Marine biofouling invertebrates in the hull of the ship ARC "20 de Julio"

Invertebrados marinos bioincrustantes en el casco del buque ARC "20 de Julio"

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Abstract

Colombia's First Scientific Expedition to the Antarctic was performed between December of 2014 and April of 2015 on board the ship ARC "20 Julio". Before and after departure, divers collected samples of marine organisms adhering to ship´s submerged external structures. The marine invertebrates were taxonomically identified and the condition of origin (native species, invasive or cryptogenic) was established. The marine fauna was represented by phylum arthropod, mollusk, annelid and porifera. The Balanidae family contributed the largest number of individuals, consisting of the species Balanus Amphitrite, Balanus reticulatus and Balanus eburneus, followed Mitilidae family, represented by species such as Brachidontes domingensis and Brachidontes exustus. The species identified are recognized as common members of fouling communities around the world and some have been listed as introduced to the Cartagena Bay. This research is developed as a basis for future studies of fouling organisms in the port of Cartagena, to minimize, control or prevent negative effects on port and shipping activities and the expansion of marine species into new marine coastal areas.

KEYWORDS: Marine invertebrates, introduced species, Biofouling, ARC "20 de Julio", Colombia's First Scientific Expedition to the Antarctic.

Resumen

A bordo del buque ARC "20 de Julio" se realizó la Primera Expedición Científica a la Antártida entre diciembre del 2014 y abril del 2015. Antes y después del zarpe, se colectaron mediante buceo, muestras de organismos marinos adheridos a las estructuras externas sumergidas del buque. Los invertebrados marinos colectados se identificaron taxonómicamente y se estableció su condición de origen (especies nativas, invasoras o criptogénicas). La fauna marina estuvo representada por los filos artrópodo, molusco, anélido y porífera. La familia Balanidae aportó el mayor número de individuos, conformada por las especies Balanus amphitrite, Balanus reticulatus y Balanus eburneus, seguida de la familia Mitilidae, representada por especies como Brachidontes domingensis y Brachidontes exustus. Las especies identificadas en el estudio, se reconocen como miembros comunes de las comunidades bioncrustantes alrededor del mundo y algunas han sido catalogadas como introducidas para la bahía de Cartagena. La presente investigación se desarrolló como base de futuros estudios sobre organismos incrustantes en el puerto de Cartagena, tendientes a minimizar, controlar o evitar efectos negativos sobre las actividades portuarias y navieras, y la expansión de especies marinas a nuevas áreas marino-costeras.

PALABRAS CLAVES: *invertebrados marinos, bioincrustantes, ARC "20 de Julio", Primera Expedición Científica Colombiana a la Antártida.*

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Introduction

It is known that worldwide it has been established that between 3000 and 7000 organisms of intrusive species are transported on ships daily (Carlton J., 1999). According to Hewitt & Campbell (2010), 1780 marine and estuarine intrusive species have been recorded in the world, of which 86.3 % have been introduced by means of ballast water and fouling of ships (Okolodkov & García, 2014). The latter corresponds to the fauna and flora that adheres to the submerged external structure of the ship (Okolodkov, *et al.,* 2007), as a product of the interaction of physical, chemical and biological processes, which favor the adsorption of the surface of organic molecules and the establishment of microfouling or "silt" (bacteria, benthic diatoms, spores, microalgae, fungi, as well as protozoa) and after a few weeks the macrofouling (sessile marine invertebrates and larger algae) (Lopez, 1998; Cuadrado, *et al.,* 2010, Abarzua and Jakubowski, 1995, Anderson, *et al.,* 2003, Callow and Callow, 2002, Yebra, *et al.,* 2004).

It should be noted however, within these so-called biofouling organisms one can find both exogenous species that are distributed mainly in port areas, favored by good environmental conditions and by international maritime traffic (Roux & Bastida, 1990); as well as a local component corresponding to endemic communities (Bastidas, 1971).

It is important to note that biofouling can generate negative impacts on human beings, animal and plant life, economic and cultural activities and the aquatic environment (MEPC.1/Circ.792, 2012). In relation to maritime activities, the presence of these organisms on the hull of ships, produces friction resistance, demanding double the power for the displacement of the vessel (Bellotti, *et al.,* 2007, Salas, *et al.*, 2010, Phys.org, 2015). Additionally, it leads to a deterioration in the corrosion protection structure and system (Yebra, *et al.,* 2004, Bellotti, *et al.,* 2007). The described situation implies an increase in economic expenses for the shipping industry, associated with a higher fuel consumption (Bellotti, *et al.,* 2007, Salas, et *al.,* 2010, Phys.org, 2015), maintenance and cleaning of the surface (Cuadrado, *et al.,* 2010; Hellio & Yebra, 2009); and environmental damage related to extra emissions of carbon dioxide (CO2) (Phys.org, 2015, Salas, *et al.*, 2010).

Related to this background and recognized the threat of the establishment of intrusive aquatic species as a result of *biofouling*, the International Maritime Organization (IMO) examined in 2001 the issue of anti-fouling systems on ships through the International Convention on the Control of Harmful Anti-fouling Systems on Ships. In October 2012, the Marine Environment Protection Committee (MEPC) of IMO approved the Guidelines to minimize the transfer of invasive aquatic species such as biofouling (MEPC.1 / Circ.792, 2012) and a year later, this Committee adopted the *Guidelines for the control and management of biofouling of ships to minimize the transfer of intrusive aquatic species* (MEPC.1 / Circ.811, 2013).

From these approaches, some biofouling studies worldwide are based on anti-fouling systems such as paints (Bellotti, *et al.,* 2007, Jaramillo, *et al.,* 2011). Others evaluate the economic expenses in the application of new technologies or management strategies to combat the fouling of ships (Schultz, *et al.,* 2011).

For Colombia, there are few studies that directly assess fouling on the external structures of vessels. Some of them present listings of marine species identified and registered as exotic for the Colombian Caribbean, and mention some species that are part of the fouling of ships and impacts on buoys and docks (Gracia, *et al.,* 2011). In the department of La Guajira (Colombian Caribbean) authors such as Gracia, *et al.* (2013) conducted a study of marine invertebrates attached to gas platforms. For the Bay of Cartagena, Suarez (2011) carried out the baseline survey of encrusting macromolluscs in natural and artificial substrates, such as dock pilings of the Port Society and on buoys of the access channel of maritime traffic to the Bay. Additionally, there is the publication of García and Salzwedel (1993) who also evaluate the growth of sessile invertebrates on artificial structures in the bay of Santa Marta. Other studies such as those of Londoño-Mesa, *et al.,* (2002), are directed to a specific community of organisms such as the polychaetos that grow as fouling of the mangrove roots of the Archipelago of San Andres and Providencia and their relationship with physical and chemical parameters (temperature, salinity and dissolved oxygen).

It should also be noted that some authors have conducted research on biological controllers of fouling. Prato-Valderrama (2009) experimentally evaluated coatings based on natural substances (from organic extracts of the sponge *Neopetrosia carbonaria,* the octocoral *Eunicea laciniata* and two varieties of habanero pepper *(Capsicum chinense)*, as possible non-toxic antifouling agents, while Cuadrado, *et al.,* (2010) directed their study to the use of the gorgonia Eunicea laciniata from biological samples collected on the island El Morro, Bahía de Santa Marta, and Cortés-Useche, *et al.,* (2011) focuses on the use of bivalve Nodipecten nodus. On the other hand, Correa (2012), evaluated the capacity of the isolated compounds from the octocoral Pseudopterogorgia elisabeth present on the Island of Providencia, to inhibit the growth and formation of the bacterial biofilm.

There are studies directed to the use of commercial chemical anti-fouling coatings, an example is the work of Meza, *et al.,* (2007) who made an assessment of antifouling coatings through the monitoring of fouling formation in artificial substrates in the bay of Cartagena.

Recognizing the implications of biofouling in maritime activities, the General Maritime Directorate (DIMAR) acted in compliance with the functions of prevention and protection of the marine environment, as part of comprehensive maritime security. Through the Caribbean Oceanographic and Hydrographic Research Center (CIOH), they carried out the identification of the encrusting marine invertebrates present on the hull of the ARC "20 de Julio" before and after the route taken by the vessel during the First Scientific Expedition of Colombia in the Antarctic, determining at the same time, the status of these species in relation to their origin and distribution.

Methodology

Divers from the Colombian Navy performed the extraction of the biological material adhered to the flying buttress that supports the ARC helix axis "20 de Julio" (Figure 1), considering this structure as one of the most susceptible to biofouling (MEPC.1 / Circ.792, 2012). The total extraction area was approximately 7.5 m^2. The samples were stored in plastic jars and preserved with 4 % formalin (Rodríguez, *et al.,* 2009).

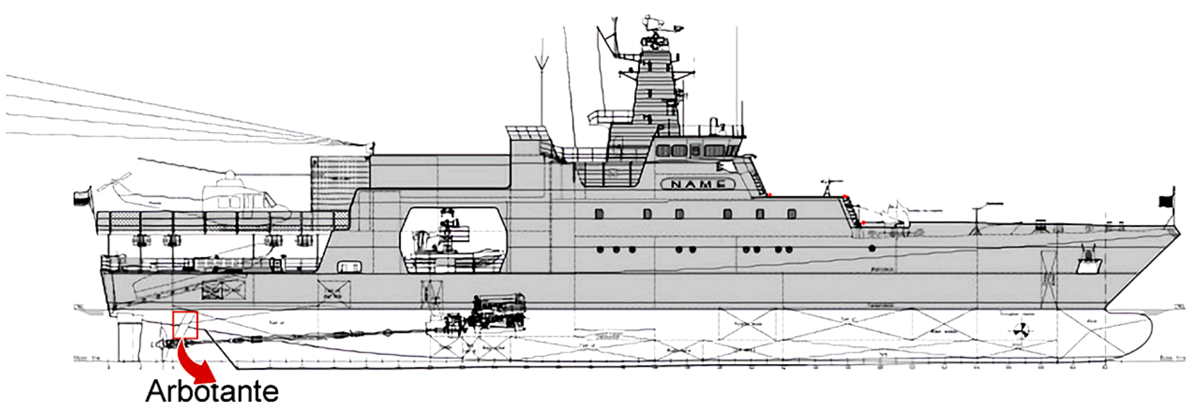

Figure 1. Ship of the Colombian Navy ARC “20 de Julio”.

In order to identify the species present on the external structure of the vessel before and after the route of the vessel during the Expedition, the collection of the organisms was carried out on two occasions. The first was made on December 15, 2014, before the departure of the "ARC 20 de Julio" and the organisms were extracted from thesurface of the flying buttress on the port side. The second sampling on the starboard side of the buttress, took place on April 7, 2015 after the journey made by the ship during the Expedition, which included berthing in ports in Ecuador, Chile, Argentina, Peru, and travelling along the strait of Gerlache (Figure 2).

Figure 2. Route of the ARC "20 de Julio" during the First Antarctic Expedition.

Once in the CIOH laboratory, the organisms were separated by groups and identified under stereoscope to the lowest taxonomic level, with the help of taxonomic guides Ortiz, *et al.,* (2002) & Yidi and Sarmiento (2011), as well as reference documents Gracia, *et al.,* (2011) & Suárez (2011).

The graphic representation of the abundance was carried out, calculated from the number of individuals per species identified in each collection (Moreno, 2001). Finally, the identified species were classified according to their origin and distribution as introduced, cryptogenic or native to the Cartagena Bay based on secondary information.

Results

In the *biofouling* extracted from the surface of the ship "ARC 20 de Julio" before and after the Antarctic Expedition, species belonging to four phylums were identified: Arthropoda, Mollusca, Annelida and Porifera (Table 1).

Table 1. Report of the species collected from the ship ARC "20 de Julio".

Phylum	Class	Family	Species	"ARC FROM JULY 20"	
				15-dec-14	07-apr-15
Athropoda	Maxillopoda	Balanidae	*Balanus amphitrite* (Darwin 1854)	x	x
			Balanus reticulatus (Darwin 1854)	x	x
			Balanus eburneus (Gould 1841)	x	x
	Malacostraca	Sphaeromatidae	Sphaeromatidae (morfo 1)	x	x
		Xanthidae	Xanthidae (morfo 1)	x	
Mollusca	Bivalvia	Mytilidae	*Brachidontes domingensis* (Lamarck, 1819)	x	
			Brachidontes exustus (Linnaeus, 1758)	x	
			Mytella guyanensis (Lamarck, 1819)	x	
			Mytella charruana (d'Orbigny, 1842)	x	
		Ostreoidae	*Ostrea equestris* (Say, 1834)	x	
		Isognomonidae	*Isognomon alatus* (Gmelin, 1791)	x	
		Pholaloide	*Martesia striata* (Linnaeus, 1758)		x
Annelida	Polychaeta	Nereididae	Nereididae (morfo 1) (Linnaeus, 1758)		x
		Serpulidae	Serpulidae (morfo 1)	x	x
Porifera	Homoscleromorpha	-	Homoscleromorpha (morfo 1)	x	

In total, the number of individuals registered in the sample collected before the departure was 691, with a specific richness of 12. The most abundant family was Balanidae with 619 individuals corresponding to 89 % of the relative abundance, and represented by the species *Balanus amphitrite, Balanus reticulatus and Balanus eburneus.* Followed by Mytilidae with a relative abundance of 5 % (32 individuals), within which organisms belonging to the species *Brachidontes domingensis, B. exustus, Mytella guyanensis and M. charruana* were identified (figures 3 and 4).

In the biological material collected after the trip made during the Antarctic Expedition, a total of 127 individuals and a specific abundance of seven were recorded. The most abundant families were Balanidae with 78 individuals (62 %), and standing out was the presence of the taxa *B. amphitrite B. reticulatus; and Serpulidae* with 40 specimens (31 %). A species of bivalve *Martesia striata* and two *polychaetes* of the family *Nereididae* were identified. In turn, the absence of species of *molluscs Brachidontes exustus, B. dominguensis, Mytella charruana, M. guyanensis, Ostrea equestri and Isognomon aleatus*, as well as, the crab of the *Xhantidae* family and the sponge of the *Homoscleromorpha* class was evidenced, and reported in the samples collected before the departure (Table 1) and (Figure 3).

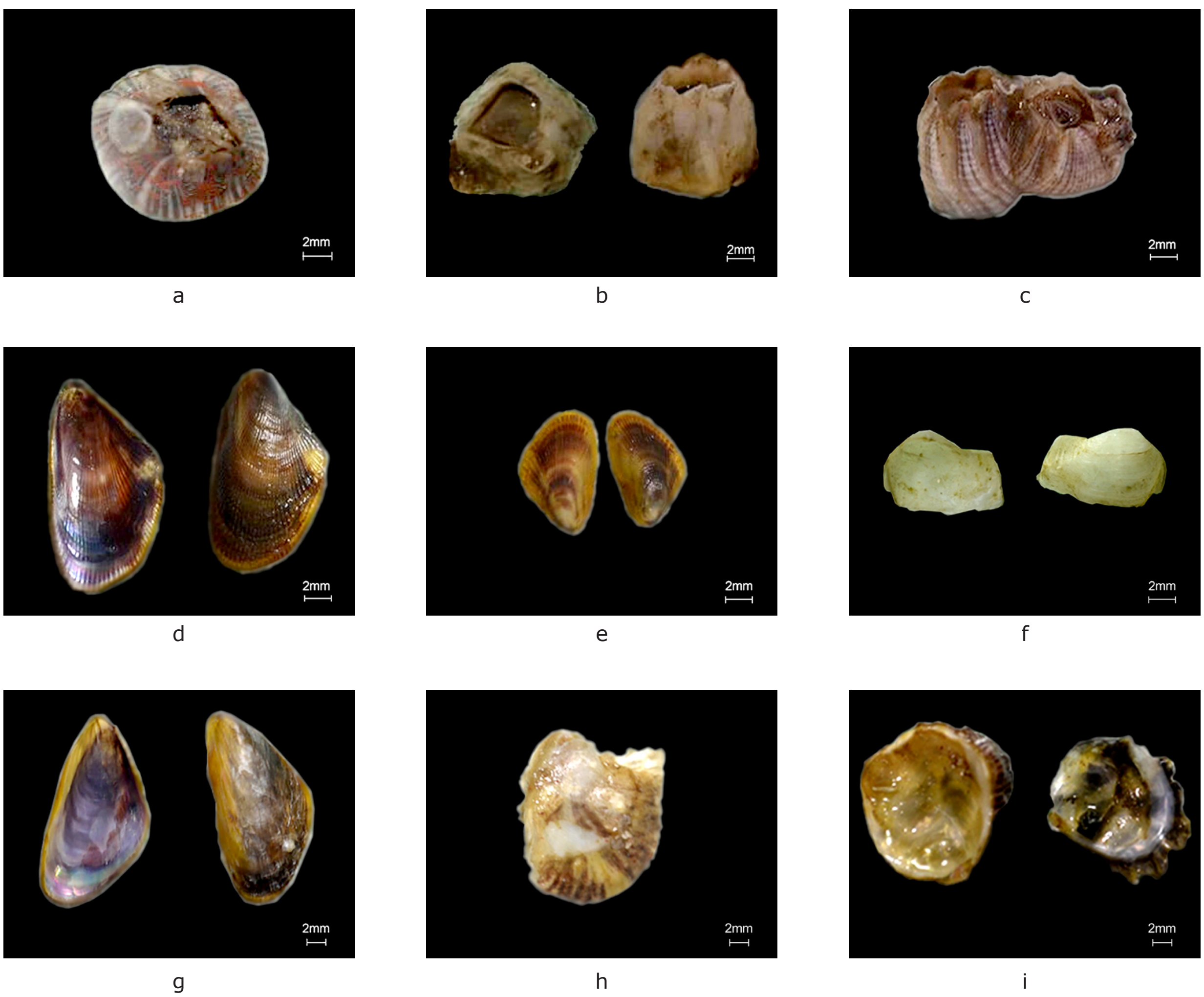

Figure 3. Species of the fouling of the ship "ARC July 20". (a) Balanus amphitrite, (b) Balanus eburneus, (c) Balanus reticulatus, (d) Brachidontes domingensis, (e) Brachidontes exustus, (f) Martesia striata, (g) Mytella guyanensis, (h) Isognomon alatus, (i)) Ostrea *equestris*.

The greatest abundance of individuals before the departure corresponded to the *Balanus* genus, with B. *amphitrite* being the species with the largest number of individuals (441); however, it decreased (38 ind) after the vessel's route (Figure 4). This behavior was also evident for B. *reticulatus* (123 ind / 26 ind) and *B. eburneus* (55 ind / 14 ind), with minor abundance after the vessel's route during the expedition. The *polychaetes* of the family *Serpulidae* (40 individuals second sampling), outnumbered those registered before the departure (30 ind) (Figure 4).

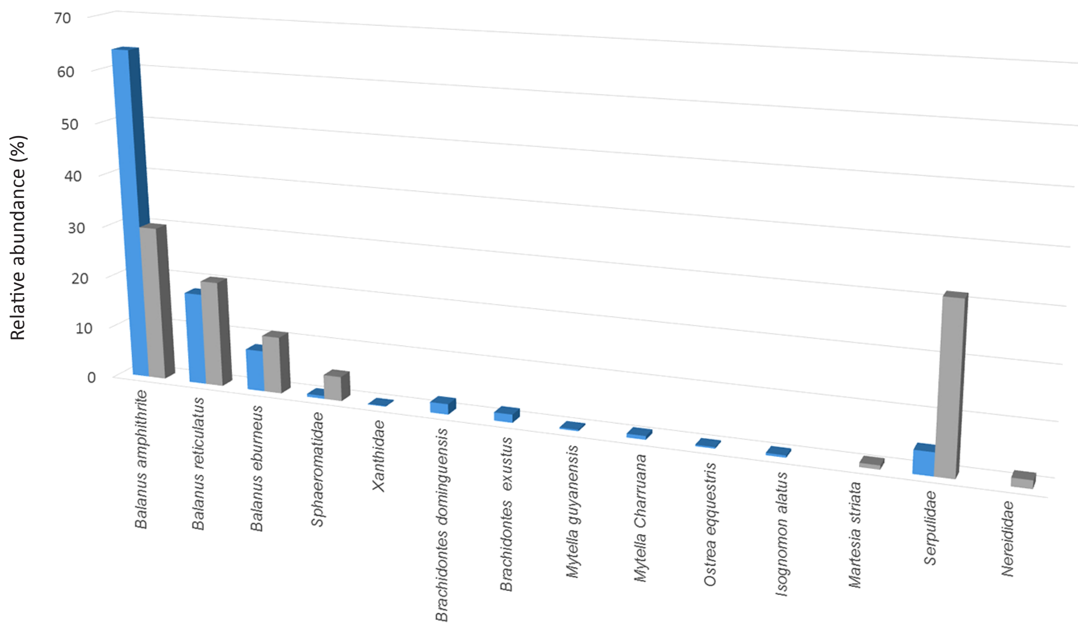

Figure 4. Relative abundance of organisms collected before and after the Antarctic Expedition. ARC "July 20".

Discussion

Artificial substrates such as ship cases, port infrastructure to support maritime activities, offshore platforms, pipelines and underwater turbines, dock pilings, and signaling buoys, all constitute new artificial habitats of marine species, because they favor the establishment of some biofouling marine, among which are seaweed, sponges, molluscs, mussels and barnacles (Manríquez, *et al.,* 1999; Bulleru and Airoldi, 2005; Pacheco and Garate, 2005, Connell, 2011, Fitridge, *et al.,* 2012; Walker, *et al.,* 2007). The majority of these groups were identified in the samples collected from the ARC "20 de Julio".

The balanos commonly known as sea acorns or rose hips, are crustaceans belonging to the Barnacle subclass (González, 1998) and are considered as typical organisms with high dominance on hulls of ships and artificial structures (dock pilings and buoys), with respect to the biomass of other encrusting invertebrates (Gracia, *et al.,* 2013). In this investigation the genus Balanus was the most abundant, being associated to physiological adaptations like adhesion glands with membranous base in adults to stay adhered to the substrate, and specialized antigens with adhesion discs, cuticle villi, secretion pores and sensory structures in larvae to explore and fix to the surface (Manríquez, *et* *al.,* 1999). Additionally, Edmondson and Ingram (1939) highlight the resistance of these sessile organisms to temperature changes, enduring environments of up to -10 ° C for several days (González, 1998), which possibly allowed individuals belonging to this subclass to resist the changes of the environmental conditions during the time of navigation, being attached to the flying buttress when the boat arrived in Cartagena. The most abundant species of barnacles coincided with the results reported by Meza, *et al., (*2007), who found in Mamonal and Bocagrande, sectors of Cartagena, high abundance of Balanus amphitrite, Balanus reticulatus and Balanus eburneus adhered to artificial hard substrates.

The *Barnacle Balanus amphitrite*, collected during the two sampling occasions, is considered cosmopolitan in the tropical and subtropical regions of the world (Celis, 2009; Gittings, 2009) and has the ability to adhere to both artificial surfaces and ship hulls, as well as natural substrates (mollusc shells and mangrove roots) (DeFelice, *et al.,* 2001; Rilov and Crooks, 2009). It is a species introduced into the Atlantic Ocean (Carlton, 2011); however, its origin is uncertain (Gracia, *et al.,* 2013). For Colombia, it is classified as invasive and has been reported in Cartagena and in the Gulf of Morrosquillo (Becerra & Jiménez, 2011).

Balanus reticulatus has been reported in studies around the world as a typical biofouling organism; it is widely distributed in tropical and subtropical waters (Motor, 1993), and is catalogued as introduced for Colombia (Young and Campos, 1988) (Table 2). Its wide distribution worldwide is associated with its easy adherence to the hulls of ships and the transport of larvae in ballast water tanks, vectors that have facilitated its dispersion (Low, *et al.,* 2014); In addition, its euryhaline physiological characteristics allows it to adapt to saline variations (Farrapeira, 2008).

Table 2. General list of species according to their origin found in the three shavings. Author: (1) Becerra and Jiménez (1989); (2) Young and Campos (1988); (3) Granadillo and Urosa (1984); (4) Yidi and Sarmiento (2011); (5) Instituto Nacional de Biodiversidad Santo Domingo (2016); (6) Gillis *et al.,* (2009); (7) Abbott *et al.,* (1995).

Species	Author	Introduced	Cryptogenic	Native
Balanus amphitrite	1	x	-	-
Balanus reticulatus	2	x	-	-
Balanus eburneus	1 y 3	-	-	x
Martesia striata	4	-	x	-
Brachidontes domingensis	4	-	-	x
Brachidontes exustus	4	-	-	x
Mytella guyanensis	5	-	x	-
Mytella charruana	6	x	-	-
Ostrea equestris	7	-	x	-
Isognomon alatus	7	-	x	-

* The Martesia striata species is considered cosmopolitan, it has been reported in the Pacific and Atlantic Oceans (Yidi and Sarmiento, 2011)

The *Balanus eburneus* species is native to the Northwest Atlantic (Table 2), including the Gulf of Mexico (Llorente, *et al.,* 2000) and is distributed from Massachusetts (USA) to the coasts of South America, in shallow waters up to 20 fathoms deep (Del Monaco and Capelo, 2000). The translocation of this species to the Pacific coast has been associated with the ability to adhere to artificial substrates, mainly external vessel structures (Galil, *et al.,* 2012).

According to Topolski and Szedlmayer (2004) and Carney (2005) molluscs represent a large part of the biomass embedded in artificial surfaces. Of the greater number of species reported on the hull of the ship ARC "20 de Julio", they were part of the bivalvia class of which the Mytilidae family had the largest number of individuals. According to Manríquez, *et al.,* (1999), artificial substrates favor the settlement, reproduction and growth of these filtering organisms.

For the mussel *Brachidontes exustus* its origin has been established in the Atlantic Ocean (Yidi and Sarmiento, 2011) and has been reported in Cartagena adhered to artificial structures (Meza, *et al.,* 2007), as well as B. domingensis Suárez (2011), characterized by being a species that adheres to exposed surfaces such as buoys, ship hulls, or water intake pipes. Its introduction causes competition with other species of native mussels (The University of Southern Mississippi, 2016).

Suarez (2011) and Puyana, *et al.,* (2012) report the presence of *Mytella charruana* on artificial hard substrates from the port area of Cartagena, and was considered according to Gillis, *et al.* (2009) and Puyana, *et al.,* (2012), a naturalized species in the bay of Cartagena before 2008. Its original distribution ranges from Guyana to Argentina (Darrigrán and Lagreca, 2005); however, it has been registered in Uruguay and, like M. *guyanensis*, there are reports in Mexico and Peru. M. *guyanensis* has also been found from Venezuela to Brazil, but its origin is unknown (National Institute of Biodiversity Santo Domingo, 2016).

The occurrence in the port area of Cartagena of the genus *Martesia* on artificial structures is not documented. This genus is considered by Railkin (2004), as highly dangerous organisms for the port and shipping industry, because it deteriorates submerged wooden structures, cellulose fiber cables and concrete structures. Specifically, the species *M. striata* identified in the samples collected after the route carried out by the ARC "20 de Julio", is a cosmopolitan species (Díaz and Puyana, 1995) and has the capacity to perforate lead coatings.

Both *Ostrea equestris* and *Isognomon alatus* have been recognized as encrusting organisms. *O. equestris* has been observed attached to ship hulls (Farrapeira, *et al.,* 2007) and it is presumed that the wide distribution of I. alatus is related to passive transport by boats (Farrapeira, *et al.,* 2007). The two species are distributed along the Northwest Atlantic Ocean and the Caribbean Sea to Brazil, but their origin is unknown (Abbott, *et al.,* 1995) (Table 2).

According to Edmondson and Ingram (1939), the *polychaetes* of the family *Serpulidae* are conspicuous members of associations of encrusting organisms and were reported by Meza, *et al.,* (2007), within the invertebrates responsible for biofouling on artificial substrates in the advanced tests carried out by the authors. Among the impacts caused by serpulid worms are corrosion damage on boat hulls and structures of marine platforms (Viéitez, *et al.,* 2004). Species of serpulid worms as well as the balano B. Amphitrite, are toxic-resistant species, which allows them to be always present on the surface of the antifouling coatings used for the protection of vessels (Railkin, 2004).

Species of the families Nereididae, Sphaeromatidae, Xanthidae and Homoscleromorpha, reported in this research, have been referred to by authors as present in artificial hard substrates, or their distribution has been related to sea transport through fouling or ballast water (Oriyama and Otani, 2004, Invasive Species Specialist Group -ISSG, 2016; Lim, *et al.,* 2009; Corsini-Foka and Kondylatos, 2015).

The permanence of some groups of organisms such as *barnacles* and *polychaetes* on the external structure of the vessel (buttress), during the route taken by the ARC "20 de Julio" from Cartagena to the Strait of Gerlache in Antarctica, passing through different ports of South America, gives an idea of the high resistance of these organisms to varying and extreme environmental conditions. Authors such as Mostafa, *et al.,* (2016), Awad (2012) and Basim *et al.,* (2011), have done research on the influence of environmental factors on the permanence of biofouling on hull surfaces and other external structures of ships.

Bearing in mind that the presence of biofouling is considered a problem that affects the naval industry, with economic effects such as an increase in fuel consumption, in the operational times for navigation activities, and in the frequency of dry dock entries, in addition to environmental impacts (Yebra, *et al.,* 2004, Bellotti, *et al.,* 2007, Schultz, *et al.,* 2011) such as the transfer of species (DIMAR-CIOH, 2009). It is recommended to implement the monitoring and control of biofouling of naval artifacts used by the Maritime Authority and the National Navy, as well as for international traffic routes used most frequently to Colombian ports. Additionally, it is important to have updated information on inventories, and study the behavior of attached marine organisms, not only on external and submerged structures of boats and port structures, but also on natural substrates. The foregoing is in order to strengthen knowledge about encrusting marine species present in the main areas influenced by maritime activities, and about their risk of introduction in new Colombian port areas or other ports of destination.

The present investigation constitutes a contribution to future studies of encrusting organisms in the port of Cartagena, tending to minimize, control or avoid negative effects on the port and shipping activities, as well as avoid the expansion of the distribution of marine species, considering the important role played by biofouling associated with maritime transport in the introduction of potentially invasive species.

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References

Invasive Species Specialist Group (ISSG). (2016). *Ecology of Alitta succinea. Global Invasive Species database.* Obtenido de http://www.issg.org

Abarzua, S. & Jakubowski, S. (1995). Biotechnological investigation for the prevention of biofouling. I. Biological and biochemical principles for the prevention of biofouling. *Mar. Ecol. Prog. Ser. 123*, 301-312.

Abbott, R., Morris, P. & Peterson, R. (1995). *A Field Guide to Shells: Atlantic and Gulf Coasts and the West Indies.* Boston, Massachussetts, : Peterson Field Guides. 512 pp.

Anderson, C., Callow, M. & Milne, A. (2003). The development of foul-release coatings for seagoing vessels. . *J. Mar. Des. Op. B. 4*, 11 – 23.

Awad, M. M. (2012). Impact of Flow velocity on Surface Particulate Fouling - Theoretical Approach. *Journal of American Science*, 442-449.

Basim , O. H., Graham, J. N., Peter, A. & Richard , A. C. (2011). the Effects of Temperature and Hydrodynamics on the Crystallization Fouling Under Cross Flow Conditions. I. *nt. J. of Applied Thermal Engineering, Elsevier Publisher.*, 210-218.

Bastida, R. (1971). Las incrustaciones biológicas en el puerto de Mar del Plata, periodo 1966/67. *Mus. Arg. Cs, Nat. B. Rivadavia, Hidrobiol., 3 (2)*, 203-285.

Becerra, J. & Jimenez, A. (2011). Evaluación cualitativa de los organismos adherentes sobre sustrato. En A. Gracia, J. Medellín, D. Gilagudelo, & V. Puentes. Guía de las especies introducidas marinas & costeras de Colombia. Bogotá, Colombia: Invemar, serie de publicaciones especiales No 23. 136 pp.

Bellotti, N., Romagnoli, R. & Del Amo, B. (2007). Pinturas no contaminantes para la protección anti-incrustante. *Congreso SAM/CONAMET*,. La Plata. Argentina. 629 - 633.

Bulleri, F. & Airoldi, L. (2005). Artificial marine structures facilitate the spread of nonindigenous green alga, Codium fragile spp. tomentosoides, in the north Adriatic Sea. *Journal of Applied Ecology 42*, 1063-1072.

Callow, M. & Callow, J. (2002). Marine biofouling: a sticky problem. *Biologist. 49 (1)*, 1 – 5.

Carlton, J. (1999). *The scale and ecological consequences of biological invasions in the world's oceans. En: Sandlund O.T., P.J. Schei & Å. Viken. (eds). Invasive speciesand biodiversity management.* Kluwer Academic Publishers. Dordrecht.195-212.

Carlton, J. (2011). History, biogeography, and ecology of the Introduced marine and estuarine invertebrates of the Pacific coast of North America. En A. Gracia, J. Medellín, D. Gilagudelo, & V. Puentes, *Guía de las especies introducidas marinas y costeras de Colombia.* Bogotá: INVEMAR, Serie de Publicaciones especiales No. 23. 68 pp.

Carney, R. S. (2005). *Characterization of algal-invertebrate mats at offshore platforms and the assessment of methods for artificial substrate studies: Reporte final.* Nueva Orleans: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS. 93 pp.

Celis, A. (2009). *Análisis panbiogeográfico y taxonómico de los cirripedios (Crustacea) de México.Tesis doctoral.* México: Instituto de Biología, UNAM. 286 pp.

Connell, S. (2001). Urban structures as marine habitats: an experimental comparison of the composition and abundance of subtidal epibiota among pilings, pontoons and rocky reefs. . *Marine Environmental Research 52(2)*, 115-125.

Correa, H. (2012). *Estudios de bioprospección del coral blando Pseudopterogorgia elisabethae como fuente de sustancias con actividad biológica. Fase IV. Trabajo doctoral. .* Bogotá.: Universidad Nacional de Colombia Facultad de Ciencias, Departamento de Química.193-194.

Corsini-Foka & Kondylatos, G. (2015). First occurrence of Actaeodes tomentosus (H. Milne Edwards, 1834) (Brachyura: Xanthidae: Actaeinae) in the Mediterranean Sea . *M. Medit. Mar. Sci., 16/1.* , 201-205.

Cortés-Useche, C., Gómez-León, J. & Santos-Acevedo, M. (2011). Erizos de mar como control biológico del "foulling" en un cultivo de Nodipecten nodosus en el área de Santa Marta, Caribe colombiano. *Bol. Invest. Mar. Cost. 40 (2)*, 233 - 247.

Cuadrado, C., Castellanos, L., Osorno, O., Ramos, F., Duque Beltrán, C. & Puyana Hegedus, M. (2010). Estudio químico y evaluación de la actividad antifouling del octocoral caribeño Eunicea laciniata. *Quim. Nova, Vol. 33, No. 3*, 656-661.

Darrigrán, G. & Lagreca, M. (2005). *Moluscos litorales del estuario del río de la Plata, Argentina.* Buenos Aires: ProBiota, FCNyM y UNLP, Serie Técnica Didáctica No. 8. 40 pp.

DeFelice, R., Eldredge, L. & Carlton, J. (2001). Nonindigenous, Marine Invertebrate. En L. Eldredge, & C. Smith, *A Guidebook of Introduced Marine Species in Hawaii. Bishop Museum Technical Report. 21*. 35-36.

Del Monaco , C. & Capelo, J. (2000). Los géneros Balanus, Chtamalus y Tetraclita (Crustacea: Cirripedia) en las costas de Nueva esparta, Venezuela. *Memoria de la Fundación La Salle de Ciencias Naturales. 154:*, 77-97.

Díaz, M. & Puyana, M. (1995). *Moluscos del Caribe colombiano: Un catálogo ilustrado. Santafé de Bogotá.* Santafé de Bogotá: COLCIENCIAS-Fundación Natura-Invemar. N. 291 pp.

Dimar-CIOH. (2009). *Dossier para el control y la gestión del Agua de Lastre y sedimentos de buques en Colombia. Dirección General Marítima - Centro de Investigaciones Oceanográfica e Hidrográficas.* Cartagena de Indias: Serie de publicaciones especiales Cioh Vol.3. 116 pp.

Edmondson, C. & Ingram, W. (1939). Fouling Organism in Hawaii. *Occasional Papers of Bernice P Bishop Museum. Vol. 14*, 251 - 300.

Farrapeira, C. (2008). Cirripedia Balanomorpha del estuario del Río Paripe (Isla de Itamaracá, Pernambuco, Brasil). *Biota Neotrop., vol. 8, no. 3.*, 31 - 39.

Farrapeira, C. De Oliveira Marrocos, A., Ferreira, A. & Euzebio, K. (2007). Ship hull fouling in the Port of Recife, Pernambuco. *Brazilian Journal of Oceanography, 55(3):*, 207-221.

Fitridge, I., Dempster, T., Guenther, J. & Nys, r. (2012). The impact and control of biofouling in marine aquaculture: a review. . *Biofouling. 28(7)*, 664-669.

Galil, B. S., Clark, P. F. & Carlton, J. (2012). In the Wrong Place — Alien Marine Crustaceans: Distribution, Biology and Impacts. Invading Nature. *Springer Series in Invasion Ecology 6. Journal of Crustacean Biology,* 7-16.

García, C. & Salzwedel , H. (1993). Recruitment patterns of sessile invertebrates onto fouling plates in the bay of Santa Marta, Colombian caribbean. *Bol. investig. mar. Cost. vol.22 no.1*, 30 - 44.

Gillis, N., Walters , L., Fernandes , F. & Hoffman , E. (2009). Higher genetic diversity in introduced than in native populations of the mussel Mytella charruana: evidence of population admixture at introduction sites. *Diversity Distrib.* 784-795.

Gittings, S. (2009). Cirripedia (Crustacea) of the Gulf of Mexico. En D. Felder. , y D. Camp, *Gulf of Mexico. Origin, waters and biota. Biodiversity.* Texas: Texas A&M Press College. 827 pp.

González, O. (1998). *El océano y sus recursos. Vol. 6. III. La vida bentónica en las facies rocosas.* México: Secretaría de Educación Pública (México). 42 pp.

Gracia, A., Cruz, N., Borrero, G., Báez, D. y Santodomingo, N. (2013). Invertebrados marinos asociados con las plataformas de gas en la guajira (Caribe colombiano). *Bol. Invest. Mar. Cost. 42 (2)*, 361-386.

Gracia, A., Medellín, J., Gilagudelo, D. & Puentes, V. (2011). *Guía de las especies introducidas marinas y costeras de Colombia.* Bogotá, Colombia: INVEMAR, serie de publicaciones especiales No 23. Ministerio de Ambiente y Desarrollo Sostenible. 135 pp.

Granadillo, L. & Urosa, L. 1984. Véase En: Monaco, C. & Capelo, J. 2002. Los géneros Balanus, Chthamalus y Tetraclita (Crustacea: Cirripedia) en las costas de Nueva Esparta, Venezuela. Memoria de la Fundación La Salle de Ciencias Naturales. Pag. 154: 77-97

Hellio, C. & Yebra, D. (2009). *Advances in Marine Antifouling Coatings and Technologies.* Hong Kong: Woodhead Publishing. 784 pp.

Hewitt, C. & Campbell, M. (2010). *The relative contribution of vectors to the introduction and translocation of invasive marine species.* Australia: Commonwealth of Australia. pags 56. 16 -17.

Instituto Nacional de Biodiversidad Santo Domingo. (14 de 07 de 2016). *Biodiversidad de Costa Rica (Mytella guyanensis)*. Obtenido de http://atta2.inbio.ar.cr

Jaramillo, F., Cartaño, G. & Echeverría, F. (2011). Evaluación en campo de formulaciones experimentales de pinturas anti-incrustantes. *Universidad Nacional. DYNA*, 135-143.

Lim, C., De Voodg, N. & Koh-Siang , T. (2009). Fouling sponges (Porifera) on navigation buoys from Singapore waters. . *The raffles Bulletin of zoology supplement No.22*, 41-58.

Llorente, E., González, E. & Papavero, N. (2000). *Biodiversidad taxonómica y biogeográfica de artropodos de México: hacia una síntesis de sus conocimientos, vols .II, III: Grupos hexapoda. Cirripedía.* México: Universidad Nacional Autónoma de México. 349 pp.

Londoño-Mesa, M., Polanía, J. & Vélez, I. (2002). Polychaetes of the mangrove-fouling community at the Colombian Archipelago of San Andrés and Old Providence, Western Caribbean. . *Wetl. Ecol. Manag., 10*, 227 - 232.

Lopez, E. (1998). *El Problema del Biofouling en Intercambiadores de Calor-Condensadores refrigerados por agua de mar.* Santander: Servicio de Publicaciones de la Universidad de Cantabria. 160 pp.

Low, A., Quijón, P. & Peters, E. (2014). *Especies invasoras acuáticas: casos de estudio en ecosistemas de México*. ISBN: 978-1-304-90189-7. Edt. Semarnat - Mexico. 629. 55-57.

Manríquez, P., Fica, E., Ortiz, V. & Castilla, J. (1999). Bio-incrustantes marinos en el canal de Chacao, Chile. Un estudio sobre potenciales interacciones con estructuras manufacturadas por el hombre. *Revista de Biología Marina y Oceanografía Vol. 49, Nº2*, 243-26.

MEPC.1/Circ.792. (2012). Guidance for minimizing the transfer of invasive aquatic species as biofouling (hull fouling) for recreational craft. International Maritime Organization.London. 7 pp.

MEPC.1/Circ.811. (2013). Guidance for evaluating the 2011 guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species. International Maritime Organization. London. 12 pp.

Meza, M., Calixto, D., Velosa, L., Acosta, E., Puyana, M., Morales, J. & Panqueva, J. (2007). Valoración de la efectividad antiincrustante de recubrimientos aplicados a embarcaciones que operan en la Bahía de Cartagena. Ship Science y Technology, Vol 1, No. 17-25.

Moreno, C. (2001). *Métodos para medir la biodiversidad. M&T-Manuales y Tesis SEA.Vol 1.* Zaragoza: CYTED, ORCYT/UNESCO y SEA . 84pp.

Mostafa , M. A., Salem , M., Helmi, G. & Asfour, F. (25 de 06 de 2016). *"Effect of Flow Velocity on the Surface Fouling".* Obtenido de http://www1.mans.edu.eg/faceng/Journal/Abstract/2007/March2007_M3.pdf

Motor, B. (1993). *The Marine Biology of the South China Sea. Volumen 1. .* Hong Kong: Hong Kong University Print. 578 pp.

Okolodkov, Y. & García, H. (2014). Agua de lastre y transporte de los organismos incrustantes, leyes y acciones: perspectivas para México. En A. Low, P. Quijón, y E. Peters, Especies invasoras acuáticas: casos de estudio en ecosistemas de México. México. 55 - 80.

Okolodkov, Y., Bastida, R., Ibáñez, A., Chapman, J., Suárez-Morales, E., Pedroche, F. & Gutiérrez-Mendie, F. (2007). Especies acuáticas no indígenas en México. *Ciencia y Mar. XI(32)*, 29-67.

Oriyama, H. & Otani, M. (2004). Paracerceis sculpta(Crustacea: Isopoda: Sphaeromatidae), a Newly Introduced Species into Osaka Bay, Central Japan. . *Benthos Research Vol. 59* , 53-59.

Ortiz, M., Lalana, R. & Varela, C. (2002). Lista de especies y clave ilustrada para la identificación de los escaramujos (Crustacea y Cirripedia), del Archipiélago. *Rev. Invest. Mar. 23(2)*, 85 pp.

Pacheco, A. & Garate, A. (2005). Bioincrustantes en estructuras de cultivo de Argopecten purpuratus en Bahía Samanco, Perú. . *Ecología Aplicada 4(1,2)*, 149 - 152.

Phys.org. (29 de 07 de 2015). *Paints and coatings containing bactericidal agent nanoparticles combat marine fouling.* Obtenido de http://phys.org

Prato-Valderrama, J. (2009). *Desarrollo de un ensayo in situ para la evaluación preliminar de extractos y compuestos de origen natural como recubrimientos antifouling no tóxicos, en la bahía de Cartagena, Caribe colombiano. Trabajo de grado.* Bogotá, D.C. : Fundación Universidad de Bogotá Jorge Tadeo Lozano. Programa de Biología Marina. 158 pp.

Puyana, M., Prato, J. & Díaz, M. (2012). Mytella charruana (d'orbigny) (Mollusca: Bivalvia: Mytilidae) en la Bahía de Cartagena, Colombia. *Bol. Invemar vol.41 no.1*, 2013-2017.

Railkin, A. (2004). *Marine Biofouling: colonization Process and Defenses. 2004. .* Boca Raton, FL.: CRC Press. 62-63.

Rilov, G. & Crooks, J. (2009). Biological invasions in marine ecosystems. Ecological, management and geographic perspectives. Ecological Studies 204 - 641 .

Rodríguez , A., Muñoz, I., Bonada, N., Gaudes, A. & Tomanova, A. (2009). La biota de los ríos: los invertebrados. Capítulo 14. En A. Elosegi, y S. Sabater, *Conceptos y técnicas en ecología fluvial.* España. : Universidad del País Vasco. 253 - 270.

Roux, A. & Bastida, R. (1990). The occurence of Sphaeroma serratum (Fabricius) in the Western South Atlantic (Crustacea: Isopoda). *Proc. Biol. Soc. Wash. 103 (2)*, 350-350.

Salas, M., Bertram, V., Höppner, V. & Fach, K. (2010). Ingeniería Avanzada para Economía de Combustible en Pesqueros. . *Universidad Austral de Chile. Revista Tecnológica ESPOL – RTE, Vol. 23, N. 3.* , 55- 60.

Schultz, M., Bendick, J., Holm , E. & Hertel, W. (2011). Economic impact of biofouling on a naval surface ship. . *Biofouling 27(1)*, 87-98.

Suarez , N. (2011). *Levantamiento de la línea base de Macromoluscos (Bivalvia- Gastropoda) en la bahía de Cartagena, Caribe Colombiano como contribución a la gestión de agua de lastre en el territorio nacional. Tesis de pregrado. Universidad del Magdalena. Facultad d Ciencia.* Santa Marta, D.T.C.H. 46-71.

The University of Southern Mississippi. (01 de 11 de 2016). *Gulf Coast Research Laboratory.* Obtenido de https://www.usm.edu/gcrl/

Topolski, M. & Szedlmayer, S. T. (2004). Vertical distribution, size structure, and habitat associations of four Blenniidae species on gas platforms in the northcentral Gulf of Mexico. *Env. Biol. F., 70:*, 193-201.

Viéitez, J., Alós, C., Parapar , J., Besteiro , C., Moreira , J., Núñez , J., . . . San Martín , G. (2004). Annelida Polychaeta. En M. Ramos , *Fauna Iberica, Vol. 25.* Madrid: Museo Nacional de Ciencias Naturales. CSIC. 530 pp.

Walker, S., Schlacher, T. & Schlacher-Hoenlinger, M. (2007). Spatial heterogeneity of epibenthos on artificial reefs: fouling communities in the early stages of colonization on an East Australian shipwreck. . *Marine Ecology 28*, 345-445.

Yebra, D., Kiil, S. & Dam-Johansen, K. (2004). Antifouling Technology: Past, Present and Future Steps Towards Efficient And Environmentally Friendly Antifouling Coatings. . *Progress in Or-ganic Coatings*, 75-104.

Yidi, E. & Sarmiento, V. (2011). *Colombian seashells from the Caribbean.* . Italia: Editorial L'Informatore. ISBN-13: 9789584475305. 400 pp.

Young, P. & Campos, N. (1988). Cirripedia (Crustacea) en la zona intermareal e infralitoral de la región de Santa Marta, Colombia. . *An. Inst. Inv. Mar. Punta Betín 18*, 153-164.