RAFFLES BULLETIN OF ZOOLOGY **68**: 662–669
Date of publication: 27 July 2020
DOI: 10.26107/RBZ-2020-0081
http://zoobank.org/urn:lsid:zoobank.org:pub:3EA4D5E1-8F01-4D60-BBD0-B6146884F4A7

Two new species of sea star (Asteroidea, Echinodermata) from mesopelagic depths in the Sunda Strait, Indonesia

David J.W. Lane[1*] & Indra B. Vimono[2]

Abstract. A joint Indonesia-Singapore Deep Sea Expedition (SJADES 2018) focusing on the benthic fauna of the little sampled, western region of the Indonesian Archipelago has resulted in an extensive collection of sea stars (Asteroidea). Of these, two new species, an astropectinid and pterasterid, are herein described from mesopelagic depths in the Sunda Strait.

Key words. deep-sea, Indian Ocean, Sunda Strait, Krakatau, Indonesia, Echinodermata, Asteroidea

INTRODUCTION

A number of oceanographic/biological deep-sea expeditions have included or focused on seas of the Indonesian Archipelago, both in earlier colonial times [e.g., Challenger (1872–1875); Siboga (1899–1900); Albatross (final cruise: 1909–1910); Snellius (1929–1930)] and subsequently, following Indonesian political independence [e.g., Corindon IV (1981); Snellius-II (1984–1985); Karubar (1991)]. However, Indonesian deep-sea benthic habitats and fauna of the Indian Ocean, particularly in the western part of the Archipelago, have hardly been investigated or reported previously. The two new sea star taxa reported here come from an extensive collection of sea stars obtained during a South Java Deep Sea Expedition (SJADES 2018) representing the first joint Indonesia-Singapore Expedition exploring the biological deep-sea resources in Indonesian waters. A full listing of the sea star taxa encountered is currently in preparation separately (Vimono & Lane, in prep.).

MATERIAL AND METHODS

The SJADES 2018 expedition was undertaken from 23 March to 5 April 2018 on the Indonesian Research Centre for Oceanography research vessel, RV BARUNA JAYU VIII. A total of 53 stations were sampled by beam trawl or dredge along a cruise track from the Sunda Strait into the Indian Ocean off southwest Java as far as Cilacap. Sampling was undertaken in the Sunda Strait (Fig. 1) and on the slopes of the Java Trench to a maximum depth of 1,800 metres. Trawled or dredged sea stars were preserved in 70% ethanol after photography of representative living examples on board the vessel using a Nikon D800 DSLR camera with a 60 mm macro lens and speedlight SU-800 flash system. Subsequent photography of dried specimens was undertaken using a Canon M mirrorless camera with an EF-M 22 mm lens, and microscope photos were taken using a Samsung Galaxy S4 cameraphone attached to the eyepiece of an Olympus SZH10 stereomicroscope. X-ray images were taken using a Faxitron LX-60 digital radiography system with the initial intention of establishing the location of gonads but this was later determined by dissection. The sea star collection was divided into two representative sets, one being deposited in the Zoological Reference Collection (ZRC) of the Lee Kong Chian Natural History Museum (LKCNHM), National University of Singapore, the other in the Reference Collection of the Research Centre for Oceanography (RCO) of the Indonesian Institute of Sciences (LIPI), Jakarta, Indonesia.

TAXONOMY

Order Paxillosida

Family Astropectinidae Gray, 1840

Dipsacaster Alcock, 1893

Dipsacaster fisheri, new species
(Figs. 3–5)

Material examined. One wet specimen, R:r = 58:26 mm (ZRC.ECH.1301), designated as the holotype and one small dry specimen (presumed immature), R:r = 27:13 mm (ZRC. ECH.1599), deposited in the Zoological Reference Collection of the LKCNHM. Two wet specimens (paratypes), R:r =

Accepted by: James Reimer

[1]Lee Kong Chian Natural History Museum, Faculty of Science, National University of Singapore, 2 Conservatory Drive, Singapore 117377; Email: david_jwlane@hotmail.com (*corresponding author)

[2]Research Centre for Oceanography, Indonesian Institute of Sciences (LIPI), Jl. Pasir Putih 1, Ancol Timor, Jakarta Utara 14430, Indonesia

ISSN 2345-7600 (electronic) | ISSN 0217-2445 (print)

Fig. 1. The Sunda Strait between the islands of Java and Sumatera (Sumatra). Inset shows the location of the Strait within the Indonesian Archipelago. This map indicates the proximity of sites CP07 (at which *Dipsacaster fisheri*, new species, was found) and DW16 (at which *Pteraster sjadesensis*, new species, was found) to the 1883 VEI 6 eruption series and remnant of Krakatau. Scale bar = 20 km.

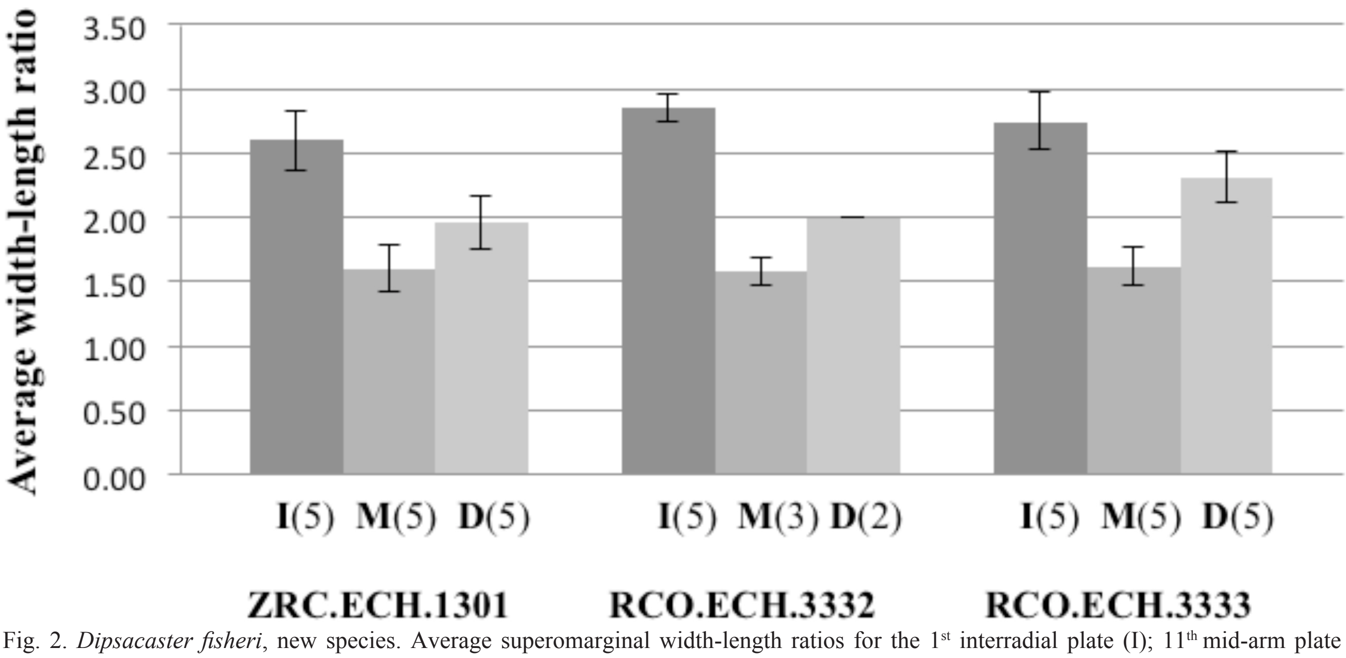

Fig. 2. *Dipsacaster fisheri*, new species. Average superomarginal width-length ratios for the 1st interradial plate (I); 11th mid-arm plate (M); and distal 18th or 19th plate (D) in the holotype (ZRC.ECH.1301) and two paratypes (RCO.ECH.3332 & RCO.ECH.3333). n values in parentheses.

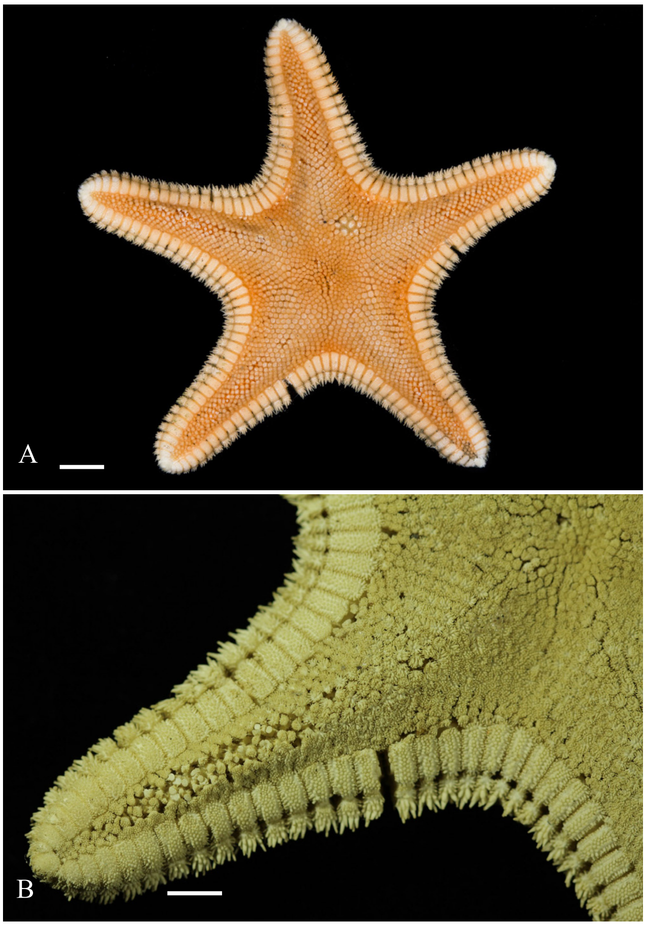

Fig. 3. *Dipsacaster fisheri*, new species, holotype. A, abactinal view of whole specimen (live); B, abactinal view of arm (specimen ethanol preserved and dried). Scale bars: A = 10 mm; B = 5 mm.

61:25.3 mm (RCO.ECH.3333) and R:r = 52.8:22.9 mm (RCO.ECH.3332), deposited in Reference Collection of the Research Centre for Oceanography. Stn. CP07, Sunda Strait between Tabuan Island and Sumatra (Fig. 1), S05°44.797′ E104°51.606′ (mid-point of beam trawl), 25 March 2018, depth = 379–409 m. Substrate: coarse sand, gravel, rubble, and wood.

Description. Stellate 5-rayed sea star with short tapering arms that are obovate apically, i.e., rounded distally with a blunt extremity. Interbrachial arcs rounded. Paxillated abactinal area extends all the way to the arm tips and is slightly inflated along the radial axes. Abactinal paxillae arranged in obliquely transverse chevrons on the arms, the series transitioning on the disc to an interradial alignment; towards the disc centre the paxillae tend to diminish in size and are less regularly arranged; the largest paxillae occur on the madreporite, located interradially, slightly closer to the inferomarginals than the disc centre. Paxillae are columnar, widening very slightly from the base to an apical end that bears a dense crown of spinelets, a central group of 5–12 larger ones being surrounded by numerous small spinelets.

Broad superomarginal plates (SMPs), numbering 20–21 (only 15 in the small immature specimen) from interradius to arm tip, form a distinct border to the paxillose abactinal area (Fig. 3A, B). SMPs are wider than long but shape and width-length ratio varies with position along the arm. Interradial superomarginals are slightly trapezoid but distally along the arm the shape transitions to oblong. In the larger, mature specimens, width-length ratio approaches 3:1 interradially, decreasing to slightly more than 1.5:1 for the mid part of the arm then, distally, the ratio increases again, approximating 2:1 at plate 17 or 18 before declining towards the arm tip. Changes in plate dimension ratios for the 3 mature specimens are indicated in Fig. 2. The broadening of distal superomarginals results in a slight curvature to the taper of the paxillose margin terminally. Then, towards the arm tip, a rapid decrease in superomarginal width, together with a decrease in the extent to which inferomarginals protrude, creates a curved, obovate or leaf-like margin of the arm terminally (Fig. 3A, B). Superomarginal plate surfaces are studded with short, cylindrical, round-ended granules (Fig. 5A).

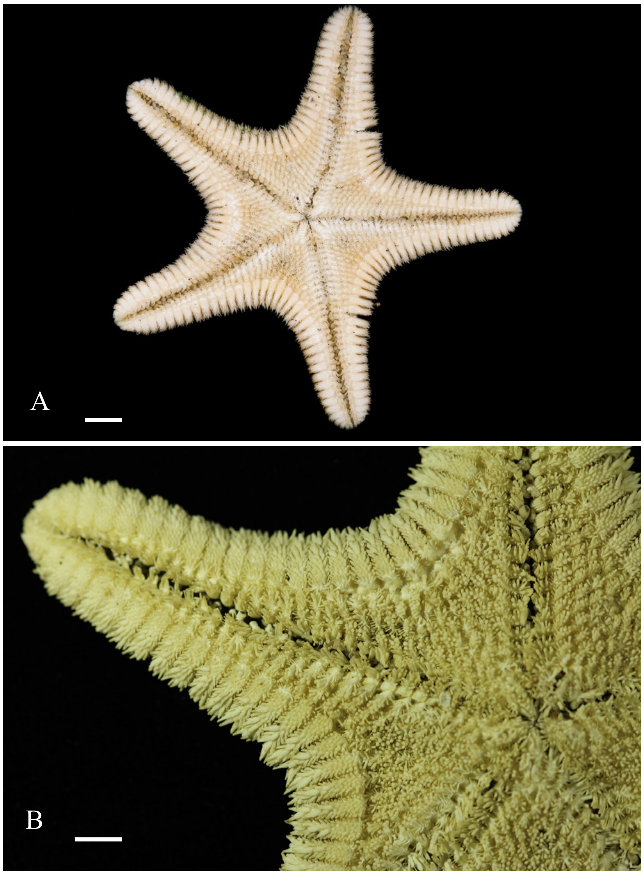

Fig. 4. *Dipsacaster fisheri*, new species, holotype. A, actinal view of whole specimen (live); B, actinal view of arm (specimen ethanol preserved and dried). Scale bars: A = 10 mm; B = 5 mm.

Inferomarginal plates are broader than the superomarginals and define the edge of the disc, their lateral margins projecting beyond the superomarginal edge by about half the width of the latter for much of the arm, except near the tip (Fig. 3A, B). The outer extension of each inferomarginal is narrower than length of the main part of the plate (Fig. 5C, D) and is a continuation of a narrow transverse ridge on the actinal side. Ridge spinelets are short, cylindrical, and flat-topped, becoming more rounded and slightly appressed peripherally, then transitioning to progressively longer, pointed, laterally

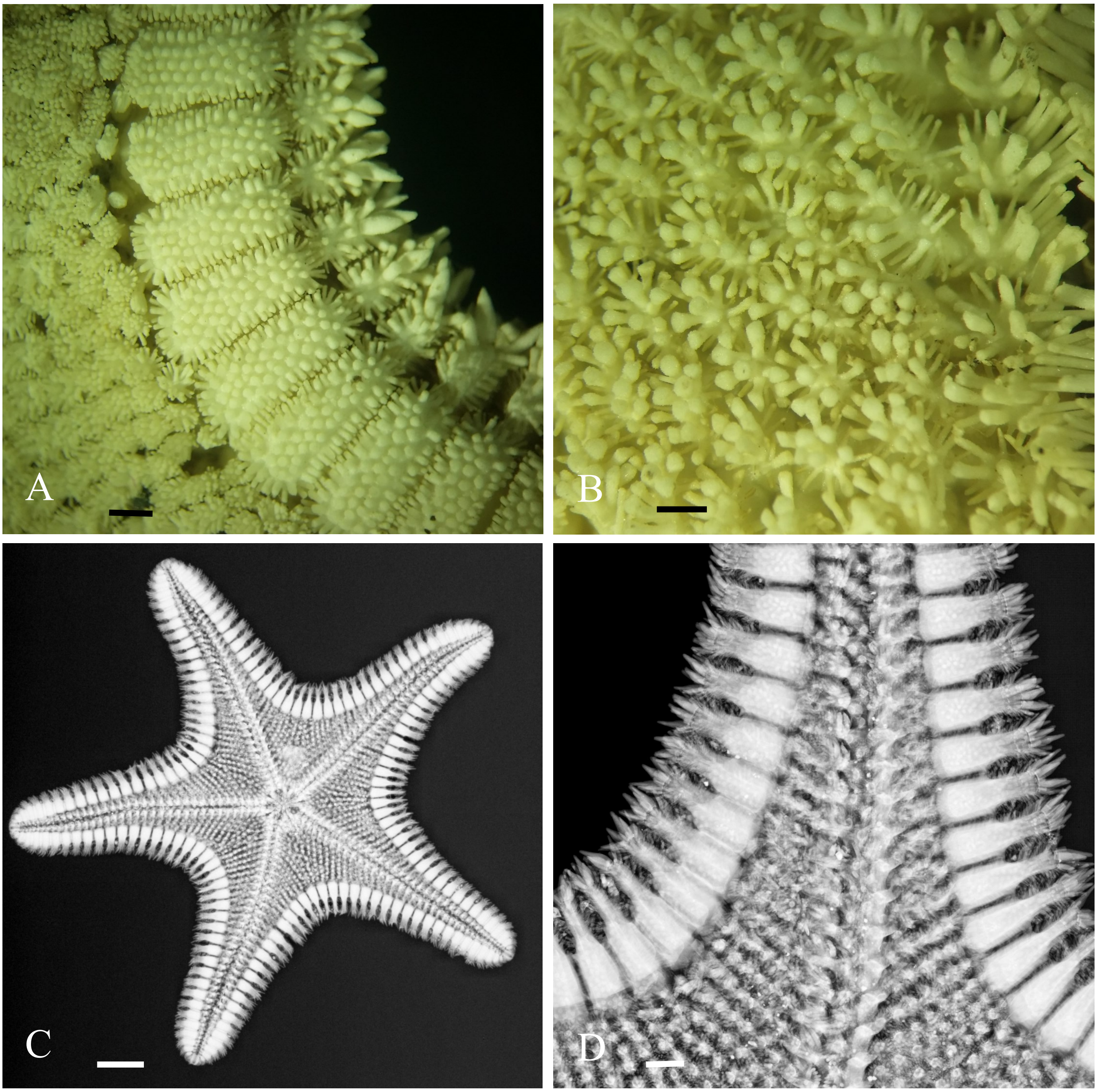

Fig. 5. *Dipsacaster fisheri*, new species, holotype (specimen ethanol preserved and dried). A, interradial superomarginal plates bordering paxillose abactinal area and fringed by protruding spinose extensions of inferomarginal plates; B, actinal plates bearing clavate (club-shaped) spines and finer spinules. The ambulacral groove with its furrow spines is aligned across the top right hand corner; C, X-ray negative radiograph of whole specimen; D, X-ray negative radiograph of arm base; inferomarginal plate extensions bearing the laterally projecting spines become narrower than the plates themselves, particularly interradially. Scale bars: A = 2 mm; B = 1 mm; C = 10 mm; D = 2 mm.

projecting spines up to ca. 2 mm in length (Figs. 4B, 5A). Opposing inferomarginal faces are densely covered with narrow fasciolar spinules. Actinal plate spine clusters comprise short, clavate, flat-topped spines with small spinules around and below them (Figs. 4B, 5B). Furrow spines number from 6 to 9 in a comb-row backed by other small adambulacral spines plus one or two that are longer and more robust than the comb row series. Mouth-plate spines number 4–5. Tube feet pointed. No pedicellariae. Gonads extend into the arms. Colour in life: abactinal paxillar area orange; marginal plates and underside paler (Figs. 3A, 4A).

Etymology. This new species is named in honour of Walter K. Fisher for his very extensive contribution to knowledge of sea star biodiversity, particularly for deep-sea material, and in recognition of the fact that in the earlier part of the last century he described a high proportion of the species in this genus.

Distribution. *Dipsacaster fisheri*, new species, was found at just a single location, namely at the Indian Ocean end of the Sunda Strait within a mesopelagic depth zone that is characteristic for most members of the genus (Table 1). This site was one of 41 mesopelagic stations sampled in the

Table 1. Character data and queries for species in the genus *Dipsacaster* Alcock, 1893b. Taxonomic authorities for the species are: [1]Fisher, 1910a; [2]Halpern, 1968; [3]Fisher, 1913; [4]Fisher, 1905; [5]Macan, 1938; [6]Goto, 1914; [7]Fisher, 1917; [8](H.L. Clark, 1916); [9]Fisher, 1906; [10]Alcock, 1893a; [11](Döderlein, 1902); [12]Hayashi, 1973; [13]Alcock, 1893b; [14]A.M. Clark, 1952. Y = yes; N = no; ? = unreported. Sources of data for the existing 16 described taxa include: the original authoritative description, additional literature and image sources cited in the World Asteroidea Database http://www.marinespecies.org/asteroidea/aphia.php?p=taxlist (accessed 23 October 2019), and other literature sources cited in a published Asteroidea index (A.M. Clark, 1989).

Character / **Taxon**	*D. anoplus*[1]	*D. antillensis*[2]	*D. borealis*[1]	*D. diaphorus*[3]	*D. eximius*[4]	*D. farquharsoni*[5]	*D. grandissimus*[6]	*D. imperialis*[7]	*D. laetmophilus*[1]	*D. magnificus*[8]	*D. nesiotes*[9]	*D. pentagonalis*[10]	*D. pretiosus*[11]	*D. sagaminus*[12]	*D. sladeni*[13]	*D. sladeni capensis*[14]	*D. fisheri*, new species
R:r ratio	2	2.4–2.7	2.3	3.1	2.3	2.7	2.3	2.9	2.6	3.1	3.1–3.3	2.5	2.3–2.9	2.3	3–3.3	2.6–3	2.2–2.4
Arm taper: curved distally	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	Y
Number of SMPs	17	18–23	34	23	32–34	30	28–30	38–40	35	46–47	33	16–17	23–28	17	33–34	35–42	20–21
Proximal SMPs wider than long	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Distal SMP width-length ratio increases	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y
IMPs define margin	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Spines at IMP edge	N	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	N	Y	Y	Y
SMPs & IMPs in register for entire ray	Y	Y	Y	Y	Y	Y	N	N	Y	Y	N	Y	N	Y	Y	N	Y
Abactinal arm paxillae in chevrons	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Paxillae smaller on central disc	Y	N	Y	Y	N	Y	N	Y	N	N	N	Y	Y	Y	N	N	Y
Squamose spinelets on IMPs	N	N	Y	Y	N	Y	N	Y	Y	N	Y	?	Y	N	N	?	N
Clavate spinelets on actinal plates	N	Y	N	N	Y	Y	N	N	Y	N	N	?	N	N	N	?	Y
Number of furrow spines	5–6	6–8	4–6	8–9	5–6	9–10	7–9	7–9	7	8	7–8	5	4–7	6	8	ca. 7	6–8
Number of oral plate spines	8–10	7–10	8–9	8–9	7–9	13	10–12	10	7–9	?	9–10	?	ca. 7	ca. 8	?	?	4–5
Gonads extend into arms	Y	Y	Y	Y	Y	?	?	?	?	?	Y	?	?	Y	?	?	Y
Known geographic range	Bering Sea to California	Bahamas, Caribbean	British Columbia to Bering Sea	Sulu Sea, Philippines	California	Maldives	Misaki, Japan	Mindoro, Philippines	Alaska	Australia & New Zealand	Hawaii & Molluca Is.	Andaman Sea	Japan & Taiwan	Sagami Bay, Japan	Andaman Sea	Cape Town, S. Africa	Sunda Strait, Indonesia
Depth range (m)	220–2,200	824–897	221–642	701–1,472	377–960	229	640	40–866	1,270	100–979	517–603	200–205	20–480	90–95	460	110–630	379–409

Sunda Strait and nearby Indian Ocean, so this new species is presumably quite rare. However, the range of the species probably extends beyond the Strait into the Indian Ocean mesopelagic realm, a supposition supported by the region's recent volcanic history. The location recorded for *D. fisheri* is just 75 km from the 1883 eruptions of Krakatau (see Fig. 1) the largest of which, at an estimated Volcanic Eruption Index of 6, represents one of the most violent volcanic eruptions in recorded history (Siebert et al., 2011). The scientific consensus is that all life within a 15 km radius of this eruption was extirpated (Simkin & Fiske, 1983), including marine life that would have been impacted by submarine pyroclastic flow deposition (Mandeville et al., 1996). Furthermore, subaerial pyroclastic flows extended over the sea for distances up to 80 km and at the periphery resulted in the deposition (on land) of several tens of centimetres of tephra material (Carey et al., 1996). If, as is likely, seabed sedimentation of pyroclastic and ash material adversely impacted the benthos tens of kilometres distant from the eruption, then the present benthic fauna within the Sunda Strait, including *D. fisheri*, may represent re-colonisation from outside the Strait within the last 130 plus years.

Remarks. Several key features—namely: inferomarginal plates projecting beyond superomarginals, spinose edge to inferomarginal series, abactinal arm paxillae aligned in chevrons and gonads extending into the arms—clearly mark this specimen as belonging to the genus *Dipsacaster* (Table 1). Other distinctive characteristics necessitate designation of the present specimens as a new member of the genus (*Dipsacaster fisheri*, new species). Unlike other members of the genus where the superomarginal width gradually decreases peripherally for the entire arm, the width, and more specifically the width to length ratio, in mature *D. fisheri* initially decreases but then increases peripherally before declining again at the arm apex. This produces a curvature in arm taper similar to the distal arm profiles of *D. borealis* Fisher, 1910a and *D. eximius* Fisher, 1905. However, the

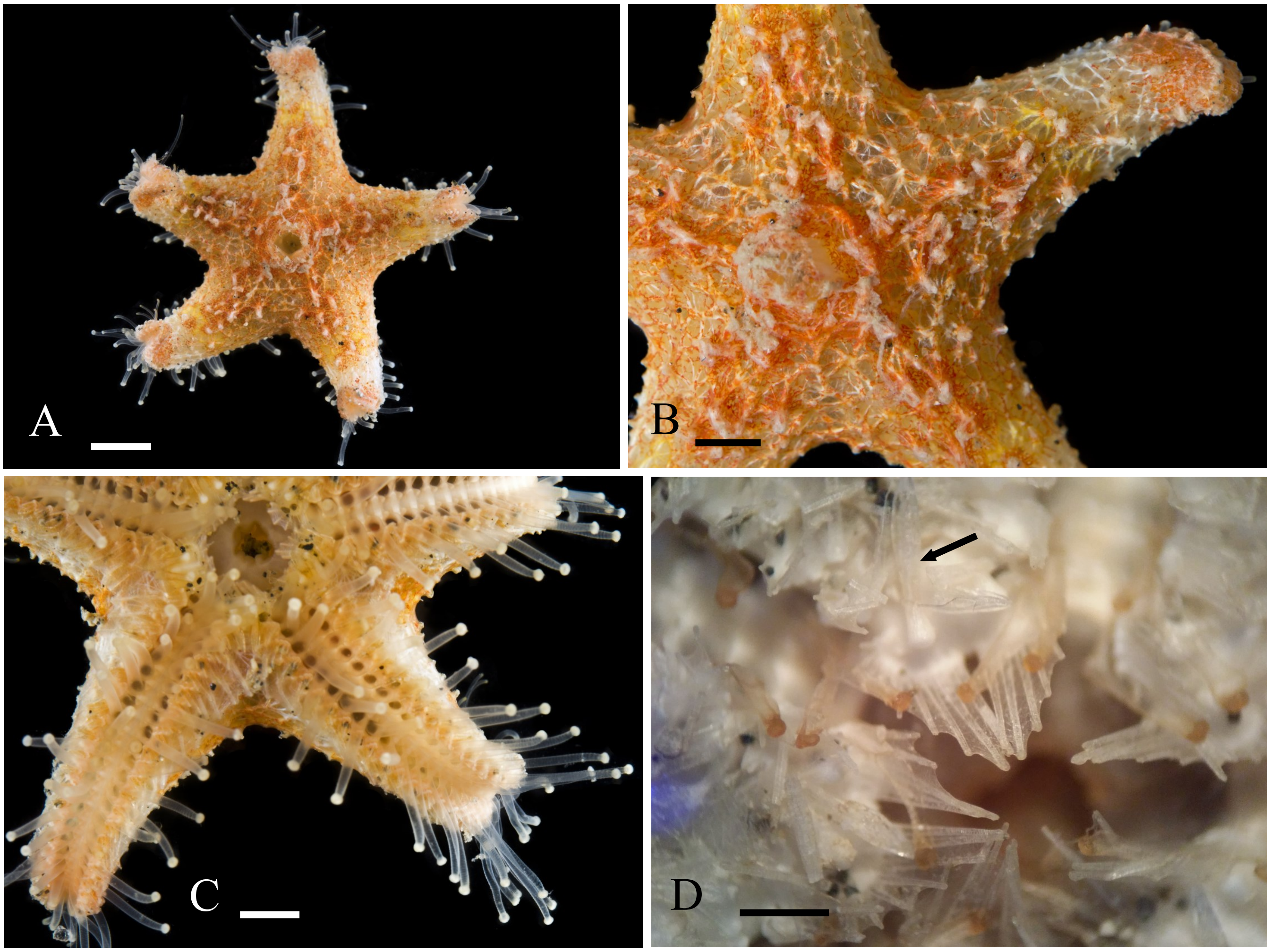

Fig. 6. *Pteraster sjadesensis*, new species, holotype. A, abactinal view (live), osculum is open; B, abactinal view of arm and disc (live), osculum closed; C, actinal view (live), open ambulacra reveal biserial tube feet rows; D, oral region (specimen alcohol preserved and dried) showing oral spine webbing that is independent for each oral plate. Arrow indicates a tricarinate suboral spine with a dense basal boss and a hyaline apical region. Scale bars: A = 5 mm; B = 2 mm; C = 2 mm; D = 1 mm.

curvature is more pronounced for *D. fisheri*, resulting in both a curved paxillar border and a characteristic obovate, leaf-like shape for the arm apex. The spine count for each oral plate in *D. fisheri* is notably fewer than for other species, where this is recorded. Missing character data for some taxa precludes a full cluster or cladistic analysis but some species relationships are apparent; the general arm shape and low R:r ratio of 2.2–2.3 indicate a similarity to the North and East Pacific deep stars, *D. borealis* Fisher, 1910a and *D. eximius* Fisher, 1905. However, in addition to distinctly different superomarginal profiles, the number of superomarginals in *D. fisheri* is far fewer than for the other two.

Order Velatida

Family Pterasteridae Perrier, 1875

***Pteraster* Müller & Troschel, 1842**

***Pteraster sjadesensis*, new species**
(Fig. 6)

Material examined. 1 wet specimen, R:r = 15:6 mm (R:r = 2.5) (ZRC.ECH.1382), Stn. DW16, Sunda Strait, (seamount reef), S06°09.803′ E104°57.976′ (drop point of dredge), 26 March 2018, depth = 92–103 m. Substrate: gravel, sand, and some mud.

Description. 5-rayed, stellate sea star with markedly tapering, triangular arms (Fig. 6A, B, C). Arm extremities recurved almost 180° in living sea star such that the terminal end of the ambulacral groove is visible from above. Supradorsal canopy supported by paxillae, single spines, and spine clusters. The single spines protrude only slightly though the membrane whereas the spine clusters, restricted to the dorsal surface, often cross apically together wigwam fashion and protrude further. Membrane muscle bands connect adjacent spines and spine clusters. The chamber beneath the supradorsal membrane connects to the exterior via a central osculum whose opening is regulated by an encircling membranous fringe embedded with at least 20 vertically oriented spines. Spiracle number is variable and difficult to count due to multiple membrane ruptures. Adambulacral plates similar in size along the furrow; each plate bears a transverse row of 4 small webbed spines linked by membrane to a large actinolateral spine furthest from the furrow; larger spines collectively are embedded in an actinolateral membrane that extends almost to the margins of the arms. Mouth plates each bear 10 peripheral spines, the second being slightly longer than the first; the series then diminishing in size distally along the plate edge (Fig. 6D). Oral spines are webbed together, to their tips, but the webbing is independent for each oral plate (Fig. 6D). A large, lanceolate, suboral spine (Fig. 6D, arrow) on each oral plate is free from membrane and articulates on a prominent boss; the hyaline outer portion is pointed or round-ended and tricarinate in cross section with concave faces. Tube feet aligned biserially (Fig. 6C). Colour in life: supradorsal membrane with irregular light and dark orange pigmentation; membrane pigmentation tends to be reduced on some of the protruding spine clusters and also tends to be lost then regained towards the arm apices.

Etymology. Species named after the SJADES 2018 Expedition during which it was collected.

Distribution. Recorded at a single location, a seamount ridge/reef at the southwest opening of the Sunda Strait to the Indian Ocean (Fig. 1). This location, just 50 km from and possibly impacted by the cataclysmic 1883 Krakatau eruption, may have been subsequently re-colonised from more widely distributed populations outside the Strait. The depth at which this new *Pteraster* species was found (ca. 100 m) in the Sunda Strait corresponds approximately to the peak species diversity-depth interval globally for the genus (Villier et al., 2004).

Remarks. *Pteraster*, currently with 56 described species (Mah, 2020) is one of two highly speciose genera in the Pterasteridae—a monophyletic family (Blake, 1987; Gale, 1987) of predominantly deep-sea stars—the other being *Hymenaster*, a genus with similar body form but distinguishable from *Pteraster*, including the present specimen, by the adambulacral spine rows not being transverse and by the absence of webbing between the oral spines (Fisher, 1911; Villier et al., 2004). There is resemblance also to sea stars of the genus *Euretaster* but, although small in size and possibly a juvenile, the present specimen can be distinguished from *Euretaster* and assigned to the genus *Pteraster* based on a number of morphological characters featured in a preliminary cladistic analysis of the family (Villier et al., 2004), namely: (a) all adambulacral plates being of similar form, (b) the adambulacral comb row of spines being transverse rather than oblique or aligned with the arm furrow, and (c) the arm being semicircular in cross section. *Euretaster* in contrast has alternating adambulacrals of two types: oblique adambulacral comb rows and, except for *Euretaster attenuatus*, arms that are circular in cross section (Villier et al., 2004). *Euretaster attenuatus*, described from New Caledonia (Jangoux, 1984) does have features in common with *Pteraster sjadesensis*, new species (semicircular arm section; stellate appearance) but, apart from generic differences in adambulacral spine row direction, the latter lacks the longer-spined, spikey appearance of *E. attenuatus*.

Pteraster sjadesensis, new species, resembles *Pteraster uragensis* Hayashi, 1940 and *Pteraster trigonodon* Fisher, 1910 (Fisher, 1910b) in the independent webbing of oral plate spines on each side and in the three-edged form of the suboral spines. It differs, however, in that the arms are longer, giving a higher R:r ratio, and oral plates have double (10) the number of webbed oral plate spines compared with *P. uragensis* and *P. trigonodon*.

ACKNOWLEDGEMENTS

The authors wish to thank the following LKCNHM staff for their support: Iffah Binte Iesa for curation and cataloguing of material lodged in the ZRC and for arranging specimen loans; Rene Ong for the photography of live specimens; Tan Heok Hui for acquisition of the X-ray radiograph images.

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