Aquatic invasion biology research in South America: Geographic patterns, advances and perspectives

Article *in* Aquatic Ecosystem Health and Management · November 2017

DOI: 10.1080/14634988.2017.1404413

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Instituto de Biologia de Organismos Marinos (IBIOMAR-CONICET)
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To cite this article: Evangelina Schwindt & Alejandro Bortolus (2017) Aquatic invasion biology research in South America: Geographic patterns, advances and perspectives, Aquatic Ecosystem Health & Management, 20:4, 322-333, DOI: 10.1080/14634988.2017.1404413

To link to this article: https://doi.org/10.1080/14634988.2017.1404413

Accepted author version posted online: 13 Nov 2017.
Published online: 13 Nov 2017.

AQUATIC ECOSYSTEM
HEALTH & MANAGEMENT

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Aquatic invasion biology research in South America: Geographic patterns, advances and perspectives

Evangelina Schwindt*[,1,2] and Alejandro Bortolus[1,3]

[1]*Grupo de Ecología en Ambientes Costeros (GEAC)*

[2]*Instituto de Biología de Organismos Marinos (IBIOMAR), CONICET, Blvd. Brown 2915, Puerto Madryn (U9120ACD), Chubut, Argentina*

[3]*Instituto Patagónico para el Estudio de los Ecosistemas Continentales (IPEEC), CONICET, Blvd. Brown 2915, Puerto Madryn (U9120ACD), Chubut, Argentin*

**Corresponding author: schwindt@cenpat-conicet.gob.ar* or *schwindtcnp@gmail.com*

In this work, we describe and discuss the current status, trends, and gaps for aquatic invasion research in South America, and we reveal the current state of multinational collaborations on these matters across the continent. First, to measure temporal change in the magnitude of invasion research for South America, we replicated a survey performed in 2001 for marine exotic species, using identical methods used back then to search publications in the Aquatic Science and Fisheries Abstracts database. Second, to compare the South America invasion research effort, in terms of the production of scientific literature on aquatic invasion biology, across time (years), countries, aquatic (freshwater, estuarine, and marine) environments, themes, and taxonomic groups, we performed a more comprehensive search of publications using multiple databases (Scielo, ASFA, Scopus and Google Scholar). This exhaustive survey included articles in international, regional and local peer reviewed journals on aquatic (freshwater, marine and estuarine) exotic species of SA that were published between 2004 and 2014 in the three dominant languages of South America. We found that the research effort for marine exotic species research in South America increased 9-fold between the two time periods (1997–2001 vs. 2002–2014), with most (90%) of recent research occurring in the Atlantic (vs. Pacific) coast. This disparity in research effort between coasts is consistently evident for individual environments (including freshwater, estuarine, and marine waters) and countries. While the focus of publications is unevenly distributed among research themes and taxa, the paucity of comparative analyses among countries is especially striking. Despite the general increment in research effort within the discipline, we consider there is an urgent need for more solid and concerted multinational efforts to address (financially, scientifically and socially) the conspicuous gaps in aquatic invasion research. Failing to make these efforts is probably the major threat hampering the development of successful long term programs and strategies directed to prevent, manage and/or control the introduction of exotic species and their many impacts in the continent.

Keywords: international cooperation, exotic species, disciplinary bias, research effort

The authors contributed equally to the article.

Aquatic Ecosystem Health & Management, 20(4):322–333, 2017. Copyright © 2017 AEHMS. ISSN: 1463-4988 print / 1539-4077 online
DOI: 10.1080/14634988.2017.1404413

Introduction

Invasion biology is currently at the top of its popularity worldwide since the classic book by Elton (1958) provided the foundational grounds for the entire discipline. During the past few decades, we have witnessed an explosive growth in the number of expert meetings, articles, reports and books on this topic, being covered in the most highly cited journals in a variety of disciplines (Richardson and Ricciardi, 2013). Nevertheless, the development of this young discipline, or the efforts directed to develop it, are unevenly distributed among regions worldwide. For instance, a simple data comparison between developed and developing countries is often a true challenge due to the unequal amount and quality of information available (Nuñez and Pauchard, 2010; Frehse et al., 2016). Pyšek et al. (2008) reported a strong geographical bias, with entire continents understudied, hampering our understanding of biological invasions as a global problem/threat. Within this context, scientists worldwide have repeatedly called for an international cooperation in order to achieve a more geographically balanced picture of biological invasions at the global scale (Speziale et al., 2012; Fonseca et al., 2013).

In some countries of South America (SA), the scientific community has struggled over the last decade to advance an integrated perspective on (a) what invasion research is currently underway and (b) how to best advance research in order to optimize efforts, available resources, and the effectiveness of the results for science and management (e.g., Quiroz et al., 2009; Anderson and Valenzuela, 2014). Yet, little information has been gathered and analyzed in order to synthesize this big picture for the entire continent, and even less advances seem to have been produced in the aquatic realms, compared to the relatively better studied inland terrestrial ecosystems (Pyšek et al., 2008; Frehse et al., 2016). The aim of this work is to address the following questions: (1) Is the research effort on marine exotic species currently increasing in magnitude over time in SA? (2) How is this research effort, in terms of the production of scientific literature on aquatic invasion biology, distributed among SA countries? (3) How is it distributed across time, aquatic (marine, freshwater, estuarine) environments, research themes and taxonomic groups in SA? By answering these questions we expose a realistic current state of multinational collaborations on this matter across SA from which to start advancing more efficiently.

Methods

To investigate whether the research on marine exotic species in SA is currently increasing in magnitude over time, we replicated the survey performed in 2001 by Orensanz et al. (2002). That survey was performed using the Aquatic Science and Fisheries Abstracts (ASFA), combining the terms "introduced species" AND "marine" for the period 1997–2001. Only works documenting geographic-specific references of non-indigenous species were retained as part of the sample. In order to maximize the validity of our comparison we used the same database and the same keywords to assembly the new search for the period 2002–2014. We compared the annual publication rate between the two time periods and also between Atlantic and Pacific coasts of SA.

To study the research effort, in terms of production of scientific literature, on aquatic invasion biology among South American countries we performed an exhaustive survey using different databases (Scielo, ASFA, Google Scholar and Scopus) to search for articles published in international, regional and local journals on aquatic exotic species between 2004 and 2014 for SA combining different terms: "non native" OR "alien" OR "introduced" OR "invasive" OR "exotic" OR "non indigenous," AND each country of SA (e.g. "Argentina," "Brazil" (and "Brasil"), "Uruguay," etc). We performed this search including the names of the environments "marine," "estuarine," "brackish" and "freshwater." Also, we searched in the three dominant languages in SA (i.e. Spanish, English and Portuguese) and also including geographic regions "South Atlantic," "Southwestern Atlantic," "Southern Atlantic," "Southern Hemisphere," and "Southeastern Pacific." We decided to be inclusive and also use "Caribbean," because during a preliminary search, we found a number of studies conducted in countries like Venezuela and Colombia, for instance, using this geographic denomination. We checked all found references individually and made sure that duplicates and references unrelated to SA were deleted. Then, we examined patterns of invasions in aquatic habitats in SA in time and space by sorting publications by date (year), country, environment (marine, freshwater and estuarine),

research theme, major taxonomic group and even by species whenever possible.

Results and discussion

Marine research effort over time

South America is producing more research on biological invasions than ever. Our search showed that the global number of scientific publications per year on marine exotic species increased 2.7 times, from 69 to 184, between the two time periods we considered (i.e., 1997–2001 and 2002–2014). Most of these publications give account of invasions in North America, Europe and Australia on both periods (1997–2001: 84.3%, $N_{total} = 344$; 2002–2014: 77.9%, $N_{total} = 2396$). However, when we focused only on invasion research in SA, we also observed an increase in research effort. In fact, research effort increased considerably faster in SA than globally, showing a 9-fold increase between time periods, from nearly one per year between 1997 and 2001, to nine publications per year between 2002 and 2014. Notwithstanding, our results also showed a strongly unbalanced production of scientific literature between the Atlantic and Pacific coasts of SA, with less than one publication per year for each time period by country along the SE Pacific (1997–2001: 0.6, 2002–2014: 0.8). In contrast, countries from the SW Atlantic produced 0.2 publication per year between 1997 and 2001 (Orensanz et al., 2002) then increasing to eight publications per year between 2002 and 2014.

Although SA is of comparable in area and coastline to North America, Europe and Australia, it lags far behind in research effort, in terms of number of publications (Pyšek et al., 2008), but it is noteworthy how the production of knowledge on marine exotic species after 2002 has increased, in particular along the SW Atlantic. Although there is a variety of factors that may explain the patterns we found, it is likely that the growing amount of researchers, is due to better funding opportunities (Malhado et al., 2014; van Noorden, 2014) as well as to a greater attention on biological invasions as a discipline, regionally and worldwide (Richardson and Ricciardi, 2013). Besides these factors, being cited 127 times between 2002 and 2014 and with a 67% of those citations made by South American researchers, the first exhaustive review on marine exotic species made by Orensanz et al. (2002) seems to have triggered great regional interest on this discipline along the SW Atlantic. In fact, this paper might be considered as a catalyst for the discipline in this region, suggesting a critical role of literature reviews in stimulating research and advancing cross-regional comparisons and global scale predictions (Mead et al., 2011).

Comparing marine, estuarine and freshwater research efforts

For SA, our search of aquatic exotic species publications in the different databases provided 1730 references between 2004 and 2014. After ruling out all duplicates and non-scientific articles, the total number of publications was 429 for the span of 11 years. Most publications focused on marine (46.1%) and freshwater (46.6%) environments compared to estuarine environment (7.2%). Overall, we found an increase in the research effort, in terms of the rate of publication of articles since 2004, when all countries and all environments are considered together (Figure 1). However, when publications were sorted by environment type, the marine and freshwater environments showed similar patterns in the number of publications, while the estuarine records showed a sustained low number of publications over time (Figure 1).

The paucity of research in estuarine habitats is noteworthy, because these habitats are often considered more vulnerable to bioinvasions than other coastal environments. Ports, considered the main gateway for aquatic exotic species, are commonly situated in estuarine sheltered habitats with many stressors that might favor biological invasions (Ruiz et al., 1999; Preisler et al., 2009), including relatively higher levels of chemical pollutants, wider thermal and salinity variations and higher levels of sedimentations than open shore habitats. In addition, the biodiversity of native species in brackish waters is usually low when compared to marine or freshwater, providing opportunities for tolerant exotic species from both ocean and inland waters (Nehring, 2006). Estuaries and sheltered areas are commonly affected by high habitat modifications due to the addition of a variety of artificial substrates, breakwaters, docks, retaining walls, coastal routes, etc., and these modifications combined with a relatively low water circulation compared to open

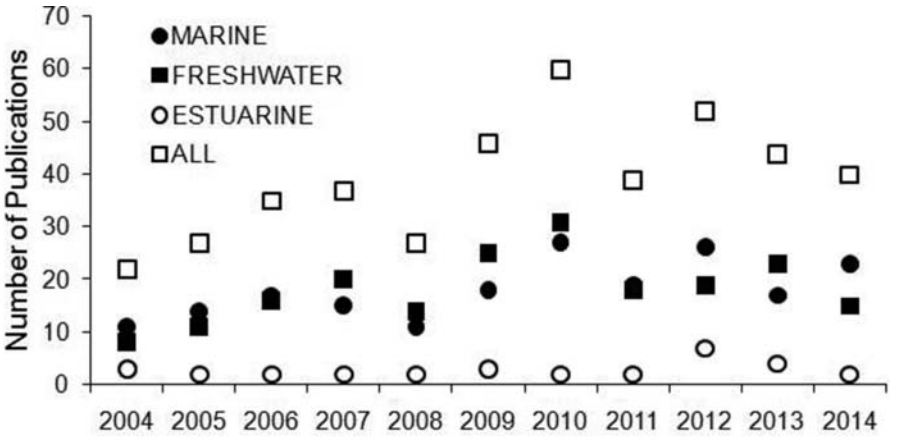

Figure 1. Number of publications on aquatic exotic species between 2004 and 2014 for South America. Data were grouped for all environments together (empty squares) and then separated in marine (black circles), freshwater (black squares) and estuarine (empty circles).

shore areas are likely to favor the settlement of new exotic species (Preisler et al., 2009). In accordance to this, in Orensanz et al. (2002), only the 10% of the aquatic exotic species documented were broadly distributed in Argentina and Uruguay, while most of the exotics were concentrated in a few locations within commercial port areas. Currently, several South American countries (including Argentina, Chile, Brazil and Uruguay) are working in their respective National Strategies of Exotic Invasive Species. However, considering the limited financial and logistic resources and the poor knowledge about the patterns and processes involving exotic species in the entire region (Pyšek et al., 2008; Quiroz et al., 2009; McGeoch et al., 2010; Nuñez and Pauchard, 2010; Early et al., 2016), we strongly recommend to concentrate efforts in studying exotic species introduced to all kind of environments.

Comparing research effort among countries and environments

The analysis of publications by country and environments revealed that Brazil, Argentina and Chile supplied the 82.5% (N = 429) of the papers published for SA between 2004 and 2014. Brazil led the number of publications in marine and freshwater environments (40.9% and 39%, respectively), followed by Argentina (29.7% and 32%, respectively) and Chile (10.6% and 14.5%, respectively, Figure 2). This pattern was different for the estuarine environment, with Argentina leading the number of publications (54.8%), followed by Uruguay (25.8%), Brazil (16.1%) and Venezuela (3.2%). No other country produced publications in estuarine environments (Figure 2). From our analysis, there are two results worthy of urgent attention. First, there are countries with zero or close to zero publications on aquatic exotic species within the 11 years we analyzed. Second, the number of publications that involves collaboration between countries is considerable low (Figure 2).

While the growth of science and scientific activities in SA increased overtime during the last 20 years, both in number of publications and number of researchers (van Noorden, 2014), our results show a strong unbalance among countries, environments and disciplines. Speziale et al. (2012)

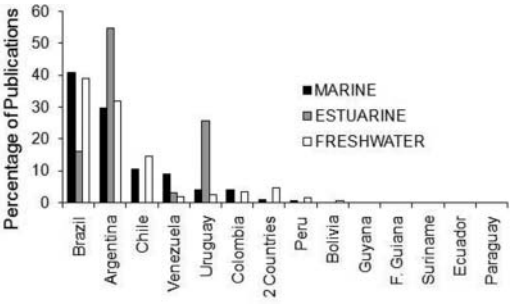

Figure 2. Percentage of publications on aquatic exotic species per country in marine (black bars), estuarine (grey bars) and freshwater environments (white bars) for the period 2002–2014. The label "2 countries" refers to research assigned to pairs of countries but not necessarily composed by the same two countries.

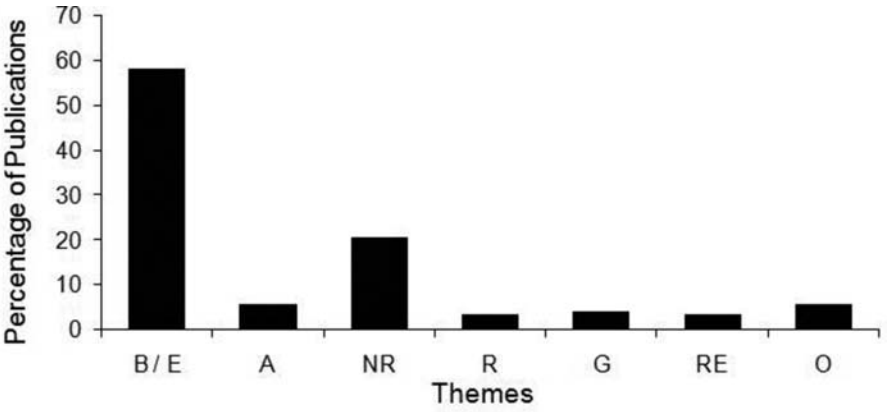

Figure 3. Percentage of publications on aquatic exotic species framed by theme for all South America countries together during the period 2002–2014 (B/E: Biology/Ecology, A: Aquaculture, NR: New Record, R: Reviews, G: Genetic, RE: Range Expansion and O: Other).

found similar results analyzing research effort by country (searching the Web of Science), and considering all exotic species in SA from 1990 to 2010. Moreover, analogous results were also reported by van Noorden (2014) after analyzing the year 2013 and considering the total number of publications in SA in all scientific disciplines. Although the research effort on marine bioinvasions is slowly increasing in countries like Ecuador during recent years (McCann et al., 2015; Keith et al., 2016), the absence of scientific publications on aquatic bioinvasions between 2002 and 2014 (Figure 2) should encourage a more profuse regional discussion. For those countries interconnected by important drainage basins like the Río de La Plata, Amazon and Orinoco, where the introduction and spread rates of exotic species is likely to be faster than in regions without river connections the need for collaboration is urgent. The best example for this necessity is supplied by the Golden Mussel *Limnoperna fortunei* (Dunker, 1857), one of the most aggressive freshwater invasive species in SA, negatively impacting the economies and societies of Argentina, Uruguay, Brazil, Bolivia and Paraguay (Boltovskoy et al., 2006).

Comparing research effort among research themes

Our analysis of the literature revealed that all publications fall in six major themes: biology/ecology, new records, range expansions, genetics, aquaculture, and general reviews. More than a half of these publications corresponds to biology/ecology (58%), followed by the publication of species new records (20.5%) and by aquaculture studies (5.5%, Figure 3). When separated by countries and environments, we found that 80.8% of the publications in marine environments were framed in biology and ecology, and produced by Brazil and Argentina, followed by Chile with a 71. % of all publications framed in aquaculture studies of marine environments. For the freshwater environment, the 89% of the publications in biology/ecology came also from Brazil, Argentina and Chile; while for the estuarine environment, 90.9% of the publications were supplied by Argentina and Uruguay. The 76% of the publications in marine habitats reporting new records of species came from Argentina, Brazil and Venezuela. In a similar vein, the 75.6% of the new species records for freshwater environments was produced in Brazil and Argentina (Figure 4).

As observed above, we found a strong bias in the themes studied by the different countries. In particular, we found a surprisingly low number of general reviews on aquatic exotic species (Figure 3). Reviews are of critical importance when trying to achieve any kind of generalization at the regional and global scales (Mead et al., 2011) and they also help identifying and ordering the best priorities before start defining new horizons and goals to achieve. Indeed, knowing what exotic species are present, what are their abundances and distributions will increase the chances to make responsible management decisions. In marine

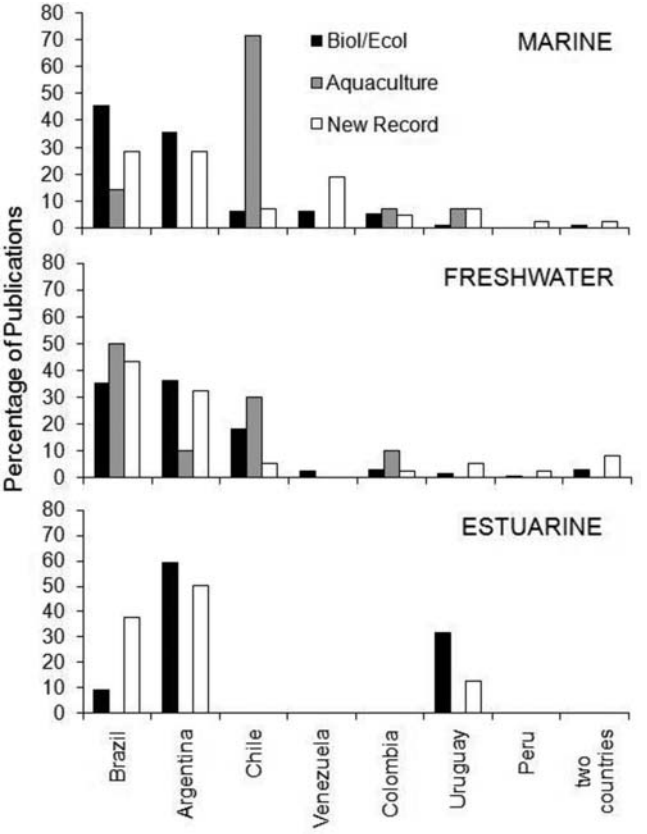

Figure 4. Percentage of publications on aquatic exotic species framed by biology/ecology (black bars), aquaculture (grey bars) and new records (white bars) by country and by environment. The label "two countries" refers to research assigned to pairs of countries but not necessarily composed by the same two countries.

environments, for instance, one of the major concerns is to design effective monitoring programs, as well as early detection and rapid response plans. This kind of work always relies inevitably on biodiversity baseline data usually unknown. The publication of general reviews is likely to make the management and control of exotic species much faster, cheaper and effective than presently. South America is far behind other regions regarding the production of general reviews on aquatic exotic species (Carlton and Eldredge, 2009; Mead et al., 2011; Katsanevakis et al., 2013; Galil et al., 2014). Although, comprehensive lists for marine exotic species were published in Argentina, Uruguay, Chile and Venezuela, they tend to be poorly updated over time (Orensanz et al., 2002; Castilla et al., 2005; Pérez et al., 2007). Brazil and Colombia published national reports of marine exotic species (Lopes, 2009; Gracia et al., 2011), but those lists only provide partial estimations of the real number of exotic species for those countries. Therefore, a critical step forward to better understand the aquatic bioinvasions in SA is to frequently review and update data on exotic species.

Taxonomic focus of publications

When the publications were separated by taxa, pooling all environments and countries together, we found that the most studied exotic taxa are fish and mollusks (26.8% and 25.2% respectively, Figure 5), followed by crustaceans, algae, cnidarians, polychaetes and ascidians (Figure 5). When the habitats were analyzed separately, the variety of exotic taxa studied was larger in the marine environment, while the least richness was in the estuarine environment (Figure 5). Fish and mollusks dominated in most of the studies in freshwater environments (72.7%), while studies in marine

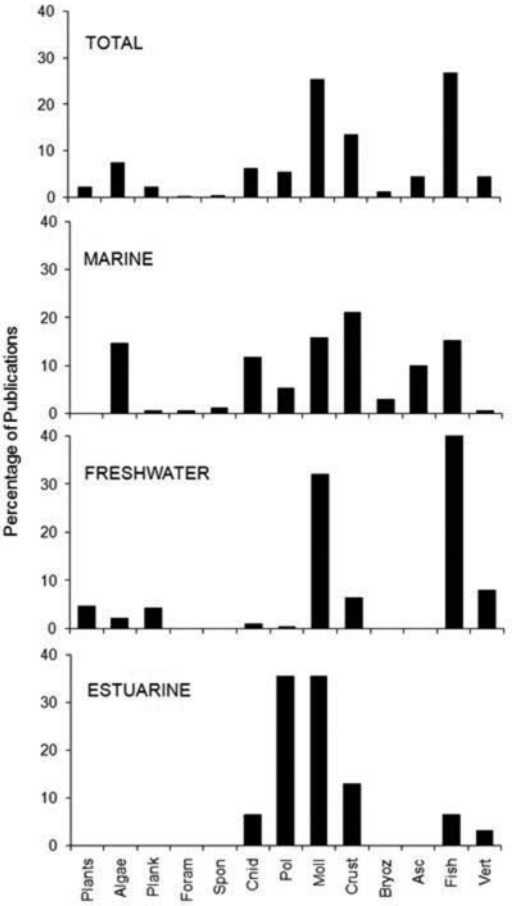

Figure 5. Percentage of publications on aquatic exotic species in South America separated by major exotic taxa considering all environments together (above) and separated by environments (i.e. marine, freshwater and estuarine) between 2002 and 2014. Fish were analyzed separately from other vertebrates due to the relatively large magnitude of its contribution within this group. References: Plank: Plankton, Foram: foraminiferans, Spon: Sponges, Cnid: Cnidarians, Pol: Polychaetes, Moll: Mollusks, Crust: Crustaceans, Bryoz: Bryozoans, Asc: Ascidians and Vert: Vertebrates.

environments were dominated by crustaceans, fish, mollusks and algae (67%). Only two major taxa (polychaetes and mollusks) grouped most of the studies in estuarine environments (70.9%). This variable pattern is not surprising since not all taxonomic groups are equally represented in all scientific studies (Pyšek et al., 2008). In particular, in all aquatic ecosystems the number and diversity of exotic species is usually underestimated (Carlton, 2009).

Taxonomic impediments, biogeographic biases and sampling issues contribute to the over- or underestimation of the real introduced biodiversity and tend to hamper our understanding of the importance of bioinvasions in natural communities as well as contributing to critical misinterpretations of (a) the history and structure of ecosystems (Carlton, 2009), inducing people to perceive "ecological mirages" (Bortolus et al., 2015, 2016) and (b) the relative importance of different taxonomic groups to cumulative invasions. For example, the biogeography of small organisms is poorly resolved compared to larger ones. Many species, because of their relative small body-size, are often understudied and typically considered naturally distributed worldwide (cosmopolitans) and thus native (Carlton, 2009). Therefore, in accordance to our data, it is not surprising to find that fish, mollusk, crustaceans, algae, ascidians are usually well represented in aquatic studies (Orensanz et al., 2002; Hewitt et al., 2004; Arenas et al., 2006; Keller et al., 2011).

For the freshwater habitats on the Atlantic coast, the Golden Mussel was the most studied species (in Argentina, Brazil and Uruguay), especially in Argentina where it represented the 56.6% of the ecological/biological publications produced for this environment. Then, several species of fish of the genus *Cichla* were the subject of different studies in freshwater habitats of Brazil and secondarily, the aquatic plant *Hydrilla verticillata* (L. f.) Royle, the snail *Melanoides tuberculata* (Müller, 1774), the Giant Prawn *Macrobrachium rosenbergii* (De Man, 1879) and the Nile Tilapia *Oreochromis niloticus* (Linnaeus, 1758) were mentioned in at least one ecological/biological study in this country (Figure 6). In contrast, in Argentina, the most studied exotic species, after the golden mussel, was the Rainbow Trout *Oncorhynchus mykiss* (Walbaum, 1792), while other vertebrates such as the American Beaver *Castor canadensis* Kuhl, 1820 received less attention even though it was introduced 45 years before the golden mussel. Species like the American Mink *Neovison vison* (Schreber, 1777) and the clam *Corbicula* spp. were mentioned in at least one ecological/biological study. In contrast, for freshwater environments along the Pacific coast (mostly for Chile), different species of exotic salmonids are the dominant taxa in ecological/biological and aquaculture studies. In addition, several species (for instance the diatom *Didymosphenia geminata* (Lyngbye) Mart. Schmidt, American Beaver and the American Mink) also introduced in Argentina, were studied

Figure 6. Freshwater exotic species most studied in biology/ecology per country in South America between 2004 and 2014. The Golden Mussel *Limnoperna fortunei* is the species with the highest percentage of publications for Argentina, Uruguay and Brazil together (56.6%).

in at least one publication each (Figure 6). In the north of SA, Colombia and Venezuela showed a low production of one or two publications on the ecology/biology of freshwater exotic species, including the snail *M. tuberculata*, the American Bullfrog *Lithobates catesbeianus* Shaw 1802 and the Tilapia *Oreochromis* sp.

Studies on marine habitats comprised the more diverse in terms of taxa of exotic species, although that may be an artifact resulting from a higher sampling effort in those habitats. One of the most studied marine exotic species in Argentina is the Japanese Algae *Undaria pinnatifida* (Harvey) Suringar, 1873, followed by species like the Acorn Barnacle *Balanus glandula* Darwin, 1854 (see Figure 7 for other species). Besides the Japanese Oyster *Magallana (= Crassostrea) gigas* (Thunberg, 1793), none of these species introduced in Argentina are present in Brazil, where the most studied exotic species were the Cup Corals *Tubastraea coccinea* Lesson, 1829 and *Tubastraea tagusensis* Wells, 1982. Several other marine exotic species had at least one publication in Brazil (Figure 7), especially in the northern part of that country. Publications on the ecology/biology of marine exotic species of Chile was considerably low, being the ascidian *Pyura praeputialis* (Heller, 1878) the most studied (Figure 7). Several marine exotic species were of major concern on the Caribbean region of Colombia and Venezuela, the Red Lionfish *Pterois volitans* (Linnaeus, 1758), the algae *Kappaphycus alvarezii* (Doty) Doty ex P.C.Silva, 1996, and the crab *Charybdis (Charybdis) hellerii* (A. Milne-Edwards, 1867), being these last two

Figure 7. Marine exotic species most studied in biology/ecology per country in South America between 2004 and 2014.

species also introduced in Brazil. Within estuarine environments, the Reef-Building Polychaete *Ficopomatus enigmaticus* (Fauvel, 1923) was the species most studied in Argentina, contributing with the 69% of the publications, while for Uruguay, the Rapa Whelk *Rapana venosa* (Valenciennes, 1846) was the most studied between 2004 and 2014.

Conclusions and recommendations

During the past decade, specialists highlighted the need for immediate attention directed to the problem of biological invasions in SA, among other developing regions and countries (Bortolus and Schwindt, 2007, Quiroz et al., 2009; Nuñez and Pauchard, 2010; Speziale et al., 2012; Schwindt et al. 2014; Frehse et al., 2016). The timing to do so is probably better than ever before since specialists worldwide tend to visualize this fast growing discipline becoming more interdisciplinary and with an increasing interest for local studies in understudied regions (Pyšek et al., 2008; Graham, 2016). Our study, focused on aquatic ecosystems of SA, strongly reinforces the urgent need for a more coordinated international collaboration. Indeed, coordinating international discussions and perspectives is something critical to succeed at slowing down the introduction rate of exotic species worldwide (Bortolus and Schwindt, 2010, page 32). The fact that each country has its own socio-political context and priorities often makes it difficult to believe we can actually build global strategies. Nevertheless, far from being a utopia, initiatives like IMO (2004), UNEP (2014), NOBANIS (2015) advocating for the global coordination of environmental management efforts are clear examples to follow.

Can we improve the way South American countries deal with the problem of aquatic biological invasions? We think so. We consider that ports and harbors geographically associated to major commercially active drainage basins, like Río de La Plata, Amazon and Orinoco, should be addressed with a coordinated multinational effort, minimizing costs per country and strengthening across-borders relationships among scientific teams focused on similar problems. The same applies to marine environments where multi-country collaborations in scientific publications within this discipline are extremely low, even though many marine aggressive species, such as the Green Crab *Carcinus maenas* (Linnaeus, 1758) and the Japanese Algae already introduced in Argentina, were predicted to move northward reaching nations like Uruguay and southern Brazil (Hidalgo et al., 2005; Dellatorre et al., 2014). For instance, Argentina, Uruguay and Brazil have a long history of maritime connections and intense shipping traffic since the early colonizers, more than 500 years ago. Nowadays, Brazil is one of the major import/export partners in SA having the harbor of Santos as the one of the most 20 important of the world only comparable to Panamá (Kaluza et al., 2010). Nevertheless, the low number of scientific collaborations does not mean that researchers are avoiding a specific theme or species or collaborations (see Nuñez and Pauchard, 2010), but rather it indicates the existence of difficulties in reaching agreements to perform trans-regional programs of prevention and regional management of aquatic exotic species. Indeed, building international collaborative research teams involves a dynamic diplomacy and political assistance, rather than only scientific willingness. Argentina and Chile are making progress on their collaboration to control the invasive American Beaver. This species was intentionally introduced in 1946 in the island of Tierra del Fuego, Argentina. Nowadays, it is known that affected more than 10,000 hectares of the island of both countries Chile and Argentina with more than 100,000 individuals (Lizarralde et al., 2008). This is a clear bi-national effort that involves political agreements to support effective continental long-term control and eradication programs. Other examples such as the Golden Mussel in Argentina, Uruguay, Brazil, Paraguay and Bolivia, the Red Lionfish along the Caribbean region including Colombia and Venezuela, and the Rapa Whelk in Argentina and Uruguay, constantly remind us why exotic species need urgent international collaboration, well-coordinated, based and focused on mutual social and economic benefits.

The design and approval of National Strategies for Invasive Exotic Species (NSIES) are another important step forward that several South American countries such as Brazil, Colombia, Argentina, Chile and Uruguay are working on to improve the management of their exotic species. The Port Section of the Argentina's NSIES, is the main initiative actually creating workshops specifically designed for different stakeholders like Prefectura

Naval Argentina, port administrators, scientists, governmental administrators and decision makers, to get training, focused on the problem of marine exotic species in major commercial ports of southern South America. Within this context, we recommend directing extra efforts to the regular organization of national, regional and international workshops and conferences. They help bring the attention and support from local administrations, while providing frameworks to request for international funding, as well as identifying new problems and original solutions.

Acknowledgements

We thank F. Sylvester and S. Bailey for the invitation to the Marine and Freshwater Invasive Species conference held in Buenos Aires where preliminary results were presented by ES. Thanks to Scientific and Organizing Committee Members for the excellent conference and for providing a nice environment for great discussions on aquatic invasive species. Special thanks to an anonymous referee and Greg Ruiz for sharing with us their thoughts, comments and suggestions, and for helping us to improve the quality of early versions of this manuscript. We are deeply grateful to our friends Carol and Wally Casper for their hospitality during the writing process of this work. Many thanks to Yanina Gonzalez (CENPAT's Library, UGI-SECEDOC) for all her kind professional assistance with the e-literature searching, to the Biodiversity Heritage Library for the exceptional database and kind assistance they constantly provide, and to the entire GEAC team (www.geaccenpat.wix.com/geac) for keeping us active. Special thanks to our always inspiring mentor Jim Carlton, who never stops wanting to work shoulder-to-shoulder every time we come to him with the wildest ideas. Finally, we thank the scientific ministry of Argentina, MINCyT, for supporting us as Co-Chairs of the Xth International Conference on Marine Bioinvasions 2018 to be held in Puerto Madryn, Patagonia, Argentina.

Funding

This research was supported by CONICET (PIP 20130100508 and 20100100089) and by ANPCyT-PICT P. BID # 2016–1083, led by the authors.

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