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ATTACHED MUSHROOM CORALS (SCLERACTINIA: FUNGIIDAE) IN SEDIMENT-STRESSED REEF CONDITIONS AT SINGAPORE, INCLUDING A NEW SPECIES AND A NEW RECORD

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***ABSTRACT*. –** Based on recent fieldwork, a checklist of four attached mushroom coral species (Fungiidae) is given with annotations on their abundance in Singapore waters. One species, *Podabacia motuporensis* Veron, 1990, is recorded as new to Singapore, so far the westernmost locality within its distribution range. Although specimens were observed and collected during earlier studies in Singapore, this species probably remained unnoticed due to its resemblance to *P. crustacea* (Pallas, 1766) and because it is not yet well-known. Another one, *Podabacia kunzmanni* new species, is new to science. Specimens of this species are usually very small. Therefore, they can easily be confused with other *Podabacia* species, but also with attached juvenile corals of the genus *Sandalolitha*. *Podabacia kunzmanni* was observed for the first time in 1995 on the heavily damaged reefs off Padang, West Sumatra, and later on (also in 1995) a reef off Jakarta. It is most remarkable that this new species is relatively small and appears to be most abundant on dead coral and on rubble, with little or no other coral cover around, especially on reefs under stress. Alive, the small corals stand out very clearly in contrast to their dead micro-habitat.

***KEY WORDS.* –** Fungiidae, *Podabacia*, *Lithophyllon*, Singapore; new species, new record.

INTRODUCTION

Mushroom corals are well known from Southeast Asian waters, because they are usually striking and abundantly present on coral reefs, including the shallow flats and slopes. Specimens of most species are free-living and therefore easy to collect and well represented in reference collections (Hoeksema, 1989; Koh & Chou, 1989). Due to this unattached mode of life, they are also easy to use in quantitative ecological studies (Koh, 1987; Claereboudt, 1988; Hoeksema & Moka, 1989, Hoeksema, 1990, 1991a, 2004; Littler et al., 1997; Goffredo & Chadwick-Furman, 2000, 2003; Gilmour 2002a, 2002b, 2004) and transplantation experiments (Hoeksema, 1988; Chadwick-Furman & Loya, 1992; Yamashiro & Nishira, 1995; De Voogd et al., 2005). However, juvenile corals of these species are still attached and remain in this anthocaulus stage until the skeleton partly dissolves at the stalk and breaks off, resulting in free-living mushroom corals in their anthocyathus stage (Hoeksema, 1989).

In contrast, specimens of a minority of the mushroom species remain in the anthocaulus stage during their life span because they have lost the ability to detach. Among most other attached stony corals, these particular mushroom corals are usually less conspicuous and they are also less numerous than their free-living relatives. Corals of some of these attached species consist of simple calices with a single mouth. They belong to the genus *Cantharellus* Hoeksema & Best, 1984, containing three species that are all absent in Southeast Asia (Hoeksema & Best, 1984; Hoeksema, 1989, 1993a). They may be confused with attached mushroom corals that show more than one mouth per calyx (Licuanan & Capili, 2004). Such misidentifications among mushroom corals are not uncommon because most species show much intra-specific variation (Hoeksema & Moka, 1989; Hoeksema, 1989, 1993b) and polystomatous corals also show a single mouth in their early anthocaulus stage (Hoeksema, 1989, 1991b, 1993a: Fig. 1d).

From Singapore and its vicinity, so far only two species of attached mushroom corals have been reported, namely *Lithophyllon undulatum* Rehberg, 1892, and *Podabacia crustacea* (Pallas, 1766) (Purchon, 1956; Searle, 1956; Hoeksema, 1989; Koh & Chou, 1989). As a result of the present study, two additional species are added, viz. *P. motuporensis* Veron, 1990, and *P. kunzmanni*, new species. It is remarkable that *Lithophyllon mokai* Hoeksema, 1989, is not represented on Singapore reefs, although it is abundantly present in the

Thousand Islands archipelago off Jakarta, which is relatively close to Singapore (Hoeksema, 1989, 1991a).

MATERIAL AND METHODS

The coastal waters around Singapore reefs appear to be characterized by strong tidal currents and poor visibility due to siltation (Chou, 1988; Chua & Chou, 1991; Hilton & Chou, 1999). The turbid water is partly due to dredging and land reclamation activities in the area, which were observed during the present study and also have been mentioned in earlier reports (Wong, 1985, 2000; Goh & Chou, 1992; Lim et al., 1994; Low & Chou, 1994; Hilton & Manning, 1995; Chou, 1996; Loh et al., 2006). This turbidity has much impact on the reef community zonation, since the poor light penetration has a limiting effect on reef coral cover, especially on the lower reef slopes (Chuang, 1977; Chou, 1988; Lane, 1991; Goh et al., 1994; Tun et al., 1994). For a detailed map of the research area, see Chou (1988, 1996) and Chou et al. (1994).

Research on the Singapore mushroom coral fauna was performed by use of SCUBA during a survey that was part of the 14th Marine Biology Workshop on the Marine Flora and Fauna of Singapore (25 March–2 April 2006). In addition, coral specimens were examined in the Zoological Reference Collection (ZRC) of the Raffles Museum of Biodiversity Research, National University of Singapore (23, 24 March 2006). Photographs in the field were made with the help of Sea & Sea DX3000 camera equipment. Material of the new species was collected off Padang, West Sumatra (25 April–4 May 1995; 8–17 December 1996). An additional specimen was collected from the Thousand Islands off Jakarta (18 April 1995). For *Podabacia kunzmanni*, new species, no collected specimens from Singapore were available for this study, but records are substantiated by photographic images. Newly collected material from Indonesian localities is deposited in the coelenterate collections at RMNH (National Museum of Natural History Naturalis, Leiden), MZB (Museum Zoologicum Bogoriense, Cibinong, Indonesia), and ZRC (Singapore).

SYSTEMATIC ACCOUNT

Most species already have been described extensively elsewhere: for references see short-listed synonymies.

Lithophyllon Rehberg, 1892

Lithophyllon – Hoeksema, 1989: 215, 216; Koh & Chou, 1989: 6; Veron, 2000: 306.

Type species. – *Lithophyllon undulatum* Rehberg, 1892.

Remarks. – This genus differs from *Podabacia*, the only other attached mushroom coral genus at Singapore, by lacking perforations in the corallum wall. Only *Lithophyllon undulatum* was recorded. The small and encrusting *L. mokai* Hoeksema, 1989, was absent. *L. ranjithi* Ditlev, 2003, which closely resembles *L. undulatum*, forms thick plates, has thickened primary septa, and has so far only been observed in northeastern Borneo, i.e. in Sabah (Ditlev, 2003) and East Kalimantan (Hoeksema et al., 2004). *Lithophyllon lobulata* (Van der Horst, 1921), which is considered a separate species by Veron (2000), is considered a synonym of *L. undulatum* by Hoeksema (1989).

Lithophyllon undulatum Rehberg, 1892
(Fig. 1a–d)

Lithophyllon undulatum – Hoeksema, 1989: 216–222, Figs. 35–36, 567–581, 509b, 664, 666–667; Veron, 1990a: 63; Hoeksema & Dai, 1991: 226, Figs. 88, 89; Hoeksema, 1993b: 14; Nishihira & Veron, 1995: 261; Veron, 2000: 308, 309.

Lithophyllon lobata – Nishihira & Veron, 1995: 262; Veron, 2000: 307.

Cantharellus noumeae – Licuanan & Capili, 2004: 286, Fig. 2.

Material examined. – Fourteen specimens from Singapore: Cyrene reefs (= Terumbu Pandan): ZRC.1987.1810; Terumbu Pempang Laut: ZRC.1991.769; Hantu Island (= Pulau Hantu): ZRC.1991.783, ZRC.1987.2133; Pillar Island: ZRC.1987.3630; Semakau Island (= Pulau Semakau): ZRC.1991.1730, ZRC.1991.1731; Raffles Lighthouse: ZRC.1991.714, ZRC.1991.715, ZRC.1991.716, ZRC.1991.773, ZRC.1991.774, ZRC.1991.780; Singapore (no further data): ZRC.1991.782.

Diagnosis. – The species differs from other attached mushroom corals by its solid corallum wall. It is polystomatous and grows large, overlapping foliaceous plates. Juveniles are cup–shaped and may still show a single mouth (monostomatous).

Distribution. – Singapore is near the westernmost distribution limit of the range of *L. undulatum*, which is in the Andaman Sea, western Indian Ocean (Hoeksema, 1989). The species has been reported before from Singapore (Koh & Chou, 1989). It has been recorded from reefs close to Singapore (Cyrene reefs) to more offshore (Raffles Lighthouse). It is common; during the survey in 2006 (Hoeksema & Koh, 2009), it has been recorded at 14 out of 18 reef sites.

Podabacia Milne Edwards & Haime, 1849

Podabacia – Hoeksema, 1989: 226; Koh & Chou, 1989: 6; Veron, 2000: 310.

Type species. – *Podabacia crustacea* (Pallas, 1766)

Remarks. – This genus differs from *Lithophyllon*, the only other attached mushroom coral genus at Singapore, by showing perforations in the corallum wall. Three species are recorded. One of these, *Podabacia crustacea* (Pallas, 1766), has been reported before from Singapore (Koh & Chou, 1989). *P. motuporensis* Veron, 1990, and *P. kunzmanni* new species, are new records for Singapore. *P. sinai* Veron, 2000, appears to be a Red Sea endemic with large corolla, small mouths, and coarse but regular septal dentations,

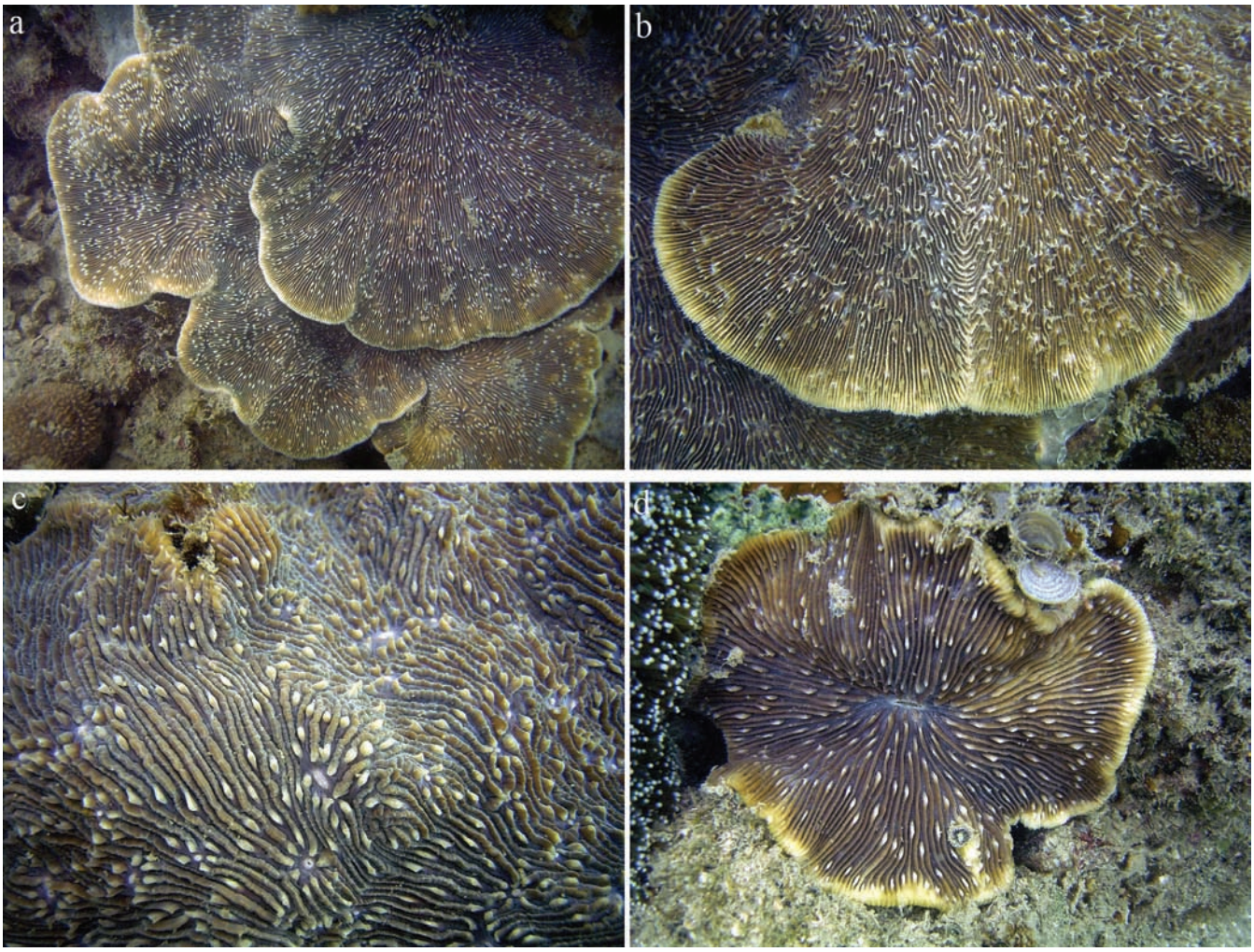

Fig. 1. Living specimens of *Lithophyllon undulatum* in Singapore: a, large coral (northeastern reef slope, Semakau Island, 31 Mar.2006); b, part of a large specimen (northern reef slope, Kusu Island, 30 Mar.2006); c, close-up of a large specimen (northern reef slope, St John's Island, 29 Mar.2006); d, close-up of a juvenile specimen (northern reef slope, Kusu Island, 30 Mar.2006); note the single mouth, which causes a similarity of juveniles of this species with corals of *Cantharellus noumeae* Hoeksema & Best, 1984, but the blue-greyish coloration of the mouth makes it distinct.

whereas *P. lankaensis* Veron, 2000, an endemic from Sri Lanka, is characterised by large, irregularly lobed corolla with fine, sharp septal dentations (Veron, 2000, 2002). The systematic position of these two species may need further investigation.

***Podabacia crustacea* (Pallas, 1766)**

(Fig. 2a–f)

Podabacia crustacea – Hoeksema, 1989: 226–231, Figs. 34, 590c, 596–609, 669–670; Veron, 1990a: 63; Hoeksema & Dai, 1991: 226, Figs. 92, 93; Hoeksema, 1993b: 14; Nishihira & Veron, 1995: 263; Veron, 2000: 310, 311.

Material examined. – Nine specimens from Singapore: Sentosa Island: ZRC.1980.3.20.101; Cyrene reefs (= Terumbu Pandan): ZRC.1991.770; Lazarus Island: ZRC.1991.775; Hantu Island (= Pulau Hantu): ZRC.1991.772, ZRC.1991.779; Semakau Island (= Pulau Semakau): ZRC.1987.1808; Raffles Lighthouse: ZRC.1991.767, ZRC.1991.768; Singapore (no further data): ZRC.1991.777.

Diagnosis. – *P. crustacea* differs from other *Podabacia* species by a combination of its large corallum size, medium–sized blunt, septal dentations, and by relatively evenly distributed and sized septa. It is polystomatous and grows large, overlapping foliaceous plates. Juveniles are cup-shaped and only in very small sizes show a single mouth (monostomatous), but this is rather theoretical since such small corals have not been reported.

Distribution. – Singapore is in the centre of the distribution range of *P. crustacea*, which is from the Red Sea to the central Pacific Ocean (Hoeksema, 1989). This is the only *Podabacia* species reported before from Singapore (Koh & Chou, 1989). It has been recorded from reefs close to Singapore (Cyrene reefs) to more offshore (Raffles Lighthouse). It is common; during the survey in 2006 (Hoeksema & Koh, 2009), it has been recorded at 15 out of 18 reef sites.

***Podabacia motuporensis* Veron, 1990**
(Fig. 3a–d)

Podabacia motuporensis Veron, 1990b: 128–130, Figs. 33, 34, 78; Hoeksema, 1993b: 14, 15, Fig. 18; Nishihira & Veron, 1995: 264; Veron, 2000: 312–313.

Material examined. – Ten specimens from Singapore: Terumbu Pempang Laut: ZRC.1991.776; Hantu Island (= Pulau Hantu): ZRC.1987.1805, ZRC.1987.1807, ZRC.1987.1809, ZRC.1987.2134; Sudong Island (= Pulau Sudong): ZRC.1980.3.20.102; Semakau Island (= Pulau Semakau): ZRC.1987.1806; Singapore (no further data): ZRC.1991.771, ZRC.1991.778, ZRC.1991.781.

Diagnosis. – *Podabacia motuporensis* differs from other *Podabacia* species by a combination of its large corallum size, small-sized, sharp, septal dentations, small mouths,

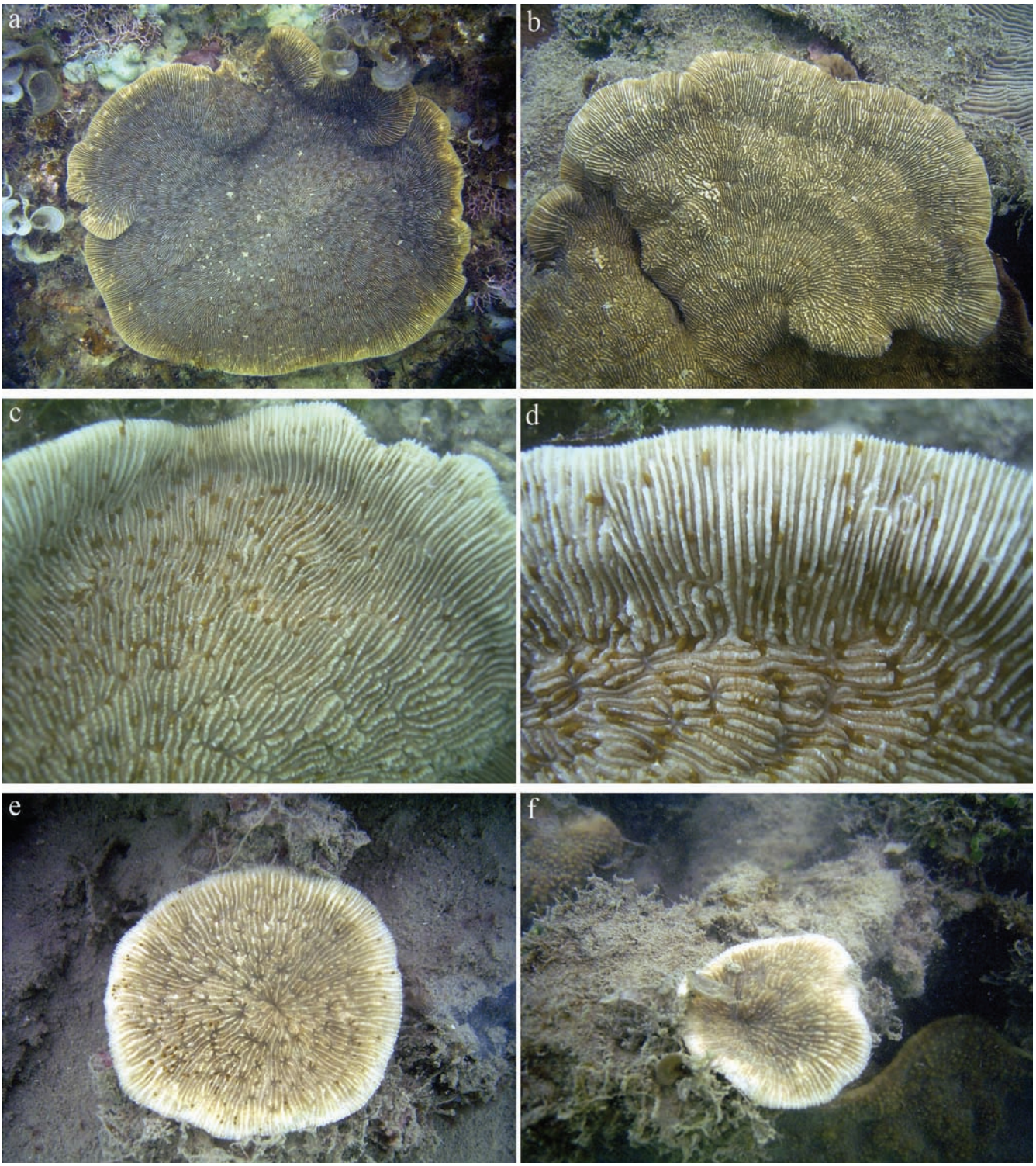

Fig. 2. Living specimens of *Podabacia crustacea* in Singapore: a, large coral (southwestern reef slope, St John's Island, 30 Mar.2006); b, part of a large coral (northern reef slope, Kusu Island, 30 Mar.2006); c, d, close-ups of a large specimen (Terumbu Semakau, 31 Mar.2006); e, f, juvenile specimens (western reef slope, Hantu Island, 2 Apr.2006).

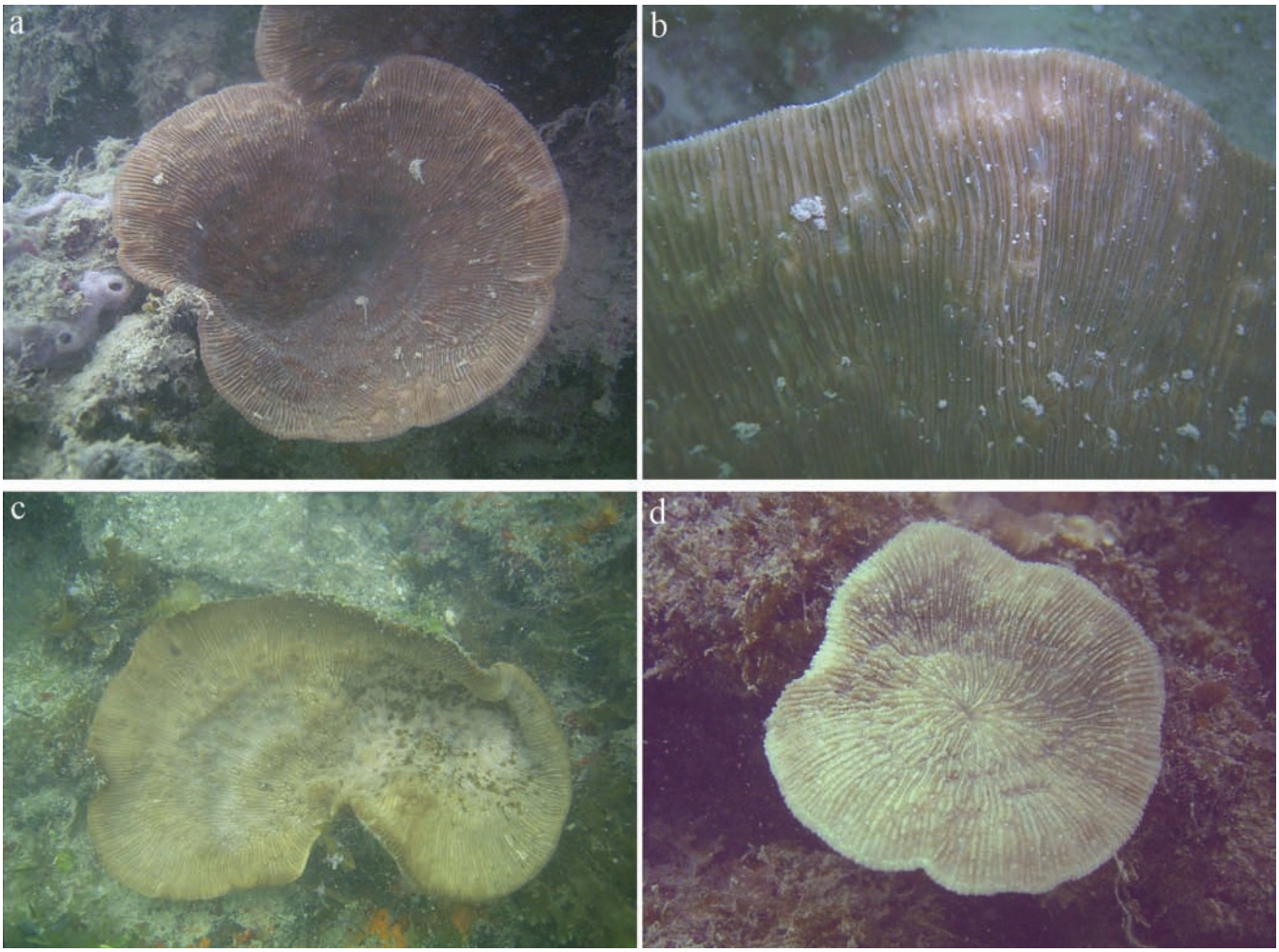

Fig. 3. Living specimens of *Podabacia motuporensis* in Singapore: a, medium-sized specimen (western reef slope, Hantu Island, 2 Apr.2006); b, close-up of a large coral (Terumbu Semakau, 31 Mar.2006); c, medium-sized specimen at Terumbu Semakau, 31 Mar.2006); d, small coral (northwestern reef slope, Subar Darat, 1 Apr.2006).

and by evenly distributed and sized septa. The small, distinct mouths (fossae), adjacent to only up to six thin septa are the most distinctive characters. It is polystomatous and grows large, overlapping foliaceous plates. Juveniles are cup-shaped and only in very small sizes show a single mouth (monostomatous), but this is rather theoretical since such small corals have not been reported.

Distribution. – Singapore is at the westernmost boundary of the distribution range of *P. motuporensis*, which extends eastward to Vanuatu in the Coral Sea and northward to southern Japan (Veron, 1990; Hoeksema, 1993). It has not been recorded from reefs close to Singapore (Cyrene reefs) and neither from more offshore reefs (Raffles Lighthouse). This is the first record from Singapore, although the species was already represented in the ZRC before but has not been recognized as such. It is not common, actually the rarest of the three *Podabacia* species at Singapore; during the survey in 2006 (Hoeksema & Koh, 2009), it has been recorded at five of 18 reef sites.

***Podabacia kunzmanni*, new species**
(Figs. 4a–h, 5a–c, 6a–d)

Material examined. – Indonesia, West Sumatra, off Padang, Sipakal Reef (= Gusung Sipakal, coll. 2 May 1995): holotype RMNH Coel. 23324; paratypes RMNH Coel. 23315, 23316, 23317, 23318, 23319, 23322, 23325, 23326; West Sumatra, off Padang, Sinyaru Island, eastern reef slope (= Pulau Sinyaru, coll. 27 Apr.1995), paratypes RMNH Coel. 23306, 23307; West Sumatra, off Padang, Pieh Island (= Pulau Pieh, coll. 29 Apr.1995), paratypes RMNH Coel. 23282, 23283 (2 specimens), 23284, 23285; West Sumatra, off Padang, Sauh Island (= Pulau Sauh, coll. 30 Apr.1995), paratype RMNH Coel. 23265; West Sumatra, off Padang, Air Island (= Pulau Air, coll. 30 Apr.1995), paratypes RMNH Coel. 23330 (39 specimens), MZB Cor. 070 (5 specimens), ZRC (5 specimens); West Sumatra, off Padang, Sipakal Reef (= Gusung Sipakal, coll. 2 May 1995), paratypes RMNH Coel. 23314, 23320, 23321, 23323; West Sumatra, off Padang, Gabuo Reef (= Gusung Gabuo, coll. 2 May 1995), paratypes RMNH Coel. 23333, 23334, 23335, 23336, 23337 (2 specimens); West Sumatra, off Padang, Ular Island (= Pulau Ular, coll. 16 Dec.1996), paratypes RMNH Coel. 31187 (7 specimens); Indonesia, NW Java, off Jakarta, Thousand Islands, northern reef slope of Panjang Island, 4 m depth (coll. 18 Sep.1995), RMNH Coel. 24176. Singapore, no material

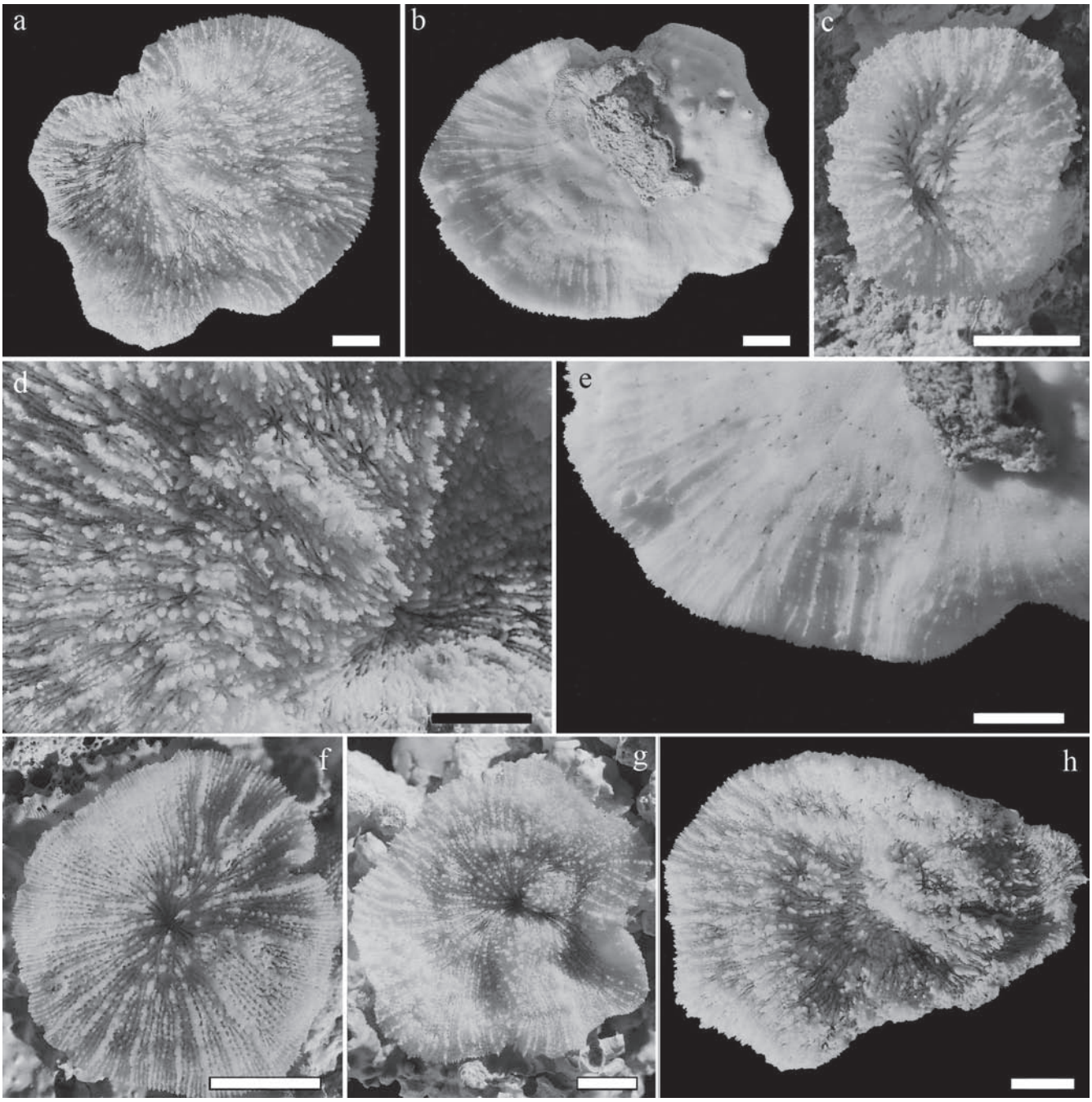

Fig. 4. Holotype and paratypes of *Podabacia kunzmanni*, new species, from the type locality, Gusung Sipakal, off Padang, West Sumatra, Indonesia (collection date 2 May 1995), and another specimen from north western Java, Indonesia: a, b, upper and lower surface of the holotype (RMNH Coel. 23324); c, Paratype RMNH Coel. 23322, upper surface, attached specimen from type locality; d, close-up of upper surface of the holotype (Fig. 4a) showing septal dentations, primary mouth and secondary mouths; e, close-up of lower surface of the holotype (Fig. 4b) showing costal spines and perforations in the corallum wall; f, paratype RMNH Coel. 23317, upper surface, attached specimen from type locality; g, RMNH Coel. 24176, upper surface, attached specimen from northern reef slope of Panjang Island, Thousand Islands, off Jakarta (coll. 18 Sep.1995); h, paratype RMNH Coel. 23317, upper surface, attached specimen from type loc. Scale bars = 1 cm.

available for further study. For maps of the West Sumatra reefs, see Kunzmann & Efendi (1996), Kunzmann (1997, 2002). For map of Thousand Island reefs, see Cleary et al. (2006).

Description. – The corals are polystomatous and attached to dead coral, usually loose rubble of fragmented branches. The diameter of the studied material ranges from 2.5 to 15 cm; most specimens are about 5–7 cm. Small specimens are encrusting or cup-shaped, only attached by a narrow base. Larger corals are small plates. The outline of the coral disc may be affected by dead coral obstructing growth along the coral edge.

There is a clear central fossa, the primary mouth, surrounded by numerous smaller mouths (stomata), which are more or less evenly distributed over the upper corallum surface. The

smaller mouths are usually surrounded by eight septa, two of which running alongside the mouth and six ending at the mouth. The six are actually three septa being interrupted when the secondary mouth was formed. Larger stomata are surrounded by additional septa. The columella is formed by a mingled mass of tightly packed and partly fused trabeculae and paliform lobes with their tips pointing upwards.

The septa are loosely arranged from the centre towards the periphery, and very unequal in height. Series of three thin and low septa are usually situated in between two thicker and higher septa of lower order. The septa of lower orders are solid; those of higher orders are perforate. Tentacular lobes are not present. The lower order septal margins are very coarsely ornamented by large (nearly conical) dentations (6–10 per cm); the higher order septa are finely dentated or slightly frayed. The septal sides are irregularly and coarsely granulated. The compound synapticulae, which connect the septa laterally, can easily be detected because of the loose septal arrangement.

The corallum wall is perforated by short, narrow slits. The costae are poorly developed. Only the primary costae may be slightly distinct and covered by small, irregulary distributed, finely granulated spines.

Diagnosis and affinities. – Corals of *Podabacia kunzmanni* are most distinguishable because of their small corallum size and irregular septa, which are variable in height, with the lower order septa coarsely ornamented. Other species grow much larger. Specimens of *P. crustacea*, *P. motuporensis* and *P. sinai* show septa that are more regularly shaped and more even in height. *P. lankensis* may be most similar to *P. kunzmanni*, but its lectotype is larger than *P. kunzmanni* corals, it shows septa that are more equal in size and costae that are much more distinct (Veron, 2000, 2002). The smallest corals may resemble attached juveniles (anthocauli) of the free-living mushroom coral *Sandalolitha dentata* Quelch, 1984, (not observed in Singapore and rare in West Sumatra), but these have a larger attachment area. Larger specimens of *P. kunzmanni* remain attached and cup-shaped and therefore do not look like *S. dentata* corals of similar size, which are dome-shaped and show a large detachment scar. Specimens of *Lithophyllon undulatum* have a solid corallum wall and also grow much larger than *P. kunzmanni* corals.

Distribution. – So far, *P. kunzmanni* is only known from Singapore and western Indonesia. No specimens are known from reefs close to Singapore (Cyrene reefs and Sentosa Island) since these were not examined in 2006, and neither from offshore reefs (Raffles Lighthouse), where they were not found. The species is not common; it has been recorded at seven out of 18 reef sites (Hoeksema & Koh, 2009).

Ecology. – Despite their coloration, varying from ocher to brown with a light brown periphery (Figs. 5, 6), which is in contrast with that of the dead substrata, the living animals are usually not easy to detect. In general they are small and may be hidden in between dead coral branches. Furthermore, they can easily be overlooked because of their resemblance with attached juveniles of *Sandalolitha dentata* (not observed in Singapore and rare in West Sumatra). Nevertheless, it is striking that they are most easily found on dead reefs. Two explanations can be given: (1) they are better survivors than corals of most other species and therefore conspicuous on otherwise nearly dead reefs or (2) they are better colonizers of dead coral substrata.

The species was especially abundant and outstanding on large areas of dead reef off West Sumatra. Here coral mortality since the early 1990s has been linked to various causes, such as disturbances induced by El Niño-Southern Oscillation (ENSO) events (Hoeksema & Cleary, 2004), but most certainly to sedimentation and destructive fisheries (Kunzmann & Efendi, 1996; Kunzmann, 1997, 2002). A single specimen (diameter 5 cm) has been reported from the Thousand Islands off Jakarta (see material examined), which was collected in 1995 by the author when the reefs here were also not in a good condition (Cleary et al., 2006). However, during a recent survey in this area, when the reefs were in better shape, the same observer did not find any specimen (Hoeksema, pers. obs.). The small corals may have become more difficult to detect on healthier reefs.

The reefs of Singapore are known to have been affected by sediment stress and various man-induced disturbances for decades (Hilton & Chou, 1999; Chou, 2006; Loh et al., 2006). This may have created an ideal habitat for corals of *P. kunzmanni*. The long-term absence of this species from scientific reports and the coral collection at ZRC is most probably not due to a recent invasion on newly available sediment-stressed habitats, but more likely because the species has been overlooked.

Etymology. – The species is named after Dr Andreas Kunzmann, who previously worked at Bung Hatta University, Pandang, West Sumatra, where he organized the field work, together with other university staff and students. At present he is employed by the Centre of Marine Tropical Ecology (ZMT) of Bremen University, Germany.

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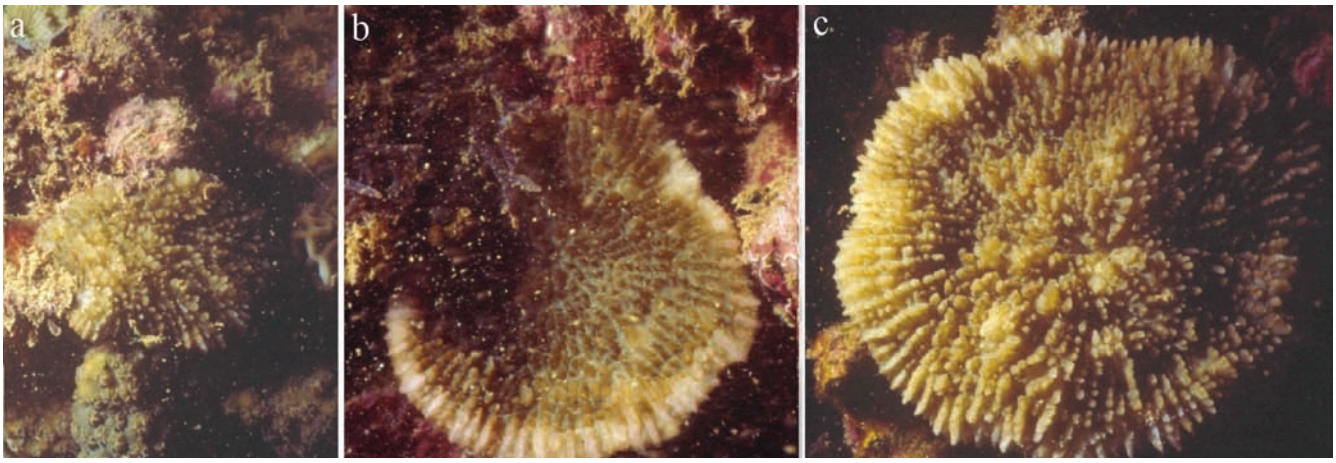

Fig. 5. Living specimens of *Podabacia kunzmanni*, new species, Pisang Island, off Padang, West Sumatra (13 Dec.1996).

Fig. 6. Living specimens of *Podabacia kunzmanni*, new species, in Singapore: a, b: medium-sized specimens (northwestern reef slope, Semaku Island, 27 Mar.2006); c, relatively large coral (southwestern reef slope, Lazarus Island, 29 Mar.2006); d, two adjacent small specimens (northeastern reef slope, Semakau Island, 31 Mar.2006).

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