



Euryalid brittle stars from the International Indian Ocean Expedition 1963–64 (Echinodermata: Ophiuroidea: Euryalida)

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Abstract

Fourteen species of euryalids are reported from collections made in the eastern and western Indian Ocean during the International Indian Ocean Expedition. Three new species are described: *Astrocladus goodingi* from the Comoro Islands, *Astrocladus socotrana* from the northwestern Indian Ocean near the island of Socotra, and *Astrocyclus somaliensis* from off northeastern Somalia. Range extensions are documented for *Asteroronyx luzonicus*, *Astroglymma sculptum*, *Astrocladus ludwigi*, *Asteromorpha capensis* and *Squamophis amamiensis*.

Key words: taxonomy, ophiuroids, new species, deep sea

Introduction

During the early 1960's, the International Indian Ocean Expedition (IIOE), coordinated by the Intergovernmental Oceanographic Commission of UNESCO, contributed greatly to our knowledge of the biology of the Indian Ocean (Humphrey, 1972; Behrman, 1981). For the echinoderms, many of which are now deposited in the National Museum of Natural History, Smithsonian Institution, Washington DC, USA, the IIOE provided much new information on composition and relationships of the great Indian Ocean fauna.

The present paper describes a collection of euryalid brittle stars collected by the late Dr R.U. “Judge” Gooding and his colleagues during their participation in various IIOE cruises on the RV *Anton Bruun* and RV *Pioneer*. The collection came to ANB (then at the National Museum of New Zealand) through the generosity of the late Dr Dennis M. Devaney, formerly of the Bernice P. Bishop Museum in Hawaii.

In this study, we examined 46 specimens from Indian Ocean although two specimens are now lost. We present an overview of these euryalid specimens with partial synonymies provided for each species; these synonymies include the original reference, along with at least one later reference which has useful descriptions and/or illustrations.

Materials and methods

Unless otherwise indicated, all specimens are catalogued into the collections of the National Museum of Natural History (USNM), Smithsonian Institution, Washington D.C., USA. The collection localities and date are given in the descriptions. All examined specimens are completely dried, and their original fixation methods are unknown.

Ossicles from the three holotypes *Astrocladus goodingi* **sp. nov.**, *Astrocladus socotrana* **sp. nov.** and *Astrocyclus somaliensis* **sp. nov.** were isolated by immersion in domestic bleach (approximately 5% sodium hypochlorite solution), washed in deionized water, dried in air, and mounted on SEM stubs using double-sided

conductive tape. The ossicles were observed and photographed with Jeol JSM 5510LV SEM of the Misaki Marine Biological Station of The University of Tokyo (MMBS).

The classification employed herein follows that of the World Ophiuroidea Database—World Register of Marine Species (www.marinespecies.org/ophiuroidea), Okanishi *et al.* (2011), Stöhr *et al.* (2012), Okanishi & Fujita (2013), Stöhr *et al.* (2018). The terms used to describe euryalid brittle stars follow Thuy & Stöhr (2011), Stöhr *et al.* (2012) and Okanishi (2016), and systematics follow Okanishi & Fujita (2013) and O’Hara *et al.* (2017).

Systematic Account

Order Euryalida Lamarck, 1816

Diagnosis. See Okanishi & Fujita (2013) for the composition of this order.

Family Euryalidae Gray, 1840

Subfamily Astroschematinae Verrill, 1899

Diagnosis. Arms simple, coiled. Disc five lobed, naked or covered with granule- plate- and/or cone-shaped external ossicles, or skin. Teeth triangular and wide, flat, situated on top of the dental plate. Radial shields narrow, multi-layered. Ventral arm plates small, disappearing on middle to distal portion of arms. Arm spines up to three. Genital slits close to periphery of disc.

Remarks. Okanishi & Fujita (2011) reduced the family Astroschematidae Verrill 1899, to a subfamily of family Euryalidae. Soon thereafter, Okanishi & Fujita (2013) restored the family-level status of Astroschematidae under the superfamily Euryaloidea. However, the molecular phylogeny of O’Hara *et al.* (2017) confirmed that the astroschematids were subfamilial rank. Therefore, in this study, we use subfamilies Astroschematinae, Astrocharinae and Euryalinae under the family Euryalidae.

Genus *Astroschema* Örstedt and Lütken, 1856 in Lütken (1856)

Astroschema cf arenosum Lyman, 1878

(Fig. 1A–D)

Astroschema arenosum Lyman, 1878: 235, pl. 3 figs. 62–64; Barboza *et al.*, 2010: 242; Frensel *et al.*, 2010: 175.

Material Examined. USNM 1072539, *Pioneer* Cruise 17, south of Lombok, eastern Indian Ocean, 10° 50’S, 117° 50’E, 1000 m, 17 March 1964, 3 specimens.

Remarks. These specimens were identified as *A. arenosum* on the basis of the disc and upper arm covering of flat polygonal plate-shaped external ossicles (Fig. 1C), the lateral arm cover of fine rounded granule-shaped external ossicles (Fig. 1D), and the presence initially of one, then two, arm spines. One complete specimen had a disc diameter of 11 mm and arms 180 mm long (Fig. 1A–B).

The type specimen of *A. arenosum* was collected in the Gulf of Mexico and its occurrence in the Indo-Pacific region is thus a very large extension of its range. Given that this species has been recorded from a depth of 1449 m in the western Atlantic (Pawson *et al.* 2009), it is likely to be a distinct taxon. However, we here refrain from describing another species here since we examined only 3 specimens. Future morphological observations and molecular analyses based on more specimens are required.

Subfamily Astrocharinae Okanishi, O’Hara & Fujita, 2011a

Diagnosis. Arms simple, coiled. Disc five-lobed or circular, covered with plate-shaped external ossicles. Teeth

triangular and widened, flat, situated on top of dental plate. Radial shields narrow, mono-layered, and naked in species of *Astrocharis*. Ventral arm plates small, disappearing on middle to distal portion of arms. Arm spines up to three. Genital slits close to periphery of disc.

Genus *Squamophis* Okanishi, O'Hara & Fujita, 2011

Squamophis amamiensis (Okanishi & Fujita, 2009)

(Fig. 1E–H)

Asteroschema amamiense Okanishi & Fujita, 2009: 152, figs. 115–129, figs. 4–6, 7B–D, 8; Okanishi *et al.*, 2011b: 6.
Squamophis amamiensis.—Okanishi *et al.*, 2011b: 6, 13.

Material Examined. USNM 1072572, *Pioneer* Cruise 17, south of Lombok, eastern Indian Ocean, 10°50'S, 117°50'E, 1000 m, 17 March 1964, 1 specimen, disc diameter 8 mm (Fig. 1E–H).

Description. Aboral and oral surfaces of disc and arms uniformly covered with slightly tumid, smooth, polygonal to rounded plate-shaped external ossicles (Fig. 1G). Oral frame and jaws similarly covered (Fig. 1H). Aboral surface external ossicles range from 300–500 µm in diameter; average diameter 370 µm (Fig. 1G). Oral surface external ossicles 111–333 µm in diameter; average diameter 228 µm (Fig. 1H). On both surfaces, external ossicles tend to be slightly larger towards disc margin. External ossicles (*sensu* Okanishi *et al.* 2011b) uncommon, of one type, granule-shaped, 80 µm in average length. Oral interradial disc with deep depressions leading to genital slits (Fig. 1H).

Five arms ca. 100 mm long, higher than wide at the base (Fig. 1E–F). First and second tentacle pores outside of oral slit without associated arm spine (Fig. 1H); thereafter one short blunt arm spine less than an arm segment in length, to each tentacle pore in the basal portion of the arms. Subsequently, the spines become progressively longer until they reach a length that is an average of 1.5 times the length of an arm segment. The spines do not reach a length of twice that of an arm segment.

Remarks. This species is characterized by a very simple smooth body cover of plate-shaped external ossicles, a few granule-shaped external ossicles, and a single arm spine to each arm segment beyond the first two. As a unique specimen is currently available in this study, we are reluctant to undertake the destructive analyses required to determine if the radial shields are multi-layered or single-layered, or to more thoroughly survey the nature and distribution of external ossicles. Therefore, as some important information of taxonomic value at the generic level is lacking, it is not possible to definitely assign the species to one of the five genera of *Asteroschematidae* as defined by Okanishi *et al.* (2011b). However, external features of this specimen match those of *Squamophis amamiensis*. For the present, therefore, we refer the species to *S. amamiensis*, and we expect that in the future a richer material will help to firmly establish its taxonomic position.

The type specimens of *S. amamiensis* were collected off Amami Ohshima Islands, southwestern Japan, 158 m depth and its occurrence in the Indo-Pacific region is thus a very large extension of its range.

Regrettably, the specimen has a four-digit catalogue number indelibly inscribed on its aboral disc surface. This was done at an institution at which the IIOE collection was temporarily stored. Various non-invasive attempts were made to remove the number, without success. Similar numbers were also inscribed on the type specimens of *Astrocladus goodingi* and *A. socotrana*. These numbers should be ignored.

Distribution. JAPAN: off Amami Ohshima Islands, southwestern Japan (Okanishi & Fujita, 2009, type locality); INDONESIA: southeastern Indonesia (this study). Depth ranges 168–1000 m.

Subfamily Euryalinae Gray, 1840, emend. Okanishi & Fujita, 2013

Diagnosis. Arms simple, or branching, coiled. Disc five-lobed or circular, covered with granule- and/or plate-shaped external ossicles, sometimes with large conical tubercles. Teeth triangular and widened, flat, situated on top of dental plate. Radial shields narrow, multi-layered. Oral furrows of vertebrae with oral bridge, or covered by ventral arm plates (*Astrobrachion*) throughout arms. Up to three arm spines. Genital slits close to periphery of disc.

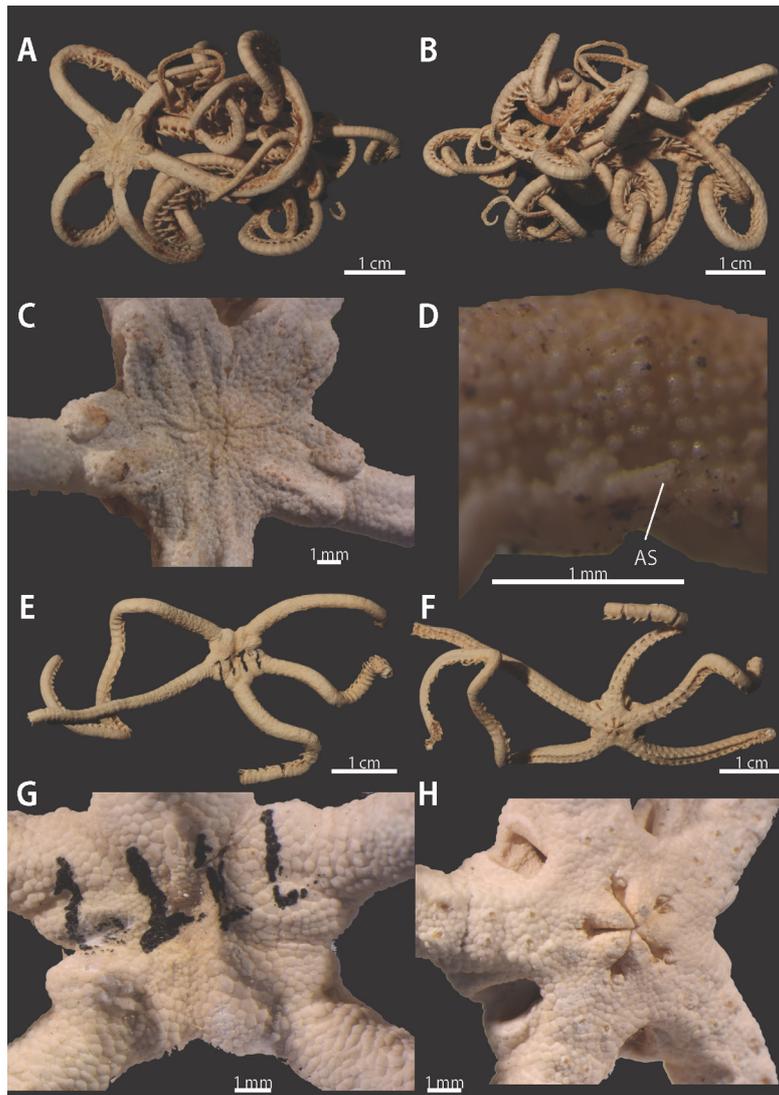


FIGURE 1. *Asteroschema arenosum* (USNM 1072539) (A–D) and *Squamophis amamiensis* (USNM 1072572) (E–H). A, aboral view; B, oral view; C, aboral disc; lateral view of distal arm; E, aboral view; F, oral view; G, aboral disc; H, oral disc. Abbreviation: AS, arm spine.

Asteromorpha Lütken, 1869

Okanishi *et al.* (2013) have revised the genus *Asteromorpha*, which now comprises four species, including the following species, formerly assigned to *Asteroschema*.

Asteromorpha capensis (Mortensen, 1925)

(Fig. 2A–D)

Asteroschema capensis Mortensen, 1925: 152, figs. 4–5.

Asteromorpha capensis.—Okanishi *et al.*, 2013: 462, figs. 2–5; Olbers *et al.*, 2014: 14, pl. 1F.

Material Examined. All from off the southern part of Mozambique, as follows: USNM 1072548, *Anton Bruun* Cruise 7, Station 371E, 24° 46'S, 35° 20'E, 132 m, 18 August 1964, 2 specimens; USNM 1072557, *Anton Bruun* Cruise 7, Station 371D, 24° 46'S, 35° 20'E, 165 m, 18 August 1964, 1 specimen (Fig. 2A–B); USNM 1072559, *Anton Bruun* Cruise 7 Station 371F, 24° 46'S, 35° 18'E, 110m, 18 August 1964, 5 specimens; USNM 1072569, *Anton Bruun* Cruise 8, Station 403E, 19° 09'S, 36° 55'E, 88 m, 9 October 1964, 7 specimens.

Remarks. This is the only the second time the species has been recorded since the type was collected off the Umvoti River, Natal, South Africa (Mortensen 1925). Sink *et al.* (2006) listed this species from Sodwana Bay in northern KwaZulu-Natal, and noted (p. 470) that it “was commonly attached to the gorgonian *Nicella dichotoma*”. Okanishi *et al.* (2013) described and illustrated the rediscovered holotype and three additional specimens collected from off Somalia and Madagascar. The present specimens are from the same general area, off the central coast of Mozambique. They align with the aforementioned descriptions. The disc is covered with granules, radial shields broad distally (Fig. 2A, C), arms annulated proximally with two short rough-tipped spines (Fig. 2B, D). The only variations noticed were the presence of two distinct sizes of granules on the aboral surface of the disc; those on the underside of the disc and arms are very fine. The arms are color-banded.

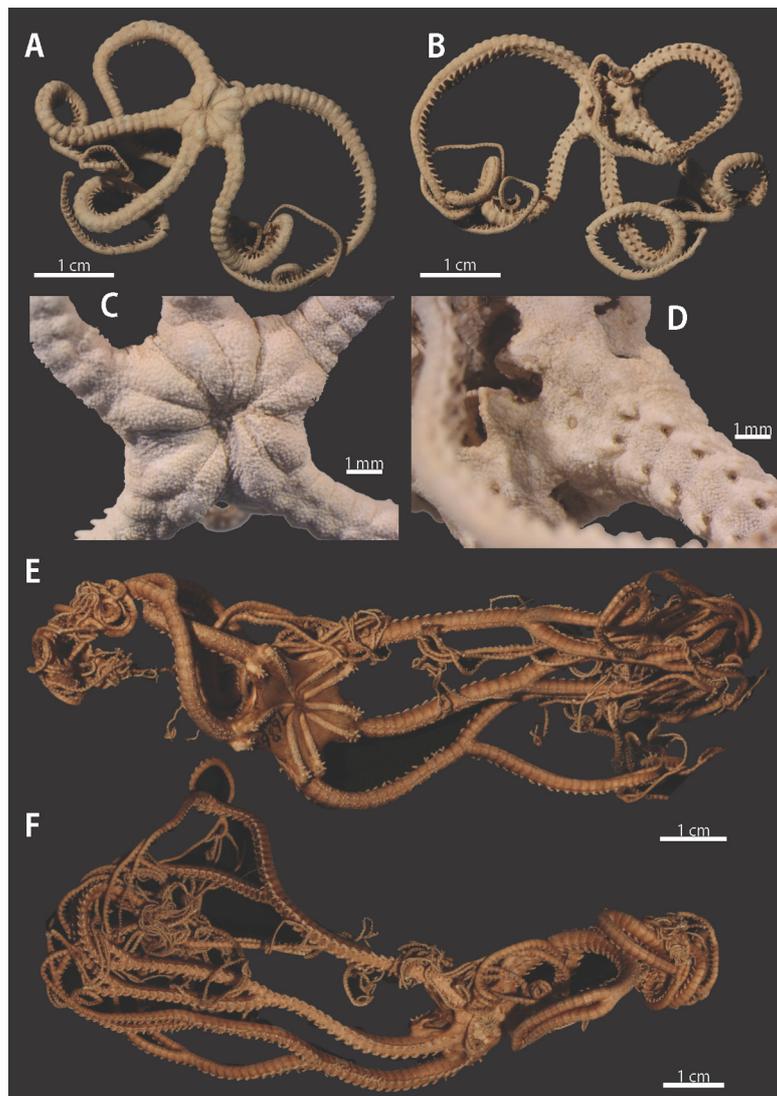


FIGURE 2. *Asteromorpha capensis* (USNM 1072577) (A–D) and *Sthenocephalus indicus* (USNM 1072462) (E–F). A, aboral view; B, oral view; C, aboral disc; D, oral disc; E, aboral view; F, oral view.

***Sthenocephalus indicus* Koehler, 1898**

(Figs. 2E–F, 3)

Sthenocephalus indicus Koehler, 1898: 112, pl. 5 figs. 48,49; Döderlein, 1927: 82, pl. 8 figs. 3-6.

Material Examined. USNM 1072462, *Anton Bruun* Cruise 1 Station 17, southern Andaman Sea, 7° 38'N 97° 09'E, 275–280m, 21 March 1963, 1 specimen (Fig. 2E–F).

Remarks. This specimen (18.5 mm disc diameter and 100 mm arm length) has 22 arm segments before the

first arm branch (Fig. 2E–F), thus identifying it as *S. indicus* rather than the closely related *S. anopla* (H. L. Clark 1911), from the East China Sea, which has 12–17 pre-branch segments (Irimura & Kubodera 1998). There are at least 6 arm bifurcations in total. The distal ends of the radial shields carry granules and fine tubercles (Fig. 2E), and the arms have a double median row of small round tubercles up to the first branch (Fig. 3A), and small grains thereafter over the rest of the arm (Fig. 3B). There are hook-shaped arm spines distally (Fig. 3C), and two club-shaped arm spines proximally (Fig. 3D). The lateral arm plates meet on the oral midline (Fig. 3D); this is a feature of this genus.

The type specimen of *S. indicus* was collected at Gaspar Strait in Indonesia by the survey vessel *Investigator* (Koehler 1898), and further material has since been recorded from the Indian Ocean in 36–467 meters. The present specimen was taken from the outer shelf in the southern Andaman Sea between Phuket and the Nicobar Islands. The material described by Liao & A. M. Clark (1995) as *Sthenocephalus indicus* may yet prove to be *Sthenocephalus anopla* (Liao & A. M. Clark 1995). *Euryale anopla* H. L. Clark, 1911, from southern Japan, was redescribed by Mortensen (1933a) as *Stenocephalus* (sic) *indicus* var. *anopla*. Irimura & Kubodera (1998) restored *anopla* as a distinct species in their new combination *Sthenocephalus anopla* (H. L. Clark, 1911), a step that was followed by Fujita & Irimura (2005).

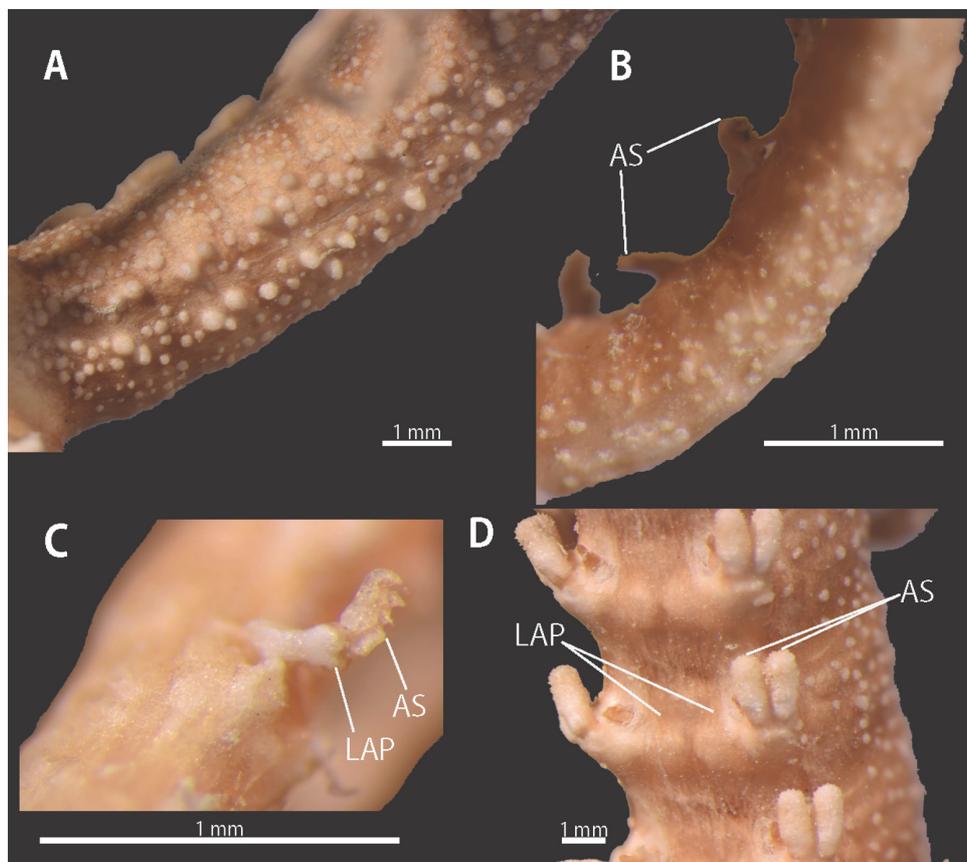


FIGURE 3. *Sthenocephalus indicus* (USNM 1072462) (A–D). A, aboral basal portion of the arm; B, aboral distal portion of the arm; C, oral distal portion of the arm; D, oral basal portion of the arm. Abbreviations. AS, arm spine; LAP, lateral arm plate.

***Trichaster flagellifer* von Martens, 1866**

(Fig. 4A–E)

Trichaster flagellifer von Martens, 1866: 87; Liao & Clark, 1995: 163, fig. 69.

Trichaster elegans Ludwig, 1878: 59.

Material Examined. USNM 1072573, *Anton Bruun* Cruise 1 Station AB39A, Andaman Sea, 14°52'N, 96°39'E, 48–64 m, 31 March 1963. 1 specimen (Fig. 4A–E).

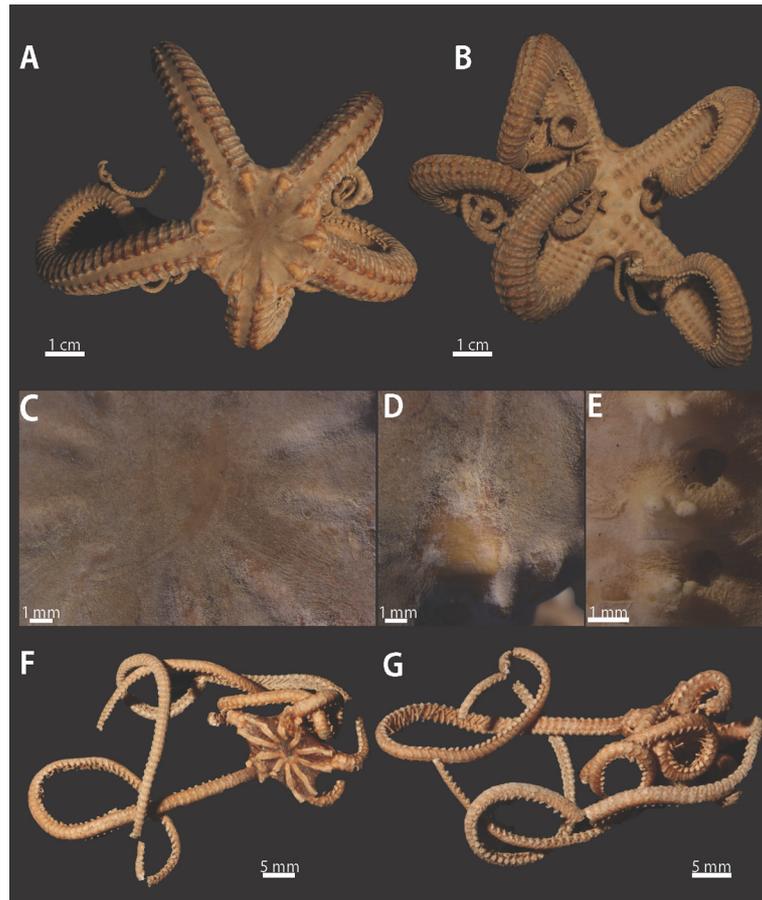


FIGURE 4. *Trichaster flagellifer* (USNM 1072573) (A–E) and *Asteronyx luzonicus* (USNM 1072474) (F–G). A, aboral view; B, oral view; C, aboral central view; D, aboral peripheral view; E, oral basal portion of the arm; F, aboral view; G, oral view.

Remarks. The specimen has a disc diameter of 32 mm, and arms 200 mm long, branched only five times in their distal half, the first branch occurring at 42 segments from the disc (Fig. 4A–B). This remote branching is a characteristic of the genus, along with longitudinal aboral, and vertical lateral, arm ridging. The disc is flat and smooth in the centre (Fig. 4C), with the radial shields exposed only distally as small triangles (Fig. 4D). There are two arm spines (Fig. 4E).

The specimen was taken at only 1 of 7 benthic shelf stations in the Gulf of Martaban in the northern Andaman Sea, an area near the type locality for this species (Bay of Bengal). It has, however, been found elsewhere in the tropical Indo-west Pacific Ocean, including the Arafura Sea, South China, Japan, and the Philippines, in 65–146 meters (Liao & A. M. Clark, 1995; Rowe & Gates, 1995).

Family *Asteronychidae* Verrill, 1899

Diagnosis. Arms simple, coiled. Disc five lobed or circular, covered with skin and/or plate-shaped external ossicles. Teeth spiniform, covering whole side of jaw. Radial shields narrow, multi-layered. Ventral arm plates limited to a few basal arm segments. Up to more than ten arm spines. Genital slits usually small, half the length of the height of the disc.

Asteronyx luzonicus Döderlein, 1927

(Figs. 4F–G, 5A–C)

Asteronyx luzonicus Döderlein, 1927: 64, pl. 7 figs. 4–6d.

Material Examined. USNM 1072474, *Anton Bruun* Cruise 1 Station 17, southern Andaman Sea, 7° 38' N 97° 09' E, 280–275 m, 21 March 1963, 1 specimen; *Anton Bruun* Cruise 7 Station 369F, off southern Mozambique, 24° 07'S, 36° 11'–15'E, 1600–1628 m, 17 August 1964, 1 specimen.

Remarks. The disc diameters of the two specimens are 15 mm (Fig. 4F–G) and 6 mm respectively. The larger specimen has narrow arms approximately 140 mm long (Fig. 4F–G). The larger specimen has a naked skin-covered disc with dark spots aborally and orally (Fig. 5A–B), and with some light calcification between one pair of radial shields (Fig. 5A). The genital slit is narrow, situated between arm segments 1 and 3, and is not in a pouch (Fig. 5B), as in the type species, *A. loveni*. At arm segment 22, the lowermost arm spine is elongate, with a terminal club (Fig. 5C). This elongate arm spine is not present on the smaller specimen, and may therefore be ontogenetic as is the number of arm spines. A similar enlargement of mid-arm spines has been noted in *A. loveni* (Baker 1980). The dark spots on their disc is a main diagnostic character of *A. luzonicus* (Döderlein, 1927).

This species has remarkable bathymetric distribution, between 109 and 2963 m. *A. luzonicus* was originally described from the Philippines; its occurrence in the southern Andaman Sea and the Mozambique Channel represents a considerable extension of its geographic range, but one that might be expected given its bathymetric range.

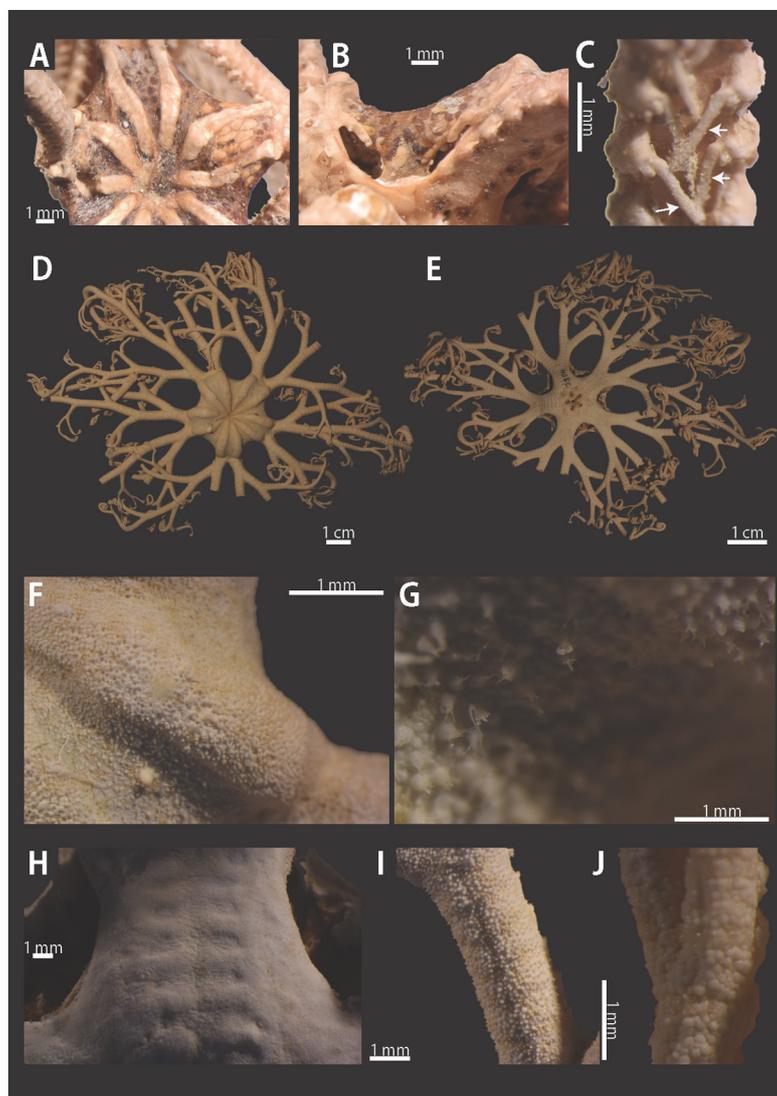


FIGURE 5. *Asteronyx luzonicus* (USNM 1072474) (A–C) and *Astroboa clavata* (USNM 1072477) (D–J). A, aboral disc; B, lateral disc; C, basal portion of the arm; arrows indicate elongated club-shaped arm spines; D, aboral view; E, oral view; F, aboral peripheral disc; G, external ossicles on a peripheral radial shield; H, oral basal portion of the arm; I, aboral middle portion of the arm; J, aboral distal portion of the arm.

Family Gorgonocephalidae Ljungman, 1867

Diagnosis. Arms simple, or branching, coiled. Disc five lobed or circular, covered with skin and/or various shaped external ossicles. Hooklets borne on at least middle to distal portion of aboral arms. Teeth spiniform. Radial shields narrow, multi-layered. Ventral arm plates limited to basal few arm segments. Up to more than ten arm spines. Genital slits usually small, approximately one half of the height of the disc.

Astroboa clavata (Lyman, 1861)

(Fig. 5D–J)

Astrophyton clavatum Lyman, 1861: 85.

Astroboa clavata. —Döderlein, 1911: 80. Pl. 5, figs 6,6a; 1912: 269, pl.16, figs 1, 1b, 16, pl. 18, fig. 8; 1927: 38, pl.5, figs 5,6; Putchakarn and Sonchaeng, 2004: 421; Venkatraman *et al*, 2013: 208.

Material Examined. *Anton Bruun* Cruise 9, Indian Ocean, Comoro islands, Mayotta Island, Bandeli Reef, 13° 30' S, 045° 16' E, 23–26 November 1964, 1 specimen, now lost; USNM 1072477, *Anton Bruun* Cruise 9 Station 465, off NE Somalia, 11° 37' N 51° 27' E, 67–72 m, 18 December 1964, 1 specimen (Fig. 5D–J).

Remarks. This species is characterised by having prominent radial shields and a covering of minute thorny granules (Fig. 5D, F, G). Similar granules extend into the oral interbrachial areas.

The arm segments are separated by marked depressions with thickened edges (Fig. 5H). There is also a median furrow along the aboral sutures of each arm (Fig. 5I). Girdle bands with hooklets occur terminally on each arm (Fig. 5J).

A. clavata was first collected off Zanzibar, and has subsequently been found in the waters of the Persian Gulf, Bay of Bengal, Mauritius, and northwestern Australia (Rowe & Gates, 1995).

Astroboa nigrofurcata Döderlein, 1927

(Figs. 6A–E, 7D)

Astroboa nigrofurcata Döderlein, 1927: 45, pl. 4 figs. 1–4; Baker, 1980: 60, figs. 23, 28, 30.

Material Examined. USNM 1072537, *Anton Bruun* Cruise 1 Station 18A, southern Andaman Sea, 7°34'N, 98° 00'E, 77 m, 21 March 1963, 2 specimens (Fig. 6A–E); USNM 1234012, *Anton Bruun* Cruise 9 Station 465, off NE Somalia, 11° 37'N, 51° 27'E, 67–72 m, 18 December 1964, 2 specimens.

Remarks. The specimens range between 17 and 40 mm (Fig. 6A–B) disc diameter. The smallest specimen has a disc cover of dense low granules, 8 in 1 mm on the radial shields (Fig. 6C). One unusual feature of this specimen, possibly related to its small size, is the presence of 2–4 transverse rows of taller granules bridging the pairs of radial shields. In the largest specimen, the arms bifurcate at least 25 times, and are covered with smooth polygonal plates, with prominent girdle bands continuing over the arm—a characteristic of this species (Figs. 6D–E, 7D). The colour pattern of this species is distinctive—disc pale green, with contrasting irregular brown or pink freckles; arms with a continuous series of dark freckles, one per segment.

This record, in the southern Andaman Sea, is an extension of the known range from the Western Australian coast, Indonesia and the Philippines (Baker 1980).

Astrocladus exiguus (Lamarck, 1816)

Euryale exiguum Lamarck, 1816: 539.

Astrocladus exiguus.—H. L. Clark, 1915: 187; Cherbonnier & Guille, 1978: 11, pl. 2 figs. 1–2; Putchakarn & Sonchaeng, 2004: 421.

Material Examined. *Anton Bruun* Cruise 8, Station 403E, off Mozambique, 19° 09'S, 36° 55'E, 88 m, 9 October 1964, 1 specimen, now lost.

Remarks. This small specimen (<8 mm disc diameter) has large tubercles on the distal ends of the radial shields, a feature typical of this species. The remaining disc cover is fine conical granules tipped with a single glassy spine. There are 3–4 arm spines from the third arm segment.

A. exiguus is widely distributed in the Indian Ocean (Mozambique Channel, Andaman Islands, Bay of Bengal, Western Australia) and in the north-western Pacific around the Philippines and southern Japan (Baker 1980).

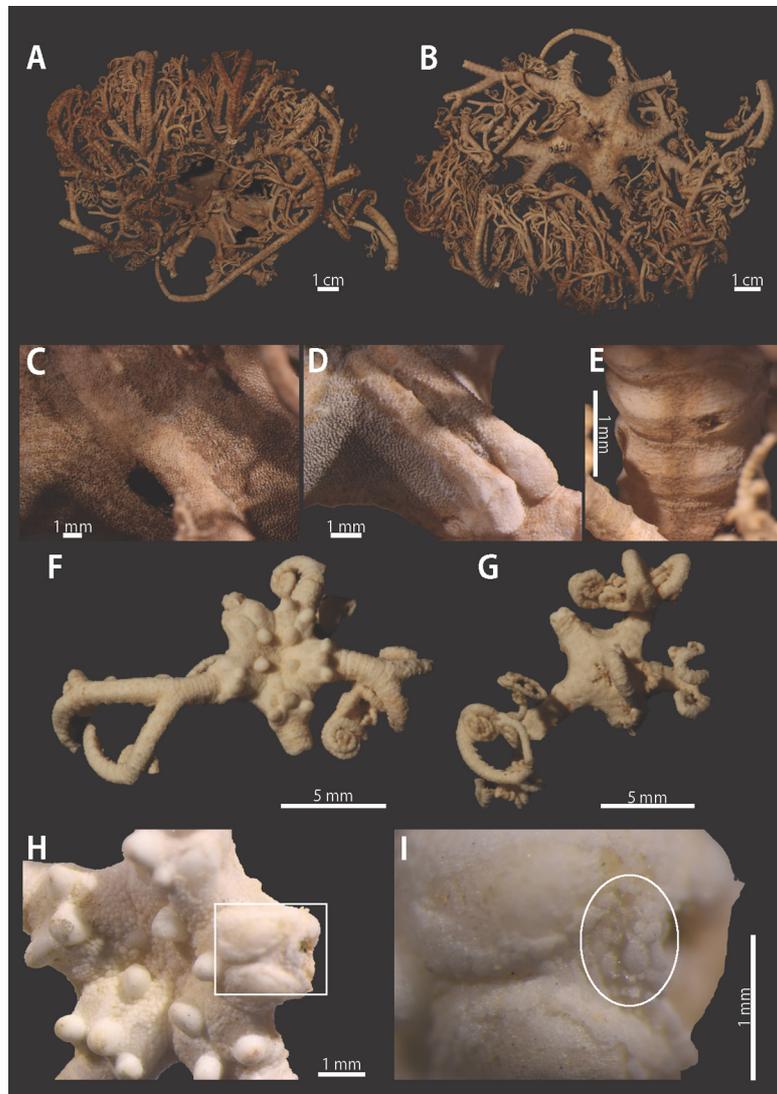


FIGURE 6. *Astroboa nigrofurcata* (USNM 1072537) (A–C, smaller specimen, D–E, larger specimen) and *Astrocladus ludwigi* (USNM 1072478) (F–I). A, aboral view; B, oral view; C–D, aboral peripheral disc; E, aboral basal portion of the arm; F, aboral view; G, oral view; H, aboral disc, a square part is enlarged in I; I, aboral peripheral disc, a circle indicates girdle hooklets.

Astrocladus ludwigi (Döderlein, 1896)

(Fig. 6F–I)

Euryale ludwigi Döderlein, 1896: 299, pl. 17 figs. 28a–c.

Astrocladus ludwigi.—Baker, 1980: 63, figs 28,33; Shin, 1998: 198.

Material Examined. USNM 1072478, *Anton Bruun* Cruise 7 Station 371E, off southern Mozambique, 24°46'S, 35°20'E, 132 m, 18 August, 1964, 1 specimen (Fig. 6F–I).

Remarks. A small (5 mm disc diameter) example, but showing the adult characteristics of a disc covering of closely set domed tubercles, with larger ones on the radial shields (Fig. 6F, H). The girdle bands on the arms begin

at the disc edge (Fig. 6I), and the girdle hooklets have the typical single secondary hooklet. There is a single madreporite at the disc edge orally.

This record, off the Mozambique coast, is a range extension of *A. ludwigi* from the eastern Indian Ocean and Indonesia.

***Astrocladus goodingi* sp. nov.**

(Figs. 7A–C, 8–11)

Astrocladus tonganus.—Cherbonnier & Guille, 1978: 14, Pl. II figs. 3–4.

Non *Astrocladus tonganus* Döderlein, 1911: 77, 107, pl. 9 fig.8.

Material Examined. **Holotype** USNM 1072479, *Anton Bruun* Cruise 9, Indian Ocean, Comoro Islands, Mayotte Island, Bandeli Reef, 12° 54'S, 45° 16.5'E, inner side of reef, depth approximately 1 m, 23–26 November 1964. Collected by R.U. Gooding (RU-297), 1 specimen, disc diameter 15 mm (Figs. 7–10).

Other material examined. Three specimens from localities in the northwest and south of Madagascar, identified by Cherbonnier & Guille 1978 as *Astrocladus tonganus* Döderlein (sent to ANB by the late Dr A. Guille, specimens now in Muséum National d'Histoire Naturelle, Paris). The three specimens were referenced by Baker (1980, p. 64). Their current catalogue numbers were unavailable.

Etymology. Named for the collector, the late Dr R.U. “Judge” Gooding of Barbados; our friend and colleague.

Diagnosis. Disc and radial shields with tubercles bearing 2–8 glassy spines; five arm spines bearing 1–5 glassy spinules, present from third arm segment; girdle bands present from disc margin; arm areas between girdles and orally with large polygonal plates, separated by narrow rows of small single plates. Genital slits bordered abradially by a row of tall spines.

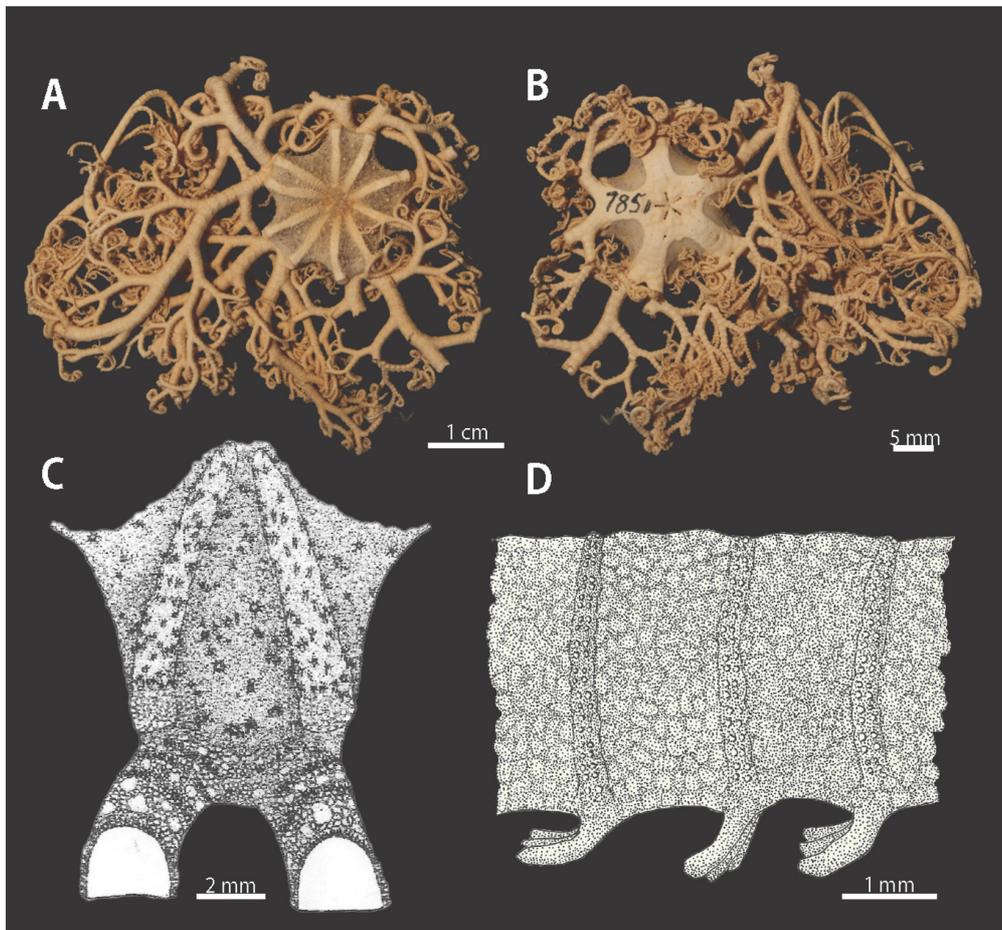


FIGURE 7. *Astrocladus goodingi*, holotype (USNM 1072479) (A–C) and *Astroboa nigrofurcata* (USNM 1072537) (D). A, aboral view; B, oral view; C, aboral disc and basal portion of the arms; D, lateral view of basal portion of the arm.

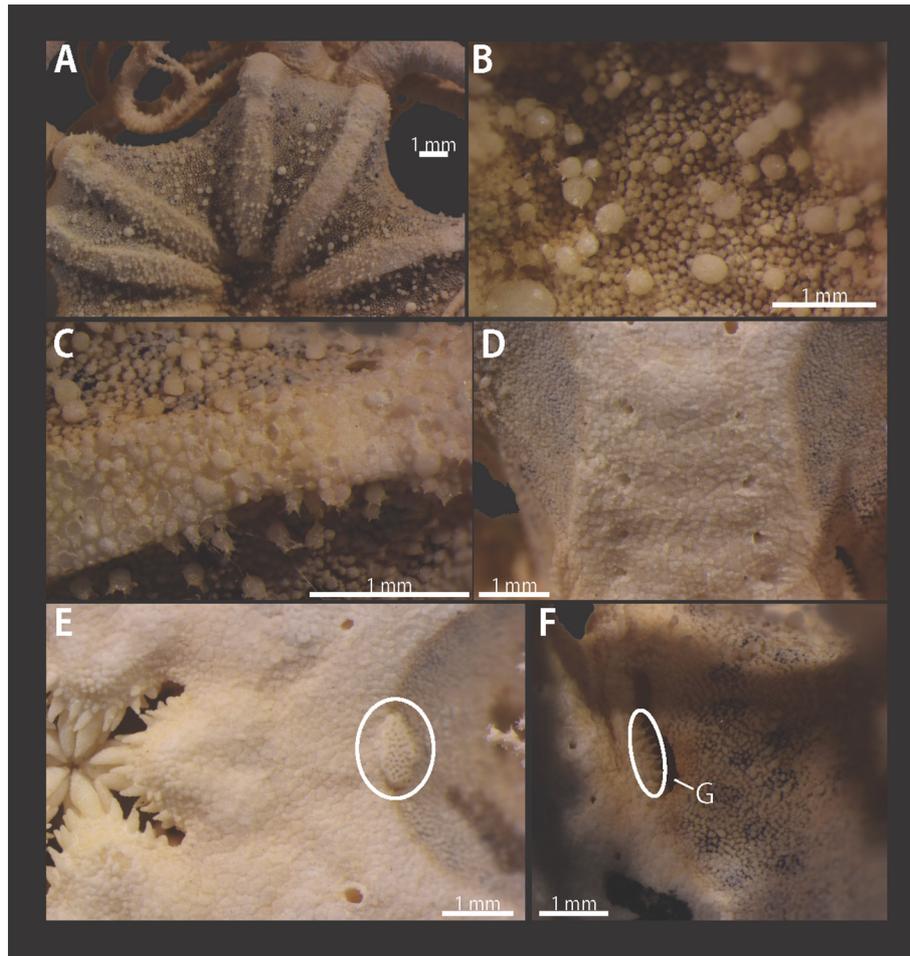


FIGURE 8. *Astrocladus goodingi*, holotype (USNM 1072479). A, aboral disc; B, aboral central disc; C, aboral peripheral disc; D, oral basal portion of the arm; E, oral disc, a circle indicates a madreporite; F, lateral disc, a circle indicates tall spines. Abbreviation: G, genital slit.

Description of the holotype. *External morphology.* Aboral disc depressed at center, aborally with scattered small <0.3 mm diameter tubercles bearing 2–8 glassy spines averaging 86 μm in length, on a dense background of small, low granules (Fig. 7A, C, 8A–B).

Radial shields prominent, narrow (ratio length to breadth 1:8), slightly divergent, not meeting centrally, covered with small (0.1 mm diameter) tubercles bearing 1–5 glassy spines interspersed with flat plates (Fig. 8A, C).

Oral disc covered by plate-shaped external ossicles, teeth large, spear-shaped; oral papillae small, spiniform (Fig. 8E). One madreporite on the inner border of the soft interbrachium (Fig. 8E).

Oral interradii with a close cover of pustules and scattered large tubercles, a few bearing spines (Fig. 8F). Genital slits narrow and short (0.25 \times 2.0 mm), bordered abradially by a row of tall spines (Fig. 8F).

Arms coiled, bifurcated at least 16 times (Fig. 7A–B). Girdles complete between disc edge and first arm branch (Fig. 9A), girdle hooklets with one secondary tooth. Between girdles, arms have a few spines basally, but mostly large flat polygonal plates, bearing low smooth knobs (Fig. 9A), those disappear toward the distal arm tip (Fig. 9D). Oral surface of arms and oral frame covered with flat, smooth polygonal plates surrounded by rows of single, smaller plates (Fig. 8D, 9B–C). Up to 5 arm spines, beginning just before third arm branch, with initially 1 or 2, then 5, glassy-tipped spines (Fig. 9C). Five arm segments to first branch, 4 to next branch.

Ossicle morphology. Hooklet-bearing plates possessing approximately 16 tubercle-shaped articulations for hooklets in the basal portion of the arm (Fig. 10A), approximately 6 articulations in the distal portion (Fig. 10H). The articulations forming two parallel rows (Fig. 10A, H). Each hooklet bears one inner tooth (Fig. 10B–C). Lateral arm plates concave on distal and basal sides, the concavity deeper on distal side (Fig. 10D–E). No

perforations visible on lateral arm plates but simple nerve openings on oral-external side (Fig. 10E–F) and on distal portion of the arms; articulations for hooklets only visible on oral surfaces (Fig. 10H). Arm spines in the basal portion of the arm ovoid and having one secondary point, approximately one-third length of the height of the spine (Fig. 10I). All vertebrae with hourglass-shaped streptospondylous articulations (Fig. 11D–E, H–I). Depressions for tube feet openings in the distal part of oral-lateral side of vertebrae (Fig. 11A, G). A pair of radial water canals opening on the lateral side of vertebrae, near depression of the tube feet (Fig. 11A, G) and radial nerve canals opening inside oral furrows (Fig. 11A).

Remarks. The genus *Astrocladus* contains 10 nominal species, of which five are now known from the Indian Ocean or nearby: *A. hirtus* Mortensen, *A. euryale* (Retzius), *A. exiguus* (Lamarck), *A. ludwigi* (Döderlein), and *A. africanus* Mortensen. Adding a further species to this fauna may seem an unnecessary complication, especially given the intra-species variations and similarity in morphology of *A. euryale* and *Astrodendrum capensis* (Mortensen, 1933b) as noted by A. M. Clark (1974) in her account of echinoderms from Southern Africa. We have, however, examined the descriptions of all the *Astrocladus* species, and cannot reconcile the Comoro and Madagascar specimens with any known taxon.

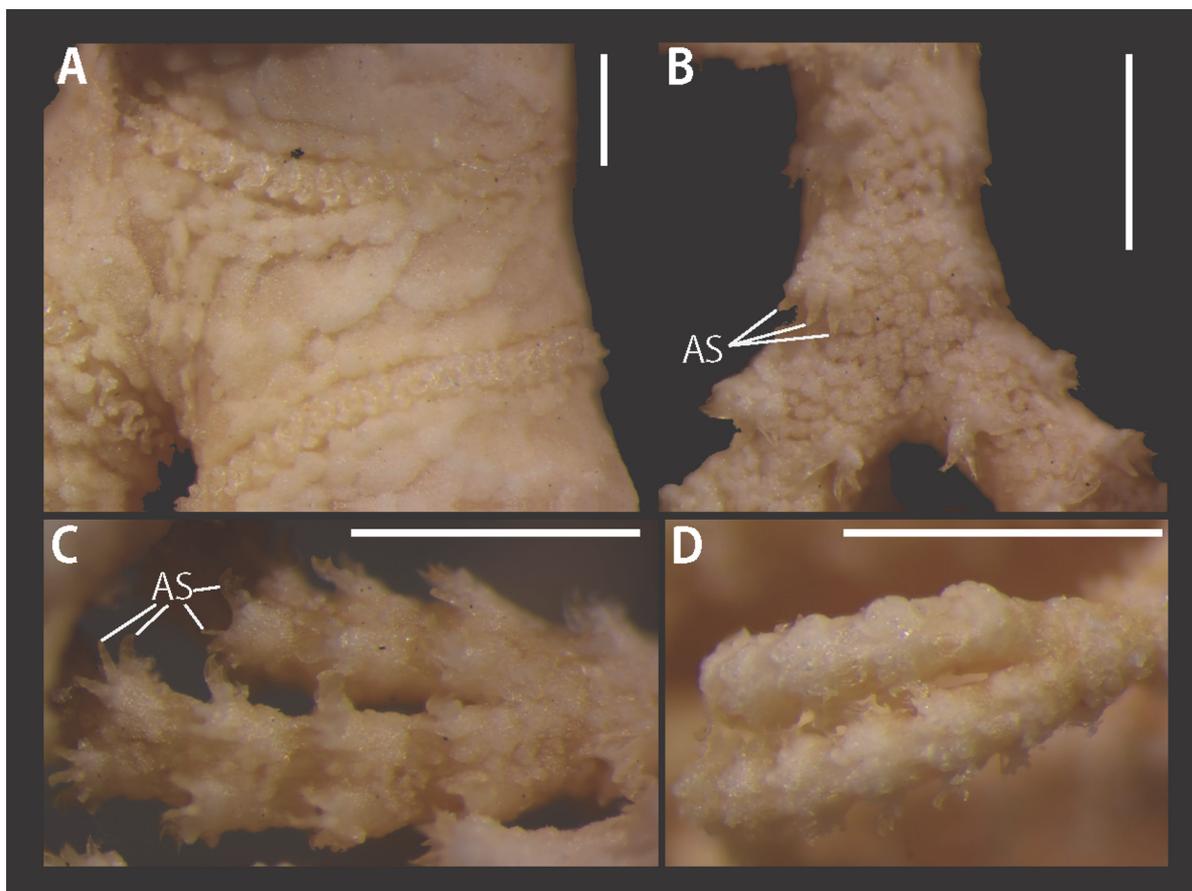


FIGURE 9. *Astrocladus goodingi*, holotype (USNM 1072479). A, aboral basal portion of the arm; B, oral middle portion of the arm; C, oral distal portion of the arm; D, aboral distal portion of the arm.

Cherbonnier & Guille (1978) referred five specimens of an *Astrocladus* collected in northwestern and southern Madagascar, to *A. tonganus* Döderlein, 1911 a species previously known only from the Pacific Ocean near the Tonga Islands. Baker (1980, p. 64) compared some of their material with *A. tonganus* from the Pacific type locality, and found that it represented a “species allied to *A. hirtus*”. The Cherbonnier & Guille (1978) material is referred here to *A. goodingi* **sp. nov.** *A. tonganus* has a disc covering of conical tubercles bearing 1–2 glassy spines, but there the external similarity with *A. goodingi* ends: the arms of *A. tonganus* are covered above with flat plates and pointed tubercles and below with closely set small plates, the girdle belts are continuous only after the 7th arm bifurcation, and the genital slits are not bordered by tall spines. *A. hirtus* from “Natal or Mozambique”, is perhaps closer to *A. goodingi* **sp. nov.**, but differs mainly in that it has fewer glassy spines on the disc tubercles, radial

shields bearing slender papillae, and complete belts of girdle hooklets from the 6th arm bifurcation (Mortensen, 1933b; A. M. Clark & Courtman-Stock, 1976).

The distinguishing features of *A. goodingi* **sp. nov.** are: Disc and radial shields bearing conical tubercles with 2–8 terminal glassy spines (Fig. 9B–C); Five arm spines bearing 1–5 terminal glassy spinules (Fig. 10I), present from third arm segment; Genital slits narrow and short, bordered abradially by a row of tall spines (Fig. 9F); Girdle bands present from disc margin, and complete between first and second arm branch (Fig. 9A); Arm surface, orally and between girdles covered with large polygonal plates, separated by narrow rows of small single plates (Fig. 9A).

Distribution. Western Indian Ocean including Mayotte Island (type locality) and the Mozambique Channel.

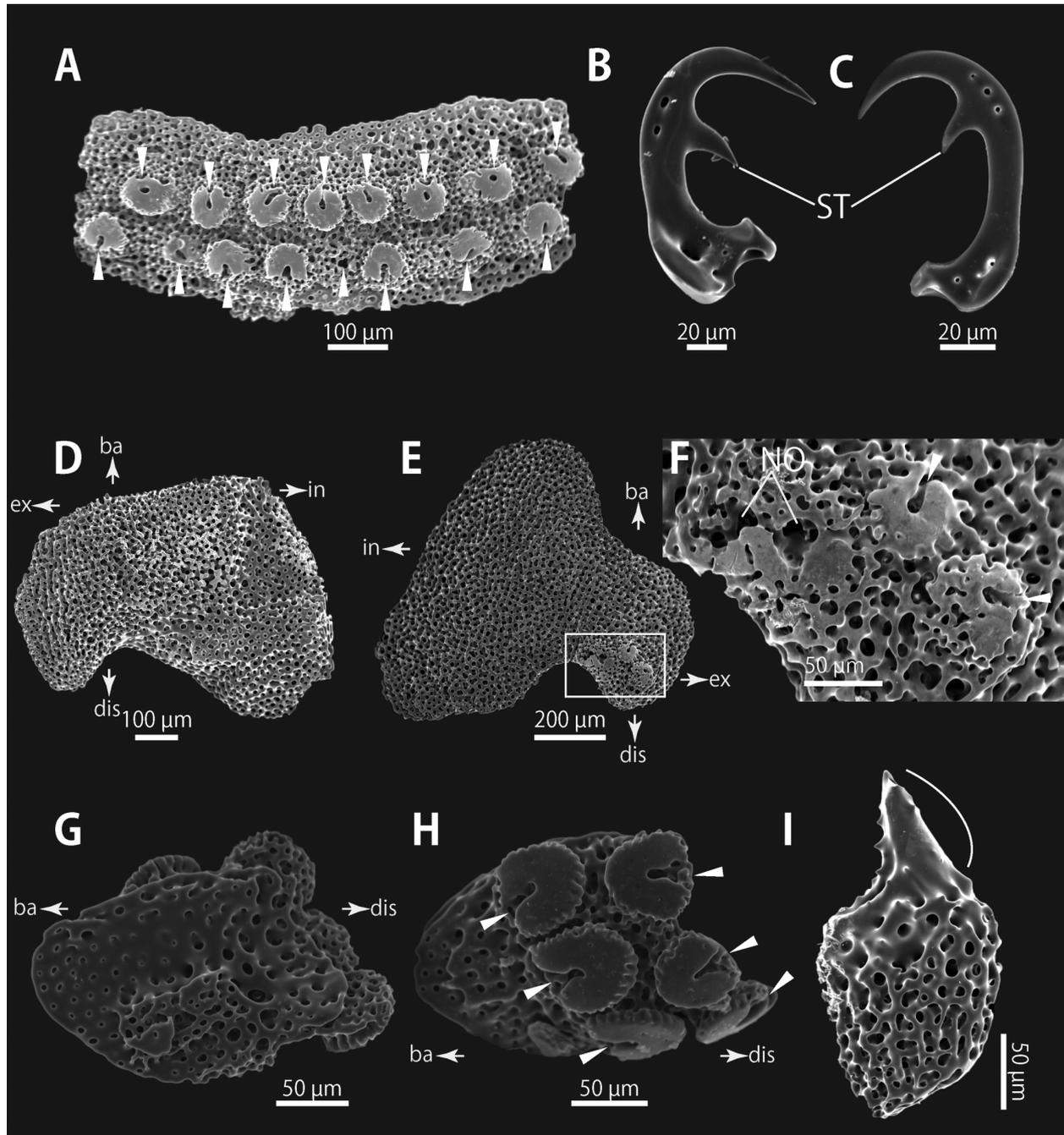


FIGURE 10. *Astrocladus goodingi*, holotype (USNM 1072479), SEM photographs of ossicles. A, a hooklet-bearing plate at the basal portion of the arm; B–C, hooklets on middle portion (B) and distal portion (C) of the arm; D–E, lateral arm plates on basal portion of the arm, internal (D) and external (E) views a square part is enlarged in F; G–H, lateral arm plates on distal portion of the arm, internal (G) and external (H) views. I, arm spine on basal portion of the arm, an arc indicates a terminal projection. Arrow heads indicate articulations for hooklets. Arrows indicate orientations: ba, basal side; dis, distal side; ex, external side; internal side. Abbreviations: ST, secondary tooth.

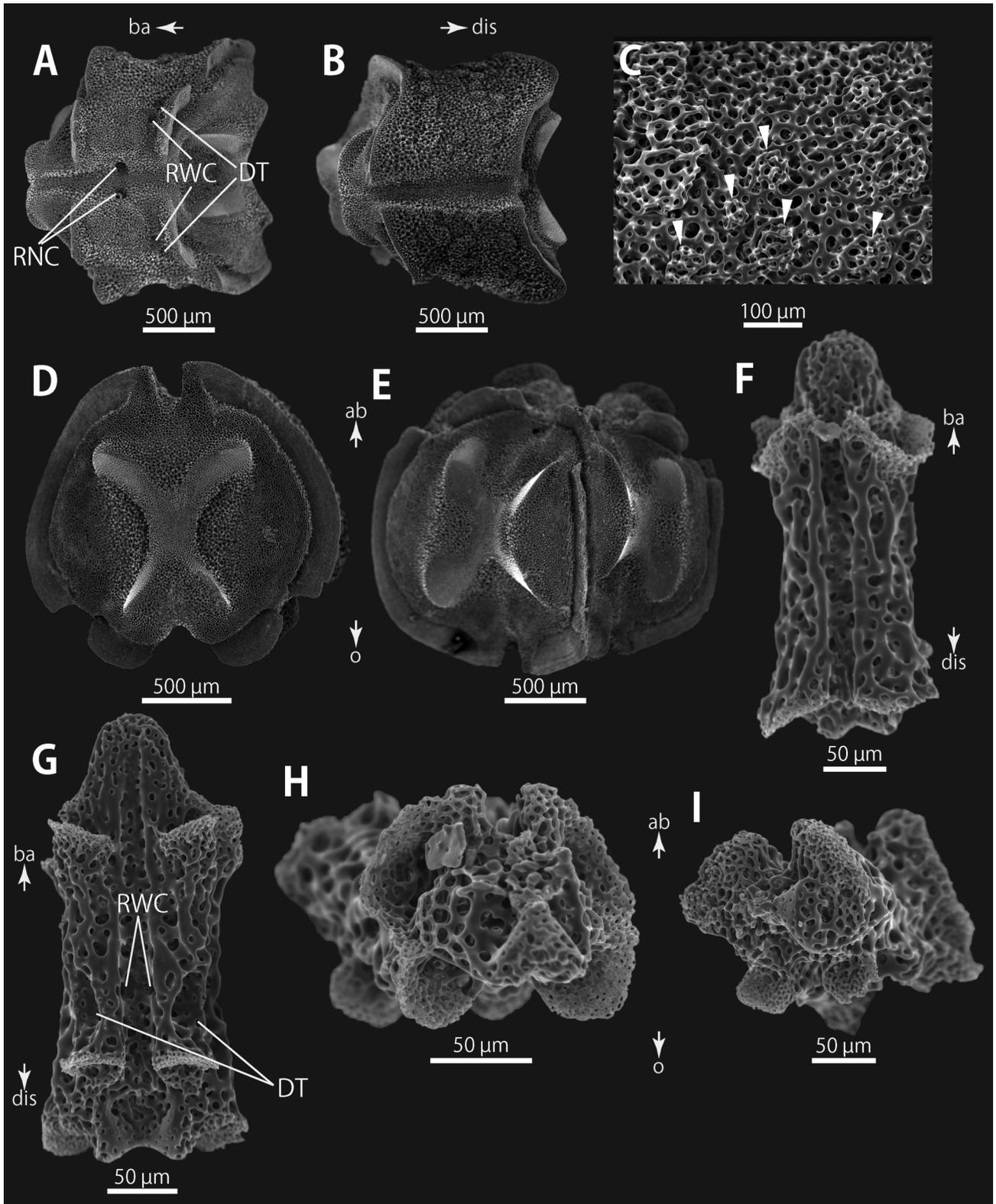


FIGURE 11. *Astrocladus goodingi*, holotype (USNM 1072479), SEM photographs of ossicles. A–E, vertebrae at the basal portion of the arms, oral view (A), aboral view (B), aboral furrow (C), basal view (D), distal branching view (E); F–I, vertebrae at the distal portion of the arm, aboral view (F), oral view (G), basal view (H), distal view (I). Orientations: ab, aboral side; ba, basal side; dis, distal side; o, oral side. Abbreviations: DT, depression for tentacle; RWC, radial water canal; RNC, radial nerve canal.

***Astrocladus socotrana* sp. nov.**

(Figs. 12–16)

Material Examined. Holotype: USNM 1072535, *Anton Bruun* Cruise 9 Station 465, south of Socotra Island, 11°37'N, 51°27'E, 67–72 m, 18 December 1964, 1 specimen, disc diameter 21 mm (Fig. 11–15). **Paratypes:** USNM 1072536, *Anton Bruun* Cruise 9 Station 463, south of Socotra Island, 11°24'N, 51°35'E, 75–175 m, 17 December 1964, 2 specimens, disc diameter 32 mm (Figure 3B) and 33 mm. USNM 1201811, same locality data as Holotype, 1 specimen, disc diameter 12 mm.

Etymology. The specific name refers to the type locality, which is also mountainous, like the aboral surface of this species.

Diagnosis. Disc closely covered with tall conical tubercles with smooth rounded apices; proximal aboral and lateral surfaces of arms with similar but smaller tubercles. Oral arm surfaces covered with flat polygonal plates with slightly raised sutures. Arms with six or seven branches.

Description of holotype. External morphology. Radial shields, center of disc, and interradial areas covered with prominent cone-shaped tubercles with smooth tops lacking any glassy spines (Figs. 12A, C, 13A–B, E). Largest tubercles tall (< 3.2 mm high), on and obscuring radial shields, becoming smaller centrally where the disc is deeply depressed (Fig. 13A–B). Genital slits bordered by minute papillae each with one fine glassy terminal point (Fig. 13D). Oral papillae clustered at proximal tip of jaw, absent distally (Fig. 13C). One madreporite at a margin of an interradius.

Five branching arms, up to 120 mm long, tightly coiled (Fig. 12A–B). First branch at disc margin, thereafter bifurcating 6–7 times. Aboral and lateral surfaces of arms out to between third and fourth branches with scattered tubercles similar to, but smaller than, those on disc (Fig. 13D–E). Distal arm surfaces with dense covering of circular, raised granules (Fig. 14A). Oral surfaces of arms covered with flat polygonal plates with slightly raised sutures (Fig. 14B–D). Six arm segments to first arm fork at disc margin, five to second fork.

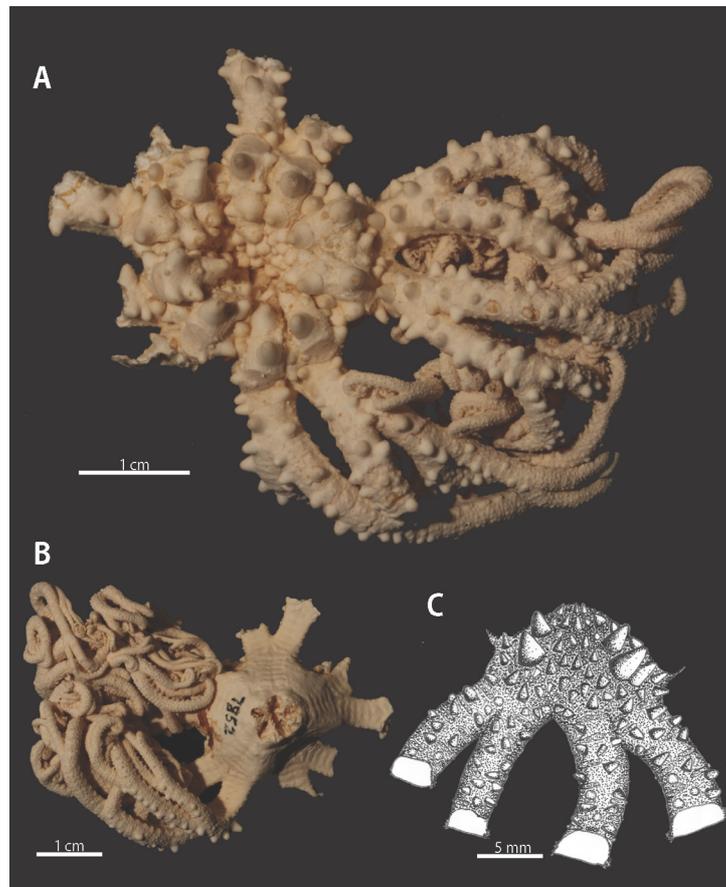


FIGURE 12. *Astrocladus socotrata*, holotype (USNM 1072535). A, aboral view; B, oral view; C, aboral disc and basal portion of the arm.

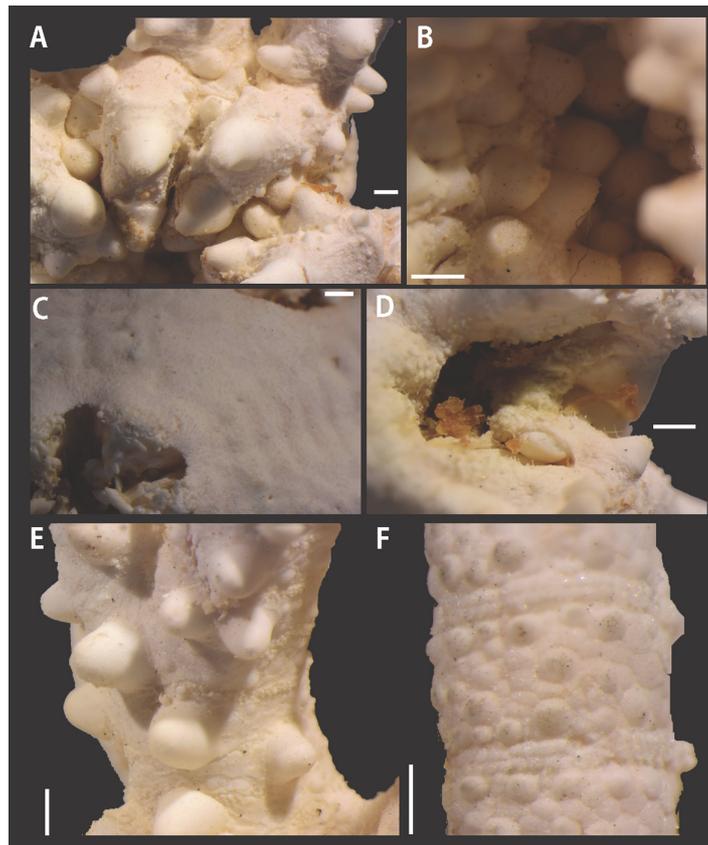


FIGURE 13. *Astrocladus socotrata*, holotype (USNM 1072535). A, aboral peripheral disc; B, aboral central disc; C, oral disc; D, lateral disc; E, aboral basal portion of the arm; F, aboral middle portion of the arm. Scale bars, 1 mm.

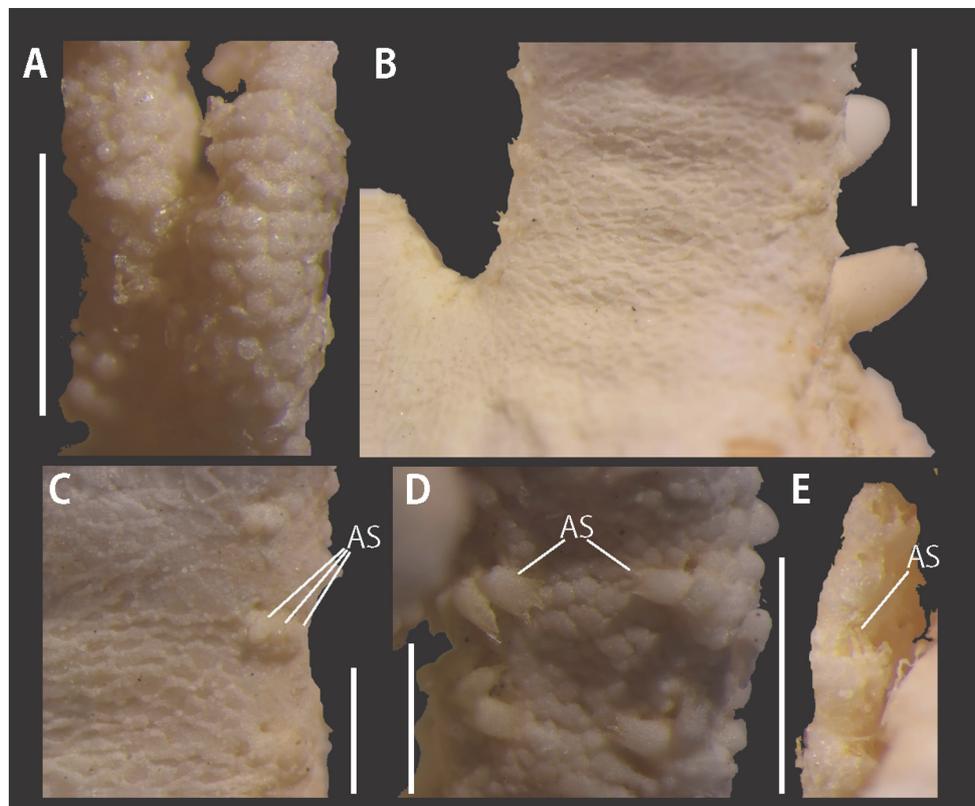


FIGURE 14. *Astrocladus socotrata*, holotype (USNM 1072535). A, aboral distal portion of the arm; B, oral basal portion of the arm; C, arm spines on oral basal portion of the arm; D, oral middle portion of the arm; E, oral distal portion of the arm. Abbreviation. AS, arm spine. Scale bars, 1 mm.

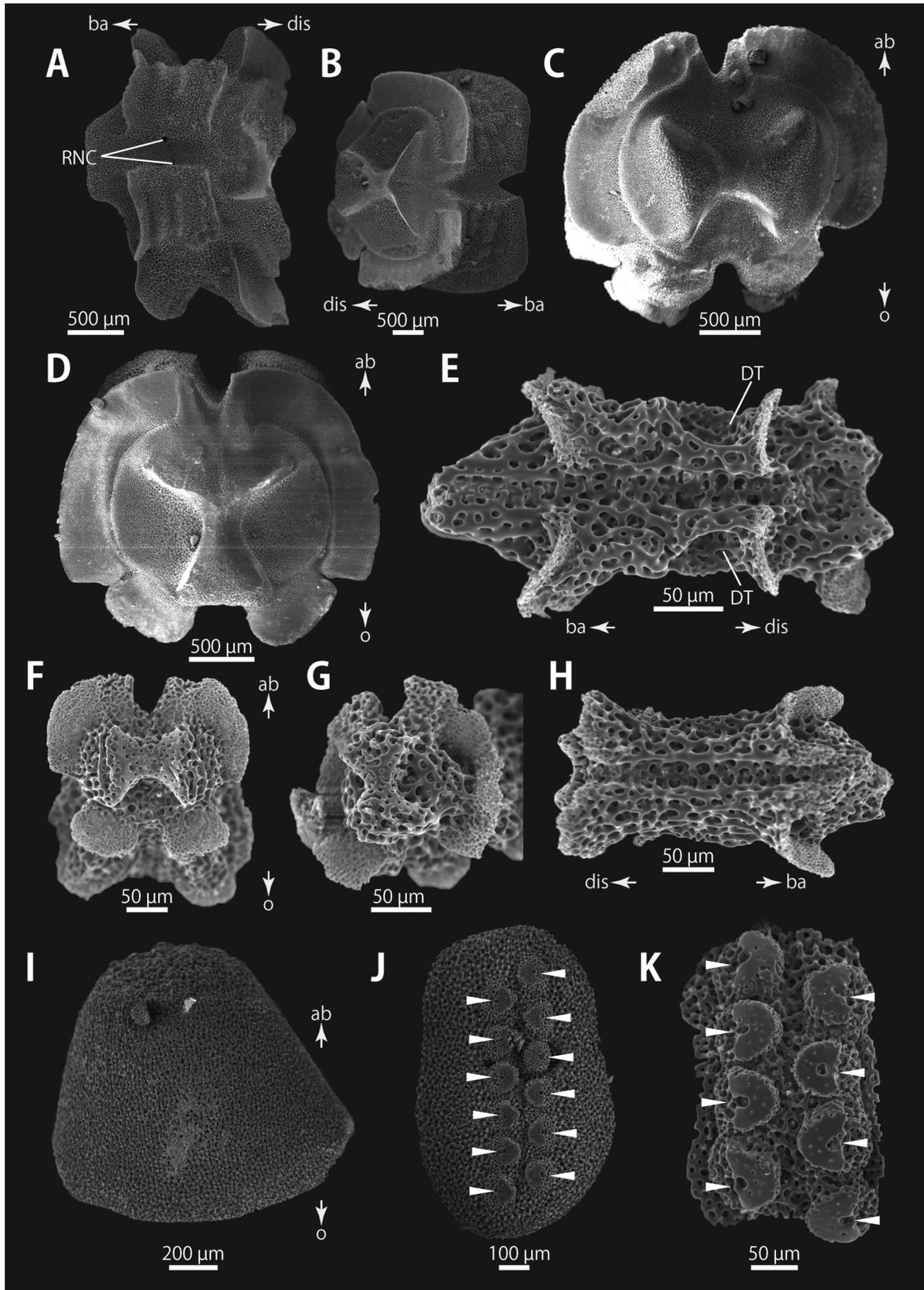


FIGURE 15. *Astrocladus socotrata*, holotype (USNM 1072535), SEM photographs of ossicles. A–D, vertebrae at the basal portion of the arms, oral view (A), aboral view (B), distal view (C), basal view (D); E–H, vertebrae at the distal portion of the arm, oral view (E), distal view (F), basal view (G), aboral view (H); I, tubercle on aboral basal portion of the arm; J–K, hooklets-bearing plates on basal portion of the arm (J) and distal portion of the arm (K), arrow heads indicate articulations for hooklets. Orientations: ab, aboral side; ba, basal side; dis, distal side; o, oral side. Abbreviations: DT, depression for tentacle; RNC, radial nerve canal.

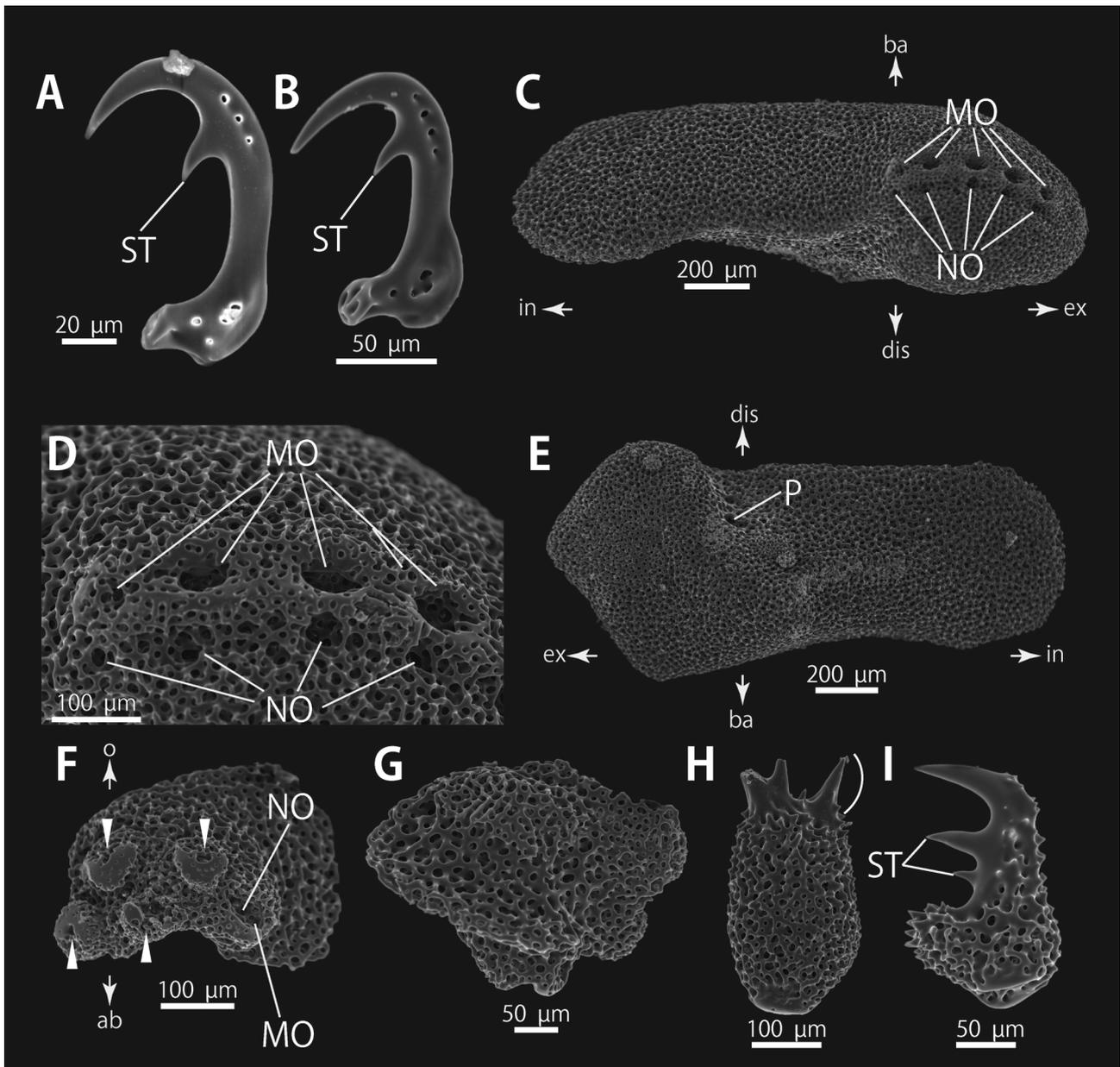


FIGURE 16. *Astrocladus socotrata*, holotype (USNM 1072535), SEM photographs of ossicles. A–B, hooklets on basal portion (A) and distal portion (B) of the arm; C–E, lateral arm plates on basal portion of the arm, external view, a square part is enlarged in D, and internal view (E); F–G, lateral arm plates on distal portion of the arm, external (F) and internal (G) views, arrow heads indicate articulations for hooklets. H–I, arm spine on basal portion of the arm (H) and distal portion of the arm (I) an arc indicates a terminal projections. Arrows indicate orientations: ab, aboral side; ba, basal side; dis, distal side; ex, external side; internal side; o, oral side. Abbreviations: MO, muscle opening; NO, nerve opening; P, perforation; ST, secondary tooth.

Arm spines present from adjacent to first arm fork (Fig. 14B), four spines throughout arm (Fig. 14B–E), spines initially simple on proximal segments, developing a glassy terminal point and three secondary points distally. Discontinuous girdle bands on arms from disc margin, becoming continuous before the third fork (Figs. 13D–E, 14A).

Ossicle morphology. All vertebrae with hourglass-shaped streptospondylous articulations (Fig. 15C–D, F–G). Surfaces of lateral and aboral furrows with tubercles on basal portion of the arm (Fig. 15B). Depressions for tube feet openings in the distal part of oral-lateral side of vertebrae (Fig. 15A, E). A pair of radial water canals opening on the oral groove of vertebrae, near depression of the tube feet (Fig. 15A, E). Tubercles on basal portion of the arms with smooth rounded apices (Fig. 15I). Hooklet-bearing plates possessing approximately 12 tubercle-shaped

articulations for hooklets in the basal portion of the arm (Fig. 15J), approximately 8 articulations in the distal portion (Fig. 15K). The articulations form two parallel rows (Fig. 15J, K). Each hooklet bearing one inner tooth (Fig. 16A–B). Lateral arm plates long, bar like, with straight distal edge and concave basal edge (Fig. 16C, E). On basal portion of arm, lateral arm plates with a perforation on inner side and pairs of simple nerve and muscle openings on oral-external side (Fig. 16C–E) and on distal portion of the arms, two nerve openings besides the dorsal lobe and three articulations for hooklets on oral surfaces (Fig. 16F). No perforation visible on inner side (Fig. 16G). Arm spines on the basal portion of the arm ovoid and having three secondary points, approximately one-seventh length of the height of the spine (Fig. 16H). Distally, the arm spines transformed into hooks with two or three inner teeth, respectively (Fig. 16I). The hook-shaped arm spines distinguished from hooklets on aboral and lateral surface of the arm by lacking reticular structure (Fig. 16A–B, I).

Remarks. *Astrocladus socotrana* sp. nov. is remarkable for its dense covering of prominent, smooth disc and arm tubercles, which distinguish it from its closest congeners, such as *A. exiguus* and *A. euryale*, which have reduced tuberculation, mostly on the radial shields.

Distribution. Known only from type locality, south of Socotra, northern Indian Ocean, 62–175 m.

Genus *Astrocyclus* Lütken, 1856

Astrocyclus somaliensis sp. nov.

(Figs. 17A–C, 18–21)

Material Examined. Holotype: USNM 1411388 Anton Bruun station 9–463, 11° 24' N, 51° 35' E, 75–175 m, 18 December 1964, off the north-eastern coast of Somalia, 1 specimen, disc diameter 27 mm (Fig. 16). **Paratypes:** USNM 1422067, same locality data as holotype, 3 specimens, disc diameter 24, 16 and 10 mm.

Etymology. The specific name refers to the collection locality.

Diagnosis. *Astrocyclus* with aboral surface of disc depressed centrally, radial shields converging at center. Radial shields partly covered with more or less continuous transverse thin white lines made up of closely packed granules (6–8/mm), which loop over the shields and partly extend into the inter-shield and interradiial areas.

Description of the holotype. External morphology. The disc five-lobed, 27 mm in disc diameter, with arms at least 115 mm long (Fig. 17A–B). The disc markedly depressed centrally (Fig. 18A); narrow, raised, radial shields converging there (Fig. 18A–B). The entire aboral surface, including the area between each of the radial shields, covered with evenly spaced low granules (Fig. 18A–B). The radial shields partly covered with more or less continuous transverse white lines made up of microscopic, closely packed granules (6–8/mm), which loop over the radial shields, with some partly extending into the inter-shield and inter-radial areas of the disc. The arm segments are conspicuously ringed laterally and aborally by narrow bands of microscopic granules, mostly in two rows, which stand out from the surface (Fig. 19B–D). There are two, then three, small arm spines with hyaline tips per segment (Fig. 18D–F). The distalmost arm segments have girdle bands, with strongly curved hyaline hooklets (Fig. 19D). The oral surface of the arms and disc are covered with evenly spaced granules, and there is one madreporite in each of the five interradiial disc areas, jaws entirely covered by spiniform teeth and oral papillae (Fig. 18C).

Ossicle morphology. All vertebrae with hourglass-shaped streptospondylous articulations (Fig. 20C–D, G–H). Surfaces of lateral and aboral furrows smooth, without ornamentations (Fig. 20A–B, E–F). Depressions for tube feet openings in the distal part of oral-lateral side of vertebrae (Fig. 20A, F). A pair of radial water and nerve canals opening on the oral groove of vertebrae on basal portion of the arm (Fig. 20A) but radial nerve canals invisible on distal portion of the arm (Fig. 20F). Lateral arm plates long, bar-like, with straight basal edge and concave distal edge (Fig. 20I–J). On basal portion of arm, perforation invisible on aboral side and pairs of simple nerve openings on oral-external side (Figs. 20J, 21A). Hooklet-bearing plates possessing tubercle-shaped articulations for hooklets, approximately 7 on distal portion of the arm (Fig. 21B). The articulations forming two parallel rows (Fig. 21B). Each hooklet without inner teeth (Fig. 21G–H). Arm spines in the basal portion of the arm ovoid, with one or two secondary points (Fig. 21D–E). In the distal portion, the arm spines transformed into hooks with one inner teeth (Fig. 21F). The hook-shaped arm spines distinguished from hooklets on aboral and lateral surface of the arm by lacking reticular structure (Fig. 21F–H).

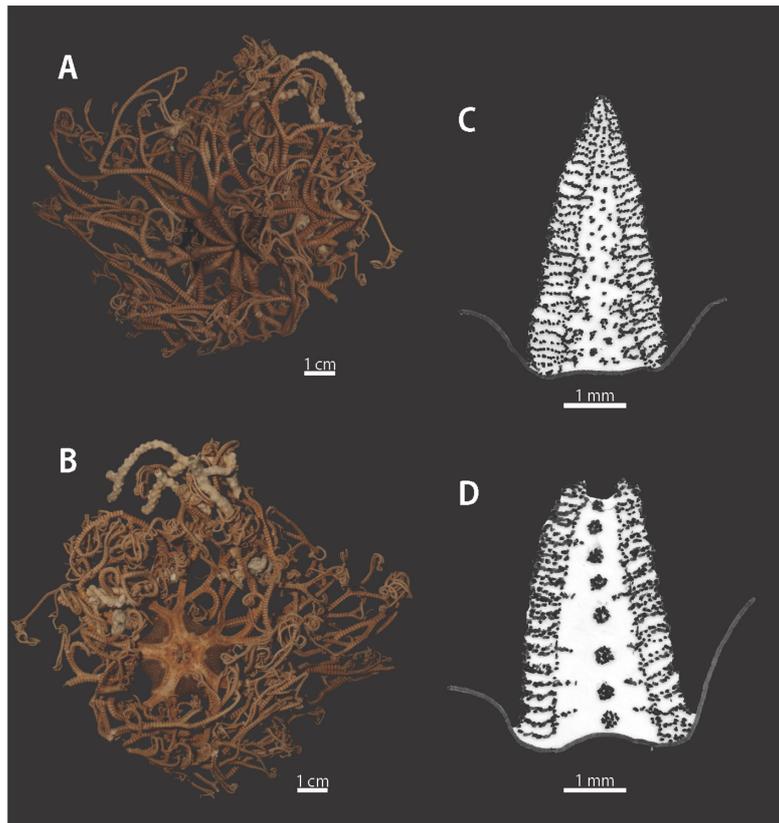


FIGURE 17. *Astrocyclus somaliensis*, holotype (USNM 1411388) (A–C) and *Astrocyclus caecilia* (after Gondim *et al.* (2014)) (D). A, aboral view; B, oral view; C, radial shields showing line and granule cover; D, radial shields showing intarradial groups of granules.

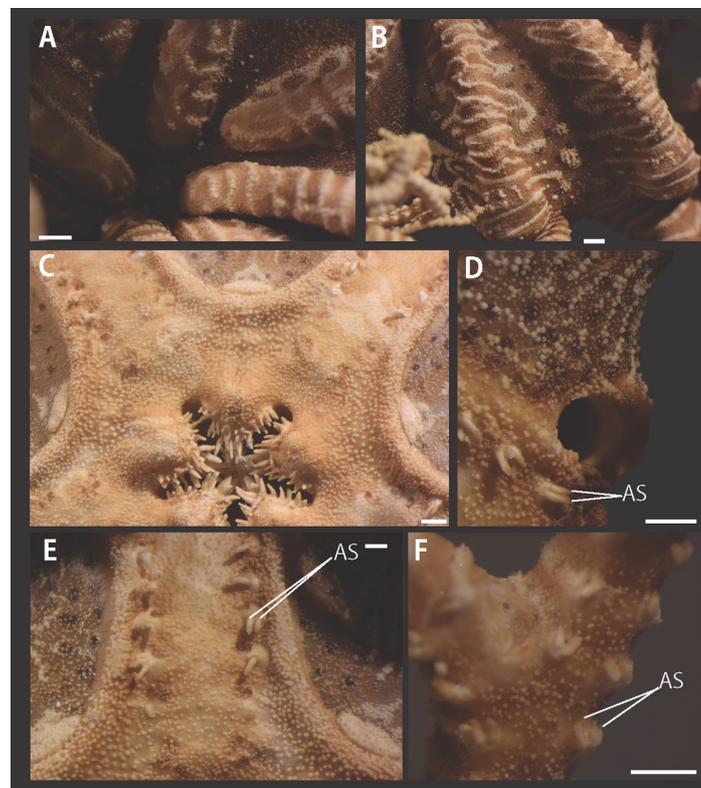


FIGURE 18. *Astrocyclus somaliensis*, holotype (USNM 1411388). A, aboral central disc; B, aboral peripheral disc; C, oral disc; D, lateral disc; E, aboral basal portion of the arm; F, oral middle portion of the arm. Abbreviation. AS, arm spine. Scale bars, 1 mm.

Variation. In the smallest specimen (USNM 1422067, dd. 10 mm), the entire area between the shields is covered with transverse lines. This feature differs from that in the Brazilian samples described and illustrated by Gondim *et al* (2014), where between each radial shield there are 6–7 discrete groups of granules running in line with the shields (Fig. 17D). In the two larger specimens (USNM 1411388, dd. 27 mm; USNM 1422067, dd. 24 mm), a few of these lines of granules extend between the shields.

Remarks. As all four examined specimens from the Indian Ocean have similar disc and radial shield coverings which differ markedly from the western Atlantic specimens, we consider that they represent a separate taxon, which we here establish as a new species. The arms bifurcate at least 15 times, the first branch within the diameter of the disc, and the second at the distal end of the radial shields (Fig. 17A–B).

Astrocyclus caecilia has been recorded from the Caribbean Sea, Gulf of Mexico (type locality), and from northeastern Brazil by Gondim *et al.* (2014), who have illustrated the species extensively. The vast geographical separation of the type species and the Somalian form, plus the obvious morphological difference in the covering of the radial shields and their interradial aboral areas, indicate that a new species, *Astrocyclus somaliensis* **sp. nov.** should be erected for this Somalian form.

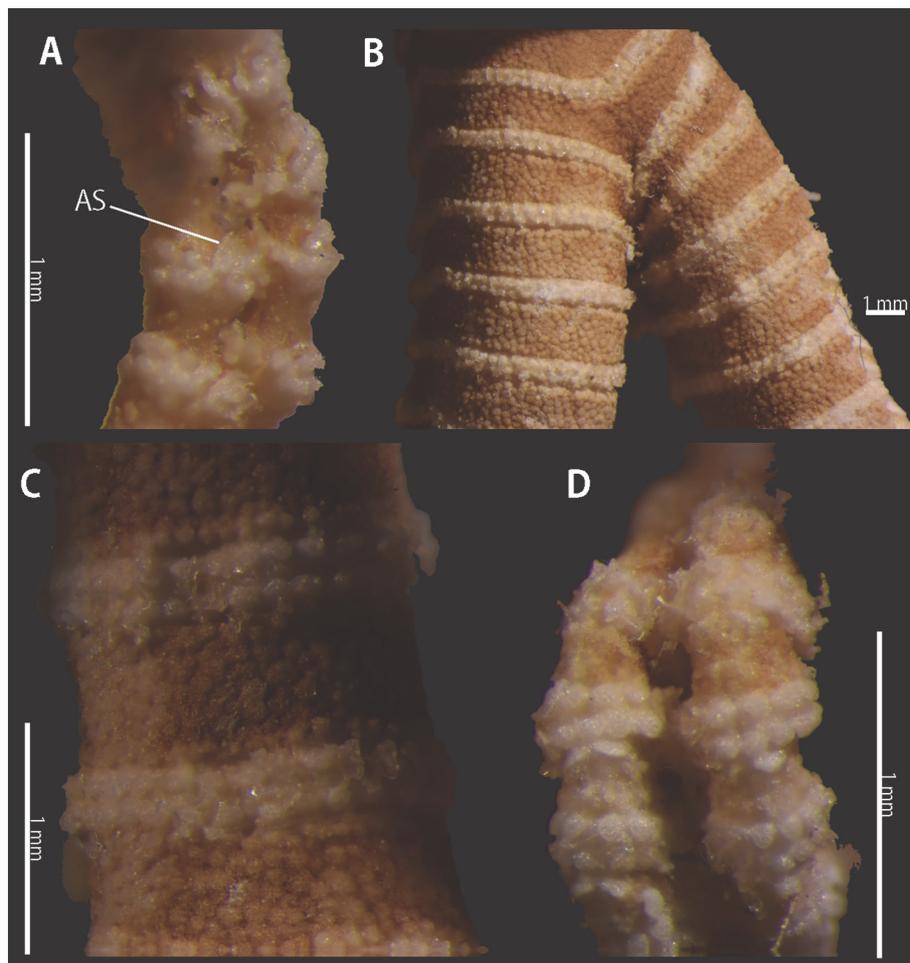


FIGURE 19. *Astrocyclus somaliensis*, holotype (USNM 1411388). A, oral distal portion of the arm; B, aboral basal portion of the arm; C, aboral middle portion of the arm; D, aboral distal portion of the arm. Abbreviation. AS, arm spine. Scale bars, 1 mm.

Astroglymma sculptum (Döderlein 1896)

(Fig. 22)

Astrophyton sculptum Döderlein, 1896: 299, pl.18 fig. 29.

Astroglymma sculptum.—Döderlein, 1927: 47, pl. 1 fig. 3,4; pl. 5 fig. 13. Baker, 1980: 66, figs. 19, 28, 31; Liao & A. M. Clark, 1995: 170, fig. 74; Rowe & Gates, 1995: 365.

Material Examined. USNM 1072476, *Anton Bruun* Cruise 8 Station 394B, off Durban, 29° 27' S, 31° 31' E, 68–70 m, 29 September, 1964, 3 specimens plus arm fragments of a 4th. USNM 1072575, *Anton Bruun* Cruise 8 Station 403E, off Mozambique, 19° 09' S, 36° 55' E, 88 m, 2 specimens, 9 October 1964. USNM 1233996, *Anton Bruun* Cruise 8 Station 394A, Off Durban, South Africa, 29° 26' S, 31° 32' E, 68 m, 25 September 1964, 1 specimen.

Remarks. Two specimens from Station 394B are very large (dd. 76 and dd. 81 mm) and are typical of the species (Fig. 22A–B). A medium-sized specimen (dd. 30 mm) is uniformly covered with fine pustules and occasional larger ones (Fig. 22C–E). The arms are bifurcated 16–17 times and carry girdle bands after the first branch. Otherwise the description matches that in Baker, (1980 p. 66) of material from the eastern Indian Ocean.

Distribution. Originally described from USFC *Albatross* material from the Philippines, this shallow water basket star is widely distributed in the Indo-Malaysian region, and in the east China Sea in 73–300m depth (Baker, 1980), and its occurrence off Durban and further north off Mozambique, is not unexpected.

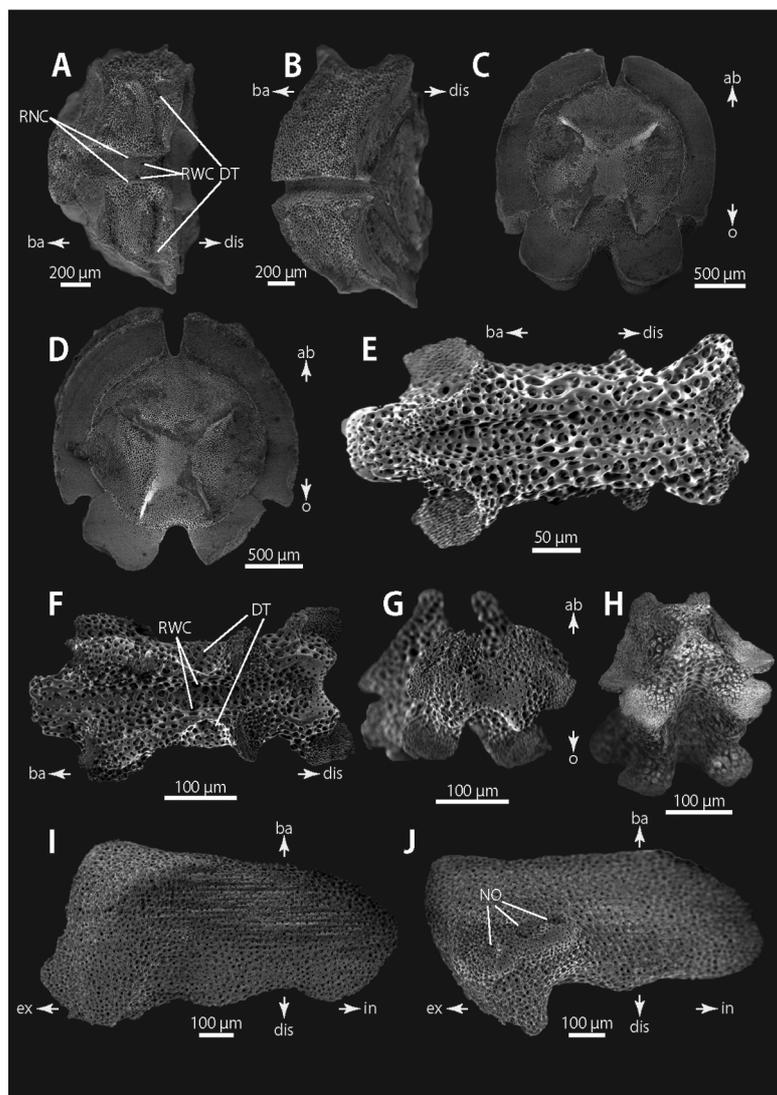


FIGURE 20. *Astrocylus somaliensis*, holotype (USNM 1411388), SEM photographs of ossicles. A–D, vertebrae at the basal portion of the arms, oral view (A), aboral view (B), basal view (C), distal view (D); E–H, vertebrae at the distal portion of the arm, aboral view (E), oral view (F), distal view (G), oral view (H); I–J, lateral arm plates on basal portion of the arm, internal view (I) and external view (J). Orientations: ab, aboral side; ba, basal side; dis, distal side; ex, external side; in, internal side; o, oral side. Abbreviations: DT, depression for tentacle; NO, nerve opening; RNC, radial nerve canal.

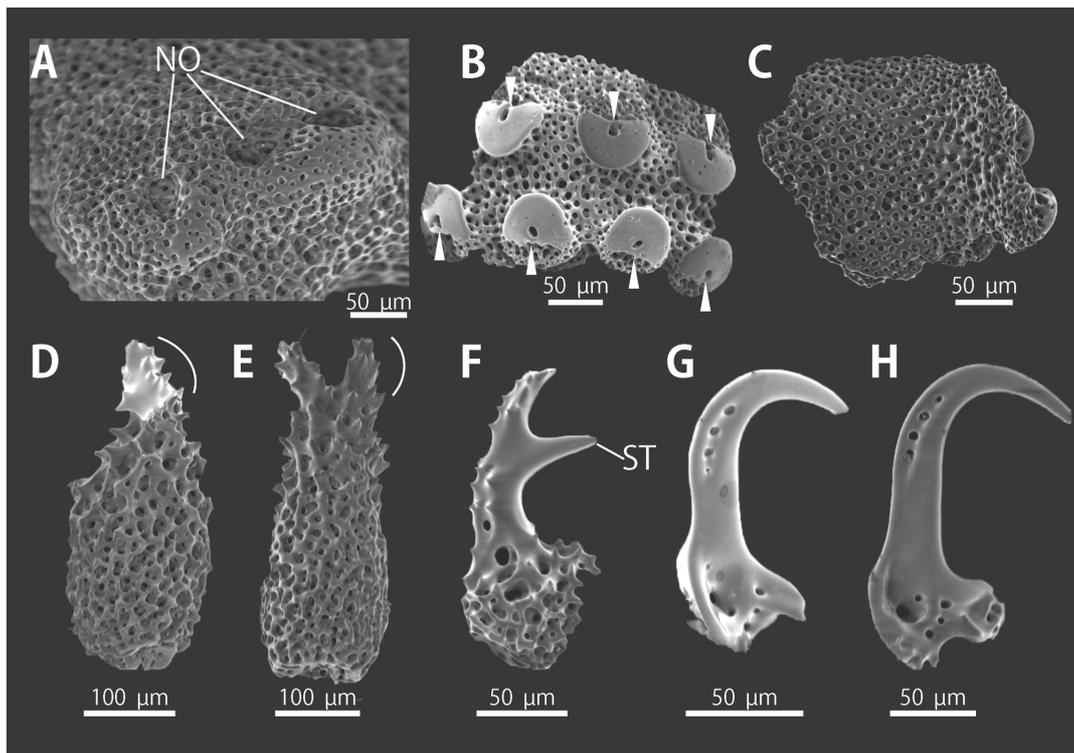


FIGURE 21. *Astrocyclus somaliensis*, holotype (USNM 1411388), SEM photographs of ossicles. A, articulations for arm spines of lateral arm plate on basal portion of the arm; B–C, hooklets-bearing plate on distal portion of the arm, external view (B) and internal view (C), arrowheads indicate articulations for hooklets; D–F, arm spines on basal (D, E) and distal (F) portion of the arm, arcs indicate terminal projections; G–H, hooklets on basal (G) and distal (H) portion of the arm. Abbreviations: NO, nerve opening; ST, secondary tooth.

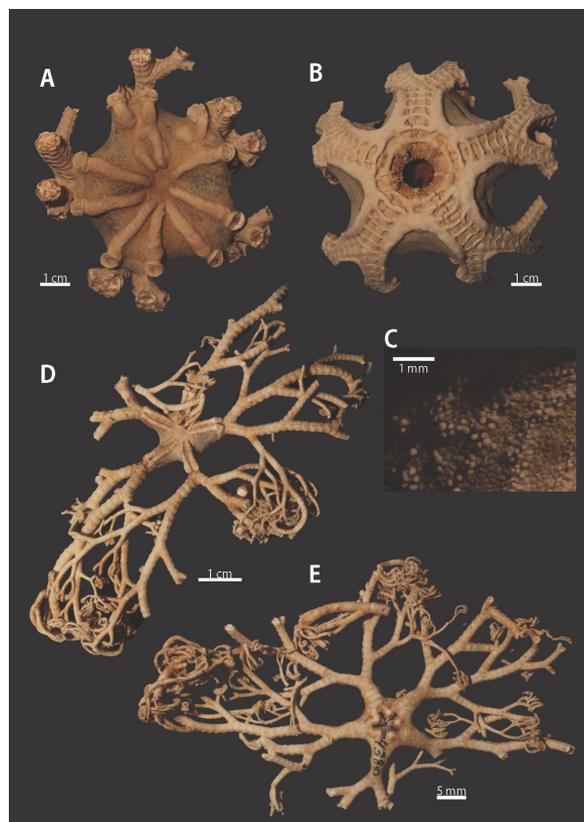


FIGURE 22. *Astroglymma sculptum* a larger (A–C) and a smaller (D–E) specimens of USNM 1072575. A, aboral view; B, oral view; C, aboral peripheral disc; D, aboral view; E, oral view.

Acknowledgments

We are indebted to the late Dr R.U. “Judge” Gooding and other scientists and crew of the research vessels *Anton Bruun* and *Pioneer*, who participated in the International Indian Ocean Expedition in 1963–64, and collected the material reported here. ANB wishes to record his appreciation of the late Dr Dennis Devaney of the Bernice P. Bishop Museum, Hawaii, who originally distributed the euryalid brittle stars for detailed study. Thanks are also extended to Dr. Manabu Yoshida, Mr. Kohei Oguchi and Dr. Toru Miura of Misaki Marine Biological Station, The University of Tokyo for their assistance in photography of the specimens with JEOL JSM-5510LV SEM and OLYMPUS SZX7. We dedicate this paper to the memory of our friends and colleagues Drs. Dennis Devaney and “Judge” Gooding. We are also grateful to Smithsonian Volunteer Mr. Bob Ford, for his skill in assembling the original illustrations.

Dr. Alan Noel Baker died on October 13, 2017, in Kerikeri, New Zealand, after a long illness. An earlier version of this paper, by Baker & Pawson, has been thoroughly revised by Dr. Masanori Okanishi. The pen-and-ink line illustrations in Figures 7, 12, and 17 were prepared by Dr. Baker; all other illustrations were prepared by Dr. Okanishi. Dr. Baker’s wife Diana, and her family, and the third author David Pawson, are most grateful to Dr. Okanishi for his great generosity.

References

- Baker, A.N. (1980) Euryalinid Ophiuroidea (Echinodermata) from Australia, New Zealand, and the south-west Pacific Ocean. *New Zealand Journal of Zoology*, 7, 11–83.
<https://doi.org/10.1080/03014223.1980.10423763>
- Barboza, C.A.M., Frensel, R. & Campos, L.S. (2010) *Asteroschema arenosum* Lyman, 1878. In: Lavrado, H.P. & Brasil, A.C.S. (Eds.), *Biodiversidade da região oceânica profunda da Bacia de Campos: Megafauna e Ictiofauna demersal*. SAG Serv, Rio de Janeiro, pp. 242–243.
- Behrman, D. (1981) *Assault on the unknown: the International Indian Ocean Expedition 1959–65*. The Unesco Press, Paris, 96 pp.
- Cherbonnier, G. & Guille, A. (1978) *Faune de Madagascar. 48. Echinodermes: Ophiurides*. Mémoires ORSTOM, Paris, 272 pp.
- Clark, A.M. (1974) Notes on some Echinoderms from Southern Africa. *Bulletin of the British Museum of Natural History (Zoology)*, 26 (6), 423–487.
<https://doi.org/10.5962/bhl.part.210>
- Clark, A.M. & Courtman-Stock, J. (1976) *The Echinoderms of Southern Africa*. British Museum of Natural History, London, 277 pp.
- Clark, H.L. (1911) North Pacific ophiurans in the collection of the United States National Museum. *United States National Museum Bulletin*, 75, 1–302.
<https://doi.org/10.5479/si.03629236.75.1>
- Clark, H.L. (1915) Catalogue of recent ophiurans: based on the collection of the Museum of Comparative Zoölogy. *Memoirs of the Museum of Comparative Zoology of Harvard College*, 25, 165–376.
- Döderlein, L. (1896) Bericht über die von Herrn Prof. Semon bei Amboina und Thursday Islands gesammelten Ophiuroidea. In: Semon, R.W. Zoologische Forschungsreisen in Australien und dem Malayischen Archipel. *Jenaische Zeitschrift für Medizin und Naturwissenschaft*, 8, 279–300.
- Döderlein, L. (1911) Beiträge zur Naturgeschichte Ostasiens. Über Japanische und andere Euryalae. *Abhandlungen der Bayerischen Akademie der Wissenschaften II*, Supplement Band 5, 1–123.
- Döderlein, L. (1927) Indopacifische Euryalae. *Abhandlungen der Bayerischen Akademie der Wissenschaften Mathematisch-naturwissenschaftliche Abteilung*, 31 (6), 1–105.
- Frensel, R.R., Barboza, C.A.M., Moura, R.B. & Campos, L.S. (2010) Southwest Atlantic deep-sea brittle stars (Echinodermata: Ophiuroidea) from Campos Basin, Brazil. In: Harris, L.G., Bottger, S.A., Walker C.W. & Lesser, M.P. (Eds.), *Echinoderms: Durham*. CRC Press, Leiden, pp. 173–180.
- Fujita, T. & Irimura, S. (2005) Ophiuroids (Echinodermata) collected by R/V Yoko-Maru off southwestern Japan in the East China Sea. In: Hasegawa, K., Shinohara, O. & Takeda, M. (Eds.), *Deep-sea fauna and pollutants in Nansei Islands. National Science Museum Monograph*, 29, pp. 357–384.
- Gondim, T., Dias, L.P. & Christoffersen, M.L. (2014) First record of basket stars *Astrocyclus caecilia* (Lütken, 1856) and *Astrophyton muricatum* (Lamarck, 1816) (Echinodermata, Ophiuroidea, Euryalida) for the state of Rio Grande do Norte, northeastern Brazil. *Check List*, 11 (1), 1–6.
- Gray, J.E. (1840) A synopsis of the genera and species of the Class Hypostoma (*Asterias* Linn.). *Annals and Magazine of Natural History*, Series 1, 6, 175–184, 275–290.

<https://doi.org/10.1080/03745484009443282>

- Humphrey, G.F. (1972) The biology of the Indian Ocean. *Unesco Intergovernmental Oceanographic Commission Technical Series*, 10, 7–22.
- Irimura, S. & Kubodera, T. (1998) Ophiuroidea in the East China Sea. *Memoirs of the National Science Museum, Tokyo*, 30, 135–143.
- Koehler, R. (1898) Echinodermes recueillis par l'Investigateur dans l'Océan Indien. II. Les Ophiures littorales. *Bulletin Scientifique de la France et de la Belgique*, 31, 55–124.
- Lamarck, J.B.P. (1816) *Stellerides*. In: *Histoire naturelle des animaux sans vertèbres. Edition 1.2*. Verdière, Paris, pp. 522–568.
- Liao, Y. & Clark, A.M. (1995) *The echinoderms of southern China*. Science Press, Beijing, 614 pp.
- Ljungman, A. (1867) Ophiuroidea viventia huc usque cognita enumerat. *Ofversigt af Kungliga Vetenskapsakademiens förhandlingar, Stockholm*, 1866 (9), 303–336.
- Ludwig, H. (1878) *Trichaster elegans*. *Zeitschrift für Wissenschaftliche Zoologie*, 31, 59–67.
- Lütken, C.F. (1856) Bidrag til Kundskab om Slangestjernerne. II Oversigt over de vistindiske Ophiurer. *Videnskabelige Meddelelser fra Dansk naturhistorisk Forening i Kjøbenhavn*, 7, 1–19.
- Lütken, C.F. (1869) Additamenta ad historiam Ophiuroidarum. Beskrivende og kritiske Bidrag til Kundskab om Slangestjernerne. *Videnskabs Selskabet Skrifter, 5 Raekke, naturvidenskabelig og matematisk*, 8, 24–109.
- Lyman, T. (1861) Descriptions of new Ophiuroidea. *Proceedings of the Boston Society of Natural History*, 8, 75–86.
<https://doi.org/10.5962/bhl.part.10220>
- Lyman, T. (1878) Reports on the results of dredging, under the supervision of Alexander Agassiz, in the Gulf of Mexico, by the U.S.S. Coast Survey Steamer “Blake”. Ophiurans and Astrophytions. *Bulletin of the Museum of Comparative Zoology at Harvard College*, 5 (9), 217–238.
- Martens, E. Von (1866) Über östasiatischen Echinodermen. *Archiv für Naturgeschichte*, 1866, 57–88, 133–189.
- Mortensen, T. (1925) On some echinoderms from South Africa. *Annals and Magazine of Natural History*, 16 (9), 146–154.
<https://doi.org/10.1080/00222932508633280>
- Mortensen, T. (1933a) Studies of Indo-Pacific Euryalids. *Videnskabelige Meddelelser fra Dansk naturhistorisk Forening i Kjøbenhavn*, 96, 1–75.
- Mortensen, T. (1933b) Echinoderms of South Africa (Asteroidea and Ophiuroidea). *Videnskabelige Meddelelser fra Dansk naturhistorisk Forening i Kjøbenhavn*, 93, 215–400.
- O'Hara, T.D., Hugall, A.F., Thuy, B., Stöhr, S. & Martynov, A.V. (2017) Restricting higher taxonomy using broad-scale phylogenomics: The living Ophiuroidea. *Molecular Phylogenetics and Evolution*, 107, 415–430.
<https://doi.org/10.1016/j.ympev.2016.12.006>
- Okanishi, M. & Fujita, T. (2009) A new species of *Asteroschema* (Echinodermata: Ophiuroidea: Asteroschematidae) from southwest Japan. *Species Biodiversity*, 14, 115–129.
- Okanishi, M. & Fujita, T. (2011) Molecular phylogeny of the order Euryalida (Echinodermata: Ophiuroidea), based on mitochondrial and nuclear ribosomal genes. *Molecular Phylogenetics and Evolution*, 61 (2), 392–399.
<https://doi.org/10.1016/j.ympev.2011.07.003>
- Okanishi, M., O'Hara, T.D. & Fujita, T. (2011) A new genus *Squamophis* of Asteroschematidae (Echinodermata, Ophiuroidea, Euryalida) from Australia. *Zookeys*, 129, 1–15.
<https://doi.org/10.3897/zookeys.129.1202>
- Okanishi, M. (2016) Ophiuroidea (Echinodermata): systematics and Japanese fauna. In: Motokawa, M. & Kajihara, H. (Eds.), *Species diversity of animals in Japan*. Springer Japan, Tokyo, pp. 651–678.
- Okanishi, M. & Fujita, T. (2013) Molecular phylogeny based on increased number of species and genes revealed more robust family-level systematics of the order Euryalida (Echinodermata: Ophiuroidea). *Molecular Phylogenetics and Evolution*, 69, 566–580.
<https://doi.org/10.1016/j.ympev.2013.07.021>
- Okanishi, M., Olbers, J.M. & Fujita, T. (2013) A taxonomic review of the genus *Asteromorpha* Lütken (Echinodermata: Ophiuroidea: Euryalidae). *The Raffles Bulletin of Zoology*, 61 (2), 461–480.
- Olbers, J.M., Rowe, F.W.E., Griffin, C.L. & Samyn, Y. (2014) The rediscovery of a collection of echinoderms, including two holotypes in the Durban Natural Science Museum, South Africa. *Durban Natural Science Museum Novitates*, 36, 11–29.
- Pawson, D.L., Vance, D.J., Messing, C.G., Solis-Marin, F.A. & Mah, C.L. (2009) Echinodermata of the Gulf of Mexico. In: Felder, D.L. & Camp, D.K. (Eds.), *Gulf of Mexico: Origins, Waters, and Biota. Biodiversity*. Texas A&M University Press, College Station, Texas, pp. 1177–1204.
- Putchakarn, S. & Sonchaeng, P. (2004). Echinoderm fauna of Thailand: history and inventory reviews. *Science Asia*, 30, 417–428.
<https://doi.org/10.2306/scienceasia1513-1874.2004.30.417>
- Rowe, F.W.E. & Gates, J. (1995) Echinodermata. In Wells, A. (Ed.), *Zoological Catalogue of Australia. Vol. 33*. CSIRO Australia, Melbourne, pp. 1–510.
- Shin, S. (1998) Echinoderms from Geojedo Island and adjacent sea waters, Korea. *Korean Journal of Systematic Zoology*, 14 (3), 193–205.
- Sink, S.J., Boshoff, W., Samaai, P., Timm, G. & Kerwath, S.E. (2006) Observations of the habitats and biodiversity of the submarine canyons at Sodwana Bay. *South African Journal of Science*, 102, 466–474.

- Stöhr, S., O'Hara, T. & Thuy, B., (2012) Global Diversity of brittle stars (Echinodermata: Ophiuroidea). *PLoS ONE*, 7(3), 1–14.
<https://doi.org/10.1371/journal.pone.0031940>
- Stöhr, S., O'Hara, T. & Thuy, B. (2018) World Ophiuroidea database. Available from: <http://www.marinespecies.org/ophiuroidea> (accessed 10 January 2018)
- Thuy, B. & Stöhr, S. (2011) Lateral arm plate morphology in brittle stars (Echinodermata: Ophiuroidea): new perspectives for ophiuroid micropalaeontology and classification. *Zootaxa*, 3013, 1–47.
- Venkatraman, C., Venkataraman, K., Rajkumar, R., Shrinivaasu, S., Padmanaban, P., Paramasivam, K. & Sivaperuman, C. (2013) Diversity and distribution of echinoderms in Palk Bay and Gulf of Mannar Biosphere Reserve, Southern India. *In*: Venkataraman, K. Sivaperuman, C. & Raghunathan, C. (Eds.), *Ecology and conservation of tropical marine faunal communities*. Springer-Verlag, Heidelberg, pp. 197–212.
https://doi.org/10.1007/978-3-642-38200-0_13
- Verrill A.E. (1899) North American Ophiuroidea. I. Revision of certain families and genera of West Indian ophiurans. *Transactions of the Connecticut Academy of Sciences*, 10 (7), 301–371.