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New records of the alien cup-corals (*Tubastraea* spp.) within estuarine and reef systems in Todos os Santos Bay, Southwestern Atlantic

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Abstract

Background: The alien cup-coral *Tubastraea* spp. has been increasingly reported in the Southwestern Atlantic since the 1980s. More recently it was observed on the East coast of Brazil, the area with the highest biodiversity in the Southwest Atlantic. In the present study, we report the actual distribution of *Tubastraea tagusensis* and *Tubastraea coccinea* around Todos os Santos Bay (TSB), an important system in the Southwest Atlantic coast.

Results: We mapped the geographic expansion of *Tubastraea tagusensis* and *Tubastraea coccinea* at 11 sites in estuarine and 2 in reef systems at TSB.

Conclusions: The findings from our study will contribute to monitor alien expansion and implement management actions to control these invasions on the Brazilian coast.

Keywords: Biological invasion, Benthic communities, Geographic distribution, Orange cup coral, Bahia, Eastern Brazil

Introduction

The native Indo-Pacific cup coral, *Tubastraea* Lesson, 1829 (Scleractinia: Dendrophylliidae) is one the most widely distributed azooxanthellate coral genera in the world and its non-native range extends to the Caribbean Sea, the Gulf of Mexico and Western Atlantic (Cairns, 2000; Castro & Pires, 2001; Ferreira, 2003; de Paula & Creed, 2004; Fenner & Banks, 2004; Mantelatto *et al.*, 2011; Sampaio *et al.*, 2012). Two species of *Tubastraea* were introduced in the Southwest Atlantic (*Tubastraea tagusensis* Wells, 1982 and *Tubastraea coccinea* Lesson, 1829) where they are considered to be alien and invasive species, mainly because of their high fecundity (de Paula *et al.*, 2014), rapid linear skeletal growth (Wellington & Trench 1985), allelochemical defenses (Lages *et al.*, 2010a, b) and competitive aggressiveness (dos Santos *et al.*, 2013; Miranda et al., 2016).

The alien cup corals (*T. tagusensis* and *T. coccinea*) were reported for first time in the Southwest Atlantic in 1980s on oil and gas platforms in the Campos Basin, Southeast of Brazil (Castro & Pires, 2001). Subsequently, these alien coral spread rapidly along the Southeastern (Ferreira, 2003; de Paula & Creed, 2004; da Silva *et al.*, 2014) and Southern (Capel, 2012) coast of Brazil, changing the native benthic community structure on rocky shores (Lages *et al.*, 2011). However, several researchers have showed great concern with the invasion of this alien coral species on the east tropical coast of Brazil (dos Santos *et al.*, 2013; Costa *et al.*, 2014), where the most important coral reefs and the highest marine biodiversity in the Southwest Atlantic can be found (Leão *et al.*, 2003).

Recently, *T. coccinea* and *T. tagusensis* were reported in Todos os Santos Bay (TSB), Bahia state in Eastern Brazil (Sampaio *et al.*, 2012). This bay is considered a priority for conservation due to its high levels of coral endemism and to the great diversity of natural systems (Leão *et al.*, 2003; Barros et al. 2012a, b; Vila-Nova *et al.*, 2014; Cruz et al., 2015). Previous studies in TSB have shown that this alien coral can modify the benthic assemblage structure on a coral reef site (Miranda *et al.*, 2016). Therefore, an expansion of

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Tubastraea species on others reefs or even to other habitats (e.g., estuaries) can potentially modify biodiversity and eventually alters dynamics and functioning of the natural systems in TSB.

To date, no studies have evaluated the geographical distribution and potential expansion of this alien around TSB. In the present study, we report the actual distribution of *Tubastraea tagusensis* and *Tubastraea coccinea* around TSB, an important system in the Southwest Atlantic coast. We reveal thirteen new records on the estuarine and reef systems in TSB and discuss how these findings will contribute to the future monitoring and management of this alien coral.

Material and methods

An extensive SCUBA diving survey was performed on 50 sites of the reef and estuarine systems around TSB between January 2011 and January 2015, to record the presence of the alien species *Tubastraea tagusensis* and *Tubastraea coccinea* (Fig. 1). The reef systems were mainly located at the entrance to the bay, in its central, northeastern, and exterior parts, and in a large estuarine system in the northwestern section of TSB (Paraguaçu estuary, Fig. 1a).

At each site, three SCUBA divers swam near the consolidated substrate in opposite directions, checking the presence of each species of *Tubastraea*. Each diver conducted three 10 m transects, spending about 5 min per each transect. The alien species were visually identified, photographed and recorded on PVC plates. The two species (*T. tagusensis* and *T. coccinea*) are morphologically different and easily distinguished from other native coral species (de Paula & Creed, 2004).

Results

Our survey showed that the alien species *Tubastraea tagusensis* and *Tubastraea coccinea* were present in 18 sites and absent in 32 sites around TSB (Figs. 1 and 2). Among the 18 invaded sites, we identified 13 new reports and confirm the establishment of the alien coral on 5 sites previously reported. Table 1 shows description of invaded sites listed by invasion chronological order.

The alien coral species were found on 12 sites in Paraguaçu estuary and on 6 different reef sites of TSB mostly in cryptic habitats with vertical and/or negative inclinations, low light incidence, and depth between 0.5 to 21 m. In the Paraguaçu estuary, the invasive species were also observed on intertidal areas where, in low tides, it was exposed to desiccation (e.g., Fig. 2c). Several invaded sites of consolidated substrata were observed in Paraguaçu estuary, mainly on artificial substrates (piers, $n = 10$ and oil platforms, $n = 1$) as well as natural rocky reefs ($n = 2$). In the reef systems, these species were observed mainly on artificial structures (seawall, nautical signs, pier and shipwreck) but also on natural coral reefs (Table 1).

Several natural coral reefs ($n = 22$) around TSB, still not invaded by *Tubastraea* species, were reported on Fig. 1 for future monitoring.

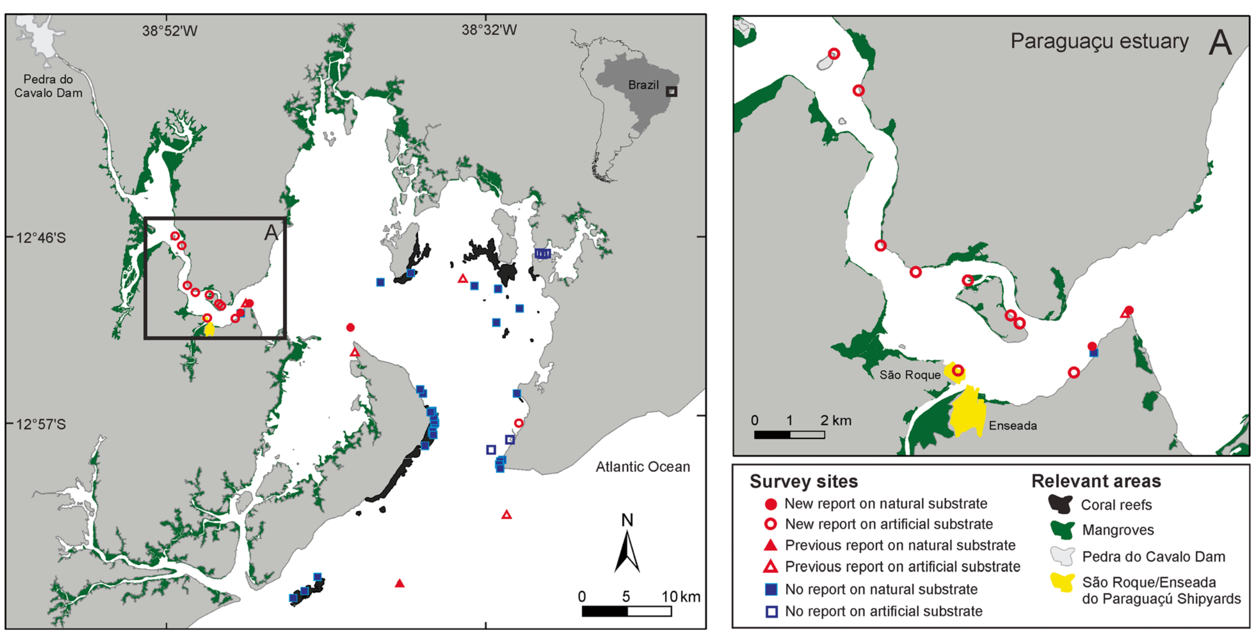

Fig. 1 Map of survey sites indicating the presence or absence of *Tubastraea tagusensis* Wells, 1982 and *Tubastraea coccinea* Lesson, 1829 around Todos os Santos Bay, Brazil, Southwest Atlantic: A- Paraguaçu estuary

Fig. 2 Sites colonized by *Tubastraea tagusensis* Wells, 1982 and *Tubastraea coccinea* Lesson, 1829 in Todos os Santos Bay, Bahia, Brazil: **a** coral reef, **b** rocky reef, **c**-**d** piers, **e**-**f** oil platform; the white arrow indicates the alien coral colonies in detail. Photos: RJ Miranda and Z Pescador

Discussion

Our results demonstrated an expansion of *Tubastraea tagusensis* and *Tubastraea coccinea* inside TSB, such that they are now distributed in over 18 sites in the estuary and on reef systems, following their first record in 2008 (Sampaio *et al.*, 2012). Possible explanations of the continuous invasion of these species are related to several biological characteristics of this invader including their reproductive strategies (e.g. high oocyte production, precocious reproduction age, short embryo incubation time and hermaphroditism; de Paula *et al.*, 2014) in addition to its ability to successfully colonize different substrates and habitats (Creed & de Paula, 2007). During spawning peaks, these species can release a large number of larvae (de Paula *et al.*, 2014) that are dispersed by currents and the planulae are highly buoyant, swimming actively through ciliary movements (Mizrahi, 2008). Therefore, several observations of this alien coral were made not only on natural rocky and coral reefs but also on artificial piers, oil platforms and seawalls in TSB.

Surprisingly, the number of invaded sites was relatively high in Paraguaçu estuary, even though the occurrence of the alien cup coral in other estuarine systems has rarely been reported (Cairns, 2000; Fenner & Banks, 2004; de Paula & Creed, 2005). Estuaries have highly variable salinity levels (Mclusky, 1993; Mclusky & Elliott, 2008) that can limit survival of many coral reef species. Moreira *et al.* (2014) experimentally showed high mortality rates of *T. tagusensis* and *T. coccinea* when exposed to low salinity (i.e., 0, 5, 10 practical salinity units). However, the *Tubastraea* invasion in the Paraguaçu estuary may have occurred due to the predominance of marine salinity levels (Genz *et al.*, 2008; Reis-Filho *et al.*, 2010; Genz & Lessa, 2015). This condition is likely to be associated with the building of the Pedra do Cavalo Dam in 1985 and Pedra do Cavalo Hydroeletric Power Plant in 2005 on the upper estuary (Fig. 1), which altered the hydrological regime by reducing freshwater flow (Genz *et al.*, 2008). Furthermore, the frequent oil platforms anchorage at São Roque do Paraguaçu shipyard in the lower estuary (Fig. 1a), may explain the high number of invaded sites in

Table 1 Date, type and location of sites invaded by *Tubastarea tagusensis* Wells, 1982 and *Tubastraea coccinea* Lesson, 1829 in Todos os Santos Bay. APA BTS = Environmental Protected Area of Baía de Todos os Santos; RESEX Iguape = Marine Extractive Reserve of Iguape (Datum WGS 84)

Invaded Site	Year Registered	System	Marine Protected Area	Coordinates	Substrate Type	Depth (m)
1. Cavo Artemide[a]	2008	reef	APA BTS	13°3.31'S 38°31.551'W	shipwreck	15
2. Recife dos Cascos[a]	2011	reef	APA BTS, APA Recife das Pinaúnas	13°7'27.34"S 38° 38'17.44"W	coral reef	13-21
3. Marina de Itaparica[a]	2011	reef	APA BTS	12°53'21.28"S 38° 41'3.44"W	pier float	0.5-1
4. Poste 4[b]	2012	reef	APA BTS	12°48'51.37"S 38° 34'16.71"W	nautical signs	6
5. Píer Paraguaçu[b]	2012	estuarine	APA BTS	12°50'24.96"S 38° 47'40.75"W	pier	2-3
6. Farol Paraguaçu[c]	2012	estuarine	APA BTS	12°50'21.91"S 38° 47'37.87"W	rocky reef	4-6
7. Maias[c]	2012	estuarine	-	12°51.341'S 38°48.457'W	pier	2-3
8. Monte Cristo 1[c]	2012	estuarine	-	12°50'33.60"S 38° 49'21.42"W	pier	2-4
9. Monte Cristo 2[c]	2012	estuarine	-	12°50.446'S 38°49.488'W	pier	2-4
10. Pedra Mole 1[c]	2013	estuarine	-	12°50.942'S 38°48.211'W	rocky reef	18
11. Ilha da Barra[c]	2013	estuarine	-	12°49'51.80"S 38° 50'10.23"W	pier	2-3
12. Estaleiro São Roque[c]	2013	estuarine	-	12°51'20"S 38° 50'10"W	pier and oil paltforms	0.5-4
13. Píer 1[c]	2013	estuarine	RESEX Iguape	12°49'44.70"S 38° 51'0.20"W	pier	2-3
14. Píer Caju[c]	2013	estuarine	RESEX Iguape	12°49'19.30"S 38° 51'33.40"W	pier	2-3
15. Píer Medrado[c]	2013	estuarine	RESEX Iguape	12°46'50.40"S 38° 51'54.30"W	pier	2-3
16. Ilha do Francês[c]	2014	estuarine	RESEX Iguape	12°46'15.60"S 38° 52'16.80"W	pier	2-3
17. Quebramar Porto Salvador[c]	2015	reef	APA BTS	12°57'42.94"S 38° 30'52.24"W	seawall	2-14
18. Pedra da Pizza[c]	2015	reef	APA BTS	12°51'51.00"S 38° 41'20.28"W	coral reef	3-10

[a]Sampaio et al. (2012) [b]Miranda et al. (2012) [c]Present study

this area. Oil platforms are one of the main vectors for alien cup coral introductions around the world (J.C. Creed et al., unpubl. data). In fact, one introduction was previously reported at the Paraguaçu estuary on April 7th 2014 (J.C. Creed et al., unpubl. data); but has not been investigated. Finally, the building of the Enseada do Paraguaçu shipyard in 2014 also increased the chances of alien cup coral establishment in this estuary.

The high number of invaded sites on Paraguaçu estuary shows the success of the alien coral colonization on consolidated substrate (natural and artificial). Several studies have shown that colonization of *Tubastraea* species on invaded areas may be facilitated by production of allelochemicals (secondary metabolites, see Lages *et al.*, 2010a, b) with anti-fouling and anti-predation properties capable of causing damage in native competitors (Lages *et al.,* 2012). Thus, *Tubastraea* species once established at Paraguaçu estuary could reduce native species abundance (e.g., oysters and barnacles) altering the benthic structure assemblage on consolidated substrate (Lages *et al.*, 2011; Mantelatto & Creed, 2014). The suspension-feeding native oyster (e.g., *Crassostrea* spp.) may play a valuable role on estuarine productivity by filtering particulate material from water column and then depositing on the bottom, which are available to the benthic deposit feeders (e.g., polychaetes and molluscs) (Mclusky & Elliott, 2008). In fact, benthic macroinfauna in soft sediments of Paraguaçú estuary is a diverse and relatively preserved assemblage (e.g., Barros et al. 2012a, b; Barros *et al.*, 2014). Therefore, changes in these assemblages could profoundly affect ecosystem processes.

Invaded sites were also found on the reef system including one coral reef site inside the bay (Pedra da Pizza, see Fig. 1 and Table 1). This was the second invaded coral reef site in TSB, after the first location was reported in 2011 outside the bay (Cascos Reef, see Sampaio *et al.,* 2012). Coral reefs are well known as important systems that harbor high diversity in some areas and provide several resources for associated organisms (e.g., Moberg & Folke, 1999; Costanza *et al.*, 2014). TSB coral reefs concentrate relatively high species richness and endemism for Brazil (Leão *et al.*, 2003). Previous studies showed that the presence of the alien coral on Cascos Reef altered the native benthic assemblage structure likely by increasing the mortality of some native coral species through efficient competition (Miranda *et al.,* 2016). Consequently, the expansion of the alien coral on TSB' coral reefs may reduce native coral cover and cause changes in the functional benthic group dominance (Cruz et al. 2014) from hermatypic to ahermatypic coral, altering coral reef functioning. Coral reefs are highly dependent on hermatypic corals (e.g., branching, tabular and massive forms) which build complex physical structures, creating several microhabitats which favor high biodiversity (Graham & Nash, 2012; Leal *et al.,* 2013; Rogers *et al.,* 2014). Thus, the change from hermatypic to ahermatipic coral dominance could impact the richness and abundance of associated species.

Tubastraea invasion might affect not only benthic assemblages as pointed out above, but also fish assemblages in TSB. For instance, changes in habitat complexity, reduction of hermatypic coral and algae cover and abundance of invertebrates associated with different habitats (coral, rocky reefs, mangroves) can lead to shifts in fish foraging microhabitat choices and flight responses (e.g., Nunes *et al*., 2013; Nunes *et al.,* 2015). However, these effects must be formally searched for.

Conclusions

Here we presented a detailed distribution and evidence of expansion of the cup corals (*T. coccinea* and *T. tagusensis*) in the TSB that will contribute to the establishment of an important baseline for the long-term monitoring of the invasion of these species in the bay. Based on the results of the present study, we urgently recommend the monitoring of all of the study sites and the discussion and implementation of management actions at the invaded sites to control the alien coral expansion. The reduction of propagule pressure is the main recommendation to control invasion success (Johnston *et al.,* 2009). Currently, manual control (i.e., colony removal by divers) is the only viable action to reduce propagule pressure of *Tubastraea* species in Brazil (da Silva *et al.,* 2014). It was first implemented on invaded rocky shores at Ilha Grande Bay (Rio de Janeiro state, see da Silva *et al.,* 2014) and on coral reefs at TSB it has been carefully conducted on a small scale. Nevertheless, as these species have high reproductive capacity (de Paula *et al.,* 2014), we suggest that studies must be carefully conducted (i) to evaluate the efficiency of manual removal for reduction of alien coral populations and (ii) to develop new methods for control.

Currently, the Paraguaçu estuary is the main source of alien coral in TSB and we agree with recommendations that all oil platforms should be cleaned more effectively (Costa *et al.*, 2014), using freshwater (low salinity, see Moreira *et al.*, 2014) before entering TSB.

Abbreviation

TSB, Todos os Santos Bay

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Authors' contributions

Collected the data: RJM. Prepared the map: RJM FLL YC. Wrote the paper: RJM YC FLL JACCN FB. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable

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