PANAMJAS
Pan-American Journal of Aquatic Sciences

Interaction of non-native bivalves and exotic dendrophylliid corals (Scleractinia, Dendrophylliidae) in the Brazilian Northeast coast

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Abstract: Biological invasions are considered one of the major concerns of conservation policies worldwide, with the introduction of exotic organisms in coastal environments threatening marine biodiversity. Indeed, mollusks are among the top invertebrates introduced around the planet, with snails and bivalves transported out of their original geographical area through human activities. With great invasive potential, bivalves can cause cascading impacts, altering the structure, and processes of the benthic assemblages. Intending to assess the distribution and associated fauna of exotic dendrophylliids in the Todos-os-Santos Bay (12°S), Southwestern Atlantic, marine mollusks were identified. From 2020 to 2022, corals were monthly collected, and examined individually, in two populations on pier decks and columns. Colonies prevailed on carbonate substrates, majorly fixed on alive barnacles and bivalves, being also observed on vermetids, ascidians, and sponges. The identification of the bivalves provided evidence of the interaction between 'sun corals' and two other introduced organisms in the TSB: *Saccostrea cucullata* and *Isognomon bicolor*. All bivalves were apparently healthy, with the soft tissues intact. For the first time, it is described as a case of epibiosis between bivalves (basebionts) and scleractinians (epibionts).

Key words: Mollusca; biological invasions; epibiosis; range expansion; Tropical Southwestern Atlantic.

Interação de bivalves não nativos e corais exóticos dendrofilídeos (Scleractinia, Dendrophylliidae) na costa Nordeste brasileira. Resumo: As invasões biológicas são consideradas uma das principais preocupações das políticas de conservação em todo o mundo, com a introdução de organismos exóticos em ambientes costeiros ameaçando a biodiversidade marinha. De fato, os moluscos estão entre os principais invertebrados introduzidos em todo o planeta, com gastropods e bivalves transportados para fora da sua área geográfica original através de atividades humanas. Com grande potencial invasivo, os bivalves podem causar impactos em cascata, alterando a estrutura e os processos das assembleias bentônicas. Com o objetivo de avaliar a distribuição e fauna associada de dendrofilídeos exóticos na Baía de Todos-os-Santos (12°S), Atlântico Sudoeste, foram identificados os organismos associados, incluindo

moluscos marinhos. De 2020 a 2022, os corais foram coletados mensalmente, e examinados individualmente, em duas populações em píeres e colunas de deques flutuantes. As colônias predominaram em substratos carbonáticos, fixadas majoritariamente em cracas e bivalves vivos, sendo também observadas em vermetídeos, ascídias e esponjas. A identificação dos bivalves forneceu evidências da interação entre coral-sol e dois outros organismos introduzidos no TSB: *Saccostrea cucullata* e *Isognomon bicolor*. Todas os bivalves estavam aparentemente saudáveis, com os tecidos e partes moles intactos. Pela primeira vez é descrito como um caso de epibiose entre bivalves (basebiontes) e escleractinianos (epibiontes).

Palavras-chave: Mollusca; Scleractinia, invasões biológicas; epibiose; expansão do alcance; Atlântico Tropical Sudoeste.

Introduction

Anthropic activities have drastically altered species distribution in recent years, increasing concern about the global climate crisis, and the expectative of an unprecedented biodiversity decline. On a regional scale, and proceeding with the impacts caused by habitat degradation, biological invasion comprises one of the major threats to marine biodiversity (Carlton 1999, Chapman *et al*. 2017, Laeseke *et al*. 2020). Species with geographic distribution different from their natural ranges are commonly known as ‘non-native’. Several other terms, including ‘nonindigenous’, ‘exotic’, or ‘alien’ species, have also been adopted to designate foreign organisms.

According to the International Union for Conservation of Nature (IUCN 2021), invasive exotic species are “*organisms that are introduced into places outside their natural range, negatively impacting native biodiversity, ecosystem services or human well-being*.” Following the literature, these organisms are referred to as bioinvasive due to variable (and measurable) adverse effects, mainly because of their high capacity to promote rapid changes in the community composition by competition, predation, and/or parasitism, as well as, high population densities, and rates of dispersion (Canning-Clode 2015, Richardson *et al*. 2011). Beyond functional and structural modifications of native communities by changing ecological interactions (and the food web), invasive exotic species may affect the distribution of native organisms, also representing a risk to the economy, and public health as well (Boltoyskoy *et al*. 2022, Hollebone & Hay 2008, Thomsen *et al*. 2014). Indeed, the factors that may locally affect the success of non-native species remain poorly understood, and predicting the intensity of the impacts of these species remains particularly difficult.

Highly diverse, mollusks are among the major invasive groups of invertebrates on the planet, with a notable inventory of records and detection events (Bailey *et al*. 2020; Carranza *et al*. 2023). The introduction of mollusks has been principally attributed to human activities (Carlton 1999, Darrigran *et al*. 2020), although long-transport (or ‘aerial dispersion’) by birds has been also suggested – including bird feathers, or even after being preyed upon and passing intact through the digestive tract of predators (Gittenberger 2012). The African pulmonate snail, *Achatina fulica* Bowdich 1822, a vector of parasitic nematodes, was introduced in the tropics and subtropics in the XIX century (Thiengo *et al*. 2007). The red-rimmed melania, *Melanoides tuberculatus* (Müller, 1774), an euryoic freshwater snail, reported for the first time to South America by late ’60s, was introduced in the Martinique Is. (Caribbean) to control the population of *Biomphalaria* snails in the ’80s (Farani *et al*. 2015). The zebra mussel *Dreissena polimorpha* (Pallas, 1771), and the golden mussel, *Limnoperna fortunei* (Dunker, 1857), are freshwater bivalves monitored worldwide (Karatayev *et al*. 2007; Ludwig *et al*. 2021).

In the marine environment, bivalves prevail over all other mollusks as potentially exotic organisms. Bivalves have great invasive potential, threatening native species, and promptly altering processes in the receiving communities (Carlton 1999, Steffani & Branch 2005). The anthropic introduction of marine bivalves is certainly multifactorial. Larval and adult transportation may occur through aquaculture activities, biofouling on ship hulls, rafting on driftwood or styrofoam, and inadequate ballast water management (Minchin *et al*. 2009, Teixeira *et al*. 2010).

Successful invasion events by bivalves may be attributed to biological and ecological variable characteristics, such as rapid recruitment and growth, reproductive pattern (Giglio *et al*. 2016) and

adaptation to environmental conditions, short longevity, ability to colonize a wide range of habitats (e.g., natural/artificial, consolidated/unconsolidated), and a changeable physiological tolerance (Barbosa & Melo 2009, Lima & Passos 2021, Linares *et al*. 2017).

Invasive bivalves often act as ecosystem engineers (Darrigran & Damborenea, 2011) and usually occur in high densities (Salimi *et al*. 2021), forming monospecific beds and reef structures (Ruesink *et al*. 2005), also contributing to the biomass of the benthic marine community (Sousa *et al*. 2009). Furthermore, invasive bivalves can associate with other non-native species mutualistically or as commensal, exploiting possibilities of successful ecological interactions (Ricciardi 2001). In this context, the literature alerts that the establishment of non-native species can facilitate continued invasions of other invaders (Heiman *et al*. 2008).

Todos-os-Santos Bay (TBS) (12°S, 38°W) is a coastal environment of clear and warm waters (under the influence of the Brazilian Current) in the littoral of the Bahia State, Brazilian Northeast Ecoregion. This section has pristine ecosystems of high biodiversity, endemism, and productivity (e.g., estuaries, mangroves, coral reefs), which contribute to the TSB status of a priority area for conservation (Leão *et al*. 2003). Nevertheless, because of commercial and other human activities, the inventory of non-native invertebrates in the TSB has shown an alarming increasing tendency, following: *Charybdis hellerii* recorded in 1996 (Carqueija & Gouvêa 1996), *Tubastraea coccinea* and *Tubastraea tagusensis* first reported in 2008 (Sampaio *et al*. 2012), *Heteropia glomerosa* observed since 2012 (Klautau *et al*. 2020), *Licornia jolloisii* and *Triphyllozoon arcuatum*, possibly introduced in 2014 (Almeida *et al*. 2015), *Ophiothela mirabilis* sampled in 2016 (Fortunato & Lôbo-Hajdu, 2021), *Sarcothelia* sp. and *Briareum hamrum* first views in 2018 (Menezes *et al*. 2021) and *Carijoa riisei* (Castro *et al*. 2010), *Ascidia tapuni* and *Cnemidocarpa irene* (Rocha *et al*. 2012) with no first registration date set.

Data on non-native bivalves in TSB have not been published so far. Indeed, and despite its ecological relevance, the taxonomic inventories of mollusks in this important area are scarce and prevalent in gray literature. Thus, as part of the scope of a major project that intends to analyze the fauna in benthic communities with and without dendrophylliid corals (‘sun corals’), we provide the first records of marine bivalves introduced in the TSB, contributing to the knowledge of two non-native species that are expanding their distribution along the Southwestern Atlantic. Based on *in situ* observations and sample analyses, we discussed the interaction between sun corals and bivalves, including non-native ones, where corals use bivalves as substrate, suggesting an epibiont-basibiont interaction.

Materials and methods

Sun coral colonies from the TSB were collected monthly in the Marina of Itaparica (12º53’20” S, 38º41’4” W) and Marina Porto Salvador (12º58’20” S, 38º30’57” W), between September 2020 and May 2022. In the same period, further additional sampling was sporadically carried out at two other sites: São Roque do Paraguaçú Shipyard (12º51’32” S, 38º50’5 W) and Marina of Bom Jesus dos Passos (12º45’42” S, 38º38’9” W) (Fig. 1), resulting a total of 21 field activities. In each sampling site, a total of 40 colonies were randomly selected and carefully removed with a spatula and hammer from floating piers, pier columns, and decks on the negative side of the supporting pillars which remain permanently submerged – thus, the benthic community was not exposed to tidal variation. For the description of the associated fauna, colonies were photographed in the field and then preserved in 90% alcohol. In the laboratory, the associated fauna was removed, and the organisms were preserved and subsequently identified to the lowest possible taxonomic level.

The bivalves were identified according to specialized literature (Amaral & Simone 2016, Domaneschi & Martins 2002, Mikkelsen & Bieler 2008, Rios 2009). Part of the material examined was deposited in the Mollusca Collection at the Museum of Zoology of the University of São Paulo (MZUSP), and in the Marine Invertebrate Collection at the Zoological Collection of the North Capixaba (CZNC - CEUNES/UFES).

Results

In the TSB, we found sun corals are settled on living carbonate substrates, being part of the biofouling communities found in artificial substrates (e.g, columns, and deck piers). These exotic corals are observed in epibiotic association, majorly with mollusks and barnacles (Figs. 2a, 2c, 2d), which are usually cemented to the substrate by a byssus or fixed with a complex, protein-binding substance (Dickinson *et al*. 2009). Other living substrates

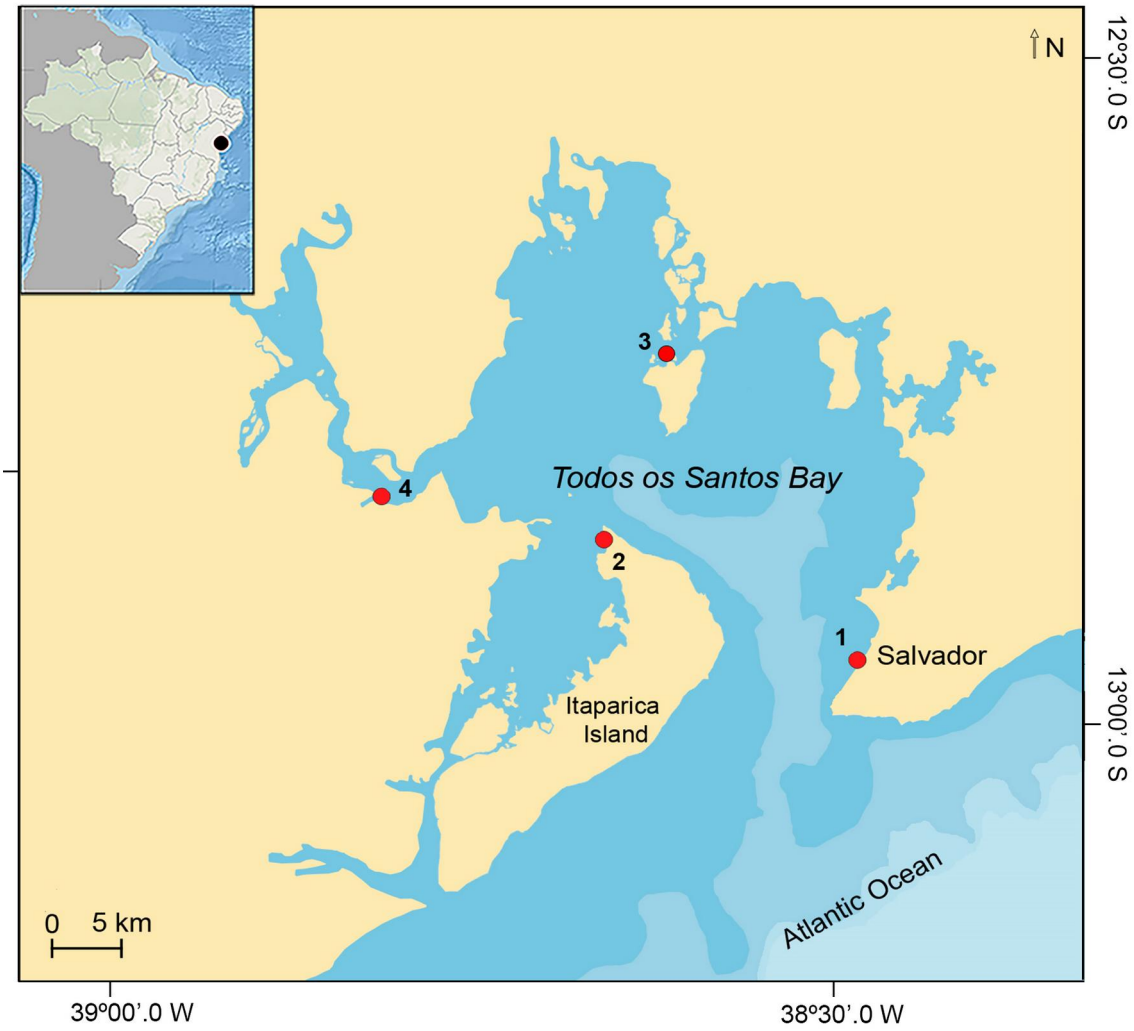

Figure 1. Map of the studied area with the sampling points in the Todos-os-Santos Bay, Bahia State. 1: Marina Porto Salvador; 2: Marina of Itaparica; 3: Marina of Bom Jesus dos Passos; 4: São Roque do Paraguaçú Shipyard.

reported were ascidian tunicates (Fig. 2b), but these were quite unusual when compared with bivalves and barnacles. The basebionts were apparently healthy (dissections visually supported tissue integrity). Colonies were observed on a single basebiont or a conglomerate of live and empty shells.

The identification of the mollusks provided evidence of the interaction between distinct categories of introduced organisms in the TSB: the dendrophylliids and two bivalves, namely, *Saccostrea cucullata* – being the first record of this oyster to warm waters to the Brazilian Northeastern Coast, and *Isognomon bicolor* – previously reported to the north littoral of the Bahia State, the species has extended southwards (12°S) (Table I). In addition, specimens of *Pododesmus rudis* Broderip, 1834, *Lamarcka imbricata* (Bruguière, 1789), and *Chama* cf. *congregata* Conrad, 1833 were also selected as substrates by sun coral larvae, however, these mollusks have been reported to the TSB.

Isognomon bicolor

Class BIVALVIA Linnaeus, 1758
Order PTERIOIDA Newell, 1965
Family PTERIIDAE Gray, 1847
Isognomon bicolor (C.B. Adams, 1845)
(Fig. 3)

New records: BRAZIL. Bahia; Salvador, Marina Porto Salvador (12º58'19,55" S, 38º30'56,58" W), MZSP (3 specs); LABIMAR coll., xi/2019. CZNC-IM nºs 2517 (1 specs), 2522 (4 specs); LABIMAR coll., ii/2022. Yacht Clube da Bahia (12º59'58" S, 38º31'51" W), MZSP (9 specs); LABIMAR coll., xii/2019. Itaparica, Marina de Itaparica (12º53'20,06" S, 38º41'4,9" W), CZNC-IM nºs 2522 (1 specs), 2526 (2 specs), LABIMAR coll., xii/2019.

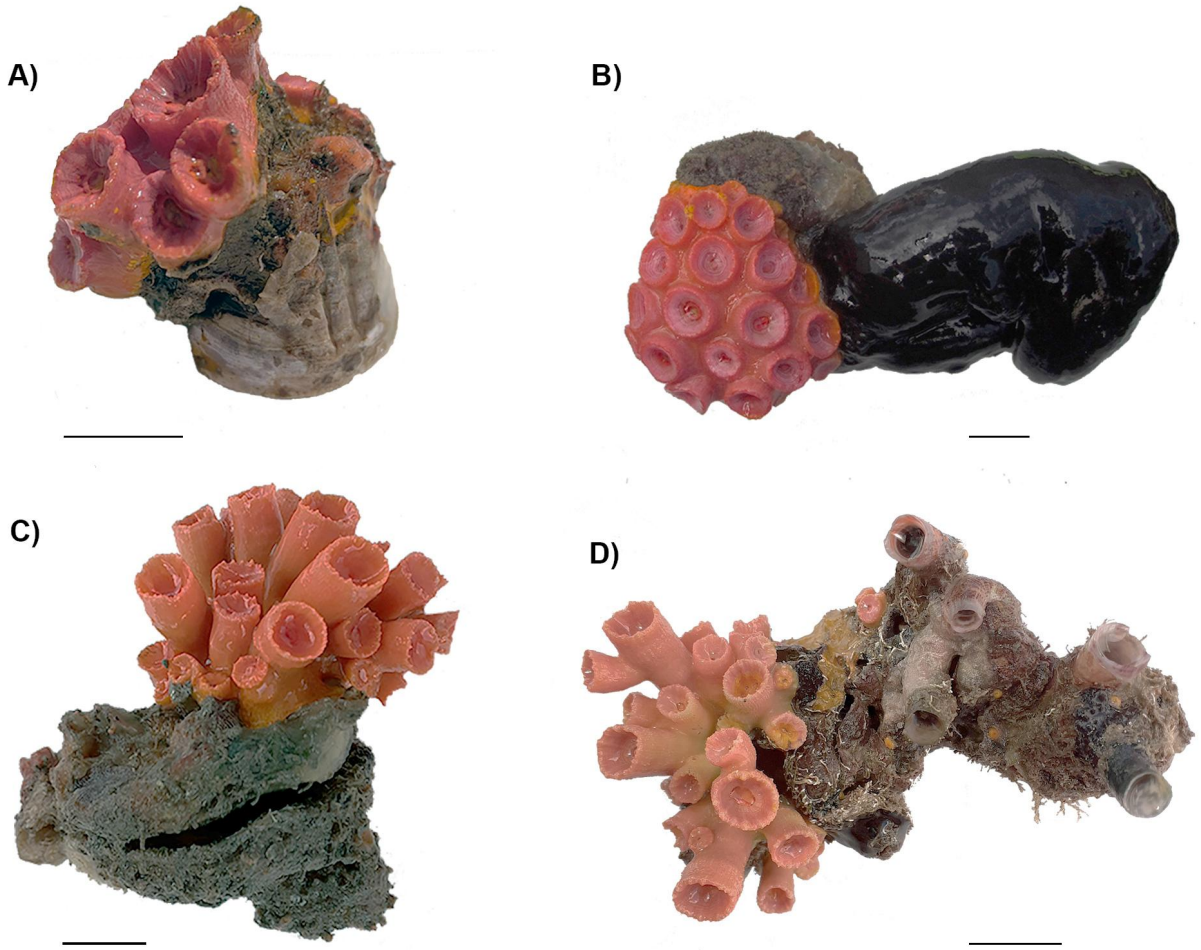

Figure 2. Sun corals in epibiotic association with other organisms: a) barnacle; b) ascidians c) bivalves, and d) gastropods (Scale bars: 10 mm).

Table I. Invasive bivalves in Todos-os-Santos Bay, with the year of the first invasion record in Brazil, areas of occurrence, and habitats of each species.

Species	First record	Occurrence	Habitats	References
Isognomon bicolor (C. B. Adams, 1845)	1994	The entire Brazilian coast, except for Amapá, Maranhão, and Sergipe states.	Epifaunal, attached to rocks, sandstone reefs, corals, calcareous algae and mangrove roots, marine debris, and artificial hard substrates.	Dias *et al*. (2013) López *et al*. (2014) Agostini & Ozorio (2016) Teixera & Creed (2020) Soares *et al*. (2022)
Saccostrea cucullata (Born, 1778)	2014	Rio de Janeiro, Paraná, São Paulo, Santa Catarina states.	Epifaunal, attached to mangrove roots, rocky shores, rocky reefs and gravels, and artificial hard substrates as breakwaters, pillars, marinas, and ports.	Galvão *et al*. (2017) Amaral *et al*. (2020)

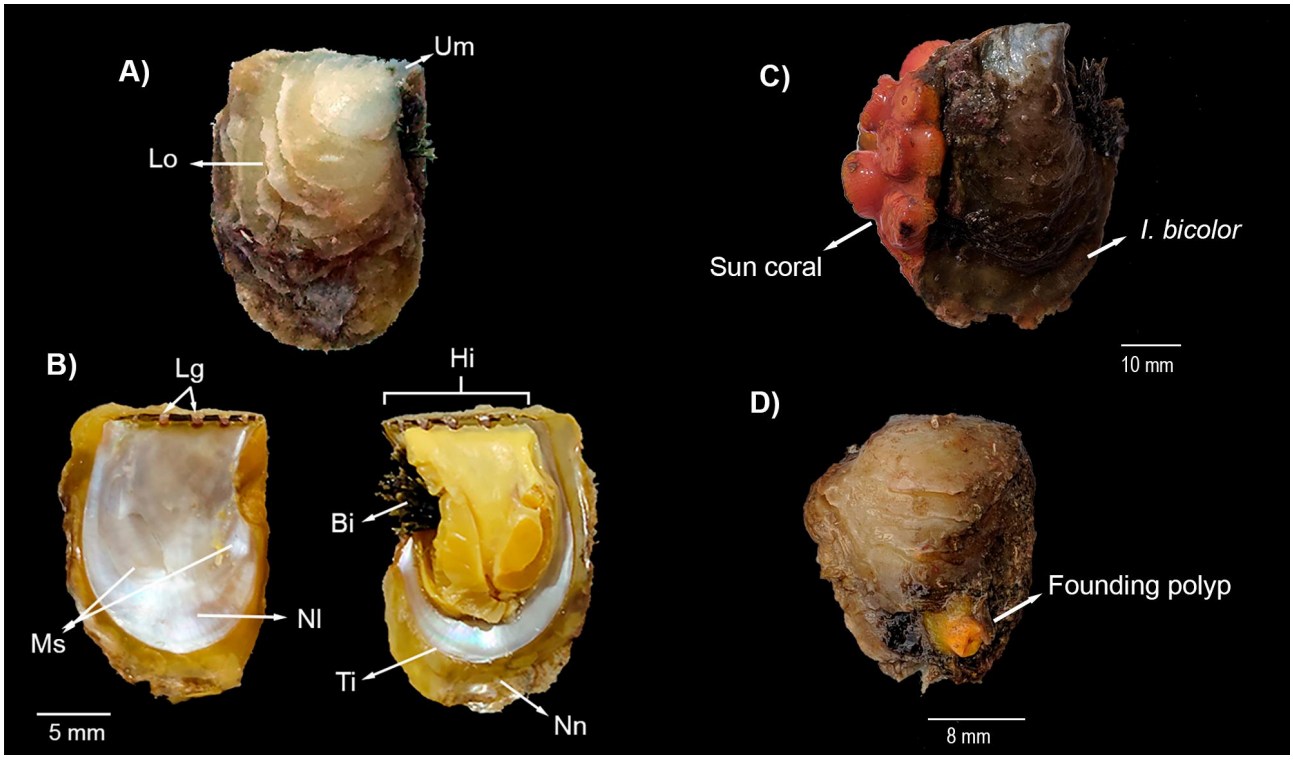

Figure 3. Some characters of *Isognomon bicolor*: A) Outer view of right valve indicating the lamellar ornamentation (Lo) and the umbo (Um); B) Inner of valve showing muscles scars (Ms), ligaments grooves (Lg) and nacreous layer (Nl); Byssus (Bi), hinge (Hi); Interruption line of nacre (Il) for the non-nacreous region (Nn), C) sun coral growing on *I. bicolor*, D) Sun coral founding polyp settled on the shell.

Diagnosis: Shell higher than wide, slightly inequivalve and inflated, with very variable shape. Straight dorsal margin, hinge small with multiple perpendicular teeth and grooves with ligament. Outer surface ornamented with irregular lamellae overlapping, scaly. Valves opaque, with yellowish-white to dark brown shells, lighter near the umbo. The inner face of the valves is nacreous, with colors ranging from white to dark purple. Body border marked by an abrupt interruption of nacre. Anterior and posterior abductor muscle scars are restricted to the nacreous part.
Identification: Specimens from the TSB are supported by the description of *I. bicolor* in Domaneschi & Martins (2002).

Saccostrea cucullata

Class BIVALVIA Linnaeus, 1758
Order OSTREIDA Férussac, 1822
Family OSTREIDAE Rafinesque, 1815
Gênero
Saccostrea cucullata (Born, 1778)
(Fig. 4)

Diagnosis: Species of *Saccostrea* Dolfuss and Dautzenberg, 1920 are common oysters living on the Indo-Pacific region's rocky shores (Lam & Morton 2006). This genus's taxonomy, as it generally occurs in ostreids, is unclear, as the morphological plasticity makes identification problematic (Lam & Morton 2006). The shells are elongated, generally cup-shaped, to 100 mm. Right (upper) valve flat or slightly convex. Left valve fixed to the substrate, cupped, and larger than the right valve. Umbonal cavity of left valve. Margins of both valves with angles sculpture in the edge; inner edge of right valve with small elongated denticles producing corresponding depressions on the left valve. Adductor muscle scar reniform, in the posterodorsal region, striate, white or grayish. Outer side of valves variable from white to gray, light or dark brown, green or purple. Inner surface white, with occasional purple spots (Amaral 2010, Amaral & Simone 2014, 2016, Amaral et al. 2020).
New records: BRAZIL. Bahia; Salvador, Marina Porto Salvador (12º58'19,55" S, 38º30'56,58" W), MZUSP nº 157503 (5 specs); LABIMAR coll., xi/2019, CZNC-IM nº 2523 (8 specs); LABIMAR coll., xii/2020; Salvador, Bom Jesus dos Passos

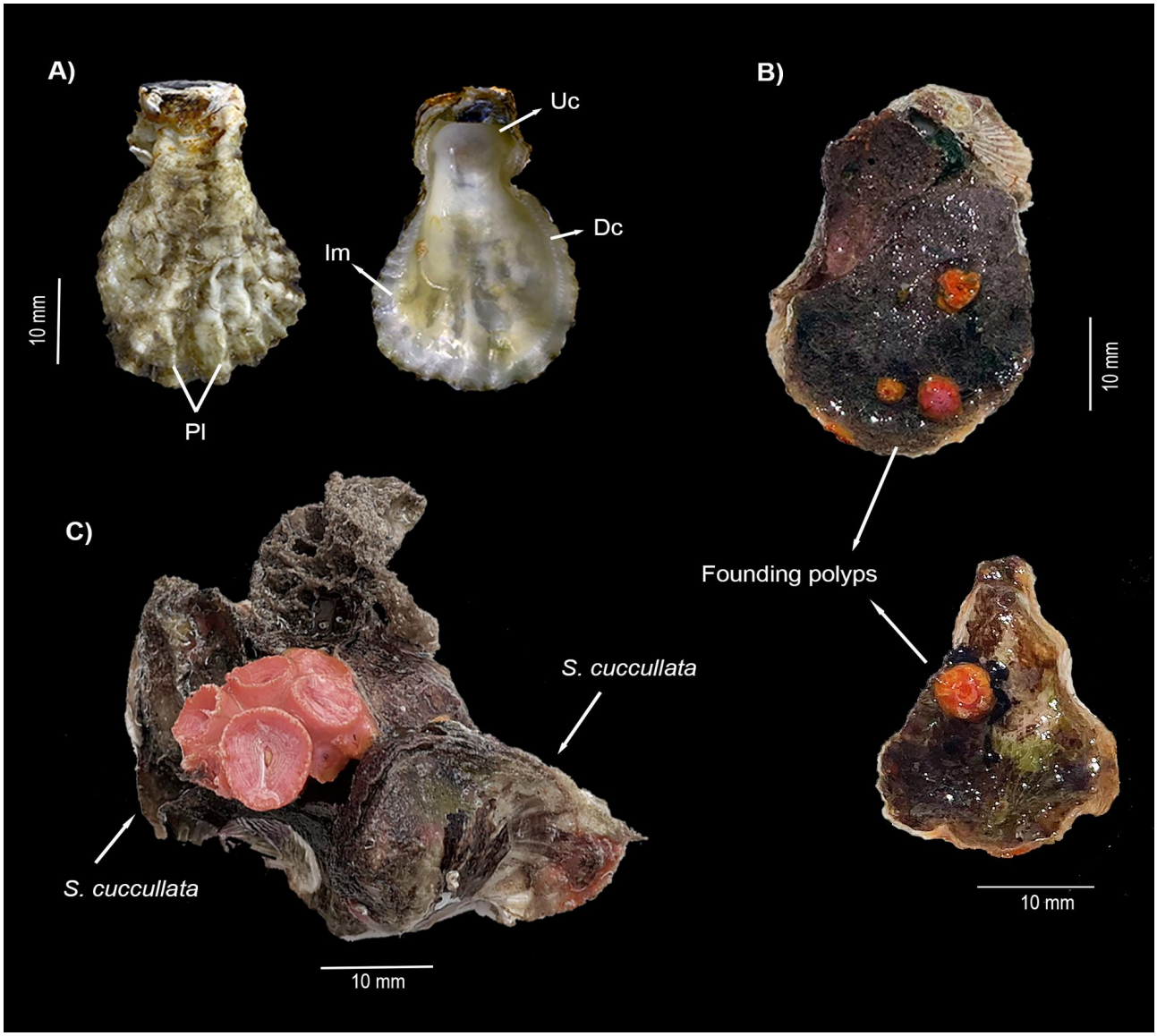

Figure 4. *Saccostrea cucullata*. a) External and internal view of the left valve, view with detail for plications (Pl) in the edge of shell; umbonal cavity (Uc); depressions of chomata (Dc) and muscle impression. (IM); b) Sun coral founding polyps settled on the oysters; c) sun-coral growing on *S. cuccullata* conglomerate.

(12º45'42,42" S, 38º38'9,32" W), MZUSP nº 157507 (1 spec); LABIMAR coll., viii/2021, Itaparica, Marina de Itaparica (12º53'20,06" S, 38º41'4,9" W), MZUSP nº 157504 (9 specs); LABIMAR coll., x/2020, CZNC-IM nºs 2508 (4 specs), LABIMAR coll., xi/2020; CZNC-IM 2525 (3 specs), LABIMAR coll., ix/2020, Maragogipe, Shipyard of São Roque do Paraguaçú (12º51'31" S, 38º51'00" W), MZUSP nº 157506 (1 spec); Neves, E.G., Farias, J.A. coll., ii/2022.

Identification: Specimens from the TSB are supported by the description of S. cuccullata in Amaral e Simone (2016).

Discussion

Marine artificial environments are highly susceptible to developing a biofouling community, attracting and trapping exotic organisms due to space availability for rapid colonization (Oricchio *et al*. 2019; Ruiz *et al*. 2009). In this paper, we add two mollusk species, *Isognomon bicolor* and *Saccostrea cucullata*, to the list of invasive invertebrates found in the artificial structures of the TSB.

Indeed, the increasing establishment of foreign benthic invertebrates in the TSB should be warily considered by Brazilian conservation policies that, instead of investing in the monitoring and

preservation of natural marine environments, support ship sinking for promoting artificial reefs and subaquatic activities - a dubious management practice that may favor the establishment of bioinvaders (Miranda *et al*. 2020).

Native from the Western Central Atlantic, Caribbean region (type locality: Jamaica *in* Adams, 1845), *Isognomon bicolor* is a bivalve found in shallow intertidal and sublittoral zones of natural and artificial substrates. It was early recorded in Brazil in the 1970s (Matthews and Kempf 1970) but identified as its congener, *Isognomon alatus* (Gmelin, 1791). In a comprehensive review of the species, Domaneschi & Martins (2002) stated that *Isognomon bicolor* is the only Isognomidae in the Brazilian coastal ecosystems. The vectors of its introduction remain controversial, but it has been attributed to the ballast water from international cargo ships (Breves-Ramos *et al*. 2010). Currently, *Isognomon bicolor* is recorded in all coastal regions, a scenario confirming this species's successful establishment in Brazilian waters. However, gaps are still challenging knowledge on the ecology and distribution of this non-native bivalve (Breves *et al*. 2014). It is noteworthy that *Isognomon bicolor* has been previously recorded on the coast of Bahia – Itapuã beach (metropolitan section), on sandstone reefs in the North Littoral, and in a rocky intertidal zone on Southern Coast (Domaneschi & Martins 2002, Gomes & Silva 2013, Souza *et al*. 2020).

The first record of *Saccostrea cucullata* (Born, 1778) to the Southwestern Atlantic Ocean occurred in the Itaguaré river (23° São Paulo State), being posteriorly found in the Guaratuba river (23ºS) and the Bertioga channel (23ºS) (Galvão *et al*. 2017). Amaral *et al*. (2020) extended the distribution of *Saccostrea cucullata* to the States of Rio de Janeiro (23ºS), Paraná (25ºS), and Santa Catarina (27ºS) (including other areas in São Paulo State). Furthermore, the authors also provided some ecological accounts and notes on its invasive behavior. Considering the high connectivity of shipping activities, especially in port areas, one may suppose that *Saccostrea* could have been introduced in Brazil by either recreational or commercial vessels, probably between 2005 and 2014 – a time interval inferred due to the absence of *Saccostrea cucullata* in museum collections and scientific literature before 2014. Indeed, Murray *et al*. (2011) alert for the risk of recreational boating acting as a worldwide vector of the introduction of marine invasive species due to hull fouling.

Given the absence of previous data in the TSB, for this meanwhile, we cannot attest that the introduction of these foreign bivalves is altering the structure of the local benthic fauna. However, impacts have been reported in other Brazilian coastal areas, particularly a ‘shrinkage’ effect and changes in distribution patterns in the receiving communities (Breves-Ramos *et al*. 2010, López *et al*. 2014, Martinez *et al*. 2012). Amaral *et al*. (2020) also suggest that *Saccostrea cucullata* may compete with equivalent species such as *Ostrea puelchana*, *Crassostrea brasiliana*, *Crassostrea mangle*, mytilids, barnacles, and algae, potentially reducing the fundamental niche and growth of native species.

Based on the scope of the present work, the interaction of non-native *Saccostrea* and *Isognomon* with exotic dendrophylliid corals represents important ecological information on invasive organisms currently found in the TSB. Indeed, it was not previously reported in the literature, even in the original distribution area. In other words, *Tubastraea* and *Saccostrea cucullata* co-occur in the Indo-Pacific, but the association between the two species in the native area has not been revealed yet.

Baird *et al*. (2003) suggest that the habitat selection process by larvae for settlement strongly influences adults' survival and distribution patterns. Harrington *et al*. (2004) demonstrated that *Acropora* planulae could recognize suitable settlement sites based on chemical signatures and preferred habitats best suited to ensure survival. Silva *et al*. (2022) evidenced that planulae of *Tubastraea tagunsensis* chose to settle and metamorphose on a substrate of crustose coralline algae, which have calcareous deposits in their cellular structure. Indeed, manipulative experiments dealing with planulae settlement and substrate preferences include only primary artificial substrates such as granite, wood, ceramics, and PVC sheets (Creed & Paula 2007, Mizrahi *et al*. 2014). Living substrates have been widely neglected.

Prevailing on artificial substrates in the TSB, where space is limited, and competition is high, sun corals are likely to overcome the unavailability of the primary substrate by exploiting other species as substrate –as barnacle and oyster shells Thus, due to the increasing local dominance of invasive *Saccostrea cucullata* and *Isognomon bicolor*, encounters among these sessile bivalves with the dendrophyllids are expected to occur (Branch and Steffani 2004). Moreover, epibiosis could be mutually beneficial for these organisms once the coral-epibiont may play a role in warding off

predators from the basibiont. Vinagre *et al*. (2018) demonstrated the association between *Leisolenus aristatus*, an invasive burrowing bivalve, and *Tubastraea* sp. in Southeastern Brazil. In this case, the authors suggested facilitation, in which *Tubastraea* is a specialized habitat, providing the invasive bivalve with a structural niche.

According to the literature, the spread and detection of the bivalves *Isognomon bicolor* and *Saccostrea cucullata* in new areas along the Brazilian coast consolidate their invasive status. Studies dealing with detection/identification, distribution, and interspecific ecological interactions are fundamental to understanding the processes involved with establishing exotic organisms in foreign environments and preventing impacts. Indeed, public policies for managing and monitoring bioinvaders are widely based on these approaches (Turbelin *et al*. 2017, McGeoch & Jetz 2019). Therefore, attention to these organisms is particularly relevant for the conservation and sustainable use of sea resources.

Ethical statement

Collection of biological samples were conducted following all applicable ethical regulations regarding collection of biological samples and experimentation with animals. Investigation was performed under permit Sisbio Nº 15161-1, issued by Chico Mendes Institute for Biodiversity Conservation (ICMBio).

Acknowledgments

We are grateful to Chico Mendes Institute for Biodiversity Conservation (ICMbio) for collecting permission (Sisbio No. 15161-1). We also would like to thank the entire LABIMAR team for its outstanding help in the field. Sabrina Neves is a doctoral student in the ‘Diversity and Evolution Graduate Program’, Biology Institute, Federal University of Bahia (PPGBIOEVO/IBIO/UFBA). This study is part of the project “Assessment and research of sun coral in Todos os Santos Bay,” a cooperation agreement between UFBA and PETROBRAS (N°5850.0107361.18.9) regulated by RD& I investments clauses of Brazilian Agency of Petroleum, Natural Gas and Biofuels (ANP Resolution 05/2015).

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Received: December 2023
Accepted: March 2024
Published: August 2024