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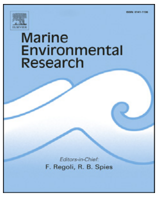

Marine fouling invasions in ports of Patagonia (Argentina) with implications for legislation and monitoring programs

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ABSTRACT

Ports are a key factor in the understanding and solving of most problems associated with marine invasive species across regional and global scales. Yet many regions with active ports remain understudied. The aim of this work was to (a) identify and quantify the marine fouling organisms in all Patagonian ports of Argentina classifying them as native, exotic or cryptogenic species through a rapid assessment survey and experimental studies, (b) survey the environmental and anthropogenic variables of these ports and (c) analyze and discuss these results in the light of the South America context for the study of marine invasive species, legislation and commerce. We found 247 fouling species, including 17 introduced, one of which is a new record for the region, and other 15 species currently considered cryptogenic species that will need further attention to clarify their status. The analysis of mobile and sessile taxa, together with the environmental variables measured in this study and the port movement, allow us to discuss individual ports' vulnerability to future introductions. This is the first large scale study performed for this region on this topic, and it will help in developing monitoring programs and early detection plans to minimize new species introductions along the marine coastline of southern South America.

1. Introduction

The introduction of invasive species is recognized as one of the top five threats to native biodiversity (Sala et al., 2000). An overwhelming number of species are transported worldwide every day by several means, and our understanding of their evolutionary history constantly reveals unexpected complexities (e.g. Geller, 1999; Fortune et al., 2008). Since ocean shipping is considered the most important vector for transporting and introducing species into new areas outside their native ranges (Ruiz and Carlton, 2003; Drake and Lodge, 2007), the monitoring of ports and harbors helps us to predict the vulnerability of local harbors and to develop regional management policies (Bishop and Hutchings, 2011). Indeed, harbors' vulnerability is extremely difficult to predict due to the complexity presented by variables such as propagule pressure

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(Johnston et al., 2009), resource availability (Olyarnik et al., 2009), diversity of resident species and environmental conditions of the receptive habitat (Byers, 2002). Within this context, it is clear necessity to create accurate baseline information about these environmental conditions (Bishop and Hutchings, 2011; Mead et al., 2011).

Port areas concentrate a variety of artificial structures that support many different organisms (Glasby, 1999; Connell, 2001), and it is known that artificial and natural habitats are not equally colonized by fouling species (Connell, 2001). In fact, man-made structures seem to favor the recruitment and survival of fouling exotic species even when the richness of native species is relatively high (Glasby et al., 2007). Indeed, man-made habitats might even act as corridors enhancing the spreading of exotic marine species, as shown by Bulleri and Airoldi (2005) for the invasive *Codium fragile* subsp. *tomentosoides*. Considering that the 90% of the global trade is carried by sea, our understanding of global marine invasion ecology is strongly related to the effort we dedicate to study port areas.

The Southwestern Atlantic (SWA) is currently placing a considerable effort to compile all the records of marine exotic and cryptogenic species (e.g. Orensanz et al., 2002; Scarabino, 2006; Schwindt, 2008). However, the lack of tradition in integrating coastal ecology and the regional maritime history hampers our ability to understand biological invasion patterns in this region (Bortolus and Schwindt, 2007). The earliest fouling studies in warm temperate Argentinean ports date from the 1960's (Bastida, 1971; Valentinuzzi de Santos, 1971), and since then, most cold temperate ports within this region have never been intensively surveyed and their biodiversity remains largely unknown. Argentina has the second longest shoreline of the SWA, after Brazil. However, in contrast with the heavily populated and industrialized coast of Brazil, Argentina has only ten major marine ports along a mostly exposed shoreline with a few marinas associated with recreational activities (Boltovskoy, 2008). Thus, the aim of this work was (a) to identify and quantify the marine fouling organisms in all Patagonian ports of Argentina by conducting a Rapid Assessment Survey (hereafter RAS) and experimental studies, and classifying them as native, exotic or cryptogenic species (b) to survey/describe the environmental and anthropogenic variables of these ports and (c) to analyze and discuss these results in the light of the South America context on marine invasion ecology, legislation and commerce. This is the first large scale study performed for this region on this topic, and it will help in developing monitoring programs and early detection plans to minimize new species introductions along the marine coastline of southern South America.

2. Materials and methods

2.1. Fouling sampling

Of the ten main marine ports of Argentina, we surveyed six, all of them situated in the Patagonian region from 40°S to 54°S: San Antonio Este (SAE), Puerto Madryn (PM), Puerto Deseado (PD), Punta Quilla (PQ), Río Gallegos (RG) and Ushuaia (U, Fig. 1). At each port, a RAS (qualitative fouling sampling) was conducted in spring 2005 on the subtidal zone (i.e. just under the intertidal zone but never exposed to the air) by scuba diving and scraping the surface of different pilings ($n = 3–5$ samples per port, 25 × 25 cm each). Samples were collected by expert scientific divers, bagged separately, labeled, fixed in formalin (4%) and then preserved in ethanol (70%) excepting for the algae, which were kept in formalin. Later, samples were sorted and identified to the lowest possible taxonomic level following the recommendations by Bortolus (2008, 2012a, 2012b). Although most authors of this work have expertise in different taxa, we had the collaboration of several other expert taxonomists in order to cover most of the taxa found (see Acknowledgment section and Appendix A). Vouchers of the collected taxa were deposited in the Centro Nacional Patagónico (CENPAT) Invertebrate Collection. Planktonic and soft-bottom organisms were out of the scope of this study.

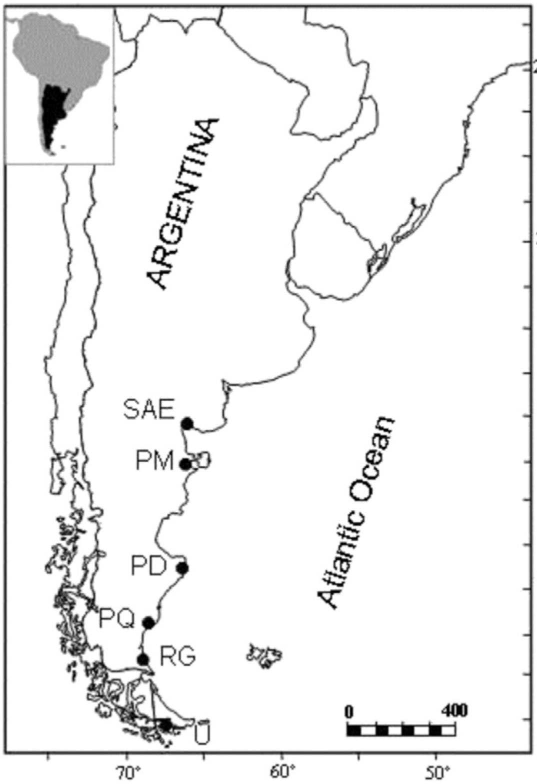

Fig. 1. Studied marine ports of Argentinean Patagonia: San Antonio Este (SAE), Puerto Madryn (PM), Puerto Deseado (PD), Punta Quilla (PQ), Río Gallegos (RG) and Ushuaia (U).

To identify the total biodiversity at each port, we complemented the RAS (qualitative sampling) with a survey with fouling plates (quantitative sampling). These plates ($n = 15$ per port, 20 × 20 cm each, one plate per piling) were vertically deployed at each port along the subtidal zone, at 1.5 m below the average low tide, during 18–22 months. All plates were made of fiberglass homogeneously scratched to increase the roughness. Plates were deployed between October and November 2005 (spring) and collected between June and July 2007 (winter). At the end of this period all plates were placed separately in plastic bags and transported in coolers at ~5 °C to the laboratory for processing. In the laboratory each plate was photographed, and the percentage cover of sessile species and the abundance of mobile species, were recorded. Then, all the organisms were removed from the plates, fixed and preserved following Hewitt and Martin (2001). All organisms collected were identified to the lowest taxonomic level possible and deposited in the Invertebrate Collection of the CENPAT. Organisms were classified as native, cryptogenic or exotic following Chapman and Carlton (1991). We noted if a species represented the first record for the region (FR), or if it was never previously mentioned in the regional literature as exotic or cryptogenic species (NM), and also those found outside their known regional geographic range (RE, range extension).

2.2. Port characterization

To assess differences and similarities among ports and to discuss the potential vulnerability of every port to marine invasive species, we developed a database with nine environmental variables based on field sampling and literature surveys (following Clarke et al., 2004, Table B.1 of Appendix B). The main variables considered were: 1) sea surface water temperature, 2) air temperature, 3) tidal amplitude, 4) wind speed, 5) surface salinity, 6) rainfall, 7) port depth, 8) type of port and 9) the environmental impact of the city. For the first seven variables we estimated their maximum, minimum and average values. The resultant matrix was composed by 26 different variables (see Appendix B for details). These variables were selected because they were identified influencing on the survivorship of intertidal and shallow subtidal organisms in the port environment, according to the studies carried on by the Globallast Programme (see for example Clarke et al., 2004 for the Port of Sepetiba, Brazil). In addition to these variables, we added wind speed because of its strong influence across the coastal area of Patagonia (Prohaska, 1976). The categorization of the environmental impact of the city was developed by Esteves (2007) considering coastal geography, the oceanographic and fluvial conditions, the pollution, and the eutrophication level recorded at each port (see Appendix B for details). In addition, to compare the port activity within the study area, we analyzed the average port movement (in tons) between 1998 and 2008 (Consejo Portuario Argentino, 2011 and the references therein) and the average number of ship entries reported for the same period for all the ports excepting PD, PQ (both 1998–2005) and RG (2000–2005). The port movement was obtained from the statistics reported at each port and it represents the total cargo movement of domestic and international ships. The shipping entries represent the total number of vessels (domestic and international) entering at each port. Since ballast water discharge reports are not mandatories in Argentinean waters, this information was not available to analyze in this study (for detailed discussion see Boltovskoy et al., 2011).

2.3. Data analysis

To explain the relationships between environmental variables and the composition of the total biological assemblages among ports, two canonical correspondence analyses (CCA) were performed independently for mobile and sessile taxa using the package Vegan (Oksanen, 2011) in the R computing environment. Previously, a correlation matrix of the 26 environmental variables was studied to detect problems of multicollinearity (see Table B. 2 of Appendix B). The final analysis of CCA was performed using the following seven variables which represented the main environmental characteristics of the ports that we studied: average annual surface water temperature, average tidal amplitude, average annual wind speed, salinity, average monthly rainfall, port's depth and type (see Table B. 3 of Appendix B for details). In addition, we used the one-way ANOVA to evaluate the null hypothesis of no differences in port movement (in tons) among ports (Zar, 1999). Another one-way ANOVA was used to evaluate the null hypothesis of no difference in taxonomic richness of the plates (mobile plus sessile taxa together) among ports (Zar, 1999). Levene and Kolgomorov–Smirnov tests were used to evaluate the homoscedasticity and normality of the data respectively. Data were square-root or log transformed to comply with the ANOVA assumptions. Finally, *a posteriori* Tukey tests were used to identify differences among means (Zar, 1999).

3. Results

A total of 247 fouling taxa and three associated fish species (Appendix A) were found; most organisms (77%) were recorded in the qualitative samples during the RAS, and most species (87%) were native. Overall, we found 17 exotic species (six macroalgae, five crustaceans, one bryozoan and five ascidians, Table 1) and 15 cryptogenic species (four macroalgae, four hydrozoans, two polychaetes, two crustaceans, one bryozoan and two ascidians, Table 1). The use of plates allowed us to detect several species unrecorded during the RAS (Appendix A), including five cryptogenic species (the macroalgae *Bangia fuscopurpurea*, *Blidingia marginata*, *Dictyota dichotoma* and *Ectocarpus siliculosus*, and the ascidian *Cnemidocarpa robinsoni*) and five exotic species (the macroalgae *Anotrichium furcellatum*, the bryozoan *Bugula stolonifera* and the ascidians *Ciona intestinalis*, *Diplosoma listerianum* and *Molgula manhattensis*, Table 1).

The port of SAE showed the highest number of exotic and cryptogenic species with a total of 20, followed by PD with 12 species (Table 1). Our record for the colonial ascidian *D. listerianum* is the first for Argentinean waters, being observed in SAE (on 12 of 15 plates) and less abundantly in PD (on two plates). We re-categorized as exotic two species previously known as native (the amphipods *Jassa marmorata* and *Crassicorophium bonnellii*), and four other species we re-categorized as cryptogenic (the hydrozoans *Amphisbetia operculata*, *Obelia bidentata* and *Halecium delicatulum*, Table 1). Finally, we detected a southward range extension for two known exotic species, the amphipod *Monocorophium insidiosum* and the ascidian *Molgula manhattensis*, found in U and PD, respectively. Nearly 50% of the surface mean cover on plates detected at SAE and PD were exotic or cryptogenic species (Fig. 2), while this percentage in the other ports was less than 13% (Fig. 2).

Mobile taxa were represented by turbellarians, polychaetes, brachyurans, carideans, isopods, amphipods, pycnogonids, gastropods, polyplacophorans, echinoderms and fishes (see Appendix A for complete species list). The first two CCA axes explained 90.9% (CCA1: 76.8% and CCA2: 14.1%) of the total variance in the analysis of mobile taxa (Fig. 3A). The ports of U, RG and PD were grouped showing similar taxa, mainly polychaetes, while PQ, SAE and PM differed their mobile taxa (Fig. 3A). Polychaetes, and particularly isopods, were abundant in PD. The port of SAE was the richest in terms of the mobile fauna. The carideans were present only in this port and the amphipods, mollusks, brachyurans and echinoderms showed their highest abundances there (Fig. 3A). Mobile fauna was almost absent in PQ. Ports were also separated by their environmental variables (Fig. 3A). The cold temperate ports of U, RG, PQ and PD were spread along the positive values of the first axis, while the warm temperate ports of SAE and PM were spread along the negative values also of the first axis. The ports of U, SAE and PM are situated in natural bays which were separated from PQ, PD and RG, located in estuarine areas. Salinity and temperature were high in SAE and PM and low in PQ and U. Rainfall was highest in U (Fig. 3A).

The cover values obtained from the plates for sessile taxa reached the maximum 100% in three ports (SAE, PD and U), ranging from 23% in RG to 72% in the remaining ports. The first two CCA axes explained 67.1% (CCA1: 37.8% and CCA2: 29.3%) of the total variance in the analysis of sessile taxa (Fig. 3B). Each port showed distinctive taxa composition, with the ascidians as the only taxonomic group common to all ports. This taxon showed the highest average cover (85%) in PD, with eight species (three exotics and two cryptogenics, Table 1). Bryozoans, polychaetes and ascidians were the dominant faunal components in the ports of PD and U (Fig. 3B). The colonization by macroalgae registered on the plates was extremely low in most ports, excepting in PQ where they were dominant (average cover = 39%, Fig. 3B). Anthozoans were dominant in PM and abundant in SAE. In the latter the dominant taxon were the hydrozoans, mostly due to the presence of the cryptogenic *Ectopleura crocea* (average cover = 53%). The port of RG was very poor in terms of cover of sessile taxa, showing the lowest average

Table 1
Exotic and cryptogenic species recorded in Patagonian ports (SAE: San Antonio Este, PM: Puerto Madryn, PD: Puerto Deseado, PQ: Punta Quilla, RG: Rio Gallegos, U: Ushuaia) and their status (exotic, cryptogenic). TS: species that need taxonomic study, FR: species that represents the first record for the Patagonian coast, NM: species that were never mentioned in the SWA literature as exotic or cryptogenic, RE: exotic species that extended the distribution range according to the earliest reports in the region, **P**: taxa found only in fouling plates but not in the qualitative sampling, S: taxa found only during the qualitative sampling but not on the plates, B: taxa found on plates and during the qualitative sampling. Next to each taxon between brackets is the Phylum to which belongs each taxon. R: Rodophyta, Cl: Chlorophyta, O: Ochrophyta, Cn: Cnidaria, An: Annelida, Ar: Arthropoda, M: Mollusca, B: Bryozoa, Ch: Chordata.

Species	Ports						Comments
	SAE	PM	PD	PQ	RG	U	
Exotics							
Anotrichium furcellatum (R)	P						Observed in Argentina since 1984 (Boraso de Zaixso and Akselman, 2005)
Lomentaria clavellosa (R)	S	S					Native to Europe (Mathieson et al., 2008)
Neosiphonia harveyi (R)	S	S					Previously described as *Polysiphonia argentinica* in 1872 (Taylor, 1939)
Rosenvingiella polyrhiza (Cl)					S		First collected in 1972 (Boraso de Zaixso, 2002)
Cutleria multifida (O)	S						First reported in Argentina around 1965 (Asensi, 1971)
Undaria pinnatifida (O)		S					See Orensanz et al. (2002)
Balanus glandula (Ar)	S	B	S				First collected in 1974 (Spivak and L'Hoste, 1976)
Monocorophium insidiosum (Ar)	S				S	S	RE. First collected in 1968 in fouling communities (López Gappa et al., 2006)
Monocorophium acherusicum (Ar)	B		S		S		First collected in Argentina in 1961 (USNM # 127701)
Crassicorophium bonellii (Ar)			S			S	NM. The species was barely observed since 1892. A recent taxonomic study confirmed its presence and suggested its native area (Alonso, 2012)
Jassa marmorata (Ar)	S						NM. Eastern North Atlantic origin (Mead et al., 2011). Observed in Argentina and Uruguay since 1968 (Alonso de Pina, 2005)
Bugula stolonifera (B)	P						From 38° to 40°S strongly associated to port areas (López Gappa, 2000)
Ascidiella aspersa (Ch)	B	B	B				See text (Tatián et al., 2010)
Ciona intestinalis (Ch)	P	P					TS. More detailed studies are needed for this region (see Caputi et al., 2007). Regional records of *Ciona robusta* belong to *C. intestinalis* (Hoshino and Nishikawa, 1985)
Diplosoma listerianum (Ch)	P		P				FR. Origin unknown
Lissoclinum fragile (Ch)	B						First observed in 2004 (Rico et al., 2012). Origin unknown
Molgula manhattensis (Ch)	P		P				RE. Strongly associated to port areas (Orensanz et al., 2002; Rico et al., 2012)
Cryptogenics							
Bangia fuscopurpurea (R)				P	S		TS. Observed in Argentina since 1969 (Mendoza, 1970). This species might be species complex (Guiry and Guiry, 2012)
Blidingia marginata (Cl)				P			TS. Idem to *B. fuscopurpurea*
Dictyota dichotoma (O)	S		P				TS. This species requires a global taxonomic revision
Ectocarpus siliculosus (O)	P						TS. Wide distribution in NE Atlantic
Ectopleura crocea (Cn)	B			B			See Imazu et al. (2014)
Obelia bidentata (Cn)					B		NM. Found only in port areas (Genzano et al., 2009). Origin unknown.
Amphisbetia operculata (Cn)			S	S	B		NM. Introduced in Australia (Hewitt et al., 2004)
Halecium delicatulum (Cn)						B	NM. Introduced in Australia (Hewitt et al., 2004)
Boccardia polybranchia (An)					S		TS. This species might be a species complex
Syllis gracilis (An)			S				See Orensanz et al. (2002)
Amphibalanus improvisus (Ar)	B						See Orensanz et al. (2002)
Caprella equilibra (Ar)	B						Strongly associated to port areas (López Gappa et al., 2006)
Conopeum reticulum (Ar)			S				Scattered records from 38° to 47°S (López Gappa, 2000)
Cnemidocarpa robinsoni (Ch)	B	B	B			P	TS. Highly similar to *Asterocarpa humilis* reported as introduced in continental Chile (Clarke and Castilla, 2000)
Corella eumyota (Ch)			B				Records in Argentina are scarce and reported for first time in the SWA in 1938 (Ärnbäck-Christie-Linde, 1938)
Total number of exotic species	**14**	**6**	**6**	**0**	**3**	**2**	
Total number of cryptogenic species	**6**	**1**	**6**	**4**	**4**	**2**	

cover (22.7%) compared to the other ports. Bivalves *Mytilus* spp. were the dominant taxon (17.3%). Environmental variables separated the ports in a similar way as the mobile taxa (Fig. 3B). The warm temperate ports of SAE and PM were also grouped by the high air and water temperatures, depth and salinity. The cold temperate ports (U, PD and PQ) were spread along the positive values of the second axis, except for RG which was closer to SAE and PM due to the high tidal amplitude. Rainfall was particularly high in U, and wind speed was highest in PQ.

The average port movement for the 1998–2008 period we analyzed showed significant differences among compared ports (square-root transformed data, $F = 123.4$, $MS_{error} = 8941$, $MS_{effect} = 1{,}103{,}881$, $df_{error} = 60$, $df_{effect} = 5$, $p < 0.05$, Fig. 4), with PM being the more active port with nearly 50% of the total movement, and significantly different from the others (Post-hoc Tukey test $p < 0.05$, Fig. 4). The U port was not significantly different from SAE or PD ($p > 0.05$). Finally, the ports RG and PQ showed the lowest values in port movement (less than 5%, $p < 0.05$, Fig. 4). These results were also accompanied by the average number of ship entries per port, excepting PD, in which the large number of ships showed a strong contrast with its port movement (Fig. 4).

Total taxonomic richness (considering both mobile and sessile taxa) was significantly different among the compared ports (square-root transformed data, $F = 78.9$, $MS_{error} = 0.22$, $MS_{effect} = 17.5$, $df_{error} = 84$, $df_{effect} = 84$, $p < 0.05$, Fig. 5A), showing the highest values for the plates deployed in SAE compared to the other ports (Post-hoc Tukey test $p < 0.05$, Fig. 5A). Also, the taxonomic richness was higher in PD than in PM ($p < 0.05$), but neither of them was found significantly different than U ($p > 0.05$). The ports of PQ and RG showed the lowest taxonomic richness, with no significant differences between them ($p > 0.05$). Finally, although the highest taxonomic richness was in SAE, the port of RG showed the highest percentage of exotic and cryptogenic species in relation to the total number of taxa found at that port (25%) mostly due to the high percentage of cryptogenic species (15.6%, Fig. 5B). In second place was SAE with 21.7% due to the high number of exotic species ($n = 14$), which was the 15.2% of the total number of the species observed (Fig. 5B).

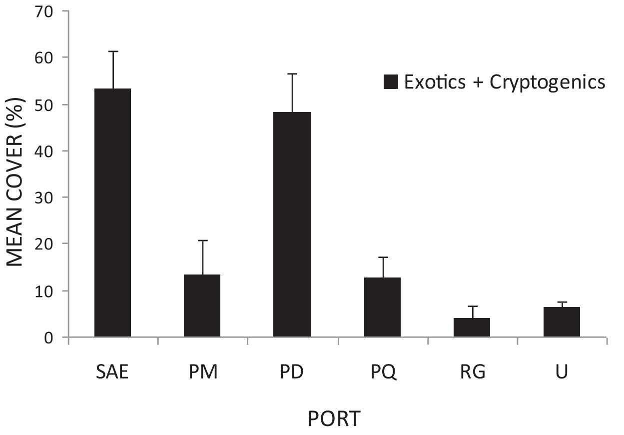

Fig. 2. Mean cover (in percentage, +SE) of exotic and cryptogenic species found on fouling plates at each port. Abbreviations are the same as in Fig. 1.

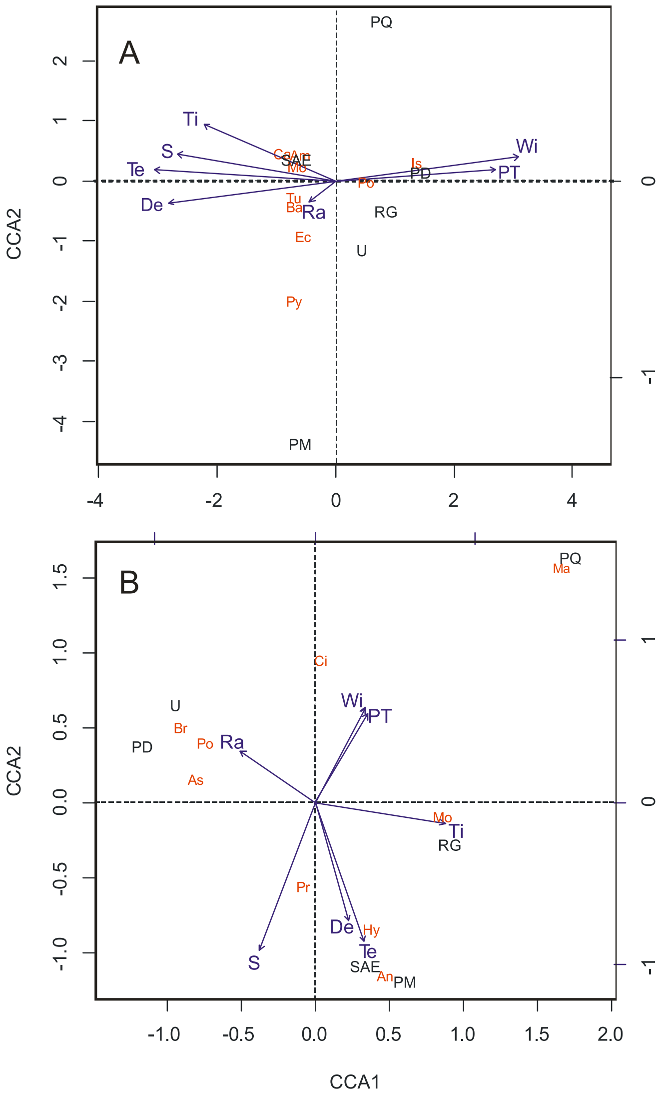

Fig. 3. Canonical correspondence analysis triplot showing the ordination of ports (SAE, PM, PD, PQ, RG and U, see abbreviations in Fig. 1), environmental variables (Te: temperature, Ti: tidal amplitude, Wi: wind speed, S: salinity, Ra: rainfall, De: depth and PT: Port type), mobile taxa (A, Is: isopods, Po: polychaetes, Py: pycnogonids, Ba: brachyurans, Ca: carideans, Am: amphipods, Mo: mollusks, Ec: echinoderms, Tu: turbellarians) and sessile taxa (B, Ma: macroalgae, Ci: cirripedia, Br: bryozoans, Mo: mollusks, Pr: porifera, Po: polychaetes, As: ascidians, An: anthozoans, Hy: hydrozoans).

4. Discussion

4.1. Assessment of marine exotic species and the port's environments

We detected a relatively large number of new records of exotic and cryptogenic species in addition to those reported in the literature for the ports we studied (see Orensanz et al., 2002; Schwindt, 2008). Some of them refer to species that had been previously misidentified as native, and which after reviewing the literature and museum collections, we re-classified them more properly as exotic or cryptogenic species. Our results include the third exotic colonial ascidian reported to have been introduced to Patagonia (*D. listerianum*, Table 1) after the stylelid *Botryllus schlosseri*, collected for the first time in 1962 (Amor, 1964), and *Lissoclinum fragile*, detected for the first time in 2004 (Rico et al., 2012) and which we recorded in SAE. *D. listerianum* and *L. fragile* are currently spread throughout the Western Pacific, South Pacific, and Indian Ocean; the Caribbean, Brazil, and West Africa (Rocha and Kremer, 2005; Carlton and Eldredge, 2009). Although *D. listerianum* is considered native to Europe (e.g. Monniot et al., 2001), its broad global distribution makes it difficult to determine a precise native area (Carlton and Eldredge, 2009) hence the need for DNA data. Ascidians are considered good indicators of anthropogenic transport over long distances because they have short lifespan and lecithotrophic larvae and, consequently, natural long distance dispersal is highly unlikely for these animals (Lambert and Lambert, 1998). Moreover, since the larval stage is so short, the primary mode of anthropogenic transport of ascidians is likely to be hull fouling, which suggests that once introduced into a new region, local dispersal via domestic shipping is highly probable as a fouling species. This is particularly important for the Patagonian region, where a large proportion of the port entries are attributable to domestic shipping (Boltovskoy et al., 2011). We actually expect these tunicate species to disperse by shipping to other ports along the region in the near future, eventually reaching the Uruguayan coast in the North. In support to this we have recently found specimens of *D. listerianum* in PM (March 2012; Schwindt and Tatián, unpubl. data).

Most the ascidians found in PM were exotic species. Of the three exotic species found in this port, *Ascidiella aspersa* is considered as pioneer organism on artificial substrates (Collins et al., 2002; Schwindt et al., 2013). In Argentina, forty years after the introduction of *Ascidiella* (Tatián et al., 2010) studies showed that this species is not only one of the first species settling on fouling plates, but also that it quickly becomes a pest, overgrowing other exotic species like the invasive *C. intestinalis* (Schwindt et al., 2013). Among the eight ascidian species found in SAE, six of them (75%), are exotics or cryptogenics. Although *D. listerianum* is a new invader, this species showed the highest cover among all the ascidians we found growing on plates, and together with other exotic fouling species, were dominant over the native sessile species in this port. These species are well known because they can recruit rapidly and dominate the substrate and resist adverse conditions such as pollution from sewage, land runoff, heavy metals and periods of low salinity. Also, they show a high physiological flexibility that facilitates their success in all kind of ports and aquaculture facilities (Lambert and Lambert, 2003). Thus, the presence of new invader species like *A. aspersa*, *Molgula manhattensis* and *D. listerianum* could change dramatically the composition of the fouling communities in a short period.

The richness of the fouling species is not homogeneous across the ports of Patagonia, as each port was characterized by different

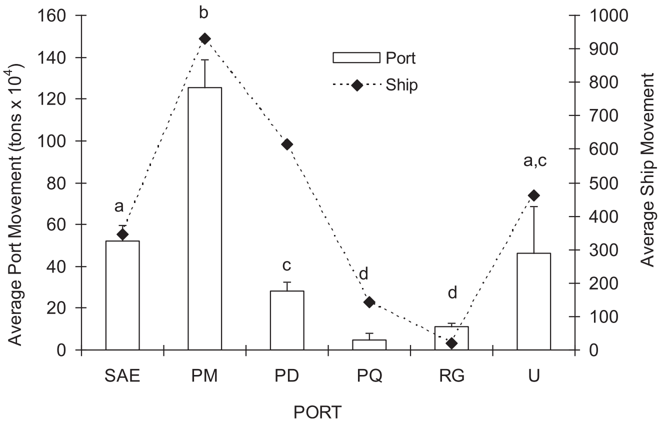

Fig. 4. Average port movement + SD (bars, left *y* axis) between 1998 and 2008 and average number of ship entries (diamonds, right *y* axis) reported for the same period for all the ports except for PD and PQ (1998–2005) and RG (2000–2005). Abbreviations of the ports are the same as in Fig. 1. Same letters indicate not statistically significant differences.

taxonomic groups. It is noteworthy that the port of SAE showed not only the highest number of sessile and mobile taxa (dominated by hydroids and amphipods respectively), but it also showed the highest number of exotic and cryptogenic species among the ports that we studied. Although the maritime activity of SAE (i.e. number of ship entries and port movement) was not the highest among the ports compared, it is still a major regional node for exporting goods, comparable to PD and U (Boltovskoy et al., 2011). In fact, these are the only ports almost exclusively receiving vessels laden with ballast water, and therefore the propagule pressure is expected to be higher there than in the other ports. Concordantly to this, we have found that SAE and PD ports have the highest number of exotic and cryptogenic species (20 and 12 respectively) among all ports studied, suggesting that a closer surveillance is needed there.

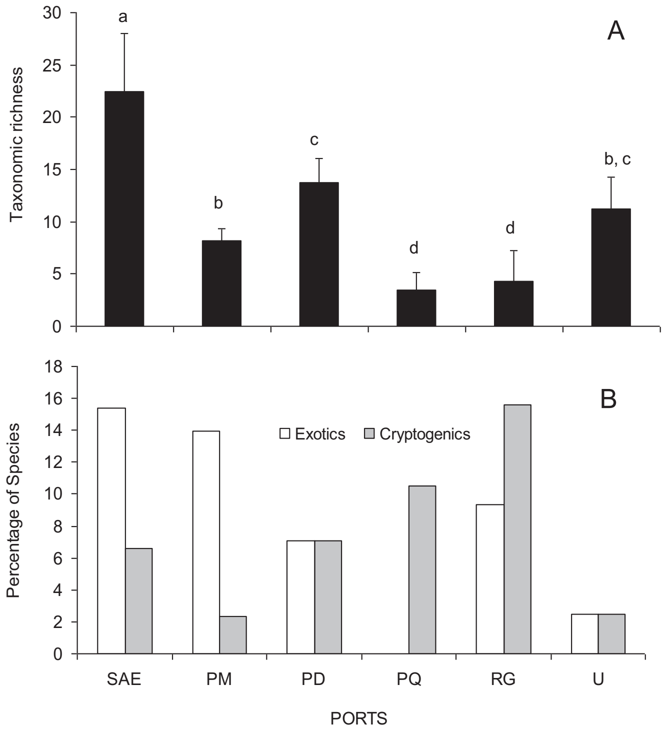

Fig. 5. Average taxonomic richness (A) and percentage of exotic and cryptogenic species (B) at each port. Same letters mean not statistically significant differences. Abbreviations are the same as in Fig. 1.

Although port movement was similar in U and SAE, which are both export-oriented ports (Boltovskoy et al., 2011), the number of exotic and cryptogenic species found in U was among the lowest recorded ($n = 4$). Only PQ had the same low number of exotic and cryptogenic species, being this port one of the least active in the region. On the other hand, we found that RG doubles the number of exotic and cryptogenic species of PQ port, which is very similar to RG in terms of regional shipping activity (scarce in both) and low taxonomic richness. The proportion of exotic and cryptogenic species in relation to the native biodiversity we found in RG is one of the highest among the ports studied. Considering that none of the non native species found in these ports were new arrivals, and that the port movement is relatively low there, it was expected that PQ and RG have a low vulnerability to new introductions. Since the sampling effort and level of expertise were the same in all ports, these unexpected results strongly support the hypothesis about the existence of environmental and biological variables able to modulate the propagule pressure for a given site, especially in the port of U (Boltovskoy et al., 2011).

The port of PM doubles the average number of ship entries of U and almost three times that of SAE. Although taxonomic richness of PM was lower than in SAE and comparable to U, the percentage of exotic and cryptogenic species found in this port was one of the highest within the ports studied. This is a striking finding since PM is not one the ports receiving important discharges of ballast water (Boltovskoy et al., 2011). This port is situated within a natural bay with signs of contamination by heavy metals and/or eutrophication (Gil et al., 1999; Diaz et al., 2002) It was through this port that the macroalga *Undaria pinnatifida* was introduced and nowadays is one of the most aggressive marine invasive species in Southern South America, affecting the abundance and richness of native organisms (Casas et al., 2004; Irigoyen et al., 2011). Therefore, the results of this study suggest that more data about the shipping activity are needed to better understand bioinvasions and the vulnerability of this port to new introductions.

4.2. The South American context of marine invasive species

While scientists have surveyed ports and coastal areas worldwide, cross-regional comparisons are still difficult to perform due to the implementation of different methods used and the often contrasting environmental conditions. Nevertheless, more efforts should be emphatically directed to coordinate international research teams to address cross-regional comparisons. In South America, other rapid assessment surveys of marine exotic species were performed in specific sites of Brazil (Ignacio et al., 2010; Marques et al., 2013), but exhaustive examinations of marine exotic and cryptogenic species were compiled only in Argentina, Uruguay (41 and 50 respectively, Orensanz et al., 2002; updated in Schwindt, 2008), Chile (51 and 47 respectively, Castilla and Neill, 2009) and Venezuela (22 and 67 respectively, Pérez et al., 2007). National reports and/or specific case-study publications were completed in Colombia (Gracia et al., 2011) and Brazil (e.g. Souza and Silva, 2004; Ferreira et al., 2009; Lopes, 2009; Farrapeira et al., 2011). The number of marine and brackish water exotic species reported in countries of South America is low if they are compared with other countries as Italy (89, Occhipinti-Ambrogi et al., 2011), South Africa (86, Mead et al., 2011), Britain (90, Minchin et al., 2013), Israel (296, Galil, 2007) and Germany (85, Gollasch and Nehring, 2006), among others. The scarce reports and compilations plus the intense maritime traffic of some South American countries (see below) calls the attention to the need of increase the surveys and monitoring programs in and around ports and ports of South America. A step forward to achieve an international cross-regional collaboration is given by the Convention for the Control and Management of Ship's Ballast Water and Sediments, signed in 2004 by 74 States. However, the only country in South America that ratified the Convention was Brazil (IMO, 2014).

Every protocol to survey marine invasive species has weaknesses and strengths (reviewed in Campbell et al., 2007) and they are strongly dependent of the budget and the availability of taxonomists. In spite of this, it is clear that the profuse maritime commercial activity linking South American countries must be complemented with effective sampling protocols to detect invasive species (Campbell et al., 2007; Bishop and Hutchings, 2011). To achieve this goal, it is critical to identify the major potential routes of introduction. For instance, the United States of America and China represent together the major import/export partners of South American countries (nearly 50% of the maritime relationships for Venezuela; The World Factbook, 2013–14). However, the countries facing the Pacific coast of South America, have more commercial relationships with USA, China and other countries of the Pacific like Japan and South Korea (ranging between 41 and 52% of exports and imports) than among them, being the intraregional commerce of imports and exports lower than 8% (The World Factbook, 2013–14). On the other hand, along the Atlantic coast of South America, Brazil, Argentina and Uruguay have more commercial interchange among them than with the countries situated on the Pacific coast. For these last group, Brazil is the major import/export partner (ranging between 16 and 27%, The World Factbook, 2013–14) and its commercial activity is so important that in 2011 the 19.1% of the total containership occurred in Latin America and the Caribbean region was operated through Brazilian ports (Sánchez, 2012). Moreover, Santos harbor (23°58′S, 46°17′W) is one of the 20 most important harbors of the world with maritime activity, only compared to Panama (Kaluza et al., 2010). Thus, Brazil appears to be a major stepping stone in the region for marine invasions problem, that would likely contribute with their own biota (native and non native) to the rest of its commercial partners in South America.

5. Conclusions

Scientists' ability to predict the vulnerability of a given habitat or community to invasions is largely hampered by the multiple variables involved (Byers, 2002; Johnston et al., 2009; Olyarnik et al., 2009). However, it is by performing the analysis of global patterns that scientists will be able to provide the best support to managers and decision-makers. The expedient and extensive rapid assessment survey we present in this study, complemented by quantitative sampling of fouling plates and an extensive compilation of significant environmental variables, provide the first large-scale information baseline of bioinvasion analysis along the Southern South American ports. We expect that these results will assist managers to design more optimal monitoring programs and will speed up the development of appropriate legislation for preventing further bioinvasions.

Author contribution

ES conceived the ideas; ES, AB, GL lead the field work; ES, MPR, MED, MMM, VS, MCS performed lab work; ES, JLG, MPR, MT, JMO, GA, MED, BD, GG, CL, MLP identified the taxa; ES, JLG analyzed the data; ES, JLG and AB led the writing. All authors have approved the final article.

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Appendix I. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.marenvres.2014.06.006.

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Appendix A

Table A.1. Taxa identified at each Patagonian port (SAE: San Antonio Este, PM: Puerto Madryn, PD: Puerto Deseado, PQ: Punta Quilla, RG: Río Gallegos, U: Ushuaia) with the name of the taxonomic specialist responsible for its identification. Taxa are separated by Phylum and between brackets are the credits for the taxonomic identifications. P: taxa found only in fouling plates but not in the qualitative sampling, S: taxa found only during the qualitative sampling but not on the plates, B: taxa found on plates and during the qualitative sampling. Name of the Institutions abbreviated: UNLP: Universidad Nacional de La Plata (Argentina), UNPSJB: Universidad Nacional de la Patagonia San Juan Bosco (Argentina), UNMDP: Universidad Nacional de Mar del Plata (Argentina), UBA: Universidad de Buenos Aires (Argentina), DINARA: Dirección Nacional de Recursos Acuáticos (Uruguay), CENPAT: Centro Nacional Patagónico (Argentina), ECOSUR: El Colegio de la Frontera Sur (México).

Major taxonomic group	**Ports**					
	SAE	**PM**	**PD**	**PQ**	**RG**	**U**
Phylum Rhodophyta (ML Piriz)						
Acanthococcus antarcticus J.D. Hooker & Harvey			S	S		
Acrochaetium sp.	P					
Anotrichium furcellatum (J. Agardh) Baldock	P					
Antithamnion sp.	S		S			
Aphanocladia robusta Pujals	S					
Ballia callitricha (C. Agardh) Kützing			S	B		
Bangia fuscopurpurea (Dillwyn) Lyngbye				P	S	
Callithamnion gaudichaudii C. Agardh			P	S		
Callophyllis sp.				S		
Ceramium tenuicorne (Kützing) Waern	B			S		
Ceramium virgatum Roth	P		S		S	
Chondria macrocarpa Harvey				S		
Cladodonta lyallii (J.D. Hooker & Harvey) Skottsberg						P
Corallinaceae		S				
Falklandiella harveyi (J.D. Hooker) Kylin				S		
Delesseria macloviana Skottsberg						B
Delesseriaceae						B
Erythrotrichia carnea (Dillwyn) J. Agardh				P		
Griffithsia antarctica J.D. Hooker & Harvey						S
Heterosiphonia merenia Falkenberg			S	S		
Hymenena falklandica Kylin						S
Hymenena laciniata (J.D. Hooker & Harvey) Kylin			S			P
Hymenena sp.				S		
Lomentaria clavellosa (Lightfoot ex Turner) Gaillon	S	S				
Lophurella hookeriana (J. Agardh) Falkenberg				S		
Medeiothamnion flaccidum (J.D. Hooker & Harvey) Brauner			B			
Neosiphonia harveyi (Bailey) M.-S.Kim, H.-G.Choi, Guiry & G.W.Saunders	S	S				
Phycodrys quercifolia (Bory de Saint-Vincent) Skottsberg			S			S
Picconiella pectinata (J.D. Hooker & Harvey) De Toni fil.						P
Picconiella plumosa (Kylin) J. De Toni						S
Plocamium secundatum (Kützing) Kützing				S		
Polysiphonia abscissa J.D. Hooker & Harvey	S					

Polysiphonia spp.	P					
Pseudolaingia larsenii (Skottsberg) Levring						P
Pterothamnion plumula (J. Ellis) Nägeli				S		
Pyropia columbina (Montagne) W.A.Nelson				B	S	
Rhabdoniaceae	B					
Rhodymenia corallina (Bory de Saint-Vincent) Greville					S	
Rhodymeniaceae						S
Streblocladia camptoclada (Montagne) Falkenberg	S					
Streblocladia corymbifera (C. Agardh) Kylin 1938	S					
Phylum Chlorophyta (ML Piriz)						
Blidingia marginata (J. Agardh) P. Dangeard				P		
Chaetomorpha aerea (Dillwyn) Kützing			S			
Cladophora falklandica (J.D. Hooker & Harvey) J.D. Hooker & Harvey			P			
Derbesia furcata Ricker						P
Derbesia sp.						S
Prasiola stipitata Suhr ex Jessen					S	
Rhizoclonium sp.			P			
Rosenvingiella polyrhiza (Rosenvinge) Silva					S	
Ulothrix flacca (Dillwyn) Thuret				P		
Ulothrix subflaccida Wille			S			
Ulva intestinalis Linnaeus			S			
Ulva lactuca Linnaeus			S		S	
Phylum Ochrophyta (ML Piriz)						
Cladostephus spongiosus (Hudson) C. Agardh				S		
Cutleria multifida (Turner) Greville	S					
Dictyota dichotoma (Hudson) Lamouroux	B		P			
Ectocarpus siliculosus (Dillwyn) Lyngbye 1819	P					
Macrocystis pyrifera (Linnaeus) C. Agardh						B
Microzonia velutina (Harvey) J. Agardh				S		
Stypocaulon funiculare (Montagne) Kützing				S		
Undaria pinnatifida (Harvey) Suringar		S				
Phylum Porifera (J López Gappa)						
Amphilectus sp.						B
Amphimedon sp.	P					
Cliona sp.	B	S				
Halichondria sp.		S				
Haliclona sp.	P		B	S		B
Mycale sp.						S
Spongia sp.		B				
Sycon sp.	B					
Phylum Cnidaria (Actiniaria: E Schwindt and MP Raffo, Hydrozoa: G Genzano and MP Raffo)						
Corynactis sp.	B	S				
Anthothoe chilensis (Lesson, 1830)	P	B				
Metridium senile lobatum (Carlgren, 1899)		B				
Antholoba achates (Drayton in Dana, 1846)		B	B			
Ectopleura crocea (Agassiz, 1862)	B			B		
Obelia geniculata (Linnaeus, 1758)		S		S		
Obelia bidentata Clark, 1875					B	
Amphisbetia operculata (Linnaeus, 1758)			S	S	B	
Symplectoscyphus milneanus (d'Orbigny, 1846)				B		

Sertularella polyzonias (Linnaeus, 1758)					S	B
Nemertesia sp.					B	
Lafoea dumosa (Fleming, 1820)						B
Halecium delicatulum Coughtrey, 1876						B
Eudendrium ramosum (Linnaeus, 1758)						B
Phylum Platyhelminthes (F Brusa, UNLP)						
Phrikoceros mopsus (Marcus, 1952)	B					
Thysanozoon sp.	P					
SO. Acotylea		B				S
Phylum Nemertea	S	S				S
Phylum Sipuncula	S		S			
Phylum Annelida (S Salazar Vallejo (ECOSUR), ME Diez, JM Orensanz)						
F. Chaetopteridae						P
F. Chrysopetalidae	P					
F. Cirratulidae	P	S	B		S	B
F. Eunicidae	P	B				
Eunice cf. *argentinensis*		S	S			
Marphysa cf. *aenea*			S			
F. Flabelligeridae	S					
Pherusa sp.	S					
Pherusa gymnopapillata Hartmann-Schröder, 1965			P			
F. Lumbrineridae	B		P		P	S
F. Nereididae		S			P	B
Perinereis sp.			S			
Platynereis australis (Schmarda, 1861)				P		S
Phylo sp.			S			
Arabella acuta (Kinberg, 1865)			P			
Halosydna patagonica Kinberg, 1857			S	S	B	
Halosydnella australis (Kinberg, 1855)	S					
Harmothoe sp.	S					
Harmothoe exanthema (Grube, 1858)		S	P			
Harmothoe madrynensis Barnich, Orensanz & Fiege 2012	S	S	B			
Harmothoe magellanica (McIntosh, 1885)				S		
Hermadion magalhaensis Kinberg, 1855						S
Lepidasthenia cf. *esbelta*	S					
Neopolynoe antarctica (Kinberg, 1858)						S
F. Phyllodocidae			S			
Eumida sp.			P		P	
Eteone sp.	S					
F. Sabellidae	B		B			
Parasabella sp.	B		S			S
Notaulax sp.			S			
F. Serpulidae	P		P			
Hydroides plateni (Kinberg, 1867)		B				
SF. Spirorbinae		S	P		P	B
Boccardia polybranchia (Haswell, 1885)					S	
F. Syllidae	B	S	B		B	
Syllis sp.			S			
Syllis gracilis Grube, 1840			S			
F. Terebellidae	B	B	B		B	B
Thelepus sp.			S	S		S

Phylum Arthropoda (Caridea: E Gómez Simes, UNPSJB, Brachyura: MP Raffo, Cirripedia: E Schwindt, Pycnogonida: R Elias, UNMdP, Amphipoda: G Alonso, Isopoda: B. Doti)						
Betaeus lilianae Boschi, 1966	B					
Nauticaris magellanica (A. Milne Edwards, 1891)			S			S
Rochinia gracilipes A. Milne Edwards, 1875	B					
Pelia rotunda A. Milne Edwards, 1875	S					
Libinia spinosa H. Milne Edwards, 1834	S					
Halicarcinus planatus (Fabricius, 1775)	B	S	B	S	B	S
Pilumnus reticulatus (Stimpson, 1860)	B	S				
Pachycheles chubutensis Boschi, 1963	B	B				
Eurypodius sp.						S
Austromegabalanus psittacus (Molina, 1782)	S		S			S
Balanus glandula Darwin, 1854	S	B	S			
Amphibalanus improvisus (Darwin, 1854)	B					
Balanus laevis Brugière, 1789						B
Elminius kingii Gray, 1831						
Anoplodactylus petiolatus (Krøyer, 1844)	B					
Achelia assimilis (Haswell, 1885)			S			S
Pycnogonum spp.			S			
Monocorophium insidiosum (Crawford, 1937)	S				S	S
Monocorophium acherusicum (Costa, 1853)	B		S		S	
Corophium s.l.						S
Crassicorophium bonnellii (Milne Edwards, 1830)			S			S
Caprella equilibra Say, 1818	B					
Caprella sp. 1	B					
Caprella sp. 2	P					
Stenothoe sp.	B					
Probolisca sp.	S					
Dulichiella sp.	S					
Leucothoe sp.	S					
cf. *Polycheria* sp.	S					
Jassa marmorata Holmes, 1905	S					
Jassa sp.	P					
Erikus sp.	B		P			
Ampithoe sp.	P					
Austroregia huxleyana (Bate, 1862)		S				
Ultimachelium barnardi (Alonso de Pina,1993)			S			
Liljeborgia octodentata Schellenberg, 1931			S			
Paramoera sp.				S		P
Atyloella dentata K.H. Barnard, 1932						S
cf. *Lembos* sp.	B					
Cymodoce cf. *bentonica*		S				
Exosphaeroma lanceolatum (White, 1843)			B			S
Exosphaeroma studeri Vanhöffen, 1914			B	P	S	
Ischyromene eatoni (Miers, 1875)			S			
Iais pubescens (Dana, 1852)			B			
Phylum Mollusca (Bivalvia: D Zelaya (UBA) and E. Schwindt, Gastropoda: D Zelaya and F Scarabino, DINARA, Polyplacophora: MP Raffo and D Zelaya)						
*Aulacomya atra (*Molina, 1782)		B	S	S	B	B
Brachidontes purpuratus (Lamarck, 1819)				S		

Musculus viator (d'Orbigny, 1846)	B					
Mytilus spp.		S		B	B	B
Hiatella meridionalis (d'Orbigny, 1846)						B
Hiatella sp.						S
Entodesma patagonicum (d'Orbigny, 1846)	S					
Ostrea puelchana d'Orbigny, 1842	B					
Ostrea stentina Payraudeau, 1826	S					
Sphenia hatcheri Pilsbry, 1899					B	
Bostrycapulus odites Collin, 2005	B					
Crepipatella cf. *dilatata*			S			
Crepipatella dilatata (Lamarck, 1822)		B				
Crepidula sp.	B					
Fissurella oriens Sowerby, 1835						S
Fissurella picta (Gmelin, 1791)						S
Fissurella radiosa radiosa Lesson, 1831		S				
Fissurellidea patagonica (Strebel, 1907)			S			
Margarella violacea (King & Broderip, 1832)			S			
Tegula patagonica (d'Orbigny, 1835)		B				
Costoanachis sertulariarum (d'Orbigny, 1839)	P					
Parvanachis paessleri (Strebel, 1905)	P					
Lachesis (?) euthrioides Melvill & Standen, 1898			P			
Pareuthria plumbea (Philippi, 1844)			S			S
Photinastoma taeniata (Wood, 1828)			B			
Trophon geversianus (Pallas, 1774)				S	B	S
Xymenopsis muriciformis (King, 1832)						S
Acteon biplicatus (Strebel, 1908)			S	P		
Odostomia sp.						S
Spurilla sp.	P					
Berghia rissodominguezi Muniain & Ortea, 1999		S				
Callochiton puniceus (Couthouy MS, Gould, 1846)						P
Chaetopleura isabellei (d'Orbigny, 1841)	S					
Plaxiphora aurata (Spalowsky, 1795)						S
Phylum Entoprocta (J López Gappa)						
Pedicellina sp.						B
Phylum Bryozoa (J López Gappa)						
Alcyonidium australe d'Hondt & Moyano, 1979					S	B
Alcyonidium sp.					S	
Beania costata (Busk, 1876)			S			
Beania magellanica (Busk, 1852)			B			B
Bugula stolonifera Ryland, 1960	P					
Cellaria malvinensis (Busk, 1852)			B			
Celleporella hyalina s.l.			S			
Chaperiopsis galeata (Busk, 1854).						B
Conopeum reticulum (Linnaeus, 1767)			S			
Electra sp.					S	S
Fenestrulina sp.	S	S	B			
Membranipora isabelleana (d´Orbigny, 1847)		S				
Menipea patagonica Busk, 1852		S				B
Tricellaria aculeata (d´Orbigny, 1847)			B			
Disporella sp.						S
Metroperiella galeata (Busk, 1854)						P
Smittoidea sp.	S					
Phylum Echinodermata (Asteroidea: T Rubilar,						

Ophiuroidea: M Brögger, UBA, Echinoidea: MP Raffo)						
Allostichaster capensis (Perrier, 1875)			S			
Anasterias antarctica (Lütken, 1857)			S			
Diplodontias singularis (Müller & Troschel, 1843)						S
Ophiactis asperula (Philippi, 1858)						B
Amphipholis squamata (Delle Chiaje, 1828)	P					
Ophioplocus januarii (Lütken, 1856)	P					
Arbacia dufresnii (Blainville, 1825)		B				
Pseudechinus magellanicus (Philippi, 1857)						B
PHYLUM CHORDATA (Ascidiacea: M Tatián, C Lagger, Osteichtheys: A Gosztonyi, CENPAT)						
Aplidium meridianum (Sluiter, 1906)						S
Aplidium variabile (Herdman, 1886)			S			B
Ascidiella aspersa (Müller, 1776)	B	B	B			
Cnemidocarpa robinsoni Hartmeyer, 1916	B	B	B			P
Polyzoa opuntia Lesson, 1830			B			P
Styela paessleri (Michaelsen, 1898)			S			P
Ciona intestinalis (Linnaeus, 1767)	P	P				
Corella eumyota Traustedt, 1882			B			
Diplosoma listerianum (Milne-Edwards, 1841)	P		P			
Lissoclinum fragile (Van Name, 1902)	B					
Eudistoma platense Van Name, 1945	P					
Molgula manhattensis (De Kay, 1843)	P		P			
Paramolgula gregaria (Lesson, 1830)	S		B	B	B	B
Pyura legumen (Lesson, 1830)						S
Sycozoa gaimardi (Herdman, 1886)						P
Sycozoa sigillinoides Lesson, 1830			B			
Patagonotothen squamiceps (Peters, 1877)						S
Patagonotothen sima (Richardson, 1845)						S
Patagonotothen cornucola (Richardson, 1844)						S
Total number of taxa observed	**92**	**43**	**85**	**38**	**32**	**80**

APPENDIX B.

Table B.1. List of variables studied at each port and the source of the information used.

Main Variable	Specific Variable	Period recorded and Source
Sea Surface Water Temperature (°C)	Annual mean (WTAM), maximum mean (WTMaxM), minimum mean (WTMinM), maximum at the hottest time of the summer season (WTMaxHS), mean during summer season (WTMS), minimum at the coldest time of the winter season (WTMinCW), mean during winter season (WTMW)	Servicio de Hidrografía Naval, Argentina (historical data from permanent oceanographic stations at the ports). For the port of San Antonio Este and Punta Quilla data were obtained from AVHRR Pathfinder, NOAA-NASA (period 1993-2003)
Air Temperature (°C)	Annual mean (ATAM), annual maximum mean (ATAMaxM), annual minimum mean (ATAMinM), mean of the maximum in summer season (ATMaxMS), mean of the minimum in winter season (ATMinMW)	Servicio Metereológico Nacional 1981, 1986 (period 1961-1980). Data from Puerto Madryn obtained from Laboratorio de Datos CENPAT-CONICET (1982-2002)
Tidal Amplitude (m)	Mean (TAM), maximum in spring tides (TAMaxS), minimum in neap tides (TAMinN), mean with spring tides (TAMS), mean with neap tides (TAMN)	Charts of the Servicio de Hidrografía Naval, Argentina
Wind Speed (km/h)	Annual mean (WSAM)	Published data of the Servicio Metereológico Nacional 1981, 1986 (period 1961-1980). Data from

		Puerto Madryn obtained from Laboratorio de Datos CENPAT-CONICET (1982-2002)
Superficial Salinity	Annual mean (SAM)	Tapella et al. (2002 for Ushuaia), Piola 2007, field surveys were performed in Punta Quilla, Río Gallegos and Puerto Deseado
Rainfall (mm)	Mean monthly (RMM), total Annual (RTA), total in the port's driest 6 months season (RTD), total in the port's wettest 6 months season (RTW)	Published data of the Servicio Metereológico Nacional 1981, 1986 (period 1961-1980). Data from Puerto Madryn obtained from Laboratorio de Datos CENPAT-CONICET (1982-2002)
Port Depth (m)	Mean (De)	Consejo Portuario Argentino (2011)
Environmental impact of the city	This variable was categorized in high, medium and low considering the coastal geography, the oceanographic and fluvial conditions, the ecosystem disturbance, the pollution, and the eutrophication recorded at each port area (EIC)	Esteves (2007)
Port Type	Classification was based following Clarke et al (2004) in natural bay, breakwater port, tidal creek, and estuary (HT)	Hydrographic charts, Consejo Portuario Argentino (2011)

Table B.2. Spearman rank order correlation matrix for the Sea Surface Water Temperature (1: WTAM, 2: WTMaxM, 3: WTMinM, 4: WTMaxHS, 5: WTMS, 6: WTMinCW, 7: WTMW), Air Temperature (8: ATAM, 9: ATAMaxM, 10: ATAMinM, 11: ATMaxMS, 12: ATMinMW), Tidal Amplitude (13: TAM, 14: TAMaxS, 15: TAMinN,16: TAMS, 17: TAMN), Wind Speed (18: WSAM), Superficial Salinity (19: SAM), Rainfall (20: RMM, 21: RTA, 22: RTD, 23: RTW), Depth (24: De), Environmental Impact of the City (25: EIC) and Port Type (26: HT). Abbreviations are the same as in Table 1. Values in italics within the grey cells show the significant results ($p < 0.05$).

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	*0.98*	*0.99*	0.76	*0.98*	*0.96*	*0.97*	*0.99*	*0.97*	*0.97*	*0.93*	0.75	0.09	0	0.47	0.03	-0.17	-0.42	0.68	-0.46	-0.47	-0.38	-0.39	*0.84*	0.49	-0.57
2		*0.95*	0.81	*0.93*	*0.93*	*0.98*	*0.94*	*0.91*	*0.91*	*0.9*	0.66	-0.04	-0.12	0.45	-0.1	-0.29	-0.58	0.7	-0.29	-0.32	-0.21	-0.23	*0.87*	0.63	-0.67
3			0.77	*0.99*	*0.95*	*0.93*	*1*	*0.99*	*0.97*	*0.95*	0.75	0.19	0.11	0.43	0.13	-0.05	-0.3	0.67	-0.58	-0.59	-0.51	-0.51	0.78	0.39	-0.45
4				0.8	0.6	0.68	0.73	0.69	0.61	*0.86*	0.17	-0.11	-0.16	0.26	-0.14	-0.24	-0.59	*0.81*	-0.28	-0.31	-0.2	-0.13	0.59	0.7	-0.43
5					*0.92*	*0.89*	*0.98*	*0.98*	*0.95*	*0.97*	0.69	0.21	0.13	0.48	0.16	-0.02	-0.32	0.73	-0.59	-0.57	-0.51	-0.49	0.71	0.43	-0.4
6						*0.95*	*0.95*	*0.96*	*0.95*	*0.81*	*0.87*	0.26	0.17	0.34	0.19	-0.02	-0.3	0.47	-0.48	-0.52	-0.42	-0.49	0.8	0.32	-0.48
7							*0.94*	*0.92*	*0.93*	*0.83*	0.78	-0.05	-0.13	0.43	-0.11	-0.32	-0.51	0.57	-0.3	-0.33	-0.22	-0.26	*0.93*	0.52	-0.71
8								*0.99*	*0.98*	*0.93*	0.79	0.16	0.08	0.46	0.1	-0.08	-0.28	0.65	-0.58	-0.57	-0.5	-0.5	0.81	0.37	-0.48
9									*0.97*	*0.91*	*0.82*	0.26	0.18	0.4	0.21	0.02	-0.2	0.59	-0.64	-0.65	-0.58	-0.59	0.76	0.29	-0.39
10										*0.9*	*0.84*	0.17	0.08	0.57	0.11	-0.09	-0.26	0.63	-0.54	-0.51	-0.46	-0.47	0.78	0.35	-0.49
11											0.53	0.09	0.02	0.57	0.04	-0.11	-0.39	*0.86*	-0.52	-0.47	-0.43	-0.37	0.66	0.54	-0.41
12												0.33	0.26	0.28	0.28	-0.08	0.07	0.11	-0.54	-0.56	-0.51	-0.61	0.7	-0.09	-0.34
13													*1*	-0.26	*1*	*0.96*	0.63	-0.22	-0.7	-0.71	-0.77	-0.81	-0.32	-0.59	0.7
14														-0.31	*1*	*0.98*	0.67	-0.27	-0.67	-0.68	-0.75	-0.78	-0.4	-0.64	0.76
15															-0.29	-0.39	-0.37	0.74	-0.01	0.18	0.08	0.16	0.33	0.5	-0.45
16																*0.97*	0.66	-0.25	-0.69	-0.7	-0.76	-0.8	-0.38	-0.63	0.75
17																	0.75	-0.33	-0.63	-0.64	-0.72	-0.73	-0.55	-0.71	*0.88*
18																		-0.57	-0.56	-0.53	-0.63	-0.63	-0.54	*-0.97*	0.81
19																			-0.18	-0.07	-0.08	0.04	0.43	0.75	-0.43
20																				*0.97*	*0.99*	*0.96*	-0.12	0.42	-0.39

21	*0.98*	*0.98*	-0.18	0.43	-0.36
22		*0.98*	-0.03	0.51	-0.48
23			-0.09	0.55	-0.44
24				0.52	*-0.85*
25					-0.75

Table B.3. Spearman rank order correlation matrix reduced for the environmental variables of the ports being Te: temperature, Ti: tidal amplitude, Wi: wind speed, S: salinity, Ra: rainfall, De: depth and PT: port type. Significant results are shown within the grey cells ($p < 0.05$).

Parameters	**Ti**	**Wi**	**S**	**Ra**	**De**	**PT**
Te	0.09	-0.42	0.68	-0.46	0.84	-0.57
Ti		0.63	-0.22	-0.7	-0.32	0.7
Wi			-0.57	-0.56	-0.54	0.81
S				-0.18	0.43	-0.43
Ra					-0.12	-0.39
De						-0.85

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