ヤミガンガゼ Eremopyga denudata (de Meijere, 1903)（ウニ綱ガンガゼ目）の琉球列島からの初報告

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Record of *Eremopyga denudata* (de Meijere, 1903) (Echinoida, Diadematoida, Diadematidae) from the Ryukyu Archipelago, Japan

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Abstract. Three specimens of a deep-water diadematid echinoid *Eremopyga denudata* (de Meijere, 1903) were recently collected from Okinawa-jima Island, the Ryukyu Archipelago, Japan. This species has been recorded from the Timor Sea, the Philippines and the Bali Sea. In Japan, this species had only been previously recorded from Shibushi Bay, Kagoshima Prefecture, and no detailed morphological description was shown for the specimen. This study provides the first detailed morphological description for Japanese individuals and some ecological information observed underwater and in aquarium.

Introduction

The genus *Eremopyga* Agassiz & Clark, 1908 is a deep-living diadematid echinoid. This genus is characterized by having hollow spines, a few primary tubercles in each interambulacra, a primary tubercle on each ambulacral plate at least near the ambitus, and narrow poriferous zones with the arcs of pores in a nearly vertical series (Agassiz & Clark 1908). *Eremopyga* includes two species, *E. denudata* (de Meijere, 1903) from the Timor Sea (de Meijere 1903), the Philippines, and the Bali Sea (Mortensen 1940), and *E. debilis* Mortensen, 1940 from only Mindanao, Philippines (Mortensen 1940). These species live in deeper waters, 70–400 m (Mortensen 1940), and their ecological information is very scarce.

Shigei (1981, 1986, 1987, 1989) reported *Eremopyga denudata* in his list of the Japanese echinoid fauna but did not show any detailed morphological description of Japanese specimens. During the latest project study by ROV of Okinawa Churaumi Aquarium, we collected *E. denudata* in Okinawa-jima Island, Japan (Fig. 1). In this study, we provide a detailed morphological description of *E. denudata* based on the specimens from Japanese waters for the first time (Fig. 2). Additionally, based on ROV and aquarium observations of living specimens, habitat environment, feeding habit, and symbionts of *E. denudata* are also given for the first time (Fig. 3).

Materials and methods

Sampling and preservation. Three live specimens were collected in the deep sea off Onna Village, Okinawa-jima Island, Japan, on 29 June 2017 and 18 July 2017 using the mechanical manipulator arm of the ROV "LEO" (Kowa Corporation) during a research project of the Okinawa Churaumi Aquarium. Two specimens were fixed in 99.5% ethanol on board immediately after sampling. Another specimen was maintained alive in a tank of the Okinawa Churaumi Aquarium (OCA-EC-20170629) for exhibition and investigation of feeding habitat. The two fixed specimens are deposited in the National Museum of Nature and Science (NSMT E-11859, NSMT E-11860). The one live specimen will be fixed in 99.5% ethanol and deposited in the Okinawa Churaumi Aquarium after death.

Morphological observation. The methodology of morphological observations used was modified from Rodriguez et al. (2013) and Coppard & Campbell (2004, 2006a, 2006b). Firstly, many ambulacral and interambulacral spines, each type of pedicellariae, and muscle tissue of primary spines were sampled from the two fixed specimens for morphological observation and future molecular studies. Then, tests were carefully immersed in bleach diluted with an equal amount of water (approximately 3% sodium hypochlorite solution) to remove soft tissue, rinsed with deionized water three times, and dried

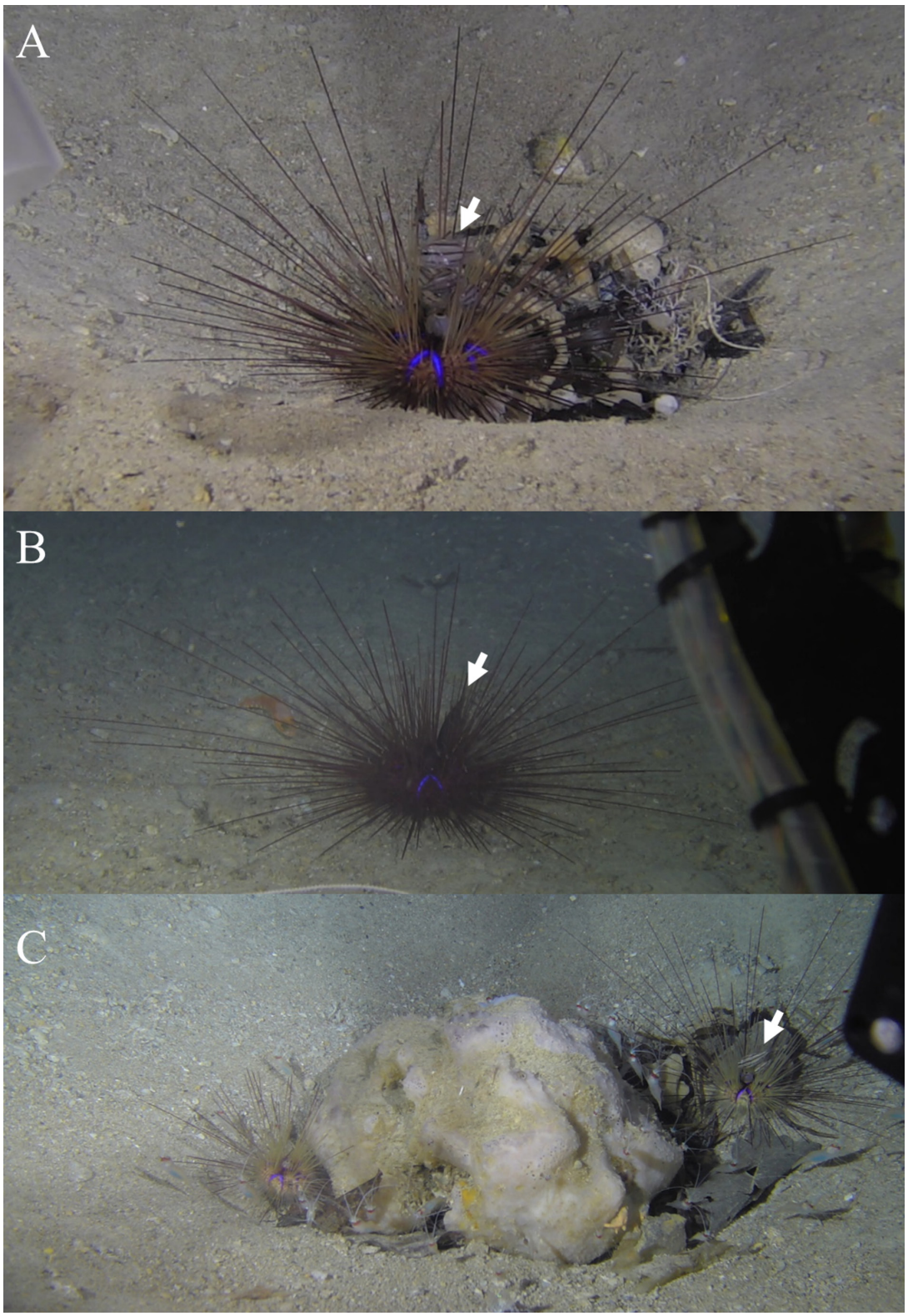

Fig. 1. Underwater photographs of *Eremopyga denudata*. A, One individual (NSMT E-11859) in a pit. Several urchin cardinalfish *Siphamia tubifer* (arrow) are found between spines; B, One individual (NSMT E-11860) on a flat bottom. An urchin cardinalfish *Siphamia* sp. (arrow) is found between spines; C, Two individuals in a pit with a sponge. A cardinalfish *S. tubifer* (arrow) is found between spines. Only the left individual was collected (OCA-EC-20170629).
図 1. ヤミガンガゼ *Eremopyga denudata* の海中写真 . A, くぼみに入った個体 (NSMT E-11859)．棘の間に数個体のヒカリイシモチ *Siphamia tubifer* (矢印) が共生する ; B, 平坦な海底上の個体 (NSMT E-11860)．棘の間に 1 個体のヒカリイシモチ属の一種が共生する ; C, くぼみに入った 2 個体 . くぼみの中には海綿の 1 種も生息している．棘の間に 1 個体のヒカリイシモチ *S. tubifer* が共生する . 左の個体 (OCA-EC-20170629) のみ採集した .

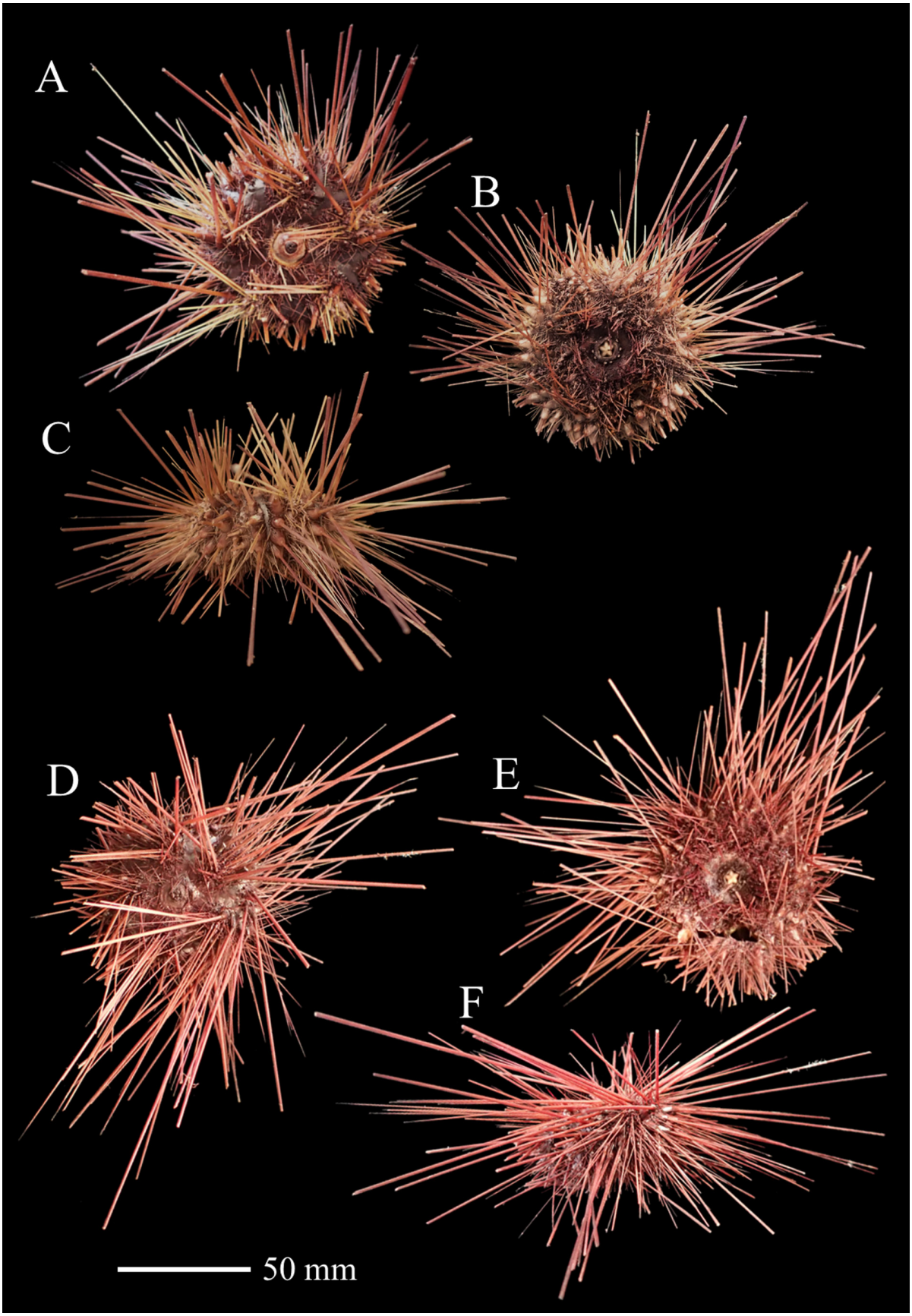

Fig. 2. Whole body of *Eremopyga denudata*. NSMT E-11859 (A–C): A, aboral view; B, oral view; C, lateral view; NSMT E-11860 (D–F): D, aboral view; E, oral view; F, lateral view.
図 2. ヤミガンガゼ *Eremopyga denudata* の全身．NSMT E-11859 (A–C): A, 反口側 ; B, 口側 ; C, 側面 ; NSMT E-11860 (D–F): D, 反口側 ; E, 口側 ; F, 側面 .

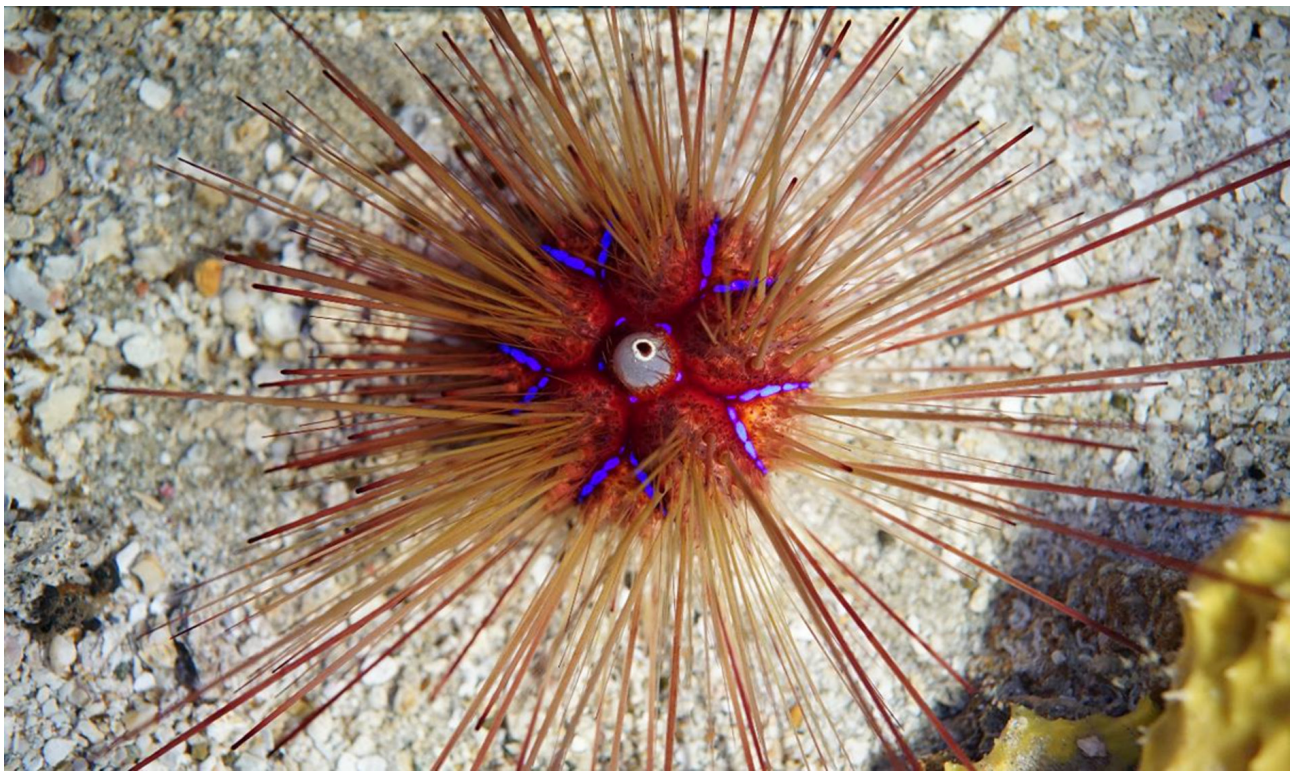

Fig. 3. Living specimen of *Eremopyga denudata* in the aquarium photographed on 27 August, 2017. OCA-EC-20170629. Aboral view.
図 3. ヤミガンガゼ *Eremopyga denudata* 生体の反口側 (OCA-EC-20170629)．2017 年 8 月 27 日沖縄美ら海水族館の水槽中で撮影 .

in air. The surface of denuded tests was observed under a stereo-microscope (Leica, M165 FC), and photographed with a digital camera (Nicon, D60 and Olympus, TG-4).

From the two specimens, four ambulacral and four interambulacral spines from the ambit, and at least five pedicellariae of each type were randomly selected for observation. The soft tissue of spines and pedicellariae was removed with the same method applied to the tests. The spines were cut into four equal-length parts, distal, proximal and two intermediate parts according to the methods of the morphological observation for diadematoids urchins of Coppard & Campbell (2004). The spines were cut with a razor to observe transverse sections of cylinder and wedge. These spines and pedicellariae samples were mounted on SEM stubs, and sputter-coated with gold-palladium, and analyses and photographic documentation were performed with a scanning electron microscope (SEM) (Keyence VHX-D510).

In the following Taxonomy section, description and measurements are based on the two fixed specimens (NSMT E-11859 and NSMT E-11860).

Taxonomy

Order Diadematoida Duncan, 1889
Family Diadematidae Peters, 1855
Genus *Eremopyga* Agassiz & Clark, 1908
***Eremopyga denudata* (de Meijere, 1903)**
New Japanese name: Yami-Gangaze
(Fig. 1–6)

Astropyga denudata de Meijere, 1903: 4; 1904: 57–59, pl. IV, figs 31–32, pl. XIV, figs. 209–214.
Eremopyga denudata – Agassiz & Clark 1908: 122; Mortensen 1940: 209–213, pl. XVII, figs 2–3, pl. XXIV, fig. 1, pl. XXV, figs 1–4, pl. XXVI, figs. 1–2, pl. XXVII, fig. 5, pl. LXXI, figs 9–11, 13–19; Shigei 1981: 199; 1986: 187; 1987: 112; 1989: 63.

Material examined. NSMT E-11859, 26°31.8124’N, 127°52.9210’E, 216.5 m depth, water temperature 21.48˚C, 18 July 2017, 10:59, coll. T. Higashiji and A. Yamashiro. NSMT E-11860, 26°31.8124’N, 127°52.9210’E, 220.3 m depth, water temperature 19.39˚C, 18 July 2017, 12:38, coll. T. Higashiji and A. Yamashiro. OCA-EC-20170629, living, 26°31.8273’N, 127°52.9526’E, 211.3 m depth, water temperature 19.33˚C, 29 June 2017, 14:34, coll. T.

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Description. The test is hemispherical, circular when viewed aborally, with a horizontal diameter of 56.5 and 52.8 mm (for NSMT E-11859 and NSMT E-11860, respectively. The same shall apply hereinafter) and a vertical diameter of 22.2 and 23.4 mm (Fig. 4). The color of the test is white, but it is particularly pearl green in interambulacra and apical system (Fig. 4).

The ambulacra are slightly raised aborally (Fig. 4C). The ambulacra have two rows of primary tubercles and an offset inner series of secondary tubercles. All primary and secondary tubercles are perforated and crenulated. Pore-pairs are non-conjugate and in monoserial from the peristome to apical system. Phyllodes are not developed adorally (Fig. 4E–F).

The interambulacra are ca. 4 times broader than the ambulacra at the ambitus (Fig. 4D). Large V-shaped naked median area is present (Fig. 4A). In aboral side, one series of primary tubercles is outside the V-shaped naked median area and 2–3 series of primary tubercles are inside it (Fig. 4A). The series of primary tubercles reach the peristome (Fig. 4B). All primary and secondary tubercles are perforated and crenulated.

The apical system is monocyclic (Fig. 4H). It measures 17.4 and 16.3 mm in diameter, 31% and 31% of the test horizontal diameter (hereafter called TL). The genital plates are wider than long (0.66 and 0.61 mm in width, 0.44 and 0.53 mm in length), and have 6 primary tubercles in the inner edge and 5–8 secondary tubercles outside the primary tubercles. The genital plates have no depression. The genital pores measure 0.04 and 0.05 mm in diameter. The ocular plates are pentagonal with a small ocular pore and have 7–9 secondary tubercles in the center of the plate.

The periproct is circular and it measures 10.3 and 10.1 mm in diameter, 18% and 19% of TL (Fig. 4H). The periproctal cone has white platelets present in the membrane.

The peristome is circular, and it measures 17.3 and 16.6 mm in diameter, 31% and 31% of TL (Fig. 4B). The peristomal membrane is black with a red tinge and has five pairs of buccal tube feet, with abundant triphyllous and small type tridentate pedicellariae. The auricles are slender (Fig. 4I). The primary spines of ambulacra and interambulacra are different in their size and structure (Fig. 5). Ambulacral spines are 62.4 and 74.9 mm in the longest length (110% and 142% of TL), 0.59 and 0.57 mm in mean width proximally and 0.45 and 0.57 mm distally (Fig. 5A).

The spines are verticillate, formed by 14–17 and 17–18 solid wedges, with radiate out from a hollow axial cavity (Fig. 5C). The solid wedges are club-shaped. There are no spikes between solid wedges. The number of trabecular rings is one.

Interambulacral spines are 95.9 and 120.8 mm in the longest length (170% and 229% of TL), 1.08 and 0.89 mm in mean width proximally and 0.87 and 0.91 mm distally (Fig. 5D). The spines are verticillate, formed by 24–30 and 27–29 solid wedges, with radiate out from a hollow axial cavity (Fig. 5F). The solid wedges are club-shaped. There are no spikes between solid wedges. The number of trabecular rings is one.

Tridentate, triphyllous and claviform ophicephalous pedicellariae are present (Fig. 6). The tridentate pedicellariae are found in three different forms, narrow, broad and forceps-like (Fig. 6A–H). The narrow form has a relatively narrow neck on a long stalk, and ca. 700 μm in head length with spoon-shaped and narrow valves (Fig. 6B–D). This form is found primarily on the oral surface, being particularly numerous around the peristome. The broad form has a relatively broad neck on a long stalk, and ca. 500 μm in head length with straight and broad valves (Fig. 6E–G). This form is found all over the test and is more abundant than the other two forms. The forceps-like narrow form has a broad neck on a long stalk, and ca. 3.5–4.0 mm in head length with forceps-like slender valves considerably larger than the other forms (Fig. 6H). This form is found on the oral surface, being particularly noticeable around the peristome. Triphyllous pedicellariae occur all over the test (Fig. 6I–K) and having broad valves that are rounded distally, with numerous small peripheral teeth in two rows. The head is supported by a long muscular neck attached to a long flexible stalk. Claviform ophicephalous pedicellariae occur all over the test and are with the expanded distal region, large stalk glands, but no valves (Fig. 6L–M).

Color in life. The color of the epithelium of test and spine is red (Fig. 2–3). Bold blue lines of iridophores are seen in the V-shaped naked median areas of the interambulacra, and a blue dot of iridophores occur on each genital plate (Fig. 1, 3). The periproctal cone is lighter than the epithelium of test. A white anal ring is present around the opening (Fig. 3)

Distribution. In Japan, Shibushi Bay, Kagoshima

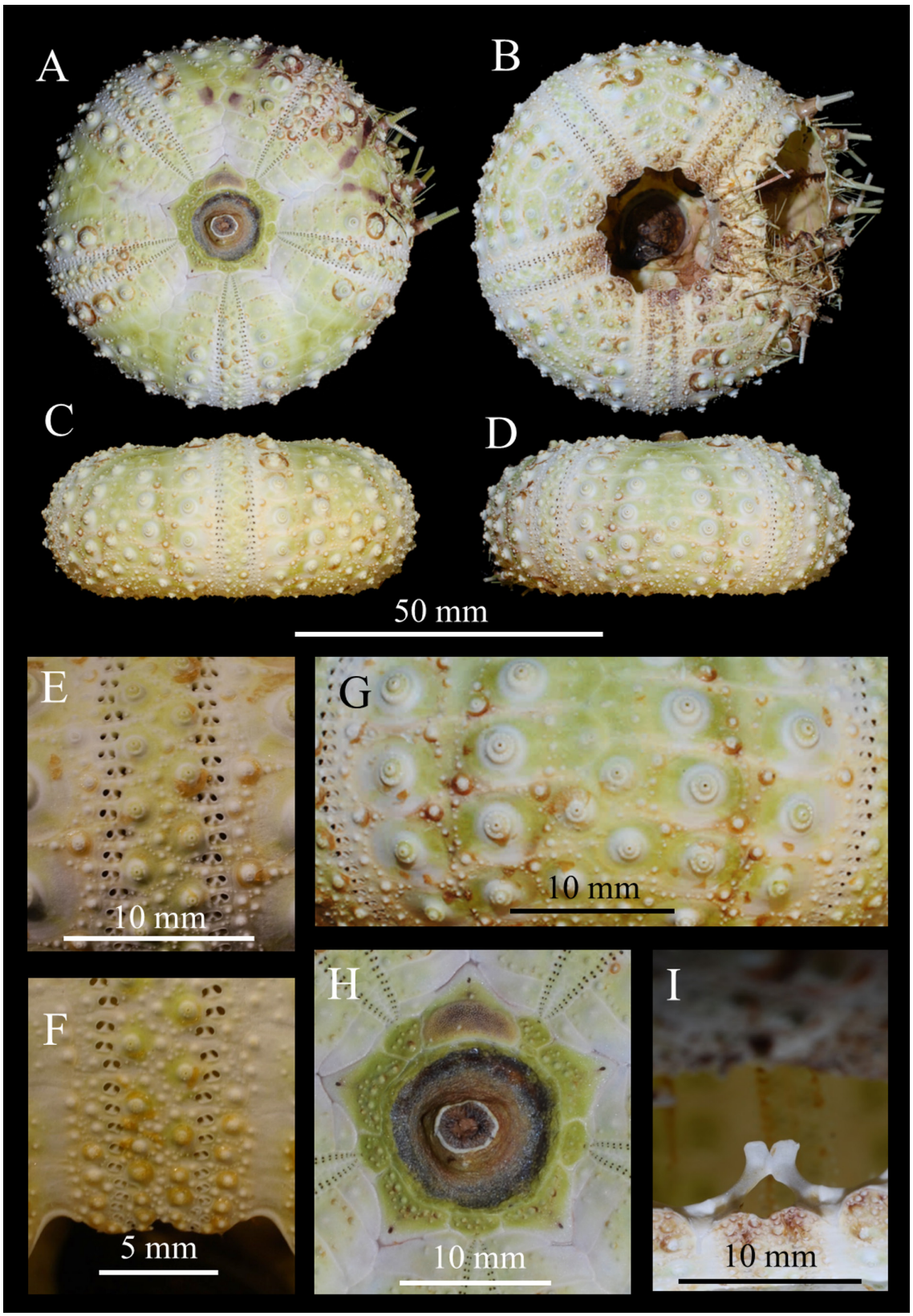

Fig. 4. Test morphology of *Eremopyga denudata*, NSMT E-11859: A, aboral view; B, oral view; C, lateral view, an ambulacrum in center; D, lateral view, an interambulacrum in center; E, close-up of the ambitus part of ambulacrum (shown in center of figure C); F, close-up of the part near peristome of ambulacrum; G, close-up of the ambitus part of an interambulacrum (shown in center of figure D); H, apical system; I, auricle viewed from oral side.
図 4. ヤミガンガゼ *Eremopyga denudata* の殻の形態 , NSMT E-11859: A, 反口側面 ; B, 口側面 ; C, 側面 , 正面は歩帯 ; D, 側面 , 正面は間歩帯 ; E, 赤道面における歩帯の拡大 ; F, 周口部周辺の歩帯の拡大 ; G, 赤道面における間歩帯の拡大 ; H, 頂上系 ; I, 口側から見た耳状骨 .

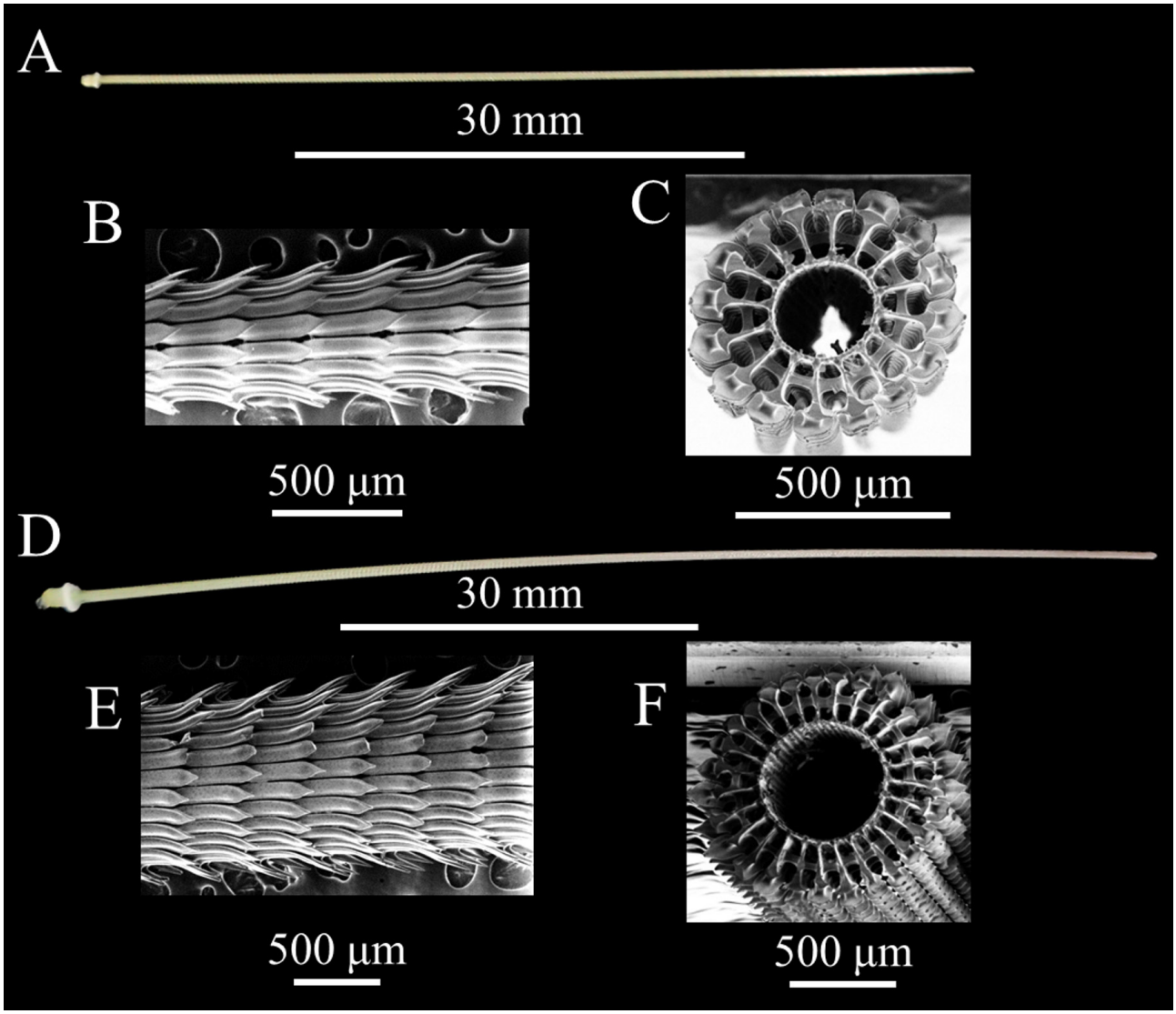

Fig. 5. Spines of *Eremopyga denudata*, NSMT E-11859. Optical microscopic photographs (A, D) and SEM photographs (B–C, E–F). Ambulacral spines (A–C): A, whole view; B, median region of spine; C, transverse section of median region; Interambulacral spines (D–F): D, whole; E, median region of spine; F, transverse section of median region.
図 5. ヤミガンガゼ *Eremopyga denudata* の棘の形態 , NSMT E-11859. 光学顕微鏡写真 (A, D) と 走査型電子顕微鏡写真 (B–C, E–F). 歩帯の主棘 (A–C): A, 全体 ; B, 棘の中間域 ; C, 中間域の断面 ; 間歩帯の主棘 (D–F): D, 全体 ; E, 棘の中間域 ; F, 中間域の断面 .

Prefecture, depth unknown (Shigei 1981) and off Onna Village, Okinawa-jima Island, 211.3–220.3 m depth (this study). The Timor Sea, 148–274 m depth (de Meijere 1903), the Philippines, 86–139 m depth, and the Bali Sea, 70–100 m depth (Mortensen 1940). In addition, Mortensen (1940) reported that this species was also distributed "off Indo-China" based on the specimen from Dr. A. Krempf, but the detailed sampling locality has not been known.

Etymology for Japanese name. The Japanese name is derived from "yami", a Japanese word meaning dark, suggesting deep water as the habitat of this species, and "gangaze" meaning long spine urchins.

Ecology. Underwater observation showed that three out of four observed individuals were in a pit of the seabed with sponges, other sessile organisms, and seagrass debris. The seagrass seems to have been transported from shallow waters because no living seagrass was found around the collecting site where sunlight is too weak for seagrass to grow. The excrements of the living specimen (OCA-EC-20170629) produced soon after collection contained sponges and seagrass debris. This specimen also fed on mackerel meat and krill given in the aquarium (Higashiji T. unpublished data). Mortensen (1940) reported that the contents of the intestinal canal of *E. denudata* were bottom material, mainly mud with a few shells and foraminifera, and some small bits of plants. Therefore, *E. denudata*

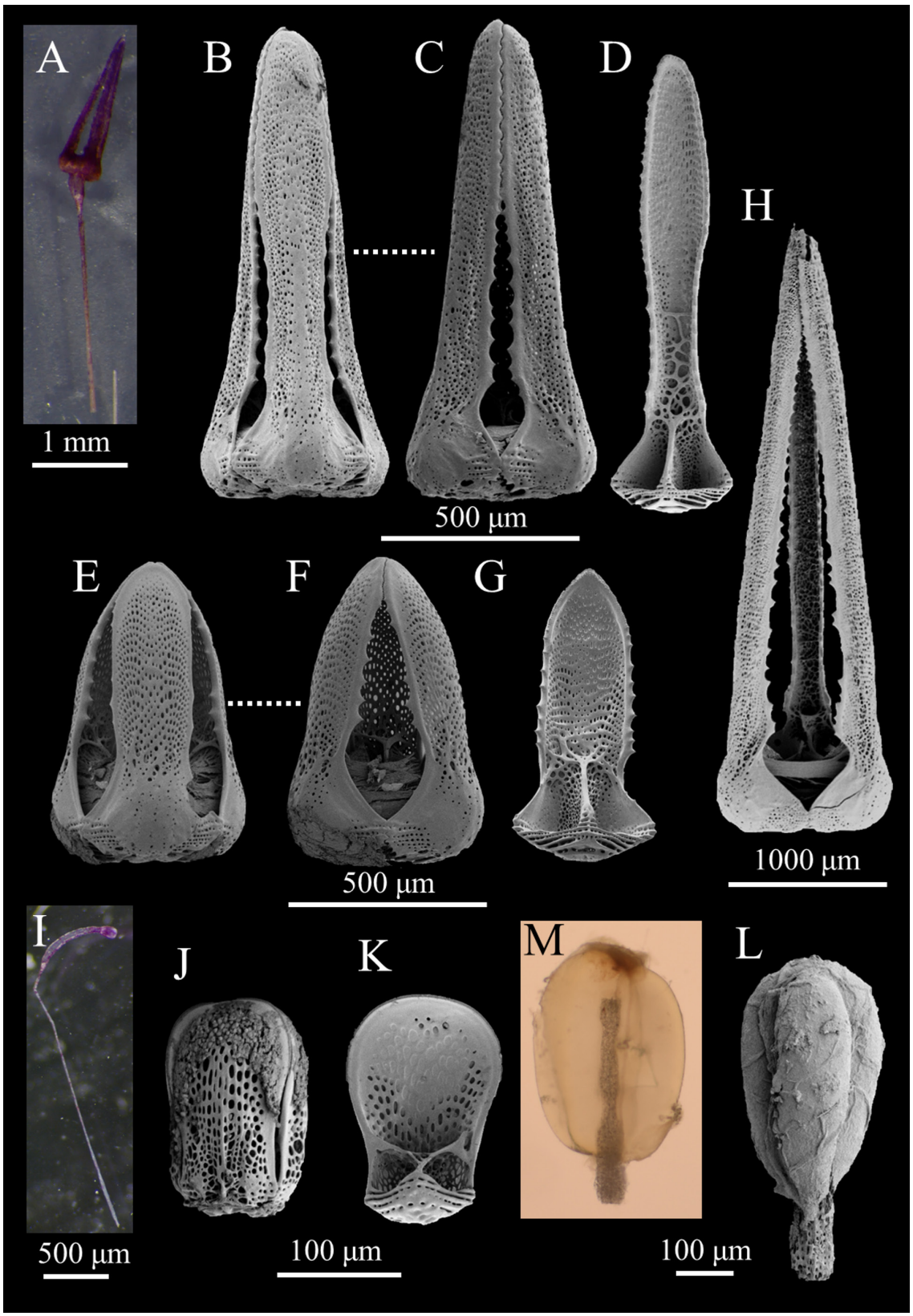

Fig. 6. Pedicellariae of *Eremopyga denudata*, NSMT E-11859. Optical microscopic photographs (B–H, J–L) and SEM photographs (A, I, M). Normal narrow tridentate pedicellariae (A–D): A, whole; B–C, head; D, valve; broad tridentate pedicellariae (E–G): E–F, head; G, valve; H, forceps-like tridentate pedicellariae; triphyllous pedicellariae (I–K): I, whole; J, head; K, valve; L–M, claviform pedicellariae.

図 6. ヤミガンガゼ *Eremopyga denudata* の叉棘の形態 , NSMT E-11859. 光学顕微鏡写真 (B–H, J–L) と走査型電子顕微鏡写真 (A, I, M). 通常の細い爪状叉棘 (A–D): A, 全体 ; B–C, 頭部 ; D, 弁 ; 広い爪状叉棘 (E–G): E–F, 頭部 ; G, 弁 ; H, 鉗子型の爪状叉棘 ; 葉状叉棘 (I–K): I, 全体 ; J, 頭部 ; K, 弁 ; L–M, 棒状叉棘 .

seems to scavenge and is omnivorous, feeding on sponges, detritus and seagrass debris. Seagrass debris probably accumulated in the pit by slow bottom current and *E. denudata* gathered at the pit to feed on the debris.

Cardinalfish *Siphamia tubifer* Weber, 1909 and *Siphamia* sp. were observed between the spines of *E. denudata* (Fig. 1). This is the first record of symbiotic association with animals for this species.

Remarks. The morphology of the examined specimens was identical to the diagnosis of the genus *Eremopyga* by Mortensen (1940), in having the round outline test, monoserial pore-pairs, crenulated tubercles, and hollow spines. *Eremopyga* shares monoserial pore pairs with *Lissodiadema* Mortensen, 1903, *Goniodiadema* Mortensen, 1939, and several species of *Chaetodiadema* Mortensen, 1903, but *Eremopyga* is distinguished from *Lissodiadema*, *Goniodiadema* and *Chaetodiadema* by having crenulated tubercles, circular test when viewed aborally, and hollow spines, respectively (Mortensen 1940).

Eremopyga consists of two species: *Eremopyga denudata* (de Meijere, 1903) and *Erempyga debilis* Mortensen, 1940. They differ in interambulacral tubercles of oral side: the rows of large primary tubercles reaching the peristome indicate the current specimens are *E. denudata*. In *E. debilis*, the oral side is densely covered by minute and close-set tubercles, and the rows of large primary only reach the ambitus (Mortensen 1940).

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ヤミガンガゼ *Eremopyga denudata* (de Meijere, 1903)（ウニ綱ガンガゼ目）の琉球列島からの初報告

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要旨 . 沖縄県国頭郡恩納村沖の水深 211.3–220.3 m より *Eremopyga denudata* (de Meijere, 1903) ヤミガンガゼ (新称) 3 個体が採集された . 本種はこれまでにティモール海 , フィリピンとバリ海から報告されている . 日本では鹿児島県志布志湾から知られていたが , 琉球列島からは初記録となる . 日本産の個体の形態の記載は本報告が初めてとなる . また , ROV による現場観察と水族館での飼育観察により , 本種の生息環境と食性 , さらにヒカリイシモチ属魚類との共生が初めて確認された .

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