

Marine Record

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First record of the exotic *Eualetes tulipa* from Bahia State, Brazil, co-occurring with *Tubastraea* corals (Scleractinia, Dendrophylliidae)

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Abstract

Extending over warmer environments in the Brazilian waters, the exotic vermetid *Eualetes tulipa* was first recorded from Ceará State (3°S) in 2005. In 2009, it was reported in cold-water environments in Rio de Janeiro State (22°S). Seven years later, *E. tulipa* was recorded from Rio Grande do Norte State (6°S) on rocky pools in sandstone reefs. In the present study, *E. tulipa* is for the first time recorded from Bahia State (12°S), associated with a bio-fouling community in the Todos-os-Santos Bay, co-occurring with exotic dendrophylliid corals (*Tubastraea*). The vermetid community recorded from Bahia State shows a great diversity of epibionts, mostly bivalves, cirripeds and sponges. The co-occurrence of *Eualetes* and *Tubastraea* corals must be monitored, once these exotic species are co-occurring in a protected environmental area, bringing concern on possible impacts on native benthic fauna.

Introduction

The knowledge of native Brazilian Vermetidae species was updated by Spotorno *et al.* (2012), comprising the most recent inventory of these gastropods from Brazil. The authors provided a checklist with 16 species, most of them determined only in genus level, distributed into four genera: *Dendropoma* Mörch, 1861, *Thylacodes* Guettard, 1770, *Thylaeodus* Mörch, 1860 and *Petalococonchus* Lea, 1843.

In the 1970s, two species, *Vermetus* (= *Dendropoma*) *irregulare* (d'Orbigny, 1842) and *Petalococonchus varians* (d'Orbigny, 1841), were commonly distributed along the Brazilian coast, the latter being the dominant species in the fossil reefs. According to previous studies, *P. varians* usually forms dense aggregations on the coast (Laborel, 1977). Nevertheless, the species began to decline at the end of the 70s. It has been conjectured that the primary process of this reduction occurred by the synergic pressure of anthropogenic and biological variables (e.g. oil pollution, water turbidity and/or competition with *Vermetus*) (Laborel, op. cit). Recent studies have also indicated the recovery of the native *P. varians* population to the Southeastern coast, with high densities reported from rocky intertidal shores in Ilha Grande Bay (23°S) (Breves *et al.*, 2017).

On the other hand, *Eualetes tulipa* (Russeau in Chenu, 1843) is the only non-native vermetid species known from Brazil. Despite the diagnosis not determining the type locality, *E. tulipa* was first recorded from the Pacific Coast, in Panamá Bay, which has been considered its probable centre of origin (Keen, 1971; Spotorno-Oliveira *et al.*, 2018; Tan *et al.*, 2021).

In 2009, this vermetid was recorded in the cold-water environment of the northern Rio de Janeiro State (22°S). Thenceforth, *E. tulipa* has spread to warmer environments in the Tropical Brazilian Province, with previous reports at lower latitudes for the States of Ceará (3°S) and Rio Grande do Norte (6°S) (Spotorno-Oliveira *et al.*, 2018). As other calcifying sessile invertebrates, the vermetid dispersion strategy is likely to occur by rafting mechanisms, using drifting marine debris such as polystyrene, pet bottle, wood and coconut, fouling on ship hull, ballast water and also through current transport of mucus strands (Thiel and Gutow, 2005; Breves and Skinner, 2014; Spotorno-Oliveira *et al.*, 2018). The pelagic short-lived larvae of *E. tulipa* may also contribute to the natural dispersion and introduction of the species in new areas, but data on the larvae competency have not been published yet (Spotorno-Oliveira *et al.*, 2018).

Eualetes Keen, 1971 comprises only two valid species, but the type locality has not been assigned to either of them. *Eualetes centiquadrus* (Valenciennes, 1846) is assumed to be restricted to the Pacific Ocean, including Colombia and West Mexico (Bieler and Petit, 2011). The congener, *E. tulipa*, has been gradually expanding its natural limits of distribution, being pointed out as introduced in some localities through the Indo-Pacific, such as the Hawaii Islands (Coles *et al.*, 2006), India (Jebakumar *et al.*, 2015), the Caribbean (Miloslavich and Penchaszadeh, 1992; Miloslavich, 2018), the Southeast Asia (Tan *et al.*, 2021) and Southwestern Atlantic, as well (Spotorno-Oliveira *et al.*, 2018; Skinner *et al.*, 2019).

Deeply involved in the organic matter flow, being also sensitive to climate changes, hydrodynamics and turbidity (Colombo *et al.*, 2009; Soares *et al.*, 2010), these cemented odd gastropods are promptly recognized by the irregular, untwisted teleoconch (the adult shell), while the embryonic, as well as the larval shell, follow the regular coiled pattern. After attaching to the substrate, the juvenile rapidly develops into a linear shell structure, with the aperture of the tubes commonly



projecting upwards. Regarding feeding habits, vermetids are filtering ‘worm-like’ molluscs that act as scavengers capturing organic particles through a mucus net (Kappner *et al.*, 2000). In this way, long shell-like tubes have a double action by (1) preventing the vermetid from overgrowth by corals, and (2) keeping free access for the mollusc to feed on food particles (Kappner *et al.*, 2000).

Finally, the vermetids have essential reproductive strategies (e.g. capsular lecithotrophic development, intracapsular adelphophagy, female long-term sperm storage, reproduction by self-fertilization and parthenogenesis) and diverse dispersion mechanisms to succeed in a foreign environment. As Strathmann and Strathmann (2006) supported, ‘Any of these reproductive traits would aid founding of a population by a dispersed individual and invasive spread of this species’ (p. 105).

In the present study, we record *E. tulipa* for the first time from the Bahia State (12 oS), occurring syntopically with *Tubastraea* in a benthic fouling community, located in a port area. An anatomical and morphological description of *Eualetes* exemplars from Bahia is provided.

Material and Methods

Study area

This study is part of a major project intending to assess the diversity, density and dispersion of sun corals in the Todos-os-Santos Bay, Bahia State (BA). Sampling was carried out in August 2019 by scuba diving at the ‘Terminal Turístico Náutico da Bahia’ – TTNB (12°58′00.0″S/38°31′31.5″ W) (Figure 1). The area is a private boat dock used for navigators and travellers from all over the world. A benthic fouling community, majorly composed of sun cup corals, sponges,

oysters, barnacles, hydroids, octocorals and ascidians, is observed attached to the decks of the dock, in an upside-down position, and vertically along the pillars – from the surface to a depth of approximately 3–5 m. The internal deck structure is covered by fiberglass, on which the community has established. The Todos-os-Santos Bay is Brazil’s second-largest navigable bay, with a maximum area of 1223 km² and an average depth of 9.8 m (Cirano and Lessa, 2007). Because of the scenic beauty, the pristine ecosystems, and the extraordinary biodiversity, it was designated an Environmental Preservation Area in 1999 (State decree no. 7.595 5th June 1999) (Hatje and Andrade, 2009).

Sampling

Quadrats were adopted as a protocol for collecting data and samples. Four quadrats (50 × 50 cm) were systematically placed in three different areas considering the densities of the *Tubastraea* spp. colonies, i.e., cover varying between 1 and 20% (low density), 40 and 60% (medium density) and 80 and 100% (high density). Considering they were never replaced at the same point, a total of 12 quadrats were obtained. As a rule, the coral cover was measured by the frequency of the occurrence of the colonies in the quadrat grids, following the cover categories previously established, being all sessile organisms inside quadrats removed and placed into plastic bags individually. To avoid skeleton and shell fragmentation, spatula, hammer and chisel were carefully used during the process. A total of 44 vermetids were selected for analysis.

Analysis

In the laboratory, animals were sorted out, being the samples of *E. tulipa* separated and preserved in an ethanol solution of 70%.

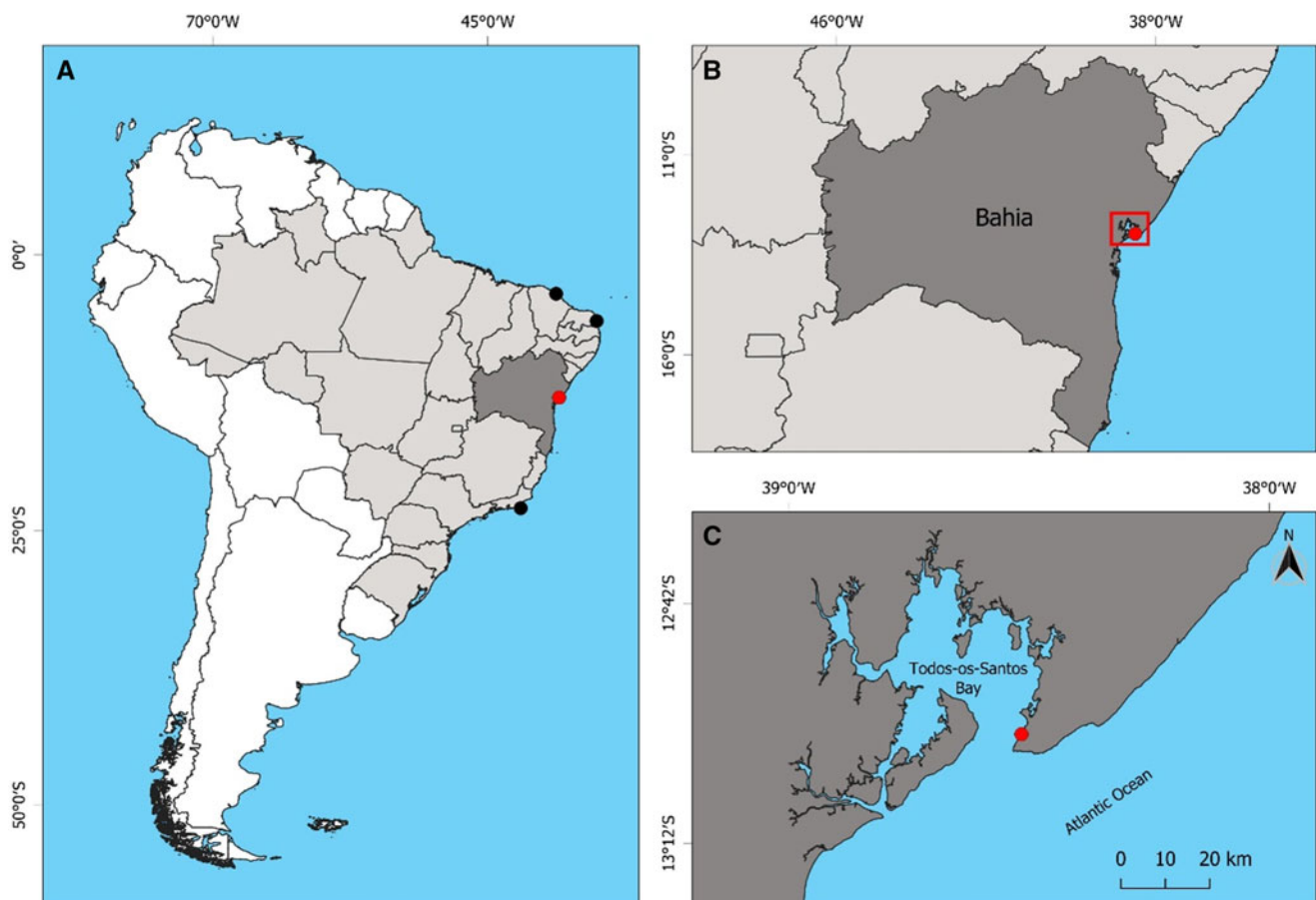


Figure 1. Map of the study area. (A) Terminal Turístico Náutico da Bahia (TTNB). (B) Numbers indicating the chronological order of appearance of *Eualetes* on the Brazilian coast: 1 = Ceará State, 2 = Rio Grande do Norte State, 3 = Rio de Janeiro State, 4 = Bahia State.

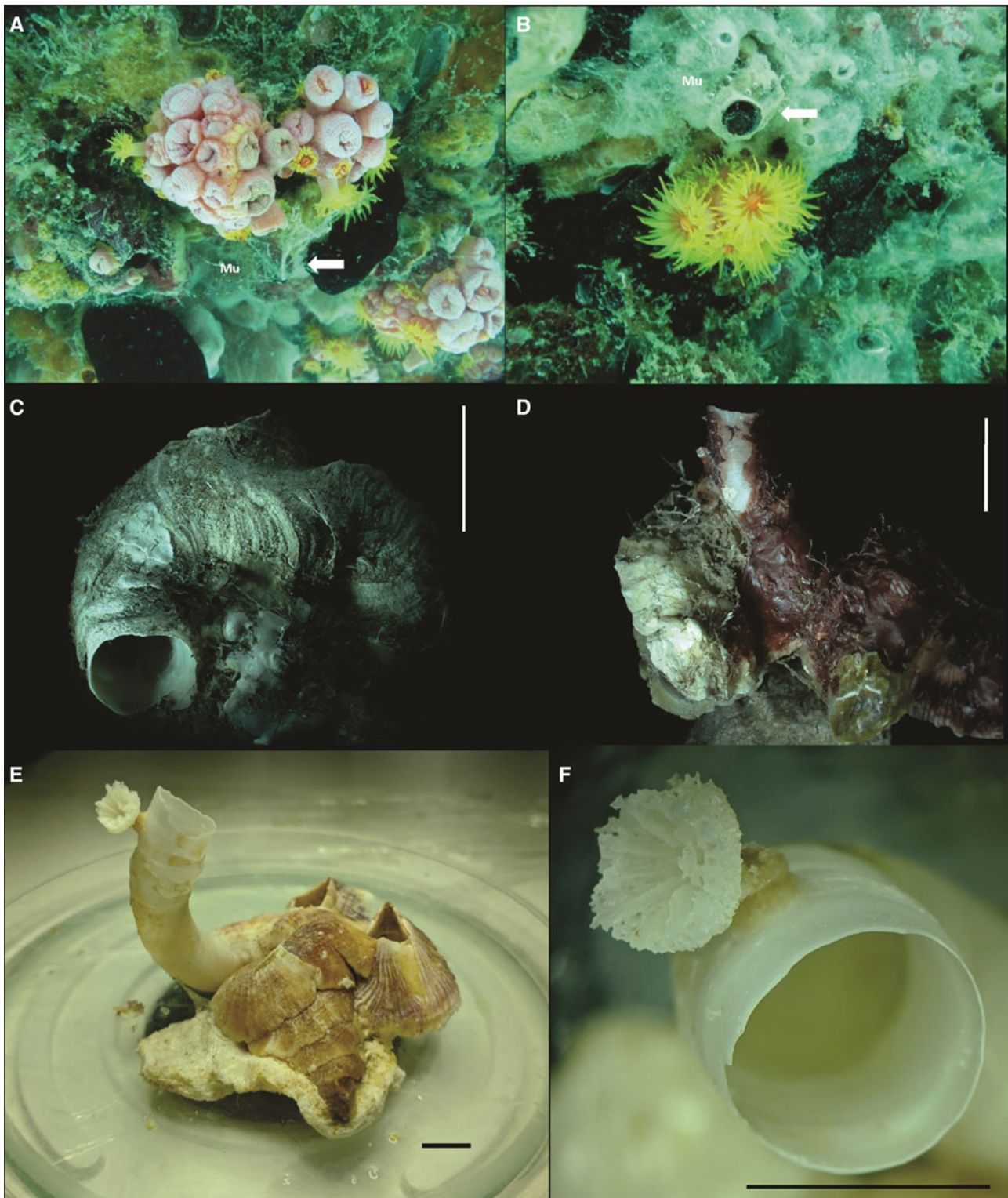


Figure 2. (A) The benthic community settled upside down on a port pier in the Todos-os-Santos Bay. (B) *Eualetes* vermetids (arrows) occurring syntopically with *Tubastraea* corals. Mucus threads (Mu) are observed around the vermetid tube shell. (C) *Eualetes tulipa* shell growth patterns. Teleoconch with piled-up whorls and apertures close to the substrate. (D) Teleoconch expanded towards forming elongated cylindrical tubes with high apertures, densely covered by epibionts. (E, F) Polyp of *Tubastraea* epibiotic of *Eualetes tulipa* shell. Scale bars: 2 cm (A–D); 1 cm (E, F).

All 44 specimens were separated according to the quadrat, considering the three *Tubastraea* densities. After that, all the specimens were measured and the epibiont fauna in each exemplar was identified and counted, bryozoans were not counted by the complex disposition of these organisms in the shell surface, being classified by presence and absence of colonies in vermetiid shells. An infographic with all the collected information was developed.

For taxonomical analyses and morphometrics, four individuals were dissected and drawn under a stereoscopic microscope (Zeiss Axio 1.6) with camera lucida. By comparing radula and shell characteristics, individuals were identified based on Spotorno-Oliveira *et al.* (2018) and Skinner *et al.* (2019). The shells were photographed and measured with a Mitutoyo digital caliper. The epibionts were counted, morphotyped and identified to the

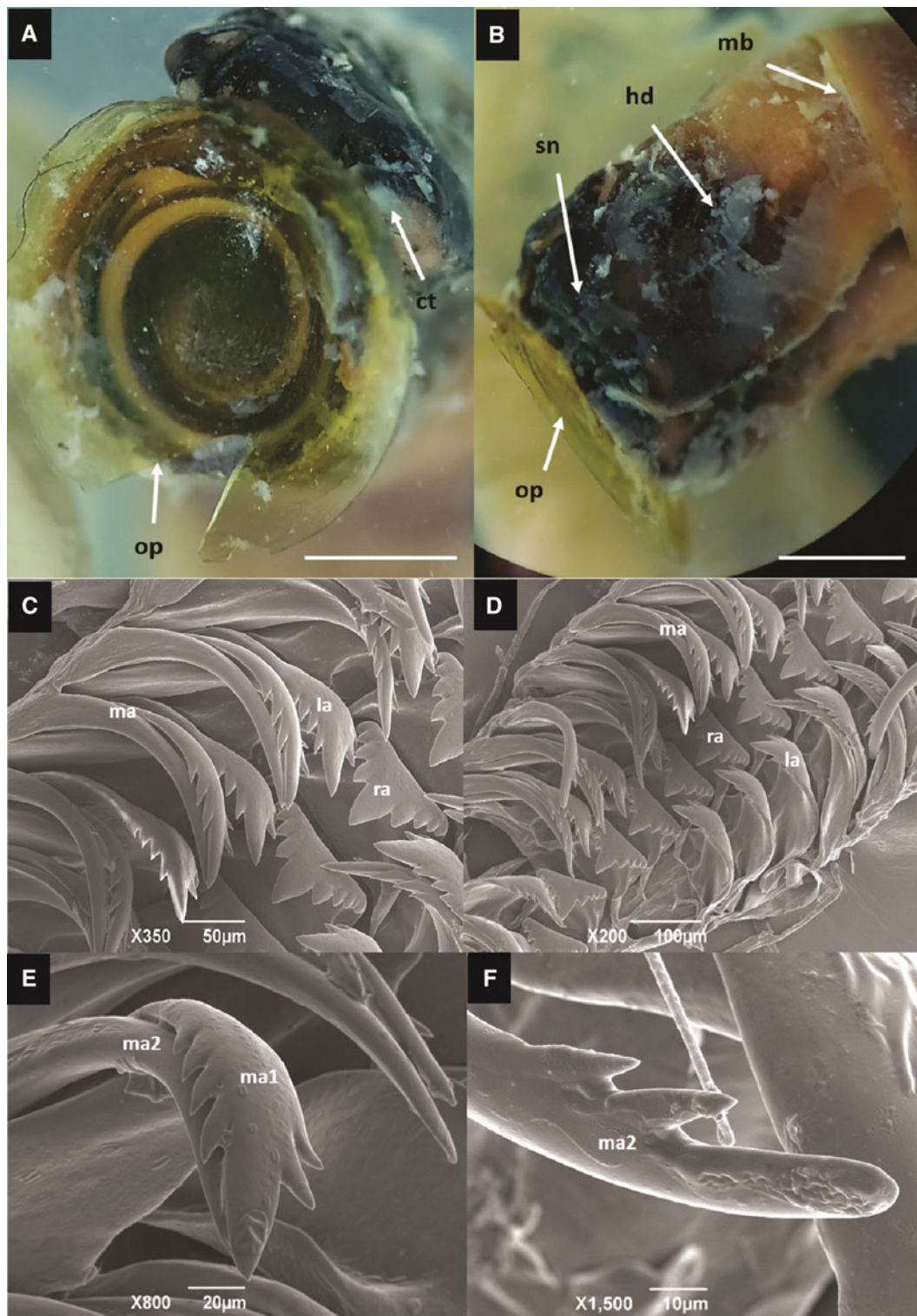


Figure 3. *Eualetes tulipa* (A) Front view of the corneous operculum. Scale bar = 3 mm. (B) Lateral view of the head. op, operculum; ct, cephalic tentacles; sn, snout; hd, head; mb, mantle border. Scale bar = 3 mm. (C, D) Radula taenioglossate, consists of a central and robust tooth (rachidian tooth), a pair of lateral teeth and two pairs of marginal ones. (E, F) Marginal teeth slender and fused, the external tooth (less serrated), with a main well-marked cusp, and only two lateral cusps. ma, marginal teeth; ma1, marginal inner tooth; ma2, marginal outer tooth; la, lateral tooth; ra, rachidian tooth.

lowest possible taxonomic level. For scanning electron microscopy, the radula was removed from dissected specimens and mounted on aluminium pin stubs, previously covered with a double-sided sticky tape, sputter-coated with 35 nm of gold in a Denton Vacuum Desk IV ion coater and examined through a Jeol JSM-6390LV, located at the Oswaldo Cruz Foundation (FIOCRUZ-BA).

Results

Systematics

CLASS GASTROPODA Cuvier, 1795
 ORDER LITTORINIMORPHA Golikov & Starobogatov, 1975
 FAMILY VERMETIDAE Rafinesque, 1815
 Genus *Eualetes* Keen, 1971

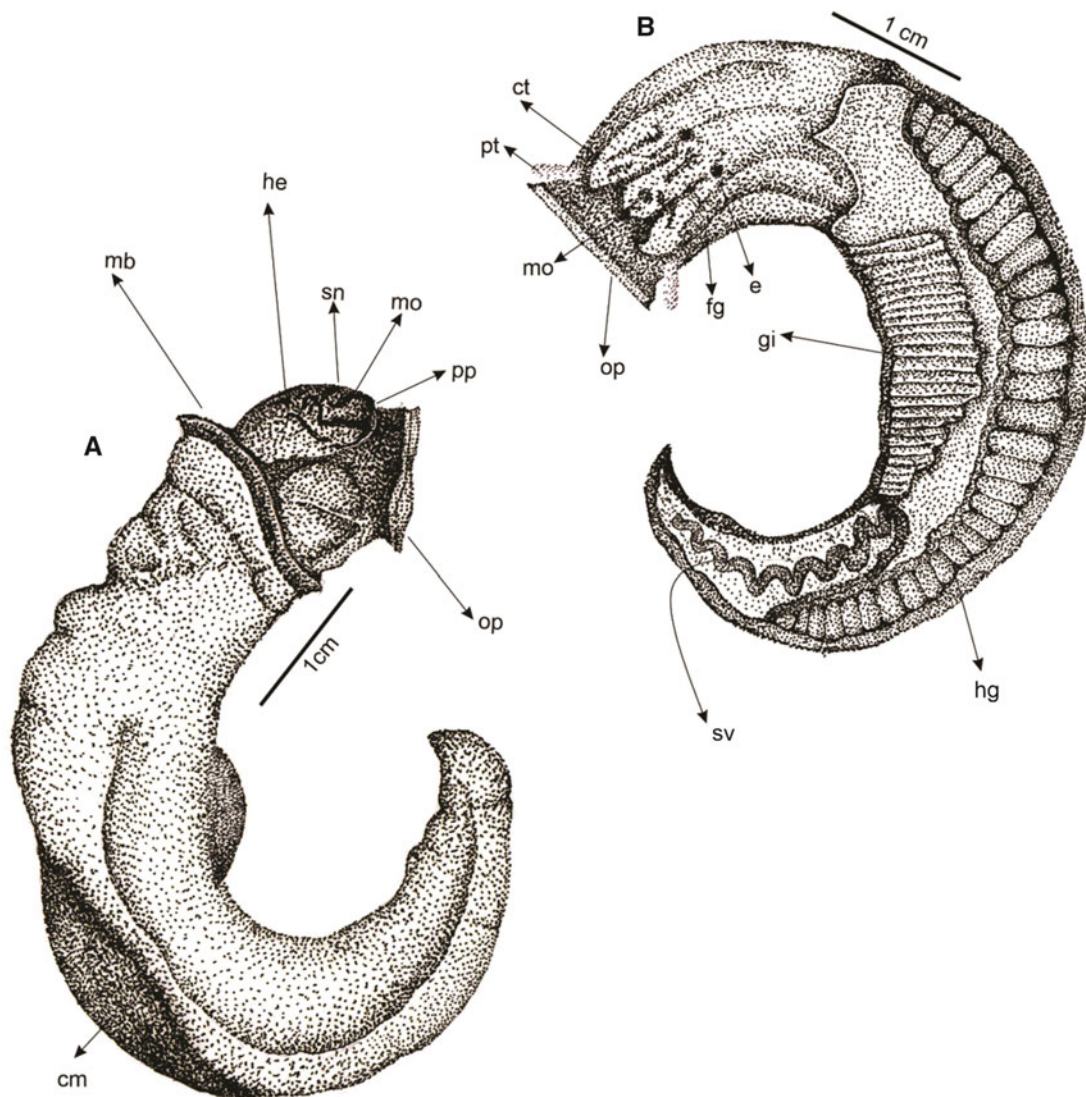


Figure 4. Scheme of the external morphology and internal anatomy of the vermetid *Eualetes tulipa*. (ct, cephalic tentacles; cm, columellar muscle; e, eye; fg, foot groove; gi, gill; he, head; hg, hypobranchial gland; mb, mantle border; m, mouth; op, operculum; pp, propodial pad; pt, pedal tentacle; sn, snout; sv, seminal vesicle).

Eualetes tulipa (Rousseau in Chenu, 1843)
(Figures 2–4)

Examined material

Four specimens. Terminal Turístico Náutico da Bahia – TTNB, Todos-os-Santos Bay, Bahia State, Brazil, (12°58'00.0" S/38°31'31.5" W), depth 3–5 m, associated with the benthic fouling community, 30th august, 2019, MZUSP 159664.

Description

Teleoconch irregularly coiled, periostracum varying in a single individual from reddish-brown to greyish in early whorls, to light-yellow to white on the bottom, opercular aperture diameter ranging from 1.73 to 9.43 mm (mean diameter = 6.12 mm). Adult shells densely covered by cementing epibionts. Head pronounced. Snout cylindrical. Mouth semicircle shaped, with a horizontal notch on the anterior margin snout. Eyes rounded and small, inserted in the cephalic tentacle bases. Operculum corneous, thin, with a translucent border and dark centre. Average diameter about 7.1 mm. Radula taenioglossate (radular formulae: 2-1-1-1-2). Pallial cavity occupying about $\frac{1}{3}$ of the soft parts length, while the visceral mass about $\frac{2}{3}$ of total length. Gills with three leaflets per mm; leaflets cylindrical, dark-grey digestive gland prevailing over the visceral

mass. Gonad beneath the digestive gland, ventrally positioned, forming a distal, thin and spiral tail.

Remarks

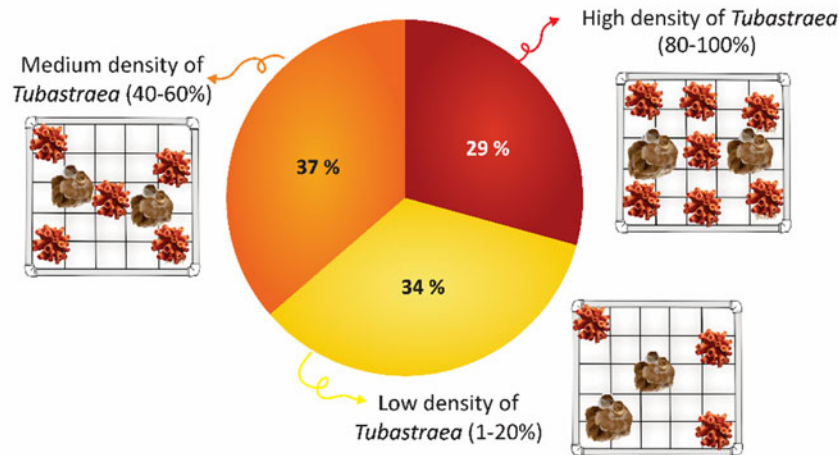
The analysed exemplars of *E. tulipa* from Todos-os-Santos Bay differ from the specimens described from Brazil by showing teleoconch opercular aperture varying from 1.73 to 9.43 mm, while previous studies described shell aperture ranging 5.22–14.07 mm in specimens recorded from Ceará, Rio Grande do Norte and Rio de Janeiro States (Spotorno-Oliveira *et al.*, 2018).

Opercular aperture is a variable measure, considering the previous records of *E. tulipa* around the world, according to Skinner *et al.* (2019), the aperture size may reflect the population density. Organisms from Rio de Janeiro show 17 mm of aperture, India and Venezuela specimens have 15 and 12 mm of aperture, respectively, whereas organisms from Hawaii show 8 mm of aperture (Miloslavich and Penchaszadeh, 1992; Jebakumar *et al.*, 2015; Skinner *et al.*, 2019).

Recent records of the vermetid from Singapore described populations with 11 mm of shell aperture (Tan *et al.*, 2021). Populations of *E. tulipa* from Rio de Janeiro are also considered well-established and more than 50% of studied individuals show shell aperture of more than 8 mm (Skinner *et al.*, 2019). The specimens here analysed have a lower aperture average of 6.12 mm, which could reflect the low age of the observed organisms.

Eualetes tulipa co-occurrence with *Tubastraea* spp.

Exemplars of *E. tulipa* studied per *Tubastraea* density area



Eualetes tulipa epibiotic fauna

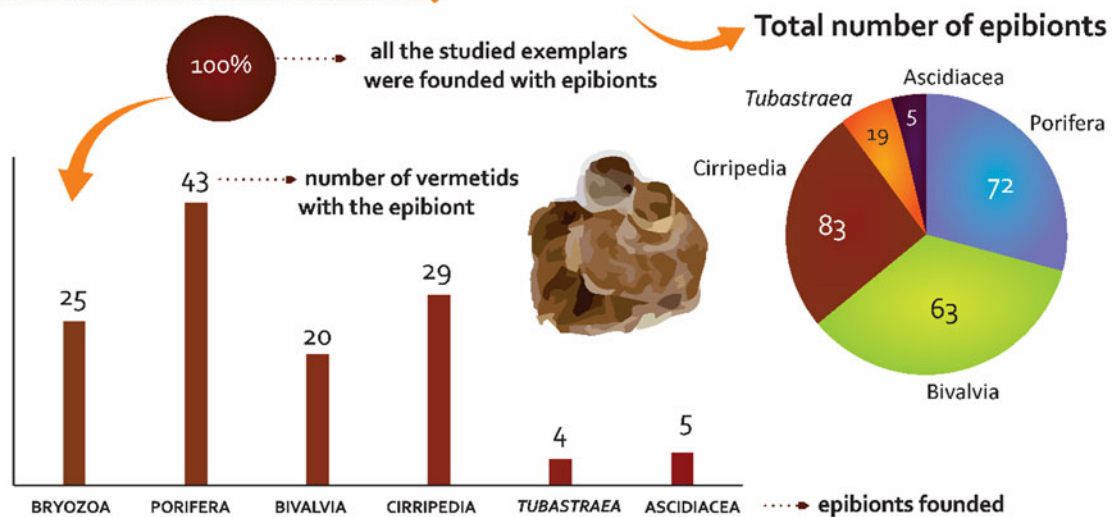


Figure 5. Infographic of *Eualetes tulipa* exposing the co-occurrence of the vermetid with *Tubastraea* and its epibionts diversity.

Ecologic notes. *Eualetes tulipa* was found in all densities of *Tubastraea*, 16 of 44 studied individuals were found in low density of *Tubastraea* (1–20%), 17 individuals were found in medium density (20–40%), and 13 individuals were found in high density (80–100%) (Figure 4). The measure of the shell aperture showed low variance, in low densities of *Tubastraea*, the vermetiids showed 6.33 mm of shell aperture on average, in medium densities, 5.42 mm on average, in high densities, the exemplars showed 6.49 mm of shell aperture on average.

All the specimens of *E. tulipa* were densely covered by epibionts of six Phyla, which are Porifera (Desmospongiae), Bryozoa, Arthropoda (Cirripedia), Mollusca (Bivalvia), Chordata (Ascidiacea) and Cnidaria (*Tubastraea* spp.) (Figure 5). A total of 73 sea sponges were found attached to 43 vermetiid specimens. Bivalvia molluscs were found in epibiotic with 20 vermetiids, a total of 83 individuals were counted. Bryozoa colonies were found in 25 vermetiid specimens (Figure 4). Five exemplars of Ascidiacea were found in five vermetiid shells, being one of the less abundant epibiotic taxa associated with *E. tulipa* (Figure 5).

In this study, *Tubastraea* colonies were found for the first time as epibiotic fauna of *E. tulipa*. The sun coral colonies (= 5) and primary polyps (= 14) were found in epibiosis with five vermetid shells,

three of them collected from a high-density *Tubastraea* cover while the others, in medium density (Figures 2E, F and 5). Up to now, *E. tulipa* has been only reported to TTNB, an artificial environment with biofouling influenced by the establishment of sun corals.

Discussion

In the Southwestern Atlantic, the number of exotic marine gastropods increased south and northwards, from cold to warmer waters, during the last 5 years. Gernet *et al.* (2019) recorded a member of the scavenger family Nassariidae, *Nassarius foveolatus* (Dunker, 1847), to Paraná State (25°S). A year later, Spotorno-Oliveira *et al.* (2020) reported the bivalve predator, *Rapana venosa* (Valenciennes, 1846), to Cassino Beach (Rio Grande do Sul State, 32°S). In 2023, another predator gastropod, *Indothais lacera* (Born, 1778), was identified in several localities in the TSB (12 oS) (Pedro *et al.*, 2023). In the same area, *E. tulipa* was for the first time observed co-occurring with *Tubastraea* colonies, alerting for a new non-indigenous species introduced in a protected environmental unit.

Milazzo *et al.* (2014) attest that the ‘vermetids form reefs in sub-tropical and warm-temperate waters that protect coasts from



Figure 6. Distribution of *Eualetes tulipa*, focusing on records from Brazil. Based on Spotorno-Oliveira *et al.* (2018) and Tan *et al.* (2021).

erosion, regulate sediment transport and accumulation, serve as carbon sinks and provide habitat for other species' (p. 1). Vermetid molluscs are also biological indicators, playing a role in the proxies to reconstruct paleoenvironments by estimating sea-level changes (Suguió *et al.*, 2013). Indeed, the impacts of *E. tulipa* on native reef communities are not fully comprehended. The species was analysed in the Caribbean, and it was suggested a negative influence on benthic marine populations caused by space competition with *Dendropoma corrodens* (d'Orbigny, 1841) (Miloslavich *et al.*, 2010). Moreover, Shima *et al.* (2013) also pointed out the deleterious effects of *E. tulipa* on the growth and survival of neighbouring coral colonies.

From warm waters in the Northeast to colder environments in the Southeast, the exotic *E. tulipa* is expanding its distribution along the Brazilian coast (Figure 6). Considering the dispersion of the sun corals through the Todos-os-Santos Bay in the last decade (Sampaio *et al.*, 2012), the presence of another exotic carbonate-producing organism associated with a biofouling community dominated by *Tubastraea* is an important record.

The exotic *E. tulipa* is expanding its distribution along the Brazilian Coast (Figure 6). Regarding previous dispersion of the sun corals across the warm waters of the TSB (Sampaio *et al.*, 2012), the presence of another exotic carbonate-producing organism associated with *Tubastraea* biofouling communities must be evaluated. Although the real risks of the *E. tulipa* on native

fauna have not been measured yet, most records of this gastropod from Brazil occurred in localities under anthropic pressure, majorly in areas of considerable vessel traffic and touristic activities (Figure 6). The co-occurrence of *Eualetes* and *Tubastraea* in artificial substrates of an anthropized environment may suggest a facilitation scenario (Tyrrell and Byers, 2007).

Because of the coverage of epibionts (e.g. algae, sponges, ascidians, bivalves, sun corals), this vermetid has a cryptic-like habit. Indeed, it may justify the few records of the species have been done over a relatively wide time interval (Spotorno-Oliveira *et al.*, 2018). In turn, overgrowth interactions do not affect these operculate snails that live inside of a calcareous tube-like shell. Due to the high shell plasticity, *E. tulipa* can change the direction of the opercular aperture, projecting it upwards, spreading the mucus net over the neighbourhood, and being capable of capturing food in all directions (Rezende *et al.*, 2021).

In a globalized world, the introduction and overspread of exotic species from the Indo-Pacific to the Atlantic Ocean become recurrent, and some of the most dispersive species will be sooner considered cosmopolitan. Undoubtedly, introduced organisms may represent a risk to local biodiversity, being also involved in facilitation processes in artificial substrates (Tyrrell and Byers, 2007). Therefore, biomonitoring programs are highly necessary to consolidate conservation and management policies to prevent bioinvasion impacts along the Brazilian Coast. Finally, treefold

research approaches, based on taxonomy, ecology and reproductive biology are expected to provide relevant data on the establishment and interaction of exotic species worldwide.

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Competing interest. None.

Ethical standards. No animal testing was performed during this study. All necessary permits for sampling have been obtained by the authors from the competent authorities and are mentioned in the Acknowledgements.

Data availability. Data will be made available on request.

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