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A Taxonomic Review of the Genus *Astrocharis* Koehler (Echinodermata: Ophiuroidea: Asteroschematidae), with a Description of a New Species

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A revision of the genus *Astrocharis* Koehler (Echinodermata: Ophiuroidea: Asteroschematidae) is based on 41 specimens, including three syntypes of *Astrocharis virgo* Koehler, one syntype of *Astrocharis ijimai* Matsumoto and the holotype of *Astrocharis gracilis* Mortensen. *Astrocharis gracilis* is a junior subjective synonym of *A. ijimai*. *A. virgo* and *A. ijimai* are redescribed. A new species, *Astrocharis monospinosa* is described from southwestern Japan. A tabular key to the three species of the genus *Astrocharis* is provided.

Key words: Taxonomy, brittle stars, *Astrocharis monospinosa*, new species, West-Pacific

INTRODUCTION

The asteroschematid brittle stars of the genus *Astrocharis* are known from deep waters (522–1089 m) of the western Pacific, including southern Japan, northeastern Indonesia, and the southern Philippines (Koehler, 1904, 1922; Matsumoto, 1911; Mortensen and Stephensen, 1918; Döderlein, 1927; Kroh, 2003).

This genus was erected by Koehler (1904) monotypically for *Astrocharis virgo* Koehler, 1904 and is currently composed of three species, *A. virgo*, *A. ijimai* Matsumoto, 1911 and *A. gracilis* Mortensen, 1918. The naked radial shields of *Astrocharis* are a unique synapomorphy among the Asteroschematidae. Taxonomic works on *Astrocharis* are few. *Astrocharis virgo* was originally described by Koehler (1904) based on three specimens, and recorded by Koehler (1922) based on another specimen. *Astrocharis ijimai* was originally described by Matsumoto (1911, 1915, 1917) based on a single specimen, and described by Irimura (1991) based on another specimen. *Astrocharis gracilis* was originally described by Mortensen and Stephensen (1918) based on a single specimen, and by Döderlein (1927) based on another specimen. The three species of *Astrocharis* were distinguished chiefly by the dimensions of the scales on the aboral surface of the disc, the position of the arm segments with two arm spines, and the presence/absence of larger plates on the aboral surface of the disc. These descriptions lacked both detailed quantitative accounts of these diagnostic characters and data on variability of characters within species.

In the present study, careful reexamination of five type

specimens of *Astrocharis virgo*, *A. ijimai*, and *A. gracilis*, and 36 additional specimens of *A. ijimai*, has led to the conclusion that *A. gracilis* is a junior subjective synonym of *A. ijimai*, and that one of the syntypes of *A. virgo* is actually *A. ijimai*. In addition, a new species of *Astrocharis*, based on four specimens collected from Japan, is described, and *A. virgo* and *A. ijimai* are redescribed based on two specimens and 39 specimens, respectively. In addition, a revised tabular key to the species of *Astrocharis* is provided.

MATERIALS AND METHODS

The 45 specimens used in this study are deposited in the Zoological Museum Amsterdam (ZMA), the Zoological Museum, University of Copenhagen (ZMUC), the Museum of Comparative Zoology, Harvard University, USA (MCZ) and the National Museum of Nature and Science, Tokyo (NSMT).

The holotype of the new species was anaesthetized in a 10% aqueous solution of magnesium chloride, photographed, and then fixed in 99% ethanol. A paratype of the new species (NSMT E-6549) was fixed in 70% ethanol. The fixation methods of all other specimens examined are unknown.

Ossicles of the new species (NSMT E-658, NSMT E-5632) and *A. ijimai* (NSMT E-1531, NSMT E-1587) 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 preparations were sputter-coated with gold-palladium and examined with a Jeol JSM 5200LV SEM.

The terms used to describe asteroschematids are those of Okanishi and Fujita (2009) and terms for structures of ossicles are those of Hendler and Byrne (1987) and Byrne (1994). The relative size of ossicles presented in terms of the length of the longest axis, and was measured using the ocular piece of a microscope with a micrometer. Mean length of the aboral disc scales, however, was estimated by dividing the disc diameter by the number of scales counted on a transect between the radial shields and across the diameter of the disc. Larger plates on the diameter of the disc were not counted, and their dimensions were excluded

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Table 1. Tabular characters key to the species of *Astrocharis*.

Species	Maximum number and length of arm spines	Mean length of scales on aboral disc (Mean \pm SD, n)	External appearance of aboral shield, vertebrae and lateral arm plate	Body color	Number of arms and reproductive mode
<i>A. monospinosa</i> sp. nov.	1; twice as long as the corresponding arm segment	0.32–0.47 mm (0.385 \pm 0.079, 3)	partly naked	arms irregularly banded brown and white	5; not fissiparous
<i>A. ijimai</i> Matsumoto, 1911	2; as long as the corresponding arm segment	0.11–0.24 mm (0.155 \pm 0.028, 41)	completely concealed	uniformly cream white	6 (rarely 5); fissiparous
<i>A. virgo</i> Koehler, 1904	2; as long as the corresponding arm segment	0.07–0.08 mm (0.075 \pm 0.007, 2)	completely concealed	uniformly brown	5; not fissiparous

from the disc diameter.

TAXONOMY

Astrocharis Koehler, 1904

Astrocharis Koehler, 1904, 160; Matsumoto, 1911, 628.

Type species: *Astrocharis virgo* Koehler, 1904, by monotypy.

Diagnosis

Radial shields naked, composed of a single ossicle. Body covered by contiguous tessellate scales, and by granules partly in contact with each other. Aboral surface of disc covered only by scales. Teeth triangular. Oral papillae present laterally on the jaws. Each tentacle pore with 1–2 associated with arm spines.

Remarks

Astrocharis species and *Asteroschema amamiense* Okanishi and Fujita, 2009 are distinguished from other *Asteroschematidae* species by their radial shields composed of a single ossicle, and a scale-covered aboral surface of the disc. *Asteroschema igloo* Baker, 1980 and *Asteroschema capense* Mortensen, 1925 have a scale-covered disk similar to that of *Astrocharis* species. This morphological similarity indicates a possible close relationship between the genus *Astrocharis* and *A. amamiense*, *A. igloo* and *A. capense* species. The internal ossicle morphology of radial shields of *A. igloo* and *A. capense*, which has never been examined, might be used to clarify the relationship between *Astrocharis* and *Asteroschema*.

Based on our analysis, *Astrocharis* currently comprises three species, *A. virgo* Koehler, 1904, *A. ijimai* Matsumoto, 1911 and *A. monospinosa* sp. nov. A tabular key to the species is given in Table 1.

Astrocharis monospinosa new species
(Figs. 2–5)

Type material

NSMT E-5632, holotype, collected by the T/S Toyoshio-maru, Ie-channel, off Izena Island, Okinawa Prefecture, southwestern Japan, 26°51.7'N, 127°59.6'E–26°51.1'N, 127°59.6'E, 260–268 m, 26 May 2007. NSMT E-658, two paratypes, collected with a gill net, off Tomioka, Amakusa, Kumamoto Prefecture, western Japan, depth unknown, 10 Aug 1965. NSMT E-6549, one paratype, collected by ROV Hakuyo 2000 of M/S Shinsei-maru, northwest off Ikema-jima Island, Okinawa Prefecture, southwestern Japan, 350–380 m, 26 February 2004 (Fig. 1).

Diagnosis

Only one arm spine at each tentacle pore. Maximum length of the arm spines about twice the length of corresponding arm segment. Aboral surface of disc covered by large polygonal scales, 0.32–0.47 mm in mean length. Arms with positionally irregular alternating orange/brown and white bands. Parts of adoral shields, vertebrae, and lateral arm plates in basal to middle portion of arms naked. Not fissiparous.

Etymology

The species name is an adjective in apposition formed as a compound of Latinized Greek, *mono* (numeral, meaning “one”) and Latin *spinosa* (adjective, meaning “spiny”),

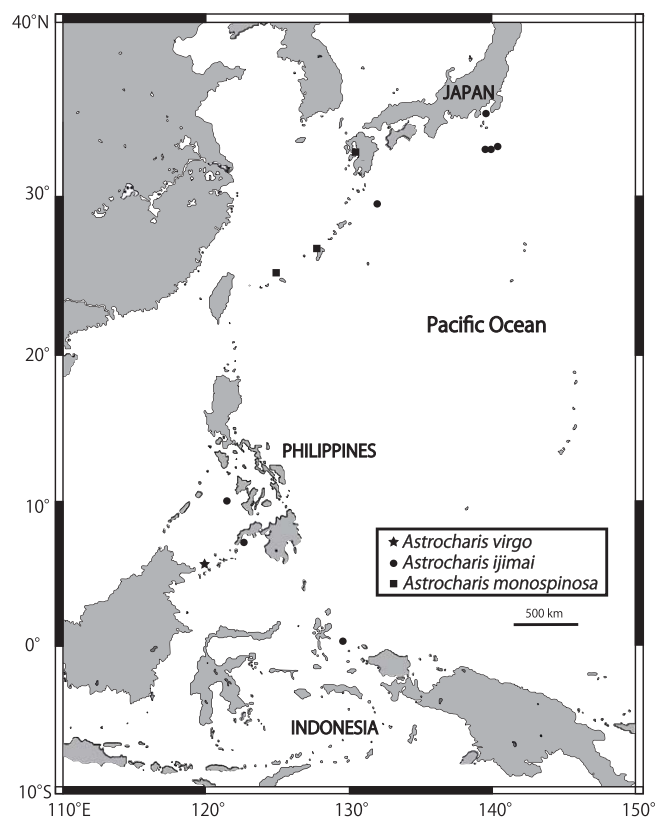


Fig. 1. Distribution of *Astrocharis virgo*, *A. ijimai*, *A. monospinosa* sp. nov.

referring to the one arm spine for each tentacle pore of this new species.

Description of holotype

NSMT E-5632: Disc diameter 5.6, arm length 115 mm (Fig. 2A–C).

Disc. Disc lacking evidence of fission, suggesting regeneration as if along a fission plane, and five-lobed with slightly notched interradiar edges (Fig. 3A). Aboral surface nearly flat, covered by flat polygonal scales (Fig. 3A). Scales at the periphery relatively large, 0.5–0.8 mm long, approximately 150 μ m thick (Fig. 3B), and at the center relatively small, 0.35–0.45 mm long, approximately 150 μ m thick (Fig. 3C). Radial shields naked, oblong or oval, 1.5–2.7 mm long and 1.0–1.2 mm wide, not reaching the disc center (Fig. 3B).

Oral surface of disc also almost entirely covered by small, polygonal scales similar to those of aboral disc center, 0.2–0.25 mm long and approximately 150 μ m thick (Fig. 3D, E). Proximal half of adoral shield naked, remainder covered by scales (Fig. 3D). Four to five triangular teeth form a vertical row on dental plate. Each side of jaw covered by oral papillae (Fig. 3E).

Lateral interradiar surface of disc nearly vertical, covered by scales similar to those on oral surface (Fig. 3F). Two genital slits (1.5 mm long and 0.1–0.3 mm wide) present in each interradius. No distinct ossicles, suggesting existence of madreporites visible on oral interradius. Stout, naked genital plates present on adradial side of entrance to genital slits (Fig. 3F).

Arms. Five arms, one arm lost accidentally. Arms slightly thickened in basal four or five segments (Fig. 2B–C); thickened portion of arm 2.5 mm wide and 2.7 mm high, almost square in cross section (Fig. 3G), followed by thin segments 1.8 mm wide and 1.9 mm high. Distal portion of arms tapering gradually (Fig. 2A–C).

Aboral surface of basal thickened portion of arm covered by polygonal, oblong scales, 0.5–0.9 mm long, approximately 100 μ m thick, similar to those on oral surface of disc (Fig. 5A). Aboral surface of distal thin portion of arm covered by rounded granules (Fig. 5B). Granules in slight contact with

μ m thick, similar to those on oral surface of disc (Fig. 5A). Aboral surface of distal thin portion of arm covered by rounded granules (Fig. 5B). Granules in slight contact with

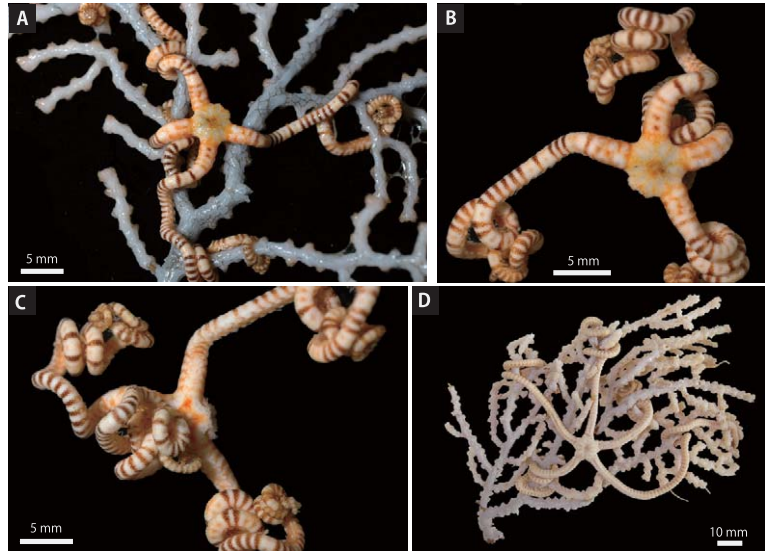


Fig. 2. *Astrocharis monospinosa* sp. nov., holotype (NSMT E-5632) (A–C) and one paratype (NSMT E-658-A) (D). A, clinging to a colony of gorgonacean; B, aboral side; C, oral side; D, clinging to a colony of gorgonaceans.

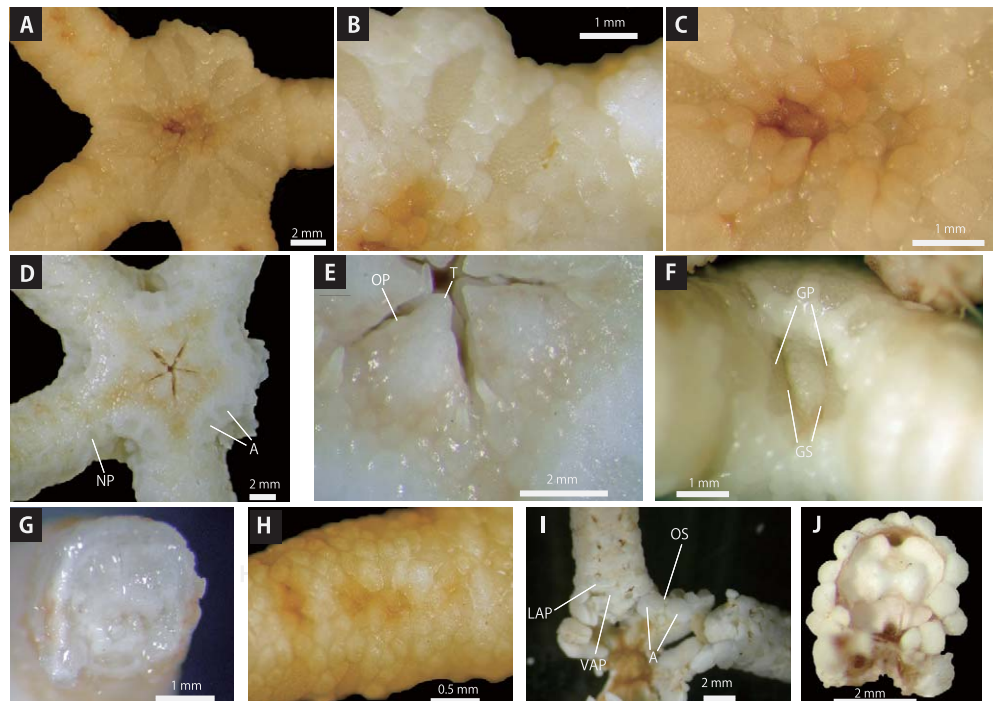


Fig. 3. *Astrocharis monospinosa* sp. nov., holotype (NSMT E-5632) (A–H) and one paratype (NSMT E-658-B) (I, J). (A) aboral disc and basal portion of arm; (B) aboral periphery of disc; (C) aboral central part of disc; (D) oral disc and basal portion of arm; (E) jaws; (F) lateral interradiar part of disc; (G) distal view of cross section of basal portion of arm; (H) aboral basal portion of arm; (I) oral periphery of disc and basal portion of arm, skin and scales removed to show internal ossicles; (J) distal view of cross section of distal portion of arm. Abbreviations: A, adoral shield; GP, genital plate; GS, genital slit; LAP, lateral arm plate; NP, naked part of a lateral arm plate; OP, oral papillae; OS, oral shield; T, teeth; VAP, ventral arm plate.

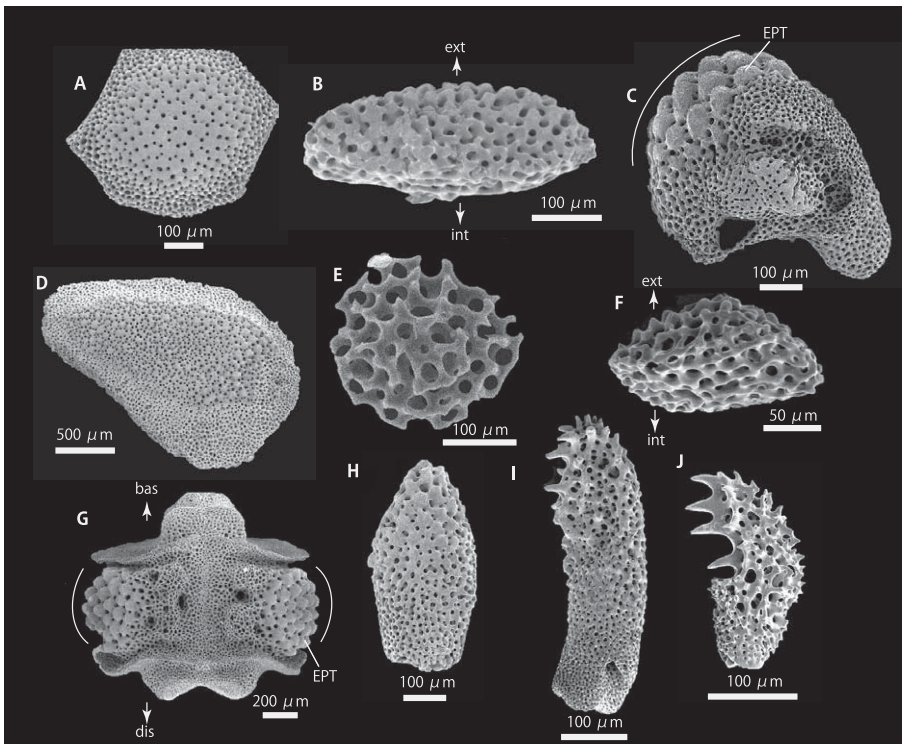


Fig. 4. *Astrocharis monospinosa* sp. nov., paratype (NSMT E-658-B). SEM photographs of internal ossicles. (A, B) scales at aboral periphery of disc, external (A) and lateral (B) views; (C) lateral arm plate at middle portion of arm, oral view, naked part of lateral surface is indicated by an arc; (D) radial shield, external view; (E, F) granule at aboral distal portion of arm, external (E) and lateral (F) views; (G) vertebrae at middle portion of arm, oral view, naked parts are indicated by arcs; (H–J) arm spines from basal portion of arm (H), middle portion of arm (I) and distal portion of arm (J). Arrows indicate orientation (B, F, G): bas, basal side; dis, distal side; ext, external side; int, internal side. Abbreviation: MK, microscopic knobs.

each other, 0.15–0.2 mm long and approximately 60 μm thick. Oral surface also covered by granules, 0.08–0.1 mm long, approximately 40 μm thick (Fig. 5C). For entire length of arms, length and thickness of scales on lateral side increasing toward oral side, up to 0.5 mm and approximately 300 μm, respectively. Scales or granules on arms gradually decreasing in size in a proximal-distal direction. In basal thickened portion of arms, lateral side of vertebrae partly naked, remainder concealed by scales (Fig. 5D: NSMT E-658-A, one paratype, 8.0 mm in disc diameter, 147 mm in arm length, ethanol preserved).

First to third tentacle pores lacking arm spine; 4th and more distal pores with one arm spine. Arm spines in basal two-thirds of arm ovoid, minute. Arm spines in basal one-thirds to two thirds of arm bearing fine spinelets at tip, twice as long as corresponding arm segment. Arm spines gradually transforming into hooks possessing conspicuous teeth along inner edge. Length of hook-shaped arm spines decreasing gradually toward distally along distal quarter of arm, and number of teeth decreasing from five to four.

Oral and lateral side of lateral arm plates partly naked, remainder concealed by scales or granules (Fig. 3D). Lateral and ventral arm plates completely concealed by scales or granules in distal quarter of arm.

Color. In life, on aboral disc surface, radial shields white, central part brown, and remainder orange. On oral side, vicinity of mouth orange, remainder white. Positionally irregular bands of different color are present throughout arms, orange in basal portion, deep brown in distal portion (Fig. 2A–C). Remainder of arms white. Only brown bands remain visible after fixation (Fig. 5B).

Ossicle morphology of paratypes

NSMT E-658-B: Disc diameter 12 mm, arm length at least 132 mm, dry, dissected (Fig. 3I, J).

Scales at aboral periphery of the disc, flat, polygonal, approximately 0.54 mm long and 155 μm thick (Fig. 4A, B). Granules at aboral surface of distal portion of arm, slightly domed and rounded, approximately 0.26 mm long and 96 μm thick (Fig. 4E, F).

Radial shield flat and triangular, approximately 2.21 mm in length and 1.46 mm in width distally, 0.62 mm in width proximally (Fig. 4D).

Adoral shields and an oral shield visible when

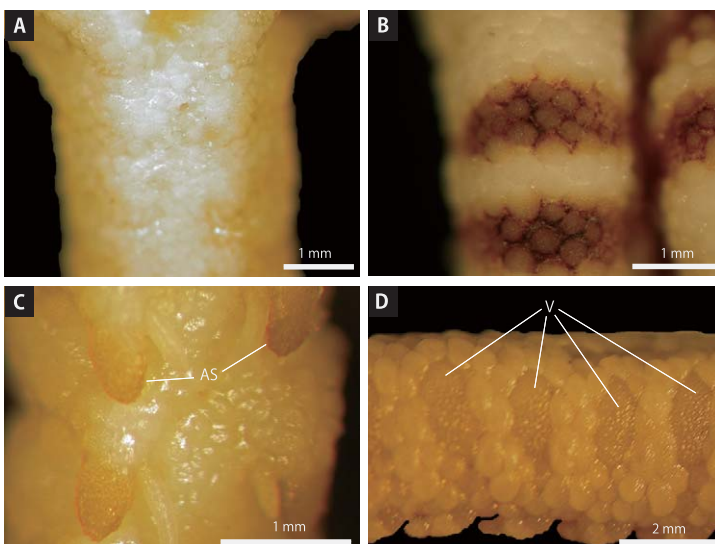


Fig. 5. *Astrocharis monospinosa* sp. nov., holotype (NSMT E-5632) (A–C) and one paratype (NSMT E-658-A) (D). (A) oral view of basal portion of arm; (B) aboral view of distal portion of the arm; (C) oral view of distal portion of arm; (D) lateral view of middle portion of arm. Abbreviations: AS, arm spine; V, vertebrae.

scales on oral surface of disc removed (Fig. 3I).

Microscopic knobs on the naked part of vertebrae larger than those on the other parts (Fig. 4G). In basal to middle portion of arms, oral, and lateral side of lateral arm plates partly naked and microscopic knobs of the naked part enlarged (Figs. 3I, 4C). Lateral and ventral arm plates concealed by scales or granules in distal quarter of arm (Fig. 3J). Ventral arm plate visible when scales on oral surface of disc removed (Fig. 3I).

Arm spines on basal one-thirds of arm ovoid (Fig. 4H). Arm spines in middle portion of arms cylindrical, bearing fine spinelets at tip (Fig. 4I). Arm spines gradually transforming into hooks possessing conspicuous teeth along inner edge (Fig. 4J). Number of teeth decreasing gradually from five to four in a proximal-distal direction along distal quarter of arm.

Variation

Basal portion of arms of holotype (5.6 mm in disc diameter) and one paratype (NSMT E-658-B, 8.0 mm in disc diameter) are slightly widened, but those of the other two paratypes (NSMT E-6549, 6.0 mm; NSMT E-658-A, 12.0 mm in disc diameter) are not widened. Brown bands present in arms of specimens from Okinawa (Holotype and a paratype, NSMT E-6549), but two paratypes from Kumamoto are uniformly creamy white (NSMT E-658-A, E-658-B).

Distribution

JAPAN: off Okinawa Prefecture, 260–380 m, off Kumamoto Prefecture (Fig. 1).

Remarks

Astrocharis monospinosa new species can be distinguished from three previously described *Astrocharis* species by the following characteristics: The mean length of the scales in this present new species is approximately 0.32–0.47 mm (three type specimens), larger than the other species. The scales are approximately 0.07–0.08 mm in *A. virgo* (three syntypes), 0.11–0.24 mm in *A. ijimai* (two syntypes and 33 specimens) and 0.18 mm in *A. gracilis* (one holotype) (for actual status of some type specimens; see Remarks in *A. ijimai* below) (Fig. 6A).

The present species has only one arm spine in each tentacle pore throughout the arms, while *A. virgo*, *A. ijimai* and *A. gracilis* have two arm spines on the 7th–13th and more distal arm segments.

Two specimens of the present species has positionally irregular, alternating orange/brown and white bands on the arms, but *A. virgo*, *A. ijimai*, and *A. gracilis* have uniform colors (brown in *A. virgo* and creamy white in *A. ijimai*, and *A. gracilis*).

The adoral shields, lateral arm plates and vertebrae of the present species are partly naked (Figs. 3D, I, 5D), whereas those of *A. virgo*, *A. ijimai*, and *A. gracilis* are completely concealed by scales or granules.

All examined specimens of the present species and *A. virgo* have five arms and a circular disc lacking evidence of

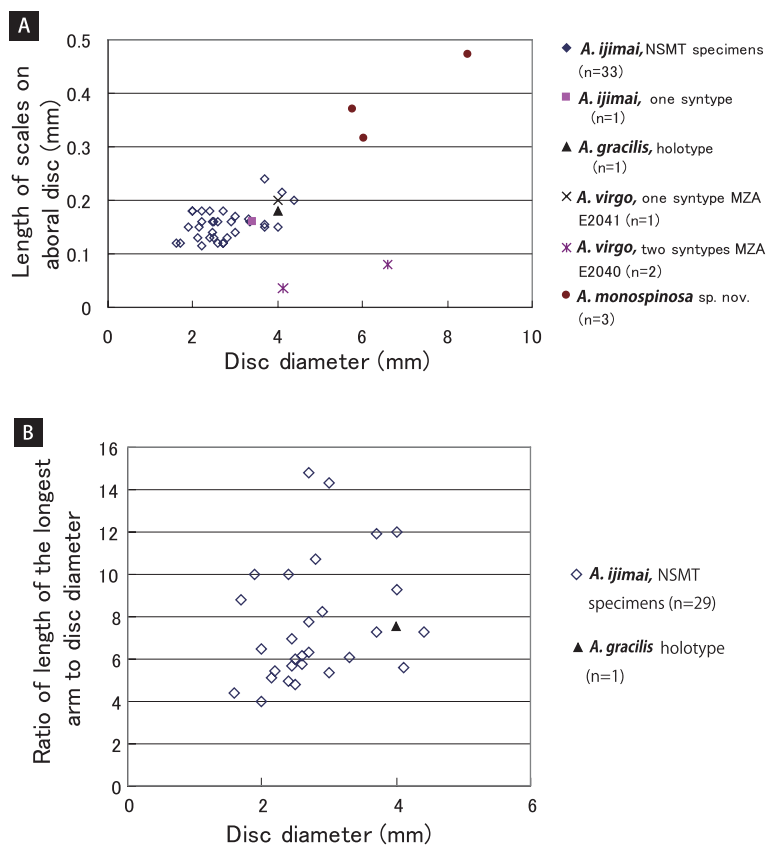


Fig. 6. (A) Length of scales on aboral disc of one syntype and 33 NSMT specimens of *A. ijimai*, holotype of *A. gracilis*, two syntypes (ZMA E2040) and one syntype (ZMA E2041) of *A. virgo* and the holotype and two paratypes (NSMT E-658-A and NSMT E-6549) of *A. monospinosa* sp. nov.; (B) Ratio of length of the longest arm to disc diameter of 29 specimens of *A. ijimai* and the holotype of *A. gracilis*.

fission. In contrast, 35 specimens including one syntype (95%) of *A. ijimai* and the holotype of *A. gracilis* have six arms, and 25 specimens, including two specimens with five arms (68%) of *A. ijimai* exhibit regeneration along a fission plane, which indicates that these specimens are fissiparous (see also Remarks in *A. ijimai* below).

Astrocharis ijimai Matsumoto, 1911 (Figs. 7–9)

Astrocharis ijimai Matsumoto, 1911, 628–629, fig. 13; 1915, 54–55; 1917, 56–58, fig. 16; H. L. Clark, 1915, 178; Irimura, 1991, 118, fig. A–B.

Astrocharis gracilis Mortensen in Mortensen and Stephensen, 1918, 264–267, fig. 1–6; Döderlein, 1927, 77–78, pl. 9 fig. 5–5c, 6–6a (new synonymy).

Astrocharis virgo Koehler, 1904, 160–161, pl. 20 fig. 1, pl. 30 fig. 8 (in part: ZMA E2041).

Type material examined

ZMUC OPH-167, holotype of *Astrocharis gracilis*, seven miles south of Olutanga, Mindanao Island, southern Philippines, 555 m, 8 March 1914. ZMA E2041, one syntype of *Astrocharis virgo*, collected in Siboga Expedition, station 150, off Gilolo Strait, east of Halmahera Island, northeastern Indonesia, 0°6'N, 129°7.2'E, 1089 m. MCZ 3899, one syn-

type of *Astrocharis ijimai*, Sagami Sea, central Japan (Fig. 1).

Other material examined

NSMT E-995, seven ethanol preserved specimens, collected by the R/V Soyo-maru, off Hachijo-jima Island, Tokyo Metropolis, central Japan, 33°4.8'N, 139°11.1'E, 505–510 m, 21 June 1972. NSMT E-1531, two dried specimens and 24 ethanol preserved specimens, collected by the R/V Soyo-maru, off Hachijo-jima Island, Tokyo Metropolis, central Japan, 33°8.0'N, 140°3.0'E, 500–510 m, 25 May 1963. NSMT E-1587, one dried specimen, collected by the R/V Soyo-maru, off Hachijo-jima Island, Tokyo Metropolis, central Japan, 33°5.7'N, 140°1.5'E, 455 m, 3 June 1962. NSMT E-3127, one dried specimen and one ethanol preserved specimen, collected by the R/V Tansei-maru, KT-92-2, station KH-2, Komahashi Sea Mount, Kagoshima Prefecture, southwestern Japan, 29°52'N, 133°19.2'E, 529–606 m, 15 February 1992 (Fig. 1).

Diagnosis

Except on basal portion of arms, two arm spines at each tentacle pore. Maximum length of the longer inner arm spines equal to the length of corresponding arm segment. Aboral surface of disc covered by relatively large polygonal scales, 0.11–0.24 mm in mean length. Body color uniformly creamy white. Adoral shields, vertebrae and lateral arm plates concealed by scales. Generally six arms, fissiparous.

Description of NSMT specimens

NSMT E-1531 (two specimens): Disc diameter 4.4 mm, arm length 21 mm and disc diameter 2.1 mm, arm length 10 mm, respectively; NSMT E-1587 (one specimen): Disc diameter 3.5 mm, arm length 31 mm.

Disc. Disc lacking evidence of fission. Six-lobed with slightly notched interradii edges (Fig. 7A). Aboral central and radial regions of disc tumid (Fig. 7A, B). Aboral surface of disc covered by flat and polygonal scales, relatively large and thin, 0.18–0.20 mm long and approximately 80 µm thick at the periphery (Figs. 7C, 8A, B), and relatively small and thick, approximately 0.15 mm long and 110–120 µm thick, in the center (Fig. 7D). Radial shields naked, short, oval, approximately 0.8 mm long and 0.25–0.50 mm wide, not reaching the disc center, and composed of a single ossicle (Figs. 7A–C, 8E).

Oral surface of disc also entirely covered by polygonal scales, similar to those of aboral disc center, approximately 0.15 mm long and 80 µm thick (Fig. 7E, F). Oral shields and oral plates covered by scales, thus the presence of madreporite(s) undetectable (Fig. 7G). Four or five triangular teeth form a vertical row on dental plate (Figs. 7G, 9A). Oral papillae present on each side of jaw (Fig. 9A). Second tentacle pores with a sheath composed of calcareous platelets just outside pores (Fig. 7G).

Lateral interradii surface of disc nearly vertical, covered by scales similar to those of oral disc. Two genital slits (0.9 mm long and 0.1 mm wide) present in each interradius on lateral face of disc (Fig. 7H). No distinct ossicles indicating existence of madreporites visible on oral interradius (Fig. 7F, H). Naked, stout genital plate present on adradial side of genital slit entrance (Fig. 7H).

Arm. Six arms. Arms thickened in basal seven or eight

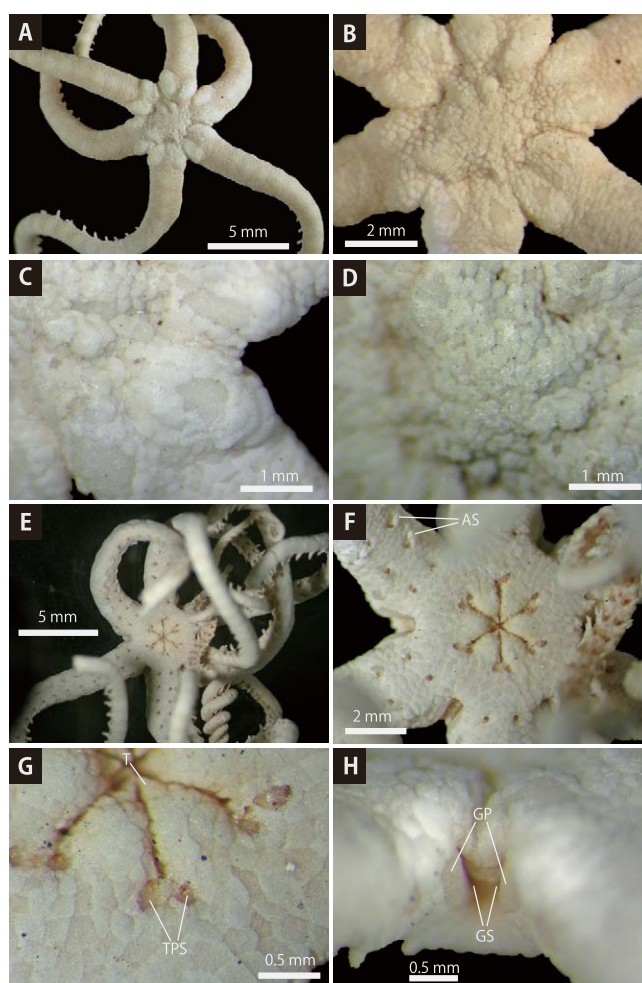


Fig. 7. *Astrocharis ijimai* Matsumoto, 1911 (NSMT E-1531, 4.4 mm in disc diameter). (A) aboral disc and basal to middle portion of arms; (B) aboral disc; (C) aboral periphery of disc; (D) aboral central part of disc; (E) oral disc and basal to middle portion of arms; (F) oral disc, jaws are enlarged in G; (G) jaws; (H) lateral interradii part of disc. Abbreviations: AS, arm spine; GP, genital plate; GS, genital slit; T, teeth; TPS, tentacle pore sheath.

segments (Fig. 7A). Thickened basal portion of arm 1.7 mm wide and 1.2 mm high. Following segments only 1 mm wide and 0.8 mm high. Distal portion of arms tapering gradually (Fig. 7A, E). Oral side flattened and aboral side arched for entire length of arms.

Aboral surface of thick basal portion of arms covered by scales similar to those at periphery of aboral surface of disc, 0.16–0.20 mm long and approximately 80 µm thick (Fig. 9B). Oral surface of arms also covered by scales resembling those on oral surface of the disc, approximately 0.1 mm long and 50–60 µm thick (Fig. 9C). Aboral surface of distal thin portion of arm covered by flat and polygonal scales, 0.12–0.15 mm long and approximately 20 µm thick (Figs. 8C, D, 9D). Oral surface of arms covered by flat and round scales, 0.07–0.09 mm long and 20–30 µm thick (Fig. 9E). Entire length of arms size of scales on lateral side similar in size to those of aboral surface (Fig. 9F). Scales on arms gradually decreasing in size distally.

First to third tentacle pores lacking arm spines (Fig. 7F);

4th to 8th–11th pores with one arm spine (Fig. 9C); more distal pores with two arm spines (Fig. 9F). Arm spines in basal quarter of arms ovoid, minute, about one-fifth to one-quarter of corresponding arm segment length (Fig. 8G). In middle portion of arms, arm spines one-third to half of arm

segment length, cylindrical. Arm spines bearing fine spinellets at tip, which gradually transform into hooks possessing four to six conspicuous teeth along inner edge (Fig. 8H). In distal quarter of arms, inner hook-shaped arm spines attain length equal to that of arm segment and number of teeth of inner and outer hook-shaped arm spines decreases to two (Fig. 8I). All outer arm spines two-thirds as long as inner arm spines along the entire length of the arms (Fig. 9F).

Lateral arm plates completely concealed by scales in basal thickened portion of arms, but visible in distal quarter where scales are more sparse (Fig. 9E).

Color. In life, white (Mortensen and Stephensen, 1918). Both ethanol preserved and dried specimens uniformly creamy white (Figs. 7A, E, 9G–I).

Variation

The three specimens described above (NSMT E-1531, E-1587) have only uniform-size scales on the aboral surface of disc. However, the other seven specimens of NSMT E-1531 have larger plates, which are approximately twice as long as scales. The larger plates are slightly sunken, darker in color, and their microscopic knobs are enlarged compared to scales (Fig. 9G, I).

Distribution

JAPAN: Sagami Sea (Matsumoto, 1911, 1915, 1917), around Hachijo-jima Island, 455–510 m deep (Irimura 1991; present study), southeastern Kagoshima Prefecture, 529–606 m (present study); **PHILIPPINES:** south of Olutanga, Mindanao Island, 555 m (Mortensen and Stephensen, 1918); **INDONESIA:** off Gilolo Strait, 1089 m (Koehler, 1904) (Fig. 1).

Remarks

Mortensen and Stephensen (1918) distinguished *A. ijimai* and *A. gracilis* based on width of the arm base, presence/absence of larger plates on the aboral disc, and arm length. However, our examination of more extensive material indicates that the three characters are not useful for distinguishing *A. ijimai* and *A. gracilis*, and that the latter name is therefore a subjective junior synonym.

The arm base of the holotype of *A. gracilis* is slightly thickened, 1.41 mm wide, and followed by thin segments of 1.17 mm wide, and the ratio of width is 1.2, which is identical to the ratio of one NSMT specimen of *A. ijimai* (NSMT E-0995; 4.0 mm in disc diameter). Moreover, as well as the holotype of *A. gracilis*, we found larger plates in seven of 36 NSMT specimens of *A. ijimai*

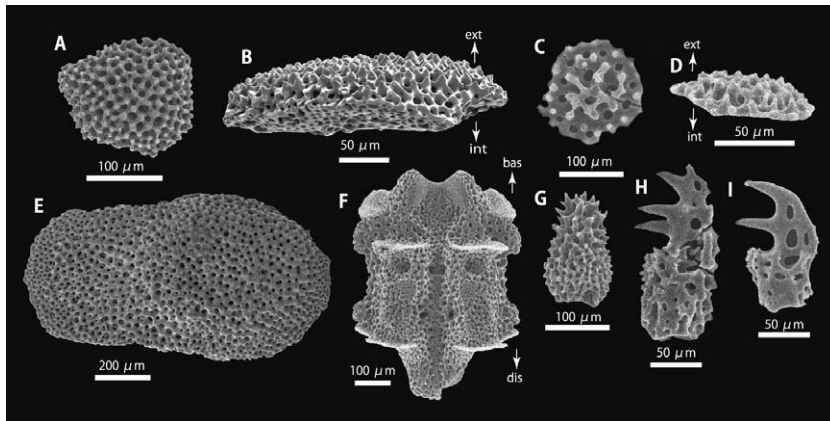


Fig. 8. *Astrocharis ijimai* Matsumoto, 1911 (NSMT E-1531, 4.4 mm in disc diameter) (A–D), (NSMT E-1587, 3.34 mm in disc diameter) (E–I). SEM photographs of internal ossicles. (A, B) scales at periphery of the disc, external (A) and lateral (B) views; (C, D) scales at aboral distal portion of arm, external (C) and lateral (D) views; (E) radial shield, external view; (F) vertebrae at basal portion of arm, oral view; (G–I) arm spines, from basal portion of arm (G), middle portion of arm (H) and distal portion of arm (I). Arrows indicate orientation (B, D, F): bas, basal side; dis, distal side; ext, external side; int, internal side.

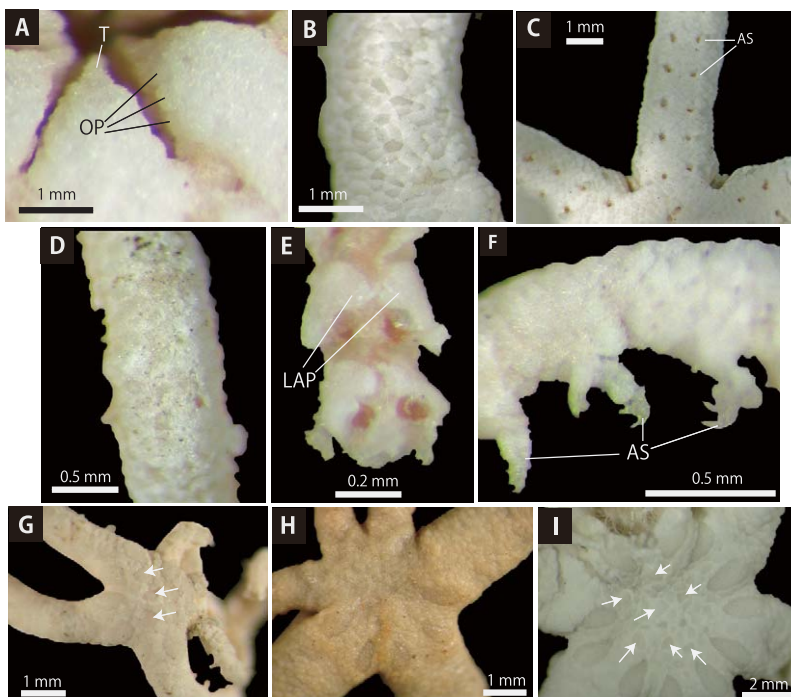


Fig. 9. *Astrocharis ijimai* Matsumoto, 1911 (NSMT E-1531, 2.1 mm in disc diameter) (A), (NSMT E-1531, 4.4 mm in disc diameter) (B–F) (NSMT E-1531, 2.15 mm in diameter) (G), *Astrocharis virgo* Koehler, 1904, syntype (ZMA E2041) (H) and *Astrocharis gracilis* Mortensen, 1918, holotype (ZMUC OPH-167) (I). (A) jaws; (B) aboral view of basal portion of arm; (C) oral view of basal portion of arm; (D) aboral view of middle portion of arm; (E) oral view of distal portion of arm; (F) lateral view of middle portion of arm; (G) aboral disc and basal portion of arms, larger plates indicated by arrows; (H) aboral disc and basal portion of arms; (I) aboral disc, larger plates indicated by arrows. Abbreviations: AS, arm spine; LAP, lateral arm plate; OP, oral papillae; T, teeth.

(Fig. 9G, I). In addition, the ratio of length of the longest arm to disc diameter of the holotype of *A. gracilis* is 7.5, which is within the range (= 4–14.3) of 29 NSMT specimens of *A. ijimai* (seven specimens are excluded because their discs and arms are incomplete) (Fig. 6B).

Except for larger plates, which don't appear in all specimens, the body of *Astrocharis* species is covered by two types of ossicles: scales, which are polygonal, flat and contiguous; and granules, which are round, domed, and in slight contact with each other. According to previous descriptions, *A. gracilis* and *A. ijimai* have both scales and granules on the aboral surface of the disc. In contrast, *A. virgo* has only granules and lacks scales (Koehler, 1904; Matsumoto, 1911, 1917; Mortensen and Stephensen, 1918; Döderlein, 1927). In fact, three syntypes of *A. virgo*, the holotype of *A. gracilis*, the syntype of *A. ijimai*, and the 35 NSMT specimens (one specimen is excluded because the scales on the aboral surface of the disc are removed) of *A. ijimai* have only scales on the aboral surface of the disc (Figs. 7A, B, 9G–I). Therefore, the shape of ossicles on the aboral surface of the disc cannot be used to distinguish these three species of *Astrocharis*.

The position of arm segments with two arm spines was also the same in *A. virgo*, *A. gracilis* and *A. ijimai*. Segments with two arm spines were observed mainly from the 10th or 11th arm segment in one syntype of *A. virgo* (ZMA E2041), and from the 8th–11th arm segment in the other two syntypes of *A. virgo* (ZMA E2040), from the 9th or 10th arm segment in the holotype of *A. gracilis*, and from the 7th–13th arm segment in the syntype and 36 NSMT specimens of *A. ijimai*.

Mortensen and Stephensen (1918) and Döderlein (1927) indicated that *A. virgo*, *A. ijimai*, and *A. gracilis* have short, medium, and long scales on the aboral surface of the disc, respectively. In this study, the mean length of the scales (not including the larger plates, described by Mortensen and Stephensen in 1918) was 0.11–0.24 mm (mean = 0.155 mm, SD = 0.028) for the syntype and 33 NSMT specimens (three specimens were excluded because two specimens lacked more than half of their disc and the scales of another specimen are removed) of *A. ijimai*; 0.18 mm for the holotype of *A. gracilis*; 0.2, 0.07, and 0.08 mm for three syntypes of *A. virgo*, respectively. The holotype of *A. gracilis* and one syntype of *A. virgo* (ZMA E2041) cannot be distinguished from the specimens of *A. ijimai* (including one syntype) by the length of the scales on the aboral surface of the disc. Only the other two syntypes of *A. virgo* (ZMA E2040) have smaller scales and were distinguishable from the specimens of *A. ijimai* (Fig. 6A).

Additionally, we found that the number of the arms and reproductive mode are different in these two syntypes of *A. virgo* (ZMA E2040). They have five arms, and their discs show no evidence of fission. In contrast, another syntype of *A. virgo* (ZMA E2041), 34 NSMT specimens of *A. ijimai* and the holotype of *A. gracilis* have six arms and only two NSMT specimens of *A. ijimai* has five arms. In 25 of the NSMT specimens (including the one specimen with five arms) of *A. ijimai*, the holotype of *A. gracilis* and one syntype of *A. virgo* (ZMA E2041), the discs show conspicuous fission planes, suggesting fissiparity.

Body colors are also different in these specimens. The

two syntypes of *A. virgo* with smaller scales (ZMA E2040) have a uniformly brown body color, and the other specimens previously identified as *A. virgo* are all uniformly creamy white (Figs. 7, 9, 10).

As a result of these findings, *A. gracilis* is here synonymized with *A. ijimai*, and one syntype (ZMA E2041) of *A. virgo* is re-identified as *A. ijimai*. *Astrocharis virgo* is a valid species with two syntypes (ZMA E2040). *Astrocharis ijimai* has relatively large scales (0.11–0.24 mm long), uniformly creamy white body color, generally six, rarely five arms, and is fissiparous. *A. virgo* has relatively small scales (0.07–0.08 mm long), a uniformly brown body color, five arms, and is not fissiparous.

Astrocharis virgo Koehler, 1904
(Fig. 10)

Astrocharis virgo Koehler, 1904, 160, pl. 20, fig. 1, pl. 30, fig. 8 (in part: ZMA E2040); 1922, 32; H. L. Clark, 1915, 178.

Type material studied

ZMA E2040, two syntypes, collected by Siboga Expedition, station 95, off Sulu Islands, southwestern Philippines, 5°43.5'N, 119°40'E, 522 m (Fig. 1). One syntype (ZMA E2041) is identified as *A. ijimai* in this study.

Diagnosis

Except for basal portion of arms, two arm spines at each tentacle pore. Maximum length of the longer inner arm spines equal to the length of the corresponding arm segment. Aboral surface of disc covered by relatively small, round scales, 0.07–0.08 mm in mean length. Body color uniformly brown. Adoral shields, vertebrae and lateral arm plates concealed by scales. Five arms, and not fissiparous.

Description of one syntype specimen

One syntype of ZMA E2040: Disc diameter 6.6 mm in disc diameter, arm length 50 mm.

Disc. Disc lacking evidence of fission, ten-lobed with strongly notched interradiar edges and slightly notched radial edges (Fig. 10A). Aboral surface depressed at center, and covered by polygonal scales and larger plates similar to those in some specimens of *A. ijimai* (Fig. 10B). Scales almost uniform in size, approximately 0.08 mm long, and larger plates approximately twice as long as scales (Fig. 10B). Radial shields naked, oval, approximately 1.3 mm long, 0.5 mm wide, not reaching disc center (Fig. 10A, B).

Oral surface of disc covered by flat, polygonal scales, approximately 0.15 mm long (Fig. 10C, D). Five to six triangular teeth form a vertical row on the dental plate (Fig. 10D). Six to seven oral papillae present on each side of jaw (Fig. 10D).

Lateral interradiar surface of disc nearly vertical, covered by scales similar to those of oral disc. Two genital slits (1.6 mm long and 0.2 mm wide) present in each interradius. Oral plates and madreporite(s), which may be covered by scales, are not visible on oral interradiar region (Fig. 10C).

Arms. Five arms. Basal 3rd to 5th arm segments, 3.0 mm wide and 2.2 mm high, with flattened aboral surface (Fig. 10A). Following 6th to 10th arm segments thickened in width, 3.6 mm wide and 2.2 mm high (Fig. 10A, E, F; see

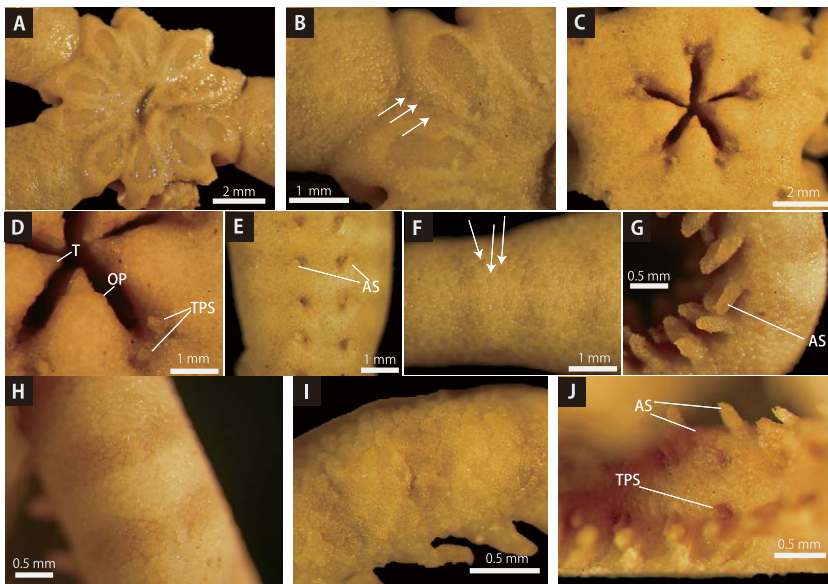


Fig. 10. *Astrocharis virgo* Koehler, 1904, one syntype (ZMA E2040). (A) aboral disc and basal portion of arm; (B) aboral periphery of disc, larger plates indicated by arrows; (C) oral disc, jaws enlarged in D; (D) jaws; (E) oral basal portion of arm; (F) aboral basal portion of arm, larger plates indicated by arrows; (G) lateral middle portion of arm; (H) aboral middle portion of arm; (I) aboral distal portion of arm; (J) oral distal portion of arm. Abbreviations: AS, arm spine; OP, oral papillae; T, teeth; TPS, tentacle pore sheath.

also Koehler, 1904: pl. 20, fig. 1). Arms tapering gradually distal to 11th arm segment (Fig. 10F). Beyond 3rd segment, oral surface flat and aboral surface arched.

Aboral surface of basal portion of arm covered by small polygonal scales similar to those on oral surface of disc, approximately 0.08 mm long (Fig. 10F) and larger plates similar to those on the aboral surface of disc (Fig. 10F). Oral surface covered by polygonal scales, slightly larger than those on aboral surface, 0.12–0.14 mm long (Fig. 10E). Thin distal portion of arm entirely covered by small scales, 0.07 mm long (Fig. 10H–J). Scales on arms gradually decreasing in size toward distally.

First to third tentacle pores lacking arm spines; from 4th to 9th pores (one arm), 4th to 12th pores (two arms), and 4th to 13th pores (two arms) with one arm spine; more distal pores with two arm spines. Inner spines on basal half of arm ovoid, minute, about one-quarter to one-third of corresponding arm segment (Fig. 10E). Outer spines on basal half of arm cylindrical, slightly shorter than corresponding inner spines. On distal third quarter of arms, both inner and outer spines cylindrical and one-third to three-quarters length of corresponding arm segment length (Fig. 10G). On distal one-quarter of arms, inner arm spines cylindrical, and one third to three-quarters length of corresponding arm segment length (Fig. 10I, J). Outer spines on distal quarter of arms also cylindrical, length three-quarters to four-fifths length of corresponding arm segment length (Fig. 10G, J). All tentacle pores have a cylindrical, hollow sheath just outside pore, with a tube foot passing through it (Fig. 10J).

Lateral and ventral arm plates concealed by scales even in distal arm segments (Fig. 10C–E, J).

Color. Ethanol preserved specimens uniformly dull

brown aborally and slightly whitish brown orally (Fig. 10A, C).

Variation

The basal portion of the arms is widened in the larger syntype (6.6 mm in disc diameter), but not in the smaller syntype (5.0 mm in disc diameter). This difference may be due to differences in sexual maturity; the thickening of basal arm segments may be due to enlargement of gonads (Hendler, 1991).

Remarks

Of the three syntypes of *A. virgo*, two specimens (ZMA E2040) with smaller scales (0.07–0.08 mm), five arms, and brown body color are confirmed to be *A. virgo*, whereas one specimen (ZMA E2041) with larger scales (0.2 mm), six arms and creamy white body is re-identified as *A. ijimai*.

Distribution

PHILIPPINES: off Sulu Islands, southwestern Philippines, 522 m (Koehler, 1904), off Cagayan Islands, central Philippines, 929 m (Koehler, 1922) (Fig. 1).

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