



Non-native marine bryozoans (Bryozoa: Gymnolaemata) in Brazilian waters: Assessment, dispersal and impacts

Adélia A. Miranda^a, Ana C.S. Almeida^{a,b}, Leandro M. Vieira^{a,*}

^a Laboratório de Estudos de Bryozoa (LAEBr), Departamento de Zoologia, Universidade Federal de Pernambuco, Recife, PE 50670-901, Brazil

^b Museu de Zoologia, Universidade Federal da Bahia, Salvador, BA 40170-115, Brazil

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ABSTRACT

Bryozoa is a phylum of aquatic invertebrates widely distributed around the world, including harbor areas. They have association to artificial structures as main mechanism of dispersal, including ships, which facilitates their introduction to new environments. The detection of exotic species is important to prevent new introductions and to propose management strategies of marine areas. Thus, after analyzing and discussing local and global criteria of exotic species, an account of exotic bryozoans from Brazil is presented, including 12 classified as exotic (six established and six detected) and 17 classified as potentially exotic (cryptogenic). Three species have been reported causing economic or environmental impacts worldwide. Of those, *Membraniporopsis tubigera* is known to cause economic impacts on the Brazilian coast. Hull fouling is the main dispersal mechanism for exotic bryozoans. The lacking of reliable data did not allow inferring on the exotic status on some fouling bryozoan species in Brazil.

1. Introduction

Marine introductions of exotic species are of increasing concern that threatens biodiversity and economy all over the world. Each introduction represents the risk of unpredictable negative consequences (Bax et al., 2001). Changes in the trophic chain, introduction of diseases and toxins and extinctions are possible biodiversity impacts caused by the arrival of a new species (Ruiz et al., 1997; Carlton, 2001; Rilov and Crooks, 2009). The social and economic values of the native species are also threatened. Pimentel et al. (2001) estimated a worldwide economic damage of US\$ 1.4 trillion per year, nearly 5% of the world economy, caused by the consequences of biological introductions. In aquatic environments, human activities may create multiple artificial dispersal vectors such as shipping, oil platforms and even plastic debris, facilitating the transportation and introduction of an exotic species to new environments (Bax et al., 2003; Almeida et al., 2015a). The economic importance of commercial shipping, with the high number of global routes, makes it the most common artificial vector of dispersal (Bax et al., 2003). Due to Brazil's long coastline with intensive shipping traffic, marine exotic species are a great concern still understudied (Lopes, 2009).

Detection of exotic species, and the study of their impacts and management, are needed to prevent and control biodiversity impacts (Carlton, 2001). Cryptogenic species, which cannot be proven either

exotic or native, also need to be studied since they might help identify introduction corridors (Carlton, 1996). Furthermore, in taxa such as Bryozoa, cryptogenic species may be as common as or more common than exotic species (e.g. Migotto et al., 2011; Marques et al., 2013). Therefore neglecting them can cause substantial errors in non-indigenous species estimates (Carlton, 1996; Rocha et al., 2013).

Among exotic aquatic invertebrates widely reported around the world, Bryozoa is a phylum of colonial, sessile and mainly marine animals, commonly found on hard substrata (Ryland, 2005). Many species are tolerant to environmental variations, have fast growth and are able to settle on artificial substrata, having a high potential to easily adapt and become invasive in non-indigenous areas, especially ports and harbors (Gordon and Mawatari, 1992; Almeida et al., 2015a). Due to their sessile habit, fouling and rafting on artificial substrata are common dispersal mechanisms for bryozoans (Gordon and Mawatari, 1992; McCuller and Carlton, 2018). From the 8000 living species estimated for the world (Ryland, 2005), about 438 species are reported from Brazil (Vieira et al., 2017), but the group is historically understudied, mainly at regions such as Northeast Brazil (Almeida et al., 2015a).

Detection of exotic and cryptogenic marine species, including bryozoans, has been done in few Brazilian surveys (i.e. Lopes, 2009; Marques et al., 2013; Rocha et al., 2013), but never specifically to the phylum. Lopes (2009) recognized three bryozoan species as exotic;

* Corresponding author.

E-mail address: leandromanzoni@hotmail.com (L.M. Vieira).

Rocha et al. (2013) classified 20 bryozoan species as cryptogenic, not considering any as exotic. More recently, Almeida et al. (2015a, 2017a) reported seven exotic species for Northeast Brazil. Thus, we here analyse local and global criteria to provide a list of exotic bryozoans from Brazil, discussing their current status, dispersal mechanisms and possible impacts on the Brazilian coast.

2. Material and methods

A compilation of the introduced and cryptogenic marine bryozoans from Brazil was made based on published literature from 1841 until 2017 (Vieira et al., 2017). Thus, the species list includes: species whose native status is doubtful, those whose exotic status was previously inferred, and widespread fouling species. Putative native species and species with no hypothesis belonging to exotic or cryptogenic taxa were not included in the analysis. For each species, information on world distribution, habitat, dispersal mechanisms and known/possible environmental impacts were compiled (Supplementary Text 1).

The classification of the exotic status was inferred based on the local and global criteria established by Chapman and Carlton (1991, 1994). The local criteria (attributes) are: (1) local appearance where not found previously; (2) local dispersal after introduction; (3) association with human mechanisms of dispersal; (4) association or dependency with other introduced species; (5) prevalence or restriction to new or artificial environments and (6) restricted distribution when compared to ecologically similar native species. The global criteria are: (7) widespread geographic distribution with isolated populations; (8) active and passive dispersal mechanisms incapable of achieving the current distribution; (9) exotic evolutionary origin. The criteria were applied based on information compiled from the literature and on data from recent surveys on the Brazilian coast, after reassignment of some misidentified species. We use the nine criteria together as an exotic status hypothesis, which may be applied as positive or negative evidence to support it. When there is positive evidence, it indicates the possibility of exotic status, while criteria with negative evidence indicate a possibly native status. When there was no information that could support either positive or negative criteria, the criteria was marked as 0 and it was not counted in the total score. A species was assigned as exotic when five criteria or more were applied positively. Taxa with less than five criteria applied positively were assigned as cryptogenic (mainly where there was insufficient information about the species). Members of species complexes were also classified as cryptogenic, regardless of how many criteria were positively assigned, since that species cannot be identified accurately and may represent native species.

Once classified as exotic, a population situation was determined following Lopes (2009) as: (1) contained, presence within controlled environments, separated from the natural environment; (2) detected, single or few records in the natural environment, without population growth or dispersion; (3) established, recurrent records with visible population growth and a complete life cycle in the natural environment or (4) invasive, when its abundance or dispersion affects the survival of other species or causes socioeconomic or health impacts. Cryptogenic species were not classified regarding their population situation since they are not certainly exotic.

Additional information used to support the classification of exotic status is explained in the supplementary material. The reference specimens are deposited at the Bryozoa Collections of Museu de Zoologia of the Universidade de São Paulo (MZUSP), Universidade Federal de Pernambuco (UFPE) and Museu de Zoologia of the Universidade Federal da Bahia (UFBA).

3. Results

A total of 29 bryozoan species from the Brazilian coast were classified based on their exotic status (Tables 1, 2). For the assessed species, the exotic score ranged from two to nine and 14 species were scored

with five or more attributes. Two of these species, *Conopeum reticulum* (Linnaeus, 1767) and *Schizoporella errata* (Waters, 1878), comprises species complexes and were classified as cryptogenic. Twelve species were classified as exotic (Table 2): *Amathia verticillata* (delle Chiaje, 1822), *Arbopercula bengalensis* (Stoliczka, 1869), *Biflustra grandicella* (Canu & Bassler, 1929), *Biflustra irregularata* (Liu, 1991), *Biflustra okadai* Almeida, Souza & Vieira, 2017, *Bugula neritina* (Linnaeus, 1758), *Bugulina stolonifera* (Ryland, 1960), *Hippopodina tahitiensis* Leca & d'Hondt, 1993, *Hippoporina indica* Madhavan Pillai, 1978, *Licornia jolloisii* (Audouin, 1826), *Sinoflustra annae* (Osburn, 1953) and *Triphyllozoon arcuatum* (MacGillivray, 1889). Among the exotic species, six were classified as detected, and six were considered established on the Brazilian coast. The other 17 species were classified as cryptogenic mainly due the lack of information. Twelve of these are possibly part of species complexes.

The main dispersal mechanism reported was hull fouling, recorded for 19 species: *Amathia verticillata*, *Amathia viduici* (Heller, 1867), *Anguinella palmata* Van Beneden, 1845, *Nolella stipata* Gosse, 1855, *Arbopercula bengalensis*, *Biflustra arborescens*, *Biflustra grandicella*, *Bugula neritina*, *Bugulina stolonifera*, *Conopeum reticulum*, *Hippopodina feegeensis* (Busk, 1884), *Hippopodina tahitiensis*, *Hippoporina indica*, *Licornia diadema* (Busk, 1852), *Savignyella lafontii*, *Schizoporella errata*, *Sinoflustra annae*, *Virididentula dentata* and *Watersipora subtorquata* (d'Orbigny, 1852). Dispersal by hull fouling was also inferred for another three species due their presence in harbor area: *Membraniporopsis tubigera* and *Triphyllozoon arcuatum* (Table 2). Dispersal by rafting is known in six species: *Arbopercula tenella* (Hincks, 1880), *Biflustra grandicella*, *Biflustra irregularata*, *Bugula neritina*, *Bugulina stolonifera* and *Membraniporopsis tubigera*, and inferred in one: *Amathia verticillata*. Marine currents, aquaculture and ballast water are dispersal mechanisms suggested for some species, however they have not yet been shown for the Brazilian coast.

4. Discussion

Brazil has one of the world's most biodiverse coastlines, however vast areas of marine territory remain unknown (Couto et al., 2003). Certain taxa, such as Bryozoa, are traditionally understudied on the Brazilian coast mainly due to the low number of taxonomy specialists (Migotto and Marques, 2003; Almeida et al., 2015b). Most historical surveys involving bryozoans were carried out on the south and south-east coasts (Vieira et al., 2008). Faunistic surveys in northeast Brazil, which represents almost a third of the Brazilian coastline, only recently were published (e.g. Almeida and Souza, 2014; Almeida et al., 2015b, c, 2017a, b; Vieira et al., 2016) and studies in the north region are still lacking (see Vieira et al., 2008 for more information).

The first report on Brazilian exotic species which included bryozoans was published in 2009, when three species, viz. *Hippopodina tahitiensis*, *Schizoporella errata* and *Virididentula dentata*, were considered exotic (Lopes, 2009). Among those, only *Hippopodina tahitiensis* is here considered exotic, with six criteria applied positively. Even though *Schizoporella errata* also had six criteria applied positively, the species is known to be a species complex (Tompsett et al., 2009; Ramalho et al., 2011; Marques et al., 2013), therefore being classified here as cryptogenic until studies including molecular techniques are done to evaluate its exotic origin. *Virididentula dentata* was classified as cryptogenic due lack of minimum criteria applied positively and also being a species complex (Fehlauer-Ale et al., 2015).

Rocha et al. (2013) classified 20 bryozoan species in Brazil as cryptogenic and the exotic status was not applied to any species due to lack of reliable data. Here, 14 species listed by Rocha et al. (2013) are included, nine of them being also classified as cryptogenic: *Amathia viduici*, *Anguinella palmata*, *Arbopercula tenella*, *Conopeum reticulum*, *Membraniporopsis tubigera*, *Savignyella lafontii*, *Schizoporella errata*, *Virididentula dentata* and *Watersipora subtorquata*. Another five species are here classified as exotic after applying Chapman and Carlton (1991,

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