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Descriptions of two new species of *Xarifia* copepods (Copepoda: Xarifiidae) with a key to the known species associated with the coral family, Euphylliidae Alloiteau, 1952

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Abstract
Five species of *Xarifia* copepods are known to live in association with the coral family, Euphylliidae Alloiteau, 1952. In this paper, three *Xarifia* copepods, including two new species and one species new to Taiwan, are described and redescribed, i.e., *Xarifia lyudaoensis* nov. sp. and *Xarifia gracilipes* Humes and Dojiri, 1983 living on *Euphyllia glabrescens* (Chamisso and Eysenhardt, 1821), and *Xarifia angusta* nov. sp. collected from *Euphyllia ancora* Veron and Pichon, 1980. The present report brings the total number of species of Xarifiidae to 95, and seven of them live in association with the coral family Euphylliidae. A comparison table and a key to the species of *Xarifia* from euphylliid corals are given herein.

Keywords Coral-associated copepods · Xarifiidae · Scleractinian corals · *Euphyllia* · New species · Taiwan

Introduction

Coral reefs are often referred to as tropical rainforests of the sea, and encompass the highest biodiversity of marine animals as well as the largest diversity of symbiotic associations. Within coral-associated invertebrates, copepods have been highly successful in forming associations on/in so many scleractinian corals in tropical/subtropical waters. Up to now, Scleractinia currently contains 1579 extant species in 243 genera, and serves as hosts to 363 copepod species representing 99 genera and 19 families. It is undoubtedly the case that the copepod is by far the most diverse group of coral-associated crustaceans (Cheng et al. 2016).

Among these coral-associated copepods, Xarifiidae Humes, 1960 is the most dominant and specious endosymbiotic copepods widely distributed in the Indo-Pacific (Humes 1985; Stock 1988). Since the first description of two species of *Xarifia* by Humes (1960), many more species belonging to the Xarifiidae have been found. It currently comprises approximately 93 species (approximately 32% of known coral-associated copepods in Poecilostomatoida) in five genera (Cheng et al. 2016; Walter and Boxshall 2016). Although 148 species of scleractinian corals representing 66 genera (approximately 9.4%) have been known as hosts to symbiotic copepods, little is known about coral-associated copepods of the widespread corals of the genus *Euphyllia*. Only one coral-associated copepod, *Xarifia gracilipes* Humes and Dojiri, 1983, was found living *Euphyllia glabrescens* (Chamisso and Eysenhardt, 1821) from Moluccas. Herein, we examined coral-associated copepods from two species of widely distributed corals, *E. glabrescens* and *Euphyllia ancora* Veron and Pichon, 1980, collected at shallow water reefs in Taiwan. Three species of xarifiids including two undescribed species and one new record were found; one new species and one new record obtained from *E. glabrescens* and the other new species collected from *E. ancora*. Thus, the total number of species of Xarifiidae is brought to 95. Combined with the results from previous studies (Humes and Dojiri 1983; Humes 1985; Cheng and Dai 2016), there are now three species of *Xarifia* copepods which have been known from *Euphyllia* corals, three species from *Galaxea* corals, and one species from *Gyrosmilia* coral. A comparison table and a key to the species of *Xarifia* associated with coral family, Euphylliidae are prepared.

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Materials and methods

Coral fragments of *E. glabrescens* and *E. ancora* were collected by scuba diving at Green Island, off Taiwan. The fragment samples were placed in separate plastic bags underwater and brought back to the laboratory for examination of copepod symbionts. In the lab, each coral together with sea water in the bag was emptied into a bucket to which sufficient 95% ethyl alcohol was added to make it approximately a 5% solution, and kept for 4–6 h for the copepods to be expelled from the coral. Then, the water was poured through a fine net (mesh size approximately 100 μm) and copepods were picked from the sediment under dissecting microscope (Olympus SZH). All copepod specimens were then preserved in 70% ethanol. For morphological studies, copepod specimens were cleared in 85% lactic acid for at least 1 h and dissected on a wooden slide under a dissecting microscope (Humes and Gooding 1964). The dissected body parts and appendages were examined under a compound microscope (ZEISS Axioskop 40) with a series of magnifications up to 1000×. All drawings were made with drawing tube.

Results

Poecilostomatoida Thorell, 1859.
Family Xarifiidae Humes, 1960.
Genus *Xarifia* Humes, 1960.

Xarifia lyudaoensis nov. sp.

Material examined: All specimens (three ♀♀ and two ♂♂) were obtained from washings of *Euphyllia ancora* Veron and Pichon, 1980 collected at 8 m depth, at Lyudao (also known as Green Island, 20°40′55.8”N, 121°29′39.4″E),Taitung, Taiwan on 6 July 2017. One female holotype (ASIZCR000392) and one male allotype (ASIZCR000393) were deposited in the Biodiversity Research Museum, Academia Sinica, Taipei, Taiwan. Remaining specimens (dissected) are retained in the first author’s private collection.

Female

Body (Figs. 1a, b) stout. Length 3.52 mm (3.10–3.88 mm) and greatest width 0.62 mm (0.56–0.68 mm), based on 3 specimens. Segmentation of somites indistinct, except for second and third pedigers. Region dorsal to fifth legs with three small knobs (Fig. 1a). Genital and postgenital somites straight or slightly flexed ventrally (Figs. 1a, b). Areas of attachment of egg sacs located dorsally. Caudal ramus (Fig. 1c) 157 μm, bearing four terminal setae. Surface of body smooth (Figs. 1a-c). Egg sac not seen.

Antennule (Fig. 1d) 5- or 7-segmented. Armature: 3, 11, 7, 5, 0, 2 + 1 aesthetasc, and 2 + 2 aesthetasc in the case of having seven segments and 3, 18, 5, 2 + 1 aesthetasc, and 2 + 2 aesthetasc in the case of having five segments. All setae naked. Antenna (Fig. 1e) three-segmented. Formula 1, 1, 2 and 1 + I.

Labrum (Fig. 1f) having rounded outer lobes at both free corners. Mandible (Fig. 1g) blade, tipped with unilateral spinules. Maxillule (Fig. 1h) tipped with two long setae, one small lateral seta, and one small anterior process. Maxilla (Fig. 1i) two-segmented; first segment large, bearing with one anterior seta, one subterminal long seta, and three minute spinules; second segment drawn out into a pointed process with lamella and one basal setae. Maxilliped (Fig. 2a) three-segmented; first segment unarmed; second segment with two unequal inner setae; small third segment tipped with two claws and one spine-like seta.

Legs 1–4 (Figs. 2b-e) with three-segmented exopod (except for leg 4, with two-segmented) and two-segmented endopod. Formula of spines (in Roman numerals) and setae (in Arabic numerals) as follows:

	Coxa	Basis	Exopod	Endopod
Leg 1	0–0	1–0	I-0; I-0; I + 2	0–0; 2
Leg 2	0–0	1–0	I-0; 0–0; I + 2	0–0; 2
Leg 3	0–0	1–0	I-0; 0–0; I + 1	0–0; 1
Leg 4	0–0	1–0	I-0; I + 1	0–0; 1

Leg 5 (Fig. 1a, b) short, bearing two terminal setae, adjacent dorsal seta not seen.

Male

Body (Fig. 3a, b) stout as in female, but slightly arched. Length 2.60 mm (1.90–3.30 mm) and greatest width 0.56 mm (0.42–0.70 mm), based on two specimens. Caudal ramus as in female.

Antennule, antenna, mandible, maxillule, and maxilla like those in female, but antennule with one aesthetasc added on second or third segment (indicated by a dot in Fig. 1d). Maxilliped (Fig. 3c) four-segmented; first and third segment unarmed; second segment with two medial setae; fourth segment a claw with trifurcate tip, bearing two proximal setae and serrated concave surface.

Legs 1–4 as in female.
Leg 5 (Fig. 3b) represented by three small setae.
Leg 6 (Fig. 3b) represented by two small setae on posteroventral flap on genital segment.

Remarks

So far, there are four species of *Xarifia* like the present new species in possessing three knobs/small process above and between the fifth legs in the female. They are: *Xarifia basilica*

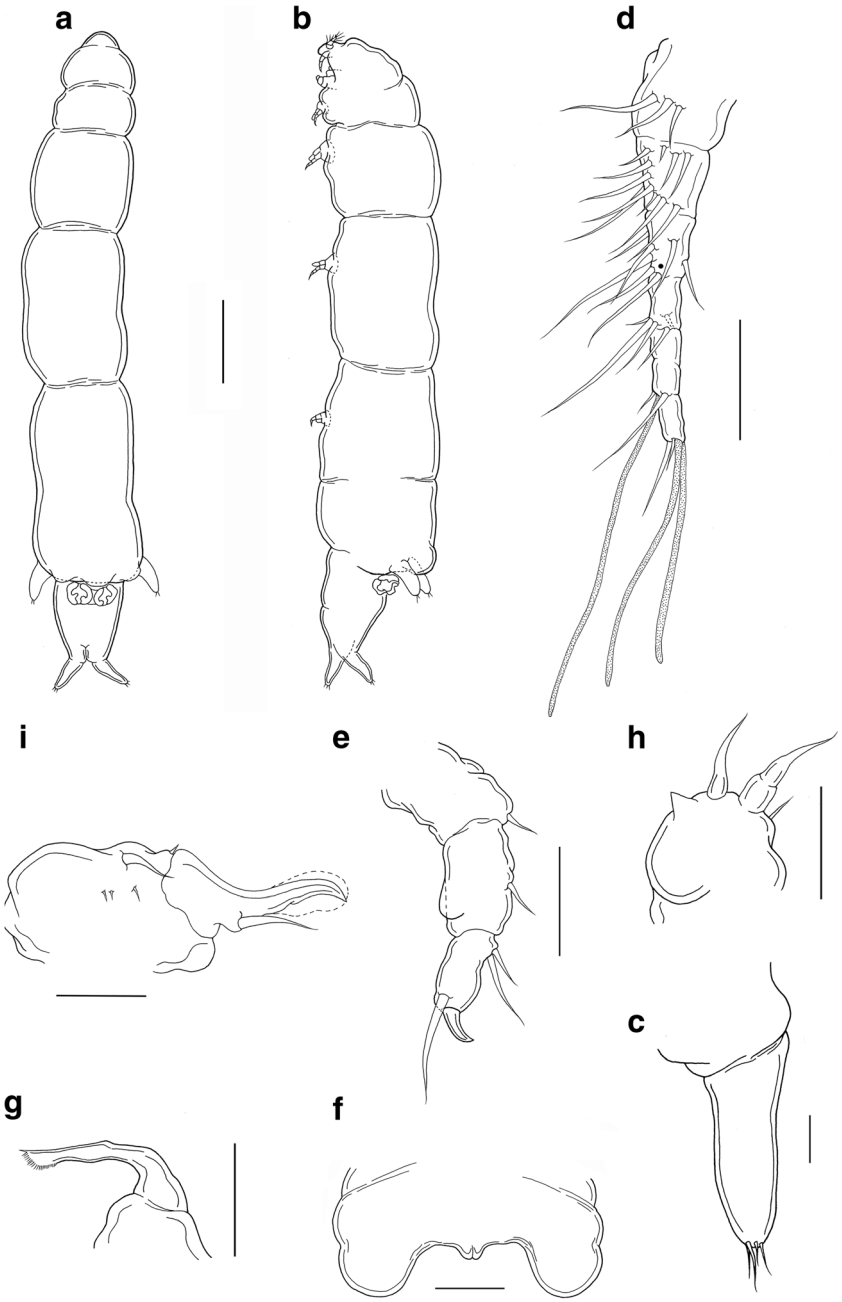

Fig. 1 *Xarifia lyudaoensis* nov. sp., Female: **a**, habitus, dorsal; **b**, habitus, lateral; **c**, caudal ramus, dorsal; **d**, antennule, anterior; **e**, antenna, anterior; **f**, labrum, ventral; **g**, mandible, ventral; **h**, maxillule, anterior; **i**, maxilla, anterior. Scale bar: **a**, **b**, 0.5 mm; **c**–**e**, 0.05 mm; **f**–**i**, 0.025 mm

Humes, 1985, *Xarifia trituberata* Humes and Dojiri, 1982, *Xarifia gerlachi* Humes, 1962, and *Xarifia exserens* Humes, 1985. The new species can be easily distinguished from the first three species by having two segments of endopods, and readily distinguished from *X. exserens* by possessing two or three different patterns of outer armature on the exopods of legs 1–4 (leg 1–2: I-0; I-0; I + 2; leg 3: I-0; 0–0; I + 1; leg 4: I-0; I + 1) and less armature (2 + 2 aesthetasc) on the terminal segment of antennule (Table 1). These two characters are unique among 93 species of *Xarifia*. Furthermore, the biggest body size in female also provides a useful preliminary to discriminate *X. lyudaoensis* nov. sp. from its congeners. The remaining dissimilarities among these species are summarized in Table 1.

Etymology: The species is named after the type-locality Lyudao (also known as Green Island).

Xarifia angusta nov. sp.

Material examined: All specimens (three ♀♀ and three ♂♂) were obtained from washings of *Euphyllia ancora* Veron and Pichon, 1980 collected at 5 m depth, at Tiaoshi (21°57′ 25.1”N, 120°46′01.8″E), Pingtung, Taiwan on 21 September 2006. One female holotype (ASIZCR000394) and one male allotype (ASIZCR000395) deposited in the Biodiversity Research Museum, Academia Sinica, Taipei, Taiwan.

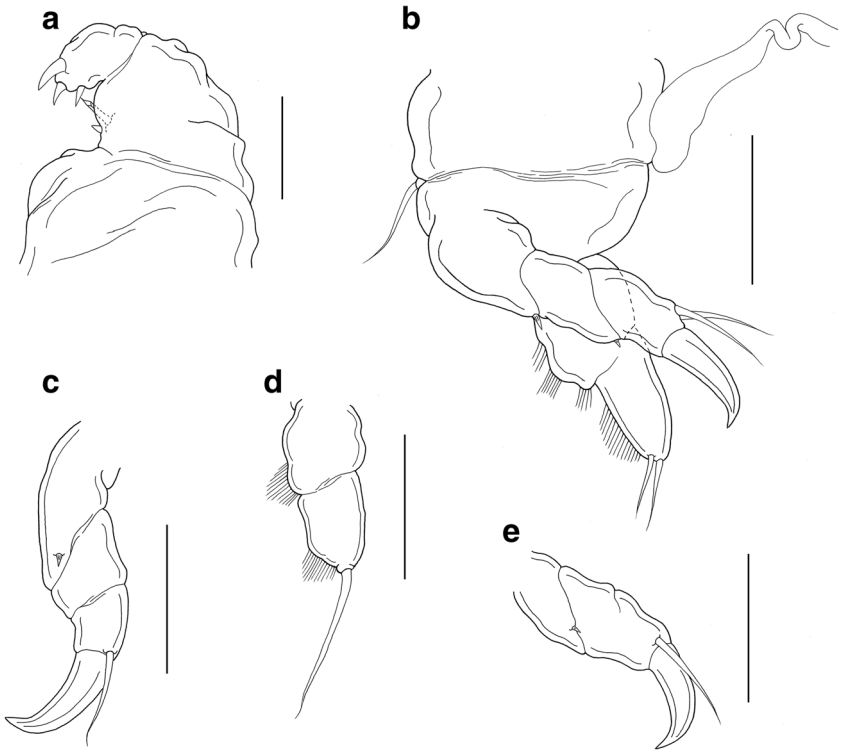

Fig. 2 *Xarifia lyudaoensis* nov. sp., Female: **a**, maxilliped, posterior; **b**, leg 1, anterior; **c**, exopod of leg 3; **d**, endopod of leg 3; **e**, exopod of leg 4. Scale bar: **a**, 0.025 mm; **b**–**e**, 0.05 mm

Remaining specimens (dissected) are retained in the first author's private collection.

Female

Body (Figs. 4a, b) slender, about 5.5–6 times longer than wide. Length 1.78 mm (1.66–1.94 mm) and greatest width 0.32 mm (0.30–0.34 mm), based on three specimens measured in lactic acid. Segmentation of somites indistinct or weak. Region dorsal to fifth legs with three long posteriorly directed processes of nearly equal length, though occasionally median process shorter than lateral processes (Figs. 4a-c). Genital and postgenital somites (Figs. 4b, c) slightly recurved upward. Areas of attachment of egg sacs located dorsally (Figs. 4a, c). Egg sac not seen. Caudal ramus (Fig. 4d) short and slightly pointed, 80 μm long, 38 μm wide near base,

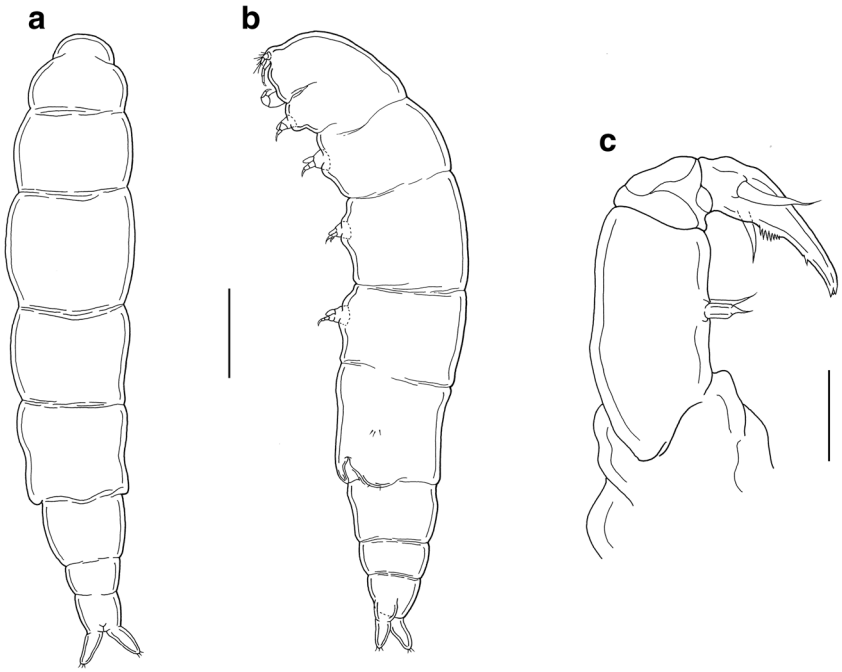

Fig. 3 *Xarifia lyudaoensis* nov. sp., Male: **a**, habitus, dorsal; **b**, habitus, lateral; **c**, maxilliped, posterior. Scale bar: **a**, **b**, 0.5 mm; **c**, 0.05 mm

Table 1 Differences between *Xarifia* copepods symbiotic with coral family, Euphylliidae

	Xarifia dongshensis	*Xarifia gracilipes*	*Xarifia apertipes*	*Xarifia exserens*	*Xarifia lyudaoensis* nov. sp.	*Xarifia angusta* nov. sp.	*Xarifia* sp.
Host corals	*Galaxea fascicularis*	*Euphyllia glabrescens*	*Gyrosmilia interrupta*	*Galaxea fascicularis*	*Euphyllia glabrescens*	*Euphyllia ancora*	*Galaxea astreata*
Distribution	Dongsha Island, Taiwan	Moluccas	Madagascar	Moluccas	Green Island, Taiwan	Taiwan	Madagascar
Processes above fifth legs	smooth	3 processes	3 processes	3 small knobs	3 small knobs	3 processes	–
No. segments of second antenna	3	4	4	3	3	4	–
Outer armature of exopods of legs 1–4	I, I, I	I, I, I	I, I, I	I, 0, I	leg 1–2: I, I, I; leg 3: I, 0, I + 1; leg 4: I; I	I, I, I	–
Terminal armature of exopods of legs 1–4	2, 2, 1, 1	3, 3, 2, 2	2, 2, 2, 2	2, 1, 1, 1	2, 2, 1, 1	3, 3, 2, 2	–
No. segments of endopods of legs 1–4	2	2	2	2	2	2	–
Terminal armature of endopods of legs 1–4	2, 2, 1, 1	2, 2, 1, 1	2, 1, 1, 1	2, 2, 1, 1	2, 2, 1, 1	2, 2, 1, 1	–
Armature of antennule	3, 16, 4, 2 + 1 aesthetasc, and 4 + 1 aesthetasc	3, 11, 7, 5, 2 + 1 aesthetasc, and 7 + 1 aesthetasc	3, ll, 7, 3+ 1 aesthetasc, 2+ 1 aesthetasc, and 7 + 1 esthete	3, 16, 3, 2 + 1 aesthetasc, and 7 + 1 aesthetasc	3, 11, 7, 5, 0, 2 + 1 aesthetasc, and 2 + 2 aesthetasc or 3, 18, 5, 2 + 1 aesthetasc, and 2 + 2 aesthetasc	3, 11, 7, 3, 2 + 1 aesthetasc, and 7 + 1 aesthetasc	–
Caudal ramus	4 setae	7 setae	6 setae	5 setae	4setae	7 setae	–
Tip of mandible	unilateral spinules	smooth, bilamellate	smooth, bilamellate	smooth	unilateral spinules	smooth, bilamellate	–
Lengths of caudal ramus (μm)	100	178	92	143	157	80	
Reference	Cheng and Dai 2016	Humes and Dojiri 1983	Humes and Dojiri 1983	Humes 1985	This study	This study	Humes 1985

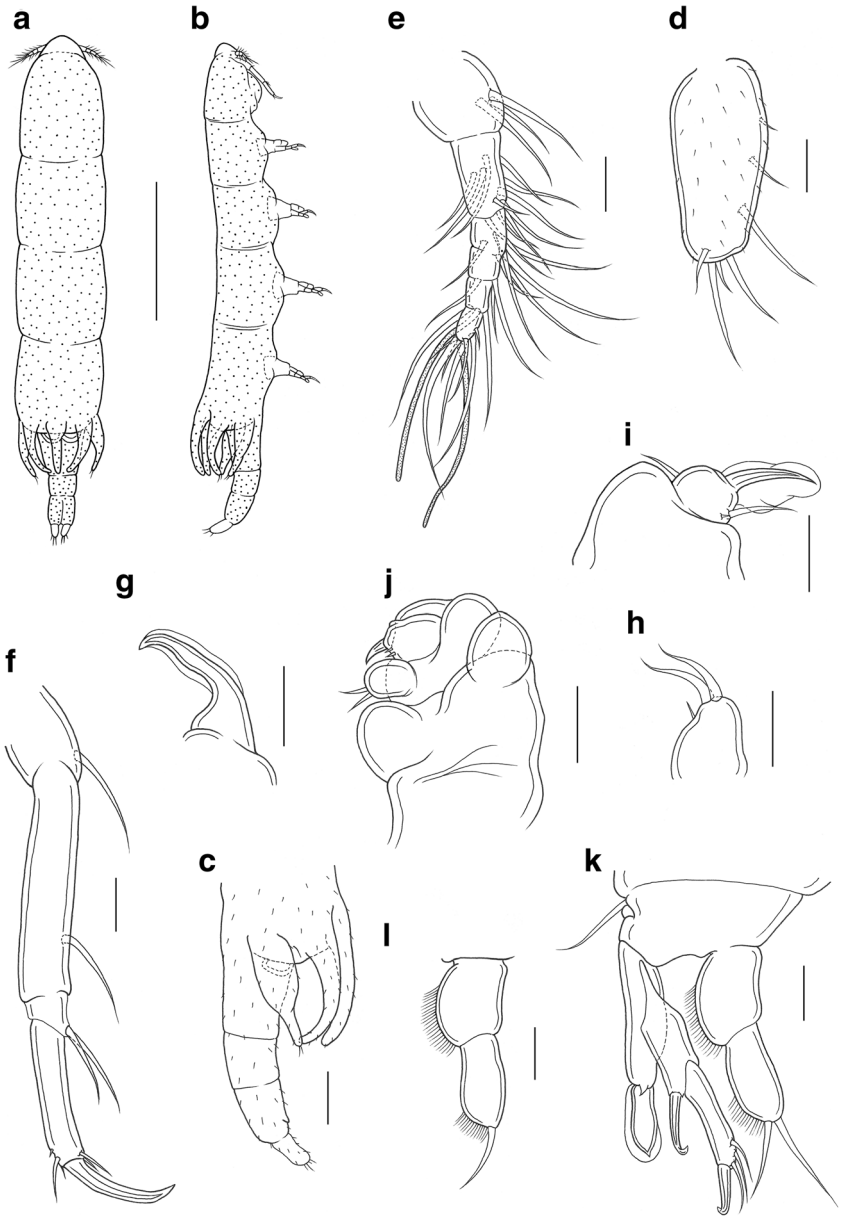

Fig. 4 *Xarifia angusta* nov. sp. Female: **a**, habitus, dorsal; **b**, habitus, lateral; **c**, processes and urosome, lateral; **d**, caudal ramus, dorsal; **e**, antennule, anterior; **f**, antenna, anterior; **g**, mandible, ventral; **h**, maxillule, anterior; **i**, maxilla, anterior; **j**, maxilliped, posterior; **k**, leg 1, anterior; **l**, endopod of leg 3. Scale bar: **a**, **b**, 0.5 mm; **c**, 0.1 mm; **d**–**l**, 0.02 mm

bearing four terminal setae, one subterminal seta, and two lateral setae; all setae smooth. Surface of body densely covered with small setules (Figs. 4a-d).

Antennule (Fig. 4e) five–six-segmented (segmentations between three-segment and four-segment unclear); first to fifth segments 30 × 32, 32 × 16, 23 × 12, 11 × 9, 11 × 8 μm respectively from anterior to posterior. Armature: 3, 11, 7, 3, 2 + 1 aesthetasc, and 4 + 1 aesthetasc. All setae naked. Antenna (Fig. 4f) four-segmented; 176 μm long (without final claw); second segment longest (85 μm); third segment shortest (16 μm); final segment with one claw and five unequal setae. Formula 1, 1, 2, I + 5. Mandible (Fig. 4g) blade, bilamellate, with recurved tip. Maxillule (Fig. 4h) one-segmented, tipped with two long terminal setae and one short subterminal seta. Maxilla (Fig. 4i) 2-segmented; first segment unarmed; second segment drawn out into a pointed process covered with large lamella and bearing with two unequal inner setae and one outer seta. Maxilliped (Fig. 4j) three-segmented; first segment largest, with two large, distal lobes; second segment with two slightly small lobes and two naked setae; small third segment tipped with one hook-like seta and two min subterminal setae.

Legs 1–4 (Figs. 4k, l) with three-segmented exopod and two-segmented endopod. Formula of spines (in Roman numerals) and setae (in Arabic numerals) as follows:

	Coxa	Basis	Exopod	Endopod
Legs 1–2	0–0	1–0	I-0; I-0; I + 3	0–0; 2
Legs 3–4	0–0	1–0	I-0; I-0; I + 2	0–0; 1

Rami of legs 1–4 elongate and slender. Spine on first segment of exopod with large lamella. Outer margin of both segments of endopods with short hairs.

Leg 5 (Figs. 4a–c) elongate, base expanded, 223 μm long, 76 μm wide near base, bearing two terminal setae and single adjacent dorsal seta.

Male

Body (Figs. 5a, b) similar to that of female, but more slender, about 6.5 times longer than wide. Length 1.42 mm (1.34–1.50 mm) and greatest width 0.24 mm (0.22–0.26 mm), based on threeee specimens measured in lactic acid. Caudal ramus as in female. Body surface with long setules as in female.

Antennule, antenna, mandible, maxillule, and maxilla like those in female, but antennule with one aesthetasc added on third segment (indicated by a dot in Fig. 4e). Maxilliped (Fig. 5c) 4-segmented; first and third segment unarmed; second segment with two medial equal setae; fourth segment a claw with trifurcate tip, bearing two proximal setae and row of denticles along concave margin.

Legs 1–4 as in female.

Leg 5 (Fig. 5d) minute, with two terminal setae and one adjacent dorsal seta.

Leg 6 (Fig. 5b) represented by two small setae on posteroventral flap on genital somite.

Spermatophore not seen.

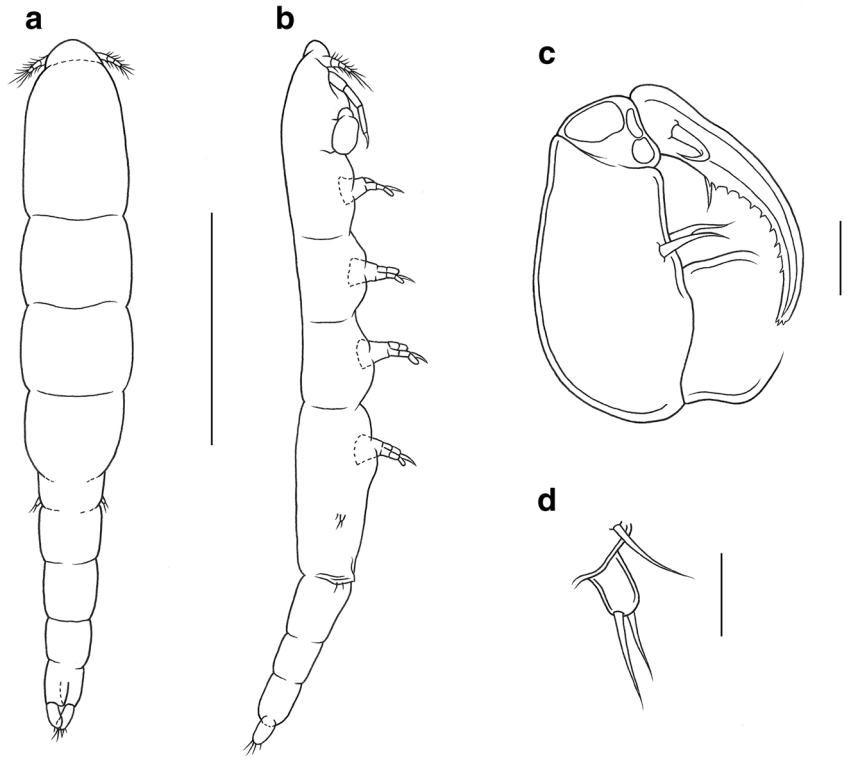

Fig. 5 *Xarifia angusta* nov. sp. Male: **a**, habitus, dorsal; **b**, habitus, lateral; **c**, maxilliped, posterior; **d**, leg 5, anterior. Scale bars: **a**, **b**, 0.5 mm; **c**, **d**, 0.02 mm

Etymology: The specific name *angusta* is Latin, meaning small and short. It refers to the small caudal ramus of the female.

Remarks

The present new species is similar to *Xarifia gracilipes* in possessing slender and elongate rami in legs 1–4 and the formula of terminal segment of the endopod of legs 1–4 being 2, 2, 1, 1. However, *Xarifia angusta* and *X. gracilipes* show the difference in the host coral preference (*X. angusta* from *E. ancora*; *X. gracilipes* from *E. glabrescens*). Besides, *X. angusta* can be distinguished from *X. gracilipes* by the following features: (1) much shorter caudal ramus, 80 μm long; (2) leg 5 shorter (223 μm) and slightly expanded at base (76 μm); (3) the armature of antennule being 3, 11, 7, 3, 2 + 1 aesthetasc, and 7 + 1 aesthetasc; and (4) the related longer spines on second and third segment of exopod of legs 1–4. The remaining dissimilarities among these species are summarized in Table 1.

Xarifia gracilipes

Xarifia gracilipes Humes and Dojiri, 1983: 257–307, Figs. 10–13.

Host: *Euphyllia glabrescens* (Chamisso and Eysenhardt, 1821).

Type locality: Moluccas.

Material examined: All specimens (five ♀♀ and two ♂♂) were obtained from washings of *Euphyllia ancora* Veron and Pichon, 1980 collected at 8 m depth, at Lyudao (20°40′55. 8”N, 121°29′39.4″E),Taitung, Taiwan on 6 July 2017.

Remarks

Female body (Figs. 6a, b) elongate. Body length of dissected specimen 1.90 mm (1.82–2.00 mm) and greatest width 0.31 mm (0.29–0.32 mm), based on three specimens in lactic acid. Region dorsal to fifth legs with three posteriorly directed processes. Caudal ramus (Figs. 6a, b) elongate, about 178 × 40 μm. Male body (Figs. 6f, g) more slender. Body length of dissected specimen 1.94 mm (1.86–2.02 mm) and greatest width 0.29 mm (0.28–0.30 mm), based on two specimens in lactic acid. The maxilliped of our specimens (Fig. 6h) is similar to that described by Humes and Dojiri (1983).

According to Humes and Dojiri (1983), the elongate rami in legs 1–4 is the main characteristic of this species (Figs. 6d, e). Our specimens with elongate rami in legs 1–4 are similar to the description of previous studies, but some tiny differences are occurred: the slender and longer caudal ramus (Figs. 6a, b, 178 × 40 μm), the shorter claw of antenna (Fig. 6c, 32 μm), and slightly longer seta (Fig. 6c, 34 μm) adjacent to the claw of antenna. Our discovery of it from southern Taiwan extends the northern limit of this species to the northern West Pacific.

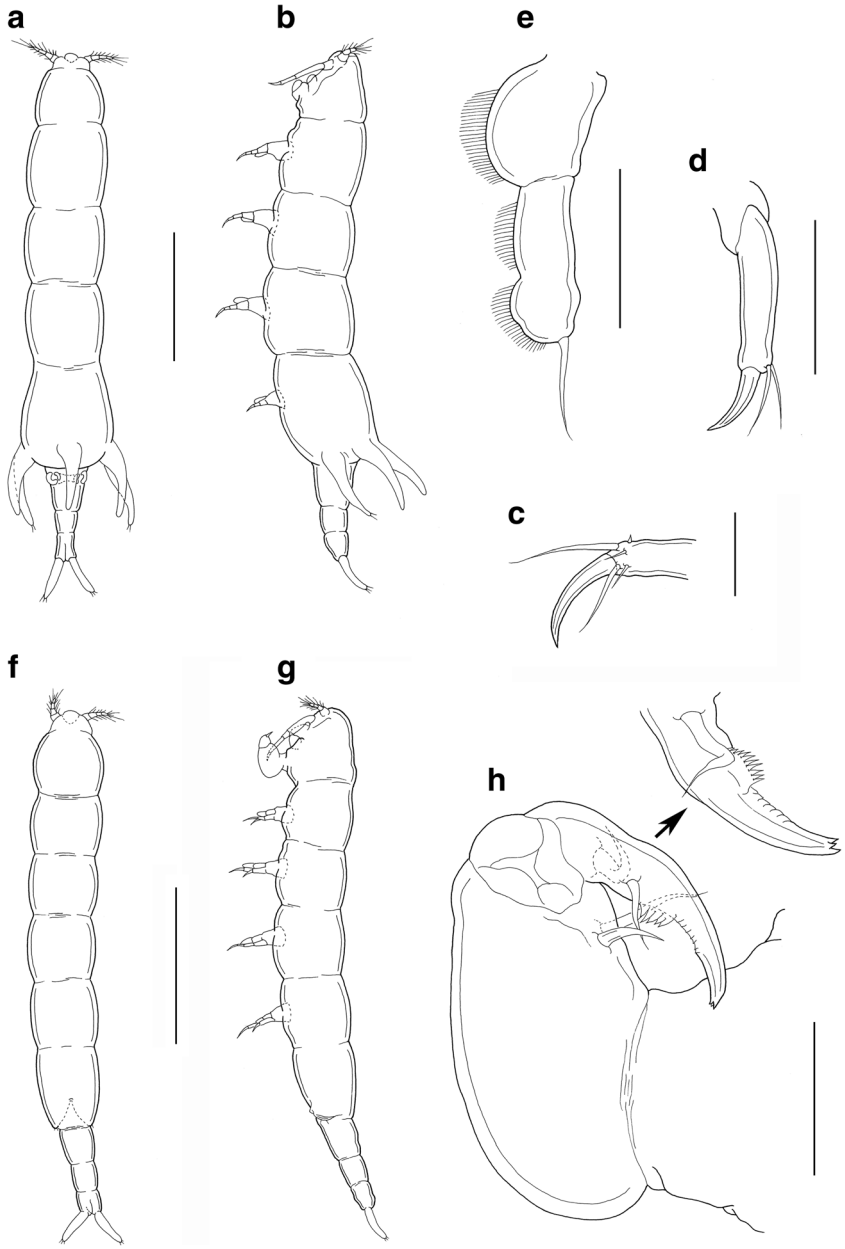

Fig. 6 *Xarifia gracilipes*. Female: **a**, habitus, dorsal; **b**, habitus, lateral; **c**, terminal segment of antenna; **d**, terminal segment of exopod of leg 3; **e**, terminal segment of endopod of leg 3. Male: **f**, habitus, dorsal; **g**, habitus, lateral; **h**, maxilliped, posterior, with a close view. Scale bar: **a**, **b**, **g**, 0.5 mm; **c**, 0.025 mm; **d**–**f**, 0.05 mm

Key to females of *Xarifia* copepods symbiotic with coral family, Euphylliidae. Host coral are indicated in the parentheses.

1a. Region dorsal to fifth legs with processes/knobs.....2
1b. Region dorsal to fifth legs smooth.....***Xarifia dongshensis*** (*Galaxea fascicularis*)
2a. Region dorsal to fifth legs with three small knobs.....3
2b. Region dorsal to fifth legs with processes.....4
3a. Exopods of legs 1–4 with the same outer armature (I, 0, I).....***Xarifia exserens*** (*Galaxea fascicularis*)
3b. Exopods of legs 1–4 with different outer armature; outer armature of exopods of leg 1 being I, I, I.....***Xarifia lyudaoensis*** nov. sp. (*Euphyllia glabrescens*)
4a. Endopods of leg 2 with two setae.....5
4b. Endopods of leg 2 with only one setae.....***Xarifia apertipes*** (*Gyrosmilia interrupta*)
5a Caudal ramus longer (ca. 178 μm); leg 5 slender; 4th segment of antennule being with five setae.....***Xarifia gracilipes*** (*Euphyllia glabrescens*)
5b. Caudal ramus shorter (ca. 80 μm); leg 5 slightly expanded; 4th segment of antennule being with three setae.....***Xarifia angusta*** nov. sp. (*Euphyllia ancora*)

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval Corals and copepods were used in this study. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed by the authors.

Field study Permits and approval of field or observational studies have been obtained by the authors.

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