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BIODIVERSIDADE DE ESPONJAS E SUA BRIOZOOFAUNA ASSOCIADA EM NAUFRÁGIOS DE PERNAMBUCO E NOS RODOLITOS ADJACENTES

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Dissertação apresentada à Coordenação do Programa de Pós-Graduação em Biologia Animal da Universidade Federal de Pernambuco, como parte dos requisitos necessários à obtenção do título de mestre.

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RESUMO

As esponjas e os briozoários marinhos estão entre os animais bentônicos mais comuns e diversos em recifes naturais e artificiais. Eles atuam como indicadores de biodiversidade devido às diversas interações e relações ecológicas que exercem nestes habitats. Recifes artificiais são resultados diretos das atividades antrópicas, destacando-se os naufrágios intencionais, e são relacionados com impactos ambientais diversos, incluindo eventos de bioinvasão. No Brasil, Pernambuco é pioneiro na prática e abriga mais de 110 embarcações naufragadas. Entretanto, pouco ou nada se sabe, em escalas locais e globais, sobre a fauna de esponjas e briozoários de naufrágios e de substratos naturais comuns adjacentes a estes naufrágios. Desta forma, o objetivo deste trabalho foi comparar a espongiofauna e a briozoofauna de naufrágios e dos seus bancos de rodolitos adjacentes do Parque dos Naufrágios Artificiais de Pernambuco. As coletas foram realizadas em quatro naufrágios (Vapor de Baixo, Pirapama, Servemar X e Taurus) e nos rodolitos adjacentes. As amostras foram coletadas usando um quadrado de 25x25 cm posicionado nas distâncias de 0, 2, 4, 6, 8 e 10 metros ao longo de um transecto horizontal que foi colocado ao longo do casco de cada naufrágio e de cada banco de rodolitos adjacente eles, totalizando 48 quadrados (24 artificiais e 24 naturais). No laboratório, as esponjas e briozoários foram identificados no menor nível taxonômico possível e os briozoários foram classificados como nativos/criptogênicos/exóticos. A frequência de ocorrência (FO) foi estimada com base na porcentagem de ocorrência das espécies em cada tipo de substrato. Para comparação das assembleias de esponjas e briozoários, foi utilizado o índice de Bray-Curtis nas matrizes de presença/ausência das espécies e foram realizadas análises de variâncias permutacionais usando o tipo de substrato como fator fixo. Os padrões espaciais das assembléias estudadas foram ilustrados em gráficos de escalonamento multidimensionais não métricos para esponjas e briozoários separadamente. As análises foram realizadas no software Paleontological Statistics Software Package, versão 4.03. Um total de 36 morfotipos de esponjas foram identificados, 20 nos rodolitos e 19 nos naufrágios. *Xestospongia muta* Schmidt, 1870 foi a mais frequente nos rodolitos com 40% de FO enquanto que *Desmapsamma anchorata* (Carter, 1882)*, Monanchora arbuscula* (Duchassaing & Michelotti, 1864) e *Tedania (Tedania) ignis* (Duchassaing & Michelotti, 1864) dominaram os naufrágios com >50% de FO. Setenta e cinco espécies de briozoários foram identificadas, 47 nos rodolitos e 29 nos naufrágios. *Licornia diadema* (Busk, 1852) foi a que apresentou maior ocorrência nos rodolitos com 46% de FO. *Bicellariella edentata* Marcus, 1955 dominou os naufrágios (67%), sendo este o seu primeiro registro em substrato artificial no Brasil. As assembleias de esponjas e briozoários dos rodolitos foram significativamente diferentes e mais ricas que aquelas dos naufrágios. As assembleias mais rica dos dois grupos foram as do naufrágio Vapor de Baixo e dos seus rodolitos adjacentes. As assembleias de esponjas dos rodolitos foram sub agrupadas provavelmente devido à proximidade geográfica das réplicas. A maioria dos briozoários são criptogênicos (38) e que não mostraram preferência quanto ao tipo de substrato, seguido dos nativos (33) e exóticos (4). Estes últimos foram encontrados apenas nos naufrágios, especialmente naqueles afundados mais recentemente, o que realça o alerta sobre a prática de afundamento poder facilitar a introdução de potenciais invasores.

Palavras-chave: Bryozoa. Espécies criptogênicas. Espécies exóticas. Espécies nativas. Porifera.

ABSTRACT

Marine sponges and bryozoans are among the most common and diverse benthic animals in natural and artificial reefs. They act as biodiversity indicators due to the diverse interactions and ecological relationships they have in these habitats. Artificial reefs are a direct result of human activities, with emphasis on intentional shipwrecks, and are related to various environmental impacts, including bioinvasion events. In Brazil, Pernambuco is a pioneer in this practice and hosts more than 110 shipwrecks. However, little or nothing is known, in local and global scales, about the sponges and bryozoan fauna of shipwrecks and of common natural substrata adjacent to these shipwrecks. Thus, the aim of this work was to compare the sponges and bryozoan fauna of shipwrecks and their adjacent rhodolith beds in the Parque dos Naufrágios Artificiais de Pernambuco. Samples were taken from four shipwrecks (Vapor de Baixo, Pirapama, Servemar X and Taurus) and its adjacent rhodoliths. Samples were collected using a 25x25 cm square positioned at distances of 0, 2, 4, 6, 8 and 10 meters along a horizontal transect that was placed firstly along the hull of the shipwreck and then along the adjacent rhodoliths beds, totaling 48 squares (24 artificial and 24 natural). In the laboratory, sponges and bryozoans were identified in the lowest possible taxonomic level and bryozoans were classified as native/cryptogenic/exotic. The frequency of occurrence (FO) was estimated based on the percentage of species occurrence in each type of substrata. To compare sponge and bryozoan assemblages, the Bray-Curtis index was used in the presence/absence matrices of species, and permutational variance analyzes were performed using the type of substrate as a fixed factor. The spatial patterns of the studied assemblages were illustrated in non-metric multidimensional scaling plots for sponges and bryozoans separately. Analyzes were performed using the Paleontological Statistics Software Package, version 4.03. Thirty-two species of sponges were identified, 20 from rhodoliths and 19 from shipwrecks. *Xestospongia muta* Schmidt, 1870 was the most frequent in rhodoliths with 40% of FO. *Desmapsamma anchorata* (Carter, 1882), *Monanchora arbuscula* (Duchassaing & Michelotti, 1864) and *Tedania (Tedania) ignis* (Duchassaing & Michelotti, 1864) dominated the shipwrecks with >50% of FO. Seventy-five species of bryozoans species of bryozoans were identified, 47 from rhodoliths and 29 from shipwrecks. *Licornia diadema* (Busk, 1852) was the one with the highest occurrence in rhodoliths with 46% of FO. *Bicellariella edentata* Marcus, 1955 dominated the shipwrecks (67%) and here we present its first record in artificial substrata from Brazil. Sponge and bryozoan assemblages from rhodoliths were significantly different and more diverse than those from the shipwrecks. The most diverse assemblages of the two groups were those of the Vapor de Baixo shipwreck and its adjacent rhodoliths. Sponge assemblages from rhodoliths were subgrouped probably due to the geographic proximity of the squares. Most bryozoans are cryptogenic (38) and did not show preference regarding the type of substrata, followed by natives (33) and exotic (4). Exotic bryozoans were only found in shipwrecks, especially in those more recently sunk, which highlights the concerns regarding creating new artificial reefs.

Keywords: Bryozoa; Cryptogenic species; Exotic species; Native species; Porifera; Artificial reef.

SUMÁRIO

1 INTRODUÇÃO

No ecossistema bentônico, o estabelecimento da fauna séssil é influenciado principalmente pelo tipo de substrato disponível para colonização e por relações entre os organismos. De forma geral, as características do substrato são responsáveis pela estruturação física e funcional das comunidades bentônicas (WAHL, 1989; GUICHARD; BOURGET, 1998; SEAMAN, 2000; SHERMAN, 2002; OIGMAN-PSZCZOL; FIGUEIREDO, 2004; PERKOL-FINKEL et al., 2006). As relações entre os organismos, por sua vez, incluem, principalmente, a competição por espaço e estratégias de sobrevivência como o rápido crescimento e estabelecimento de associações diversas (AGOSTINI, 2011; TRACY BAYNES; ALINA SZMANT, 1989).

As esponjas e os briozoários marinhos estão entre os grupos bentônicos mais diversos em substratos rígidos, atuando como indicadores de biodiversidade destes ambientes devido às diversas interações e relações ecológicas que exercem (CERRANO et al., 2006; PIOLA; JOHNSTON 2009; IGNACIO *et al.,* 2010; VIEIRA *et al.,* 2012, VIEIRA *et al.,* 2013). As diversidades morfológicas apresentadas por esponjas e briozoários fornecem, por exemplo, ambientes seguros para a reprodução, abrigo e proteção contra predadores para diversos organismos, desde microcrustáceos a peixes, além de constituírem substratos consolidados para grupos sésseis (DUARTE; NALESSO, 1996; RIBEIRO; OMENA; MURICY, 2003). A ocorrência de esponjas e briozoários em ambientes com substratos rígidos também pode estar relacionada com as diferentes condições dadas por fatores bióticos e abióticos (ALMEIDA et al., 2017; ALMEIDA; SOUZA, 2014; CAVALCANTI; SANTOS; PINHEIRO, 2015; KLITGAARD, 1995; PADUA; LANNA; KLAUTAU, 2013; RIBEIRO; OMENA; MURICY, 2003; VIEIRA et al., 2012).

No ambiente marinho, uma grande disponibilidade de substratos rígidos que compõe recifes tanto naturais quanto artificiais, é encontrada na zona costeira e na plataforma continental (DOS SANTOS; DE OLIVEIRA PASSAVANTE, 2007; K. MARTENS et al., 2006). Os recifes naturais (RNs), incluem, principalmente, recifes de corais, afloramentos e costões rochosos, e bancos de rodolitos (CARNEIRO et al., 2022). Além de serem altamente vulneráveis a impactos antrópicos diretos, os recifes naturais também são suscetíveis a eventos de bioinvasão. As consequências podem atingir comunidades marinhas em vastas extensões como as presentes em bancos de rodolitos, responsáveis por abrigar grande parte dos estoques pesqueiros e da biodiversidade bentônica (PASTOROK; BILYARD, 1985; GRIGSON et al., 2000; BHAGIRATHAN et al., 2008; MOURA et al., 2021).

Os recifes artificiais ou RAs, por sua vez, são resultados diretos das atividades antrópicas, sobretudo relacionadas com a ocupação da faixa costeira e tráfego marítimo, compreendendo desde muros de contenções, quebra-mares e píeres a estruturas navais submersas, como os naufrágios (CHALLINOR; HALL, 2008; ROUSSEAU, 2008). O aumento da disponibilidade de substratos artificiais deve ser considerado preocupante, uma vez que favorece a introdução e estabelecimento de espécies exóticas e potencialmente invasoras (COUTINHO, 2002, LECLERC et al., 2020), reconhecidas como uma das principais causas da perda de biodiversidade em todo o mundo (SOARES et al., 2022). Ainda, os naufrágios podem atuar como trampolins para dispersão de espécies exóticas, tornando o ambiente natural suscetível a eventos de bioinvasão afetando diretamente comunidades nativas (SCHULZE et al., 2020). Espécies são classificadas como nativas quando estão distribuídas dentro de sua região de origem, como criptogênicas quando sua origem e distribuição geográfica são incertas ou não conhecidas e como exóticas quando ocorrem fora de sua área de distribuição natural conhecida (BULLOCK et al., 1996; CARLTON, 1996; XAVIER et al., 2021).

É discutido que estruturas artificiais também possam causar efeitos econômicos e ambientais negativos (SEAMAN, 2000; SEAMAN; JENSEN, 2000; MIRANDA et. al, 2020). Após a implementação de RAs, estudos relatam alterações na caracterização de estoques pesqueiros (PICKERING; WHITMARSH, 1997; SOARES et. al, 2020), na direção das correntes (MOURA et al., 2006), no hidrodinamismo local (GUICHARD; BOURGET, 1998; SPAGNOLO et. al, 2014), na granulometria da sedimentação juntamente com a fauna associada (DANOVARO, 2002, ZALMON et al., 2012), e na biodiversidade bentônica. Há indícios, inclusive, que quando há o assentamento e fixação de larvas em um RA, a disponibilidade destas para o ambiente natural pode diminuir (STEPHENS, 2002; CARNEIRO et. al, 2022). Entretanto, os RAs têm sido sugeridas como ferramentas potenciais para mitigação de impactos antrópicos em RNs, buscando também cumprir com objetivos e metas de desenvolvimento costeiro (CULTER, 1997; CLARK; EDWARDS, 1999; DEL-PILAR-RUSO et al., 2015; MOUSAVI et al.,2015; FONTES et. al, 2020; GLAROU et. al, 2020).

Os principais instrumentos utilizados como RAs são as embarcações naufragadas, denominadas de naufrágios (KIRKBRIDE-SMITH; WHEELER; JOHNSON, 2013; LIRA et al., 2010). No Brasil, o Estado de Pernambuco é pioneiro na prática de afundamentos de embarcações e, atualmente, mais de 110 embarcações estão naufragadas ao longo da costa do Estado (SANTOS et. al, 2008). Os primeiros registros oficiais do Parque são de naufrágios localizados na costa da cidade de Recife e sinalizam a ocorrência de amplos bancos de rodolitos circundantes às embarcações (COSTA; MALLMANN; GUERRA, 2010; SANTOS et al., 2008). Até o momento, há pouco conhecimento sobre a fauna séssil dos naufrágios e dos rodolitos adjacentes a estes em Pernambuco, especialmente em relação à detecção de espécies exóticas. Apesar de alguns trabalhos relatarem a ocorrência de esponjas e briozoários em naufrágios da área (AMARAL et al., 2010; LIRA et al., 2010), coletas sistematizadas e realizadas por especialistas nestes grupos nunca foram realizadas. Ao mesmo tempo, não há trabalhos com a fauna associada aos rodolitos adjacentes aos naufrágios da costa Pernambucana. Contudo, o estudo da fauna de substratos rígidos naturais e artificiais é essencial para a compreensão de processos ecológicos, bem como para avaliação da integridade ambiental (ASELTINE-NEILSON et al., 1999; PERKOL-FINKEL; BENAYAHU, 2005; MACEDO, 2006; CREED et al., 2017).

2 FUNDAMENTAÇÃO TEÓRICA

2.1 RECIFES NATURAIS E ARTIFICIAIS COMO FORMADORES DE ECOSSISTEMAS

Os ecossistemas recifais são são ambientes tropicais que apresentam elevada diversidade biológica e grande número de organismos (CORREIA; SOVIERZOSKI, 2005), podendo ser classificados como artificiais ou naturais.

Os RNs são formados por estruturas de constituição inorgânica ou orgânica, como os recifes de arenito e rodolitos, respectivamente (CORREIA; SOVIERZOSKI, 2005; FONTES et al., 2020). Rodolitos são nódulos de algas calcárias não-articuladas de vida livre incluídas nos grandes grupos Rhodophyta, Corallinales e Sporolithales (FOSTER, 2013). Estas algas crescem não aderidas a um substrato e se depositam no fundo marinho de zonas como o entre-marés e poças de maré (PEÑA; BARBARA, 2008), até em profundidades onde haja condições de luminosidade para o processo de fotossíntese (FOSTER, 2013). Em grande concentrações, os rodolitos comumente formam bancos e atuam como “engenheiros de ecossistemas” e fornecem diversos habitats para a fauna marinha bentônica, especialmente para os grupos sésseis, atuando, sobretudo, como berçário e abrigo para diversas espécies (ÁVILA et al., 2011, VILLAS-BÔAS et al., 2014).

Os rodolitos apresentam ampla utilização econômica como fertilizantes, corretivos de solo, purificadores de água potável e nas indústrias farmacêutica e de cosméticos (DIAS, 2000; DE GRAVE et al., 2000) e com isso, têm sido alvos de intensa exploração (AMADO-FILHO et al., 2007). O Brasil agrega o título de maior área de bancos de rodolitos do mundo (AMADO-FILHO et al., 2012), mas ainda são escassas as pesquisas relacionadas à fauna associada a esse tipo de ecossistema. Mesmo apresentando o status de alta prioridade de conservação, diversas empresas de mineração buscam a permissão de exploração dos recursos carbonáticos desses rodolitos (NEVES, 2015), indicando a necessidade de maior conhecimento desses RNs.

Os RAs são estruturas incluídas ao fundo aquático (propositalmente ou por acidente), sejam elas de material natural (como rochas e madeira) ou de origem humana (estruturas de ferro, concreto ou borracha). Os RAs podem ser utilizados para fornecer substratos rígidos para a colonização e desenvolvimento de uma ampla gama de seres vivos, o que os caracterizam como formadores de ecossistemas (BOAVENTURA et al., 2006; SANTOS, 2006; BARROS, 2016). Nas últimas duas décadas, com a popularização do mergulho autônomo (Self Contained Breathing Apparatus – SCUBA), os programas de implantação de naufrágios estão sendo significativamente utilizados em prol do desenvolvimento do turismo costeiro (SOUSA, 2021). Além disso, os RAs também são relacionados com a criação de áreas marinhas protegidas, com objetivo de recuperar habitats degradados, mitigar o impacto do turismo sob RNs e conservar a biodiversidade costeira (SVANE; PETERSEN, 2001; RILOV; BENAYAHU, 2002; PERKOL-FINKEL et al., 2006).

Os naufrágios, como as mais populares estruturas artificiais afundadas propositalmente para criação de RAs, são utilizados para proporcionar substratos estáveis, abrigo, berçário, formação de cadeias tróficas e áreas de desenvolvimento para a biota (MACÊDO, 2006; LIRA et al., 2010). Entretanto, enquanto alguns trabalhos indicam que os naufrágios fornecem boas condições para o estabelecimento de espécies devido a complexidades estruturais que mimetizam ambientes naturais (e.g., ZINTZEN et al., 2006; GLAROU; ZRUST; SVENDSEN, 2020; PERKOL-FINKEL; SHASHAR; BENAYAHU, 2006; WALKER; SCHLACHER, 2014), outros alertam para o favorecimento da ocorrência de espécies exóticas e facilitação de eventos de invasão biológica (e.g., MIRANDA et al., 2021; KIRKBRIDE-SMITH; WHEELER; JOHNSON, 2013; SCHWINDT et al., 2020; SOARES et al., 2022; TEIXEIRA; CREED, 2020; TYRRELL; BYERS, 2007).

No Brasil, os primeiros estudos com RAs são datados a partir da década de 90, abordando processos de produtividade biológica (BRANDINI; SILVA, 2001), bioincrustação (CARREIRO-SILVA; MCCLANAHAN, 2001), e características estruturais (ZALMON ; GOMES, 2003). Uma comparação entre a fauna de RNs e RAs do Brasil não existe na literatura e os resultados de trabalhos com outras regiões marinhas são conflitantes. Enquanto alguns autores encontraram grande similaridade entre os ecossistemas pelo compartilhamento de espécies bentônicas (ASELTINE-NEILSON et al. 1999; PERKOL-FINKEL et al., 2006; PERKOL-FINKEL ; BENAYAHU, 2009; THANNER et al., 2006), outros encontraram pouca similaridade entre as comunidades (BURT et al., 2009; COELHO et al., 2012). A heterogeneidade e a orientação do substrato (HUNTER; SAYER, 2009), assim como a influência do tempo em grande escala (PERKOL-FINKEL et al., 2005), são fatores relacionados com as diferenças entre tais resultados.

2.2 FILO PORIFERA: CARACTERÍSTICAS GERAIS E RELAÇÕES COM O ECOSSISTEMA RECIFAL

Constituído por cinco classes, Calcarea Bowerbank, 1864, Demospongiae Sollas, 1885, Hexactinellida Schmidt, 1870, Homoscleromorpha Bergquist, 1978 e Archaeocyatha Bornemann, 1884, o Filo Porifera abriga 9527 espécies viventes, das quais cerca de 598 são registradas para o Brasil (DE VOOGD et al., 2023; MURICY, 2023). Demospongiae é a classe que apresenta o maior número de representantes com cerca de 85% de todas as espécies descritas.

Os poríferos são metazoários sésseis que apresentam um sistema aquífero diferenciado e um plano corporal simples, consistindo em uma série de câmaras e canais onde ocorre a circulação de água (HOOPER et al., 2002; ERWIN; THACKER, 2007). As esponjas, como popularmente conhecidas, apresentam sustentação corporal feita por um esqueleto espicular de sílica ou carbonato de cálcio. Em alguns grupos, as espículas podem ser complementadas ou substituídas por fibras de espongina (MURICY, 2008; DUNN et al., 2015). A organização corporal dos poríferos é dada em três camadas: a pinacoderme, o mesoílo, e a coanoderme. Esta última é composta por células flageladas (coanócitos) que constituem um sistema de câmaras que bombeiam a água, conferindo papel indispensável na alimentação e na maioria das funções fisiológicas desses animais (MALDONADO; RIESGO, 2008; DEGNAN et al., 2015). Esponjas estão entre os organismos mais ricos em complexidade de caracteres morfológicos existentes (LOPES et al., 2011).

Dentre os importantes papéis desempenhados por esponjas, destacam-se a manutenção da biodiversidade e estruturação de ecossistemas aquáticos (MURICY, 2011; DEGNAN et. al, 2015; KLAUTAU et.al, 2020). Associações de diversos organismos com esponjas são comumente reportadas na literatura e relatam vantagens para a biota associada com o fornecimento de abrigo, proteção contra predadores, disponibilização de ambiente seguro para a reprodução e alimentação e pelo substrato oferecido para o assentamento de outros organismos (DUARTE; NALESSO, 1996; RIBEIRO et al., 2003; WULFF, 2012; NASCIMENTO, 2019; PRAXEDES, 2020). Poríferos também produzem diversos compostos bioativos de interesse farmacológico e biotecnológico, o que agrega um alto potencial econômico a estes animais (GARSON, 1994; LIZARAZO et. al, 2020).

Representantes do filo Porifera se destacam entre os organismos mais abundantes em RNs e RAs (BARROS, 2016; DE MORAES, 2011; JOOP W P COOLEN et al., 2020; KLITGAARD; TENDAL, 2004; TRACY BAYNES; ALINA SZMANT, 1989; WULFF, 2012). Por serem dominantes, sésseis e se alimentarem das menores frações orgânicas, esponjas também atuam como indicadores ecológicos e têm sido sugeridas como biomonitores de poluição em RAs devido à localização pontual destes ecossistemas (MURICY, 1989; PÉREZ, 2000; ROCHA et. al, 2019). Tais características poderiam, inclusive, conferir ao filo sucesso em eventos de bioinvasão. No entanto, pelo conhecimento ainda limitado sobre a origem, diversidade e distribuição de esponjas em geral, poucas espécies de esponjas são reconhecidas como verdadeiramente invasoras (e.g., DAVIDSON et al., 2010; ENRÍQUEZ; AVILA; CARBALLO, 2009; EVCEN; GÖZCELIOĞLU; ÇINAR, 2020; KLAUTAU et al., 2020; KLAUTAU; MONTEIRO; BOROJEVIC, 2004; KNAPP et al., 2015). Cerca de 18 espécies de esponjas já foram consideradas como espécies exóticas, quatro delas causando danos locais e, então, podendo ser reconhecidas como bioinvasoras: *Chalinula nematifera* (de Laubenfels, 1954), *Mycale* (*Mycale*) *grandis* Gray, 1867, *Terpios hoshinota* Rützler & Muzik, 1993, e a esponja calcárea *Paraleucilla magna* Klautau, Monteiro & Borojević, 2004. Esta última foi o primeiro registro de esponja exótica no Oceano Atlantico (COLES; BOLICK, 2007; ENRÍQUEZ; AVILA; CARBALLO, 2009; KNAPP et al., 2015; LONGO; MASTROTOTARO; CORRIERO, 2007).

2.3 FILO BRYOZOA: CARACTERÍSTICAS GERAIS E RELAÇÕES COM O ECOSSISTEMA RECIFAL

Constituído por três classes: Gymnolaemata Allman, 1856, Phylactolaemata Allman, 1856, Stenolaemata Borg, 1926, Bryozoa é um filo com mais de 8.000 espécies viventes, das quais 492 são registradas para o Brasil (VIEIRA & ALMEIDA, 2022). Gymnolaemata é a classe que apresenta o maior número de representantes (GONTAR et al. 2001; VIEIRA; MIGOTTO et al. 2011).

Os briozoários são invertebrados predominantemente sésseis, exclusivamente filtradores e coloniais, sendo formados por unidades funcionalmente independentes chamadas de zoóides (GONTAR et al. 2001; MIGOTTO et al. 2011). Os zoóides compreendem uma câmara calcificada ou quitinosa, chamada de zoécio, e a parte orgânica responsável pelas funções vitais que constitui o trato digestivo e o lofóforo filtrador, chamada de polipídeo (MIGOTTO; VIEIRA; WINSTON, 2011). As colônias apresentam formas diversas, desde incrustantes a eretas e discóides, podendo ter aspecto externo gelatinoso ou calcificado (WINSTON, 1982).

Os briozoários compreendem um grupo bastante diverso podendo ser encontrados em todos os tipos de ecossistemas aquáticos, tanto em substratos artificiais quanto naturais. (HAYWARD; RYLAND 1998; KUKLINSKI; BARNES 2005; ALMEIDA et al. 2017). Além de serem utilizados como bioindicadores e construtores de ecossistemas, podem ser utilizados como indicadores de biodiversidade por interações diretas com invertebrados marinhos (ELIA et al. 2007; PIOLA; JOHNSTON 2009; IGNACIO et al. 2010; VIEIRA et al. 2012, VIEIRA et al. 2013).

A comum associação de briozoários com mecanismos humanos de dispersão, como cascos de navios, plataformas de petróleo e lixo marinho, e o fácil estabelecimento de algumas espécies em estruturas artificiais, pode resultar no questionamento da distribuição atual conhecida dos táxons e, consequentemente, na reconsideração de sua condição nativa/criptogênica/exótica nas áreas que ocorrem (MCCULLER; CARLTON, 2018).

A ocorrência de espécies exóticas pode influenciar no deslocamento ou extinção das espécies nativas (BAX et al., 2001; LOPES, 2009). A importância de estudos referentes à detecção de espécies exóticas de briozoários no Brasil (e.g. MARQUES et al., 2013; ROCHA et al., 2013; ALMEIDA et al. 2015a, 2017a; MIRANDA et al. 2018; LOPES et. al., 2009; GORDON, 2006; ROCHA et al., 2013, XAVIER et. al., 2021) ganha vulto pois, atualmente, eventos de bioinvasão são considerados a segunda maior causa da perda de biodiversidade no mundo (BAX et al., 2001; LOPES, 2009; SOARES et. al, 2022).

O aumento do número de estudos publicados sobre a fauna de briozoários no Brasil que incluem dados moleculares e distribuição de espécies possibilita também o aumento do conhecimento referente à detecção de espécies exóticas (e.g. ALMEIDA et al., 2015, 2017; FERREIRA et al., 2009; MIRANDA; ALMEIDA; VIEIRA, 2018; ROCHA et al., 2013; XAVIER; ALMEIDA; VIEIRA, 2021). Nota-se um esforço crescente dentre os trabalhos publicados, onde Ramalho (2006) registrou quatro espécies exóticas e 25 criptogênicas para o estado do Rio de Janeiro, enquanto Almeida et al. (2015) e Almeida, Souza e Vieira (2017) classificaram sete espécies como exóticas para a Bahia. Miranda, Almeida e Vieira (2018) apresentaram 12 espécies exóticas e 17 espécies criptogênicas para o Brasil e o estudo mais recente, publicado por Xavier e colaboradores (2021), atualiza o conhecimento e classificação de espécies de briozoários encontrados em áreas artificiais, com 33 classificadas como criptogênicas, nove nativas e treze espécies exóticas. A costa brasileira é caracterizada pela heterogeneidade de habitats, o que aumenta a possibilidade de introdução e estabelecimento de espécies invasoras, tornando assim levantamentos da fauna exótica cada vez mais essenciais para compreensão de eventos de bioinvasão (ALMEIDA et al., 2015; FERREIRA et al., 2009).

3 OBJETIVOS

3.1 Objetivo geral

Comparar a fauna de esponjas e briozoários marinhos de naufrágios e dos rodolitos adjacentes aos naufrágios da costa do Recife, Pernambuco, nordeste do Brasil.

3.2 Objetivos específicos

- Inventariar a espongiofauna dos naufrágios e rodolitos amostrados;
- Inventariar a briozoofauna dos naufrágios e rodolitos amostrados;
- Classificar o status exótico/nativo da fauna de briozoários dos naufrágios e rodolitos adjacentes; e
- Avaliar a composição faunística de esponjas e briozoários marinhos dos naufrágios e rodolitos amostrados.

4 HIPÓTESES

H1. Rodolitos e naufrágios diferem em termos de composição faunística de esponjas e briozoários marinhos.

H2: Os recifes naturais mostram diferenças quanto à composição da fauna quando comparados entre si.

H3: Os recifes artificiais mostram diferenças quanto à composição da fauna quando comparados entre si.

H4. Há mais briozoários marinhos exóticos em naufrágios do que em rodolitos.

5 CAPÍTULO ÚNICO

Este capítulo contém o artigo intitulado:

Diversity of sponges and bryozoans from natural and artificial reefs from northeastern Brazil

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Diversity of sponges and bryozoans from natural and artificial reefs from northeastern Brazil

Abstract

Marine sponges and bryozoans are among the most common and diverse benthic animals in natural and artificial reefs. Currently, artificial reefs are related to various environmental impacts, including bioinvasions. In northeastern Brazil, Pernambuco hosts more than 110 shipwrecks with adjacent large rhodoliths beds, but poor is known regarding the associated fauna. Here we characterized and compared the sponges and bryozoan assemblages of four shipwrecks and its adjacent rhodoliths, using samples from 48 squares (24 artificial and 24 natural). In general, assemblages were composed by taxa common in the Western Atlantic. Sponge and bryozoan assemblages from rhodoliths were significantly different and more diverse than those from the shipwrecks. The most diverse assemblages of the two groups were those of the Vapor de Baixo shipwreck and its adjacent rhodoliths. Most bryozoans are cryptogenic (38) and did not show preference regarding the type of substrata, followed by natives (33) and exotic (4). Exotic bryozoans were only found in shipwrecks, especially in those more recently sunk, which highlights the concerns regarding creating new artificial reefs. This paper represents the most comprehensive inventory of sponges and bryozoans from rhodoliths beds and shipwrecks from Brazil.

Keywords: Bryozoa. Porifera. Rhodoliths. Shipwrecks. Western Atlantic.

Introduction

Reef environments are coastal or oceanic marine ecosystems characterized by being structurally rigid (PEREIRA; GOMES, 2021; REAKA-KUDLA, 1997). Reefs are also recognized as one of the most productive types of ecosystems on the planet, hosting a distinct species biodiversity in tropical areas, as in the Western Atlantic (WE) (WAHL, 1989; SVANE; PETERSEN, 2001). Most natural reefs from the WE are placed near the coast, including close to mangroves, beaches, bays and in regions with intense human activities, making them susceptible to several potential environmental impacts (LEWSEY; CID; KRUSE, 2004). In this sense, artificial reefs are being pointed as alternative and complementary habitats to natural ones (CULTER, 1997; LUKENS, 1997; GIRALDES et al., 2012). However, whereas some results can indicate an increase in species diversity with the inclusion of artificial reefs (BURT et al., 2009; CLARK; EDWARDS, 1999; GROSSMAN; JONES; SEAMAN JR, 1997; LIMA et al., 2020; PERKOL-FINKEL; BENAYAHU, 2005), other authors highlight that artificial reefs can end up acting as a stepping stones that facilitate bioinvasion events (ASELTINE-NEILSON et al., 1999; PERKOL-FINKEL; BENAYAHU, 2005).

Among the associated fauna of natural and artificial reefs, sponges and bryozoans are abundant components, being considered as biodiversity indicators due to the huge range of ecological interactions and relationships they present (ELIA et al. 2007; PIOLA; JOHNSTON, 2009; IGNACIO et al. 2010; VIEIRA et al. 2012, VIEIRA et al. 2013). Despite the expressive number of shipwrecks along Brazilian coast and its large surrounding rhodoliths beds, there is little knowledge about the diversity of sessile organisms such as sponges and bryozoans in these two types of ecosystems (e.g. KUKLINSKI; BARNES, 2005; ALMEIDA et al., 2017, NASCIMENTO et al., 2021). The study of this fauna is essential for understanding ecological processes and assessing ecosystem performance, since reefs are subject to rapid ecological transformations such as the dominance of exotic species (ASELTINE-NEILSON et al., 1999; PERKOL-FINKEL; BENAYAHU, 2005). The detection of cryptogenic and exotic species can help identify introduction routes, thus being essential for estimates in bioinvasion studies to be assertive and avoid consequences in social, environmental and economic areas (CARLTON, 1996; ROCHA et al., 2013).

Over the last few decades, the natural and artificial reefs of the WE have been particularly affected by environmental disturbances that mainly affect the geological and ecological functions they perform (HE et al., 2012; JACKSON et al., 2014; BARROS, 2016; WILKINSON; SOUTER, 2008; SCHWINDT et. al, 2020). However, studies including the associated fauna of shipwrecks and rhodolith beds in tropical waters are still rare (BARROS, 2016), including in Brazil. Brazilian reefs are included in the WE and encompass large underwater historical artificial parks and the largest rhodoliths beds in the world, with studies showing that their total coverage area and their importance are still underestimated (LIRA et al., 2010; AMADO-FILHO et al., 2012). In northeastern Brazil, the coast of Pernambuco state is considered a reference for national and international underwater tourism with the city of Recife being considered the “Brazilian Capital of Shipwrecks” and owning the title of the first Artificial Shipwreck Park in Latin America (DOS SANTOS et al., 2010; SANTOS, 2006). Even so, to date, few studies investigated the fauna, including sponges and bryozoans, of rhodoliths and shipwrecks from the area (LIRA et al., 2010; AMARAL et. al., 2010). Thus, in this study we aim to answer: (i) What is the composition of sponges and bryozoans assemblages from rhodoliths beds and shipwrecks from Parque dos Naufrágios Artificiais de Pernambuco? (ii) Are there differences in sponges and bryozoans assemblages from the natural (rhodolith beds) and artificial (shipwrecks) studied reefs? (iii) What is the exotic/native status of the bryozoans from rhodoliths beds and shipwrecks from Parque dos Naufrágios Artificiais de Pernambuco?

Materials and Methods

Study area and sampling procedures

Samples were obtained in April 2022 by scuba diving in four shipwrecks and in the rhodoliths beds adjacent to these shipwrecks in the Parque dos Naufrágios Artificiais de Pernambuco (08º03' -08º04'S and 34º45'- 34º43' W), Pernambuco state, northeastern Brazil (Figure 1). The area is located on the continental shelf at depths corresponding to the middle shelf zone, between 16 and 40 m deep. The four shipwrecks studied here were selected based on previous collections that showed the occurrence of sponges and bryozoans in these areas, as well as due the methodological feasibility of sampling, thus comprising the shipwrecks Vapor de Baixo, Pirapama, Servemar X and Taurus (Table 1).

Fig. 1 Study area with location of shipwrecks in the he Parque dos Naufrágios Artificiais de Pernambuco, Pernambuco state, northeastern Brazil.

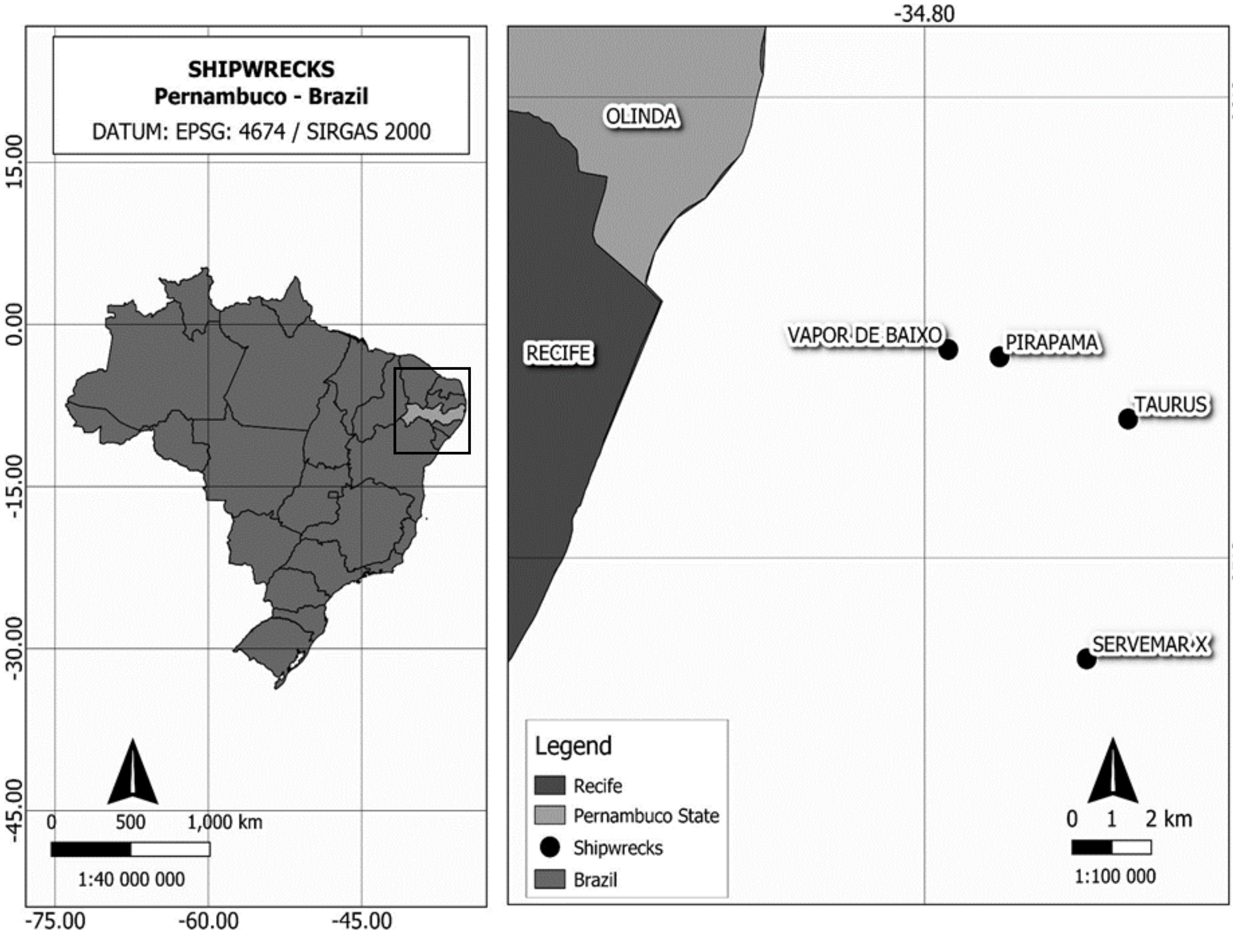


Table 1. Coordinates, characteristics of the selected wrecks and sampling date.

Wreck	Coordinates	Year of the wreck	Material	Depth (min-max)	Type	Sampling date
Vapor de Baixo	08° 03.230' S, 034° 46.580' W	1850	Iron	18-23m	Wheeled steamer	27/04/2022
Piparama	08° 03.289' S, 034° 47.673' W	1889	Iron	19-23m	Wheeled steamer	12/04/2022
Servemar X	08° 07.190' S, 034° 45.460' W	2002	Steel	20-25m	Tugboat	27/04/2022
Taurus	08° 04.193' S, 034° 45.196' W	2006	Steel	18-25m	Tugboat	12/04/2022

With a standardization of three divers and one photographer for each replicate, samples were collected using a 25x25 quadrat placed in six distances (0 m, 2 m, 4 m, 6 m, 8 m, and 10 m) along a horizontal transect placed firstly along the hull of the shipwreck and then along the rhodoliths beds adjacent to the shipwrecks, totalizing 48 squares (24 artificial and 24 natural) (Figure 2). All samples were photographed underwater and obtained under similar conditions of luminosity and positioning regarding the incidence of currents. Samples from shipwrecks were collected manually by scraping its surface whereas rhodoliths were entirely collected, thus ensuring the integrity of the associated fauna (Figure 3). After collecting, all samples were placed in plastic bags, labeled, fixed with 80% ethanol, and transported to the laboratory.

Fig. 2 Sampling replicas of A) Natural reef (rhodolith bed) and B) Artificial reef (shipwreck).

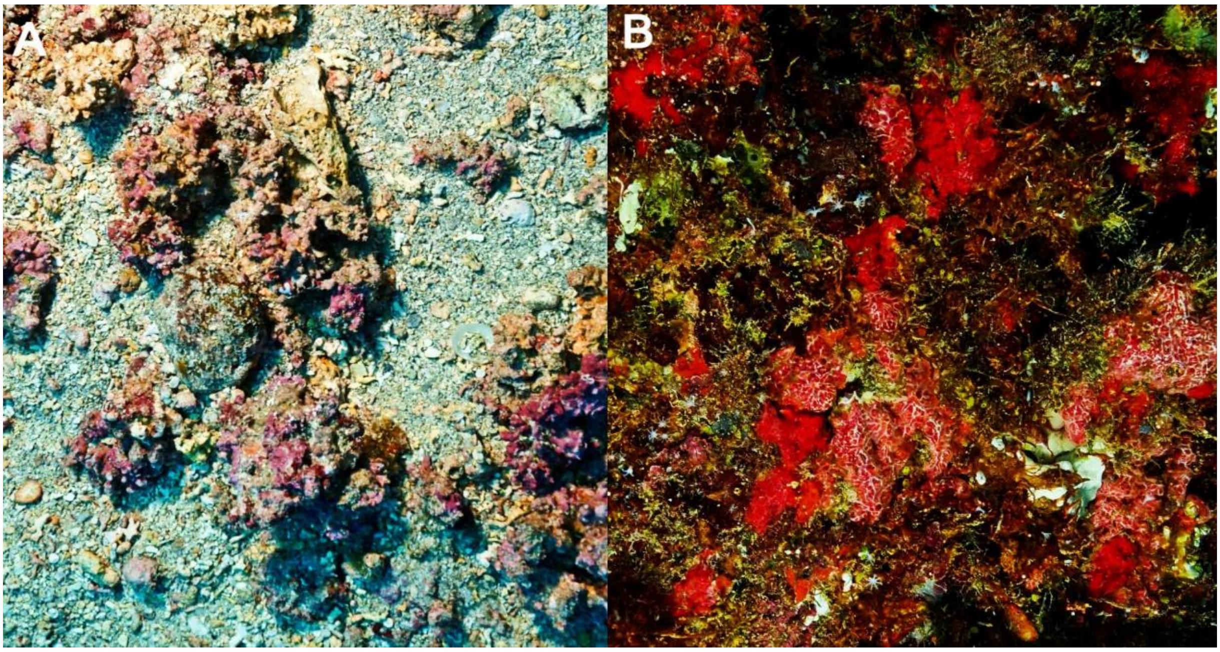
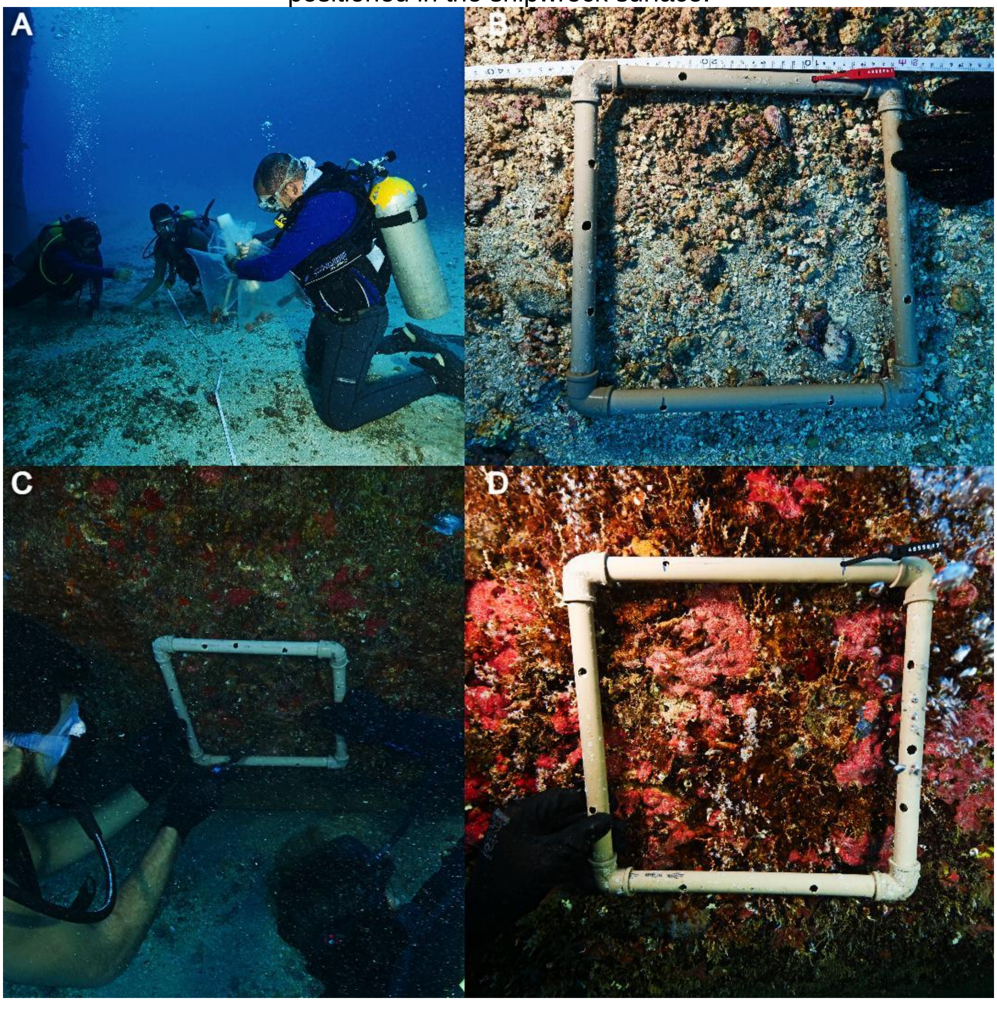


Fig. 3 Underwater reefs sampling. A) Transect being positioned along a rhodolith bed; B) Quadrant positioned in a rhodolith bed; C) Transect being positioned along a shipwreck; D) Quadrant positioned in the shipwreck surface.



Taxonomic identification of sponges and bryozoans

Sponges were analyzed following the procedures described by Hajdu et al. (2011). Dissociated spicules and thick sections were prepared with or without paraffin embedding. Micrometric measurements were conducted for each category of spicular and skeletal assemblies using an optical microscope. The taxonomy was based on the description of the external morphology of the specimens (consistency, shape, surface texture, pattern of arrangement of pores and oscules), skeletal architecture (delimitation of the arrangement and disposition of the different categories of spicules in the sponge body) and the types of spicules of each analyzed species, following recent literature and considerations made by different authors (BERTOLINO et al., 2022; CAVALCANTI, 2019; ERESKOVSKY; LAVROV, 2021; GOLDSTEIN; FUNCH, 2022; LIZARAZO et al., 2020; NASCIMENTO, 2019; OLINGER et al., 2019; POMPONI et al., 2019; PRAXEDES, 2020).

Bryozoans were identified at the lowest taxonomic level possible using a stereoscopic microscope, based on morphological characters referring to autozooids, heterozooids, and reproductive structures (ALMEIDA et al., 2020). The taxonomy was based on recent and specific literature (e.g.,VIEIRA et al., 2014a, 2014b, 2016; FEHLAUER-ALE et al., 2015; ALMEIDA et al., 2015, 2017).

Voucher specimens of sponges and bryozoans are deposited at the Coleção de Porifera and Coleção de Bryozoa of the Departamento de Zoologia of the Universidade Federal de Pernambuco.

Classification of bryozoan species status

We followed the eight criteria used by Xavier et al. (2021) to non-native bryozoans detection. Therefore, here we considered five local (1–5) and three global (6–8) criteria: (1) local appearance of a species where it was not found previously; (2) local dispersal after introduction, with significant growth in the extent of species occurrence, i.e. increase in the number of occurrences and/or widening of its distribution area; (3) specimens found in association with human mechanisms of dispersal; (4) prevalence or restriction in new or artificial environments; (5) restricted distribution when compared to ecologically similar native species, with species found only in (or adjacent to) artificial habitats; (6) widespread geographical distribution with isolated populations; (7) active and passive dispersal mechanisms incapable of achieving the current distribution; and (8) exotic evolutionary origin. To be considered exotic, a species should have five or more criteria applied positively and cryptogenic is when four criteria (including criterion 6) or less are applied positively. Members of species complexes and undetermined species are also classified as cryptogenic, with no application of any criteria (acc. Xavier et al., 2021).

Statistical analyses

The frequency of occurrence of sponges and bryozoans for natural and artificial reefs was calculated based on the total number of squares for type of reef (n=24) expressed as a percentage and illustrated in graphs. For each shipwreck and rhodolith bed, the frequency of occurrence was based on the number of squares at each point (n=6) and summarized into three frequency classes: +++ = presence in 5-6 squares; ++ = between 3–4 squares; + = between 1-2 squares.

To understand the distribution of sponges and bryozoans along the shipwrecks and rhodoliths beds adjacent to these in the studied area, a Bray-Curtis index was applied to calculate the resemblance index on the presence/absence matrices, as a distance measure among samples, to balance the contribution of frequent and rare species. After that, distance-based permutational multivariate analysis of variance (PERMANOVA) were performed to sponges and bryozoans, respectively, using the reef type (natural and artificial) as fixed factor. To illustrate the spatial patterns of the studied faunal assemblages, non-metric multidimensional scaling graphs (n-MDS) were performed to sponges and bryozoans separately. Also, to investigate the relationship between the assemblages and the different reefs, we used similarity percentage analysis (SIMPER) in the PAST program, which indicates the dissimilarities and the most distinctive species at the different types of reef. All the statistical analyses were performed using the software using PAST (Paleontological Statistics Software Package, version 4.03).

Results and discussion

A total of 32 morphotypes of sponges were identified in this study, with 20 species found from the rhodoliths and 19 species found in the shipwrecks (Table 2). Here we present the most comprehensive inventory of sponges from rhodoliths beds from Brazil once, to date, studies were mostly made based on generic records (e.g. AMADO-FILHO; PEREIRA-FILHO, 2012; TÂMEGA et al., 2014; FOSTER et al., 2013; HORTA et al., 2016).

Table 2. Distribution and frequency of occurrence (-, absent; +, present in 1-2 replicas; ++, present in 3-4 replicas; +++, present in 5-6 replicas) of sponges from rhodoliths beds (VPR, adjacent to Vapor de Baixo; PPR, adjacent to Pirapama; SXR, adjacent to Servemar X; TAR, adjacent to Taurus) and shipwrecks (VPS, Vapor de Baixo; PPS, Pirapama; SXS, Servemar X; TAS, Taurus) from Parque dos Naufrágios Artificiais de Pernambuco, northeastern Brazil.

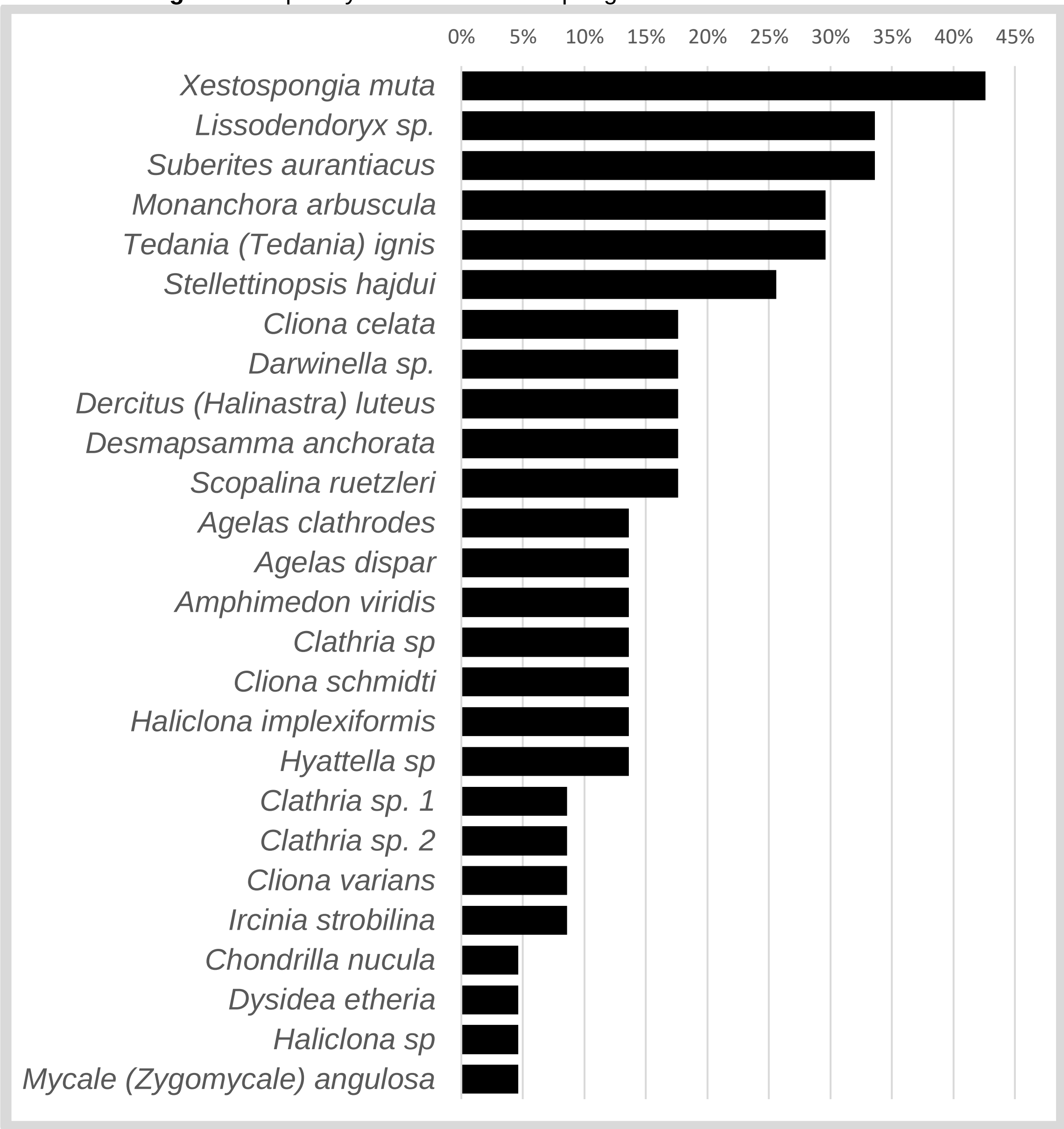
SPONGES	**SITES**							
	VPR	**PPR**	**SXR**	**TAR**	**VPS**	**PPS**	**SXS**	**TAS**
*Agelas clathrodes (*Schmidt, 1870)	+	-	+	+	+	++	+	+
Agelas dispar Duchassaing & Michelotti, 1864	-	-	+	+	-	-	-	-
*Aiolochroia crassa (*Hyatt, 1875)	-	-	-	-	++	++	++	-
Amphimedon viridis Duchassaing & Michelotti, 1864	+	+	-	+	-	-	-	-
*Aplysina fistularis (*Pallas, 1766)	-	-	-	-	+	-	+	-
*Aplysina fulva (*Pallas, 1766)	-	-	-	-	+	-	-	-
*Chelonaplysilla erecta (*Row, 1911)	-	-	-	-	+	-	-	-
Chondrilla caribensis Rützler, Duran & Piantoni, 2007	-	-	-	+	+	+	-	+
Chondrilla nucula Schmidt, 1862	+	-	-	-	-	-	-	-
*Chondrosia collectrix (*Schmidt, 1870)	-	-	-	+	+	-	+	+
Clathria sp.	+	+	+	-	+	-	-	-
Cliona celata Grant, 1826	+	+	+	-	++	++	+	+
Cliona delitrix Pang, 1973	-	-	-	-	+	-	+	++
*Cliona schmidtii (*Ridley, 1881)	+	+	-	-	-	-	-	-
Cliona sp.	-	-	-	+	-	-	-	+
*Cliona varians (*Duchassaing & Michelotti, 1864)	+	-	-	+	-	-	-	-
Darwinella sp.	-	-	++	-	-	-	-	-
*Dercitus (Halinastra) luteus (*Pulitzer-Finali, 1986)	+	+	+	-	-	-	-	-
*Desmapsamma anchorata (*Carter, 1882)	+	+	+	-	++	++	+	+
Dysidea etheria de Laubenfels, 1936	+	+	-	-	++	+	+	+
*Dysidea janiae (*Duchassaing & Michelotti, 1864)	-	-	-	-	++	+	++	+
*Haliclona implexiformis (*Hechtel, 1965)	+	-	-	-	-	-	-	-
Haliclona sp.	-	+	-	-	-	-	-	-
Hyattella sp.	+	+	-	+	-	-	-	-
*Igernella notabilis (*Duchassaing & Michelotti, 1864)	-	-	-	+	-	+	-	+
*Ircinia strobilina (*Lamarck, 1816)	-	-	+	+	+	++	+	-
Stellettinopsis hajdui (Moraes, 2011)	+	-	+	+	-	-	-	-
Lissodendoryx sp.	+	+	+	+	-	-	-	-
Monanchora arbuscula (Duchassaing & Michelotti, 1864)	+	+	++	+	+++	++	+++	++
Mycale (Carmia) microsigmatosa Arndt, 1927	-	-	-	-	++	-	-	+
Mycale (Zygomycale) angulosa (Duchassaing & Michelotti, 1864)	-	-	-	++	-	-	-	-
Scopalina ruetzleri (Wiedenmayer, 1977)	+	-	++	-	++	-	-	+

Table 2 continued								
Suberites aurantiacus (Duchassaing & Michelotti, 1864)	+	-	++	+++	-	-	-	-
*Tedania (Tedania) ignis (*Duchassaing & Michelotti, 1864)	+	+	++	+	+++	+++	++	++
Timea stenosclera Hechtel, 1969	+	+	+	+	-	-	-	-
Topsentia ophiraphidites (de Laubenfels, 1934)	-	-	-	-	-	-	+	+
Xestospongia muta (Schmidt, 1870)	++	+	++	+	-	-	-	-

Sponges found here have a common distribution that globally comprises the WE (LERNER et al., 2005; MURICY, 2023). *Chelonaplysilla erecta*, *Chondrilla nucula*, *Cliona celata* and *Ircinia strobilina* are also known to the Mediterranean Sea (BERTOLINO et al., 2013; LERNER; MOTHES; CARRARO, 2005; MANCONI et al., 2013). All sponges were already recorded in northeastern Brazil (GONDIM; CHRISTOFFERSEN; DIAS, 2020; MURICY, 2011), but *Amphimedon viridis, Chondrosia collectrix, Cliona celata, Cliona varians, Dercitus (Halinastra) luteus, Dysidea janiae, Haliclona implexiformis, Mycale (Zygomycale) angulosa, Stellettinopsis hajdui, Suberites aurantiacus, Timea stenosclera and Xestospongia muta* are here first recorded to the coast of Recife. The species *Chondrilla nucula, Ircinia strobilina, Monanchora arbuscula, Scopalina ruetzleri* were previously known only from Recife’s shipwrecks (AMARAL et al., 2010; LIRA et al., 2010), but were also found here in the rhodoliths beds. *Lissodendoryx sp.* probably represent a new species to science and is being described to publication.

Among the studied sponges, *Xestospongia muta* stood out with a frequency of occurrence greater than 40% in rhodoliths (Figure 4). Another five species – *Timea stenosclera*, *Suberites aurantiacus*, *Monanchora arbuscula*, *Tedania (Tedania) ignis* and *Stellettinopsis hajdui* – showed values ranging from 25% to 33%. All these species have already been recorded in rhodoliths beds around the world (ARAÚJO, 2015; ÁVILA et al., 2013b; ÁVILA; RIOSMENA-RODRIGUEZ, 2011; PEREIRA-FILHO et al., 2015; PIEROZZI JUNIOR, 2015; RIOSMENA-RODRÍGUEZ, 2013) and are known from northeastern Brazil (MURICY, 2011). Other nine species – *Agelas clathrodes, Agelas dispar, Amphimedon viridis, Cliona celata*, *Cliona schmidti*, *Dercitus (Halinastra) luteus*, *Desmapsamma anchorata*, *Haliclona implexiformis* and *Scopalina ruetzleri* – were present in 13% and 17% of the studied rhodoliths and are widely distributed in Brazil (DE MORAES et al., 2019; JOHNSON, 1971; MURICY, 2011; MURICY et al., 1991). Finally, five sponges – *Chondrilla nucula, Cliona varians, Dysidea etheria, Ircinia strobilina* and *Mycale (Zygomycale) angulosa* – presented a frequency of occurrence lower than 10% and except for *Ircinia strobilina* (VALE et al. 2022), the other represents new records of sponges-rhodoliths associations.

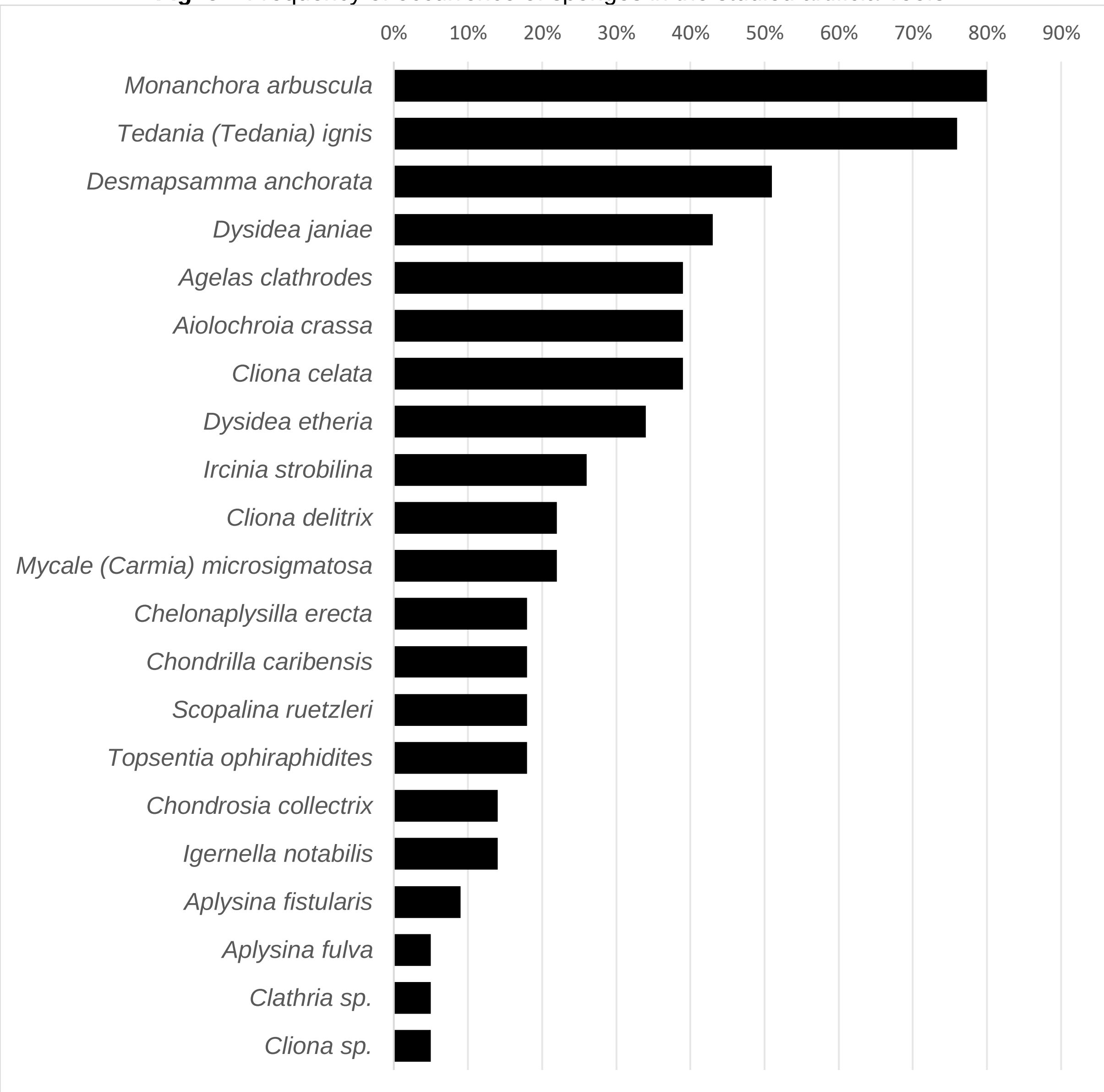
Fig. 4 – Frequency of occurrence of sponges in the studied natural reefs.



Regarding sponges from shipwrecks, all species reported in the present study are common along the Brazilian coast (MURICY, 2011) and twelve – *Agelas clathrodes, Aiolochroia crassa, Aplysina fistularis, Aplysina fulva, Chondrilla nucula, Cliona delitrix, Desmapsamma anchorata, Ircinia strobilina, Monanchora arbuscula, Mycale microsigmatosa, Scopalina ruetzleri, Tedania ignis* – were already reported from shipwrecks off the coast of Pernambuco (AMARAL et al., 2010; LIRA et al., 2010). We emphasize that all sponges identified in the present study at the species level are classified as native except for *Desmapsamma anchorata* and *Tedania (Tedania) ignis*.

They had frequencies of occurrences greater than 50% occurring in all shipwreck's squares (Figure 5) and are considered cryptogenic species, having a distribution restricted to the WE (e.g., ESTEVES et al., 2018; KLITGAARD and TENDAL, 2004; LANNA et al., 2021; LERNER et al., 2005; MURICY, 2011; VILANOVA, 2004). Even the species with the lowest frequencies of occurrences (<10%) – *Aplysina fistularis* and *Aplysina fulva* – also have records in Atlantic Ocean shipwrecks (BAYNES; SZMANT, 1989; OLINGER ET AL., 2019; SOARES et al., 2020).

Fig. 5 – Frequency of occurrence of sponges in the studied artificial reefs.



There was a significant difference in the assemblages of sponges (F= 4.156; P= 0.0267; Table 3) between the studied rhodoliths and shipwrecks. Sponges assemblages presented dissimilarity of approximately 66% by the SIMPER analysis, with *Xestospongia muta*, Lissodendoryx sp., *Stellettinopsis hajdui*, *Dysidea janiae* and

Timea stenosclera, as the species that most contributed to the dissimilarity. All these species are distributed in northeastern Brazil and characteristic of rocky reefs (ARAÚJO, 2015; TÂMEGA; SPOTORNO-OLIVEIRA; FIGUEIREDO, 2013; VALE et al., 2022).

Table 3. Results of the permutational multivariate analyses of variance (PERMANOVA) with the 'area type' as fixed factor on the composition of assemblages of sponges and bryozoans.

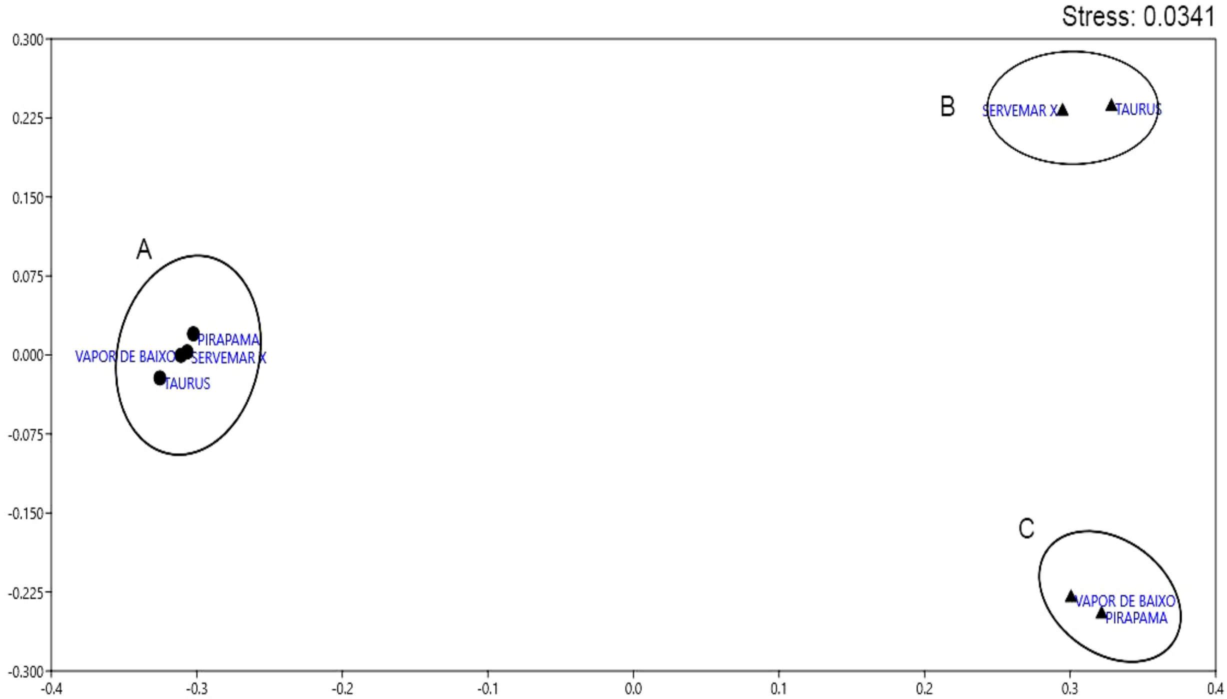
	SS	MS	Pseudo-F	P
Bryozoa	1,388	0,7583	4,983	0,0286
Porifera	1,038	0,303	4,156	0,0267

Despite presenting a slow establishment due to selectivity regarding environmental conditions, sponges are always among the dominant groups in the occupation of natural and artificial reefs (CARBALLO; NARANJO; GARCÍA-GÓMEZ, 1996; CEDRO et al., 2007; LIRA et al., 2010; PERKOL-FINKEL; BENAYAHU, 2005; WALKER; SCHLACHER; SCHLACHER-HOENLINGER, 2007).

There is much emphasis on the role of sponge larval behavior in determining their distribution on different types of surfaces (MALDONADO & URIZ 1998; URIZ et al. 1998). However, larval dispersal is just one of many factors that influence group distributions. An increase in population size can be a result of the immigration of sexual propagules or asexual propagation and it is seen that settlement and post-settlement processes can also be important in determining the final distribution of sponges in the types of reefs studied here (MARIANI et al. al, 2006). In sponges, recruitment rates from new environments such as reefs are generally low (ZEA, 1993), especially when compared to other sessile invertebrates such as bryozoans (MARIANI 2003; MARIANI et al. 2005).

Our results also showed a significant dissimilarity between sponges assemblages from rhodoliths (Figure 6). The nMDS shows a clear subdivision of the assemblages from rhodoliths into two groups (B and C). Group B comprises the rhodolith beds adjacent to the wrecks sunk in the 21st century and Group C includes two secular wrecks (sunk in the 19th century). Thus, probably the sinking time, the material and geographic proximity of the wreck may be influencing sponges composition in the area.

Fig. 6 – Non-metric multidimensional scaling (nMDS) plot in two dimensions of the Bray-Curtis dissimilarity of sponges assemblages from artificial (circles) and natural (triangles) reefs.



In general, rhodoliths beds had the greatest diversity of species than shipwrecks. The Vapor de Baixo shipwreck and its rhodolith beds had the greatest diversity for both bryozoans and sponges. On a world scale and in addition to structural characteristics, studies documenting sponges and bryozoans in rhodolith beds relate species diversity to the density of white nodules and degree of sedimentation, while for shipwrecks the influence of biotic and abiotic factors is more significant (CREED et al., 2017; PIEROZZI JUNIOR, 2015; PRISCILLA H WENDT et al., 1989; VALE et al., 2022).

A total of 63 morphotypes of bryozoans were studied here, with 47 species found in the rhodoliths beds and 29 species found in the shipwrecks (Table 4). All species are common from northeastern Brazil (VIEIRA; ALMEIDA, 2023). It is also the most comprehensive inventory of bryozoans from rhodoliths beds and shipwrecks from the Western Atlantic once previous records were taxonomic studies not focused specifically on these fauna (e.g., AMADO-FILHO; PEREIRA-FILHO, 2012; ÁVILA; RIOSMENA-RODRIGUEZ, 2011; HORTA et al., 2016; PEREIRA-FILHO et al., 2015).

Table 4. Composition and frequency of occurrence (+, present in 1-2 replicas; ++, present in 3-4 replicas; +++, present in 5-6 replicas) of bryozoans from rhodoliths beds (VPR, adjacent to Vapor de Baixo; PPR, adjacent to Pirapama; SXR, adjacent to Servemar X; TAR, adjacent to Taurus) and shipwrecks (VPS, Vapor de Baixo; PPS, Pirapama; SXS, Servemar X; TAS, Taurus) from Parque dos Naufrágios Artificiais de Pernambuco, northeastern Brazil.

NATIVE BRYOZOANS	**SITES**							
	VPR	**PPR**	**SXR**	**TAR**	**VPS**	**PPS**	**SXS**	**TAS**
Amathia distans Busk, 1886	-	-	-	-	+	-	-	-
Ammatophora arenacea Winston & Vieira, 2013	++	+	-	+	-	-	-	-
Beania americana Vieira, Migotto & Winston, 2010	+	-	-	-	-	-	-	-
Beania australis Busk, 1852	-	-	-	+	+	-	-	-
Beania cupulariensis Osburn, 1914	+	+	-	+	-	-	-	-
Beania mirabilis Johnston, 1840	++	-	-	-	+	-	-	-
Bicellariella edentata Marcus, 1955	+	+	-	+	+	+++	+++	++
Bugula gnoma Vieira, Winston & Fehlauer-Ale, 2012	-	-	-	-	-	+	-	+
*Calyptotheca triangulata (*Canu & Bassler, 1928)	+	+	+	+	-	-	-	-
*Celleporaria atlantica (*Busk, 1884)	++	+	-	+	+	-	-	-
Cradoscrupocellaria calypso Vieira, Spencer Jones & Winston, 2013	-	+	+	-	++	+	++	+
Exechonella brasiliensis Canu & Bassler, 1928	+	-	++	-	-	-	-	-
Fodinella atlantica Winston, Vieira & Woollacott, 2014	-	-	+	-	-	-	-	-
Hippothoa brasiliensis Morris, 1980	-	-	+	+	-	-	-	-
Labioporella tuberculata Winston, Vieira & Woollacott, 2014	+	+	+	+	-	-	-	-
*Licornia jolloisii (*Audouin, 1826)	-	-	+	+	-	-	-	-
Micropora angustiscapulis Winston, Vieira & Woollacott, 2014	+	+	+	-	-	-	-	-
Mollia elongata Canu & Bassler, 1928	-	-	+	+	-	-	-	-
*Pasythea tulipifera (*Ellis & Solander, 1786)	+++	-	-	-	+	-	-	-
Table 4. continued								
Poricella frigorosa Winston, Vieira & Woollacott, 2014	-	-	-	-	-	+	+	-
*Pourtalesella carvalhoi (*Marcus, 1937)	+	-	-	-	-	-	-	-
Reptadeonella aspera Almeida, Souza, Sanner & Vieira, 2015	-	-	+	-	-	-	-	-
Rhynchozoon brasiliensis Almeida, Souza, Menegola & Vieira, 2017	-	-	-	-	-	-	-	+
Smittipora sawayai Marcus, 1937	-	+	+	+	-	-	-	-
Smittipora tuberculata (Canu & Bassler, 1928)	++	+	++	-	-	-	-	-
*Smittoidea numma (*Marcus, 1949)	+	-	+	-	-	-	-	-
*Steginoporella magnilabris (*Busk, 1854)	-	-	+	-	-	-	-	-
*Steginoporella transversalis (*Canu & Bassler, 1928)	-	-	-	-	-	-	+	++
Stylopoma aurantiacum Canu & Bassler, 1928	+	-	+	++	-	-	-	-
Stylopoma hastata Ramalho, Taylor. & Moraes, 2018	++	-	++	+	-	-	-	-
Trypostega tropicalis Winston, Vieira & Woollacott, 2014	+	+	+	+	-	-	-	-
Vasignyella ovicellata Vieira, Gordon & Correia, 2007	-	-	+	-	++	-	++	-
*Vitrimurella fulgens (*Marcus, 1955)	+	+	+	+	-	+	-	-
CRYPTOGENIC BRYOZOANS	**SITES**							
	VPR	**PPR**	**SXR**	**TAR**	**VPS**	**PPS**	**SXS**	**TAS**
Aetea arcuata winston & hayward, 2012	+	-	-	++	+	-	+	+

Aetea cultrata Vieira, Almeida & Winston, 2016	+	++	+	-	+++	-	+	+
Aetea curta Jullien, 1888	-	+	+++	++	++	+	-	+
*Amathia vidovici (*Heller, 1867)	-	-	-	-	+	-	-	-
Arthropoma sp.	+	-	-	-	-	-	-	-
*Biflustra arborescens (*Canu & Bassler, 1928)	-	+	-	-	-	-	-	-
Bugula sp.	-	-	-	-	-	+	-	-
Caberea boryi (Audouin, 1826)	-	++	-	-	-	-	-	-
*Catenicella contei (*Audouin, 1826)	++	-	+	++	+	-	-	-
*Catenicella uberrima (*Harmer, 1957)	+	+	+	+	+	-	-	+
*Caulibugula dendrograpta (*Waters, 1913)	-	-	-	-	-	-	+	-
Caulibugula sp.	+	-	-	-	-	-	-	-
Celleporaria sp.	-	-	-	-	-	-	+	-
Crepidacantha sp.	+	-	-	-	-	-	-	-
*Arbocuspis ramosa (*Osburn, 1940)	-	-	+	-	-	-	-	-
Exechonella vieirai Cáceres-Chamizo, Sanner, Tilbrook & Ostrovsky, 2017	++	-	+	+	-	-	-	-
Hippopodina sp.	+	-	-	-	-	+	-	-
Hippoporina sp.	+	-	-	-	-	-	-	-
*Jellyella tuberculata (*Bosc, 1802)	-	-	+	+	-	-	-	-
*Licornia diadema (*Busk, 1852)	++	++	+	+	++	++	++	++
Licornia sp.	+	-	-	-	-	++	-	-
Nellia tenella(Lamarck, 1816)	++	-	-	-	+	-	-	-
Nolella stipata Gosse, 1855	-	-	-	++	++	++	-	+
Onychocella sp.	+	-	+++	++	-	-	-	-
Parasmittina sp.	-	+	-	-	-	-	-	-
Plesiocleidochasma sp.	-	-	+	-	-	-	-	-
Poricella sp.	-	+	-	-	-	-	+	-
Puellina sp.	++	-	++	+	-	-	+	-
*Savignyella lafontii (*Audouin, 1826)	+	-	++	++	+++	++	++	++
Schizobrachiella sp.	+	-	+	-	-	-	-	-
Scrupocellaria frondis Kirkpatrick, 1890	+	-	-	+	-	-	-	-
Scrupocellaria sp.	-	-	-	-	-	-	-	+
Smittoidea pacifica Soule & Soule, 1973	-	-	-	+	-	-	+	+
Stylopoma sp. 1	++	+	+	-	-	-	-	-

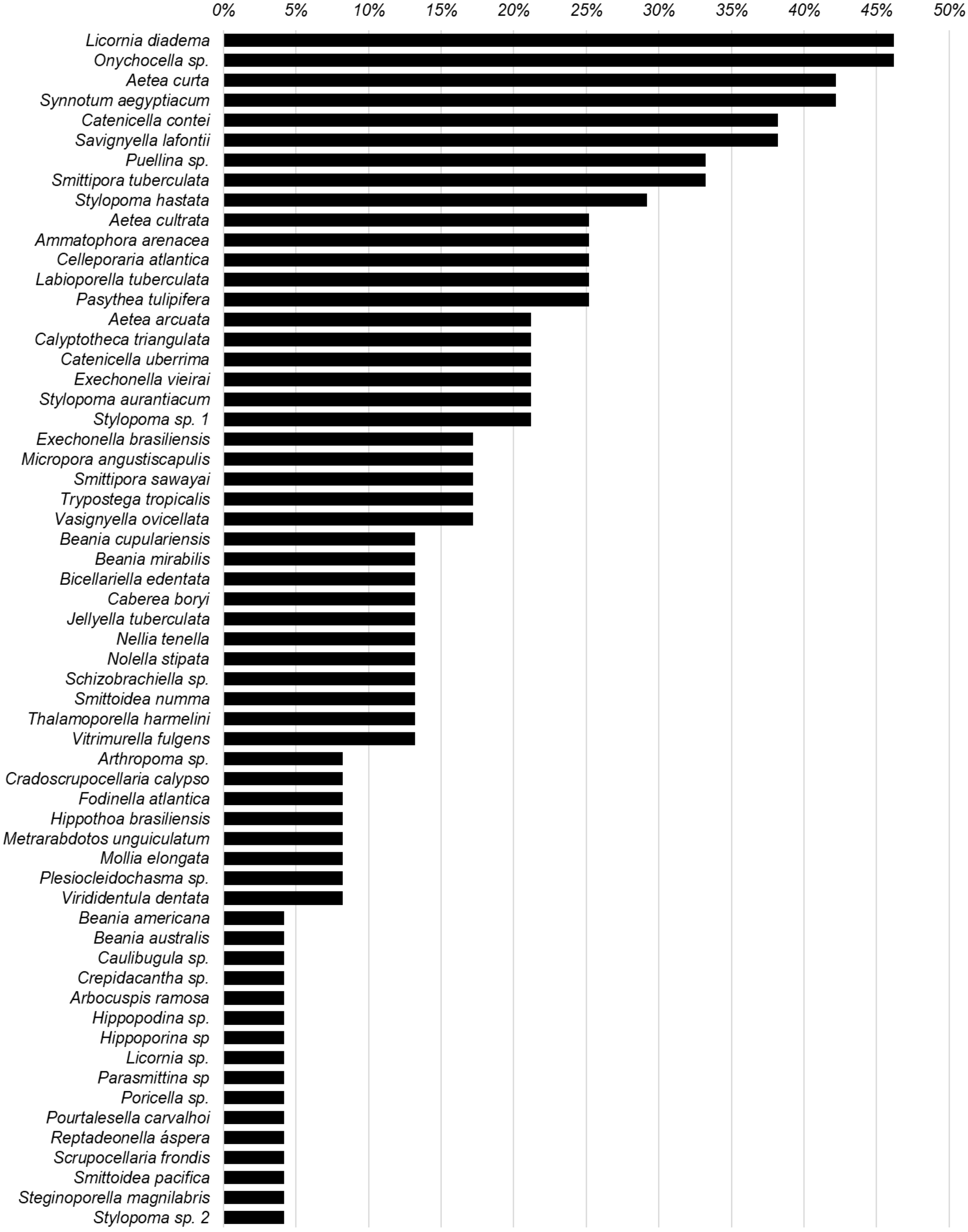
Table 4. continued

Stylopoma sp. 2	-	+	-	-	-	-	-	-
*Synnotum aegyptiacum (*Audouin, 1826)	-	++	+	+++	++	-	-	-
Thalamoporella harmelini Soule, Soule & Chaney, 1999	+	-	+	-	-	-	-	-
Viridentula dentata (Lamouroux, 1816)	-	-	-	+	-	+	-	-
EXOTIC BRYOZOANS	**SITES**							
	VPR	**PPR**	**SXR**	**TAR**	**VPS**	**PPS**	**SXS**	**TAS**
Amathia verticillata (delle Chiaje, 1822)	-	-	-		++	-	-	-
Buskia socialis Hincks, 1886	-	-	-	-	-	-	+	+
Hippoporina indica (Pillai, 1978)	-	-	-	-	-	+	+	+
Licornia jolloisii (Audouin, 1826)	-	-	-	-	+	-	+	++

Among the studied bryozoans, *Licornia diadema* and *Onychocella* sp. have the highest frequency of occurrence in rhodoliths, occurring in more than 45% of the squares (Figure 7). These results are not unlike since *Licornia diadema* represent a species complex that is known to be widespread along Brazilian coast, including natural and artificial substrata (e.g., ALMEIDA et al., 2017; VIEIRA et al., 2014). Also, species of *Onychocella* are commonly known from hard substrata (YANG; SEO;

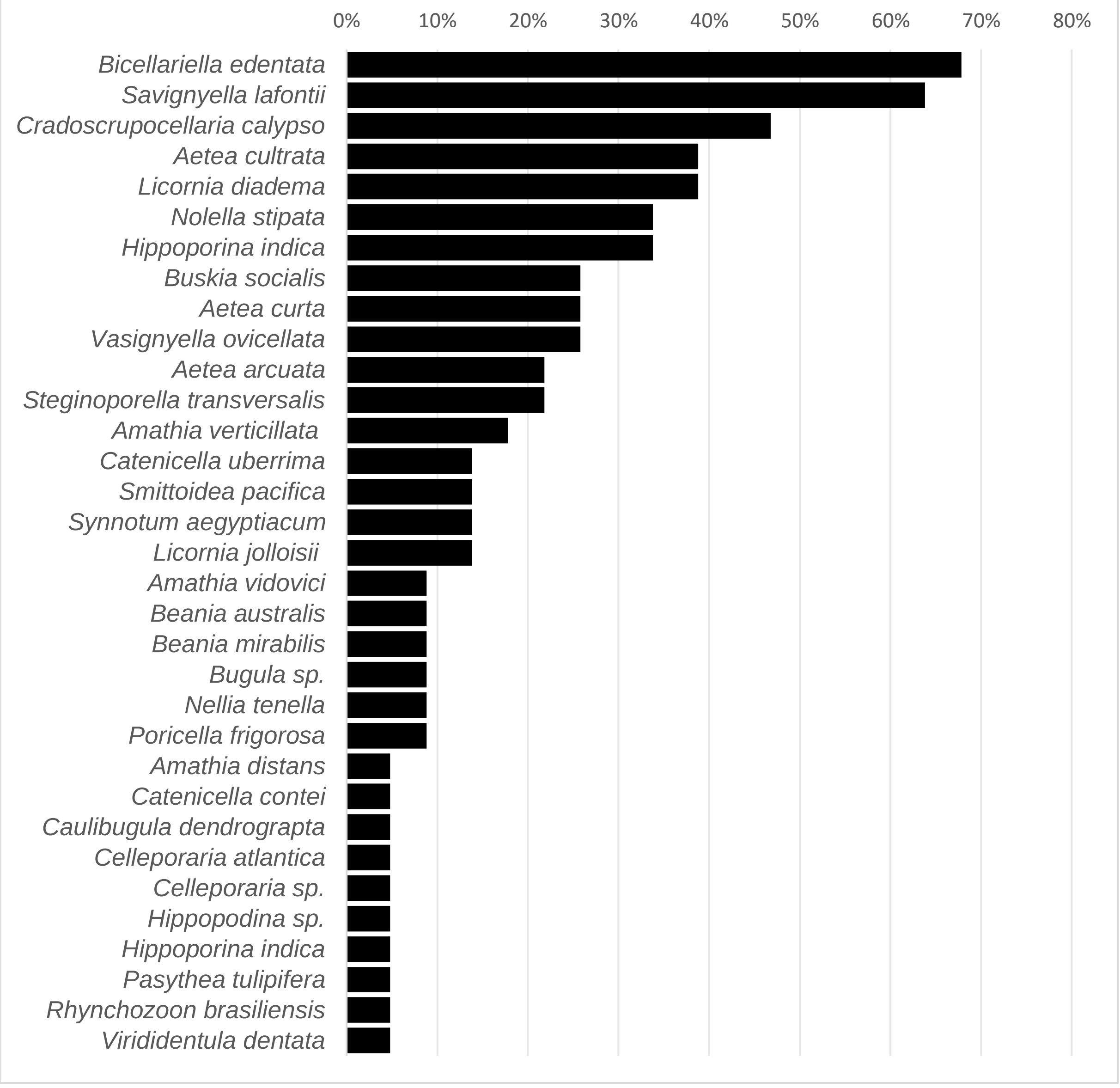
GORDON, 2018). Other common bryozoans from rhodoliths studied here were *Aetea curta*, *Synnotum aegyptiacum*, *Catenicella contei* and *Savignyella lafontii*.

Fig. 7 - Frequency of occurrence of bryozoans in the sampled natural reefs.



Regarding bryozoan assemblage from shipwrecks studied here, *Bicellariella edentata*, which had the highest frequency of occurrence (67%) (Fig. 8), was present in all four shipwrecks, is here presented as a new record from Brazilian artificial reefs. The species was reported to be endemic to Brazil until Lopez-Gappa et al. (2022) recorded it from an artificial harbor-type reef off the coast of Argentina. *Savignyella lafontii*, second highest in frequency of occurrence (63%) is recognized for its wide distribution in warm tropical waters, both in marine and estuarine environments, and without clear preference for any type of natural or artificial surface (MIRANDA; ALMEIDA; VIEIRA, 2018; VIEIRA et al., 2012, 2014). *Cradoscrupocellaria calypso* e *Aetea cultrata* were also common and are endemic species of the Brazilian coast (VIEIRA; ALMEIDA, 2023).

Fig. 8 - Frequency of occurrence of bryozoans in the sampled artificial reefs.

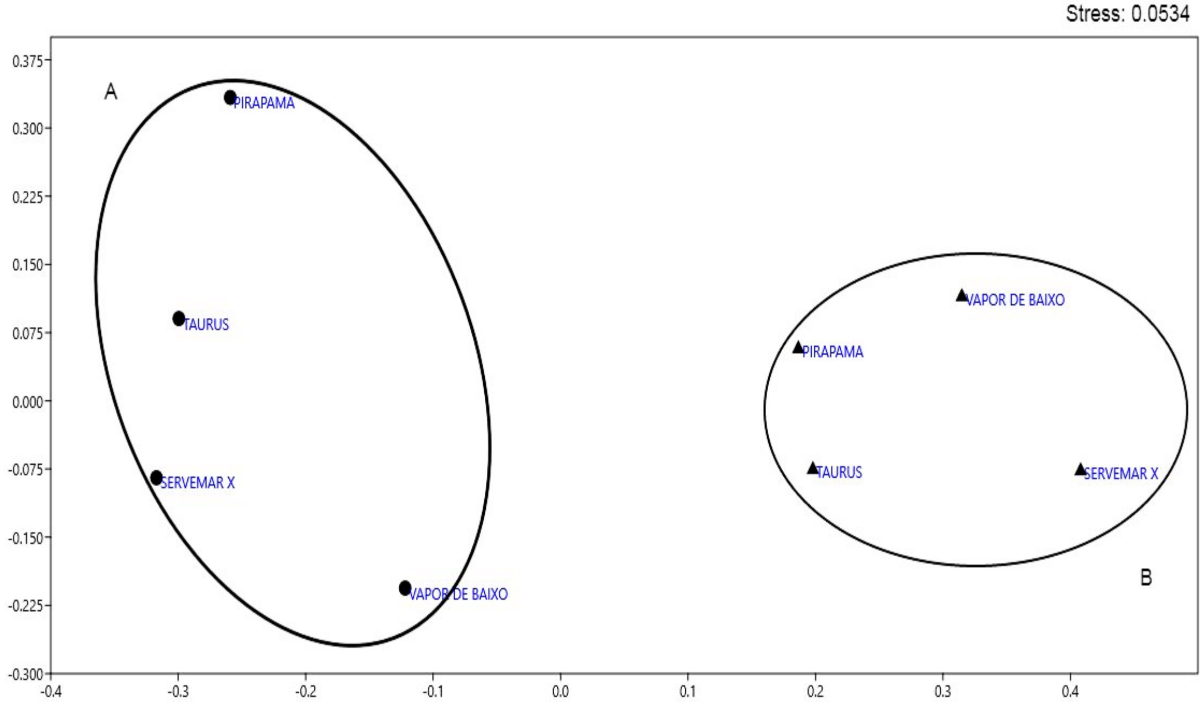


Artificial reefs, such as shipwrecks, are considered a main vector of expanding the geographic distribution of bryozoan species (CARLTON et al., 2017; WATTS et al., 1998). At least 55 bryozoans were already recorded from artificial habitats from Brazil (XAVIER et al. 2021). Among these, 16 species were also found in the present study, including taxa related to human mediated activities and bioinvasion events – *Amathia distans*, *Amathia verticillata*, *Amathia vidovici*, *Catenicella uberrima*, *Nolella stipata* and *Savignyella lafontii* (ALMEIDA et al., 2015; FERREIRA et al., 2009; ROCHA et al., 2013; SCHWINDT et al., 2020; SOARES et al., 2022).

It worth mentioning that species frequently recorded from artificial habitats from Brazil and other regions of the world (e.g., *Caulibugula armat*a, *Membraniporopsis tubigera*, *Sinoflustra annae*, *Thalamoporella harmelini* and *Triphyllozoon arcuatum*) (MIRANDA et al., 2018; ROCHA et al., 2013; XAVIER et al., 2021) were not found in the present study. However, more sampling is needed, including the study of environmental parameters, to determine which factors are involved with the occurrence or not of these bryozoans in the study area.

There was a significant difference in the assemblages of bryozoans (F= 4.983; P=0.0286; Table 3) between the studied rhodoliths and shipwrecks Bryozoan assemblages from rhodoliths and shipwrecks studied here showed 75% of dissimilarity according to the SIMPER analysis and illustrated in the nMDS (Fig. 9). *Trypostega tropicalis*, *Calyptotheca triangulata* and *Labioporella tuberculata*, were the species that most contributed to the dissimilarity, being exclusively found in rhodoliths. All these species are common in hard substrata from Brazil (e.g., Almeida et al., 2018; Vieira et al., 2016; Winston et al., 2014). Eighteen species – *Aetea arcuata, Aetea cultrata, Aetea curta, Beania australis, Beania mirabilis, Bicellariella edentata, Catenicella contei, Catenicella uberrima, Cradoscrupocellaria calypso, Licornia diadema, Nellia tenella, Nolella stipata, Pasythea tulipifera, Savignyella lafontii, Smittoidea pacifica, Synnotum aegyptiacum, Vasignyella ovicellata, Virididentula dentata* – occurs in both rhodoliths and shipwrecks and are taxa with a common distribution in tropical waters (VIEIRA; ALMEIDA, 2023; XAVIER et al., 2021; ALMEIDA et al., 2017; VIEIRA; ALMEIDA; WINSTON, 2016).

Fig. 9 - Non-metric multidimensional scaling (nMDS) plot in two dimensions of the Bray-Curtis dissimilarity for the bryozoans of natural (circles) and artificial (triangles) reefs.



Perkol-finkel (2005; 2006) stated that when an artificial reef is introduced adjacent to natural ones, the faunal composition tends to be similar over time. However, when the substrata complexity is different, whether artificial or natural, the communities will be different even after more than a century (PERKOL-FINKEL et al., 2006; WALKER et al., 2007; HUNTER; SAYER, 2009). Another factor that can be related to the dissimilarity found among bryozoan assemblages from rhodoliths and shipwrecks studied here is the active behavior of substrate selection by the larvae. The larval settlement of bryozoans is influenced by biotic factors such as biofilm composition (SATHEESH; WESLEY, 2011; ZARDUS et al., 2008) and abiotic factors such as substrate composition (SPAGNOLO et al., 2014; TYRRELL; BYERS, 2007). Such characteristics can directly determine the species community composition, including the selectivity of the reef type for native, cryptogenic and/or exotic species since a successful settlement of an individual includes the recognition and establishment in an environment suitable for its development (BULLERI; CHAPMAN, 2004; GLASBY; CONNELL, 2001; NYDAM; STACHOWICZ, 2007).

Twenty-eight native bryozoans were found in rhodoliths, including 20 species endemic to Brazil (VIEIRA; ALMEIDA, 2023), and thirteen native bryozoans were found in the studied shipwrecks. *Pasythea tulipifera* presented 100% frequency of occurrence in the secular wreck Vapor de Baixo, corroborating with results obtained by Tyrrel and Byers (2007) who conclude that shipwrecks can act actively in the larval recruitment of native species representing the benthic fauna. The highest richness of native species was found in the shipwreck Vapor de Baixo and this result may be related to the vessel's age and hull material, which is made of iron, which is considered one of the most surfaces that share similar communities to natural reefs and ends up mimicking them (GLASBY, 2001). However, all species occurred in more than one shipwreck while the rhodoliths sheltered most of the native species in a non-shared way.

A total of 21 cryptogenic species were found in this study, 18 from rhodoliths and 16 from shipwrecks. The high number of cryptogenic bryozoans found here and in studies with fouling from Brazil is related with taxonomic uncertainties and lack of information about the biogeographic origin of taxa, thus preventing a confident native/exotic attribution (acc. XAVIER et al., 2021). However, it also highlights the importance of more studies with these fauna as cryptogenic bryozoans were already related with bioinvasion events worldwide, including in Brazil (VIEIRA; MIGOTTO, 2015). Also, cryptogenic taxa commonly represent early succession species with high capacity for colonization and dispersion (FERRARIO et. al., 2018) that can influence and even modify native communities.

Several studies including fouling bryozoan fauna from Brazil (e.g. LOPES et al., 2009; MARQUES et al., 2013; ROCHA et al., 2013) and worldwide (e.g. MCINTYRE et al., 2013; GARTNER et al., 2016) reported the dominance of cryptogenic species over native ones on artificial reefs.

All species classified as exotic in the present study – *Amathia verticillata*, *Buskia socialis*, *Hippoporina indica*, *Licornia jolloisii* – were found only on shipwrecks, corroborating the alert published by Ferrante et al. (2020) about the attractiveness of these ecosystems to potential invasive species. *Amathia verticillata* occurred exclusively in the Vapor de Baixo shipwreck, with a frequency of occurrence of 67%. This exotic bryozoan is widely known to cause negative impacts in human activities such as fishing and aquaculture (GORDON, 1992; GORDON et al., 2006; WINSTON, 1982; GORDON et al., 2008; MARCHINI et al., 2015; ALMEIDA et al., 2017), thus being a cause of concern.

The implantation of artificial reefs in Brazilian waters is ensured by Programa Nacional de Revitalização do Ecoturismo Náutico and based on the Decreto n° 5.382/05, that includes stimulating the construction of floating and submerged structures to be used in activities of teaching, research, exploration and sustainable use of marine resources. However, as shown in this study, artificial reefs have the potential to be used by exotic and cryptogenic species as stepping stones to natural environments, with unpredictable consequences. Our results also show that the most recently sunk wreck (Taurus in 2006) hosted the highest number of exotic bryozoans, but more studies are needed to understand the correlation between the shipwreck age and the occurrence of exotic/native species. More efforts are also needed to understand the adaptations to artificial substrata and possible dispersal of potential invasive bryozoans along the Brazilian coast.

Conclusion

Here we presented the most comprehensive inventory of sponges and bryozoans from shipwrecks and rhodoliths beds from the WE. The assemblages of sponges and bryozoans found here are composed mainly by species common in the WE. The large number of bryozoans classified as cryptogenic are in accordance with recent studies with fauna from artificial habitats and adjacent areas worldwide. We found that sponges and bryozoans assemblages from the natural and artificial studied reefs are significantly different, with the associated fauna from rhodoliths beds being more diverse than fauna from the shipwrecks. Also, exotic bryozoans were only found in the shipwrecks, especially in those more recently sunk, which highlights the concerns regarding creating new artificial reefs that may facilitate bioinvasion events.

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6 CONSIDERAÇÕES FINAIS

- Os naufrágios e os rodolitos estudados são diferentes quanto a composição faunística de esponjas e briozoários marinhos.
- As assembleias de esponjas e briozoários dos rodolitos, aqui considerados como modelo de recife natural, apresentaram maior riqueza.
- As esponjas marinhas encontradas apresentam distribuição comum para o Atlântico Ocidental, e reportamos pela primeira vez a presença de onze espécies de esponjas (*Amphimedon viridis, Chondrosia collectrix, Cliona celata, Cliona varians, Dercitus (Halinastra) luteus, Dysidea janiae, Haliclona implexiformis, Mycale (Zygomycale) angulosa, Suberites aurantiacus, Timea stenosclera, Xestospongia muta)* para a cidade do Recife, incluindo a ocorrência de uma provável nova espécie para a ciência (*Lissodendoryx* sp.).
- Há diferença entre as assembleias de esponjas amostradas entre os rodolitos, que foram sub agrupadas provavelmente devido ao tempo de afundamento e da proximidade geográfica entre as réplicas.
- Os briozoários encontrados têm distribuição previamente conhecida para o nordeste do Brasil e estruturas artificiais já foram consideradas como vetores potenciais para dispersão de muitas espécies ao longo da costa. *Licornia diadema* apresentou maior ocorrência nos rodolitos enquanto que *Bicellariella edentata* apresentou domínio nos naufrágios, sendo este seu primeiro registro para substratos artificiais no Brasil.
- A maioria dos briozoários são criptogênicos e não mostraram preferência quanto ao tipo de recife. Briozoários exóticos foram encontrados apenas nos naufrágios.
- O naufrágio mais antigo e seu banco de rodolitos adjacente apresentou maior riqueza e diversidade de espécies de esponjas e briozoários enquanto que o naufrágio afundado mais recentemente em relação aos demais amostrados apresentou a maior ocorrência de briozoários exóticos, enfatizando o alerta sobre a prática de afundamento poder facilitar a introdução de potenciais espécies invasoras.

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