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A report on new sponge-ophiuroid associations and reinforcement of scientific knowledge

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ABSTRACT

Sponge-ophiuroid ecological associations, which are important in the dynamics of marine populations and communities, have been recorded for a long time. In this study, we report new records of interactions between sponges and ophiuroids, which were obtained by analyzing biological collections, to increase knowledge about the associations between these animals. The study observed 14 interactions between sponges and ophiuroids, eight of which are new to science: *Ophiocnida scabriuscula* and *Agelas* sp., *Ophiothrix* sp. and *Monanchora arbuscula*, *Ophiactis quinqueradia* and *M. arbuscula*, *O. quinqueradia* and *Callyspongia* (*Cladochalina*) *aculeata*, *Ophiactis savignyi* and *Agelas dispar*, *O. savignyi* and *M. arbuscula*, *O. savignyi* and *Topsentia ophiraphidites*, and *O. savignyi* and *Dysidea etheria*. The specimens found were collected in four areas of the northeastern Brazilian coast (tropical southwestern Atlantic), including a conservation area and a mesophotic coral ecosystem. Thus, the continuation of studies and the implementation of conservation strategies for these environments are essential. Finally, the importance of biological collections as a crucial data source for biodiversity studies is reinforced.

Keywords: Ecological associations, Biological collections, Biodiversity, Ophiuroidea, Porifera

The ecological interactions existing in nature are essential for the maintenance of biodiversity. The good structuring of a community is due to an important network of interspecific relationships that occur between individuals, whether mutualistic or cooperative, in which there is a beneficial relationship between the species involved, or antagonistic, as in competition and parasitism (Mougi and Kondoh, 2012).

The association between sponges (Porifera) and other animals has been documented for a long time (Pearse, 1934, 1950; Rützler, 1976; Peattie and Hoare, 1981; Klitgaard, 1995; Ribeiro et al., 2003). Due to the diversity of endobiont or epibiont animals associated with sponges, they are known as true hosts (Pearse, 1950; Koukouras et al., 1985).

Sponge-ophiuroid associations are often seen in the marine environment (Pearse, 1934; Fortunato and Lôbo-Hajdu, 2021). It has been

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scientifically proven that ophiuroids associate with sponges, where they find shelter, protection, and food availability due to their morphology (external indentations and their channel system) (Bakus, 1966; Duarte and Nalesso, 1996; Pansini, 1970; Henkel and Pawlik, 2005). Ophiuroids are also attracted by chemical metabolites that have properties against predation and fouling by other living beings (Clavico et al., 2006).

Bejarano Chavarro et al. (2004) observed that *Ophiothrix suensonii* Lütken, 1856 was associated with different sponge species, according to the advantages conferred by their growth forms. This ophiuroid species was found both in sponges whose morphology provided cryptic refuges for protection against predators (columnar sponges with large oscula) and in sponges without this possibility of protection, but which occupied a region in the substrate favorable to suspension-feeding activity, in addition to allowing the aggregation of several individuals as an alternative form of protection (Bejarano Chavarro et al., 2004). However, the benefits of this association for both sponges and ophiuroids are still unclear (Mosher and Watling, 2009). In order to contribute to the knowledge of sponge-ophiuroid associations, this study reports new records of interactions.

Data were obtained by analyzing specimens from the Echinodermata collection of the Departamento de Biologia, Universidade Federal do Ceará, Brazil, and the Porifera collections of the Departamento de Biologia (Universidade Federal do Ceará) and the Museu Nacional do Rio de Janeiro (Brazil). Sponges and ophiuroids were identified with the help of specialized literature (Hooper and Van Soest, 2002; Gondim et al., 2013; Hendler et al., 1995; Santana et al., 2020).

We found four species (Figure 1) of ophiuroids associated with 11 species of sponges (Figure 2), totaling 14 interactions, eight of which are new to science. The four ophiuroid species were: *Ophiocnida scabriuscula* (Lütken, 1859), *Ophiothrix* sp., *Ophiactis savignyi* (Müller & Troschel, 1842), and *Ophiactis quinqueradia* Ljungman, 1872. The ophiuroid species *O. savignyi* was the most abundant, with 209 specimens and the highest number of sponge-associated hosts. In turn, the sponge species were distributed in eight families, which include Callyspongiidae, Aplysinidae, Agelasidae, Irciniidae, Niphatidae, Crambeidae, Halichondriidae, and Dysideidae (Table 1).

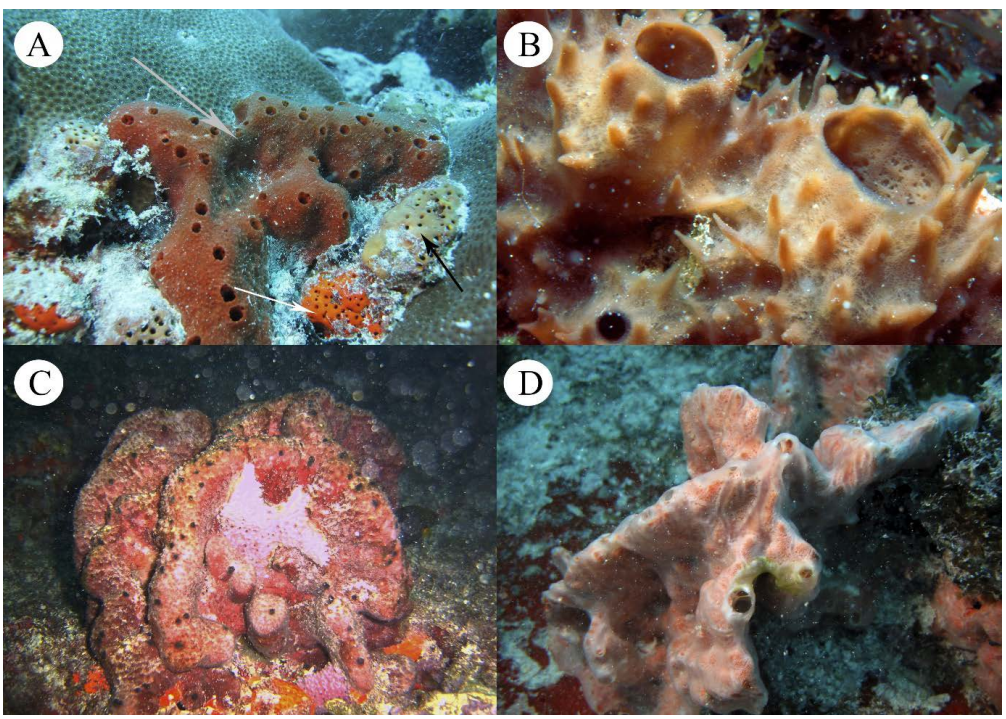

Figure 1. *In situ* sponge colonies of some of the studied species. A) *Amphimedon* aff. *compressa* (grey arrow), *Agelas dispar* (black arrow), and *Agelas* sp. (white arrow); B) *Callyspongia* (*Cladochalina*) *aculeata*; C) *Ircinia felix*; D. *Monanchora arbuscula*.

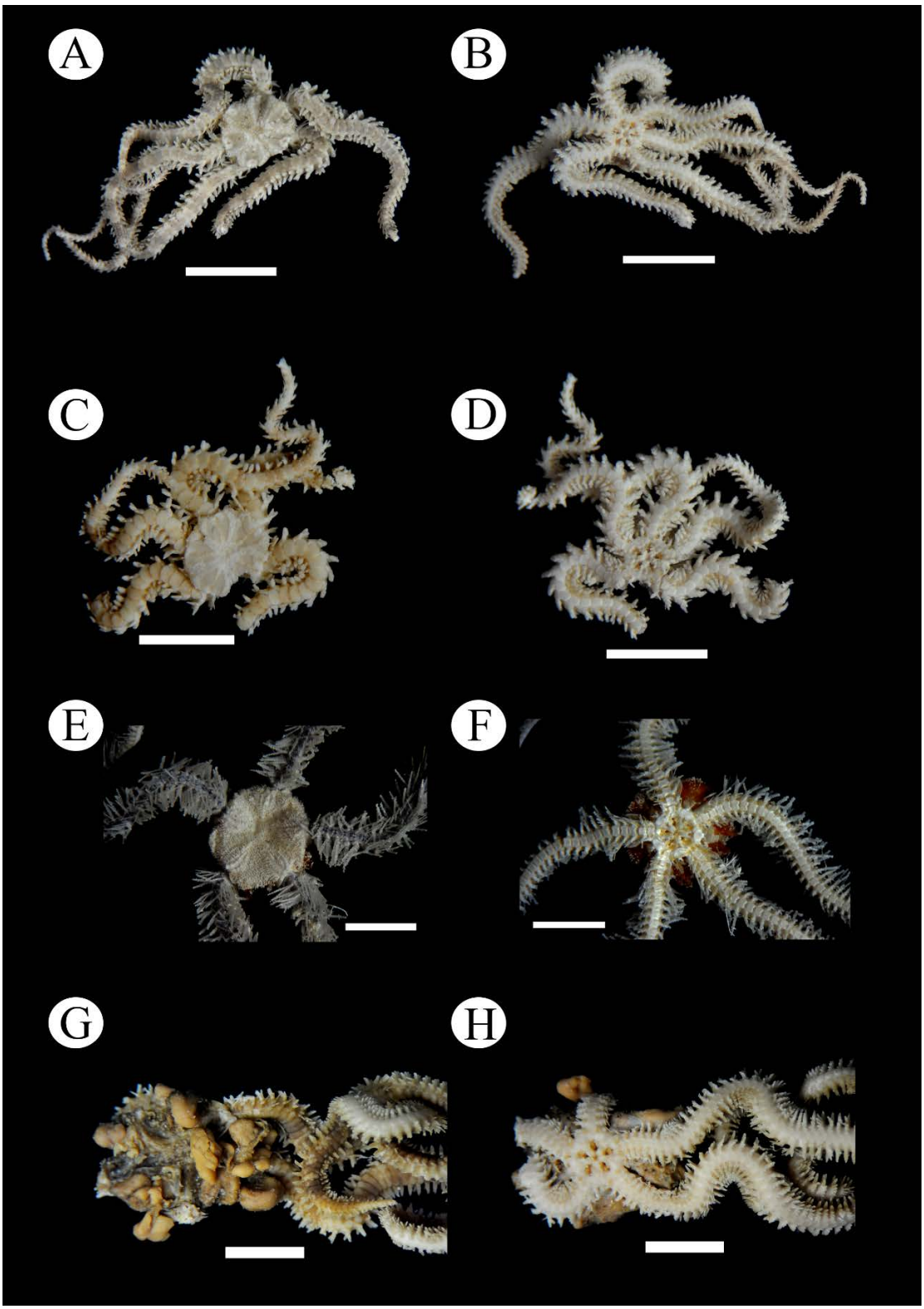

Figure 2. Representatives of the ophiuroids analyzed in the study (*ex situ*). A-B) *Ophiactis savignyi*, dorsal (A) and ventral (B); C-D) *Ophiactis quinqueradia*, dorsal (C) and ventral (D); E-F) *Ophiothrix* sp., dorsal (E) and ventral (F); G-H) *Ophiocnida scabriuscula*, dorsal (G) and ventral (H). Scale bars: A-B, E-H: 5 mm; C-D: 3 mm.

Table 1. Records of the association between ophiuroids and sponges and their collection sites in the state of Ceará, northeastern Brazilian coast, tropical southwestern Atlantic.

Ophiuroid species	Number of ophiuroid specimens	Sponge species	Collection sites
Ophiocnida scabriuscula (Lütken, 1859)	2	*Agelas* sp. [a]	Canal das Arabaianas [b]
Ophiothrix sp.	7	*Callyspongia* (*Cladochalina*) *aculeata* (Linnaeus, 1759)	Pedra da Risca do Meio Marine State Park [c]
	1	*Monanchora arbuscula* (Duchassaing & Michelotti, 1864) [a]	Pedra da Risca do Meio Marine State Park [c]
Ophiactis savignyi (Müller & Troschel, 1842)	18	*Ircinia felix* (Duchassaing & Michelotti, 1864)	Pedra da Risca do Meio Marine State Park [c]
	1	*Agelas dispar* (Duchassaing & Michelotti, 1864) [a]	Pedra da Risca do Meio Marine State Park [c]
	1	*Agelas* sp.	Pedra da Risca do Meio Marine State Park [c]
	2	*Agelas clathrodes* (Schmidt, 1870)	Pedra da Risca do Meio Marine State Park [c]
	8	*Aplysina* sp.	Pedra da Risca do Meio Marine State Park [c]
	1	*Amphimedon* aff. *compressa* (Duchassaing & Michelotti, 1864)	Pedra da Risca do Meio Marine State Park [c]
	9	*Monanchora arbuscula* (Duchassaing & Michelotti, 1864) [a]	Pedra da Risca do Meio Marine State Park [c]
	127	*Topsentia ophiraphidites* (de Laubenfels, 1934) [a]	Pedra da Risca do Meio Marine State Park [c]
	42	*Dysidea etheria* (de Laubenfels, 1936) [a]	Flecheiras Beach [d]
Ophiactis quinqueradia (Ljungman, 1872)	3	*Callyspongia* sp.	Pecém Beach [e]
	1	*Monanchora arbuscula* (Duchassaing & Michelotti, 1864) [a]	Pedra da Risca do Meio Marine State Park [c]
	1	*Callyspongia* (*Cladochalina*) *aculeata* (Linnaeus, 1759) [a]	Pedra da Risca do Meio Marine State Park [c]

[a] New records of sponge-ophiuroid associations; [b] 3°32'45.24''S, 38°16'10.74''W (Barroso et al., 2021); [c] 3°33'80''-3°36'00''S, 38°21'60''-38°26'00''W (Soares et al., 2011); [d] 3°22'S, 39°25'W (Matthews-Cascon and Lotufo, 2006); [e] 3°33'S, 38°50'W (Matthews-Cascon and Lotufo, 2006).

The new interactions between ophiuroids and sponges described here were: *Ophiocnida scabriuscula* and *Agelas* sp., *Ophiothrix* sp. and *Monanchora arbuscula* (Duchassaing & Michelotti, 1864), *Ophiactis quinqueradia* and *M. arbuscula*, *Ophiactis quinqueradia* and *Callyspongia* (*Cladochalina*) *aculeata* (Linnaeus, 1759), *Ophiactis savignyi* and *Agelas dispar* Duchassaing & Michelotti, 1864, *O. savignyi* and *M. arbuscula*, *O. savignyi* and *Topsentia ophiraphidites* (de Laubenfels, 1934), and *O. savignyi* and *Dysidea etheria* de Laubenfels, 1936 (Table 1).

All the specimens analyzed were collected in four areas along the coast of the state of Ceará (Northeastern Brazil, tropical southwestern Atlantic): Canal das Arabaianas (3°32'45.24''S, 38°16'10.74''W; 32-35 m depth) in July 2009; Pedra da Risca do Meio Marine State Park

(3°33'80''-3°36'00''S, 38°21'60''-38°26'00''W; 18-30 m depth) in July 2014; Flecheiras Beach (3°22'S, 39°25'W; intertidal zone) in November 2015; and Pecém Beach (3°33'S, 38°50'W; intertidal zone—material found in beach sand, but characteristic of infralittoral species) in October 2021 (Tables 1 and 2)

Table 2. Collection voucher numbers of the analyzed ophiuroid and sponge specimens and documented distribution of the species found in the Western Atlantic. Legends: ECH: Echinodermata collection of the Departamento de Biologia, Universidade Federal do Ceará; POR: Porifera collections of the Departamento de Biologia, Universidade Federal do Ceará, and Museu Nacional do Rio de Janeiro (MNRJ).

Species	Collection voucher numbers	Distribution in the Western Atlantic
Echinodermata		
Ophiocnida scabriuscula (Lütken, 1859)	ECH-491	Western Atlantic: Florida, the Antilles, the Mexican Caribbean, Bermuda, Panama, Colombia, Venezuela, and Brazil. Brazilian states: Maranhão, Paraíba, Pernambuco, Alagoas, Bahia, Rio de Janeiro, São Paulo, and Paraná[a].
Ophiothrix sp.	ECH-306; ECH-354	
Ophiactis savignyi (Müller & Troschel, 1842)	ECH-331; ECH-332; ECH-333; ECH- 334; ECH- 335; ECH-336 ECH-337; ECH-353; ECH-376; ECH-379; ECH-386; ECH-536	Western Atlantic: Cosmopolitan (warm waters) (South Carolina, Florida, Bermuda, the Mexican Caribbean, Honduras, and Brazil). Brazilian states: Amapá, Pará, Maranhão, Ceará, Paraíba, Pernambuco, Alagoas, Bahia, Rio de Janeiro, and São Paulo[a].
Ophiactis quinqueradia (Ljungman, 1872)	ECH-359; ECH-387	Western Atlantic: Florida, Mississippi, Texas, the Antilles, the Mexican Caribbean, Bahamas, Cuba, Belize, Panama, and Brazil. Brazilian states: Maranhão, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, and Espírito Santo[a].
Porifera		
Agelas clathrodes (Schmidt, 1870)	MNRJ 8669	Western Atlantic: Florida[b], Southern Gulf of Mexico[b], Bahamas[b], Cuba[d], Jamaica[b], Dominican Republic[b], Puerto Rico[b], Barbados[b], Panama[b], Bonaire[b], Colombia[b], Venezuela[b], and Brazil. Brazilian states and islands: Amapá[b], Pará[b], Ceará[b], Rocas Atoll[e], Rio Grande do Norte[b], Fernando de Noronha Archipelago[e], Pernambuco[b], Bahia[b], Espírito Santo[b], and Rio de Janeiro[b].
Agelas dispar (Duchassaing & Michelotti, 1864)	MNRJ 8682; MNRJ 8691	Western Atlantic: Barbados, Bonaire, Colombia, Cuba, Jamaica, Venezuela, and Brazil[b]. Brazilian states and islands: Pará[b], Ceará[b], Rocas Atoll[d], Rio Grande do Norte[b], Fernando de Noronha Archipelago[d], Pernambuco[b], Alagoas[b], Bahia[b], Espírito Santo[b], and Rio de Janeiro[b].
Agelas sp.	POR-397; MNRJ 8678	
Amphimedon aff. *compressa* (Duchassaing & Michelotti, 1864)	MNRJ 8677; MNRJ 8693; MNRJ 8694	Western Atlantic: Florida, the Virgin Islands, Bahamas, Mexico, Cuba, Puerto Rico, Jamaica, Dominican Republic, Panama, Belize, Colombia, and Brazil[b]. Brazilian states and islands: Alagoas[b], Ceará[b], Rocas Atoll[e], Fernando de Noronha Archipelago[e], Rio Grande do Norte[b], and Pernambuco[b].

continued

Species	Collection voucher numbers	Distribution in the Western Atlantic
Aplysina sp.	MNRJ 8672, MNRJ 8697, MNRJ 8700	
Callyspongia (*Cladochalina*) *aculeata* (Linnaeus, 1759)	MNRJ 8671	Western Atlantic: Florida, Bahamas, Bermuda, the Virgin Islands, Cuba, Jamaica, Dominican Republic, Puerto Rico, Belize, Panama, Colombia, Curaçao, Bonaire, Venezuela, and Brazil[b]. Brazilian states and islands: Amazonas[b], Maranhão[b], Ceará[b], Rocas Atoll[e], Rio Grande do Norte[b], Pernambuco[b], and Bahia[b].
Callyspongia sp.	POR-307	
Dysidea etheria (de Laubenfels, 1936)	POR-86	Western Atlantic: Florida[b], Curaçao[b], Cuba[b], Bahamas[b], Puerto Rico[b], Jamaica[b], Panama[b], Bermuda[b], Belize[b], Colombia[b], Guyana[f], and Brazil[b]. Brazilian states and islands: Saint Peter and Saint Paul Archipelago[b], Ceará (new record), Alagoas[b], Bahia[b], Rio de Janeiro[b], and São Paulo[b].
Ircinia felix (Duchassaing & Michelotti, 1864)	MNRJ 8669	Western Atlantic: Florida[b], the Virgin Islands[b], Bahamas[b], Belize[b], Bermuda[b], Cuba[b], Jamaica[b], Puerto Rico[b], Colombia[b], Venezuela[b], Bonaire[b], Curaçao[b], Barbados[b], Panama[b], Guyana[f], and Brazil[b]. Brazilian states and islands: Ceará[b], Rio Grande do Norte[b], Fernando de Noronha Archipelago[e], Bahia[b], and Trindade Island[b].
Monanchora arbuscula (Duchassaing & Michelotti, 1864)	MNRJ 8670	Western Atlantic: Florida[b], the Mexican Caribbean[b], Panama[b], Barbados[b], Jamaica[b], Puerto Rico[b], Bonaire[b], Curaçao[b], Colombia[b], Suriname[g], and Brazil[b]. Brazilian states and islands: Amapá[b], Ceará[b], Rio Grande do Norte[b], Fernando de Noronha Archipelago[e], Paraíba[b], Pernambuco[b], Bahia[b], Rio de Janeiro[b], and Santa Catarina[b].
Topsentia ophiraphidites (de Laubenfels, 1934)	MNRJ 8680	Western Atlantic: Southern Gulf of Mexico[c], Belize[h], Dominican Republic[b], Puerto Rico[b], Barbados,[b] Bonaire[b], Curaçao[b], Colombia[b], Venezuela[b], Guyana[f], and Brazil[b]. Brazilian states and islands: Maranhão[b], Ceará[b], Rio Grande do Norte[b], Rocas Atoll[e], Fernando de Noronha Archipelago[e], Pernambuco, Bahia[b], and Trindade Island[b].

[a] (Gondim et al. 2013); [b] (Muricy et al. 2011); [c] (Ugalde et al. 2021); [d] (Alcolado 2002); [e] (Moraes 2011); [f] (Van Soest 2017); [g] (Esteves et al. 2018); [h] (Rützler et al. 2000).

Despite at least one hundred years of knowledge of the relationships between ophiuroids and sponges (Pearse, 1934), it is remarkable how much remains to be discovered about these interactions. Although some sponge-ophiuroid associations found here have already been reported in previous studies [*Ophiothrix* sp. and *Callyspongia* (*Cladochalina*) *aculeata* (Hendler, 1984); and *Ophiactis savignyi* with *Ircinia felix* (Duchassaing & Michelotti, 1864), *Agelas* sp., *Agelas clathrodes* (Schmidt, 1870), *Amphimedon* aff. *compressa* (Duchassaing & Michelotti, 1864), and *Aplysina* sp. (Villamizar and Laughlin, 1991; De La Cruz-Francisco et al., 2018)], almost 60% are new to science.

Of the eight new interactions, seven were observed in important areas for biodiversity conservation: the Pedra da Risca do Meio Marine

State Park (a conservation area) and the Canal das Arabaianas [a mesophotic coral ecosystem (MCE)]. Although it was created in 1997, the biodiversity of the Pedra da Risca do Meio Marine State Park has only recently been better known (Soares et al., 2011; Mota et al., 2017; Freitas et al., 2019), including the description of a new sponge species (Salani et al., 2006). Its management plan was recently elaborated (Soares et al., 2019), providing better support for the effectiveness of its conservation. In turn, the biodiversity of the Canal das Arabaianas still needs to be better investigated (Freitas and Lotufo, 2015; Barroso et al., 2021). Due to their potential use as refuge areas for natural and anthropogenic impacts and unique ecosystems with characteristic biotas (Bongaerts et al., 2010; Rocha et al., 2018), MCEs have received attention in the last few years. This study reinforces that there is still much to be studied in these areas, as here we described eight new records of ecological interactions. The effectiveness of conserving marine protected areas and MCEs is directly reflected in discoveries and more specific studies on the ecology, taxonomy, and protection of local biodiversity.

Most of the interactions observed in this study involved the ophiuroid species *Ophiactis savignyi*, which is known to be a circumtropical species, a generalist in host choice, with reports of association with different species of algae, coral, bryozoans, ascidians, and sponges (De La Cruz-Francisco et al., 2018; Bueno et al., 2018; Carrera-Parra and Vargas-Hernández, 1996; Gondim et al., 2013). *Ophiactis savignyi* represents a species complex exotic to the Atlantic Oceanic region (Roy and Sponer, 2002) and highly adapted to the Brazilian coast (Soares et al., 2022). The fissiparous strategy of this species could explain the high density of individuals found in a single sponge here (*Topsentia ophiraphidites*, 127 individuals; and *Dysidea etheria*, 42 individuals) and in other studies previously performed (Neves et al., 2007; Gondim et al., 2013; Clavico et al., 2006; McGovern, 2002).

Topsentia ophiraphidites and *D. etheria* occur in the tropical western Atlantic (Hajdu et al., 2011), with *T. ophiraphidites* being associated especially with tunicates and other sponges (Hajdu et al., 2011), while *D. etheria* is commonly associated with microorganisms (Batista et al., 2018) and other animals, such as crustaceans (Paixão et al., 2021), bryozoans (Almeida et al., 2015), and echinoderms, including associations with the exotic species *Ophiothela mirabilis* (Verrill, 1867) (Mantelatto et al., 2016). Despite the generalist behavior of this ophiuroid, these associations can be facilitated by the erect (despite the variety of forms that *T. ophiraphidites* may present) and massive structures of these sponges, which make the environment favorable for the life of ophiuroids; by the extracts released that can favor feeding; and by the environment in which they are inserted (Frith, 1976). According to Clavico et al. (2006), *O. savignyi* would preferentially associate with the sponge *Geodia tylastra* (Boury-Esnault, 1973) on the Brazilian coast due to the high densities of ophiuroids found in the sponge and the attraction to the *G. tylastra* extract observed experimentally. However, this chemical attraction has not yet been observed in other organisms with which *O. savignyi* is also commonly associated, including other sponges.

The sponges *Agelas dispar*, *Ircinia felix,* and *Callyspongia* (*Cladochalina*) *aculeata* are true ophiuroid hosts, given their well-known associations (also documented here). *Agelas dispar* and *I. felix* present a diversity of associations, possibly due to their lobed shape, which allows them to host a higher density of species (Neves and Omena, 2003). *Callyspongia* (*Cladochalina*) *aculeata* was associated with two out of four ophiuroid species in this study (*Ophiothrix* sp. and *Ophiactis quinqueradia*, a new relationship). A previous study already showed the relationship between this sponge and other *Ophiothrix* species — *Ophiothrix lineata* (Lyman, 1860), which seems to be both commensal, in which ophiuroid takes advantage of the tubular shape of the sponge and lives inside it or on its surface, and parasitic, in which the ophiuroid feeds on *C. aculeata* larvae (Henkel and Pawlik, 2014).

There are few records in the literature on the associations between *Monanchora arbuscula* and ophiuroids, but Fortunato and Lôbo-Hajdu (2021) recorded several *Ophiothela mirabilis*

associated with *M. arbuscula*. In this study, we added three new records of ophiuroids (*Ophiothrix* sp., *Ophiactis savignyi*, and *Ophiactis quinqueradia*) associated with *M. arbuscula*. The conditions that facilitated these associations are not yet known. However, the erect or branched morphology of *M. arbuscula* (Hajdu et al., 2011) may be one of the characteristics that make this sponge a good host. That is, the structure of the sponge may favor the association by offering refuge against predators.

Although the interactions in this study were observed in the equatorial portion of the southwestern Atlantic, some of the new interactions recorded here may probably be observed in other locations due to overlapping geographic distribution of species along the Western Atlantic (e.g., *O. quinqueradia* and *M. arbuscula*, *O. quinqueradia* and *C. aculeata*, *O. savignyi* and *A. dispar*, *O. savignyi* and *M. arbuscula*, *O. savignyi* and *T. ophiraphidites*, and *O. savignyi* and *D. etheria*) (Table 2).

Our results also reinforce the importance of biological collections as valuable sources of information that aid biodiversity knowledge, enabling taxonomic and ecological studies. Significant amounts of data on invertebrates are present in museum collections and are used to develop conservation plans (Ponder et al., 2001). In addition, the study of biological materials deposited in collections helps to find solutions to current environmental problems, such as habitat degradation. Therefore, the importance of always keeping collections well-structured and preserved is emphasized (Meineke et al., 2018).

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AUTHOR CONTRIBUTIONS

M.O.; M.Q.M.S.: Conceptualization; Investigation; Writing – original draft; Writing – review & editing.

C.X.B.; S.S.: Conceptualization; Methodology; Supervision; Writing – review & editing.

H.M.C.: Supervision; Resources; Funding Acquisition; Writing – review & editing.

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