area of Recife (Farrapeira et al., 2007) are compared to what was recorded in Natal. Additionally, with the exception of *Didemnum psammatodes* recorded for Rio Grande do Norte state (LOTUFO, 2002), the remaining species are new occurrences for the Brazilian coast in the northward direction. When added to their pattern of space occupation, this fact suggests that all of these species have been established there for a long time. The extensive overgrowth of compound ascidians over fouling organisms is a common fact observed in many harbor areas worldwide. Ascidians are often strong spatial competitors and exhibit dominant growth patterns in both their native and introduced range (OREN and BENAYAHU, 1998; CASTILLA et al., 2005, ROCHA et al., 2009). When introduced into a new environment, nonindigenous ascidians rapidly colonize artificial substrates in harbors such as pilings, floating marina docks, boat hulls and buoys. Then once they become established in a new location they may persist and become dominant members of the new community (LAMBERT and LAMBERT, 2003).

Many ascidians have experienced recent range expansions due to human mediated transportation, such as unintentional transport on the hulls of recreational and commercial ships (MONNIOT and MONNIOT, 1994; LAMBERT and LAMBERT, 2003; WASSON et al., 2001). Another means of ascidians transportation and distribution, though in lesser proportion, is that via introduced oysters, mussels and seaweeds that carry settled individuals or colonies on their surfaces (LAMBERT, 2005).

Among the species found in Natal, only three had been considered traveling species that disperse by ship transportation and are also common on the harbor's substrata and in nearby areas, particularly on pier piles: *Botrylloides nigrum* (WHOI, 1952; ROCHA et al., 2009), *Microscosmus exasperatus* (MONNIOT and MONNIOT, 1994; LAMBERT and LAMBERT, 1998; LAMBERT, 2001; ZIBROWIUS, 2002; GODWIN et al., 2004; ROCHA and COSTA, 2005; FERREIRA et al., 2006) and *Symplegma rubra* (GOODBODY, 1993; LAMBERT, 2001; FERREIRA et al., 2006). Another species deserving of consideration is *Botryllus* cf. *primigenus,* currently undergoing taxonomic reassessment. The species was first described for Japan (OKA, 1928) and all later references still indicate that it is endemic to the Indo-Pacific Ocean. If its species identity is confirmed, the only means of dispersion from there to the western Atlantic Ocean is shipping.

Among the remaining species found on the tugboat were another eleven customarily dispersed by ship hulls: the bivalves *Brachidontes exustus, Crassostrea rhizophorae* and *Ostrea equestris* (FARRAPEIRA et al., 2007), the bryozoan *Biflustra savartii*, and the barnacles, as shown in Table 1. This last group aggressively occupies a great variety of marine substrata and is frequent among the fouling communities of ship hulls (remote dispersion); in fact, they are the most common encrusting organisms in harbors throughout the world (FOSTER and WILLAN, 1979; FARRAPEIRA et al., 2007).

Among the barnacles, two deserve to be highlighted: the nonindigenous species *Amphibalanus reticulatus* and *Striatobalanus amaryllis*, invasive for the Brazilian coast, as pointed out by Farrapeira (2008; 2009). Both species have been expanding their distribution since they were first recorded. Both have, thus far, been recorded from the northeastern coast all the way down to the southern states. The occurrence of *A. reticulatus* in Rio Grande do Norte state enlarges their northward distribution, which reinforces the initial supposition that its introduction and dispersion are dependent on shipping movements.

Amphibalanus reticulatus (as well as *Balanus trigonus*) is dominant on artificial substrates in areas with various degrees of eutrophication in Ilha Grande Bay, Rio de Janeiro (MAYER-PINTO and JUNQUEIRA, 2003), an area where the cryptogenic established striped barnacle *A. amphitrite* was dominant some decades ago (SILVA-BRUM and MARTINS, 1997). The same fact occurred in Paranaguá Bay, Paraná, as observed by Neves et al. (2007), where at the present time, *A. reticulatus* is the numerically dominant barnacle on the artificial substrata, rather than *A. amphitrite.* On the basis of a comparison with the analysis carried out by Young (1994) on Brazilian barnacle fauna, in which the presence of the nonindigenous species is not recorded, it seems that *A. reticulatus* has become numerically dominant wherever it has been introduced in Brazilian states, occupying the ecological niche of *A. amphitrite*. This is a somewhat similar process of ecological impact, in the inverse direction, to that noted by Iwasaki (2006) when *A. amphitrite* was introduced into Japan; its predominance on the estuarine hard substrata is suggested to have drastically decreased the density of the native (to Japan) barnacle *A. reticulatus*.

Striatobalanus amaryllis had the same effect in the marine environment on the Brazilian littoral, in relation to the previously dominant giant barnacle *Megabalanus tintinnabulum*. The barnacles' community that occurs on the sandstone reefs of Pernambuco State, as recorded by Farrapeira (2009), differs from that which was presented by Young

(1994) of a sampling carried out in this region in the 1980's. The comparison of these data shows that *S. amaryllis* is presently sharing the biotope of the borderline region between the intertidal and the sublittoral fringe, near the surf zone, with the cryptogenic established species *M. tintinnabulum*.

Emphasis should be given to the fact that both nonindigenous species (*A. reticulatus* and *Striatobalanus amaryllis*), classified as invasive, belong to the fouling community, and in the light of their record of association with ships´ hulls lead to economic losses to human society. According to WHOI (1952), the fouling of ships results in a reduction in their speed, thus leading to increased fuel costs, and losses in time and money in the application of the necessary remedial measures. The immediate effect is an increase in the resistance to the movement of the hull through the water, a phenomenon known as frictional resistance.

An interesting fact is that *Musculus lateralis* had not previously been mentioned as associated with vessel hulls, even though the congeneric species *M. discors* (Linnaeus, 1767) and *M. niger* (J.E. Gray, 1824) use this vector (GOLLASCH, 2002). Furthermore, *M. lateralis* also uses another transportation pathway – as a commensal species of the turtle *Caretta caretta* - under and among the encrusting organisms, as well as the bivalve *Sphenia fragilis* (FRAZIER et al., 1985). In this study, the presence of ascidians on the vessel's hull permitted the arrival of these sedentary bivalves, as they were found mainly in the ascidians' siphons (*M. lateralis*) and/or frequently occurred in the crevices between colonies or individuals (*S. fragilis*). In the Lambert (2005) review of ascidian ecology and natural history it is mentioned that these associations are very common. *Musculus lateralis* usually attaches itself to shallow water hard substrates by the byssus, but acts as a nest-building bivalve settling in a commensal relationship on compound or solitary ascidians (BERTRAND, 1971; GARCÍA-CUBAS, 1981; RUPPERT and FOX, 1988). As for *Sphenia fragilis*, a crevicolous species sporadically common on hard surfaces, it usually lives nestling in the confined spaces between other organisms such as tunicates and mussels, or may form dense mats on hard surfaces (RUPPERT and FOX, 1988). In these cases it could prove that some introduced species can facilitate subsequent invasions, if mutualistic and commensal relationships are considered (SIMBERLOFF and VON HOLLE, 1999; WILLIAMS and GROSHOLZ, 2008).

Another fact that deserves to be highlighted refers to the two well defined communities observed on the vessel. WHOI (1952) recorded that ships are usually fouled at the water line by a *Balanus* community, in which algae predominate, and this was also observed in the tugboat analyzed here. Yet the author cited also states that mussels rarely attach to ships unless they are moored for long periods, a fact also noted by Farrapeira et al. (2007) for the harbor area of Recife. The area where the tugboat is active and the lower speeds it customarily uses on the Potengi River estuary in towing cargo ships may make this settling pattern possible and appears to permit the accommodation of a greater biomass of fouling biota. Additionally, Southgate and Myers (1985) have noted that slow vessels may have periods of permanence and immersion, which leads to the establishment of extensive fouling communities. Furthermore, their relatively slow passage or inactivity and long port tenancies give fouling communities much longer to settle (MINCHIN and GOLLASCH, 2003; HEWITT et al., 2009).

Parallels can be found between the dense aggregations of the mussel *Mytella charruana* on the hull's sublittoral surface and its distribution patterns in the natural environment. It is an euryhaline species that occurs in shallow lagoons and in bay mud flats, where its populations can reach very high densities (LEONEL and SILVA, 1988) due to its gregarious behavior. Moreover, Farrapeira et al. (2007) found this species on 14 vessels in the port of Recife, including the Scorpius H2G.

The data given in this study indicate clearly how efficient vector fouling of ships´ hulls is in propitiating the introduction of species, as occurred in the cases of *Mytilopsis leucophaeta, Amphibalanus eburneus* and *A. reticulatus*. This suggests that many benthic organisms may be transported easily and rapidly either from other localities or along the long and highly diverse Brazilian coastline (FERREIRA et al., 2006), which creates opportunities for new invasions due to the spreading (transfer) of organisms originating in very restricted populations. Wasson et al. (2001) and Davidson et al. (2008a) also noted the importance of intraregional transport and that even the coastwise movement of vessels that have undergone long lay-ups and navigate over relatively short distances could play this role, even between adjacent bays.

As species introductions are irreversible, the extension of their distribution area and increase in abundance is an ongoing process (NEHRING, 2006). Once the fouled vessel is re-immersed in a waterway it is likely that the species will continue to spread along the coast if the biota thus transported becomes established (MINCHIN and GOLLASCH, 2003). Thus, it is deplorable that the hull of the tugboat had not been cleaned before it was loaned to the port of Natal and thus propitiated the introduction of the false dark mussel *M. leucophaeta* there. As Rylov and Crooks (2009) stated, it is better to try to prevent an invasion rather than try to manage it after the event. It is also worrisome that the Scorpius H2G may return to the port of Recife without any prior preventive cleaning of the hull.

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