Taxonomic revision of the southwestern Atlantic Madracis and the description of Madracis fragilis n. sp. (Scleractinia: Pocilloporidae), a new coral species from Brazil

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SUMMARY: The genus Madracis has been known in Brazil from four deep water species, namely M. mirabilis, M. asperula, M. brueggemanni, and M. pharensis, and one zooxanthellate species from shallow water environments, M. decactis. Delicate fragments of a small branching colony of an undescribed Madracis were collected at 73 m depth, northern Salvador (Bahia State). Although resembling the congeners M. asperula and M. brueggemanni, the new species has distinct features including reduced branch thickness, smaller diameter of corallite and columella structure and pattern of coenosteum ornamentation. Because of the worldwide focus on reef-building corals, knowledge of azooxanthellate scleractinians remains scarce. In addition to contributing to the inventory of Brazilian coral fauna, the occurrence of a new species of Madracis provides further evidence of the high diversity of deep-water coral communities in the tropical South Atlantic.

Keywords: biodiversity, systematics, morphology, azooxanthellate coral, deep sea, South Atlantic.

INTRODUCTION

The genus Madracis is primarily represented by azooxanthellate colonial species from deep-water environments. Varying from fragile branching or dense ramose coralla to massive columnar, nodular or encrusting forms, Madracis is expected to be a well-defined group commonly with cryptic habits (Veron, 2000). Some taxonomical controversies involving the description of Madracis have been attributed to Milne-Edwards and Haime (1849) during simultaneous designation of the referred genus and Axhelia. Following Cairns (1979), Locke et al. (2007) provided a concise historical summary of
conflicting nomenclature between Madracis and Axhelia, which affected the designation of type species and species authority until Vaughan and Wells (1943) placed Axhelia myriaster and Axhelia asperula within Madracis, with Axhelia being definitively regarded as a junior synonym. Although Madracis is closely related to the Pocilloporidae, morphological data concerning the columella structure have supported the inclusion of Madracis in the family Astrocoeniidae (Veron, 2000). According to Veron et al. (1996), ‘Pocilloporidae and Astrocoeniidae both have Triassic origins and probably diverged from other extant Scleractinia near or before the evolution of skeletogenesis’. However, because of the sexual similarities between Madracis and pocilloporids, the replacement has been argued to be doubtful (see Vermeij et al., 2004). In fact, Kerr’s (2005) supertree analysis concatenating molecular (ITS1 and 2.5 8S) and morphological data available from the literature pointed out a close relationship between Madracis and Pocilloporidae, but he placed the genus within the clade Astrocoeniidae at the base of the robusta group (sensu Romano and Palumbi, 1996). The ‘conflict’ remains apparently unsolved, and similarly to other highly controversial genera (e.g. Acropora, Montastraea, see Fukami et al., 2004), Madracis’ species definition has challenged taxonomy and the evolutionary concept. Phylogenetically, the genus may comprise mono-, para- and polyphyletic species, which are likely to hybridise, complying with Veron’s (1995) model of reticulate speciation (Diekmann, et al. 2001; Vermeij et al., 2004; Kerr, 2005). Following this pathway, the zooxanthellate M. carmabi Vermeij, Diekmann and Bak, 2003 has been proposed to be a hybrid, resulted from the interbreeding of M. decactis (Lyman, 1859) and M. formosa Wells, 1973. From a morphological standpoint, Locke et al. (2007) pointed to another taxonomical issue by suggesting that the shallow-water M. auretenra Locke et al., 2007 has been misidentified as M. mirabilis (Duchassaing and Michelotti, 1860), the latter an ‘invalid species’ considered to be a junior synonym of M. myriaster (Milne Edwards and Haime, 1849). Actually, concerning ‘the history of the synonymy of M. myriaster’, Cairns (1979) previously emphasised the need of a new name for M. mirabilis.

Providing a key to Madracis identification, Wells (1973) recognised seven Atlantic species (up to 100 m): M. asperula Milne Edwards and Haime, 1849, M. myriaster (Milne Edwards and Haime, 1849), M. decactis (Lyman, 1859), M. mirabilis (Duchassaing and Michelotti, 1860) (M. auretenra sensu Locke et al., 2007), M. pharensis (Heller, 1868), M. brueggemannii (Ridley, 1881) and M. formosa Wells, 1973. Including the hybrid M. carmabi and the recently described M. auretenra, six species occur on Caribbean reefs: M. decactis, M. pharensis, M. senaria Wells, 1974 and M. formosa. Differing partially in composition and number of species, in Brazil the genus is represented by M. asperula, M. decactis, M. brueggemannii, and M. pharensis. The common M. decactis has a highly variable bathymetric distribution, being found from shallow-water environments (from 3 to 30 m) to deep-water coral communities (Laborel, 1970; Cairns, 2000). Madracis asperula and M. pharensis were both reported by Laborel (1967) on the Bahia coast, up to 30 m, the former also being mentioned by Fernandes and Young (1986) on the Rio de Janeiro coast at 24 to 98 m depth.

Concerning influence of abiotic factors, variation in light may regulate morphology and distributional pattern of coral species. Indeed, light availability has been attested to affect colony shape of M. decactis and M. pharensis, and due to their distinct strategies the species have been considered as different ‘ecotypes’ (Fenner, 1993; Vermeij and Bak, 2002). Madracis auretenra (M. mirabilis sensu Wells, 1973) has also been documented responding to physical gradients (Fenner, 1993; Bruno and Edmunds, 1997, 1998; Sebens et al., 1997). However, M. auretenra and M. senaria have been recognised as ‘true’ or monophyletic genetic species, whereas, because of the absence of striking genetic differentiation, M. pharensis and M. decactis together with M. formosa and M. carmabi form ‘species complexes’ (Diekmann et al., 2001; Vermeij and Bak, 2002; Vermeij et al., 2004).

Despite the ecological importance of the Brazilian Province and the expressive distinctness of the geological architecture and biological assemblage of Brazilian reefs, information on coral communities located in this area is scarce and somewhat restricted to shallow-water environments (Laborel, 1970; Neves et al., 2002). Recent studies have provided significant changes in the inventory of zooxanthellate species, and in knowledge of population structure (Neves, 2004; Neves et al., 2006; Neves et al., 2008). Under a similar perspective, deep-water coral assemblages have been poorly explored and few species have been reported in Brazil (Cairns, 2000). Most studies concentrated on the southern platform, along the south-southeastern coast, have provided considerable perspective on new occur-
References, including new species and genera (Kitahara and Cairns, 2005; Kitahara, 2006).

Therefore, in addition to improving the number of scleractinian species known worldwide, upgrading the azooxanthellate coral inventory of the South Atlantic, this study provides a comparative taxonomical analysis between *M. fragilis* n. sp. and all previously reported congeners in Brazil (*M. asperula*, *M. decactis*, *M. brueggemanni*, and *M. pharensis*). The description of a new branching *Madracis* in the Bahia State also reinforces the impressive marine diversity of the northeast coast, helping to assess the faunistic composition of the Brazilian Province.

**MATERIALS AND METHODS**

Samples of *M. fragilis* were unexpectedly obtained during logistical experiments of the ‘Biskaia Bat’ fishing boat along the coast of Bahia State. Colony fragments were removed from trap-cages tested for capturing commercial demersal fishes and crustaceans on the upper limit of the continental slope known as ‘Paredes de Itapuã’ (12°59’771”S, 38°15’807”W), off Itapuã beach (nearly 11 km off the coast), northern Salvador, Bahia State, at 73 m depth (Fig. 1). Material was fixed in 90% alcohol. In the laboratory, fragments were selected and bleached in a solution of 2% sodium hydrochloride overnight. After complete tissue removal, skeletons were rinsed in fresh water and dried for morphometric analysis and identification. The taxonomical approach (including relevant structures and terms) was partially based upon criteria adopted by Locke *et al.* (2007), Cairns (2000), Veron (2000) and Wells (1973) for *Madracis*. A total of 100 corallites were analysed. Measurements were developed under a Nikon SMZ 1000 stereomicroscope with an eyepiece micrometer and a Nikon Coolpix 995 digital camera attached. Tip and basal skeleton fragments were mounted on aluminum pin stubs, previously covered with a double-sided sticky tape, sputter-coated with 35 nm of gold in a Shimadzu IC-50 ion coater, and examined through a Shimadzu Superscan SS-550. Type-species and paratypes were deposited at the Cnidaria Collection of the ‘Museu de Zoologia da Universidade Federal da Bahia’, acronym: UFBA/CNI.

**RESULTS**

**SCLERACTINIA Bourne, 1900**

**Pocilloporidae Gray, 1842**

*Madracis* Milne-Edwards and Haime, 1849


Type species. *Madracis asperula* Milne-Edwards and Haime, 1850, Recent, Madeira (according to Wells, 1973: unnumbered types in British Museum of Natural History).

Diagnosis (after Cairns, 1979, 2000; Veron, 2000). Massive or ramose colonies formed by extratentacular budding; corallites plocoid with 6, 8, 9 or 10 septa and well-developed costae; primary septa fused with a styliform columella, usually bearing paliform lobes; S2 often absent or rudimentary; coenosteum solid, costate or spinose.

*Madracis fragilis* n. sp.

(Fig. 2)

Holotype. Dry parts of a single specimen, including two bifurcating fragments, the largest one 3.0 cm in height, 7.5 cm in width, MZUFBA/CNI 473, collected Apr 2004 by C. Sampaio.

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![Map of Brazil and Bahia State](image-url)  
**Fig. 1.** – Area of collections of *Madracis fragilis* n. sp. (black star) in Bahia State, northeastern Brazil.
**Type locality.** Off Itapuã beach, Salvador (Bahia State), 12°59’771’’S, 38°15’807’’W. Depth 73 m.

**Paratypes.** Three fragments of alcohol fixed colony from the same type-species locality and depth, represented by its distal and basal parts (the latter infested by serpulids), MZUFB/CAEI 617, collected Apr 2004 by C. Sampaio.

**Description.** Colony very fragile with slender, delicate three dimensional branches (primary branch segments varying from about 3.2 to 6.5 cm in length); branch anastomosis rare (observed in tertiary branches); distal branches slim and homogeneous in thickness (2.0-2.2 mm); tertiary branch tips thinner (1.0-1.2 mm) sometimes sharp-edged; median and basal branch segments varying from 2.0 to 2.8 in diameter. Corallum tissue pale beige. Budding extramural. Corallites regularly circular, plocoid, ranging from 0.6 to 1.4 mm in diameter (X= 0.85, SD= 0.25), not crowded, separated regularly from each other by a distance of 0.7 to 1.0 mm (X= 0.82, SD= 0.11). Calices contain predominantly 8 exsert septa (occasionally 9, rarely 10), distributed in a single cycle (S1) fused to columellar platform. Septa vertical, projecting upwards through the theca margin. Septa margins irregularly dentate with coarse spines uniformly distributed along lateral faces. S2 absent. No paliform lobes. Columella varying from...
0.3 to 0.6 mm (X= 0.4, SD= 0.06) in diameter, with a central styliform papilla (papillar surface finely granular). Coenosteum striate with fine spinules and short tubercles distributed around the corallite and linearly along low ridges.

DISCUSSION

A summary of diagnostic characteristics of South Atlantic Madracis is provided in Table 1. Following all descriptions, Madracis fragilis is a distinct species, differing from the congeners in branch thickness, diameter of corallite and columella, columella structure, and pattern of coenosteum ornamentation. Despite the intracolonial variation of the number of septa, 77.8% of the corallites examined had 8 septa whereas 14.8% and 7.4% had 9 and 10 septa, respectively. A similar condition may be observed in M. brueggemannii: most corallites contain 8 septa, but occasionally they contain 6, 7, 9, 10 or even 11 septa—these usually distributed in a single cycle (S1). Nevertheless, according to Cairns (2000: p. 39), ‘those with less than 8 septa being more common than those with more’. Indeed, other diagnostic characters support the species identities: M. brueggemannii has small paliform lobes that form a crown encircling the columella—in contrast, M. fragilis n. sp. has no paliform lobes as well as no corallite with fewer than 8 septa. With a well-defined decameral septal arrangement, M. asperula, another branching colony, may occasionally exhibit corallites with 8 exsert septa. In this circumstance, other traits such as the corallite size, rudimentary S2 (reduced to spines), septa margins (smooth), and the small paliform lobes, may readily distinguish M. asperula from M. fragilis n. sp.

The occurrence of an octameral septal arrangement has constrained the identification of Atlantic Madracis. As for most scleractinian species complexes, septal number may be an unreliable character if considered exclusively. Ecological requirements related to habitat preferences have been used to separate the species and their morphotypes (Laborel, 1974). In this context, intergrading forms of M. decactis, comprising those that are more or less photophilous, and also differing in skeletal calcification, have been found in a graded light exposure—colonies developing in full sunlight, and others living in darker places (Laborel, 1974; Cairns, 2000). Depth and environment illumination may influence tissue pigmentation. Although inconspicuous among scleractinians (it is not consistent as a taxonomical attribute, because it may be highly variable intraspecifically), in a few particular cases polyp/tissue colour may contribute to recognition of the species in their natural habitat. Thus, according to Fenner (1993), the tissue of M. mirabilis is always light yellow. M. decactis may vary from dark-green to yellow-green, while M. pharensis, with the most variable palette, is concomitantly cream in colour with pink polyps in dark caves (at 20 m) or in shades of brown and green in shallower habitats. The intracolonal colour pattern of the three species was also described, revealing a gradual variation between illuminated and shaded areas of a single colony. Because of the few specimens originally analysed, some supposedly well-established characteristics for M. decactis as uniform septa (see Milne-Edwards and Haime, 1849) and the absence of costae (see Duncan, 1884) were subsequently refuted or restricted. Actually, in the late 19th century, Gregory (1895) observed a rudimentary set of septa (reduced S2) and costae in specimens from Barbados being designated as M. decactis variant forms. Invariably, some species with extended bathymetric distribution may be facultative zooxanthellate (or ‘apooxanthellate’ sensu Stanley and Cairns, 1988), a condition regularly observed among Madracis species (e.g. M. asperula, M. decactis, M. pharensis). Being apparently restricted to deep-water environment, M. fragilis n. sp. has no zooxanthellae (corallum tissue being pale beige in situ), and levels of intercolonial variation are expected to be low among azooxanthellate species. Therefore, even representing one of the most conspicuous Brazilian species (with variant forms from deep-waters), the chances of misidentifying M. decactis as M. fragilis n. sp. are low. In addition to all the characteristics listed in Table 1, M. decactis (as M. asperula and M. pharensis) also has smooth septal margins. In the field, M. decactis and M. pharensis are interrelated because the corallum morphology (encrusting, nodular) is very different from that of the slender, ramose species. As emphasised by Vermeij and Bak (2002), these two species show noticeable morphological and genetic (see Diekmann et al., 2001) similarities, which make it doubtful to maintain them as distinct species. In fact, branch thickness and distance among corallites may primarily support the identification of M. asperula, M. mirabilis, M. brueggemannii and M. fragilis n. sp. Based on branch thickness, Wells (1973) described...
the Caribbean *M. formosa* from Ridley (1881) specimens of *Axhelia* (*Madracis*) *brueggemanni*, the new species comprising those with thick, blunt branches while *M. brueggemanni* is represented by the one with slender, twiglike branches. However, data on branch thickness may be inconspicuous in the literature. As pointed out by Locke et al. (2007), the deep-water *M. asperula* ‘has extremely slender branches’. Depending upon the branch segment measured during the analyses, great discrepancies may be found. Considering Milne-Edwards and Haime’s (1949) original diagnosis, *M. asperula* would have the largest branches of about 5-6 mm. Regarding the same species, additional descriptions have suggested 3 mm (slender and attenuate—Wells, 1973), 1.4-1.7 mm (slender distal branches, Cairns, 2000) and 1.7 mm (J.M. Locke based upon USNM specimens 99046, 99048 and 45507). Furthermore, Bruno and Edmunds (1997, 1998) attested high levels of phenotypic plasticity for several skeletal traits in *M. auretenra* (*M. mirabilis sensu* Wells, 1973), including branch tip diameter, branch density and branch spacing as well. Basically, *M. asperula* could be suggested as one of the most fragile and delicate of all ramose *Madracis*, despite the indefatuitably slim aspect of *M. fragilis* n. sp. branches. Nevertheless, other characteristics including septa with smooth margins, small paliform lobes and higher cycles reduced to spines would ensure undoubted distinction of *M. asperula* from *M. fragilis* n. sp.

The taxonomic status of *M. auretenra* remained for a long time controversial. The description originally provided by Vaughan (1919) as ‘*M. mirabilis*’ did not match Wells (1973), mainly in respect to branch thickness. According to Vaughan (1919: p. 345), the specimen from Limon (Costa Rica), had ‘2 mm in diameter at the lower end, and 3 mm in diameter just below trifurcation at the upper end’. There is a huge distance between 2-3 mm and the 6-10 mm pointed out by Wells (1973) for the same species. The conflict seemed purely based on morphological incongruence. Cairns (1979: p. 28) examined the holotype of ‘*M. mirabilis*’ from the Museo ed Instituto di Zoologia Sistematica (Torino, Italy) confirming that the striate specimen was in fact *M. myriaster* and arguing that ‘...the common, shallow-water, nonstriate species, known today as *M. mirabilis sensu* Wells, 1973 requires a new name.’ In a

### Table 1. – Corallum and corallite diagnostic characters for the identification of southwestern Atlantic *Madracis* (including *M. fragilis* n. sp.). Data summary based on Wells (1973), Fenner (1993), Cairns (2000), Veron (2000) and Locke et al. (2007). Within parenthesis (*) all possible variable values.

<table>
<thead>
<tr>
<th>Character/Species</th>
<th><em>M. asperula</em></th>
<th><em>M. decactis</em></th>
<th><em>M. brueggemanni</em></th>
<th><em>M. pharensis</em></th>
<th><em>M. fragilis</em> n. sp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corallite form</td>
<td>plocoid, circular to elongate (branch tips), relatively closely spaced</td>
<td>plocoid to subcerioid, circular to polygonal, closely packed</td>
<td>plocoid, circular to elliptical (branch tips), well spaced</td>
<td>ceroid, circular to polygonal, closely packed</td>
<td>plocoid, mostly circular, slightly ellipsoidal on branch tips</td>
</tr>
<tr>
<td>Colony form</td>
<td>branched to nodular, delicate</td>
<td>submassive, nodular, large-branched, laminar or encrusting</td>
<td>small, sparsely branched in three dimensions</td>
<td>stoloniferous chains of encrusting corallites, nodular growths, cylindrical to clavate in shape (not a true branch)</td>
<td>branched, delicate</td>
</tr>
<tr>
<td>Branch anastomosis</td>
<td>rare</td>
<td>absent</td>
<td>rare</td>
<td>absent</td>
<td>rare</td>
</tr>
<tr>
<td>Branch thickness</td>
<td>1.4-1.7 mm (3 mm, 5-6 mm)*</td>
<td>14-28 mm</td>
<td>3.0-4.0 mm</td>
<td>2.5-3.5 mm</td>
<td>2.0-2.8 mm</td>
</tr>
<tr>
<td>Corallite size</td>
<td>1.3-2.2 mm</td>
<td>1.0-1.5 mm</td>
<td>0.85-1.4 mm</td>
<td>1.5-2.3 mm</td>
<td>0.6-1.4 mm</td>
</tr>
<tr>
<td>Septa number</td>
<td>10 (8)*</td>
<td>10 (9,11)*</td>
<td>8 (6,7,9,10,11)*</td>
<td>12 (S1=6, S2=6)*</td>
<td>8 (9,10)*</td>
</tr>
<tr>
<td>S2</td>
<td>absent or rudimentary</td>
<td>absent or rudimentary</td>
<td>absent or rudimentary</td>
<td>well developed, forming a crown encircling the corallum</td>
<td>present (S2= 6)</td>
</tr>
<tr>
<td>Paliform lobes</td>
<td>small, bordering the columella</td>
<td>none</td>
<td>small, forming a crown encircling the corallum</td>
<td>forming a crown encircling the corallum</td>
<td>none</td>
</tr>
<tr>
<td>Columella structure</td>
<td>solid, massive with a compressed styliform rod</td>
<td>solid, styliform</td>
<td>small (0.17 mm), with a compressed styliform rod</td>
<td>massive, pointed style, finely granular</td>
<td>solid platform (0.3-0.6 mm) with a central styliform papilla</td>
</tr>
<tr>
<td>Coenosteum ornamentation</td>
<td>fine spination arranged linearly</td>
<td>smooth or with fine spines (which may form a ridge between corallites)</td>
<td>spination similar in arrangement to <em>M. asperula</em> but spines are larger</td>
<td>fine spines (surrounding the corallites)</td>
<td>striate with fine spinules and short tubercles distributed linearly along low ridges</td>
</tr>
</tbody>
</table>
personal communication Dr. S. Cairns has also stated ‘Nonetheless, the name *mirabilis* was used by Wells to refer to another species with 6 mm branch tips. It is a true and distinct species, but the name *mirabilis* cannot be used for it. Thus Locke and collaborators suggested the new name *auretenra*. Indeed, Locke et al. (2007: p. 217) supporting the description of *M. auretenra*, have concisely summarised this entire circumstantial dilemma, requesting special attention for the puzzling situation of ‘undescribed species’ attributed to ‘*M. mirabilis*’.

Despite the nomenclatural misunderstanding involving Caribbean species, branch aspect and diameter are clearly distinctive characters for Brazilian *Madracis*. Ongoing morphometric analyses of *Madracis* samples collected from several sites along the coast of Bahia State (basically from shallow-water areas) have suggested remarkable variation in corallum and corallite structures of the colonies, most forms being encrusting or submassive, slightly nodular, with cerioid corallites (each bearing 10 smooth septa) and no apparent coenosteum—a transitional unbranched pattern between the common *M. decactis* and *M. pharensis l. luciphila* (sensus Fenner, 1993). The material has not yet been identified but none of these specimens may be confounded with *M. fragilis* n. sp. It is not clear how abundant branching *Madracis* forms may be along the Brazilian coast, because there is no concise information on the distributional range or colonial cover of the species in deeper environments. In the literature, *M. decactis* is the only Brazilian pocilloporid supported by biological data (Castro and Pires, 2006), and all other aspects remain unpublished. Further efforts are necessary to clarify relevant aspects related to the diversity and structure of this complex genus with highly variable biological and evolutionary strategies. Finally, *Madracis fragilis* n. sp. may be endemic to Brazil, even restricted to Bahia State, supporting the species richness of the southwestern Atlantic and the tropical Brazilian Province.

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