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FOULING SPONGES (PORIFERA) ON NAVIGATION BUOYS FROM SINGAPORE WATERS

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ABSTRACT. – A total of 62 sponge species was identified from subtidal (0–2 m depth) marine fouling communities present on 30 navigation buoys in the Singapore and Johor Straits examined between 2003 and 2006. Of these sponges, eight were new records for Singapore. Systematic descriptions are given for the six most prevalent fouling sponge species, which occurred on at least nine buoys of a total of 30 buoys examined. These are: *Suberites diversicolor*, *Tethya robusta*, *Mycale* (*Carmia*) sp. "red, encrusting", *Mycale* (*Zygomycale*) *parishi*, *Amorphinopsis excavans* and *Cladocroce* sp. "massively encrusting". The number of sponges on any single buoy ranged between two and 23 species with between four and nine species seen on the majority of buoys examined. A large proportion (67%) of the fouling sponge species were rare, occurring on fewer than three buoys during the three-year study period. This is possibly due to the small surface area of the buoys. In the present study, only 19% (12 species) of specimens were identified to species level. A further 16% were tentatively assigned to known species, but these require comparison with type material for confirmation. The remaining 65% were assigned to genera and treated as operational taxonomic units (OTUs). An inventory of all fouling sponge species associated with navigation buoys in Singapore is also provided.

KEY WORDS. – Fouling, Porifera, sponge, biodiversity, port, buoy, Singapore, *Suberites*, *Tethya*, *Mycale*, *Amorphinopsis*, *Cladocroce*.

INTRODUCTION

Marine fouling communities are typically highly diverse and can comprise up to ten phyla represented by some 100 taxa (e.g., Godwin et al., 2004; Hewitt et al. 2004; Cohen et al., 2005). Sponges are a common component of marine fouling communities in many parts of the world (e.g. Esmero, 1978; Sutherland, 1981; Butler & Connolly, 1999; Connell & Glasby, 1999; Stachowitsch et al., 2002; Cohen et al., 2005), but are often conveniently ignored due to difficulties in taxonomy and lack of expertise. However, where expertise has been available, as many as 30 species of fouling sponges were reported from European waters (Sarà, 1974) and 25 species were recorded on artificial substrata at Cebu harbour in the Philippines (Esmero, 1978). Similarly, other studies have shown high diversity of fouling sponges in Hawaii (Godwin et al., 2004) and Australia (Hewitt et al. 2004).

Singapore has one of the busiest ports in the world (see Chou, 2006) and more than 100 navigation buoys are deployed to aid vessel traffic in the Singapore and Johor Straits. Marine fouling occurs worldwide, but it is most serious in the tropical waters. Navigation buoys are typically heavily fouled within 2 years and their growth biomass can weigh up to 40kg/m^2 in wet weight (pers. obs.). Hence, sponges can comprise a significant proportion of the fouling biomass, but their species composition and their role in the development and persistence of the subtidal fouling community remain poorly understood. A major task in modern sponge biology is still to document the biodiversity of living species (Hooper & Van Soest, 2002). This is especially relevant in the Indo-Malayan region, which has an exceedingly rich sponge fauna (Van Soest, 1990; De Voogd & Van Soest, 2007) but where very little work has been done. Reviews by Van Soest (1989, 1990 & 1994) and Hooper et al. (2000) show that sponge biodiversity in Southeast Asia could be the highest in the world, with over 1500 species recorded in scientific literature (Hooper et al., 2000).

The sponge fauna in Singapore waters is likewise poorly known and records are few and fragmentary. *Cliona* (as *Spongia*) *patera* (Hardwicke, 1822) was the first sponge described from Singapore. In the late 1800s, *Leucosolenia flexilis* (Haeckel, 1872), *Cinachyrella globulosa* (Gray, 1873), *Cinachyrella hemisphaerica* (Gray, 1873), *Coelocarteria singaporensis* (Carter, 1883) and *Callyspongia* (*Cladochalina*) *diffusa* Ridley (1884) were described from specimens collected in Singapore. Dragnewitsch (1906) later recorded 24 sponge species from Tanjong Pagar and Pulau Brani in the Singapore Strait. Recent additions include observations from general biodiversity studies (Chuang, 1961, 1973, 1977; Chou & Wong, 1985) and sponge biochemistry (e.g. Pettit et al., 1996). Hooper et al. (2000) provided an annotated checklist of sponges of the South China Sea region and some 80 species from Singapore were listed, although many were identified only as Operational Taxonomic Units (OTUs). In addition, De Voogd and Cleary (2009, this volume) recorded some 80 sponge species from coral reefs in Singapore.

The present study provides a preliminary assessment of subtidal sponges occurring on navigation buoys. It is intended as a small step towards documenting and describing the fouling sponge fauna present in Singapore waters.

MATERIAL AND METHODS

Sponges were collected over four years between 2003 and 2006 from 30 navigation buoys in Singapore waters, comprising 20 buoys from the Singapore Strait and another ten buoys from the Johor Strait (Fig. 1). These five-ton buoys are lifted up and retrieved approximately every three years for cleaning and general servicing. The submerged surface of buoys varied between 14 to 23 m^2 and were up to 2 m deep in water. The service schedule allowed us direct access to living material. During each visit to the buoy depot, buoys were carefully examined for sponges. Specimens were photographed on site, and voucher specimens were collected and preserved in 70% ethanol. Sponges were examined and identified as far as possible to the highest taxonomic level. These were also compared with undetermined material in the Zoological Reference Collection (ZRC), Raffles Museum of Biodiversity Research, National University of Singapore. Six most common fouling sponges species (i.e., sponge species that appeared on at least 9 buoys of the total 30 buoys sampled) are described in detail below. Voucher specimens were deposited in ZRC (see Table 1 for museum reference numbers).

To examine skeletal architecture, paraffin-embedded sponge tissue was sectioned either by hand or by using a microtome. The sections were then cleared in either Histoclear™ or a phenol-xylene mixture and mounted in Dpex™ on glass slides. Spicule preparations were made on a glass slide by dissolving a small piece of the specimen in a few drops of concentrated nitric acid over an alcohol flame. These were mounted either in Dpex™ on glass slides for light microscopy or transferred onto brass stubs for scanning electron microscopy, following the methods described by Hooper (1997). Spicule size range was estimated by measuring 25 spicules from one specimen, (unless stated otherwise), and presented as lowest value range–mean–highest value range of length by lowest value range–mean–highest value range of width. The classification used here adheres to the current scheme described in Systema Porifera (Hooper & Van Soest, 2002).

RESULTS

A total of 62 sponge species (see Table 1) was identified, although many could not be named or identified to a known taxon and are named provisionally, here as operational taxonomic units (OTUs). Of these, two were calcareous sponges and the remaining were Demospongiae representing 9 orders, 22 families and 28 genera (Table 1). Of the 62 species, twelve (19%) were identified to species, a further nine (15%) were assigned to a known species (the species name is preceded by cf.) but still require confirmation of identification through comparison with type material. *Cladocroce* aff. *burapha* Putchakarn et al., 2004 was very similar to but differed slightly from the type, hence we have used the term ‘affinis’. The remaining 40 species (65%) were identified to genus. The number of sponge species on a single buoy ranged between two and 23 species. The most diverse order was Haplosclerida (30 species), followed by Poecilosclerida (11 species), Hadromerida (six species), Dictyoceratida (six species), Halichondrida (five species), Astrophorida (one species), Chondrosida (one species), Leucosolenida (one species) and Clathrinida (one species). *Haliclona* and *Callyspongia* species (order Haplosclerida) accounted for about half of the total fouling sponge species identified in this study.

Six species (9%) were common, found on at least nine buoys (i.e., 30% of the total number of buoys). The six prevalent fouling sponge species were *Mycale* (*Zygomycale*) *parishi* (Bowerbank, 1875), *Mycale* (*Carmia*) sp., *Cladocroce* sp. “massive, encrusting”, *Suberites diversicolor* Becking & Lim, 2009, *Tethya robusta* (Bowerbank, 1873) and *Amorphinopsis excavans* Carter, 1887, in descending frequency of occurrence. These are described in detail in

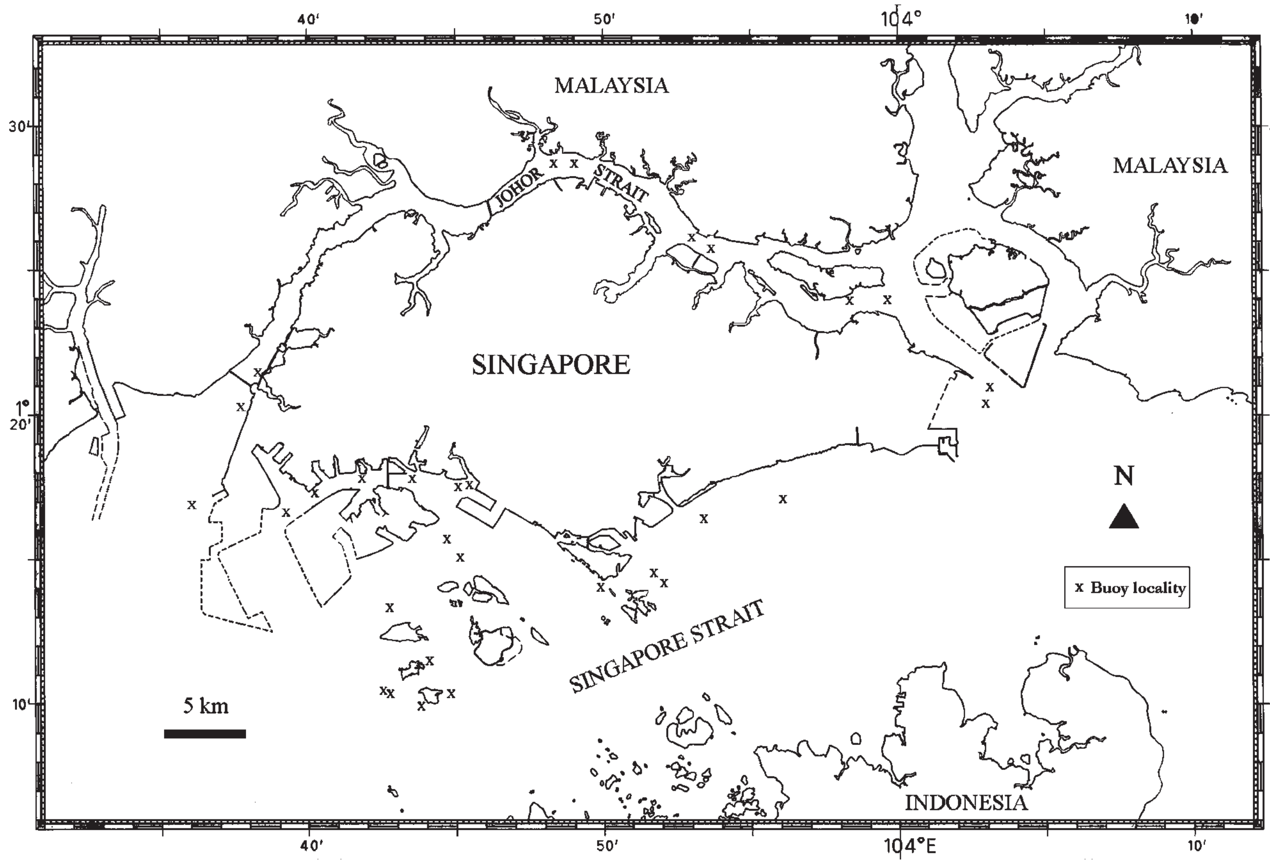

Fig. 1. Location of 30 navigational buoys examined for sponges in the Singapore and Johor Strait.

the following section. Eight new records for Singapore were obtained in this study based on material from navigation buoys as well as those in the ZRC. These are indicated with an asterisk against the species in Table 1. Some 10 species, including the widely distributed *Callyspongia* (*Cladochalina*) *diffusa* Ridley, 1884, *Mycale* (*Aegogropila*) *sulevoidea* (Sollas, 1902), *Prosuberites oleteira* De Laubenfels, 1957, and *Psammochela psammodes* (Hentschel, 1911) were seen frequently (up to eight buoys) but the majority of the sponge species occurred on less than three buoys. For example, *Chondrilla australiensis* Carter, 1875 and *Iotrochota baculifera* Ridley, 1884, both very common and abundant in shallow-water reefs in Singapore (pers. obs.), occurred only once on navigational buoys over the period of sampling.

Mycale (*Zygomycale*) *parishi*, *Mycale* (*Carmia*) sp., *Tethya robusta* and *Amorphinopsis excavans* were widely distributed on the buoys throughout the Johor and Singapore Straits. In contrast, *Psammochela psammodes* and the calcareous sponges (*Leucetta* sp. and *Leucosolenia* cf. *flexilis*) occurred only in the Singapore Strait. There seemed to be no sponge species that were confined to the Straits of Johor but *Suberites diversicolor* was common in the largely estuarine waters of Johor Strait and estuaries in the Singapore Strait near freshwater discharge. The fouling sponge fauna on buoys were visibly dominated by *Mycale* (*Zygomycale*) *parishi* in biomass (i.e., estimated visually) but members of the Haplosclerida was highest in species richness (30 species).

TAXONOMY

Phylum Porifera Grant, 1835
Class Demospongiae Sollas, 1885
Order Hadromerida Topsent, 1894

Suberitidae Schmidt, 1870

***Suberites* Nardo, 1833**

***Suberites diversicolor* Becking & Lim, 2009**
(Figs. 2A, 3A–B)

Material examined. **–** ZRC.POR.006, Singapore; Johor Strait, 1–2 m depth, 01°28.50’N, 103°48.31’E; 14 Jan 2004, coll. Lim, S.C.; ZRC.POR.0005, paratype of *Suberites diversicolor*, Singapore, Johor Strait, 0 m depth, 01°26’2.34” N, 104°02’54.31”E

Description. **–** Encrusting (Fig. 2A), sometimes with digitate projections of approximately 10 mm in length and 5 mm in diameter at the base. Living individuals has a wide range of colour: orange, red, purple, blue, green and gray; beige in ethanol. Oscules are less than 1 mm in diameter in the field, and generally not visible when out of water or after preservation. Texture firm, slightly compressible and elastic. Surface texture-micro hispid to velvety. The commensal barnacle, *Acasta dofleini*, was sometimes observed to inhabit this sponge species.

Table 1. Fouling sponges from Singapore waters.

Taxa	ZRC Catalogue No.
Class Demospongiae Sollas, 1885	
Order Astrophorida Sollas, 1888	
Family Ancorinidae Schmidt, 1870	
1. *Stelletta* sp. "yellow, spherical"	ZRC.POR.0017
Order Hadromerida Topsent, 1894	
Family Clionaidae D 'Orbigny, 1851	
2. *Cliona* cf. *celata* Grant, 1826	ZRC.POR.0018
Family Suberitidae Schmidt, 1870	
3. *Prosuberites oleteira* De Laubenfeld, 1957*	ZRC.POR.0019
4. *Suberites diversicolor* Becking & Lim, 2009	ZRC.POR.0006
Family Tethyidae Gray, 1848	
5. *Tethya* cf. *japonica* Sollas, 1888	ZRC.POR.0020
6. *Tethya robusta* Bowerbank, 1873*	ZRC.POR.0007
7. *Tethya* sp. "violet"	ZRC.POR.0021
Order Chondrosida Boury-Esnault & Lopès, 1985	
Family Chondrillidae Gray, 1872	
8. *Chondrilla australiensis* Carter, 1873*	ZRC.POR.0022; +ZRC.1997
Order Poecilosclerida	
Suborder Microcionina Hajdu, van Soest & Hooper, 1994	
Family Microcionidae Carter, 1875	
9. *Clathria* (*Clathria*) sp. "brown, thinly encrusting"	ZRC.POR.0023
10. *Clathria* (*Microciona*) *mima* (de Laubenfels, 1954)*	ZRC.POR.0024
Family Raspailiidae Hentschel, 1923	
11. *Echinodictyum conulosum* Kieschnick, 1900	ZRC.POR.0025
Suborder Myxillina Hajdu, van Soest & Hooper, 1994	
Family Coelosphaeridae Dendy, 1922	
12. *Lissodendoryx* (*Lissodendoryx*) sp. "encrusting"	ZRC.POR.0026
Family Tedaniidae Ridley & Dendy, 1886	
13. *Tedania* (*Tedania*) sp. "bright orange, encrusting"	ZRC.POR.0027
Family Iotrochotidae Dendy, 1922	
14. *Iotrochota baculifera* (Ridley, 1844)	ZRC.POR.0028
Family Myxillidae Dendy,1922	
15. *Psammochela psammodes* (Hentschel, 1911)*	ZRC.POR.0029
Suborder Mycalina Hajdu, van Soest & Hooper, 1994	
Family Mycalidae Lundbeck, 1905	
16. *Mycale* (*Aegogropila*) *sulevoidea* (Sollas, 1902)*	ZRC.POR.0030; +ZRC.1997
17. *Mycale* (*Carmia*) sp. "red, encrusting"	ZRC.POR.0008
18. *Mycale* (*Parasperella*) sp. "yellow, massive"	ZRC.POR.0031
19. *Mycale* (*Zygomycale*) *parishi* (Bowerbank, 1875)*	ZRC.POR.0009
Order Halichondrida Gray, 1867	
Family Halichondriidae Gray, 1867	
20. *Amorphinopsis excavans* Carter, 1887*	ZRC.POR.0010
21. *Amorphinopsis* sp. "purple, big oscules"	ZRC.POR.0032
22. *Halichondria* sp. "blue, translucent, paper-like"	ZRC.POR.0033
23. *Halichondria* sp. "yellow-brown, encrusting"	ZRC.POR.0034
24. *Halichondria* sp. "brown, thin-walled fistules"	ZRC.POR.0035
Order Haplosclerida Topsent, 1928	
Suborder Haplosclerina Topsent, 1928	
Family Callyspongiidae de Laubenfels, 1936	

Table 1. (continued)

Taxa	ZRC Catalogue No.
25. *Callyspongia* (*Callyspongia*) cf. *communis* (Carter, 1881)	ZRC.POR.0036
26. *Callyspongia* (*Callyspongia*) cf. *globosa* Pulizer-Finali, 1982	ZRC.POR.0037
27. *Callyspongia* (*Callyspongia*) sp. “yellow, repent”	ZRC.POR.0038
28. *Callyspongia* (*Callyspongia*) sp. “centrotylote oxea”	ZRC.POR.0039
29. *Callyspongia* (*Callyspongia*) sp. “violet, lobate”	ZRC.POR.0040
30. *Callyspongia* (*Cladochalina*) *diffusa* (Ridley, 1884)	ZRC.POR.0041
31. *Callyspongia* (*Cladochalina*) sp. “brown, fistules with apical oscules”	ZRC.POR.0042
32. *Callyspongia* (*Cladochalina*) sp. “pale violet, irregularly-sized oscules”	ZRC.POR.0043
33. *Callyspongia* (*Euplacella*) sp. “dull purple, cushion-shaped”	ZRC.POR.0044
34. *Callyspongia* (*Toxochalina*) cf. *folioides* (Bowerbank, 1875)	ZRC.POR.0045
Family Chalinidae Gray, 1867	
35. *Chalinula* sp. “purple, encrusting”	ZRC.POR.0046
36. *Chalinula* sp. “brown”	ZRC.POR.0047
37. *Cladocroce* aff. *burapha* Putchakarn et al., 2004	ZRC.POR.0048
38. *Cladocroce* sp. “massive, encrusting”	ZRC.POR.0011
39. *Cladocroce* sp. “purple, branching, repent”	ZRC.POR.0049
40. *Cladocroce* sp. “green, encrusting”	ZRC.POR.0050
41. *Haliclona* (*Halichoclona*) sp. “greyish-black, encrusting”	ZRC.POR.0051
42. *Haliclona* sp. “opaque pink”	ZRC.POR.0052
43. *Haliclona* sp. “yellow, irregular”	ZRC.POR.0053
44. *Haliclona* sp. “translucent pink, apical oscules”	ZRC.POR.0054
45. *Haliclona* sp. “pink, small stout fistule with apical oscules”	ZRC.POR.0055
46. *Haliclona* sp. “bright blue, thin-walled”	ZRC.POR.0056
47. *Haliclona* sp. “yellow, anastomsed short branches”	ZRC.POR.0057
48. *Haliclona* sp. “dark green, encrusting”	ZRC.POR.0058
49. *Haliclona* sp. “violet, irregular”	ZRC.POR.0059
50. *Haliclona* sp. “yellow, translucent, thinly encrusting”	ZRC.POR.0060
51. *Haliclona* sp. “black”	ZRC.POR.0061
52. *Haliclona* sp. “green, translucent”	ZRC.POR.0062
53. *Haliclona* sp. “ violet, opaque”	ZRC.POR.0063
Family Niphatidae van Soest, 1980	
54. *Gelliodes* sp. “violet, massive”	ZRC.POR.0064
Order Dictyoceratida Minchin, 1900	
Family Thorectidae Bergquist, 1978	
55. *Lendenfeldia* cf. *chondrodes* (de Laubenfels, 1954)	ZRC.POR.0065
Family Dysideidae Gray, 1867	
56. *Dysidea* sp. “yellow, repent”	ZRC.POR.0066
57. *Lamellodysidea herbacea (*Keller, 1889)	ZRC.POR.0067
Family Darwinellidae Merjkowsky, 1879	
58. *Chelonalysilla* cf. *erectus (Row, 1911)**	
59. *Darwinella* sp. “pink”	ZRC.POR.0069
Family Dictydendrillidae Bergquist, 1980	
60. *Dictyodendrilla* sp. “green tissue, brown fibre”	ZRC.POR.0070
Class Calcarea Bowerbank, 1864	
Order Clathrinida Hartman, 1958	
Family Leucettidae de Laubenfels, 1936	
61. *Leucetta* sp. “white”	ZRC.POR.0071
Order Leucosolenida Hartman, 1958	
Family Leucosoleniidae Minchin, 1900	
62. *Leucosolenia* cf. *flexilis* (Haeckel, 1872)	ZRC.POR.0072

Skeleton
Ectosomal skeleton consists of smaller tylostyles at the periphery directed outwards in palisade, carried by larger tylostyles. Tangential spicules are absent, and there is no recognizable cortex. The interior skeleton consists of densely packed tylostyles in vague tracts and/or in confusion. Peripheral choanosomal skeleton consists of closely packed diverging tracts about 70 µm in diameter, comprising tylostyles that are much larger than those forming the ectosomal skeleton (Fig. 3A). However, the tylostyles have a wide size range and the typical two size categories tylostyles found in *Suberites* species (see definition in Van Soest, 2002) are overlapping in this species.

Spicules
Only tylostyles (Fig. 3B) are present. These are straight, smooth, and sharply pointed. Size: 176–465.9–830 µm x 2.5–6.5–15 µm. Modified tylostyles include lobate and subterminal forms.

Remarks. – *Suberites diversicolor* was described recently based on material from India, Vietnam, Indonesia and Northern Australia (Becking & Lim, 2009). The paratype material of *Suberites diversicolor* (ZRC.POR.0005) from Singapore intertidal shore was examined and found to conform to the fouling sponge material. We also examined *Suberites carnosus* reported by Pulitzer-Finali (1993; 1996) from Kenya and New Guinea and this species has a similar spiculation and skeletal structure as *S. diversicolor*. However, *S. carnosus* (Johnston, 1842) was originally described from Britain. It is very probable that the Kenyan *S. carnosus* is not conspecific with the British *S. carnosus*. In addition, it has a wider spicule size range of 180–820 µm compared to the British *S. carnosus*, which has a substantially narrower tylostyles size range of 330–410–500 µm (Van Soest et al. 2000; Picton et al., 2007). Only spicule dimensions were given by Pulitzer-Finali (1993 & 1996). The material from Kenya and New Guinea available at MSNG (Museo Civico di Storia Naturale 'Giacomo Doria', Genoa, Italy) was unfortunately insufficient to give a good idea of the habit. Hence we were unable to determine if these specimens are conspecific with *S. diversicolor*. It would be interesting to look at molecular data to determine if they are the same species, or alternatively, part of a species complex.

TETHYIDAE Gray, 1848

Tethya Lamarck, 1814

Tethya robusta (Bowerbank, 1873)
(Figs. 2B, 4A–E)

Tethea robusta Bowerbank, 1873: 10, pl. II. – Bowerbank 1858: 287, 307 & 308
Tethya robusta – Bergquist & Kelly-Borges 1991: 54, fig. 34; Sará 1992: 485, fig. 7; Sarà & Sarà 2004: 148, fig. 17A–H.

Material examined. – ZRC.POR.0007, Singapore; Singapore Strait, 01°16.63'N, 103°56.01'E; 14 Apr 2005.

Description. – Shape spherical, hemi-spherical or globose (Fig. 2B), up to 5 cm in diameter, with numerous rooting processes attaching it to the substratum, seen in almost all the specimens found on buoys. Live external colour yellow, pink or red, turning pale or beige after preservation in ethanol. Cortex is yellowish-brown to pale orange, also turning pale or beige in ethanol. Oscules are not visible to the naked eye in the field when out of water or preserved. Texture is very firm, difficult to tear, but slightly compressible. Surface covered with numerous rounded tubercles 1–2 mm in diameter and 0.5–1.5 mm in height. Buds are often present.

Skeleton
Main megascleres bundle (Fig. 4A) 250–500 μm in diameter radiates through the choanosome, expanding slightly in the cortex but not branched into secondary tracts. Interstitial megascleres are present between the main bundles and a high density of megasters is usually present throughout the cortex. Smaller megasters are in the peripheral choanosome and a dense micraster crust is evident on the surface. Tylasters and oxyasters are both scattered throughout the choanosome. The thickness of the cortex (without tubercles) ranges between 2–3 mm. Cortical lacunae are absent.

Spicules
The megascleres are strongyloxeas (Fig. 4B) ranging between 700 and 2125 μm in length and 5–40 μm in width. The megasters are spherasters (Fig. 4C) with diameters between 60 to 90 μm and R/C = 0.3–0.5, the smaller size spherasters are found in the outer choanosome. In the cortex, micrasters are tylasters (Fig. 4D) 10–12.5 μm in diameter. In the choanosome, in addition to the tylasters similar to the cortical ones, oxyasters (Fig. 4E) are present. Some of these are spiny with forked tips, 12.5–35 µm in diameter.

Remarks. – *Tethya robusta* can reach a relatively large size, up to 5 cm in diameter. This species can easily be distinguished from other *Tethya* species in the Indo-Pacific by its external morphology and spiculation (Sarà & Sarà, 2004). It is characterized by its spherical or subspherical shape and rounded, uniformly distributed distinct tubercles on its surface, with large strongyloxeas more than 2000 μm in length. A dense distribution of spherasters and tylasters occurs in the cortex. Spherasters are large, ranging between 70–90 μm in diameter, R/C is generally 0.3–0.5. Oxyasters and tylasters are present in the choanosome. Microoxyspherasters, 4–5 μm in diameter, could not be verified in the buoy material. They are too small to be determined with certainty under the light microscope and they very rarely appear in spicule preparations for SEM. *Tethya robusta* is very similar in shape and spiculation to *T. ingalli* but *T. robusta* lacks the elaborate tertiary megascleres tracts that characterize *T. ingalli*. *Tethya robusta* also has larger megascleres greater than 2000 μm in length, larger spherasters of 60–100 μm in diameter, smaller spherasters R/C of less than 0.6, and has more rays (usually more than 20 rays) than *T. ingalli*. *Tethya japonica* Sollas, 1888, was also present on buoys but it can be distinguished from *T. robusta* and *T. ingalli* by the absence of oxyasters. A widely distributed species *Tethya seychellensis* (Wright,

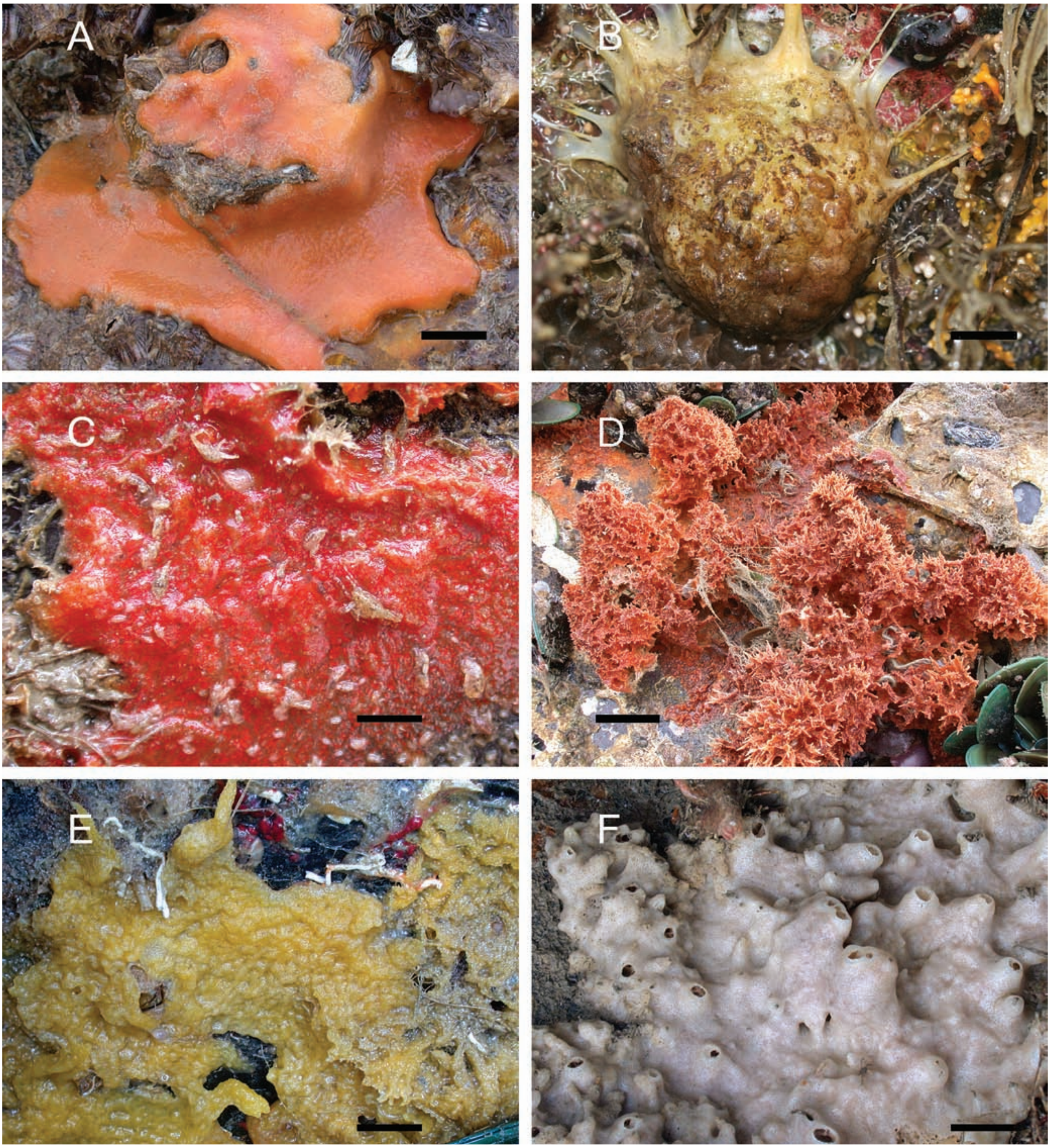

Fig. 2. A, Common sponges on navigational buoys in Singapore. *Suberites diversicolor* Becking & Lim, 2009; B, *Tethya robusta*; C, *Mycale* (*Carmia*) sp. "red, encrusting";D, *Mycale (Zygomycale) parishi* (Bowerbank, 1875); E, *Amorphinopsis excavans*; F, *Cladocroce* sp. "massive, encrusting". Scale bars: A, 15 mm; B–D, 10 mm; E, 8 mm; F, 20 mm.

1881) was not found on buoys, although it is present on sedimented intertidal areas in Singapore (S. C. Lim, pers. obs.). *Tethya seychellensis* is essentially distinguished by its having compact cortical spiny tylasters with reduced ray number, and very large choanosomal oxyasters with forked, flexuous and sometimes apically spined long rays (Sarà & Sarà, 2004).

Order Poecilosclerida Topsent, 1867
Suborder Mycalina Hadju, Van Soest & Hooper, 1994

Mycalidae Lundbeck, 1905

***Mycale* Gray, 1867**
Subgenus *Carmia* Gray, 1867

***Mycale* (*Carmia*) sp. "red, encrusting"**
(Figs. 2C, 5A–D)

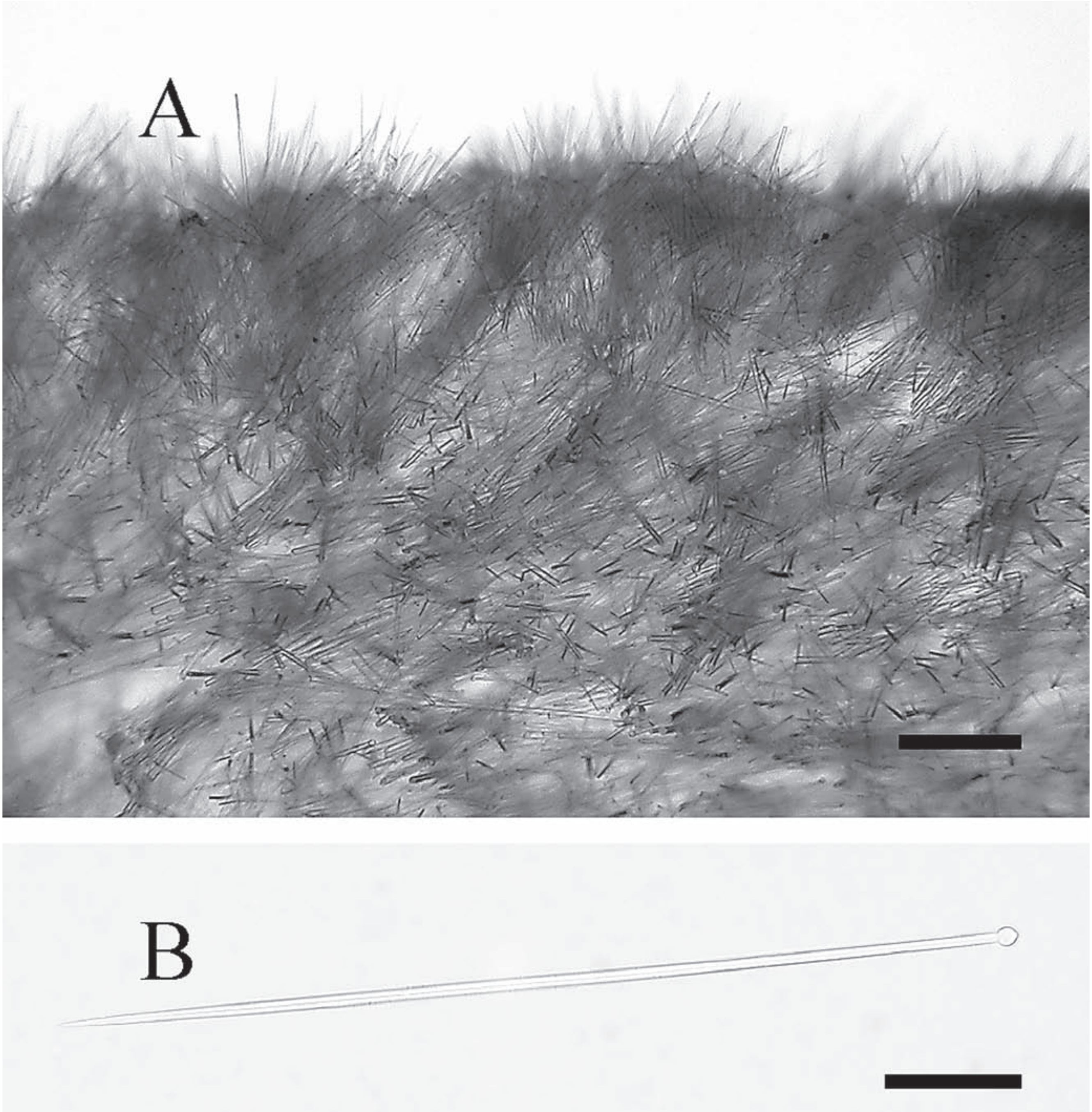

Fig. 3. *Suberites diversicolor* Becking & Lim, 2009: A, transverse section of skeleton; B, tylostyle. Scale bars: A, 150 µm; B, 70 µm.

***Material examined.* –** ZRC.POR.0008, Singapore; Johor Strait, 01°20.52'N, 103°37.84'E; 17 Nov.2006.

***17 Nov.2006. Description.* –** Thinly encrusting, ranging between 2 and 10 mm in thickness and up to 30 x 30 cm in surface area (Fig. 2C). Live colour varies from orange to red, beige in ethanol. Oscules are not visible when out of water or when preserved. Texture soft, compressible and fragile. Surface smooth.

Skeleton

Choanosomal skeleton consists of wispy, plumose bundles of megascleres that have little or no cohesion (Fig. 5A). A coherent ectosomal skeleton is absent.

Spicules

Mycalostyles (Fig. 5B) of a single size category, straight or slightly curved: size 200–240–275 µm x 5–5.4–6 µm. Palmate anisochelae (Fig. 5C) of single size category, 12.5–20 µm C-sigma (Fig. 5D) of single size category, smooth: size 27.5–32.4–35 µm.

***Remarks.* –** This species is a very abundant, widespread component of the fouling fauna in Singapore waters. It was present on 25 of the 30 buoys from both Singapore and Johor Straits. This species seems to be a part of the complex of orange-red thinly encrusting *Mycale* (*Carmia*) species (see Van Soest, 1982) found in different parts of the world that possess a single category of palmate

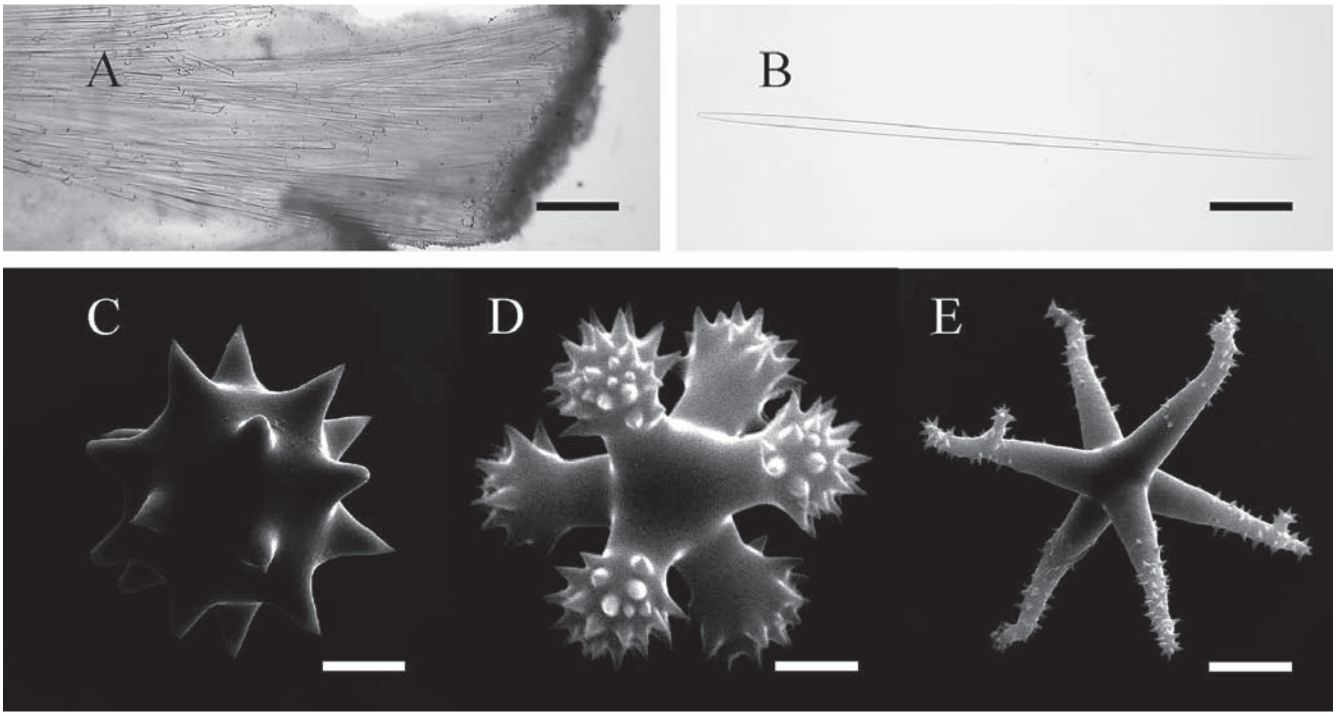

Fig. 4. *Tethya robusta* (Bowerbank, 1873): A, transverse section of skeleton; B, strongyloxea; C, spheraster; D, tylaster; E, oxyaster. Scale bars: 10 mm. Scales bars: A, 300 µm; B, 150 µm; C, 20 µm; D, 2 µm; E, 10 mm.

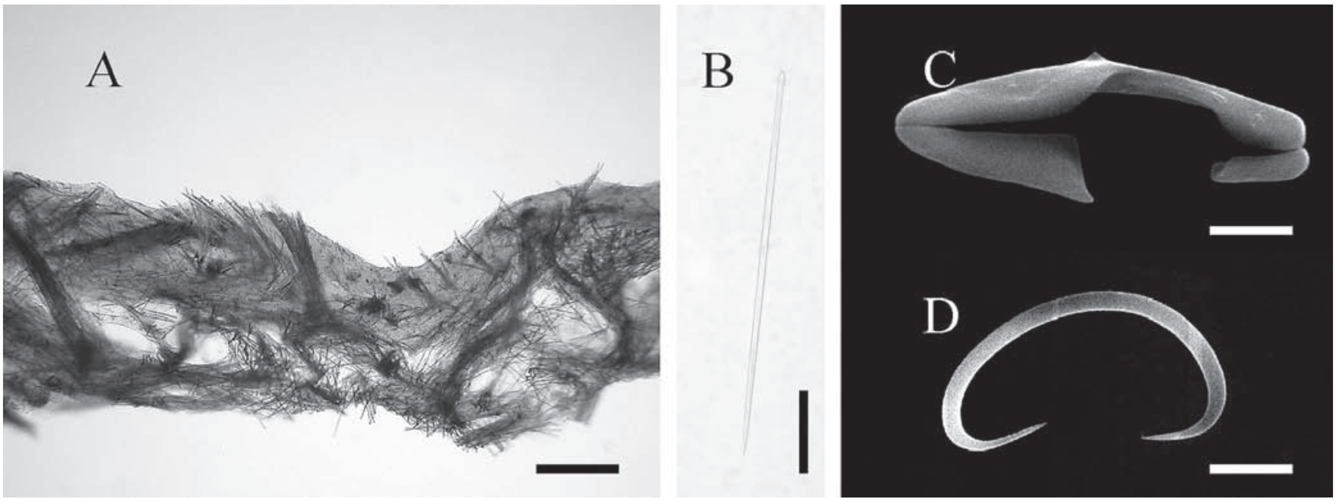

Fig. 5. *Mycale* (*Carmia*) sp. "red, encrusting":A, transverse section of skeleton; B, mycalostyle; C, palmate anisochelae;. D, sigma. Scale bars: A, 200 µm; B, 20 µm; C, 2.5 µm; D, 10 µm.

anisochelae and sigmas. The species-complex includes *M*. (*C*.) *microsigmatosa* (Arndt, 1927) from the Caribbean, *M*. (*C*.) *sanguinea* (Tsurnamal, 1969) in the Mediterranean, *M*. (*C*.) *senegalensis* Lévi, 1952 in West Africa and *M*. (*C*.) *lissochela* Bergquist, 1965 in the West Pacific Ocean. The Eastern Pacific species *Mycale* (*Carmia*) *cecilia* De Laubenfels, 1936 occurring in the Pacific side of Panama is also similar in spiculation and structure to the species here but differs in that it is bright green and red-speckled. However in a later study, De Laubenfels (1950) found *M*. (*C*.) *cecilia* yellow, pale orange, pink to lavender in Kaneohe Bay, Hawaii. *Mycale* (*Carmia*) *cecilia* was recently reported by Cruz-Barrara & Carballo (2008) to be growing over corals in the East Pacific. More work is needed to resolve the species complex comprising these orange-red, thinly encrusting *Mycale* (*Carmia*) species, with the possibilities that they might either be widely distributed introduced species in major ports, carried by ship hulls and bilge water, or morphologically conservative but genetically distinct regional faunas.

Mycale Gray, 1867

Subgenus *Zygomycale* Topsent, 1929

Mycale (*Zygomycale*) *parishi* (Bowerbank, 1875)
(Figs. 2D, 6A–G)

Raphiodesma parishi Bowerbank, 1875: 283
Esperella parishi Ridley & Dendy, 1887: 65
Zygomycale parishii – Topsent, 1930: 431 (vide De Laubenfels, 1950) – Thomas, 1973: 38, pl. II, fig. 10.

Material examined. **–** ZRC.POR.0009, Singapore; Singapore Strait, 01°14.68'N, 103°52.18'E; 21 Jun.2003.

Description. **–** Usually encrusting (Fig. 2D), 5 to 25 mm in thickness and occupying up to 30 cm x 30 cm in area. Arboreal and branching forms were observed in several specimens. Two colour morphs, reddish orange and purplish blue, are observed. Both turned beige in ethanol. Oscules are not visible when out of water or when preserved. Texture is firm, compressible and resilient. Surface uneven due to projecting choanosomal spicule tracts.

Skeleton
Choanosomal skeleton consists of irregular plumoreticulate multispicular tracts (Fig. 6A), 20–50 µm in diameter. Mycalostyles are of a single category. Ectosomal skeleton consists of a dense tangential reticulation or intercrossing of mycalostyles in tracts (Fig. 6B).

Spicules
Mycalostyles (Fig. 6C) of a single size category, straight but often slightly curved: size 280–306.4–340 µm x 7.5–9.2–10 µm. Toxas (Fig. 6D) smooth, width not proportional to length, size 17.5–56.1–90 µm x 0.25–1.5–2.5 µm. Palmate anisochelae (Fig. 6E) of two size categories: 1) 47.5–51.8–55 µm and 2) 17.5–19.75–20 µm. Palmate isochelae (Fig. 6F), 10–11.13–12.5 µm. C-sigma (Fig. 6G), smooth in three size categories: 1) 12–13.6–15 µm (n=15), 2) 22.5–26.3–32.5 µm and 3) 77.5–81.25–85 µm. Raphides, straight, smooth: 32.5–35.6–37.5 µm x 1 µm.

Remarks. **–** Singapore specimens can be easily identified with the type description of *Mycale* (*Zygomycale*) *parishi* Bowerbank (1875) with the exception of the presence of raphides (32.5–37.5 µm) in trichodragmas observed in specimens examined from buoys but not mentioned by Bowerbank. However, type material (BMNH 1877.5.21.2113) has abundant raphides, size 30–35.7–42.5 µm. Ridley (1884) made similar observations in the type specimen and many subsequently recorded specimens from elsewhere in Indo-Pacific. There are only two valid species in this subgenus (Van Soest et al., 2008); the other species is the bluish ramose *M.* (*Z.*) *angulosa* (Duchassaing & Michelotti, 1864) from the Atlantic Ocean. *Mycale* (*Zygomycale*) *parishi* has very similar spiculation to that of *M.* (*Z.*) *angulosa* sensu Van Soest (1984). Only colour appears to differentiate the two species: *M.* (*Z.*) *parishi* is grey-brown according to Bowerbank (1875) whilst *M.* (*Z.*) *angulosa* is blue (Van Soest & Hadju, 2002). It is generally agreed that *M.* (*Z.*) *parishi* only occurs in the Indo-Pacific and *M.* (*Z.*) *angulosa* in the Atlantic.

Order Halichondrida Gray, 1867

Halichondriidae Gray, 1867

Amorphinopsis Carter, 1887

Amorphinopsis excavans Carter, 1887
(Figs. 2E, 7A–D)

Amorphinopsis excavans Carter, 1887: 77, pl.5, figs 12–15. – Hooper et al., 1997: 25, figs 15–16.
Amorphinopsis excavans digitifera Annandale, 1915: 467, fig. 4A.
Amorphinopsis excavans robinsonii Annandale, 1918: 198, pl. II, fig. 3; pl. IX, fig. I

Material examined. **–** ZRC.POR.0010, Singapore, Johor Strait, 01°23.676'N, 103°59.936'E; 9 December 2004.

Description. **–** Encrusting (Fig. 2E), up to 10 x 5 x 3 cm (length x width x thickness) in size. Specimens found on the interior of buoys not exposed to sunlight were bright yellow, whilst those on exterior surfaces exposed to sunlight were dark greyish-green with or without a yellow tinge. Both turn beige in ethanol. Oscules are not visible to the naked eye when out of water or after preservation. Texture is firm but compressible. Specimens become fragile and friable when dried. Surface is opaque, usually smooth but some parts can be convoluted.

Skeleton
The ectosomal tangential skeleton (Fig. 7A), which peels easily, consists of vague, intercrossing tracts of oxeas and styles. Small styles are oriented paratangential to "echinating" and protrude through the surface. Collagen sparse. Choanosomal skeleton (Fig. 7B) tightly packed, confused, with vague, irregular tracts of spicules bound together with very little collagenous spongin producing elongated and oval cavities throughout the skeleton. Towards the periphery, spicules tracts become more paratangential. No significant size differences of the spicules were observed for both oxeas and styles at the surface and the choanosomal skeleton.

Spicules
Oxeas (Fig. 7C) of a single size category, smooth, straight or slight curved; size 260–636–980 µm x 5–14.7–25 µm. Styles (Fig. 7D) smooth, straight or slightly curved; size 160–212–350 µm x 5–5.2–7 µm.

Remarks. **–** Approximately 14 *Amorphinopsis* species have so far been described from the Indo-Pacific. The specimens from Singapore best fit the description of *Amorphinopsis excavans* given by Hooper et al. (1997). Attempts to locate type material at BMNH were not successful. However, a holotype (slide) BMNH 1981.10.14.3 of *A. excavans* is described in the Systema Porifera and the type specimen is supposedly in the Indian Museum at Calcutta (Erpenbeck & Van Soest, 2002). To limit the discussion, only species with a similar encrusting habit are discussed. *Amorphinopsis*

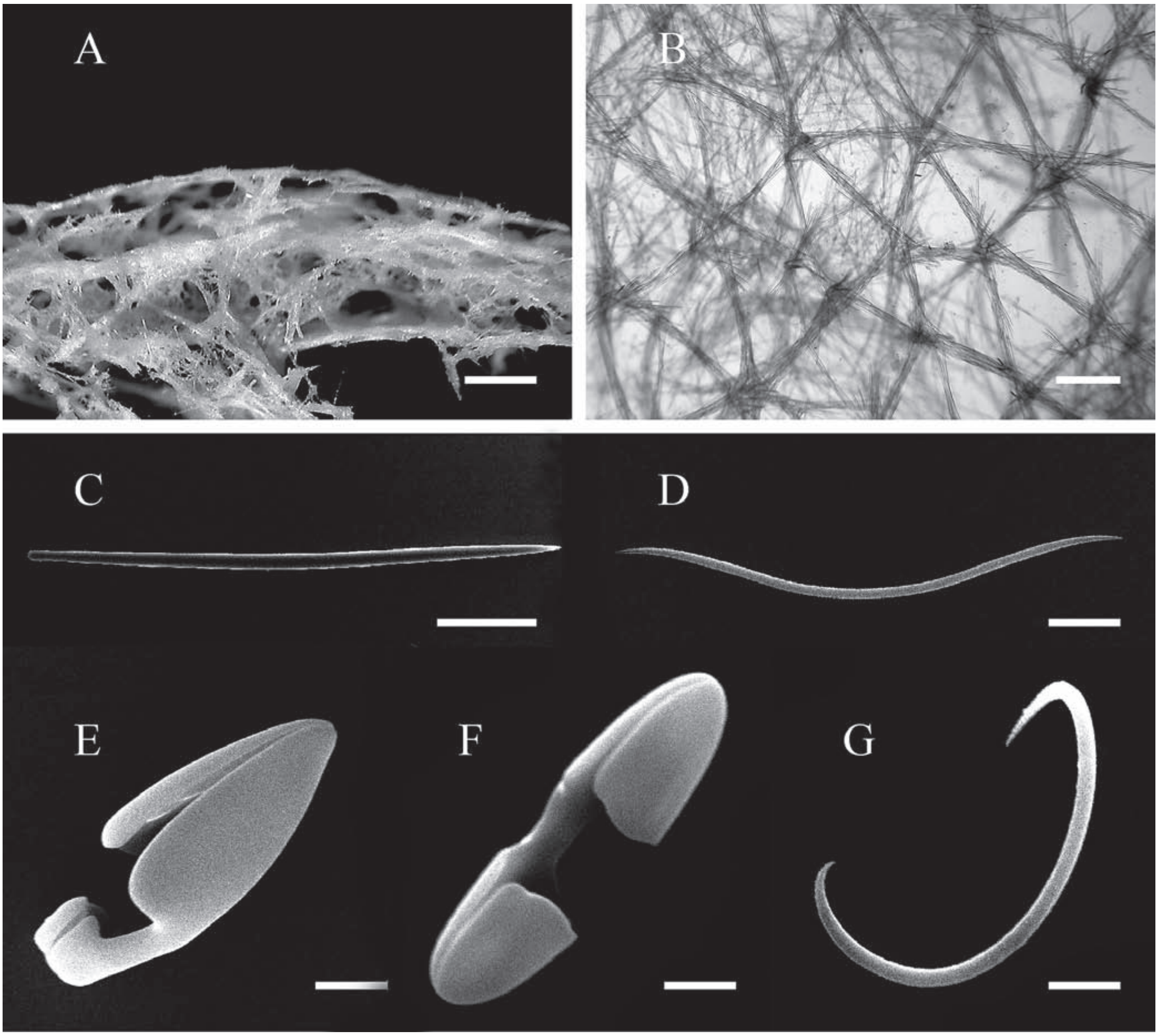

Fig. 6. *Mycale (Zygomycale) parishi* (Bowerbank, 1875): A, transverse section of skeleton; B, tangential ectosomal skeleton; C, anisostrongyle; D, toxa; E, Palmate anisochelae; F, palmate isochelae; G, sigma. Scale bars: A, B, 250 µm; C, 60 µm; D, 7 µm; E, 10 µm; F, 2 µm; G, 6 µm.

sacciformis (Thiele, 1903) described from Ternate, Indonesia, differs from *A. excavans* in having two categories of oxeas and whose size can be up to 1105 µm x 35 µm (Hooper et al., 1997), much larger than those of *A. excavans*. *Amorphinopsis reptans* (Kirkpatrick, 1903) described from South Africa differs from *A. excavans* in having a growth form with narrow sharp-edged ligulate bands averaging about 1 mm in diameter, branching and occasionally anastomosing to form an incomplete reticulate pattern. *Amorphinopsis maza* (De Laubenfels, 1954) described from Micronesia differs from *A. excavans* in having larger styles of size 540 µm x 12 µm and big oscula that are 5 mm in diameter. *Amorphinopsis subaceratus* (Ridley & Dendy, 1886) described from the Philippines differs from *A. excavans* in having irregular anastomosing trabeculae and larger oxea size of 1200 x 31µm. Similarly, *Amorphinopsis siamensis* (Topsent, 1925) described from Thailand has anastomosing branches that are between 3–20 mm in thickness and larger oxea up to 980 x 40 µm. *Amorphinopsis foetida* (Dendy, 1889) described from India has low volcano-shaped fistules with large oscules up to 8 mm in diameter and long, slender styles, 448–609.8–794 µm x 8–16.4–23 µm (Hooper et al., 1997), which clearly differ from *A. excavans*. The morphology and skeletal features of *Amorphinopsis papillata* (Baer, 1906) described from Polynesia are very similar to *A. excavans*. While the oxeas are slightly larger, the size of styles in the type material (between 200–220 µm in length) is similar to *A. excavans*. Amorphinopsis papillata might be therefore conspecific with A. excavans but more work is required to ascertain their status.

The description of *A. rudis* (Bowerbank, 1875) is very brief, incomplete and spicule measurements were not provided. However, the description suggests that the sponge belongs to the genus *Amorphinopsis*, supporting Van Soest et al. (2008) decision to place it there, but a slide from the type material, BMNH 1877.5.12.1347, contains onychaetes (size 255–355µm x 2.6–6.0µm), styles (size 240–345 x 7.5–12.5) and rare micro-spined tylotes (240–270µm x 4–5µm) refuting this conclusion. Oxeas are absent but Bowerbank could have mistaken the onychaetes for oxeas. The presence of onychaetes and styles would place *Isodictya rudis* in the genus *Tedania*.

Order Haplosclerida Topsent, 1928

Chalinidae Gray, 1867

***Cladocroce* Topsent, 1892**

***Cladocroce* sp. "massive, encrusting"**
(Figs. 2F, 8A–B)

***Material examined.* –** ZRC.POR.0011, Singapore; Singapore Strait, 01°16.68'N, 103°52.63'E; 6 Apr. 2004.

***Description.* –** Massively encrusting, occupying up to 25 x 25 cm in area, with numerous mounds and/or fistules (Fig. 2F), height 5–25 mm. Oscules always at the terminal end of mounds or fistules, diameter 3–10 mm. Live colour white tinged with pink, green and/or violet, turning pale white in ethanol. Texture firm, crumbly and fragile. Surface smooth. An anastomosing network of spicule tracts is visible just below the surface.

Skeleton
Choanosomal network is an isotropic reticulation of free spicules, reinforced by an irregular network of multispicular fibres or tracts (Fig. 8A) that occasionally anastomose. There are numerous free oxeas. Ectosomal skeleton is a multilayered compact crust with a single layer of tangential, unispicular, isotropic, reticulated oxeas above an anastomosing, subdermal multispicular tract (Fig. 8B).

Spicules
Oxeas of two size categories, often curved: (a) size 162.5–173.5–185 µm x 6–8.6–10 µm, and (b) 137.5–155.1–170 µm x 2.5–3.5–5 µm. The thinner and slightly shorter oxeas are less abundant. There is some overlap in the length of the two categories of oxeas but not in thickness. The smaller oxeas seldom exceed 5 µm in thickness while the oxeas in the larger category are seldom less than 6 µm in thickness.

***Remarks.* –** The material described above best fits the definition of the genus *Cladocroce* as redefined by De Weerdt (2002), i.e., members of the Chalinidae which have their choanosomal skeleton reinforced by multispicular primary tracts that occasionally anastomose with rather dense, subisotropic, paucispicular reticulation in between. *Cladocroce burapha* Putchakarn, De Weerdt, Sonchaeng & Van Soest, 2004 (paratype, ZMA Por. 17921) is very similar to examined material in skeletal structure and both species fit the definition of *Cladocroce* by De Weerdt (2002). However, the two species differ in growth form and spicule size, *C. burapha* being tubulo-ramose whilst the buoy specimens are massively encrusting. *Cladocroce burapha* also has smaller oxeas that are between 107–117

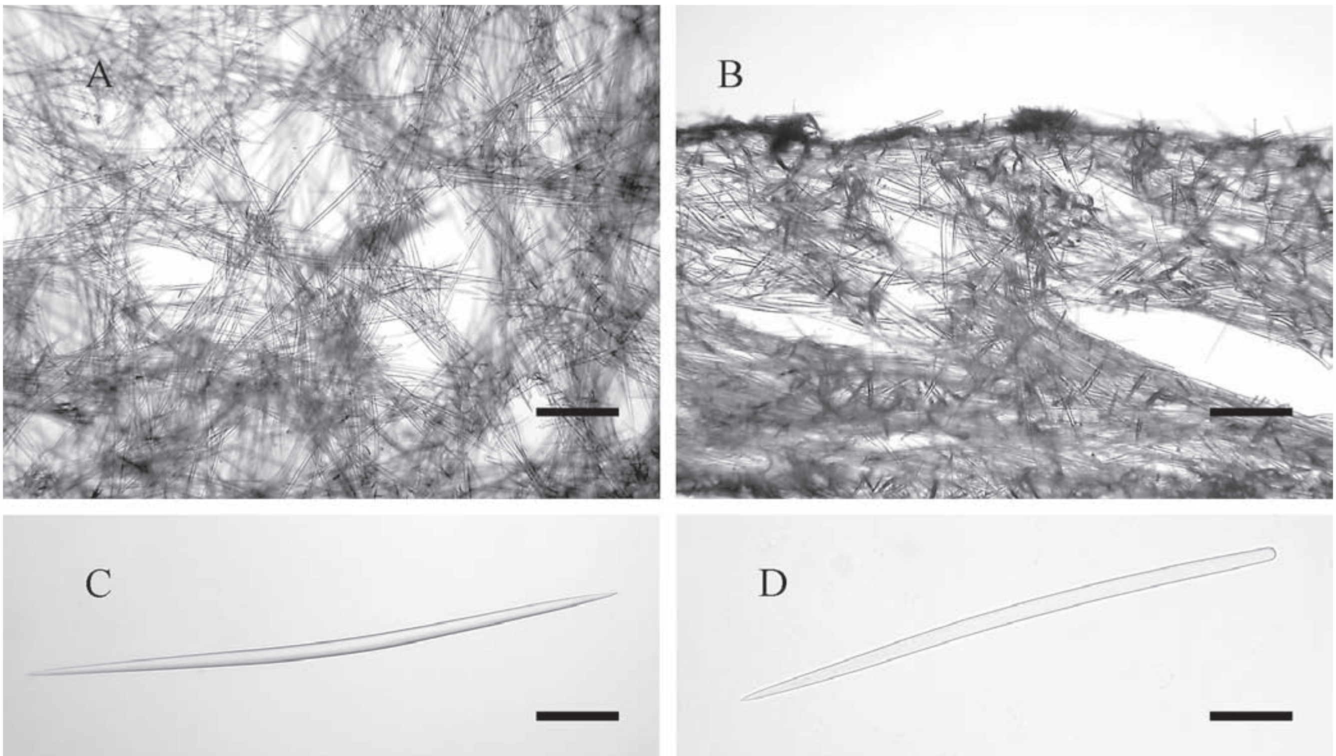

Fig. 7. *Amorphinopsis excavans* Carter, 1887: A, ectosomal tangential skeleton, top view; B, Transverse section of choanosomal skeleton (arrow indicates the surface); C, oxea; D, style. Scale bars: A, 150 µm; B, 300 µm; C, 75 µm; D, 30 µm.

µm in length while the current material has oxeas that are 137–185 µm in length. We refrain from describing this as a new species of *Cladocroce* as its allocation here is still equivocal.

Cladocroce is a poorly known genus compared to other members of the Chalinidae (De Weerdt, 2002), with only eight species described from deep water including the type species, and three species from shallow-water habitats. All eight deep-water species are lamellate or spathiform. *Cladocroce ventilabrum (Fristedt, 1887) (512 m), C. fibrosa (Topsent, 1890) (1300 m), C. parenchyma (Lundbeck, 1902) (2304 m), C. spatula (Lundbeck, 1902) (100 m), C. spathiformis Topsent, 1904 (1165 m), C. gaussiana (Hentschel, 1914) (350 m), C. osculosa Topsent, 1927 (310-749 m) and C. incurvata Levi & Levi, 1983 (170 m).* However, all three shallow-water species, namely *C. aculeata* Pulitzer-Finali, 1982, *C. tubulosa* Pulitzer-Finali, 1993 and *C. burapha* Putchakarn et al., 2004, are somewhat tubular in form and do not exhibit lamellate or spathiform morphology. The limits of the genus *Cladocroce* may best be confined to sponges that are lamellate or spathiform in form that occur in deep water (more than 100 m depth). However, based on the current classification, *Cladocroce* seems to be the best provisional genus allocation for current material.

DISCUSSION

This first inventory of fouling sponges in Singapore comprises a total of 62 species, possibly the highest number recorded so far for any tropical subtidal fouling community. The high diversity of sponges that can colonize and persist on a smooth, artificial substratum with a surface area of approximately 20 m^2 in area submerged in shallow water at two to three meters depth, is remarkable. Up to 23 sponge species were recorded on a single buoy in the Singapore Strait. By comparison, Esmero (1978) recorded 25 sponge species at Cebu Harbour in the Philippines that focused on sponge fauna on artificial substrata. Interestingly, none of the fouling sponge species recorded in Philippines were found in this study. In a study of the fouling community on buoys in the South China Sea, only one species of sponge, *Mycale adhaerens*, was recorded from seven buoys (Huang & Lin, 1993) and 12 sponge species from a ships hull in Hawaii (Godwin et al., 2004). Fouling sponge species richness on buoys is expectedly lower than those in natural habitats comprising different kinds of substrata such as rock, gravel, sand, mud and coral rubble. De Voogd & Cleary (2009, this volume) recorded 82 sponge species from coral reefs in Singapore waters in a much shorter collection period compared to this study. Species composition of sponges on natural and artificial substrata appears to be markedly different (Lim et al, in prep.).

Some 65% of our sponges could only be determined to genus level, reflecting the poor state of sponge taxonomy in this tropical region characterized by high diversity and compounded by the difficulty of identifying sponges with certainty to species level. As such, the sponge fauna in Southeast Asia is probably the least documented fauna among marine organisms (Hooper et al., 2000). Identifying largely encrusting and cryptic sponges on these buoys is made more difficult as even less work has been done on sponge fauna inhabiting artificial substrata. Some of these fouling specimens may be juveniles whose characteristic growth forms of adult sponges living on adjacent reefs have not yet been achieved, making identification even more challenging. It is also interesting to note that sponges from the highly speciose genera *Haliclona* and *Callyspongia* (Haplosclerida) accounted for nearly half of the total fouling sponge species recorded. This high proportion of *Haliclona* and *Callyspongia* species contrasts markedly from sponge assemblages elsewhere in the Indo-West Pacific. For example, *Haliclona* and *Callyspongia* only accounted for about 10% of the sponge fauna diversity in the Mariana Islands (Kelly et al., 2003), coral reefs in Mo Ko Thale Tai National Park in Thailand (Putchakarn, 2007) and, significantly, coral reefs in Singapore waters (De Voogd & Cleary, 2009, this volume). Such disparity could be attributed to cryptic and encrusting species of *Haliclona* and *Callyspongia* that may have been overlooked in the sponge faunas on natural habitats. There may also be biological

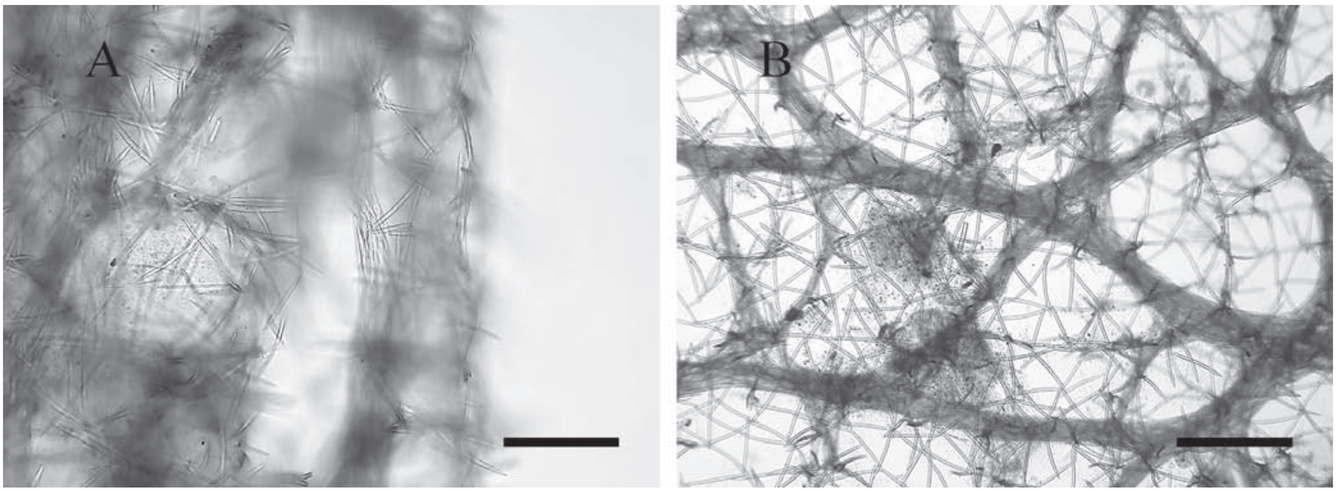

Fig. 8. *Cladocroce* sp. "massive, encrusting": A, transverse section of skeleton; B, tangential skeleton. Scale bars: 175 µm.

reasons why species in these genera are predominant in the fouling fauna, such as faster growth rates. These casual explanations are presently unsubstantiated and certainly require further investigation.

Eight new records (as indicated by an asterisk against each species in Table 1) are reported for the first time from Singapore based on material from navigation buoys, supplemented by material previously deposited in the Zoological Reference Collection (ZRC). These species were not recorded, notably by Hooper et al. (2000) from their short survey of Singapore subtidal reefs in 1997. However, the eight species all appear to have a tropical Indo-Pacific distribution. *Tethya robusta* has been reported from Australia (Bowerbank, 1973), Seychelles (Thomas, 1973) and Hong Kong (Van Soest, 1982); *Clathria* (*Microciona*) *mima* from the West Pacific (De Laubenfels, 1954) and Australia (Hooper, 1996); *Mycale* (*Zygomycale*) *parishi* from peninsular Malaysia (Bowerbank, 1875), Hawaii (Bergquist, 1967), Seychelles (Thomas, 1973) and Australia (Hooper & Wiedenmayer, 1994); *Amorphinopsis excavans* from Myanmar (Carter, 1887), Seychelles (Thomas, 1973) and Australia (Hooper et al., 1997); *Chondrilla australiensis* from Australia (Carter, 1873), the Red Sea (Keller, 1891 as *C. globulifera*), Madagascar (Vacelet & Vasseur, 1971) and Seychelles (Thomas, 1973). *Prosuberites oleteira* (described from Hawaii by De Laubenfels, 1957) and *Psammochela psammodes* (described from Western Australia by Hentschel, 1911) are reported for the first time from Southeast Asia. *Mycale* (*Aegogropila*) *sulevoidea* is also reported from Singapore for the first time since its description by Sollas (1902) from peninsular Malaysia.

Mycale (*Zygomycale*) *parishi* was the most common fouling sponge species on navigation buoys, being present in over 73% of the buoys examined. *Mycale* (*Carmia*) sp. was the second most common fouling sponge on navigation buoys, occurring on 70% of the buoys. *Cladocroce* sp. “massively encrusting”, *Suberites diversicolor*, *Tethya robusta* and *Amorphinopsis excavans* occurred on some 30% to 40% of the buoys examined while the majority of sponge species (76%) occurred on less than three buoys. Many were only collected once, e.g., *Chondrilla australiensis* Carter, 1873 and *Callyspongia* (*Toxochalina*) cf. *folioides* (Bowerbank, 1875). *Chondrilla australiensis* is one of the most common and abundant sponge species in intertidal and shallow water habitats around Singapore (Lim et al., 2008) but, surprisingly, it was only found once on navigational buoys.

Although we can reasonably expect the sponge fauna assemblage to be dissimilar in the Singapore and Johor Straits as they have different physical and chemical characteristics (see Chan et al., 2006; Gin et al., 2006), all six common fouling sponge species were distributed across the two water bodies, as were many other less common sponge species.

As one of the busiest ports in the world, Singapore is both a likely recipient as well as donor of species from and to other biogeographic regions. The transport of organisms on ship hulls and in ballast water through commercial shipping activities typically result in port environments becoming major points of biological invasions (Carlton, 1996; Hewitt, 2002 and Hewitt et al., 2004). A well-known example of a marine invasion in Singapore is the Caribbean false mussel *Mytilopsis sallei* (see Tan & Morton, 2006). Introduced sponge species are more likely to settle on new and artificial substrata such as buoys, pontoons and pilings than on mature natural habitats (e.g. Bergquist, 1967; Kelly et al., 2003; Hutchings et al., 2002; Godwin et al., 2004 and Hewitt et al., 2004). However, as this is the first inventory of fouling sponges in Singapore, we are unable determine if any of these are introduced. Only regular monitoring of an area documented thoroughly will reveal true invasions. In general, tropical high diversity areas are insufficiently known for well-founded conclusions (Van Soest et al., 2007). For example, one of the new records found this study, *Prosuberites oleteira*, which was fairly common on navigation buoys in Singapore waters, was first described from Pearl Harbor, Hawaii (De Laubenfels, 1957). This species is reported here in Southeast Asia for the first time. Its geographical distribution is thus greatly extended from Hawaii to Southeast Asia, However, it is not possible to determine if this species is an introduced species as baseline distribution data of this species are lacking. Interestingly, *Mycale* (*Mycale*) *grandis* Gray, 1967, an invasive sponge species reported from Hawaii (Coles et al., 1999, 2006; Coles & Bolick, 2007) was notably absent on all the 30 buoys in this study. This species was described from the India and we would expect it to be present on artificial substrata if it had traveled to Hawaii from India Ocean or Central Indo-Pacific. However the species is commonly found on natural substrata in Singapore waters (Lim et al., 2008).

According to De Laubenfels (1936) all fouling sponges are also shallow-water sponges and Godwin et al. (2004) remarked that fouling organisms are typical species found in natural marine intertidal and subtidal communities. On the other hand, Esmero (1978) observed that the sponge species composition of a fouling sponge assemblage was different from a natural shore assemblage. Smith and Rule (2002) and Qvarfordt et al. (2006) demonstrated that artificial structures are not surrogates for the natural hard substrates for sessile marine organisms. Comprehensive records of the native sponge fauna in the Singapore natural shores are lacking and, similarly, knowledge of sponge fauna in Malacca Strait, South China Sea and Java Sea in proximity to Singapore is poor. Having a good understanding of the native intertidal and shallow-water subtidal sponge fauna is the most important criterion in the determination of introduced species (Chapman & Carlton, 1991). Further detailed studies on intertidal and shallow water sponge fauna on natural habitats and continued monitoring of fouling sponges are necessary before we can have a satisfactory answer as to whether introduced sponge species exists on navigation buoys.

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