Marine Pollution Bulletin 67 (2013) 241–243

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Correspondence

The need of more rigorous assessments of marine species introductions: A counter example from the Brazilian coast

Brazil has an extensive coast spreading along three biogeographical provinces and eight ecoregions (Spalding et al., 2007), comprising many distinct marine ecosystems (Migotto and Marques, 2006). Most areas of the Brazilian continental shelf have a recent history of biodiversity surveys, or have never been studied at all (cf. Marques and Lamas, 2006; Migotto and Marques, 2006; Rocha and Boeger, 2009). Brazilian coast has experienced significant transoceanic ship traffic as early as the 16th century, but awareness on the consequences of maritime transport to biological introductions in regional aquatic ecosystems is recent.

The Brazilian Ministry of the Environment organized in 2004–2005 a national program to evaluate the existing information on invasive species in terrestrial and aquatic biomes. A list of 58 exotic species of planktonic and benthic invertebrates, fish, macroalgae, and phytoplankton, updated till late 2008, was generated in a marine ecosystem assessment study carried out by a group of 14 specialists, including three invited reviewers (Lopes, 2009). The study made use of a conservative approach by only including species with well-supported evidence of introduction, based on established criteria (e.g., Chapman and Carlton, 1991). Evidently, lists of exotic or introduced species need to be accurate because they shall serve as fundamental elements for public conservation policies, influencing economic and social stakeholders. Periodic re-assessment of such validated lists is clearly necessary, but the same concern and criteria followed by Lopes (2009) shall be applied unless new arguments or data demonstrate incorrectness or caveats in his approach.

A more recent study reported 343 introduced (65% of the total records) and cryptogenic (35%) species of marine benthic invertebrates associated to ship biofouling in Brazil (Farrapeira et al., 2011). This is a quite large number compared to the 40 exotic species of benthic invertebrates listed by Lopes (2009). Here we demonstrate that Farrapeira et al. (2011) overestimated the number of introduced species because they adopted inconsistent criteria, and we generated an amended species list with new assignments on the introduction status of each species reported by Farrapeira et al. (2011), including corrections of records, taxonomy, and geographic distributions.

Farrapeira et al. (2011) adopted two main criteria to determine the introduction status of a species. The first criterion was imposed in the construction of their database, which considered exclusively “macro-invertebrates that was [sic] cited in association with hull fouling” (p. 833). The presence of one or many individuals on a vessel fouling community is not indicative of an introduction event, although it may provide an interesting reference in risk assessment studies for a particular area. Evidently, not all ship-associated species travel long distances, and knowledge of the vessel type and route is crucial to determine whether the transport is transoceanic or regional. The Farrapeira et al. (2011) database (p. 833 and Table 1) does not distinguish between long-course vessels (container ship, drilling ship, cargo ship, oil tanker, passenger/tourist liner) and local or regional-transport vessels (barge, dredger, fishing boat, leisure boat, sailboat, tugboat, yacht). Maritime transport within the same Economic Exclusive Zone (EEZ) or biogeographic province could at most account for regional or secondary introductions. Besides, many of the transported species may be native within the region covered by this mean of transportation, especially those that are substrate-generalists and are able to colonize artificial substrata – therefore, their presence on a vessel does not necessarily mean that they have been introduced. Further, the authors mentioned they “aimed to list nonindigenous and cryptogenic benthic macro-invertebrates … that have been cited as associated with vessel hulls in coastal aquatic environments around the world”. This means that any species ever recorded on a vessel biofouling community elsewhere in the world (e.g., in a bay of the Pacific or Indian Oceans) was listed as cryptogenic or introduced in Brazil, even if that vessel never came close to a Brazilian coastal area, and most of the citations in the database is from abroad (Farrapeira et al., 2011, Table 1). Additionally, they apparently also included shipwrecks (e.g., published records of sponges collected on hulls of ships currently in operation are rare, cf. Godwin, 2003) and infaunal animals (e.g., the Tanaidacea Apseudidae such as *Paradoxapseudes intermedius* (Hansen 1895) are not expected to be transported by ship hulls).

The second criterion Farrapeira et al. (2011) used to determine the populational status of a species was the type locality: “nonindigenous species were those presenting great geographic discontinuity between the region <u>where they were originally described as native</u> and the area where they were found on the Brazilian coast” (Farrapeira et al., 2011, p. 833 our underline), and reinforced in <u>“The original distribution of species was indicated to classify their distribution status. This included type of locality,</u> complementary paleontological data on distribution (when available) and the geographical distribution recorded in historical articles. […] <u>species were classified as cryptogenic when there was no information regarding type locality</u> […]” (Farrapeira et al., 2011, p. 833 our underline). The use of type locality as an evidence of native geographical distribution is misleading. Carlton (2009) recently reviewed and gave 21 examples of ‘pseudoindigenous species’, or “introduced species that are mistakenly considered as native (indigenous or endemic) to a location […what may happens when…] introduced species [are] first described as new after introduction, and later found elsewhere […]. Thus, the type locality of a species does not necessarily imply where a species is native” (Carlton, 2009, p. 30).

DOI of original article: http://dx.doi.org/10.1016/j.marpolbul.2010.12.014

0025-326X/$ - see front matter
http://dx.doi.org/10.1016/j.marpolbul.2012.12.009

The geographic discontinuity in distribution, assumed by Farrapeira et al. (2011) to infer the introduced status of a species, may be actually caused by many reasons other than introductions. The first reason is that this may be the natural distribution of the species, derived from historical geological reasons (e.g., Miranda et al., 2012) or from idiosyncrasies of its natural history (e.g., Marques, 2011), such as ecology and succession of the community, or dispersal capabilities by rafting (Thiel and Gutow, 2005). For instance, the tanaid *Hexapleomera robusta*, considered to be cryptogenic by Farrapeira et al. (2011, Table 1) is widely distributed because of its commensal association with turtles and manatees (Morales-Vela et al., 2008), with no need of human mediated transport.

A second common reason is that this discontinuous distribution is based on incomplete geographical or historical knowledge of the fauna. This is particularly true for Brazil, because of the inexistence of historical series of faunal surveys capable of revealing the first date of arrival of the species. For instance, the tanaid *Paradoxapseudes intermedius* was recorded in Rio de Janeiro in 1969 based on two individuals (Brum, 1969) and the next report occurred recently (Araújo-Silva, 2010), based also on only two damaged individuals.

Sometimes, the effect of putative barriers such as that of the Amazon River was overestimated (Farrapeira et al., 2011, p. 833), and used to corroborate the impossibility of natural discontinuities. However, even though the Amazon River may be a barrier for some marine organisms, it is not for all of them (e.g., Lazoski et al., 2001; Vieira et al., 2010). The Amazon River barrier dates from 6 to 10 my bp meaning that wide distributions of very conservative taxa (e.g., Cartwright et al., 2007 for medusozoans) are possible. Examples of introduced species in Brazil by Farrapeira et al. (2011, Table 1) distributed along the West Atlantic are the barnacles *Conopea galeata* and *Newmanella radiata* and five sponge species (see Supplementary material), which are suggested as probably native until further studies establishes their endemic areas.

Geographic discontinuity in a reported species distribution may further arise as a consequence of taxonomical difficulties, even in relatively well-studied areas. This is usually the case for (1) small-sized species and species with cryptic habits (e.g., the ascidian *Perophora multiclathrata*, usually collected by chance with other solitary ascidians because of its transparency and small size), (2) species with complex and highly variable life cycles (e.g., the only record of *Coryne eximia* Allman, 1859 in Brazil was assigned by Vannucci (1957) for the medusa stage only, the polyp stage is restricted to temperate waters and the occurrence of the species in Brazil was regarded as uncertain by Vannucci (1957), p. 10), including those species with resting stages (e.g., many hydrozoans, which undergo through resting stages during their life cycles, like species of *Obelia*, Slobodov and Marfenin, 2004), (3) species with seasonal, episodic or rare occurrence. All these possibilities can give raise to a misleading definition of population status by non-specialists.

Another cause of "pseudo" discontinuous distribution, also related to taxonomical intricacies, is the crypticism observed in species or species groups, leading to 'composite' distributions. This happens, for instance, with many species of bryozoans recorded during the 1940s and 1950s, previously thought to have wide distributions, but actually comprising two or more species, each with a much more restricted distribution (Vieira et al., 2010). Also, some sponges with simplified morphology, i.e. few potential characters available to be used in their taxonomy, have been proved to be cryptic species within a complex (Pinheiro et al., 2007). In this regard, molecular studies are a useful tool to help clarify species complexes and to understand morphological variation in species previously considered to be widespread in warm tropical waters (e.g., Collins et al., 2011, for medusozoans; Fehlauer-Ale et al. 2011, for benthic bryozoans). Farrapeira et al. (2011) addressed this issue, although they decided not to consider it as important: "In the case of controversy around the geographical distribution of certain 'cosmopolitan' species, these were considered as such – and not as possible 'species complexes' (p. 834)". Examples in Farrapeira et al. (2011) of species related to this condition are the amphipod *Quadrimaera inaequipes*, which is part of a species complex early recognized by Barnard (1972), within which *Q. cristianae* and *Q. pietri* occur in Brazil (Krapp-Schickel and Ruffo, 2000).

In addition, we have noticed that Farrapeira et al. (2011) database has many mistakes, compromising the analysis (see examples in column "comments" in the Supplementary material). Further, we missed a list of references of the records of species on hulls, in order to allow evaluation of the identifications. The authors mentioned that they consulted local databases, most likely also including ecological papers with lists of species, usually not checked by experts. When dealing with bioinvasion, a good taxonomic background is crucial for a correct detection of introductions. The inference of marine introductions in a country with over 8000 km of coastline should certainly involve many specialists. Farrapeira et al. (2011) reported 223 nonindigenous and 120 cryptogenic benthic invertebrates associated with hull fouling in Brazilian waters. After our reconsiderations, the list comprises only 265 species, among which 42 nonindigenous, 187 cryptogenic, 25 native, and 11 probably native benthic invertebrates. In this essay, we do not intend to present a comprehensive list of exotic species along the Brazilian coast, but only to put some light on the need of broad and more rigorous assessments.

Concluding, we agree that lists of exotic and introduced species are important to motivate public consciousness for the subject, to guide governmental policies of control and management, to establish priorities of investment in research, etc. Consequently, the accuracy of these lists is of paramount importance, in order to preserve social and economic responsibilities.

Acknowledgements

We thank Carlo M. Cunha (UFRJ), Luciana Gusmão (IBUSP), and Roger Bamber (AARTOO Marine Biology Consultants LLP) for sharing their knowledge about nudibranchs, anthozoans, and tanaidaceans, respectively. This study was supported by CAPES PROCAD (ACM, AEM, RMR), CNPq (integrative grants to ACM; personal grants to ACM, AEM, CA, LRLS, MT, RML, RMR), and FAPESP (2010/52324-6; 2011/50242-5. This contribution has the participation of several scientists of NP-BioMar, USP.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.marpolbul.2012.12.009.

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Rosana M. Rocha
Departamento de Zoologia, Universidade Federal do Paraná, CP 19020, 81531-980 Curitiba, Brazil
E-mail address: rmrocha@ufpr.br

Leandro M. Vieira
Departamento de Zoologia, Instituto de Biociências, Universidade de São Paulo, R. Matão Tr.14, 101, 05508-090 São Paulo, Brazil
Centro de Biologia Marinha, Universidade de São Paulo, Rodovia Manoel H. do Rego km 131, 5, 11600-000 São Sebastião, Brazil
E-mail address: leandromanzoni@gmail.com

Alvaro E. Migotto
Centro de Biologia Marinha, Universidade de São Paulo, Rodovia Manoel H. do Rego km 131, 5, 11600-000 São Sebastião, Brazil
E-mail address: aemigott@usp.br

Antonia Cecília Z. Amaral
Departamento de Biologia Animal, Instituto de Biologia, Universidade Estadual de Campinas, CP 6109, 13083-970 Campinas, Brazil
E-mail address: ceamaral@unicamp.br

Carlos Renato R. Ventura
Cristiana S. Serejo
Museu Nacional, Universidade Federal do Rio de Janeiro, Quinta da Boa Vista s/n, 20940-040 Rio de Janeiro, Brazil
E-mail addresses: ventura@acd.ufrj.br (A. Ventura), csserejo@acd.ufrj.br (A. Serejo)

Fábio B. Pitombo
Departamento de Biologia Marinha, Universidade Federal Fluminense, CP 100.644, 24001-960 Niterói, Brazil
E-mail address: fpitombo@vm.uff.br

Kátia Christol Santos
Luiz R.L. Simone
Marcos Tavares
Museu de Zoologia, Universidade de São Paulo, Avenida Nazaré, 481, 04263-000 São Paulo, Brazil
E-mail addresses: tanaidaceadobrasil@gmail.com (A. Santos), lrsimone@usp.br (A. Simone), mdst@usp.br (A. Tavares)

Rubens M. Lopes
Instituto Oceanográfico, Universidade de São Paulo, Praça do Oceanográfico 191, 05508-120 São Paulo, Brazil
E-mail address: rubens@usp.br

Ulisses Pinheiro
Departamento de Zoologia, Centro de Ciências Zoológicas, Universidade Federal de Pernambuco, 50373-970 Recife, Brazil
E-mail address: uspinheiro@hotmail.com

Antonio Carlos Marques *
Departamento de Zoologia, Instituto de Biociências, Universidade de São Paulo, R. Matão Tr.14, 101, 05508-090 São Paulo, Brazil
* Tel.: +55 11 3091 7530; fax: +55 11 3091 7802.
E-mail address: marques@ib.usp.br