New record of the stalked crinoid Saracrinus angulatus *(Echinodermata: Crinoidea: Isocrinida) from Andaman Sea, Northern Indian Ocean*

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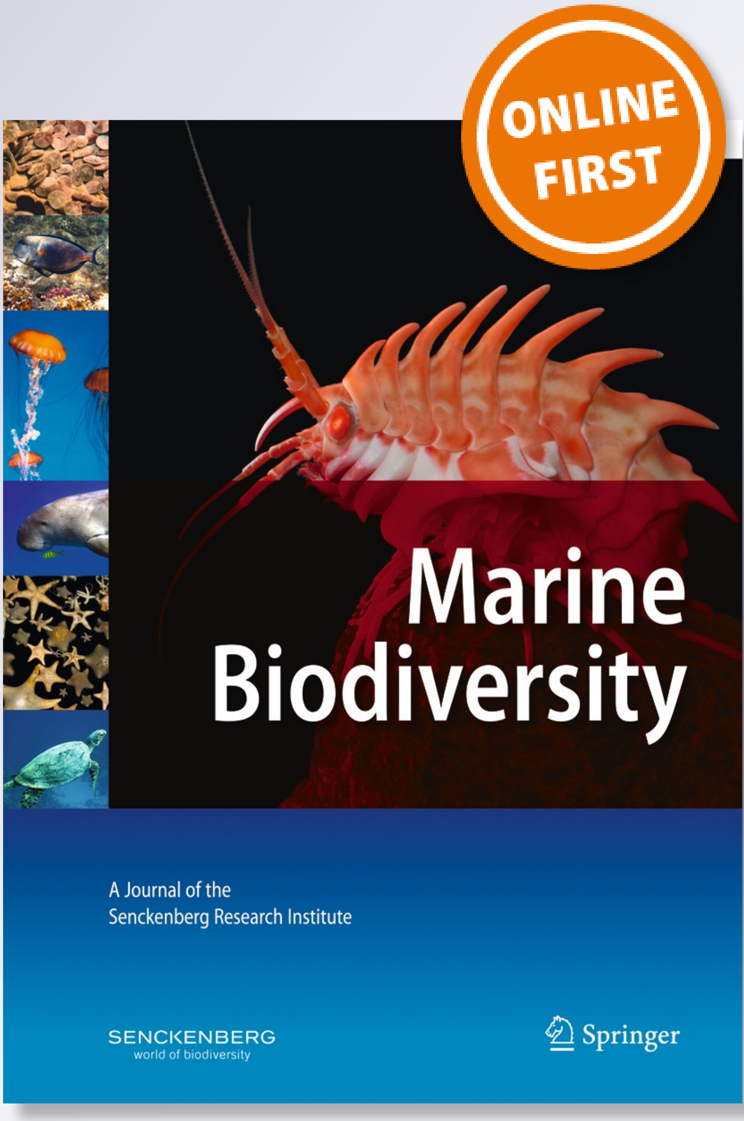

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ORIGINAL PAPER

New record of the stalked crinoid *Saracrinus angulatus* (Echinodermata: Crinoidea: Isocrinida) from Andaman Sea, Northern Indian Ocean

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Abstract This is the first record of the stalked crinoid *Saracrinus angulatus* (Carpenter, 1884), from the Andaman Sea, Northern Indian Ocean. The species is described based on a single specimen collected from a depth of 601–643 m by the Fishery Oceanographic Research Vessel *Sagar Sampada* (FORV SS). A general view of the specimen, with descriptions of morphological features, size parameters, arm branching and ossicle articulations, are provided. Stalk ossicles were examined using scanning electron microscopy (SEM).

Keywords Stalked crinoids · Andaman Sea · Northern Indian Ocean · *Saracrinus angulatus* · New record

Introduction

Twenty-seven species of living stalked crinoids belonging to six genera were described by Carpenter (1884) in his monograph based on the collections of the H.M.S. *Challenger* Expedition. About a century later, Améziane and Roux (1997) estimated the species diversity of extant stalked crinoids up to 95 species and Roux et al. (2002) listed 29 genera, these being completely absent in shallow waters and with a majority occurring at bathyal (<1000 m) rather than abyssal depths. As new taxa (any among isocrinids) were described during the last decade, about 118 species are now known in 37 genera (Roux, personal communication). Hess (2011) mentioned eight extant genera in the order Isocrinida. Améziane-Cominardi (1991) revised the genera *Metacrinus* and *Saracrinus* and retained seven species in the genus *Metacrinus* and four in the genus *Saracrinus*. Later, an additional species was described in the genus *Saracrinus*, *S. moosai* Améziane, 1997.

The highest diversity of stalked crinoid species in the world has been recorded from the western tropical Pacific Ocean (Améziane and Roux 1997). The genus *Teliocrinus* Döderlein, 1912 is the only extant genus restricted to the Northern Indian Ocean amongst the isocrinid (also referred to as pentacrinid) stalked crinoids (Roux et al. 2009). The type species for the genus *Teliocrinus*, *T. springeri* (Clark, 1909), was first described from north of the Laccadive Islands, Lakshadweep, India, from a depth of 1164 m. Within the Northern Indian Ocean, *Teliocrinus* is distributed in the Arabian Sea, Bay of Bengal, Andaman Sea and off the coast of Burma.

Among the other genera of isocrinid stalked crinoids, *Saracrinus* and *Metacrinus* are distinguished only by the number of primibrachials: mode at four in *Saracrinus* and at seven in *Metacrinus* (Roux 1981; Améziane-Cominardi 1991; Tunnicliffe et al. 2016). High variability and frequent morphological convergences corresponding to the ecophenotypes make it very difficult to determine the species under *Saracrinus* from external morphology alone (Améziane-Cominardi 1991). Améziane-Cominardi (1991) and Améziane (1997) reduced the number of recognised species within the genus *Saracrinus*, which had been interpreted as a consequence of ecophenotypic or geographical variations. The species *S. angulatus* (Carpenter, 1884) is extremely variable, as the stems and arms of this species exhibit intraspecific polymorphism (Améziane 1997). *Saracrinus angulatus* was previously reported only from the northwestern Pacific

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Ocean. The current study forms the first report of this species from the Andaman Sea, Northern Indian Ocean.

Materials and methods

A single specimen of *S. angulatus* was collected during the deep-sea fishery survey of the Fishery Oceanographic Research Vessel *Sagar Sampada* (FORV SS) conducted by the Centre for Marine Living Resources & Ecology (CMLRE) in the vicinity of Central Nicobar Islands along the Andaman Sea. The specimen was collected by a high opening trawl (HOT) operated at a speed of 2.8 knots during Cruise 334 Leg II at station no. 7A from depths between 601 and 643 m (Fig. 1). The specimen was preserved in 70% ethanol upon collection, assigned the voucher number IO/SS/ECD/00124 in the shore lab, subsequently transferred to fresh 70% ethanol and deposited with the CMLRE Referral Centre.

Following the original descriptions, illustrations (Carpenter 1884; Améziane-Cominardi 1991) and taxonomic keys (Roux et al. 2002; Eléaume et al. 2007), the specimen was identified as *S. angulatus*. Measurements were taken from the preserved specimen using a digital vernier caliper (for linear measurements ≥1 mm). For finer measurements of features that were difficult to make directly, a Leica DFC425 digital microscope camera mounted on a Leica S8APO microscope was used to take photographs, and the measurements were made using Leica LAS Image Analysis software. Skeletal ossicles were cleaned by digesting the tissues in an aqueous 10% solution of sodium hypochlorite, rinsed in cold distilled water and air dried. Cleaned ossicles were mounted on stubs, gold plated and photographed using the JSM-6390LA analytical scanning electron microscope at the Sophisticated Test & Instrumentation Centre (STIC), Kochi, India. The mode of description and nomenclature used follow Roux et al. (2002), Eléaume et al. (2007) and Tunnicliffe et al. (2016). The abbreviations used herein are as follows: Dp = stalk proximal diameter; Dd = stalk distal diameter; SL = stalk length; IN = number

Table 1 Morphological features of *Saracrinus angulatus* (Carpenter, 1884), from Andaman Sea, IO/SS/ECD/00124

Meristic data in numbers and metric data in mm	IO/SS/ECD/00124
Dp	6.1
Dd	4.3
IN	$8^{9}, 9^{5}$
NL	7.3
InL	1.2
NL	1.7
Po	11
CL	51
ArtC	49
c_1L	0.6
c_1W	1.4
C_LL	1.2
C_LW	1.6
Arms	>25
BW	2.3
BL	1.5
RW	3.5
RL	1.1
IBrax	4^{5}
IIBrax	$7^{8}, 8^{1}, 11^{1}$
IIIBrax	$9^{1}, 11^{4}, 13^{5},14^{1}, 17^{1},21^{1}$
IVBrax	$13^{1}, 14^{2}, 15^{1}, 16^{1}, 19^{5}, 20^{1}$
IBrW	4.6
IIBrW	3.2
IIIBrW	2.6
P_1L	9.9
$ArtP_1$	13
$1P_1L$	1.1
$1P_1W$	1.7

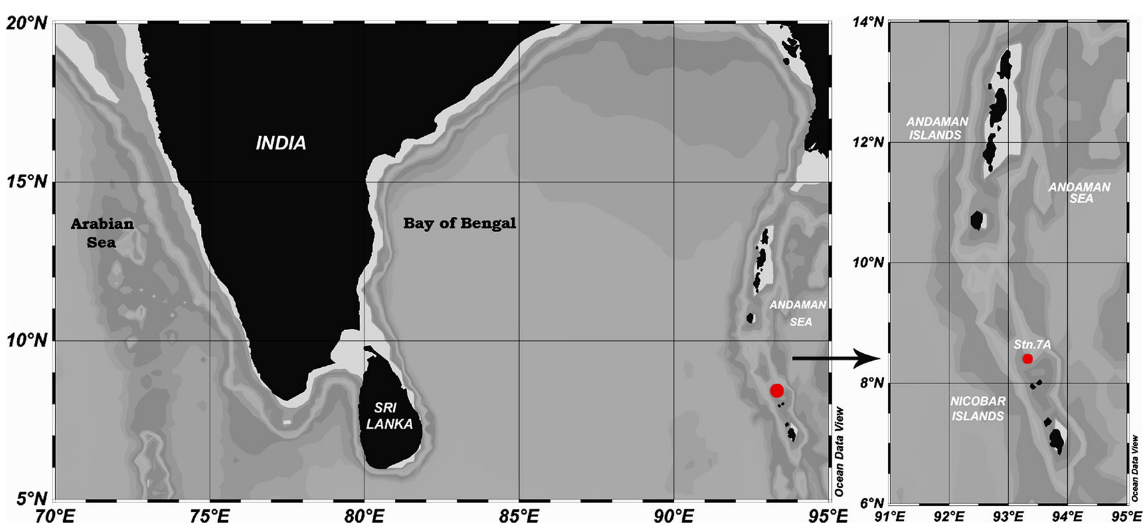

Fig. 1 Map of Andaman & Nicobar Islands showing the collection location (*red dots*) of *Saracrinus angulatus* (Carpenter, 1884)

Fig. 2 *Saracrinus angulatus* (Carpenter, 1884), collected from Andaman Sea, IO/SS/ECD/00124 (general view)

of internodals per internode; NL = noditaxis length; InL = internodal length; nL = nodal length; Po = number of proximal internodes with articular pores; CL = cirrus length; ArtC = number of cirrals per cirrus; c_1L = first cirral length; c_1W = first cirral width; C_LL = longest cirral length; C_LW = longest cirral width; Arms = number of arms; BW = basal width; BL = basal length; RW = radial width; RL = radial length; AL = arm length; IBrax = axil position on first brachitaxis; IIBrax = axil position on second brachitaxis; IIIBrax = axil position on third brachitaxis; IVBrax = axil position on fourth brachitaxis; Ibr_1W = first brachial of first brachitaxis width; Ibr_2L = second brachial of first brachitaxis length; $IIbr_1W$ = first brachial of second brachitaxis width; $IIbr_2L$ = second brachial of second brachitaxis length; $IIIbr_1W$ = first brachial of third brachitaxis width; $IIIbr_2L$ = second brachial of third brachitaxis length; P_1L = first pinnule length; $ArtP_1$ = number of pinnulars along first pinnule; lP_1L = first pinnular of first pinnule length; lP_1W = first pinnular of first pinnule width. Details of all measurements are given in Table 1. As studies on molecular phylogeny reveal the need for a deep reappraisal of the extant crinoid classification (Roux et al. 2013), we follow the practical classification proposed by Tunnicliffe et al. (2016).

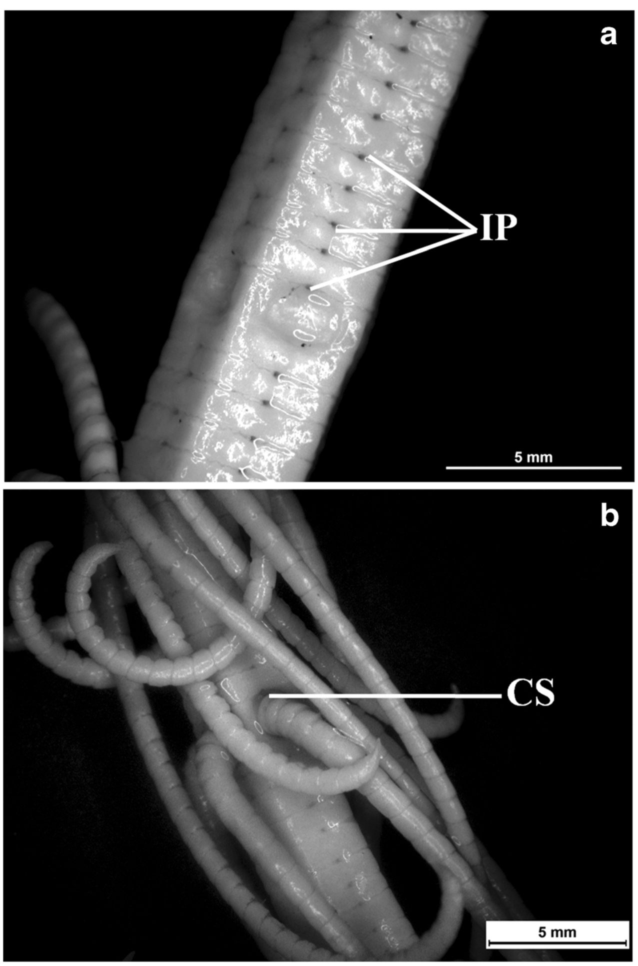

Fig. 3 *Saracrinus angulatus* (Carpenter, 1884): **a** general view of nodals and internodals, *IP* interarticular pores; **b** general view of cirri, *CS* cirrus sockets

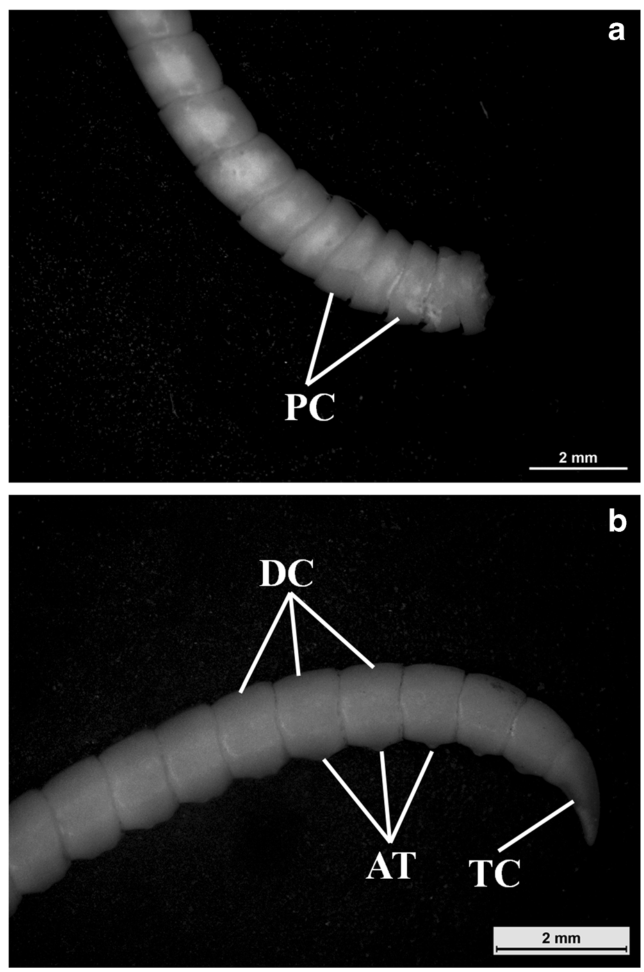

Fig. 4 *Saracrinus angulatus* (Carpenter, 1884): **a** proximal portion of cirrus, *PC* proximal cirrals; **b** distal portion of cirrus, *DC* distal cirrals, *AT* aboral tubercles, *TC* terminal claw

Systematics

Class Crinoidea Miller, 1821
Order Isocrinida Sieverts-Doreck, 1952
Family Isocrinidae Gislén, 1924
Subfamily Metacrininae Klikushin, 1977
Genus *Saracrinus* AH Clark, 1923
***Saracrinus angulatus* (Carpenter, 1884)**
(Fig. 2)

Metacrinus angulatus Carpenter, 1884: 344; Clark, 1908: 671; Roux, 1977: 45.
Metacrinus tuberosus Carpenter, 1884: 369.
Metacrinus cingulatus Carpenter, 1884: 347.
Metacrinus acutus Döderlein, 1907: 35.
Metacrinus suluensis Döderlein, 1907: 47.
Metacrinus batheri Clark, 1909: 85.
Saracrinus acutus Clark, 1923: 9.
Saracrinus angulatus Clark, 1923: 9; Roux, 1981: 484; Bourseau & Roux, 1989: 117; Améziane, 1997: 631.

Material examined

FORV Referral Centre, IO/SS/ECD/00124, FORV *Sagar Sampada* Cruise 334 Leg II, Station 7A; Central Nicobar Islands, 8° 23.352′N 93° 20.534′E, 601–643 m; coll. 29 January 2015, high opening trawl (HOT), one specimen, sandy bottom.

Description

Stalk stout, pale yellow to straw coloured in fresh specimen, with crowded cirri; total stalk length around 18 cm; crown robust with more than 25 arms; arm length around 9–12 cm. Arm branching isotomous; pinnule length progressively decreasing distally. The arm tips are moderately long and lack pinnules (Fig. 2).

Proximal diameter (Dp) 6.1 mm, stellate in outline. Interarticular pores reach 10–11 internodes (Fig. 3a). Some internodals possess strong horizontal ridges,

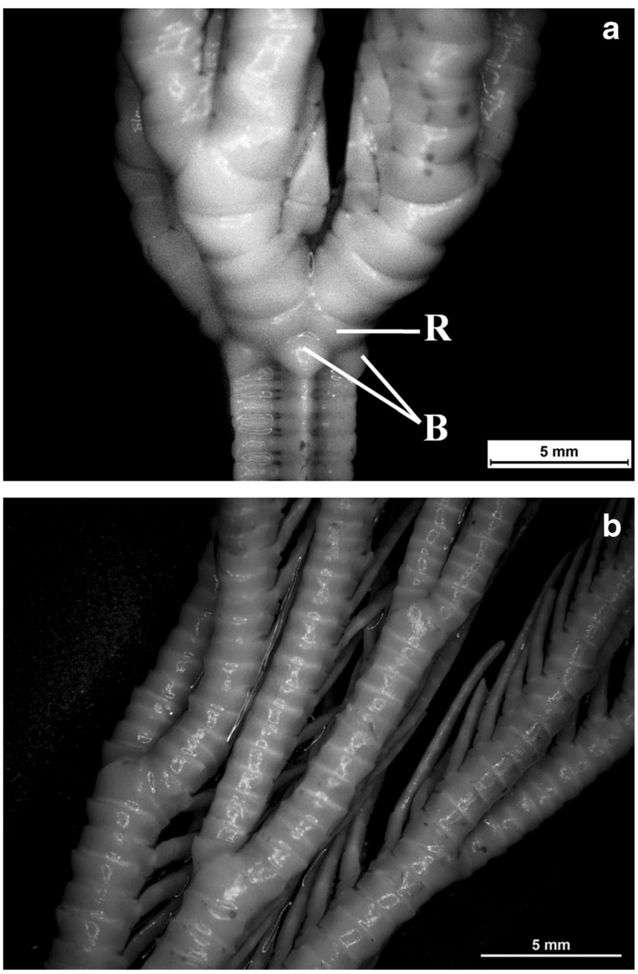

Fig. 5 *Saracrinus angulatus* (Carpenter, 1884): **a** general view of crown, *B* basals, *R* radial; **b** general view of arms showing branching pattern

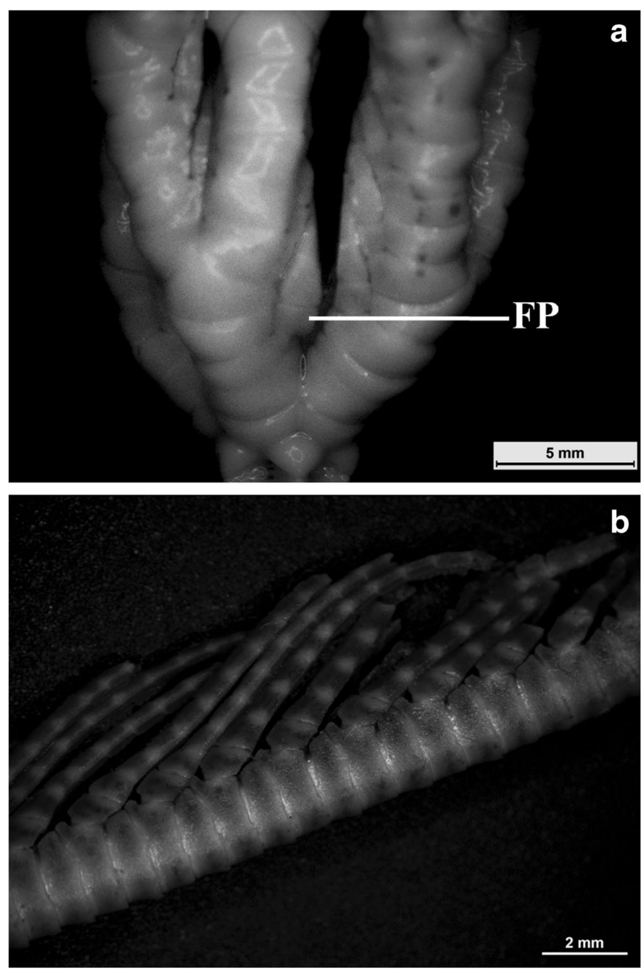

Fig. 6 *Saracrinus angulatus* (Carpenter, 1884): **a** general view of crown, *FP* first pinnule; **b** general view of pinnules

whereas the nodals are more markedly star shaped in outline than internodals and without horizontal ridges. Cirrus sockets are oval (Fig. 3b). Cirri with 42–51 stout cirrals; c_1L shorter than wide; c_9 to c_{13} longest; following cirrals gradually shorter. Distal cirrals sometimes with small aboral tubercles (Fig. 4a). Terminal claw small (Fig. 4b).

Basals distinctly quadrilateral; radials rectangular (Fig. 5a). The basals are united into a complete ring, prominent on the calyx exterior and extending downwards over the proximal columnals. Arms more than 25; rarely more than three divisions per ray; rays in close apposition (Fig. 5b). Brachitaxes usually IBr4ax (1 + 2), IIBr7ax (3 + 4 or sometimes 2 + 3), IIIBr13ax (3 + 4) and IVBr19ax (3 + 4). IBr4ax pentagonal.

P_1 usually arising on Ibr2, sometimes on Ibr3 (Fig. 6a), of up to 13–15 short pinnulars, 13–14 mm long, often much stouter than following pinnules. Basal pinnular much broader than succeeding pinnulars (Fig. 6b). Beyond the secondary axillary, pinnule length gradually decreasing; middle pinnules of 16–19 segments.

Stalk articulations

Symplexies with small interpetaloid furrows (Fig. 7a, b). Petaloid areolas distinctly lanceolate and surrounded by a closed crenularium (Fig. 8b). 11–13 crenulae per petaloid area. Synostoses (Fig. 9a) with interpetaloid furrows. Petaloid areas lanceolate. Axial canal pentagonal (Fig. 9b).

Distribution

Saracrinus angulatus is a robust species previously known from the northwestern Pacific Ocean (Fig. 10), from Japan to northwestern Australia, including Taiwan, Timor and Indonesia, at depths from 169 to 632 m (Améziane-Cominardi 1991; Eléaume et al. 2007; Tunnicliffe et al.

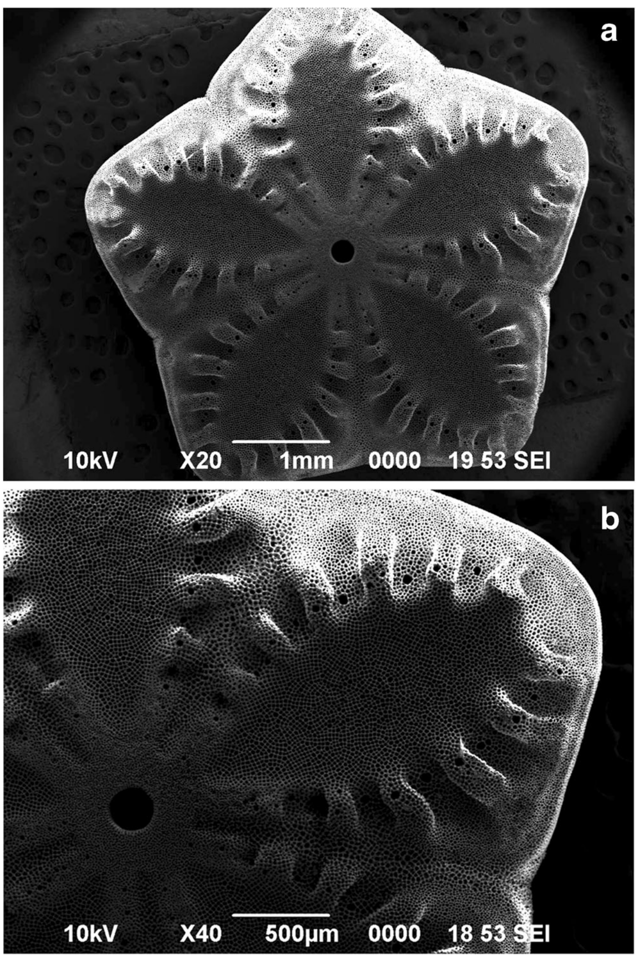

Fig. 7 *Saracrinus angulatus* (Carpenter, 1884): **a** SEM, symplexy of internodal, *10 kV* accelerating potential, *X20* magnification, *0000* counter, *19* working distance, *53* spot size, *SEI* secondary electron image; **b** SEM, closer view of the petaloid area, *10 kV* accelerating potential, *X40* magnification, *0000* counter, *18* working distance, *53* spot size, *SEI* secondary electron image

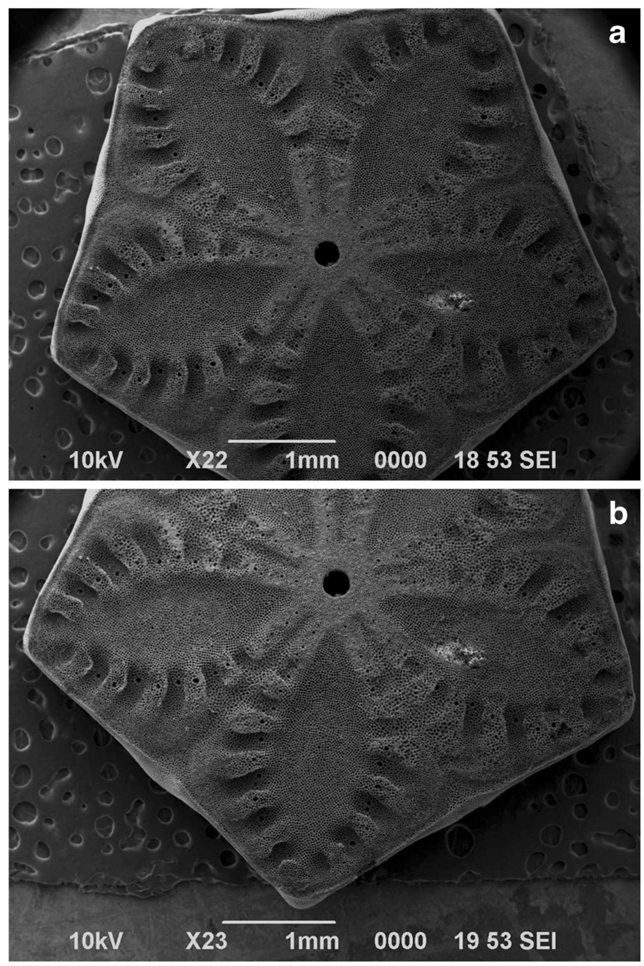

Fig. 8 *Saracrinus angulatus* (Carpenter, 1884): **a** SEM, symplexy of another internodal, *10 kV* accelerating potential, *X22* magnification, *0000* counter, *18* working distance, *53* spot size, *SEI* secondary electron image; **b** SEM, closer view of the petaloid areolas, *10 kV* accelerating potential, *X23* magnification, *0000* counter, *19* working distance, *53* spot size, *SEI* secondary electron image

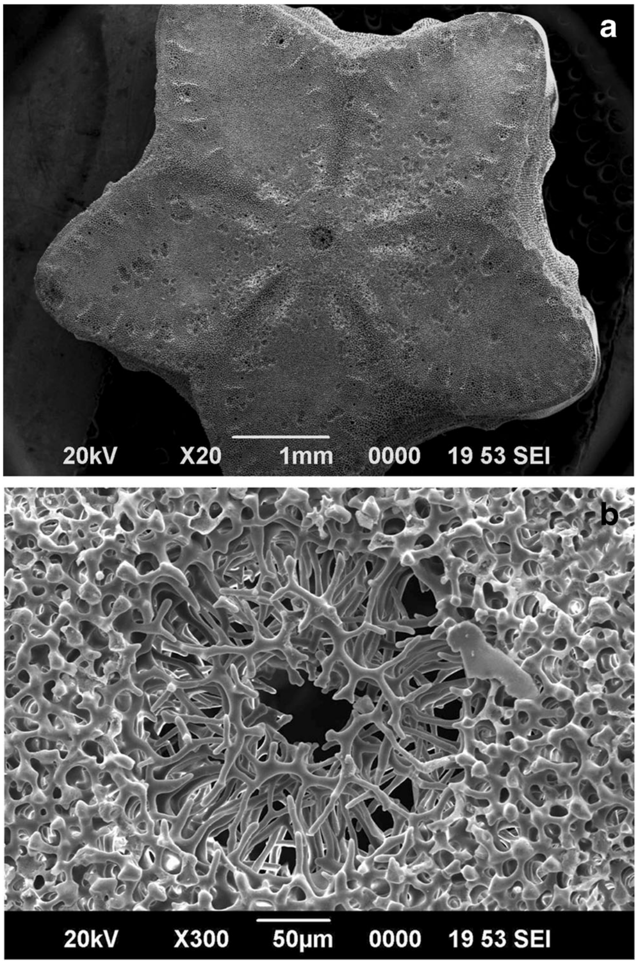

Fig. 9 *Saracrinus angulatus* (Carpenter, 1884): **a** SEM, synostosis of nodal, *20 kV* accelerating potential, *X20* magnification, *0000* counter, *19* working distance, *53* spot size, *SEI* secondary electron image; **b** SEM, detail of axial canal, *20 kV* accelerating potential, *X300* magnification, *0000* counter, *19* working distance, *53* spot size, *SEI* secondary electron image

2016). The current study is the first report of the species from the Andaman Sea, which extends its distribution to the Northern Indian Ocean. Table 2 gives a bibliography of the world distribution of *S. angulatus*, with sampling locations and other available details. *Saracrinus angulatus* has never been collected from the southwestern Pacific. The species is highly variable (Améziane 1997; Eléaume et al. 2007). An analysis of six discontinuous variables from 96 specimens of *S. angulatus* among six different localities, namely Japan, Taiwan, Philippines, Kei Islands, Timor and Australia, showed that the number of arms increases along a latitudinal north–south line (Eléaume et al. 2007). The Taiwan specimens have their second and fourth (but not third) brachitaxes composed of a greater number of brachials, and specimens from Japan have a greater number of internodals per noditaxis and a reduced interarticular pore area.

Discussion

Oji (1990) observed the disappearance of *Teliocrinus*, *Isocrinus* and *Isselicrinus* from the western Pacific, and the introduction of *Metacrinus* and *Saracrinus* into this area during the late Early Miocene and Recent. Thus, the isocrinid fauna of the Pacific clearly differs from that of the Indian Ocean, with *Metacrinus* and *Saracrinus* in the Pacific and *Teliocrinus* in the Indian Ocean (Oji 1990). As a possible explanation, Oji (1990) considered the north-westward movement of oceanic plates and a collision of a part of Gondwana (Australia/New Guinea) with Eurasia, which probably brought *Metacrinus* and *Saracrinus* to the western Pacific region, and created a barrier separating the deep-water isocrinid fauna into two provinces.

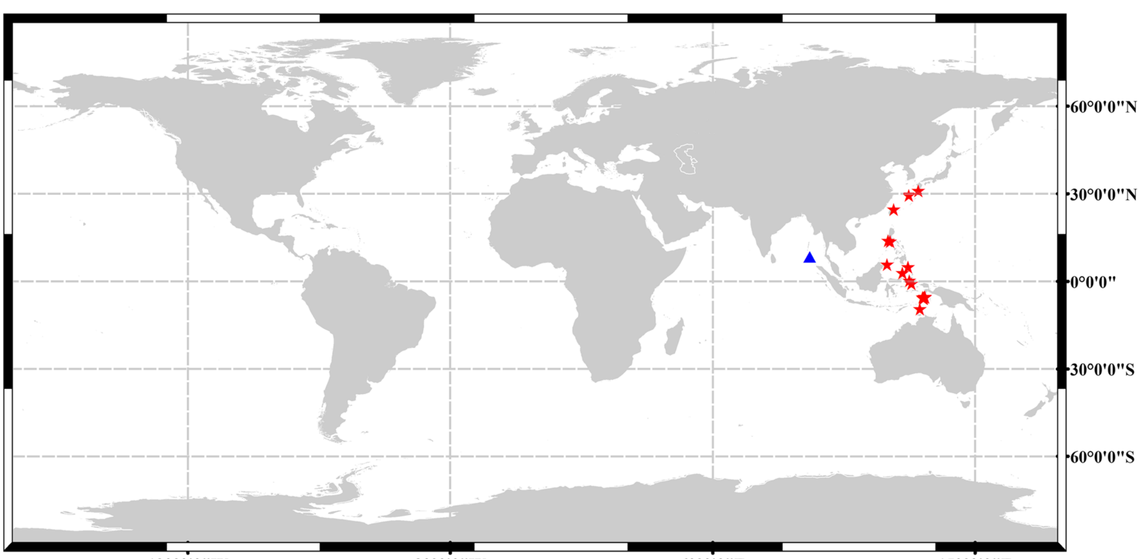

Fig. 10 Worldwide distribution of *Saracrinus angulatus* (Carpenter, 1884). The *red stars* indicate previous records of *S. angulatus*, based on all known material (a single symbol may represent more than one capture). The *blue triangle* indicates the present study location

Table 2 Distributional records of *Saracrinus angulatus* (Carpenter, 1884), with sampling locations and other available details

Type	Author	Expedition/research vessel (RV)	Date of collection	Depth (m)	Station	Locality	Latitude (°N/S)	Longitude (°W/E)	Sampling gear	Nature of bottom	Number of samples
Metacrinus angulatus	Carpenter (1884)	H.M.S. Challenger, 1873–76	26-09-1874	256	192	Arafura Sea, South Pacific Ocean	5° 49′S	132° 14′E	Dredge	Blue mud	7 plus
M. tuberosus	"	"	26-09-1874	256	192	"	5° 49′S	132° 14′E	Dredge	Blue mud	A stem fragment
M. cingulatus	"	"	26-09-1874	256	192	"	5° 49′ S	132° 14′E	Dredge	Blue mud	2
Saracrinus acutus	Clark, A. H.	Albatross/Northwestern Pacific Expedition	16-08-1906	188–278	4934	Off Kagoshima Bay, North Pacific Ocean	30° 58′N	130° 35′E	Trawl, Agassiz beam	–	1
S. acutus	"	"	16-08-1906	188–278	4934	"	30° 58′N	130° 35′E	Trawl, Agassiz beam	–	6
M. acutus	Döderlein (1907)	Siboga Expedition, 1899–1900	12-08-1899	204	251	Kei Insein	5° 28.4′S	132° 0.2′E	Dredge	Hard coral sand	2
M. acutus	"	"	–	304	253	"	5° 48.2′S	132° 13.0′E	Dredge	On grey tone	10
M. acutus	"	"	–	310	254	"	5° 40.0′S	132° 26.0′E	Dredge	On fine, grey mud	7
M. suluensis	"	"	–	564	97	Sulu Archipelago, Pacific Ocean	5° 48.7′N	119° 49.60′E	Dredge	On coarse, coralline sand	1
S. acutus	Clark, A. H.	Albatross/Northwestern Pacific Expedition	–	329	–	–	13° 34′N	121° 07′E	–	–	1
S. acutus	"	"	16-07-1908	214	5275	Verde Island Passage, North Pacific Ocean	13° 55′N	120° 10′E	Trawl, Agassiz beam	–	1
S. angulatus	"	"	–	545	–	–	0° 15′N	127° 24′E	–	–	1
M. angulatus	Clark (1908)	–	–	–	–	Eastern sea near Kagoshima	–	–	–	–	–
M. batheri	Clark (1909)	–	–	292.6	–	Malay Archipelago	–	–	–	–	–
S. acutus	Clark, A. H.	Albatross/Philippines Expedition	02-12-1909	375	5629	Halmahera Island, Pacific Ocean	0° 49′ 60′S	128° 12′E	Trawl, Agassiz beam	–	5
S. angulatus	"	"	29-11-1909	498	5623	Halmahera Island, Pacific Ocean	0° 16′N	127° 30′E	Trawl, Agassiz beam	–	1
S. angulatus	Bourseau and Roux (1989)	MUSORSTOM 2	–	204–230	31	Philippines	13° 40.5′N	120° 53.7′E	–	–	5
S. angulatus	"	"	–	192–220	32	"	13° 40.5′N	120° 53.9′E	–	–	2
S. angulatus	Améziane-Cominardi (1991)	MUSORSTOM/BIOCAL/-BIOGEOCAL/CALSU-B/SMIB III	–	295	–	–	9° 53′S	120° 534′ E	–	–	2
S. angulatus	"	"	–	426	–	–	17° 18′S	119° 04′E	–	–	1
S. angulatus	"	"	–	405	–	–	17° 28′S	118° 53′E	–	–	7
S. angulatus	Améziane (1997)	KARUBAR Cruise	22-10-1991	296–299	CP 05	Off Kai Islands, Western Pacific Ocean	5° 49.0′S	132° 18′E	–	–	26
S. angulatus	"	"	22-10-1991	298–287	CP 06	"	5° 49.0′S	132° 21′E	–	–	1
S. angulatus	"	"	24-10-1991	417–425	DW 13	"	5° 26.0′S	132° 38′E	–	–	1
S. angulatus	"	"	24-10-1991	315–249	CP 16	"	5° 17.0′S	132° 50′E	–	–	27
S. angulatus	"	"	26-10-1991	336–346	CP 25	"	5° 30.0′S	132° 52′E	–	–	6
S. angulatus	"	"	04-11-1991	219–215	CP 82	Off Tanimbar Islands, Pacific Ocean	9° 32.0′S	131° 02′E	–	–	2
S. angulatus	Lane et al. (2000)	–	–	192–230	–	South China Sea, Pacific Ocean	–	–	–	–	–

Table 2 (continued)

Type	Author	Expedition/research vessel (RV)	Date of collection	Depth (m)	Station	Locality	Latitude (°N/S)	Longitude (°W/E)	Sampling gear	Nature of bottom	Number of samples
S. angulatus	Kogo and Fujita (2005)	*Yoko-Maru*, 1997	27-09-1997	169	250 (T-13)	East China Sea, Japan	29° 25.8′N	127° 18′E	Otter trawl	–	1
S. angulatus	Eléaume et al. (2007)	TAIWAN 2000 Cruise/Fishery Researcher I	04-08-2000	221	CP 58	Taiwan, Pacific Ocean	24° 35.1′N	122° 05.8′E	Dredge	–	13
S. angulatus	Tunnicliffe et al. (2016)	INDEX-SATAL 2010 expedition (Indonesia Exploration of the Sangihe Talaud Region)/Okeanos Explorer	–	632–537	III-01	Mid Sangihe Arc, Indonesia	2° 50.87′N	125° 03.93′E	ROV imagery	–	6
S. angulatus	"	"	–	311–280	III-10	Talaud Ridge, Zona Senja, Indonesia	4° 53.47′N	127° 0.90′E	ROV imagery	–	6
S. angulatus	Present study	Cruise 334 Leg II/FORV *Sagar Sampada*	29-01-2015	601–643	7A	Andaman Sea, Indian Ocean	8° 23.352′ N	93° 20.534′E	High opening trawl (HOT)	Sandy	1

Several investigations have emphasised the close affinity between the Indian and Pacific Ocean faunas. Many different groups of marine organisms, with distributions spanning much of the tropical Indo-Western Pacific region, have been reported from the Northern Indian Ocean (Ekman 1953; Stöhr et al. 2012; Chippy et al. 2016; Sumod et al. 2016). Their broad ranges are apparently due to the large-scale interchange of water between the Pacific and Indian Oceans through the Indonesian Archipelago. In addition, cold-water species exhibit continuous ranges between the two oceans south of Australia (Wyrtki 1973). Tunnicliffe et al. (2016) suggested that, even though the complex channels and basins of the Indonesian seas still present a biogeographic barrier between the Pacific and Indian Oceans, a tropical Indo-Western Pacific distribution of stalked crinoids could be expected. They also suggested that a distribution restricted to the north-west or south-west Pacific cannot be used to argue an origin from Eurasian or Gondwanan tethyan margins and that a widespread distribution in the western Pacific (from the south to the north) could be due to relatively recent dispersal with respect to geological times, especially for metacrinins. The present study establishes the distribution of the stalked crinoids in the Northern Indian Ocean, as suggested by Tunnicliffe et al. (2016). Even though systematic benthic surveys using grab and dredge at depths of 50–200 m (~150 sites) and deep-sea surveys using bottom trawls up to 850-m depths (~10 sites) have been carried out all around the Andaman and Nicobar Islands, *S. angulatus* was collected for the first time around the Central Nicobar Islands. This can be an indication that *S. angulatus* has extended its geographical range recently.

The specimen of *S. angulatus* was collected from a sandy bottom composed of biogenic sand (Geological Survey of India, unpublished). Previous reports of the species from blue mud, hard coralline sand, grey mud and coarse coralline sand (Table 2) suggest the preference of the species for a variety of substrata. Near-bottom (630-m depth) mean temperature, mean salinity and mean dissolved oxygen of the sampling location were 8.74 ± 0.0124 °C, 34.96 ± 0.0002 ppt and 0.76 ± 0.0022 ml/L, respectively. Glass sponges, sea pens, bivalves and gastropods were also collected in the bottom trawl.

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