

## Morphological changes associated with the growth of feather star *Clarkcomanthus exilis* (Echinodermata, Crinoidea)

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**Abstract:** The first description of the morphological changes associated with the growth of the feather star *Clarkcomanthus exilis* is presented here, based on external morphological observations. Of the three specimens, with arm lengths of ca. 14 mm, 60 mm and 90 mm, the following changes were recognized. Centrodorsal cirri sockets arise from the entire flank of the centrodorsal region and are arranged in 1-2 annular, irregular rows, but as they grow, one or two cirri sockets arise in each radial and change to an annular row; division series of juveniles range up to IBr (first division series), mainly IBr 2, IIBr 4 (3+4), and as they grow, the series range up to mainly IBr 2, IIBr 4 (3+4), and IIIBr 4 (3+4); the aboral color is crimson red, and there are several thick brownish-white lateral stripes with some color on the arms that have a characteristic round-centered pattern when the arms are spread out. However, as it grows, the brownish-white thick transverse stripes on the aboral surface of the arm become blurred and move to the sides, and the characteristic round-centered pattern disappears. This study newly revealed that the length of the cirri shortens as this species grows. On the other hand, coloration and the presence of small spines at the pinnular ends of the distal pinnule, arising from the arm distal, are proven to be stable and characteristic through from small to large individuals of this species.

**Key words:** Taxonomic character, Sagami Bay, Pacific Ocean, juvenile

### Introduction

The feather star (Echinodermata, Crinoidea, Comatulida) comprises 550 extant species (Messing, 2020) and among them, about 140 species are known from the waters of Japan (Kogo, 1998, 2002; Kogo & Y. Fujita, 2000; Pilcher & Messing, 2001; Kogo & T. Fujita, 2005; Obuchi *et al.*, 2009; Fujita & Obuchi, 2012; Obuchi, 2013, 2014; Obuchi & Omori, 2015).

Although the current taxonomic study of extant feather stars is based on a series of monographs by Austin Hobert Clark (A. H. Clark, 1915, 1931, 1941, 1947, 1950; A. H. Clark & A. M. Clark, 1967), it is believed that there are a substantial number of synonyms among the species described in these monographs. The reason being that some of them are poorly described, according to the modern more stringent standards for descriptions currently being utilized, and others do not fit into newly agreed upon taxonomic systems (Messing, 1997). In general, the bodies of feather stars are physically brittle so it is difficult to obtain undamaged specimens. Because of this, many species are described based on a small number of specimens; this has led to a poor understanding of morphological variation within the species. Some of the

characteristics used for species identification are also known to change as individuals develop; this is a major source of confusion in the taxonomic study of feather stars. (Messing, 1997).

The *Clarkcomanthus exilis* (Rowe, Hoggett, Birtles & Vail, 1986) in the family Comatulidae, have been reported from 3–25 m depths from Japan in: Sagami Bay (Kogo & Fujita, 2014), Oki Islands, Shimane Prefecture (Kohtsuka, 2017), Kii Peninsula (Kogo, 1998), Ashizuri-Uwakai Sea, Kochi Prefecture (Obuchi, 2016), Hirado, Nagasaki Prefecture (Kohtsuka *et al.*, 2011: misidentification of *O. comanthipinna*), Goto Islands, Nagasaki Prefecture (Kogo & T. Fujita, 2005), and Kerama Islands, Okinawa Prefecture (Kogo, 2002). Globally they have been reported in: Timor Sea (Rowe & Gates, 1995), Papua New Guinea (Messing, 1998), Torres Strait (Rowe *et al.*, 1986), Great Barrier Reef (Rowe *et al.*, 1986; Row & Gates, 1995), Northwest Australia (Row & Gates, 1995), New Caledonia (Rowe *et al.*, 1986), Palau (Messing, 2007), Guam (Kirkendale & Messing, 2003), Fiji, Solomon Islands (Rowe *et al.*, 1986). These reports are primarily based on medium to large individuals, with an arm length of 50–110 mm, there is currently no knowledge of smaller individuals of this species. As such, young individuals of this species should also be distributed in this area, and understanding their morphology will undoubtedly help to

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clear up the taxonomic confusion caused by the changes in morphology during growth in sea feathers.

We collected three specimens of *Clarkcomanthus exilis* encompassing small to large sizes around Misaki Marine Biological Station (MMBS)(Kanagawa Prefecture, Japan). In this study, we report on the comparison of external morphological changes between small and large individuals of *C. exilis* based on the collected specimens.

### Materials and methods

A small individual (14 mm arm length) of *Clarkcomanthus exilis* (OMNH-Iv 8424) was collected on 12 May 2017 from a rearing basket of *Ciona robusta* (Hoshino & Tokioka, 1967) that had been lowered from a raft owned by MMBS. Medium (OMNH-Iv 8425) and large (OMNH-Iv 8426) individuals with arm lengths of 60 mm and 90 mm respectively were collected by scuba diving on 9 June 2018 at a depth of 14 m at the mouth of Koajiro Bay (Misaki, Miura Peninsula, Kanagawa, Japan). For convenience we will henceforth refer to the three specimens studied as small (14 mm in arm length), medium (60 mm), and large (90 mm) (See also discussion). Medium and large individuals were photographed with an SLR camera (K-5II; Pentax, Tokyo, Japan) after observations were made of the coloration in a living state. All three specimens were fixed in 99% ethanol. Photographs (taken using a DMC-GH4; Panasonic, Osaka, Japan) for the purpose of species

identification were performed using a stereomicroscope (SZX7; Olympus, Tokyo, Japan) and a phase-contrast microscope (CKX 41; Olympus, Tokyo, Japan).

The specimens were deposited in the Osaka Museum of Natural History (OMNH-Iv). Abbreviations in their descriptions follows the standards set in Kogo & Fujita (2014).

### Result

Family Comatulidae

*Clarkcomanthus exilis*

(Rowe, Hoggett, Birtles & Vail, 1986)

(Figs. 1–3)

#### Description of the small individual

OMNH-Iv 8424 (Fig. 1: arm length 14 mm, centrodorsal diameter 0.7 mm)

The centrodorsal region is 0.7 mm in diameter and slightly pentagonal, with an uneven dorsal pole (Fig. 1C). Cirri bases and sockets arise from all aspects of the centrodorsal and are arranged in 1–2 irregular rows on the ring (Fig. 1C). The centrodorsal has 9 cirri observed in a total of 14 cirri sockets with 8 segments, 2.8 mm in maximum length. The 4<sup>th</sup> to 6<sup>th</sup> segments of the cirri are the longest, about 1.2 times long as they are wide, the distal segments are similar in length and width, with no dorsal spine. Opposing spines and terminal claws are prominent (Fig. 1E).

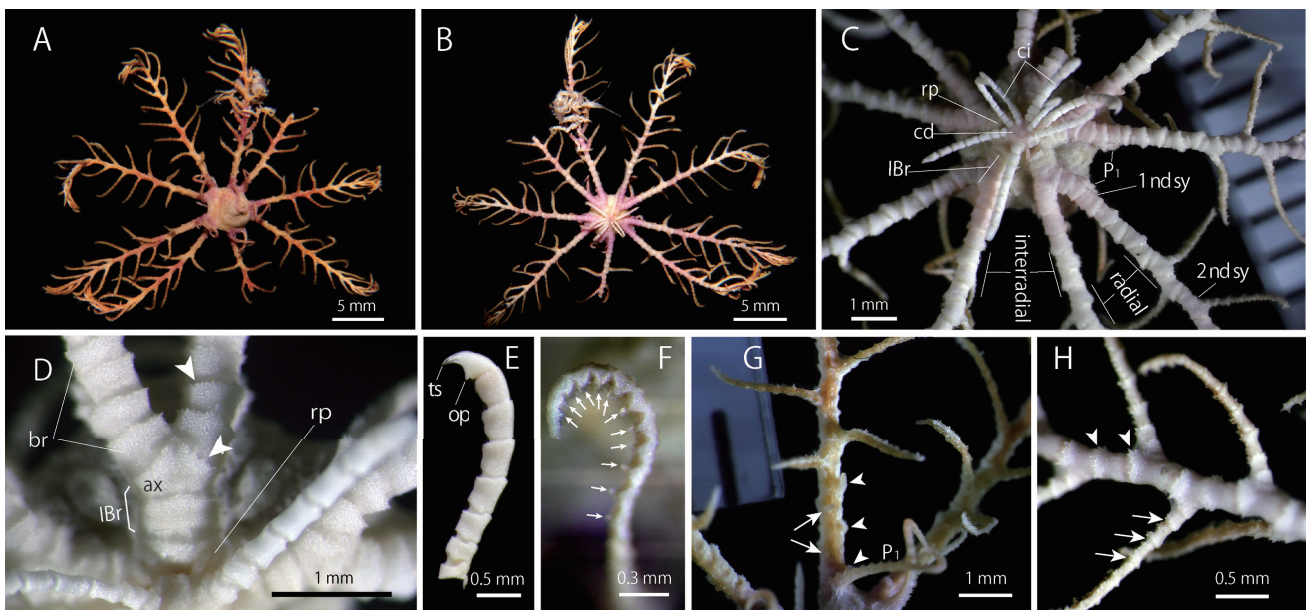


Fig. 1. *Clarkcomanthus exilis* with an arm length of 14 mm (OMNH-Iv 8424). A: Specimen (oral), B: Specimen (aboral), C: The central area of the aboral, ci: cirri, cd: centrodorsal, P<sub>1</sub>: first pinnule, rp: radial plate, 1nd sy: first syzygy, 2nd sy: second syzygy, IBr: first division series, D: First division series, ax: axillary, br: brachials (white arrowhead: Sharp small spines on the brachial of the arm), E: Cirri, op: opposing spine, ts: terminal claw, F: P<sub>1</sub> and comb tooth (white arrow), G: Arm and proximal pinnules (white arrow: second pinnule (P<sub>2</sub>) and third pinnule (P<sub>3</sub>), white arrowhead: P<sub>a</sub>, P<sub>b</sub> and P<sub>c</sub>), H: Arm and distal pinnules (white arrowhead: Sharp small spines on the brachial of the arm, white arrow: Sharp small spines on the distal of the Pinnular).

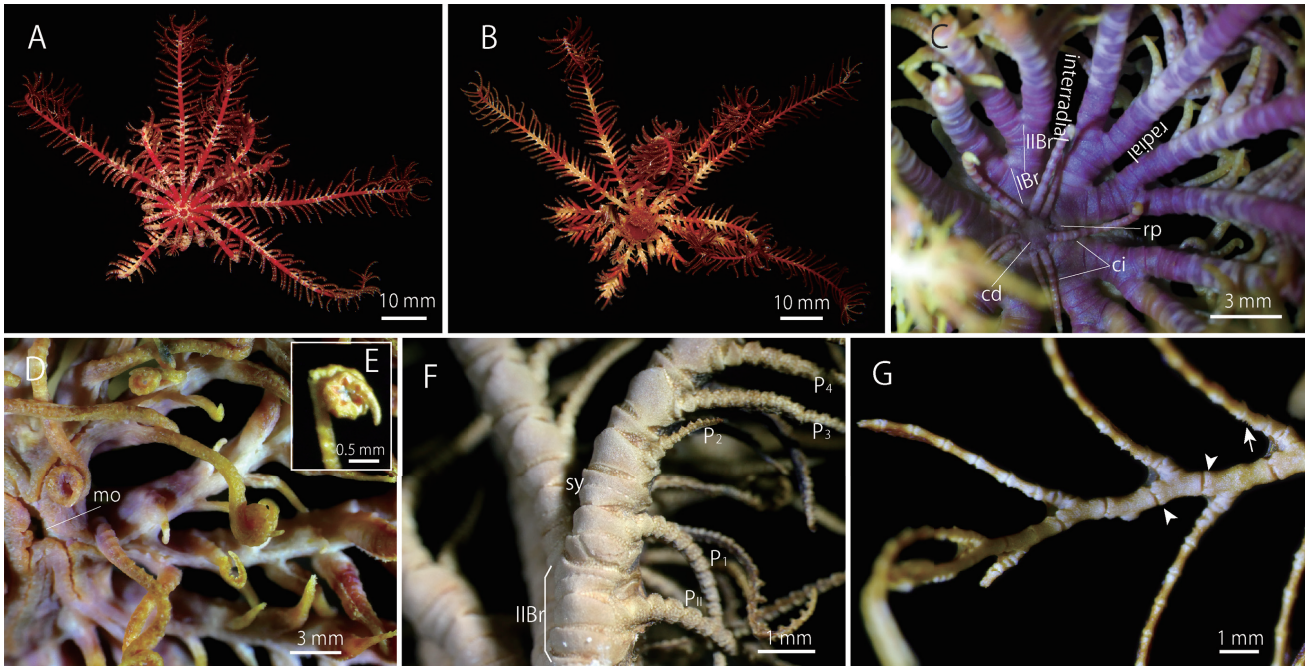


Fig. 2. *Clarkcomanthus exilis* with an arm length of 60 mm (OMNH-Iv 8425). A: Living (aboral), B: Living (oral), C: Central area of specimen, ci: cirri, cd: centrodorsal, rp: radial plate (aboral), IBr: First division series, IIBr: Second division series, D: Oral pinnules (oral), mo: Mouth, E: PII and comb tooth, F: Proximal arms and pinnules, P1: First pinnule, P2: Second pinnule, P3: Third pinnule, P4: Fourth Pinnule, PII: pinnule arising from IIBr2, sy: syzygy, G: Distal arm and pinnules (white arrowhead : Sharp small spines on the brachial of the arm, white arrow: Sharp small spines on the distal of the Pinnular).

Division is up to the first division series and is mainly IBr 2 (Figs. 1C, D), with a slightly lateral trapezoidal plate surrounding the centrodorsal. The base of the arm extends flatly, but the gap between the brachial series widens, more interradial than radial (Fig. 1C).

Free arms are 10 in number, approximately 14 mm in maximum length, and approximately 0.5 mm in width (first syzygy part). From the middle of the arm, the articular surfaces of the brachials tilts slightly alternately in the aboral view. From the fifth brachials onwards, the length and width of the brachials are almost equal, or in some cases, slightly longer in length. Distal edges of all brachials have a small spine, which becomes more pronounced at the tip of the arm (Figs. 1D, H). First syzygy occurs at br3+4 and second syzygy at br10+11 (Fig. 1C); the appearance of syzygy is difficult to identify after the middle part of the arm.

The pinnule arising from the base of the arm is largest, with P<sub>1</sub> arising from the outer most base of the free arm, the subsequent P<sub>2</sub> and P<sub>3</sub> are short and small, approximately 0.1 mm in length. They are not visible from the aboral and slightly more visible from the oral side. Pa, Pb, and Pc in the medial part of the free arm, as well as P<sub>2</sub> and P<sub>3</sub>, are also not visible from the aboral; P<sub>a</sub> is 0.2 mm long and P<sub>b</sub> and P<sub>c</sub> are 0.1 mm long (Figs. 1C, F). After P<sub>1</sub>, a slightly shorter pinnule occurs in the 9th brachial, followed by a pinnule at the tip. P<sub>1</sub> is 3–4 mm long, has 23–25 segments, is multisegmented, and has 8–10 comb-like structures with no lateral bias. A few

apical segments are not fused and the comb-like structure is separated (Fig. 1E).

**Color in life.** No living color was available, but according to the observation recorded under natural conditions: the ground color of the aboral surface is pinkish-red; there are distinct thick horizontal stripes of brownish-white with some ground color remaining on the arms, roughly on the sixth to eleventh brachials on the arms; a few less distinct horizontal stripes are found thereafter, which, when spread out over the arms, becoming a distinctive round-centered pattern. The pinnule is dark red with light brown stripes. The ground color of the centrodorsal dorsal pole is dull red, and the center is light brown. The oral color pattern is the same as that of the aboral, but the ground color is dull red.

#### Description of the medium individual

OMNH-Iv 8425 (Fig. 2: Arm length 60 mm, centrodorsal diameter 1.5 mm)

Centrodorsal is a thin, slightly pentagonal disk. Dorsal pole of the centrodorsal is uneven. There are one or two cirri and their bases, sockets in each radial and one row in the ring (Fig. 2B). Short 9 cirri are observed in a total of 11 cirri sockets, 11 segments, and 4.0 mm in maximum length. Fourth to sixth segment of the cirri is the longest, about 1.3 times as long as wide, and the distal segments are shorter than wide, with a low dorsal spine. Opposing spine and terminal claw are prominent.

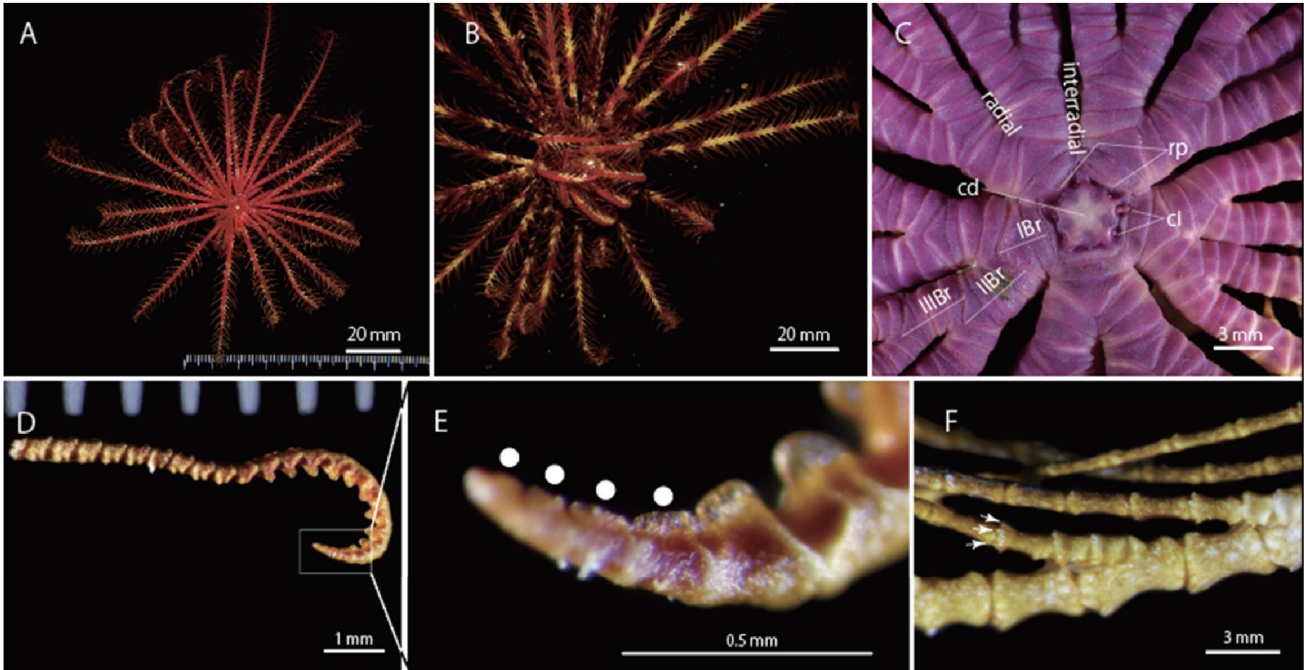


Fig. 3. *Clarkcomanthus exilis* with an arm length of 90 mm (OMNH-Iv 8426). A: Living (aboral), B: Living (oral), C: Central area of specimen (aboral), ci: cirri, cd: centrodorsal, rp: radial plate, IBr: First division series, IIBr: Second division series, IIIBr: Third division series, D: P<sub>II</sub> and comb tooth, E: Distal of P<sub>II</sub> (white dot: Comb teeth of distal, not fused), F: Distal arm and pinnules (white arrow: Sharp small spines on the distal of the Pinnular).

The radial plate, obscured by the cirri, is a horizontal rectangle that surrounds the centrodorsal. Division series is up to the second, mainly IBr 2 and IIBr 4 (3+4) (Fig. 2B). The base of the arm is flattened, and the gap between the brachial series is the same width as the radial and interradial (Fig. 2B).

19 free arms are 60 mm in maximum length, and approximately 1.5 mm width (first syzygy part). In the middle part of the arm, the articular planes of the brachials tilt alternately in aboral view and a well-developed muscular articulation is noted. Distal edge of the arms distal brachials has small spines (Fig. 2E). First immobile joint arises between br3+4 and br10+11 to 12+13, and the second immobile joint arises every 3–5 joints after the middle part of the arm.

The proximal pinnule is multisegmented, the teeth of the comb-like structure are not laterally biased, the segments of this structure at the tip of the pinnule are fused (Figs. 2C–D), the comb-like structure is restricted to P<sub>II</sub> and does not arise thereafter (Figs. 2C, D), P<sub>II</sub> has 27–29 segments, 10–11 comb teeth and 6.5–7 mm long; P<sub>I</sub> has 8–10 segments, no comb teeth and 2–3 mm; P<sub>2</sub> has 10–12 segments, no comb teeth, and 3–4 mm long; P<sub>3</sub> has 12–13 segments, no comb teeth, and 4–5 mm long; P<sub>M</sub> has 18 segments, 5 mm long; P<sub>D</sub> has 15 segments, 5 mm long, and the sides of the pinnule are interspersed with small spines sharper than the distal of the pinnular (Fig. 2E).

**Color in life.** No living color was available, but according to observation records under natural conditions: the ground

color of the aboral is pinkish-red with distinct and thick, brownish-white horizontal stripes with some ground color remaining on the arms. Stripes lying on roughly the sixth to eleventh brachials of the arms and a few less distinct horizontal stripes thereafter. When spread out over the arms, these become a distinctive round-centered pattern. The pinnule is dark red, with light brown stripes or patches, the radial plate is brownish white and the center of the dorsal pole of the centrodorsal is pinkish-red. The pinnule has pinkish-red and brownish-white stripes or a mottled pattern. The oral has the same color pattern as the aboral, but with a dull red ground color.

#### Description of the large Individual

OMNH-Iv 8426 (Fig. 3: arm length 90 mm, centrodorsal diameter 2.2 mm)

The centrodorsal is slightly pentagonal and thinly discoidal. The dorsal pole of the centrodorsal is uneven; there are 1–2 cirri sockets in each radial and one row in the ring; the cirri is extremely short and 10 in number (in actuality only 6 of the 10 cirri sockets were filled, which are significantly poorly identified); 2–5 segments 0.1–0.2 mm long. No opposing spine or terminal claw can be identified, making it a non-functional cirrus.

The radial plate is a narrow horizontal trapezoid that surrounds the centrodorsal. Division is up to the third division series, primarily IBr 2, IIBr 4 (3+4), and IIIBr 4 (3+4). The base of the arms are planarly spread, the gaps between

the brachial series are narrower in the radial plane and are considerably wider in the interradial; some of the arms overlap (Fig. 3A).

There are 34 free arms, 90 mm in maximum length and approximately 1.7 mm wide (first syzygy part). In the middle part of the arm, the articular planes of the brachials tilt alternately in view of the aboral and a well-developed muscular articulation is noted. Distal edge of the arm's distal brachials are fairly obscured (Fig. 3E), although there are small spines. First syzygy occurs between br3+4 and br9+10 to br11+12, and the second syzygy occurs every five joints after the middle part of the arm.

Proximal pinnule is multisegmented, and the comb tooth of the comb-like structure is not laterally biased. Several segments of the comb-like structure at the tip of the pinnule do not fuse (Figs. 3C, D). This structure is present in  $P_{II}$  and in  $P_1$  and  $P_2$  and does not arise thereafter;  $P_{II}$  has 30 segments, 11 comb tooth, 10 mm long;  $P_1$  has 2 segments, 9 comb tooth, 8 mm long;  $P_2$  has 28 segments, 10 comb tooth, 8 mm long;  $P_3$  has 14 segments, no comb tooth, 6mm;  $P_M$  has 15 segments, 5 mm long;  $P_D$  has 14 segments, 5 mm long and the distal of the pinnular is interspersed with small spines (Fig. 3E).

**Color in life.** No living color was available, but according to the observation recorded under natural conditions: the ground color of the aboral is pinkish-red, and in many parts, is a ground color. The arms are spotted with light brownish-white patches on the sides and lack the characteristic round-centered pattern; the radial plate is brownish-white; the center of the dorsal pole of the centrodorsal has a pentaradial light brownish-white pattern; the pinnule has dark red and brownish-white stripes or spots; the oral has five thick brownish-white horizontal stripes on a dull red ground color with a characteristic round-centered pattern.

#### Remarks

Our comparison of the examined three specimens (arm lengths 14 mm, 60 mm, 90 mm) revealed some morphological changes associated with the growth of this species.

*Centrodorsal* 0.7–2.2 mm in diameter and slightly pentagonal. The dorsal pole is uneven through all developmental stages. Cirri sockets arise from all aspects of the centrodorsal and line the ring in 1–2 irregular rows, but as it grows, one or two cirri sockets arise in each radial, and line the ring in a row (Figs. 1C, 2C and 3C).

*Cirri* Number of cirri ranged from 11 (9 of the 11 cirri sockets were identified) in the large individual, 10 (actually 6 poorly curled branches were identified out of 10 cirrus sockets) in the medium individual and 14 (actually only 9 cirri were identified out of 14 cirrus sockets) in the small

individual. Thus, the number of curled branches became smaller and smaller as it grew, with 2.8 mm long for 8 segments, 4 mm long at 11 segments, and 0.1–0.2 mm long at 2–5 segments, with the large individual (OMNH-Iv 8424) having significantly shorter length instead of functional curled branches (Figs. 1C, 2C and 3C).

*Radial Plate* The radial plate of the small individual is a horizontal rectangle surrounding the centrodorsal, but of a horizontal length with some vertical width. As it grows, the radial plate changes into a narrow horizontal rectangle with a narrow vertical width and a narrow trapezoid (Figs. 1C, 2C and 3C).

*Division series* The small individual in the division series are up to the first division series, and it has? mainly IBr 2. As it grows, IBr 2, IIBr 4 (3+4), and IIIBr 4 (3+4) occur up to the third division series. The base of the arm extends flatly, but in small individuals the gap between the brachial series are wider in the interradial than in the radial. However, as it grows, the gap between the brachial series becomes as wide as the radial and interradial. This is narrower in the radial in large individuals and much wider in the interradial, with some arms overlapping each other (Figs. 1D, 2C and 3C).

*Free arm* The small individual has 10 free arms, reaching a maximum arm length of 14 mm. The arm width reaches 0.5 mm. The middle individual has 19 free arms, with maximum arm length of 60 mm, and arm width of 1.5 mm. The large individual has 34 free arms and the longest arm length is 90 mm, with an arm width of 1.7 mm. The small spines of the distal edge of the brachials are more pronounced in juveniles and change only to the distal of the arms as they grow. The position of the first syzygy does not always change at Br 3+4 (Figs. 1D, 2G and 3F).

*Pinnule* The pinnule (proximal pinnule) from the base of the arm of the small individual is not yet full-grow. The firm plumage is only from  $P_1$  arising from the base of the outer most part of the free arm, followed by  $P_2$ ,  $P_3$  etc. and  $P_a$ ,  $P_b$  etc. on the inside of the free arm. After  $P_1$ , a slightly shorter pinnule arises, then in the 9th brachials and the subsequent pinnule, arises with increasing apicality. The comb teeth at the tip of the pinnule (from small individuals to large individuals) are also separated near the distal. In addition, sharp and small spines are scattered across the distal of the pinnular of the pinnule after the middle part of the arms of small individuals to large individuals (Figs. 1D, 2G and 3F).

*Color in life* The ground color of the aboral is pinkish-red with a few thick brownish-white horizontal stripes, with some ground color on the arms; the characteristic round-centered pattern is observed when the arms are spread out. As this species grows, the thick brownish-white horizontal stripes of the free-armed aboral become more obscure and

the characteristic round-centered pattern of the orals is less pronounced. However, the round-centered pattern of the oral side remains (Figs. 1B, 2B and 3B).

### Discussion

Detailed morphological studies of juveniles in Comatulids are scarce, with only a few examples known of changes in taxonomic features such as the morphology of the base of the arms, and the length of pinnules as they grow (Kohtsuka & Nakano, 2005).

The small specimen obtained in this study (OMNH-IV 8424) is a juvenile with 14 mm arm length and 10 arms and no pinnule growth. Species identification of juveniles of feather stars is difficult due to the lack of aligned taxonomic characteristics and morphological changes in the characteristics with growth (Messing, 1997). Actually, in this study, the following diagnostic characters for adult *C. exilis* were not found in the examined small individual: the radial plate was visible from the aboral; gap between the brachial series was considerably wider in the interradial; distal segments of the cirri were shorter than they were wide; the opposing spine and terminal claw were prominent with a low dorsal spine; articular surface of the brachial alternately tilted in view of the aboral in the middle part of the free arm, with well-developed muscular articulation; first syzygy occurred between br3+4 and br10+11 to 11+12 and every five joints after the middle part of the free arm; and the comb-like structure was limited to P<sub>II</sub> and P<sub>I</sub> only. Only the most characteristic coloration of *C. exilis* being red and white transverse stripes, the presence of small spines on the distal edges of the free-armed distal brachials, and the distal edges of the pinnular (Rowe *et al.*, 1986) were confirmed for our examined specimens including the juvenile.

In this study, we showed that coloration and the small spines at the end of the pinnular of the distal pinnule, arising from the arm distal, are stable characteristics in that they are retained from small individuals to large individuals, and they enable us to identify juvenile sea feathers. In the future, accumulation of such steady characters for juveniles of multiple taxa, will help to resolve the confusion in the classification of sea feathers, which may have been caused by relying solely on the adult characters.

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