Mar Biodiv (2018) 48:1651–1654
DOI 10.1007/s12526-016-0623-x

SENCKENBERG

SHORT COMMUNICATION

Northward range expansion of the invasive coral (*Tubastraea tagusensis*) in the southwestern Atlantic

Marcelo de Oliveira Soares[1,2] · **Marcus Davis**[3] · **Pedro Bastos de Macêdo Carneiro**[1]

Received: 26 October 2016 / Revised: 12 December 2016 / Accepted: 13 December 2016 / Published online: 20 December 2016

Abstract Invasive species are recognized as a major threat to marine biodiversity. The scleractinian coral *Tubastraea tagusensis* has been expanding its range into the southwest Atlantic Ocean, causing negative impacts on marine ecosystems. In 2016, the species was recorded on a shipwreck located 40 km off the Brazilian coast of Ceará State (latitude 2°30′ S), at densities ranging from 16 to 872 colonies × m^{-2}. This is the first documented occurrence and density of *T. tagusensis* in the northern region of Brazilian coral reefs (NBR), expanding the range of the genus along the Brazilian coastline to ca. 3850 km. Here it may form a threat to marine environments such as coral reefs, rocky shores, mussel beds, and fouling communities on manmade structures. Considering that the NBR contains vulnerable marine ecosystems, such as the reef system off the Amazon River, and that it is connected by both the North Brazil Current and shipping lanes associated with oil and gas platforms, a monitoring programme is needed to study the population dynamics of this invasive species.

Keywords Biological invasions · coral reefs · manmade structures · non-indigenous corals

Communicated by B. W. Hoeksema

✉ Marcelo de Oliveira Soares
marcelosoares@pq.cnpq.br

[1] Instituto de Ciências do Mar (LABOMAR), Universidade Federal do Ceará (UFC), Fortaleza, Brazil

[2] Institut de Ciència i Tecnologia Ambientals (ICTA), Universitat Autònoma de Barcelona (UAB), Barcelona, Spain

[3] Mar do Ceará, Fortaleza, Brazil

Introduction

Invasive coral species have negative impacts on Caribbean and southwest Atlantic marine biodiversity (Carlos-Júnior et al. 2015; Sammarco et al. 2015). To date, two alien species of the azooxanthellate scleractinian genus *Tubastraea* Lesson, 1829 occur on the Brazilian coast: *T. tagusensis* Wells, 1982 and *T. coccinea* Lesson, 1829 (De Paula and Creed 2004; Carlos-Júnior et al. 2015; Creed et al. 2016). Both have been described as dominant invaders of marine environments (Mizrahi et al. 2016) such as coral reefs (Miranda et al. 2016), subtidal rocky shores (De Paula and Creed 2004, 2005; Creed 2006 Creed and De Paula 2007 Silva et al. 2014), mussel beds (Mantellato and Creed 2015), and artificial substrates (Costa et al. 2014; Ho et al. 2016).

Scleractinian reef corals (21 native and two invasive species) are distributed along the Brazilian coast in four major geographic regions, including the northern, northeastern, eastern, and southern regions (Leão et al. 2016), with a northern marginal area occurring between the Amazon River mouth and Cape São Roque (0°30′ to 5°29′ S). Although previous records of invasive *Tubastraea* spp. exist from the eastern and southern regions, the present contribution is the first to report occurrence and density data of *T. tagusensis* above latitude 5° S, in the northern region of Brazilian coral reefs (NBR).

Materials and methods

The study was conducted on the continental shelf along the coast of the state of Ceará (Brazil, southwestern Atlantic) in the NBR. This shelf area is characterized by a western boundary current, strong winds, and mesotidal regimes. The dynamic coast here is the origin of some unique features of Atlantic

Ocean circulation, such as the equatorial undercurrent fed by the North Brazil Current flowing along the southwestern coast near the equator (Dias et al. 2013). The surface temperature stays within a range of 27–29 °C without much seasonal variation (Soares et al. 2016a).

The occurrence of *T. tagusensis* was documented on the 136-m long shipwreck *SS Eugene V.R. Thayer* (nicknamed *Petroleiro do Acaraú*), which sunk in 1942, 40 km off Ceará State (2°30′S 39°50′W). Data collection was conducted during SCUBA diving in May 2016 using 50 × 50 cm photo quadrats (n = 40), haphazardly distributed at 20–22 m depth. Coral densities were calculated as colonies × m^{-2}, using ImageJ and Coral Point Count with Excel Extensions.

Results and discussion

These are the first occurrence and density records of *T. tagusensis* in the northern region of Brazilian coral reefs (NBR), expanding its known distribution to approximately 3850 km along the Brazilian coastline (Fig. 1a). Previously, the northernmost record of *T. tagusensis* on the Brazilian coast was from oil platforms off the state of Sergipe (at ca. 11° S), confirmed in an official report by the Brazilian Institute of Environment and Natural Resources - IBAMA 2013 (unpublished data). The present location is approximately 1400 km north of these platforms. Other records southward from the newly recorded area (Fig. 1a) were published by Costa et al. (2014), Creed et al. (2016), and Leão et al. (2016). The range expansion of *T. tagusensis* along the entire Brazilian coast, including the NBR, was predicted by Riul et al. (2013), who used computational models based on dispersal capability and habitat-match.

The identity of *T. tagusensis* (Fig. 1c) was determined based on morphological characters (De Paula and Creed 2004). However, considering the taxonomic difficulties posed by *Tubastraea* species (Cairns 2001; Arrigoni et al. 2014; Capel et al. 2016), further analyses, particularly employing DNA data, may also reveal the presence of invasive *T. coccinea* in the region, since both species are frequently found co-occurring (De Paula and Creed 2004; Creed and De Paula 2007).

The coral density varied from 16 to 872 colonies × m^{-2} (mean 247 colonies × m^{-2}). De Paula and Creed (2005) found a similar maximum density (792 colonies × m^{-2}) on rocky shores in Southeast Brazil (Rio de Janeiro), where the mean density of *T. tagusensis*, 17 months after settlement on artificial settlement plates, varied from 202 to 512 colonies × m^{-2} (Creed and De Paula 2007). Our results suggest that density of *T. tagusensis* is variable and that the spatial distribution of coral colonies at the study site in equatorial waters was highly gregarious. Furthermore, video footage from 2012 does not show clear signs of *Tubastraea* at this diving site, which is indicative of recent colonization.

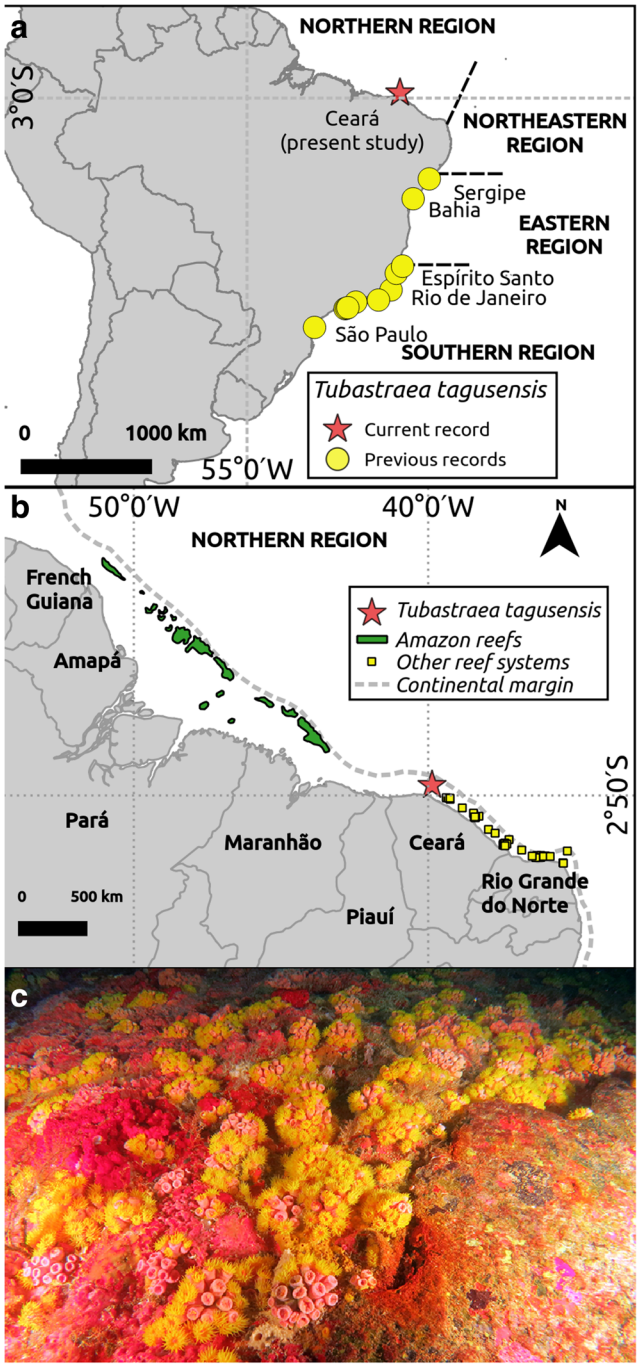

Fig. 1 Northernmost (present) record of *Tubastraea tagusensis* along the Brazilian coast, Ceará State. **a** Records of invasive *Tubastraea tagusensis* along the Brazilian coast (references in the main text). **b** New record in relation to adjacent reef systems. **c** *Tubastraea tagusensis* colonies on a shipwreck at 20 m depth in the research area

The present findings suggest that *T. tagusensis* was introduced to the Ceará coast via biofouling on oil and gas platforms and/or drill ships. With offshore production platforms in shallow waters, the Rio Grande do Norte and Ceará

regions are important for oil production in Brazil. The oil platforms are located on the western part of the Ceará coast, where the present study was conducted. The point of introduction for *T. tagusensis* is probably linked to the nearby port facilities of Paracuru and Pecém harbor, used by oil and gas industry. Creed et al. (2016) suggest that *Tubastraea* spp. are fouling organisms strongly associated with oil and gas platforms, which are primary vectors for new introductions. Whether this applies to the coast of Ceará can be studied by phylogeographic analyses.

Manmade structures such as shipwrecks and oil platforms facilitate the introduction of *Tubastraea* spp. into natural habitats (Riul et al. 2013; Hoeksema and Ten Hove 2016). After the successful initial introduction, colonization of new areas via dispersion is expected. In previous studies, *Tubastraea* species did not show clear preferences for specific substrate types, they reproduced asexually, and were able to tolerate wide temperature ranges, suggesting a high potential for colonization (Creed and De Paula 2007; Carlos-Júnior et al. 2015). Moreover, *Tubastraea* colonies exhibit a high oocyte production, a precocious reproduction age, a short embryo incubation time, hermaphroditism, and producing buoyant larvae viable for up to 18 days. All of these features are favorable for a wide dispersion (De Paula et al. 2014).

To date, the poorly studied cnidarian fauna of Ceará coast comprises five species of native scleractinian corals, three zoantharians, and two hydrocorals (Rabelo et al. 2015; Leão et al. 2016, Portugal et al. 2016; Soares et al. 2016a). *Siderastrea stellata* Verrill, 1868, *Montastraea cavernosa* (Linnaeus, 1767), and *Favia gravida* Verrill, 1868 are the most common reef coral species in this tropical region. *Tubastraea* species successfully compete for food and space with, for example, *S. stellata* and *M. cavernosa*, causing tissue necrosis and partial mortality (Creed 2006; Miranda et al. 2016). These invasive corals can dominate communities by excluding other sessile eco-engineering species, likely reducing species richness, and recruitment of native species (Lages et al. 2011). Lages et al. (2011) found a strong correlation between *Tubastraea* cover and reduction of benthic cover by native species, estimating that the maximum dissimilarity among assemblages is reached when *Tubastraea* spp. occupy 45% of the substrate surface area.

Among the four geographical regions along the Brazilian coast, the NBR is the least studied, representing a knowledge gap on the boundary between the Caribbean and southwestern Atlantic reefs (Leão et al. 2016; Soares et al. 2016b). As such, the NBR still holds poorly known reef systems, such as subtidal sandstone reefs (Freitas and Lotufo 2014; Soares et al. 2016a) and the recently discovered mesophotic coral reef system off the Amazon River (Cordeiro et al. 2015; Moura et al. 2016; Fig 1b). The northwestward direction of the warm, fast-flowing North Brazil Current (NBC), with oil and gas platforms as stepping stones, may connect these NBR ecosystems and facilitate the introduction and dispersion of *T. tagusensis* along the Amazon coast (Fig. 1b).

Despite the sub-optimal conditions for coral growth due to low light penetration due to the river plume and mesophotic depths of 30–120 m in the Amazon reefs (Moura et al. 2016), there seems to be a considerable potential for a successful invasion by *T. tagusensis*. As it is an azooxanthellate coral, it does not depend on sunlight for development and it can be found down to 40 m deep (De Paula and Creed 2004). Furthermore, nearby reef systems east of the present record (e.g., Araújo and Amaral, 2016; Soares et al. 2016a, b; Fig. 1b) may allow an eastward expansion of the species in the Northeastern Brazilian Region (Leão et al. 2016).

In Brazil, *Tubastraea* colonies have been reported on platforms and ships associated with oil and gas exploration and production (Creed et al. 2016). In the past decade, 20 exploration blocks are oil-productive on the Amazon continental shelf. In 2013, new exploration blocks for oil drilling were offered in an international auction, and 35 blocks were acquired by transnational and national companies. These blocks will soon be producing oil near the extensive tropical reef recently re-discovered at the mouth of the Amazon (Moura et al. 2016), increasing the risk of bioinvasion here. Therefore, a monitoring programme is needed in NE Brazil to track the population growth and range of this invasive species.

Acknowledgements Financial support was provided by the Conselho Nacional de Desenvolvimento Científico e Tecnológico — CNPq (Grants 233808/2014-0 to MOS) and INCT AmbTropic (National Institute of Science and Technology for the Tropical Marine Environment). We thank the editor and three anonymous reviewers for their constructive comments, which helped us to improve the manuscript.

References

Araújo PVN, Amaral RF (2016) Mapping of coral reefs in the continental shelf of Brazilian Northeast through remote sensing. Revista de Gestão Costeira Integrada 16:5–20. doi:10.5894/rgci629

Arrigoni R, Kitano YF, Stolarski J, Hoeksema BW, Fukami H, Stefani F, Galli P, Montano S, Castoldi E, Benzoni F (2014) A phylogeny reconstruction of the Dendrophylliidae (Cnidaria, Scleractinia) based on molecular and micromorphological criteria, and its ecological implications. Zool Scr 43:661–688. doi:10.1111/zsc.12072

Cairns SD (2001) A generic revision and phylogenetic analysis of the Dendrophylliidae (Cnidaria: Scleractinia). Smithson Contrib Zool 615:1–75

Capel KCC, Migotto AE, Zilberberg C et al (2016) Complete mitochondrial genome sequences of Atlantic representatives of the invasive Pacific coral species *Tubastraea coccinea* and *T. tagusensis* (Scleractinia, Dendrophylliidae): Implications for species identification. Gene 590:270–277. doi:10.1016/j.gene.2016.05.034

Carlos-Júnior LA, Neves DM, Barbosa NPU, Moulton TP, Creed JC (2015) Occurrence of an invasive coral in the southwest Atlantic and comparison with a congener suggest potential niche expansión. Ecol Evol 5:2162–2171. doi:10.1002/ece3.1506

Creed JC (2006) Two invasive alien azooxanthellate corals, *Tubastraea coccinea* and *Tubastraea tagusensis*, dominate the native

zooxanthellate *Mussismilia hispida* in Brazil. Coral Reefs 25:350. doi:10.1007/s00338-006-0105-x

Creed JC, De Paula AF (2007) Substratum preference during recruitment of two invasive alien corals onto shallow-subtidal tropical rocky shores. Mar Ecol Prog Ser 330:101–111. doi:10.3354/meps330111

Creed JC, Fenner D, Sammarco P, Cairns S, Capel K, Junqueira AOR, Cruz I, Miranda RJ, Carlos-Junior L, Mantelatto MC, Oigman-Pszczol S (2016) The invasion of the azooxanthellate coral *Tubastraea* (Scleractinia: Dendrophylliidae) throughout the world: history, pathways and vectors. Biol Invasions. doi:10.1007/s10530-016-1279-y

Cordeiro RTS, Neves BM, Rosa-Filho JS, Pérez CD (2015) Mesophotic coral ecosystems occur offshore and north of the Amazon River. Bull Mar Sci 91:491–510. doi:10.5343/bms.2015.1025

Costa TJF, Pinheiro HT, Teixeira JB, Mazzei EF, Bueno L, Hora MSC, Joyeux JC, Carvalho-Filho A, Amado-Filho G, Sampaio CLS, Rocha LA (2014) Expansion of an invasive coral species over Abrolhos Bank, Southwestern Atlantic. Mar Pollut Bull 85:252–253. doi:10.1016/j.marpolbul.2014.06.002

De Paula AF, Creed JC (2004) Two species of the coral *Tubastraea* (Cnidaria, Scleractinia) in Brazil: a case of accidental introduction. Bull Mar Sci 74:175–183

De Paula AF, Creed JC (2005) Spatial distribution and abundance of nonindigenous coral genus *Tubastraea* (Cnidaria, Scleractinia) around Ilha Grande, Brazil. Braz J Biol 65:661–673. doi:10.1590/S1519-69842005000400014

De Paula AF, Pires DO, Creed JC (2014) Reproductive strategies of two invasive sun corals (*Tubastraea* spp.) in the southwestern Atlantic. J Mar Biol Assoc UK 94:481–492. doi:10.1017/S0025315413001446

Dias FJS, Castro BM, Lacerda LD (2013) Continental shelf water masses off the Jaguaribe River (4S), northeastern Brazil. Cont Shelf Res 66:123–135. doi:10.1016/j.csr.2013.06.005

Freitas JEP, Lotufo TMDC (2014) Reef fish assemblage and zoogeographic affinities of a scarcely known region of the western equatorial Atlantic. J Mar Biol Assoc UK 95:623–633. doi:10.1017/S0025315414001404

Ho MJ, Chia MH, Cen CA (2016) Wall of orange cup coral, *Tubastraea coccinea*, at the inlet breakwaters of a nuclear power plant, southern Taiwan. Mar Biodivers. doi:10.1007/s12526-016-0469-2

Hoeksema BW, Ten Hove HA (2016) The invasive sun coral *Tubastraea coccinea* hosting a native Christmas tree worm at Curaçao, Dutch Caribbean. Mar Biodivers. doi:10.1007/s12526-016-0472-7

Lages BG, Fleury BG, Menegola C, Creed JC (2011) Change in tropical rocky shore communities due to an alien coral invasion. Mar Ecol Prog Ser 438:85–96. doi:10.3354/meps09290

Leão ZMAN, Kikuchi RKP, Ferreira BP et al (2016) Brazilian coral reefs in a period of global changes: a synthesis. Braz J Oceanogr 64:97–116. doi:10.1590/S1679-875920160916064sp2

Mantellato MC, Creed JC (2015) Non-indigenous sun corals invade mussel beds in Brazil. Mar Biodivers 45:605–606. doi:10.1007/s12526-014-0282-8

Miranda RJ, Cruz ICZ, Barros F (2016) Effects of the alien coral *Tubastraea tagusensis* on native coral assemblages in a southwestern Atlantic coral reef. Mar Biol 163:45. doi:10.1007/s00227-016-2819-9

Mizrahi D, Kitahara MV, Barbosa AC, Flores AA (2016) Possible interference competition involving established fish and sun coral incursion. Mar Biodivers. doi:10.1007/s12526-016-0477-2

Moura RL, Amado-Filho GM, Moraes FC, Brasileiro PS, Salomon PS, Mahiques MM, Bastos AC, Almeida MG, Silva JM, Araujo BF, Brito FP, Rangel TP, Oliveira BCV, Bahia RG, Paranhos RP, Dias RJS, Siegle E, Figueiredo AG, Pereira RC, Leal CV, Hajdu E, Asp NE, Gregoracci GB, Neumann-Leitão S, Yager PL, Francini-Filho RB, Froes A, Campeão M, Silva BS, Moreira APB, Oliveira L, Soares AC, Araujo L, Oliveira NL, Teixeira JB, Valle RAB, Thompson CC, Rezende CE, Thompson FL (2016) An extensive reef system at the Amazon River mouth. Sci Adv 2:e1501252

Portugal AB, Carvalho FL, Carneiro PBM, Rossi S, Soares MO (2016) Increased anthropogenic pressure decreases species richness in tropical intertidal reefs. Mar Env Res 120:44–54. doi:10.1016/j.marenvres.2016.07.005

Rabelo EF, Soares MO, Bezerra LEA, Matthews-Cascon H (2015) Distribution pattern of zoanthids (Cnidaria: Zoantharia) on a tropical reef. Mar Biol Res 11:1–9. doi:10.1080/17451000.2014.962542

Riul P, Targino CH, Júnior LAC, Creed JC, Horta PA, Costa GC (2013) Invasive potential of the coral *Tubastraea coccinea* in the southwest Atlantic. Mar Ecol Prog Ser 480:73–81. doi:103354/meps10200

Sammarco PW, Porter SA, Genazzio M, Sinclair J (2015) Success in competition for space in two invasive coral species in the western Atlantic – *Tubastraea micranthus* and *T. coccinea*. PLoS One 10:e0144581. doi:10.1371/journal.pone.0144581

Silva AG, Fleury BG, Paula AF, Creed JC (2014) Eleven years of range expansion of two invasive corals (*Tubastraea coccinea* and *Tubastraea tagusensis*) through the southwest Atlantic (Brazil). Estuar Coast Shelf Sci 141:9–16. doi:10.1016/j.ecss.2014.01.013

Soares MO, Martins FAS, Carneiro PBM, Rossi S (2016a) The forgotten reefs: benthic assemblage coverage on a sandstone reef (Tropical South-western Atlantic). J Mar Biol Assoc UK. doi:10.1017/s0025315416000965

Soares MO, Davis M, De Paiva CC, Carneiro PBM (2016b) Mesophotic ecosystems: Coral and fish assemblages in a tropical marginal reef (northeastern Brazil). Mar Biodivers. doi:10.1007/s12526-016-0615-x