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Ship Hulls and Oil Platforms as Potential Vectors to Marine Species Introduction

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ABSTRACT

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The process of species introduction has been reported to strongly contribute to loss of biodiversity. Despite vectors like ballast water was claimed as most important in translocation of non-native species, hull fouling has been demonstrated to be an efficient vector for benthic organisms. In the vast Brazilian coast (ca. 8,000 Km), the lack of basic monitoring programs make the problem of species introduction a real danger to biodiversity conservation and consequently ecosystem function. Arraial o Cabo region, located southeastern Brazilian coast, has unique features regarding its marine ecosystems and could be considered as hot spot to biodiversity conservation. As the region provides calm conditions and a local harbor, the risk of species translocation via hull fouling by the intense maritime traffic had enhanced. During a period of two years, drill-ships, platforms and cargo ships were underwater inspected. Qualitative as well as quantitative data of benthic organisms were made by counts utilizing quadrats in different parts of hulls and platform legs. About 118 species of benthic organisms were listed, including 22 species considered as exotic to the Brazilian coast. Among these exotic species, 12 have previous report to the coast and 10 were first records. Three species were classified as cryptogenic, as having widespread distribution, but not demonstrably introduced or native. Drill-ships and platforms presented higher levels of species diversity than cargo-ships. The results confirmed the hull fouling as an efficient vector to species introduction, thus deserving special managing strategies. The use of precautionary principle must be considered when treat the hull fouling vector and monitoring programs should be established along the coast.

ADDITIONAL INDEX WORDS: *Exotic species, biofouling, oil platforms, biodiversity conservation.*

INTRODUCTION

In the last decades, it was detected an accentuated lost of biodiversity caused by habitat deterioration and different impacts associated to the human population exponential growth and its consequent need for protein. At the same time, humans have been enlarging the distribution of many species by the introduction of alien species, a process called exotic introduction. Such process contributes to loss of diversity, being reported nowadays as one the most serious and potentially sources of stress to the marine systems (CARLTON and GELLER, 1993). Centuries of maritime transport have obscured our understanding about the natural patterns of widespread (= cosmopolite) species distribution (CARLTON and RUCKELSHAUS, 1997). Only when a pronounced ecological impact take place, such as the toxic dinoflagelates (HALLEGRAEFF and BOLCH, 1991), or drastic shifts in communities composition (MEINESZ *et al.*, 1993), the process of exotic introduction could be detected, by the contrary the process could occur without immediate detection.

The lack of faunistic and floristic surveys as well as monitoring programs, make the scenario even worse. In Brazil, the lack of basic surveys in several natural environments as well as in harbors and similar artificial substrates, make difficult a precise evaluation of the exotic introduction process. Despite the presence of larvae and cysts of marine organisms in ballast water of cargo ships (usually pointed out as the main cause of the increase of exotic species (CARLTON, 1985; SMITH *et al.*, 1999), other vectors like the release by the ornamental market and/or aquaculture, rafting and hull biofouling are also important vectors. However, only recently biofouling in ship hulls and oil platforms have been considering as important to exotic introductions in the marine realm (GOLLASCH, 2002). Despite a long time association of high efficiency of antifoulant based organotin paints (especially TBT), recent works have put in evidence that several benthic organisms were yet resistant to antifouling agents or could find wounds on the paint or special refuges in the hulls for their transport (RAINER, 1995; GOLLASCH, 2002). The hull fouling includes sessile and mobile benthic organisms which are well proved to be transported by long distances, transposing ecological, physical and/or chemical barriers. Groups like ascidians and bryozoans have larvae with short planctonic duration (SVANE and YOUNG, 1989), make them good candidates to be introduced via hull fouling.

The Arraial do Cabo region has unique features related to its marine environment. Due to coastal morphology (a pronounced cape) and predominant east and northeast winds, an upwelling bath the exposed rocky shores with cold water (VALENTIN, 1984),enriching primary production and consequently the local food web. In addition, the presence of islands and inlets provide a sheltered environment where a rich tropical reef fauna and flora flourish (BARREIRA-CASTRO *et al.*, 1995; GUIMARAENS and COUTINHO, 1996; FERREIRA *et al.*, 2001). Hence, the region sustains both tropical and subtropical marine components, presenting high levels of marine biodiversity and consequently being considered a hot spot to conservation priorities. Since 1997, the whole region was decreed as a Marine Harvest Reserve, a sort of conservation unit where local resources are explored and managed only by local fishermen. Paradoxically, the region could act as receptor to species from both high and/or low latitudes. The local harbor (500 m) was built (ca. 50 y. ago) specifically to receive domestic cargo to supply a factory of calcareous elementary material. In this way, it has been characterised by a low shipping traffic. However, in the last years due to an increasing in offshore oil exploration effort, platforms and suppliers increase their passing and pauses in the area.

Our main aim in this paper is to list the exotic organisms detected in ship hulls and platforms during the last years in Arraial do Cabo region, as well as, to review the major problems and possible solutions concerning the introduction processes by these vectors.

METHODS

We monitored two cargo ships, two drill-ships and two oil platforms during a period of two years. All these ships and platforms entry the calm Anjos Bay (Figure 1) in order to take off cargo (docked at the harbor) or to receive some repair (not necessarily docked at the harbor). The methods consist of a quantitative underwater survey (by means of SCUBA) at two different depths (1- 3 and 4 - 6 m) in both ships (hull) and platforms (legs). The percentage coverage of benthic organisms was estimated by counting animals with a quadrat (20 x 20 cm) within 30 random intercept points, while data was written in acrylic slates. Counts were replicated for ship hulls (3 quadrats at different depths plus in the stern, middle line and bow) and for platform legs (3 quadrats in 3 different legs). After quantitative surveys, the diver initiates a qualitative check out in the whole area sampled. When necessary, organisms were photographed (with a Nikonos V), collected manually and maintained in plastic bags. In the lab, organisms were separated in groups, fixed with 10% formalin and sent to identification by taxonomists.

RESULTS

Underwater inspections on ships and platforms totaling 118 species of benthic organisms, including algae, sponges, hydrozoans, anthozoans, polychaetes, crustaceans, mollusks, bryozoans, echinoderms, ascidians and fishes (Table 1). About 90 species fouling hulls are confirmed as native (N), and more three (one coral and two algae species) are shown to be extension of their ranges (RE) from northeast to the southeast coast.

A total of 22 species are considered exotic to the Brazilian coast, with 12 species having previous report (ER) and 10 as first records (E) for the entire coast. Among those not reported to the Brazilian coast, sponges were represented by 4 species and 1 family, bryozoans by 3 species, crabs by 1 and 1 brittlestar species (Table 1).

Considering those species with previous register to the coast 6 bryozoans, 2 barnacles, 2 crabs, 1 coral and 1 mollusk were found. From the total species listed at Table 1, three species were classified as cryptogenic (C) including the bivalve *Perna perna*, the bryozoan, *Bugula neritina* and the octocoral, *Carijoa rissei*. Drill-ships presented higher number of species than platforms and cargo ships, as well as higher numbers of organisms in all categorization groups (N, RE, ER, C and E see Table 1). Percent cover of groups indicates that bryozoans, macroalgae, barnacles and hidrozoans were the dominant groups in drill-ships, while barnacles, sponges, echinoderms and macroalgae predominated in platforms. In cargo ships, where fouling level was the lowest, only barnacles and algae were the dominant fouling organisms (Figure 2).

DISCUSSION

The invasion process and its complex effects on ecosystem diversity and function is now of worldwide concern. Most of this burden is a reflection of the threats the bioinvasion process poses to species diversity and ecosystem services and human welfare in general (SIMBERLOFF, 2001). Despite the emphatic approach the subject have been debated and reported on scientific literature in the last decade (LODGE, 1993; VITOUSEK *et al.*, 1996; ROSS *et al.*, 2003), our understanding of the environmental consequences is still fragmented.

The data shown herein clearly indicate the efficient vector fouling on hulls is. This suggests that various benthic organisms are easily and fast being transported either from other provinces to the Brazilian coast, as well as within the huge and diverse Brazilian coast. Both possible introductions paths are virtually dangerous to coastal habitats as they could be introducing non "native" species. The results made evident that drill-ships has over the double species found in platforms and about seven fold the species number found in cargo ships. Despite all ships and platforms inspected were totally covered by fouling, the thickness, not herein considered, was higher in drill-ships and platforms (about 20 cm in the formers and only 0,5 cm in the late). Fouling thickness, for most organisms considered, means high complexity, which in turn, means an increase in microhabitat availability and high species diversity. Definitely, higher thickness in drill-ships and platforms is due to their long periods of oil explorations activities which provide optimal conditions to fouling settlement. This process is strong accentuated in fixed platforms, which could be halted for years in a fixed point. Based on these evidences, when these floating structures are travelling for different purposes, they are carrying representative gene pools of benthic species.

In recent years the Brazilian government by means of flexibility of its exploration monopoly had made available its oil reservoirs for international companies exploration. Such scenario imposes real danger to fouling hull aliens introduction in the coast, as the traffic of attached organisms is rapidly increasing. Our data exemplified with restrictions, the diversity of benthic organisms in Campos Basin, 70 nautical miles from Arraial do Cabo region, where all ships and platforms inspected operate. The Campos Basin oil field has nowadays about 60 points of explorations including floating and fixed structures, as well as drill-ships (PETROBRAS domain only, see MAGALHAES, 2002). Based on the data herein presented and additional unpublished data (authors, unpublished data), (authors, unpublished data), including underwater videos, it is becoming evident that the artificial structure formed by platforms in Campos Basin harbors great richness of exotic benthic organisms. Definitely, it sustains a significant larval pool of either benthic or pelagic organisms, which by the way, have been acting as center of dispersion to other points of the Brazilian coast. The Brazilian biogeographic province is well recognized for fishes, mollusks and algae (RIOS, 1994; FLOETER *et al.*, 2001; CASTRO and PIRES, 2001). Water temperature is the main factor dividing subtropical (south and southeastern coasts) and tropical (north and northeastern coasts) organisms within the Brazilian Province (FLOETER *et al.*, 2001). Although, the Campos Basin is placed in the transition zone between subtropical and tropical environments, most of platforms and oil exploration is occurring in oceanic, blue water, characteristically tropical. If one consider a mean of submerged shallow, hard substrate area of fixed platforms (7,000 m^2) and multiplied by the total number of producing platforms nowadays in Campos Basin (14 considering only PETROBRAS), a total artificial reef area of 98,000 m^2 is

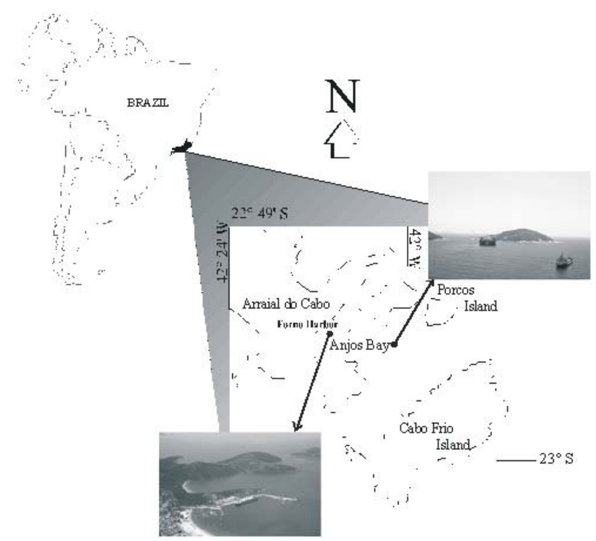

Figure 1. Mapa of Arraial do Cabo region, indicating the Anjos Bay and Forno Harbor where the platforms and ships were inspected.

Table 1. *List of benthic organisms found at platforms, drilling and cargo ships at Arraial do Cabo, RJ, Brazil.*

Taxa	Cientific name	PLATFORMS					DRILL SHIPS					CARGO SHIPS				
		N	RE	ER	C	E	N	RE	ER	C	E	N	RE	ER	C	E
ALGAE	*Ulva fasciata*	X					X					X				
	Enteromorpha flexuosa											X				
	Chaetomorpha brachygona											X				
	Cladophora montagneana											X				
	Codium intertextum						X									
	Codium isthmocladum	X														
	Feldmannia irregularis											X				
	Bachelotia antillarum						X									
	Padina gymnospora						X									
	Dictyota bartayresiana	X														
	Dictyopteris delicatula	X														
	Dictyota mertensii						X									
	Dictyota ciliolata						X									
	Dictyopteris plagiogramma		X													
	Lobophora variega	X														
	Sargassum vulgare						X									
	Gelidiopsis variabilis	X														
	Spyridia filamentosa						X									
	Corallina officinalis	X					X									
	Jania capillacea	X					X									
	Jania adhaerens	X														
	Herposiphonia secunda f. secunda						X									
Total of Algae	22	9	1	0	0	0	11	0	0	0	0	5	0	0	0	0
PORIFERA	*Clathrina ascandroides*						X									
	Clathria sp	X														
	Leucosolenia sp										X					
	Leucilla sp										X					
	Chelonaplysilla erecta	X														
	Paraleucilla sp						X									
	Terpios aff. fugax						X									
	Mycale microsigmatosa	X					X									
	Cacospongia sp	X														
	Crella sp										X					
	Haposclerida sp										X					
	Family Chalinidae										X					
	Callyspongia sp	X														
	Disidea janiae	X					X									
Total of Porifera	14	6	0	0	0	0	5	0	0	0	5	0	0	0	0	0
CNIDARIA Class Hydrozoa	*Eudendrium carneum*	X					X									
	Pennaria disticha						X									
	Ectopleura ralphi						X									
	Sertularia marginata						X									
	Dynamena sp	X					X									
	Obelia dichotoma						X					X				
Total of Hydrozoa	6	2	0	0	0	0	6	0	0	0	0	1	0	0	0	0
Class Anthozoa	*Tubastraea coccinea*			X					X							
	Astrangia rathbuni	X					X									
	Porites sp		X													
	Heterogorgia uatumani	X														
	Carijoa rissei				X					X						
	Bunodosoma caissarum						X									
Total of Anthozoa	6	2	1	1	1	0	2	0	1	1	0	0	0	0	0	0
ANNELIDA Class Polychaeta	*Hermodice sp*	X														
	Eunice rubra						X									
	Syllis sp						X									
	Serpula sp	X					X									
Total of Polychaeta	4	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0
ARTHROPODA Class Crustacea	*Balanus trigonus*						X									
	Balanus reticulatus													X		
	Balanus amphitrite											X				
	Megabalanus tintinabulum	X					X					X				
	Megabalanus coccopoma			X					X							
	Panulirus laevicauda						X									
	Newmanella radiata						X					X				
	Charibdis hellerii			X					X							
	Tesseropora atlantica										X					
	Stenorhynchus seticornis						X									
	Piluminus dasypodus						X									
	Piluminus floridanus								X							
	Lepas anatifera							X								
	Ampithoe ramondi						X									
	Corophium sp						X									
	Photis longicaudata						X									
	Erichtonius brasiliensis						X									
	Podocerus fissipes						X									
	Elasmopus rapax						X									
Total of Crustacea	19	1	0	2	0	0	12	1	3	0	1	3	0	1	0	0

Taxa	Cientific name	PLATFORMS					DRILL SHIPS					CARGO SHIPS				
		N	RE	ER	C	E	N	RE	ER	C	E	N	RE	ER	C	E
MOLLUSCA	*Perna perna*									X						
	Isognomum bicolor			X					X							
	Lioberus castaneus						X									
	Modiolus carvalhoi						X									
	Fissurella rosea						X									
	Collisella subrugosa						X									
	Amygdalium dentriticum						X									
	Pinctada imbricata	X					X									
	Chaetopleura spinulosa						X									
	Family Ostreidae						X									
	Hyatela arctica											X				
Total of Mollusca	11	1	0	1	0	0	8	0	1	1	0	1	0	0	0	0
ECTOPROCTA	*Aetea sica*						X									
Bryozoa	*Aetea anguina*	X					X									
	Membronipora savartii											X				
	Scrupocellaria bertholetii								X							
	Scrupocellaria diadema										X					
	Bugula dentata								X							
	Bugula neritina									X						
	Bugula uniserialis						X									
	Thalamoporella falcifera	X					X									
	Scruparia ambigua								X							
	Catenicella contei	X					X									
	Microporella ciliata								X							
	Schizoporella errata						X									
	Parasmittina tripinosa								X							
	Savignyella lafontii								X							
	Watersipora cucullata						X									
	Amanthia distans						X									
	Amanthia sp										X					
	Crisevia pseudosolena						X									
	Crista sp										X					
	Tubulipora sp	X														
Total of Bryozoa	21	4	0	0	0	0	9	0	6	1	3	1	0	0	0	0
ECHINODERMATA	*Eucidaris tribuloides*	X					X									
	Tripiometra carinata						X									
	Ophiocoma paucigranulata					X					X					
Total of Echinodermata	3	1	0	0	0	1	2	0	0	0	1	0	0	0	0	0
CHORDATA	*Symplegma rubra*						X									
Class Ascidiacea	*Styela plicata*						X									
	Phallusia nigra	X					X									
	Clavelina oblonga						X									
	Didemnum sp						X									
	Microcosmus exasperatus						X									
Total of Ascidiacea	6	1	0	0	0	0	6	0	0	0	0	0	0	0	0	0
VERTEBRATA	*Labrisomus cricota*						X									
Perciformes	*Labrisomus nuchipinnis*						X									
	Parablennius pilicornis	X					X									
	Scartella cristata						X									
	Holocentrus ascensionis	X														
	Cantherines pullus	X														
Total of Perciformes	6	3	0	0	0	0	4	0	0	0	0	0	0	0	0	0
		N	RE	ER	C	E	N	RE	ER	C	E	N	RE	ER	C	E
TOTAL	118	32	2	3	1	1	68	1	11	3	10	11	0	1	0	0

** N: native species; RE: native species range expansion; ER: exotic species already reported in the coast; C: cryptogenic species (not demonstrably introduced or native); E: exotic species not reported in the coast.*

*** Phylogenetic classification based on BRUSCA and BRUSCA, 2003.*

available for benthic colonization. This is by far a gross, underestimated artificial area in the region as it not includes flotation systems, perforation and drilling apparatus, FPSO and a diverse set of submerged hard structures (e.g. manifolds, Christmas tree) in full operation in the region (MAGALHAES, 2002). It is really a meaningful reef area that deserves consideration in terms of stepstone for larvae migration (basically southward due to prevalent current regime). Additionally, based on the high frequency of exotic species found, a new sub-province in the coast should be considered.

Among the problems that make our understanding and decisions about aliens introduction, the lack of preterit data regarding benthic surveys along the coast is vital. Without these kind of data, a rapid analysis and consequent categorization of species range extension as presented in Table 1, became difficult. Also, except for few groups, our systematic specialists are also poor recognized (NORSE, 1993).

Efficiency of antifouling paints is another point to be re-considered. Since 1960s, organotin compounds were found to be highly effective antifouling biocides and subsequent developments led to the formulation of self-polishing copolymer (SPC) antifouling paints based on tributyltin (TBT) copolymers. These paint systems could provide effective antifouling performance for more than 5 years (LEWIS, 2002). However, TBT released from antifouling paints has been found to be highly dangerous to the marine environment and the International Maritime Organization (IMO) recently adopted a new convention to globally ban the application of TBT antifouling paints (IMO, 2001). The alternatives to the TBT ban includes conventional copper-based products, self-polishing copper-based antifouling paints, silicone-based non-toxic fouling release coatings, novel coats based on new natural products as well as physical, electronic and chemical deterrents. Despite these alternatives, the risk of hull fouling is still critical,

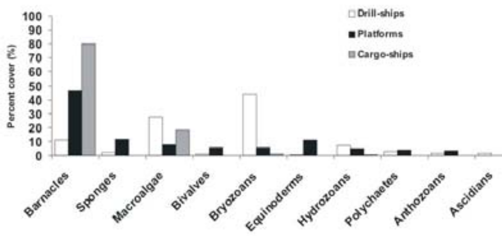

Figure 2. Comparative percent cover of dominant benthic groups in the different floatable structures inspected in Arraial do Cabo, RJ.

Specifically for slower, less active vessels, which the use of self-cleaning products is not economic viable. In such cases, in-water cleaning is necessary if the hull is to be kept fouling-free for when it leaves port. In-water cleaning is essential also in the case of platforms when they came to coastal habitats to general repairs or when travelling to other exploration sites. The fouling biomass in platforms proves to be a real threat to species translocations and introduction.

Although efforts and funds have been available to study and manage the ballast water vector in Brazil (NETO and JABLONSKI, 2003), nothing has been done regarding hull fouling. This vector has been nationally neglected and only in the last years it has been raised as an environmental problem (FERREIRA, in press; FERREIRA *et al.*, in press). Despite the IBAMA (Brazilian Environmental Agency) exigency of fouling inspection in ships and platforms entering Arraial do Cabo harvest reserve, local politic and economic pressure make the program to fail, consequently prolonging the environmental hazard. The process of species introduction is beyond political and economic concerned, as having profound environmental, social and cultural outcomes. Treat the problem using the wait and see principle is simply delaying the actions to be accomplished and increase the impacts at environmental, social and economic spheres.

The precautionary principle set out in the Rio Declaration and adopted by the IMO Convention (IMO 2001), should be used to establish monitoring programs on natural and artificial substrates along the entire Brazilian coast. Only by means of extensive monitoring and basic studies the species introduction in the huge Brazilian coast could be controlled. The scientific community, the government agencies and authorities as well as local fishermen should interact as stakeholders to reduce the problem.

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