New Distributional Records of Three Species of Euphylliidae (Cnidaria, Anthozoa, Hexacorallia, Scleractinia) from the Ryukyu Islands, Japan

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(Received 6 December 2019; Accepted 11 March 2020)

Three species of the family Euphylliidae (Cnidaria, Anthozoa, Hexacorallia, Scleractinia) have been formally recorded for the first time from the Ryukyu Islands, Japan, based on specimens. Their unique polyp morphology, such as the combination of extended tentacle, are considered to be useful for taxonomy at the species level in genus *Fimbriaphyllia* Veron and Pichon, 1980 and *Euphyllia* Dana, 1846. One reason that their distribution might have been overlooked is the insufficiency of environmental surveys, including turbid, sheltered, and upper mesophotic environments.

Key Words: Anthozoa, Scleractinia, Euphylliidae, Ryukyu Islands, *Fimbriaphyllia*, *Catalaphyllia*.

Introduction

The family Euphylliidae (Cnidaria, Anthozoa, Hexacorallia, Scleractinia) currently consists of eight genera (Luzon *et al.* 2018). Specimens of most of its species expand their fleshy soft body to protrude from the corallites when they are alive. In contrast to their unique polyp morphology, the skeletal features of the species within this family are not sufficiently varied to utilize for their taxonomy. Recently, a reconstruction of the classification based on molecular phylogenetic studies has been performed, and they proposed the resurrection of the genus *Fimbriaphyllia* Veron and Pichon, 1980 (Luzon *et al.* 2018), the shift of the genus *Galaxea* Oken, 1815 into the family, and the removal of the genera *Plerogyra* Milne Edwards and Haime, 1848, *Physogyra* Quelch, 1884, and *Nemenzophyllia* Hodgson and Ross, 1982, which are now temporarily classified as family *incertae sedis* (Benzoni *et al.* 2014), respectively. However, a comprehensive understanding of their taxonomy has not yet been achieved. One of the obstacles is the difficulty in collection of some rare species.

Previously, three species of the genus *Fimbriaphyllia*, including *F. ancora* (Veron and Pichon, 1980), *F. divisa* (Veron and Pichon, 1980), and *F. yaeyamaensis* (Shirai, 1980), were known in Japan and found to be widely distributed in the Indian Ocean to the Western and Central Pacific, (*e.g.*, Cairns 1999). In addition to the three known species, *F. paraancora* (Veron, 1990) and *F. paradivisa* (Veron, 1990) were mentioned or photographed as species with a possible distribution in Japan (Eyal *et al.* 2016; Miyakojima City Board of Education 2016; Yokochi *et al.* 2019), although

there has not been a specimen-based record in Japan thus far. *Catalaphyllia jardinei* (Saville-Kent, 1893) is known as a widely distributed euphylliid species as well but has been designated as a vulnerable species by the Ministry of Environment in Japan as well as the IUCN Red List because of its rarity (Ministry of Environment, Japan 2017; International Union for Conservation of Nature 2019). Additionally, *C. jardinei* is considered to be distributed discontinuously in Japan, as it is known only in temperate regions and has not been formally reported based on the specimens or photographs in the subtropical regions of the Ryukyu Islands, although it is known in Southeast Asia (Nishihira and Veron 1995; Ministry of Environment, Japan 2017).

In this study, we formally report on three zooxanthellate species of the family Euphylliidae, *i.e.*, *F. paraancora*, *F. paradivisa*, and *C. jardinei*, based on voucher specimens from the Ryukyu Islands, Japan.

Materials and Methods

The specimens were collected by hand or by using a hammer with a chisel by divers utilizing SCUBA after *in situ* photos were taken with digital cameras. The skeletal specimens were preserved by removing the tissues with bleach and drying. The measurement was performed using a vernier caliper with units of 0.1 mm. The specimens were deposited in the Kagoshima University Museum (KAUM), Coastal Branch of Natural History Museum and Institute, Chiba (CMNH), and the Smithsonian National Museum of Natural History (USNM).

Results

Family **Euphylliidae** Alloiteau, 1952
Genus ***Fimbriaphyllia*** Veron and Pichon, 1980

Fimbriaphyllia paraancora (Veron, 1990)
[New Japanese name: Tsutsu-nagarehana-sango]
(Figs 1A, D, 2A–D)

Euphyllia paraancora Veron, 1990: 159–162, figs 65–69, 90;

Fig. 1. Underwater appearance of living corals. A, *in situ* photograph of the colonies of *Fimbriaphyllia paraancora* (KAUM-CN-10) on the left and *F. paradivisa* (KAUM-CN-11) at Tean, Amami-Oshima island, Kagoshima, Japan, on 21 December 2017; B, an aggregation of *F. paradivisa* approximately 3–5 m in diameters on the muddy bottom in the usually turbid inner bay at a depth 28 m, Henoko, Okinawajima island, Okinawa, Japan, on 25 November 2010; C, extended polyps of *F. paradivisa* showing branching tentacles with spherical ends; D, extended polyps of *F. paraancora* showing tentacles with anchor-shaped tips; E, *in situ* photograph of *Catalaphyllia jardinei* (KAUM-CN-14) at Tean, Amami-Oshima island, Kagoshima, Japan, on 21 December 2017; F, polyps of *C. jardinei* showing small bubble-shaped tentacles at the edge of the oral disc.

Wolstenholme *et al.* 1997: 389, table 2; Kenyon *et al.* 2011: 3, table 3; Hsieh *et al.* 2001: 316–317; Hoeksema and Waheed 2012: 299, fig. 2; Turak *et al.* 2012: 53–58; Waheed *et al.* 2015a: fig. 8c; Luzon *et al.* 2018: 1–11.

Specimens examined. KAUM-CN-100, a corallum of 81 mm height from the base, with three corallites of 14.4–34.2 mm greater calicular diameter (GCD), Tean, Oshima Strait, Setouchi, Amami-Oshima island, Kagoshima, Japan (28°9′38.98″N, 129°17′35.04″E), 32 m in depth,

collected by Takuma Fujii on 21 December 2017; CMNH-ZG 09105, a corallum of 55 mm height, with seven corallites of 15.2–35.3 mm GCD, Tean, Oshima Strait, Setouchi, Amami-Oshima island, Kagoshima, Japan (28°9′39.00″N, 129°17′35.00″E), 35 m in depth, collected by Hiroyuki Tachikawa on 3 February 2018; CMNH-ZG 08523, a corallum of 154 mm height, with six corallites of 21.9–37.1 mm GCD, Wase, Sumiyo Bay, Amami, Amami-Oshima island, Kagoshima, Japan (28°17′36.04″N, 129°28′32.00″E), 9 m in

Fig. 2. Corallum of *Fimbriaphyllia* species currently reported from the Ryukyu Islands, Japan, *F. paraancora* (A–D) and *F. paradivisa* (E–H). A, KAUM-CN-10, Tean, Amami-Oshima island, Kagoshima, Japan, depth of 32 m; B, CMNH-ZG09105, Tean, Amami-Oshima island, Kagoshima, Japan, depth of 35 m; C, CMNH-ZG 08523, Wase, Amami-Oshima island, Kagoshima, Japan, depth of 9 m; D, CMNH-ZG 07195, Ii-nanshi, Ogamiyima island, Okinawa, Japan, depth of 10 m; E, KAUM-CN-11, Tean, Amami-Oshima island, Kagoshima, Japan, depth of 32 m; F, CMNH-ZG 09661, Tean, Amami-Oshima island, Kagoshima, Japan, depth of 32 m; G, KAUM-CN-12, Henoko, Okinawajima island, Okinawa, Japan, depth of 28 m; H, CMNH-ZG-09661, Henoko, Okinawajima island, Japan, depth of 28 m.

depth, collected by Hiroyuki Tachikawa on 11 September 2017; and CMNH-ZG 07195, a corallum of 108 mm height from base, with five corallites of 23.1–35.0 mm GCD, Iinanshi, Miyakojima, Ogamijima island, Okinawa, Japan (24°55'29.13"N, 125°18'20.48"E), 10 m in depth, collected by Hiroyuki Tachikawa on 7 July 2015.

Morphology. The morphological features of the soft body and the skeletal characteristics examined in this study agreed with the original description. Colony phaceloid with fleshy tentacles with anchor-shaped tips extend during day (Fig. 1A, D). Tubular corallum branching with weak costae, epitheca absent. Corallites greater diameter 14–37 mm in this study, up to four cycles of fine granulated septa without pali (Fig. 2A–D). Columella absent.

Habitat and distribution. Specimens collected in the current study were from hilly, muddy, and rubbly seafloor areas at depth greater than 30 m inside a bay (Teau) or on the undulating reef wall in comparatively turbid and sheltered coral reef areas at the mouth of a bay (Wase). This species was previously known from Bolinao (the Philippines) of the type locality, Motupore (Papua New Guinea) (Veron 1990), Penghu (Taiwan) (Hsieh *et al.* 2001), Kota Kinabalu (Malaysia) (Hoeksema and Waheed 2012), Spratly Islands (Waheed *et al.* 2015a), Bali (Indonesia) (Turak *et al.* 2012), Northern Australia (Wolstenholm *et al.* 1997), and Guam (Randall and Myers 1983; Randall 2003). A photograph in a field guide to coral in Japan representing the features of this species showed the possibility of its distribution in Japan (Nishihira and Veron 1995); however, no information about the photograph was available. Yokochi *et al.* (2019) listed this species from Iriomotejima island, Japan without any vouchers. The specimens in this study formally represent the northernmost distributional record and the first record from Japan.

Remarks. The soft body of *F. paraancora* resembles *F. ancora* in its anchor-shaped tentacles (Fig. 1D), but it was easy to distinguish through its colony shape, as the latter forms a flabello-meandroid corallum (Fig. 2A–D). It is difficult to distinguish from other phaceloid species in the family Euphyllidae, such as *Euphyllia glabrescens* (Chamisso and Eysenhardt, 1821), *E. paraglabrescens* Veron, 1990, and *F. paradiuisa* by its skeletal features alone, with the exception of *Euphyllia baliensis* Turak, Devantier, and Erdman, 2012, which has a unique tetra or octermal septal pattern and small calicular diameter. This species can be distinguished from the other species in the same genus by genetic sequencing as well (Luzon *et al.* 2018).

***Fimbriaphyllia paradiuisa* (Veron, 1990)**

[New Japanese name: Tsutsu-koeda-nagarehana-sango]

(Figs 1A–C, 2E–H)

Euphyllia paradiuisa Veron, 1990: 157–159, figs 63, 64, 89; Kenyon *et al.* 2011: 3, table 3; Eyal *et al.* 2016: 91–100; Luzon *et al.* 2018: 1–11.

Fimbriaphyllia paradiuisa: Montgomery *et al.* 2019: 54, 158.

Specimens examined. KAUM-CN-11, a corallum of 95.1 mm height from the base, with five corallites of 18.1–

29.4 mm and a dividing corallite of 46.1 mm GCD, Teau, Oshima Strait, Setouchi, Amami-Oshima island, Kagoshima, Japan (28°9'38.98"N, 129°17'35.04"E), 32 m in depth, collected by Takuma Fujii on 21 December 2017; CMNH-ZG 09104, a fragment of a corallum of 80 mm height, with two corallites of 38.6–41.1 mm GCD, 32 m in depth, the same site as KAUM-CN-11, originally a part of the colony of KAUM-11 and separated by Takuma Fujii on 21 December 2017 and collected by Hiroyuki Tachikawa on 3 February 2018; KAUM-CN-12, a corallum of 140 mm height, with five oval corallites of 19.5–27.2 mm, two dividing corallites of 34.0–29.8, and a dead corallite of 30 mm GCD, Henoko, Oura Bay, Nago, Okinawajima island, Okinawa, Japan (26°31'50.85"N, 128°3'17.98"E), 28 m in depth, collected by Masaru Mizuyama on 16 September 2018; and CMNH-ZG 09661, a corallum of 101 mm height from the base, with five corallites of 21.0–27.8 mm GCD with a dividing corallite of 33.4 mm GCD, Henoko, Oura Bay, Nago, Okinawajima island, Okinawa, Japan (26°31'50.85"N, 128°3'17.98"E), 28 m in depth, collected by Masaru Mizuyama on 16 September 2018.

Morphology. The morphological features of both the soft body observed *in situ* and the skeletal characteristics examined in this study agree with the original description. Colony phaceloid, tentacles branching with spherical ends (Fig. 1A–C). Tubular corallum branching with weak costae, epitheca absent. Corallites greater diameter 14–30 mm in this study, up to four cycles of fine granulated septa without pali. Columella absent (Fig. 2E–H).

Habitat and distribution. Specimens collected by the current study were from hilly, muddy, and rubbly seafloor areas of depth greater than 30 m inside two bays of Okinawajima island and Amami-Oshima island, respectively (Henoko and Teau). This species was described from a depth of 8 m in Bolinao, Philippines, by Veron (1990), and, at present, is known from Lian (Philippines; Luzon *et al.* 2018), American Samoa (USA) (Montgomery *et al.* 2019), and Eilat (Israel) (Eyal *et al.* 2016). In Japan, *in situ* photographs of the large assemblage of presumed members of this species were posted in a book (Diving Team Snuck Snufkin 2015); however, no specimen-based record has been made thus far. Additionally, specimens from Okinawajima island were suggested by Eyal *et al.* (2016), but they are in a private collection, and the information is unavailable. The present study formally represents the new and northernmost distributional record of *F. paradiuisa* from Japan based on the available specimens.

Remarks. The soft body of *F. paradiuisa* resembles that of *F. divisa* in its branching tentacles with spherical ends (Fig. 1C), but it is easy to distinguish through its colony shape, as the latter forms a flabello-meandroid corallum (Fig. 2E–H). This species can also be distinguished from other species in the same genus by genetic sequencing (Luzon *et al.* 2018). Although this species was previously known only from a few locations, it is likely that immature colonies of *F. paradiuisa* were confused with *F. divisa* and overlooked in some places. The species' habit of forming assemblage at greater depths, such as mesophotic zones, might have been overlooked as

well, as suggested by Eyal *et al.* (2016).

Genus *Catalaphyllia* Wells, 1971
Catalaphyllia jardinei (Saville-Kent, 1893)
 (Figs 1E, F, 3, 4)

Pectinia jardinei Savill-Kent, 1893: 158, pl. 4.

Catalaphyllia jardinei: Wells 1971: 368–370; Veron 2000: 82–83; Nomura and Mezaki 2015: 35, pl. 2.

Euphyllia sabiuraensis Eguchi, 1973: 82–83, pl. 1.

Cattalaphyllia sabiuraensis: Eguchi and Miyawaki 1975: 54, pl. 6; Kushimoto Marine Park Center 1977: 3, 48.

Catalaphyllia sabiuraensis: Shirai 1977: 584.

Specimens examined. KAUM-CN-13, a fan-shaped corallum with a pointed base, corallum height of 126.4 mm, elongated calice of 209.3×26.8 mm calicular diameter, calice bifurcated and trifurcated at each end, Tean, Oshima Strait, Setouchi, Amami-Oshima island, Kagoshima, Japan (28°9′38.98″N, 129°17′35.04″E), 32 m in depth, collected by Takuma Fujii on 20 December 2018; CMNH-ZG 09662, a fan-shaped corallum with a pointed base; corallum height of 78.1 mm; elongated calice of 123.0×34.2 mm calicular diameter, Tean, Oshima Strait, Setouchi, Amami-Oshima

island, Kagoshima, Japan (28°9′38.98″N, 129°17′35.04″E), 32 m in depth, collected by Takuma Fujii on 21 December 2017; and KAUM-CN-14, a fan-shaped corallum with a pointed base, 96.8 mm in height, elongated calice of 177.9×33.6 mm calicular diameter, Nishikomi, Oshima Strait, Setouchi, Amami-Oshima island, Kagoshima, Japan (28°14′28.86″N 129°10′6.33″E), 31 m in depth, collected by Takuma Fujii on 03 May 2019.

Comparative specimens examined. Photographs of the previously collected specimens are shown in Fig. 4. USNM 1259568, Horseshoe Cliffs, Onna, Okinawajima island, Okinawa, Japan, depth range 52–55 m, collected by Robert F Bolland on 21 December 1988. USNM 94409, off Nago City, Nago, Okinawajima island, Okinawa, Japan, 27 m in depth, collected by Robert F. Bolland on 21 February 1992.

Morphology. The specimens collected at Amami-Oshima island show typical features of the current monotypic genus *Catalaphyllia* Wells, 1971, solid flabello-meandroid corallum with wide V-shaped valley moderately and linearly became hollow into the center, septa with a few teeth developed only in the inner margin (Fig. 3). The living polyp also shows the unique feature of the genus in thick fleshy oral disc which is expanded during the day and tubular to small

Fig. 3. Corallum of *Catalaphyllia jardinei* currently reported from Amami-Oshima island, Japan. A, side view of the corallite of KAUM-CN-14; B, view from the top side of the corallite and the calice of KAUM-CN-14; C, side view of the corallite of CMNH-ZG 09662; D, view from the top side of the corallite and the calice of CMNH-ZG 0966 showing three-forked branching of the calice.

bubble-shaped tentacles with a spherical tip at the edge (Fig. 1E, F).

Habitat and distribution. Specimens collected in the current study were from hilly, muddy, and rubbly seafloor areas at a depth greater than 30 m inside two different bays in the Oshima Strait (Teian and Nishikomi). *Catalaphyllia jardinei* was originally described from the Great Barrier Reef, Australia (Saville-Kent 1893), and is also known from the northern Great Barrier Reef (Veron and Pichon 1980), New Caledonia (Wells 1971), Malaysia (Waheed and Hoek-

sema 2014) and Indonesia (Best *et al.* 1989). In Japan, this species has been reported only in temperate (northern) localities such as Miyazaki (Fukami pers. comm.; Ministry of Environment, Japan 2017), Kumamoto, Kagoshima, Nagasaki (Ministry of Environment, Japan 2017), Kochi (Nomura and Mezaki 2015), and Wakayama (*e.g.*, Eguchi 1973; Nomura and Hirabayashi 2018). Although the Ryukyu Islands have been considered as a distributional gap in the species (*e.g.*, Nishihira and Veron 1995; Veron 2000), two specimens from the east shore of Okinawajima island, in

Fig. 4. Specimens of *Catalaphyllia jardinei* preserved in the Smithsonian National Museum of Natural History (Photographs taken by Alison Becker) (USNM). A–B, corallite of USNM 1259568, collected at 52–55 m deep off Manza Horshoe Cliffs, Onna, Okinawajima island, Okinawa, Japan, on 21 December 1988, by Robert F. Bolland; C–D, corallite of USNM 94409, collected at 27 m deep off Nago City, Nago, Okinawajima island, Okinawa, Japan, on 21 February 1992, by R. F. Bolland.

the middle of the Ryukyu Islands, have been kept at USNM without publication (USNM 94409 and USNM 1259568; Fig. 4). Both specimens from Amami-Oshima island in the current study and the USNM specimens from Okinawajima island fill the distributional gaps of *C. jardinei* between the tropical Western Pacific region and temperate Japan. Sinniger *et al.* (2019) observed *C. jardinei* at mesophotic region of Sesokojima island, Okinawa.

Remarks. Two nominal species of *Catalaphyllia*, *C. sabiu-raensis* Eguchi, 1973, and *C. okinawaensis* Eguchi and Shirai, 1977, have been described from Japan. At present, these two species are considered to be junior synonyms of *C. jardinei* and *E. glabrescens*, respectively (Veron 1992). Currently, the genus *Catalaphyllia* is considered to be monospecific, with its sole member being *C. jardinei*. Because of its rarity, not much information about the genus has been reported in Japan, and a taxonomical reexamination including its phylogenetic position is necessary.

Discussion

Amami-Oshima island, the second-biggest island in the Ryukyu Islands, is located close to the northernmost area with developed coral reef. In addition, it is known as the area where the climate and fauna shift from tropic to temperate. Despite its biogeographic importance, the marine biodiversity of this area is currently poorly studied (e.g., Nakae *et al.* 2018). With regard to the zooxanthellate corals, no specimen-based distributional records have been made since Yabe and Sugiyama's pioneering study in this area (e.g., Yabe *et al.* 1936; Yabe and Sugiyama 1941). Additionally, the major known habitats of the three euphylliid corals currently reported, such as turbid, sheltered, and mesophotic zones, have tended to be outside the research interests of coral surveys. One of the unique features of the geography of Amami-Oshima island is its many bays with a great depth range (<30 m) originating from the Rias Coast. This might have caused coral assemblages to remain that are dominated by zooxanthellate corals, which are tolerant to low light intensity, such as those belonging to the genus *Leptoseris* (Fujii *et al.* 2018). Although it remains to be verified that the observed habitat and the morphological features of *F. parancora* in this study were comparatively different from the other two species (Veron 2000), the three euphylliid corals reported in the present study were found in comparatively sheltered environments. Further examination focused on turbid, sheltered environments or on the upper mesophotic zones will help us to more thoroughly understand the diversity and distributional patterns of not only the three euphylliid corals but also other zooxanthellate corals, such as mushroom corals occurring on sandy habitats (e.g., Gittenberger *et al.* 2015; Waheed *et al.* 2015b; Hoeksema and Suharsono 2019).

Acknowledgments

We thank the following for providing the precious specimens and their support for the sampling: Shin Nishihira, Chihiro Watanabe, Masaru Mizuyama (Diving Team Snuck Snufkin), and James Davis Reimer (University of the Ryukyus) at Okinawajima island; Sadao Yokoyama (Setouchi Marine Biological Institute) at Amami-Oshima island; and the Japanese Society for Coral Taxonomy at Amami-Oshima island and Miyako Islands. We also thank Allen G. Collins and Allison Becker (Smithsonian National Museum of Natural History) for providing information on the deposited specimens in USNM. We also thank for the two anonymous reviewers for their suggestions and comments to improve this report. The sample collections were conducted with the agreement from Setouchi fishery association and both Kagoshima and Okinawa prefectures.

This study was partially supported by JSPS KAKENHI Grant Numbers 17K15198 and 17H01913 and the "Establishment of Research and Education Network on Biodiversity and Its Conservation in the Satsunan Islands" project of Kagoshima University adopted by the Ministry of Education, Culture, Sports, Science and Technology, Japan.

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