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Supplementary Description of Three *Acartiella* Species (Crustacea: Copepoda: Calanoida) from Estuarine Waters in Thailand

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Three species of calanoid copepods belonging to the genus *Acartiella* Sewell, 1914 are redescribed from three estuaries in Thailand. Two species, *Acartiella kempi* Sewell, 1914 and *A. nicolae* Dussart, 1985, were collected from the Kraburi Estuary and Prasae Estuary, respectively, representing the first records of these species from Thailand. In addition, *A. sinensis* Shen and Lee, 1963, collected from the Bangpakong Estuary on the northeast coast of the Gulf of Thailand, is redescribed, as the original description is poor. This genus is zoogeographically unique as it is restricted to tropical and subtropical Asian estuarine waters, and this study increases our understanding of the evolution of estuarine copepods in the Indo-West Pacific.

Key Words: Acartiella, Acartiidae, Andaman Sea, Gulf of Thailand.

Introduction

The family Acartiidae Sars, 1903 currently comprises the following genera and species: *Acartia* Dana, 1846 with 64 species, *Acartiella* Sewell, 1914 with 11 species, *Paracartia* Scott, 1894 with five species, *Paralabidocera* Wolfenden, 1908 with three species, and *Pteriacartia* Belmonte, 1998 with one species (Boxshall and Halsey 2004; Razouls *et al.* 2014). Species of the genus *Acartiella* Sewell, 1914 are predominantly found in estuarine and coastal river systems in the Indo-Malayan region (Sewell 1919; Tranter and Abraham 1971). The coastal/estuarine genus *Acartia* has been intensively studied by ecological researchers due to its high abundance (see Mauchline 1998). In contrast, *Acartiella* has rarely been investigated, possibly because of its restricted distribution in tropical and subtropical brackish waters in Asia. However, *A. sinensis* Shen and Lee, 1963 was introduced from Asian waters to San Francisco Bay, USA via ship ballast water (Orsi and Ohtsuka 1999), and has been suggested to play a pivotal role in this highly disturbed ecosystem (York *et al.* 2013).

Surveys of the estuarine copepod fauna in Thailand are limited. Recently, a new species of *Pseudodiaptomus* was found in estuarine waters of the Gulf of Thailand (Srinui *et al.* 2013), an indication that a more extensive faunal survey is required. Prior to the current study, only a single species of the brackish water genus *Acartiella, A. sinensis*, was known from the Bangpakong Estuary, Thailand (Suwanrumpha 1987); it was subsequently also recorded in the Chanthaburi River, Chanthaburi Province (Ohtsuka *et al.* unpublished data). Although Pinkaew (2003) intensively studied the copepod fauna of the Bangpakong Estuary, no other species of *Acartiella* was recorded there. Our faunal investigation of brackish water copepods in Thailand has turned up two previously described species of *Acartiella* that are reported herein for the first time from Thailand, namely *A. kempi* Sewell, 1914 and *A. nicolae* Dussart, 1985. Since no species of *Acartiella* has ever been described on the basis of the homology scheme proposed by Huys and Boxshall (1991), modern redescriptions of all three Thai species of *Acartiella* are provided herein. The zoogeography of the genus is also commented upon.

Materials and Methods

Copepod samples were collected from three sites in the Kraburi Estuary, Ranong Province, on the coast of the Andaman Sea (09°57′32.30″N, 98°35′15.58″E, depth 1.5 m) on November 7, 2011 (local time 17:30), the Prasae River, Rayong Province (12°44′45.48″N, 101°41′40.22″E, depth 1.5–4 m) on August 13, 2012 (local time 10:12) and March 5, 2013 (local time 11:40), and the Bangpakong Estuary, Chon Buri Province (13°29′67″N, 100°59′63″E, depth 3 m) on July 22, 2012 (local time 9:22) (Fig. 1). At each sampling location, plankton was collected during daytime by a series of vertical tows of a conical plankton net (diameter 30 cm, mesh size 0.33 mm) from the river bed to the surface. All samples were immediately fixed in 4% neutral-

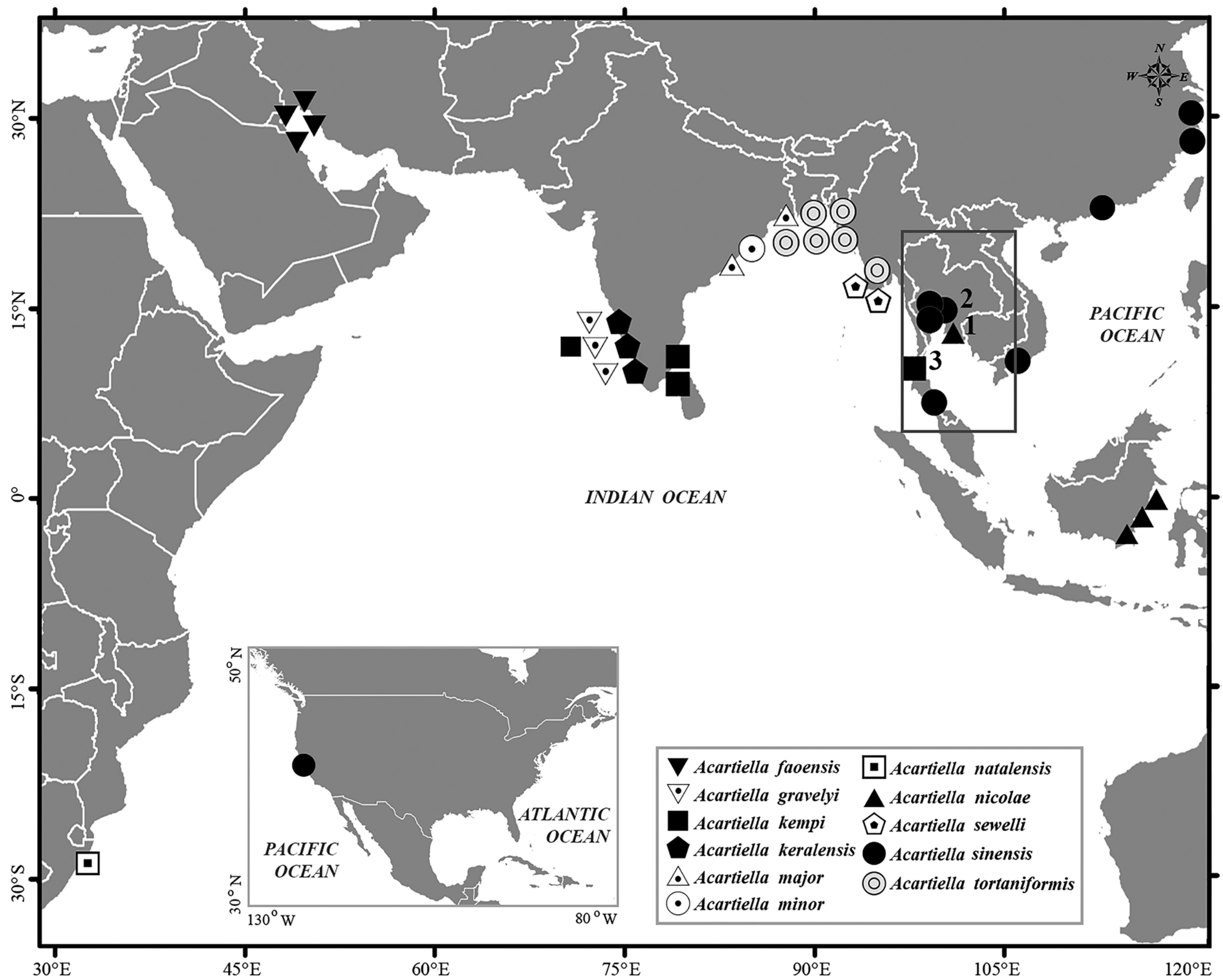

Fig. 1. Distribution of the genus *Acartiella* based on the present and previous data. Three sampling sites in the present study in Thailand: Station 1, Prasae Estuary, Rayong Province, Gulf of Thailand (black triangle); Station 2, Bangpakong Estuary, Chon Buri Province, Gulf of Thailand (black circle); Station 3, Kraburi Estuary, Ranong Province, Andaman Sea (black square);. Previous distributional data: *A. nicolae* (Dussart 1985; Mulyadi 2004; Razouls *et al.* 2014); *A. sinensis* (Shen and Lee 1963; Zheng *et al.* 1982; Suwanrumpha 1987; Pholpunthin 1997; Orsi and Ohtsuka 1999; Pinkaew 2003; Shang *et al.* 2007; Razouls *et al.* 2014); *A. kempi* (Sewell 1914; Razouls *et al.* 2014); *A. gravelyi* (Sewell 1919; Razouls *et al.* 2014); *A. keralensis* (Wellershaus 1969; Razouls *et al.* 2014); *A. major* (Sewell 1932; Razouls *et al.* 2014); *A. minor* (Sewell 1919; Razouls *et al.* 2014); *A. natalensis* (Connell and Grindly 1974; Razouls *et al.* 2014); *A. sewelli* (Steur 1934; Razouls *et al.* 2014); *A. tortaniformis* (Sewell 1932; Razouls *et al.* 2014); and *A. faoensis* (Khalaf 1991; Ali *et al.* 2009; Peyghan *et al.* 2011; Razouls *et al.* 2014).

buffered formalin/seawater. In the laboratory, calanoid copepods were sorted into genera under a stereo-microscope (SZX16, Olympus, Tokyo), and specimens were dissected using a stainless steel pin (No. 00) and two needles to remove mouthparts and legs from the cephalothorax before transferring the dissected parts into polyvinyl lactophenol solution. All drawings were made using a camera lucida attached to a compound microscope (Olympus BX51, Olympus, Tokyo). The female genital double-somites of all three *Acartiella* species were examined with a scanning electron microscope (JSM-6510LV, Jeol Ltd., Tokyo). Terminology follows Huys and Boxshall (1991). The specimens of *Acartiella kempi, A. nicolae,* and *A. sinensis* have been deposited in the Institute of Marine Science, Burapha University (BIMS-Zoo-0262-0265).

Acartiella kempi Sewell, 1914
(Figs 2–4, 10A)

Acartiella kempi Sewell, 1914: 246, pls 20–21, figs 1–5 (original description); 1919: 17; 1947: 324, 429; Wellershaus 1969: 269–270, figs 53–54.

Material examined. Ten females and 13 males, Kraburi Estuary, Andaman Sea (station 3 in Fig. 1), November 7, 2011 (BIMS-Zoo-0262).

Female. Total length 0.80–0.96 mm (mean±SD=0.88±0.05 mm, N=10); prosome length 0.57–0.64 mm (0.60±0.03 mm); prosome width, 0.19–0.23 mm (0.20±0.01 mm).

Body (Fig. 2A, B) slender; cephalosome and first pedigerous somite separate; cephalosome anteriorly round in dorsal view; rostrum absent; pedigers four and five fused; prosomal ends symmetrical and round posterolaterally.

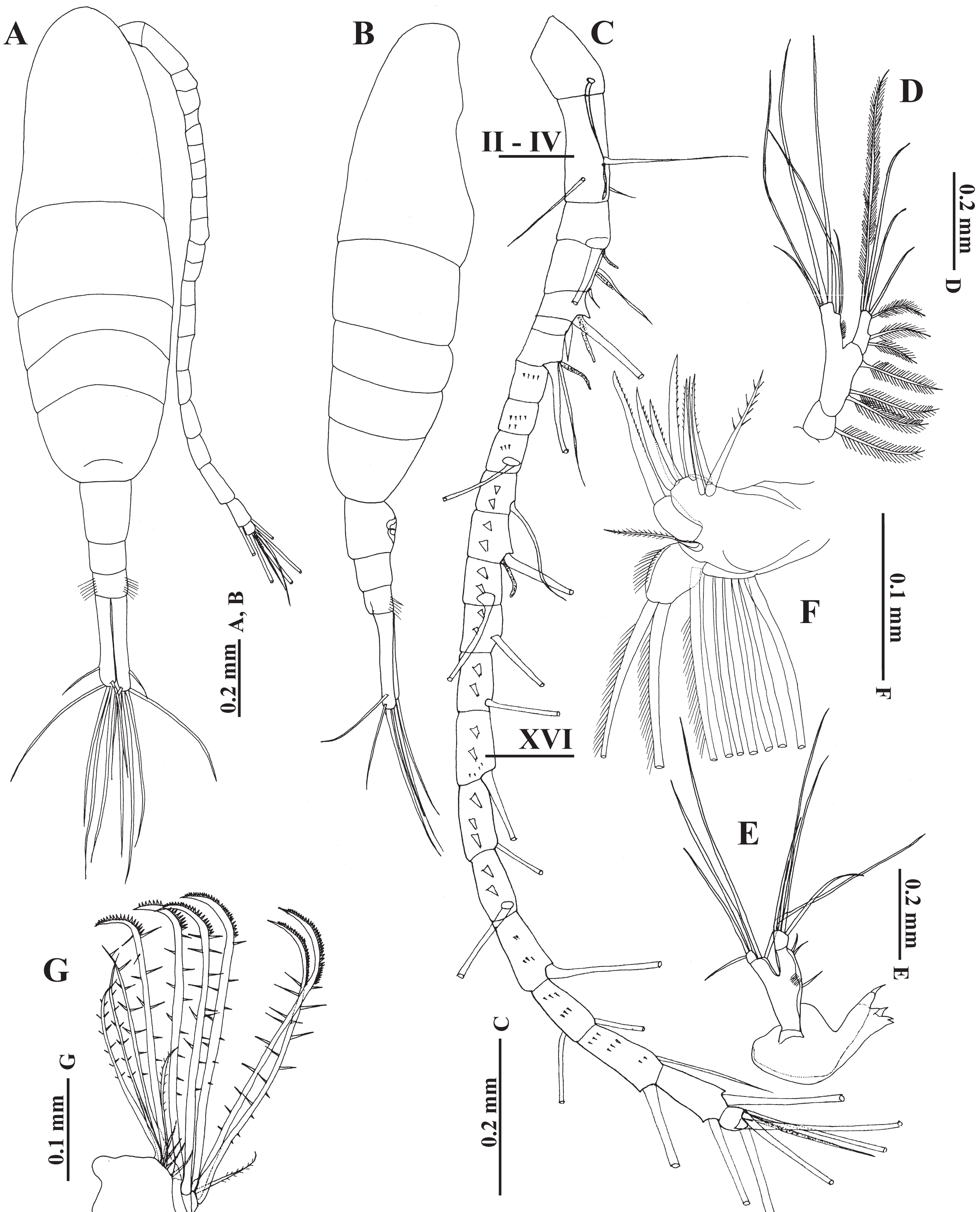

Fig. 2. *Acartiella kempi* Sewell, 1914, female. A, habitus, dorsal view; B, habitus, lateral view; C, right antennule; D, left antenna; E, left mandible; F, right maxillule; G, right maxilla. Roman numerals in C indicate numbers of ancestral segments following Huys and Boxshall (1991).

Urosome composed of three somites; symmetrical in dorsal view (Fig. 2B); genital double-somite about 2.5 times longer than anal somite; genital operculum trapezoidal, located slightly behind ventro-central midpoint (Fig. 10A); caudal rami asymmetrical, right ramus longer than left, with five plumose setae and one small seta. Both rami fused basally with anal somite.

Antennule (Fig. 2C) reaching beyond posterior end of

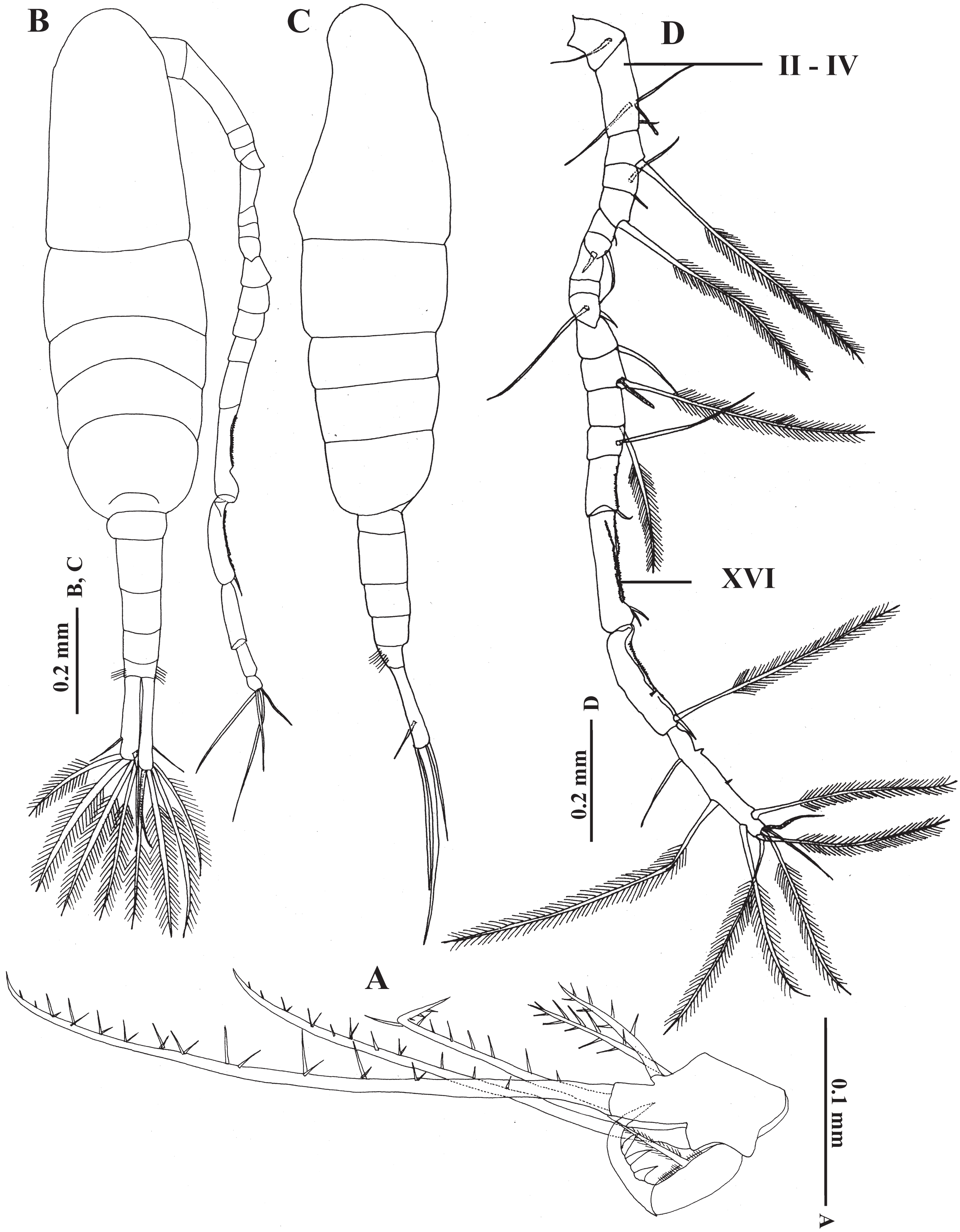

Fig. 3. *Acartiella kempi* Sewell, 1914, female (A) and male (B–D). A, left maxilliped; B, habitus, dorsal view; C, habitus, lateral view; D, right antennule. Roman numerals in D indicate numbers of ancestral segments following Huys and Boxshall (1991).

genital double-somite, symmetrical, 23-segmented; segments 2–4 incompletely fused; segments 2, 3, 4, 5, 7, 12, 23 each with aesthetasc (ae). Armature elements as follow: 1=1, 2(2–4)=3+ae, 3=1+ae, 4=2+ae, 5=1+ae, 6=(1 spiniform element), 7=2+ae, 8–9=0, 10=1, 11=1+(1 spiniform element), 12=1+(2 spiniform elements)+ae,

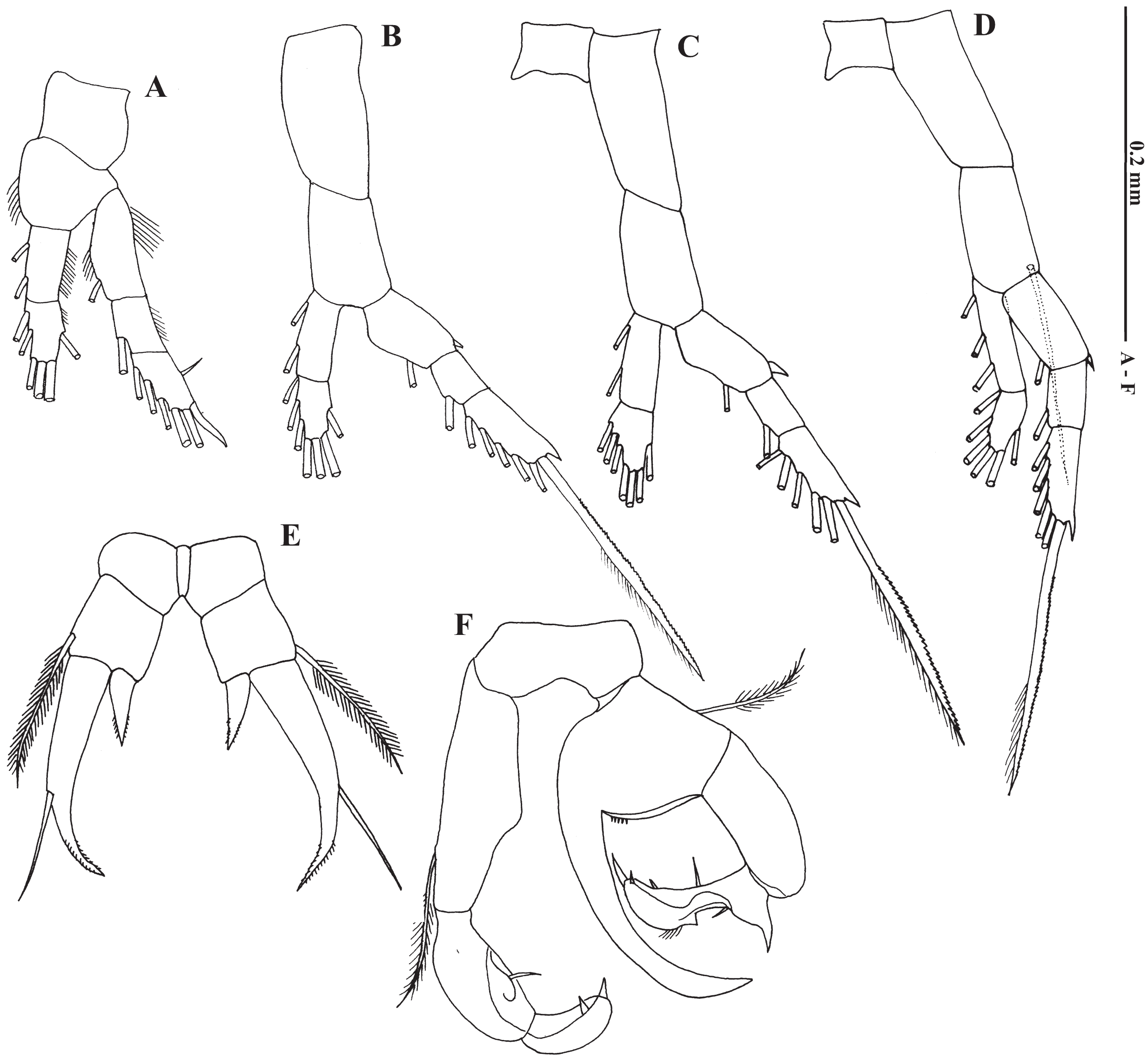

Fig. 4. *Acartiella kempi* Sewell, 1914, female (A–E) and male (F). A, right leg 1; B, right leg 2; C, right leg 3; D, right leg 4; E, legs 5; F, legs 5.

13=1+(2 spiniform elements), 14=1+(2 spiniform elements), 15=1+(2 spiniform elements), 16=1+(2 spiniform elements), 17=1+(3 spiniform elements), 18=1+(2 spiniform elements), 19=1, 20=2, 21=2, 22=2, 23=4+ae.

Antenna (Fig. 2D) bearing thick-walled setae along anterior margin of coxa, basis, and endopod; coxa with single seta; basis fused to both rami with two setae at midlength and a terminal seta; free endopodal segment with two setae at midlength and five terminal setae; exopod completely fused to basis, with four long and two medium long setae.

Mandible (Fig. 2E) with two cuspidate processes and two small teeth on gnathobase; basis with one seta at midlength, two terminal setae, and short row of fine setules near median margin; first endopodal segment fused to basis and, second segment with four setae terminally; proximal part of exopod also fused to basis, with two inner setae, free exopodal segment, with three distal setae.

Maxillule (Fig. 2F) with 7 praecoxal arthrite bearing (1 slightly long thick seta , 4 strong setae, and a thin anterior seta); coxal endite with thick seta; coxal epipodite with six long setae; basal exite with single seta; exopod partly fused with basis and bearing one proximal seta, two terminal setae, and row of fine hairs along inner margin. Endopod totally reduced.

Maxilla (Fig. 2G) robust with unarmed praecoxa; syncoxal endite with three long, one medium, and four short setae; basis with one stout serrate seta; endopod with one short and five long serrate setae.

Maxilliped (Fig. 3A) highly reduced; syncoxa with three endites, first endite with two strong setae, second with one medium and one long setae, third endite with medium long seta; basis with small seta at midlength and row of fine hairs along inner margin; endopod unisegmented, with three inner spines and inwardly curved terminal claw.

Legs 1–4 (Fig. 4A−D) biramous, with 2-segmented endopod and 3-segmented exopod; coxa unarmed. Seta and spine formula as shown in Table 1.

Legs 5 (Fig. 4E) nearly symmetrical; coxa unarmed, separated from intercoxal sclerite by suture; basis with outer plumose seta; endopod represented by conical process with fine

Table 1. *Acartiella kempi* Sewell, 1914: armature formulae for legs 1 to 4, with spines and setae indicated by Roman and Arabic numerals, respectively.

	Coxa	Basis	Exopod	Endopod
			1 2 3	1 2
Leg 1	0-0	0-0	0-1; 0-1; I,I,5	0-2; 1,2,3
Leg 2	0-0	0-0	I-1; 0-1; 0,I,5	0-2; 1,2,4
Leg 3	0-0	0-0	I-1; 0-1; 0,I,5	0-2; 1,2,4
Leg 4	0-0	1-0	I-1; 0-1; 0,I,5	0-3; 1,2,3

serration at tip; exopod about 3.6 times longer than endopod, bearing outer seta at distal one-third of its length and fine teeth along terminal on both sides margin.

Male. Total length 0.79–0.90 mm (0.82±0.03 mm, N=13); prosome length 0.51–0.64 mm (0.60±0.13 mm); prosome width 0.16–0.18 mm (0.17±0.007 mm).

Body (Fig. 3B, C) similar to that of female except for 5-segmented urosome.

Right antennule (Fig. 3D) geniculate, incompletely 18-segmented; segments 2–3 and 9–12 partly fused; armature elements as follows: 1=1, 2 (2–4)=3+ae, 3=1, 4=2, 5=1, 6=1, 7=1+(1 spiniform element), 8–9=0, 10=1+(1 spiniform element), 11=1, 12=1+ae, 13=1, 14=1, 15=1+(1 process), 16=2+(1 process), 17=1+(1 spiniform element)+(1 process), 18=8+(2 spiniform elements)+ae. Left antennule incompletely 18-segmented, reaching beyond posterior end of genital somite. Armature elements as in female.

Legs 5 (Fig. 4F) asymmetrical and uniramous; coxae fused to each other. Right leg basis with sub-terminal plumose seta; exopod 2-segmented, first segment with small seta, second segment with small spine on inner margin and one terminal spine. Left leg with thickened basis with large acuminate proximomedial projection, also bearing single plumose seta on outer margin and row of small spinules on inner terminal margin. Exopod comprising of two segments; first segment unarmed, longer than wide; second segment with irregular margins, a small spine and fine hairs, outer proximal margin with crested projection, inner segment with a small spine at central, and three unequal spines on tip.

Remarks. *Acartia kempi* was originally described from the Gulf of Mannar in the Indian Ocean by Sewell (1914). The present specimens differ from the original description in the following respects: (1) the antennules of the present females are 23-segmented with an incomplete fusion of segments 2–4, while those in the original description had 21 separate segments, with an incomplete fusion of segments 2–6; (2) the left caudal ramus is slightly shorter than the right in males in the present study (Fig. 2A, B) whereas, although the original paper did not describe the caudal rami in the text, the drawings suggest that the caudal rami were of equal length; (3) the body lengths of the females (range 0.80–0.96 mm, mean 0.88 mm) and males (0.79–0.90 mm, 0.82 mm) examined in the present study are slightly less than those from the Gulf of Mannar (1.0 mm, 0.9 mm).

Barthélémy (1999) observed the internal and external structures of the female reproductive system of six species of the genus *Acartiella* and found that the relative positions of the opercular pad and gonopores on the genital double-somite are species-specific. The present study represents the first report of these being located slightly behind mid-length of the ventral surface of the genital double-somite in *A. kempi* (see Fig. 10A).

Distribution. This species has so far been reported from the waters of Paumben and Kilakarai in the Gulf of Mannar, southern India (Sewell 1914, 1919) and the Cochin Backwater on the southwestern coast of India (Wellershaus 1969) (see Fig. 1). The specimens in the present study were collected from the Kraburi Estuary in the Andaman Sea during the dry season (November, 2011), when the water temperature and salinity ranges were 31.4–32.1°C and 13–22 ‰, respectively.

Acartiella nicolae Dussart, 1985
(Figs 5–6, 10B)

Acartiella nicolae Dussart, 1985: pls 49–51, fig. 1 (original description); Mulyadi 2004: 144–151, fig. 85 a–j.

Material examined. Ten females, Prasae Estuary, Gulf of Thailand (station 1 in Fig. 1), August 13, 2012, and March 5, 2013 (BIMS-Zoo-0264).

Female. Total length 0.86–0.99 mm (0.91±0.03 mm, N=10); prosome length 0.25–0.31 mm (0.29±0.01 mm); prosome width 0.18–0.25 mm (0.21±0.01 mm).

Body (Fig. 5A, B) similar to that of female *A. kempi* except genital double-somite (Fig. 10B) about seven times longer than anal somite, protruding ventrally near terminal portion of somite, and about twice as long as broad; genital operculum crescent-shaped (Fig. 10B), located behind ventro-central midpoint; second urosomite about 1 : 1 in length : width ratio; anal somite partly fused with left caudal ramus but separate from right ramus; caudal rami asymmetrical with six setae, right ramus longer than left.

Antennule (Fig. 5C) symmetrical, reaching beyond posterior end of third urosomite, 23-segmented. Armature elements as follows: 1=1, 2=(2–4)=3+ae, 3=2, 4=1+ae, 5=1, 6=1+(1 spiniform element), 7=2+ae, 8=0, 9=(1 spiniform element), 10=1+(1 spiniform element), 11=1+(2 spiniform element), 12=1+(2 spiniform element)+ae, 13=1+(2 spiniform element), 14=1+(2 spiniform element)+ae, 15=1+(2 spiniform element), 16=1+(2 spiniform element), 17=1+(3 spiniform element), 18=1+(2 spiniform element), 19=1, 20=2, 21=2, 22=2, 23=4+ae. Segments 15–19 with row of small spinules.

Antenna (Fig. 5D) similar to that of *A. kempi*, but armature slightly different in basis having two setae medially, endopod with fine hairs along both margin; free endopodal segment with four setae at midlength and five terminal setae, and exopod with three setae at midlength and five terminal setae.

Mandible (Fig. 6A) similar to that of *A. kempi*, but armature different in having four cuspidate teeth on gnaththobase, basis unarmed, and exopod completely fused to basis

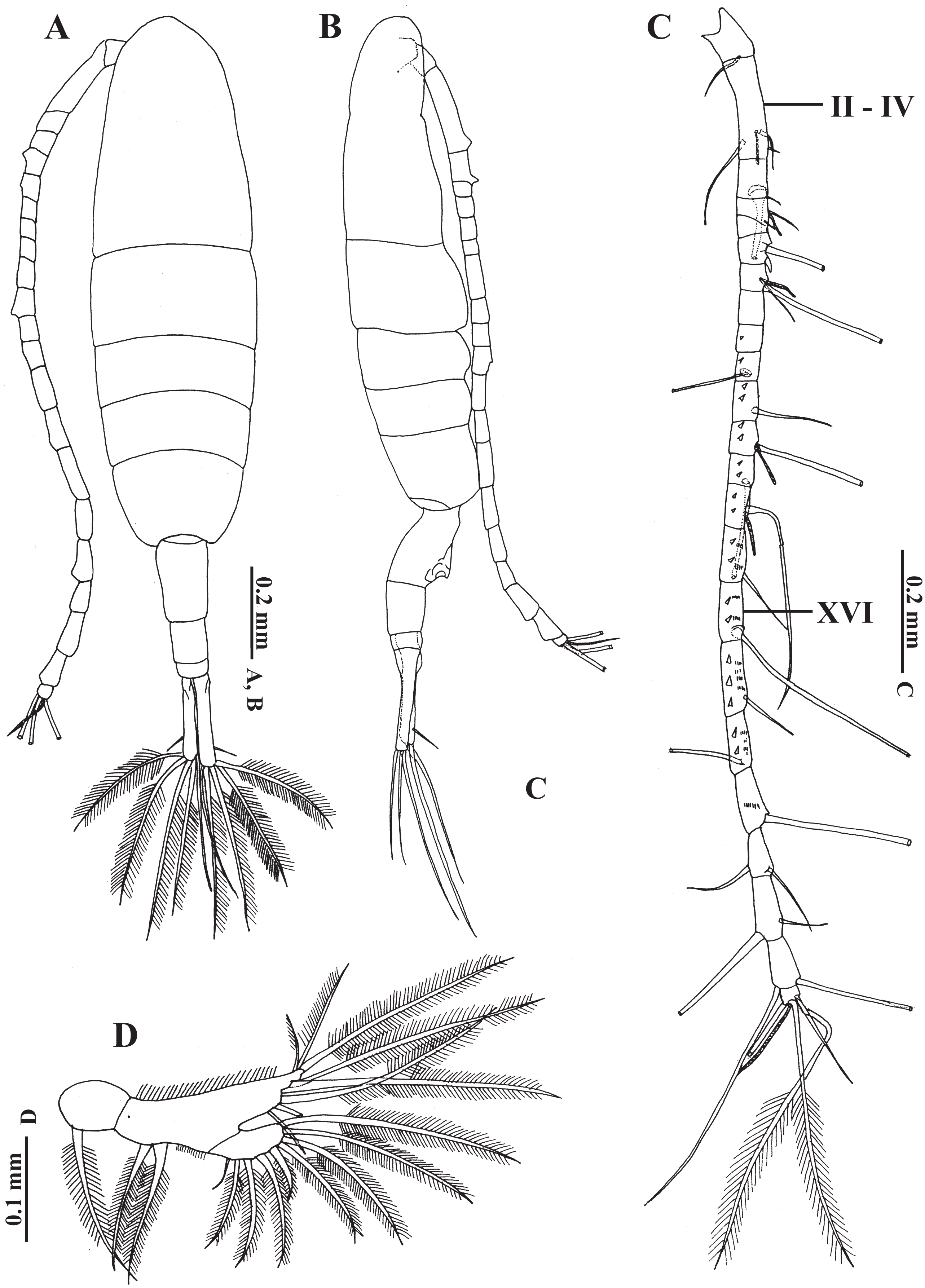

Fig. 5. *Acartiella nicolae* Dussart, 1985, female. A, habitus, dorsal view; B, habitus, lateral view; C, right antennule; D, left antenna. Roman numerals in C indicate numbers of ancestral segments following Huys and Boxshall (1991).

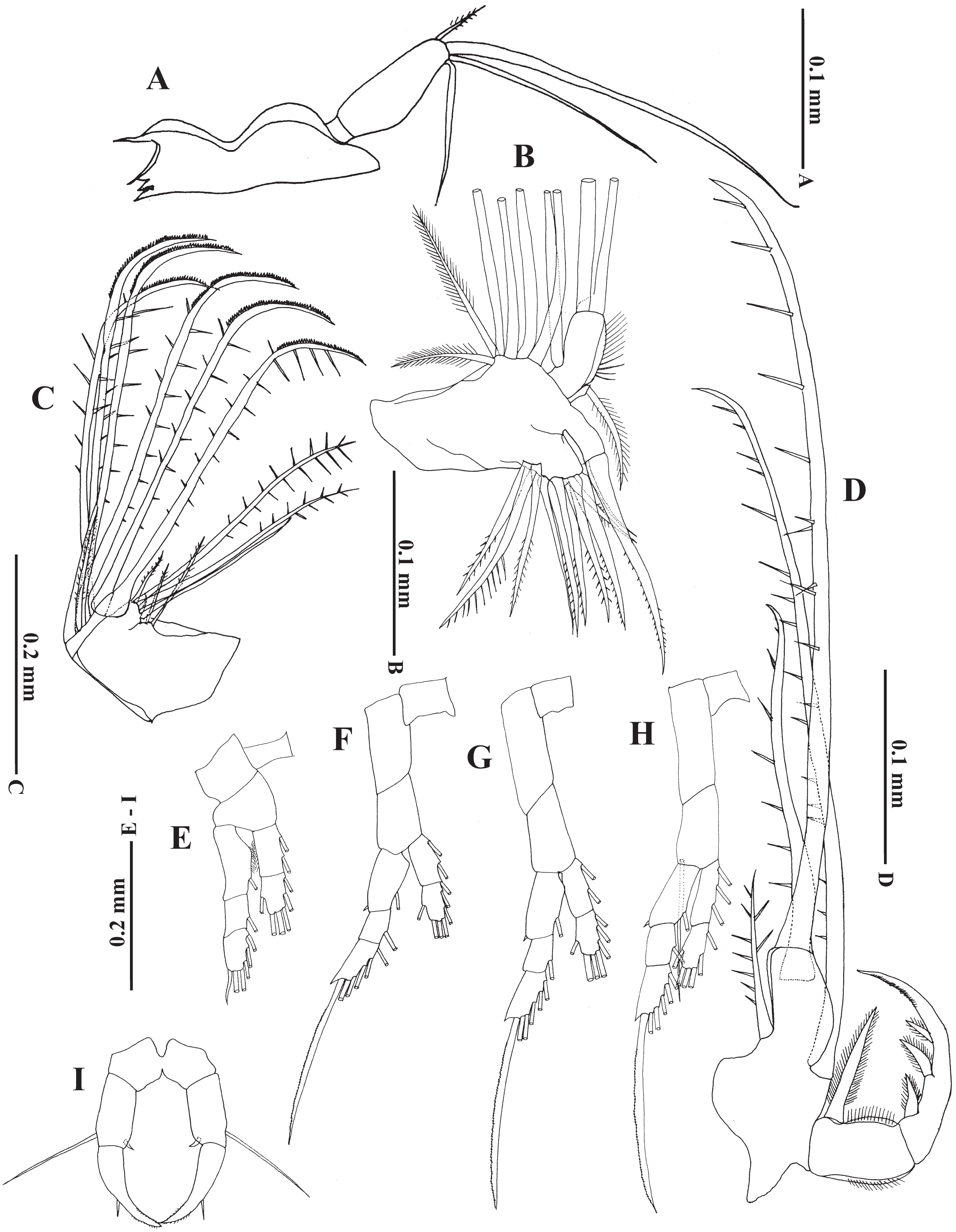

Fig. 6. *Acartiella nicolae* Dussart, 1985 female. A, right mandible; B, right maxillule; C, left maxilla; D, right maxilliped; E, right leg 1; F, right leg 2; G, right leg 3; H, right leg 4; I, legs 5.

with four setae terminally, all greatly different in length. Endopod fused to basis, represented by single inner seta.

Maxillule (Fig. 6B) similar to that of *A. kempi*, but armature slightly different in praecoxal arthrite having eight approximately equal strong and thin setae, and coxal endite with one thick seta.

Table 2. *Acartiella nicolae* Dussart, 1985 and *Acartiella sinensis* Shen and Lee, 1963: armature formulae for legs 1 to 4, with spines and setae indicated by Roman and Arabic numerals, respectively.

	Coxa	Basis	Exopod	Endopod
			1 2 3	1 2
Leg 1	0-0	0-0	0-1; 0-1; 0,I,5	0-2; 1,2,3
Leg 2	0-0	0-0	I-1; 0-1; 0,I,5	0-2; 1,2,4
Leg 3	0-0	0-0	I-1; 0-1; 0,I,5	0-2; 1,2,4
Leg 4	0-0	1-0	I-1; 0-1; 0,I,5	0-3; 1,2,3

Maxilla (Fig. 6C) similar to that of *A. kempi*, but armature slightly different in having syncoxal endite with three long, three medium, and two short setae, and endopod with one short and five long serrate setae.

Maxilliped (Fig. 6D) similar to that of *A. kempi*, but armature slightly different in first coxal endites, single strong seta.

Legs 1–4 (Fig. 6E–H) similar to those of *A. kempi*, but armature slightly different in first endopodal and first exopodal segments having fine hairs along inner margin. Seta and spine formula as shown in Table 2.

Legs 5 (Fig. 6I) symmetrical; coxa unarmed and fused with intercoxal sclerite, basis with outer seta, and about two times longer than wide; endopod reduced to small prominence; exopod with curved segment bearing distal outer seta, terminal end with serration on both margins.

Male. Unknown.

Remarks. *Acartiella nicolae* was originally described by Dussart (1985) as an estuarine species from the Mahakam Estuary, East Kalimantan, Indonesia. The body lengths of females examined in the present study (0.86–0.91 mm) were greater than those in the original description (0.80–0.85 mm) but similar to those of females from the Mahakam Estuary, Cilacap, and off Tegal Bay, Indonesia (0.90 mm) (Mulyadi 2004).

The present observations agree with those of Barthélémy (1999) concerning the female genital operculum of *A. nicolae*, which is located near the posterior edge of the ventral surface of the genital double-somite (Fig 10B).

Distribution. This species was previously recorded exclusively from the brackish waters of Indonesia: the Mahakam Estuary (Dussart 1985; Mulyadi 2004), the Cilacap Estuary, and Tegal Bay (Mulyadi 2004) (Fig. 1). The present study extends the distribution of the species into other Southeast Asian estuarine waters. The present specimens were collected from the Prasae Estuary, Gulf of Thailand, where the water temperature and salinity ranges were 28–29.9°C and 1–4‰, respectively.

Acartiella sinensis Shen and Lee, 1963
(Figs 7–9, 10C)

Acartiella sinensis Shen and Lee, 1963: pls 583–584, figs 30–40 (original description); Chen and Zhang 1965: pls 114–115, 51, figs 3–7; Zheng *et al.* 1982: pls 93–94, Fig. 54, a–e; Suwanrumpha 1987: pl 38, fig. 73 A–E; Pholpunthin 1997: pl 31, figs 8–15; Orsi and Ohtsuka 1999: pls 128–130; Pinkaew 2003: pls 8, 10, 23, 25–26, 62, 111, fig 7 a–e.

Material examined. Six females and 5 males, Bangpakong Estuary, Gulf of Thailand (station 2 in Fig. 1), July 22, 2012 (BIMS-Zoo-0265).

Female. Total length 1.28–1.49 mm (1.36±0.08 mm, N=11); prosome length 0.42–0.48 mm (0.45±0.02 mm); prosome width 0.32–0.37 mm (0.34±0.02 mm).

Body (Fig. 7A, B) similar to that of *A. kempi*, but armature slightly different and urosome asymmetrical; prosomal ends each with row of small spines. Genital operculum located midventrally (Fig. 10C); anal somite totally fused with both caudal rami; caudal rami each with six setae and distorted, with left ramus more severely twisted than right.

Antennule (Fig. 8A) similar to that of *A. kempi*, but right antennule incompletely 23-segmented; segments 2−5 partly fused, entire antennule curved toward ventral part of body. Armature elements as follows: 1=1, 2 (2−5)=4+ae, 3=2, 4=1+ae, 5=1, 6=0, 7=2+ae, 8=1, 9=1+(1 spiniform element), 10=1+(2 spiniform elements)+ae, 11=1+(2 spiniform elements), 12=1+(2 spiniform elements)+ae, 13=1+(2 spiniform elements), 14=1+(2 spiniform elements), 15=1+(2 spiniform elements), 16=1+(2 spiniform elements)+ae, 17=1+(2 spiniform elements)+ae, 18=1+(2 spiniform elements), 19=1, 20=2, 21=2, 22=2, 23=4+ae.

Antenna (Fig. 7C) similar to that of *A. kempi*, basis having thick-walled on both sides with row of fine hairs on outer margin, three plumose setae on inner margin, and fine hairs on inner edge in two groups separated by proximal two plumose setae; exopod completely fused with basis, having seven long plumose setae on tapered terminus; free endopodal segment with 10 setae.

Mandible (Fig. 7D) similar to that of *A. kempi* but armature consisting of two cuspidate teeth and three small teeth on gnathobase instead of two small teeth as in *A. kempi* (Fig. 2E); basis with inner seta just beyond midlength; first endopodal segment with short inner seta, second segment with one long seta, one medium long seta, and one short seta terminally; first exopodal segment fused to basis, with long inner distal seta, free exopodal segment with one long and two medium long setae.

Maxillule (Fig. 7E) similar to that of *A. kempi* except preacoxal arthrite bearing one strong, four medium thick, and three thin spinules on anterior surface; coxa with four setae on epipodite; exopod with three terminal setae.

Maxilla (Fig. 7F) endite with three long, one medium long, and three small setae; basis with one stout serrate seta; endopod with one small, one medium long and four long serrate setae.

Maxilliped (Fig. 8B): first syncoxal endite with one strong seta and one small seta; basis with row of fine spinules along both margins; endopod composed of two segments, with first segment bearing three small spines and second segment represented by inward-curving claw.

Legs 1–4 (Fig. 8C–F) similar to those of *A. kempi* but coxa and basis of leg 1 different, armed with small spinules along inner margin; first exopodal segment with small prox-

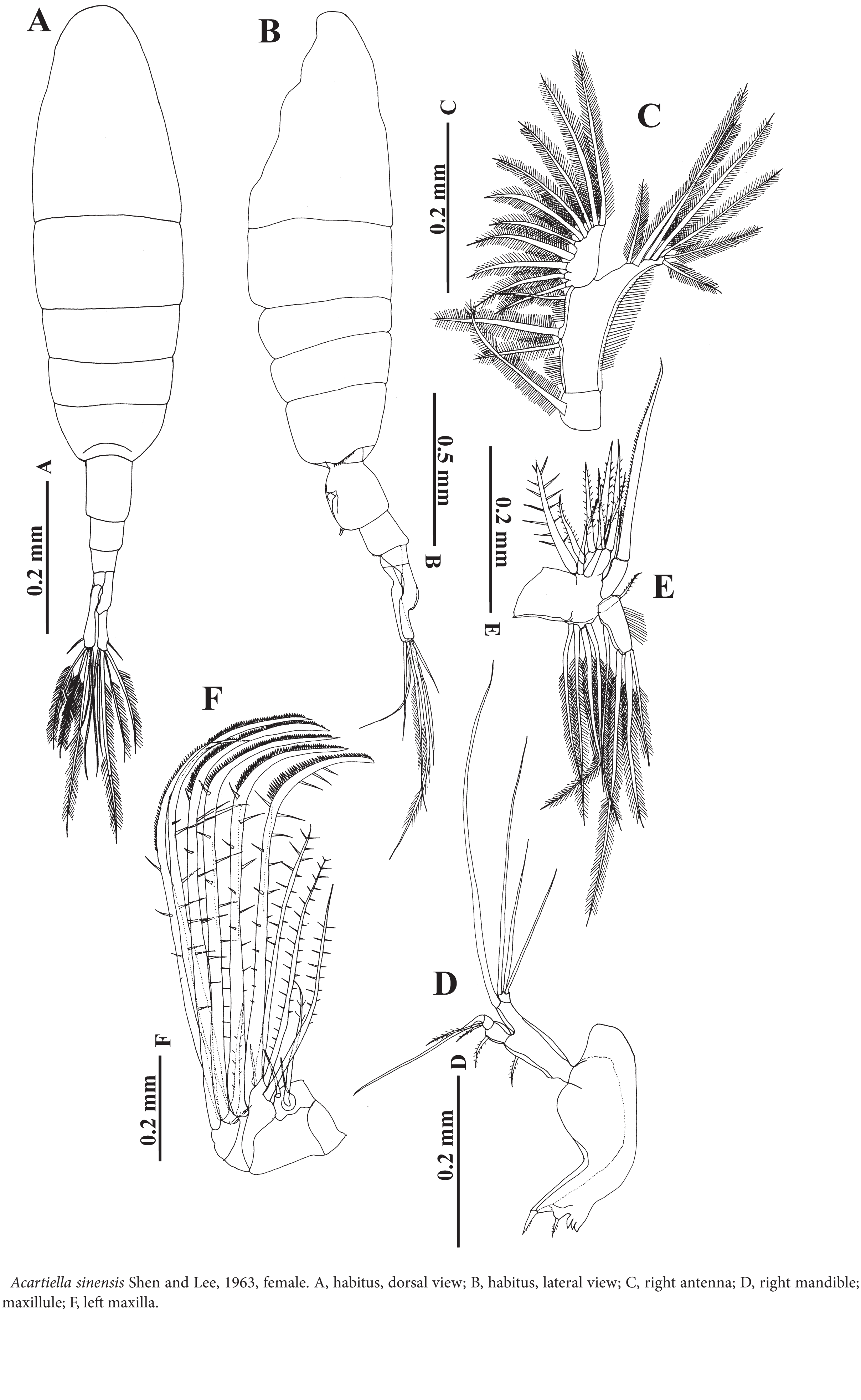

Fig. 7. *Acartiella sinensis* Shen and Lee, 1963, female. A, habitus, dorsal view; B, habitus, lateral view; C, right antenna; D, right mandible; E, right maxillule; F, left maxilla.

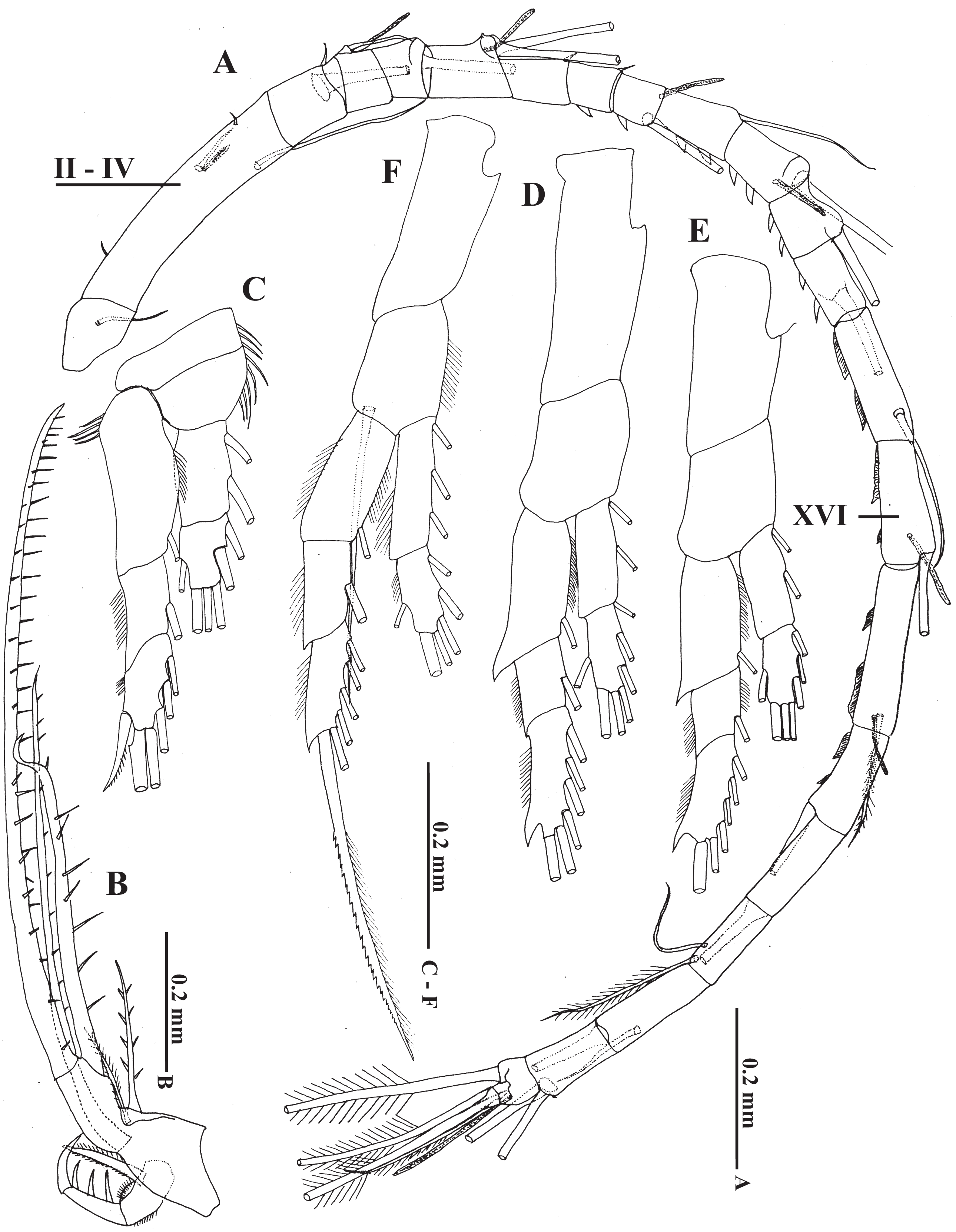

Fig. 8. *Acartiella sinensis* Shen and Lee, 1963, female. A, right antennule; B, left maxilliped; C, right leg 1; D, right leg 2; E, right leg 3; F, right leg 4. Roman numerals in A indicate numbers of ancestral segments following Huys and Boxshall (1991).

imal spinules on outer margin and fine hairs along inner margin edge, second and third exopodal segments with fine hairs on outer margin; first exopodal segment of leg 2 and leg 3 with fine hairs on inner margin, second exopodal segments of leg 2 and leg 3 with fine hairs on both sides, third exopodal segments of leg 2 and leg 3 with fine hairs along

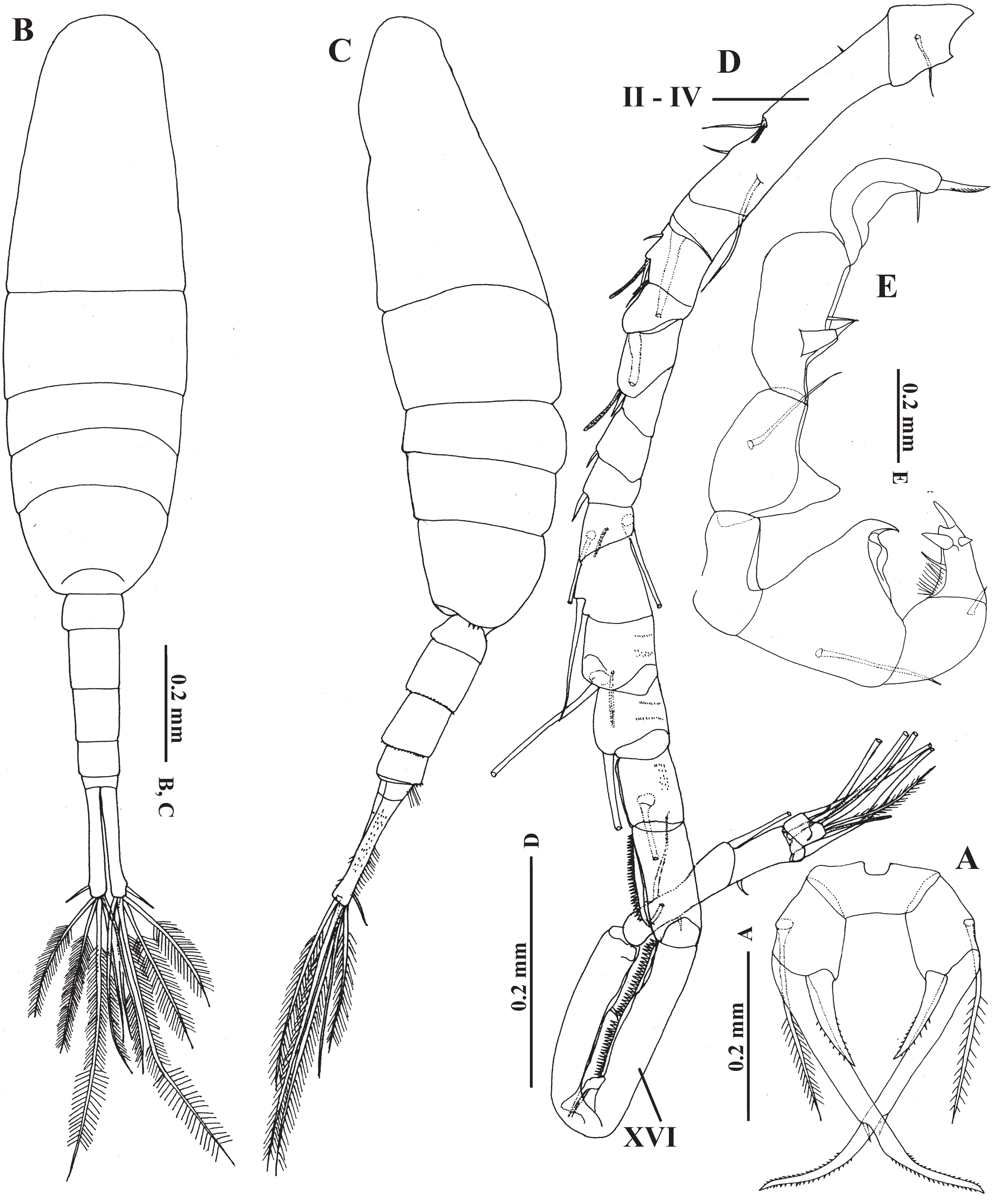

Fig. 9. *Acartiella sinensis* Shen and Lee, 1963, female (A), male (B–E). A, legs 5; B, habitus, dorsal view; C, habitus, lateral view; D, right antennule; E, legs 5. Roman numerals in D indicate numbers of ancestral segments following Huys and Boxshall (1991).

outer edge; leg 4 with fine hairs along inner margin of basis and both side of first and second exopodal segments, third exopodal segments and first to second endopodal segments with fine setules along outer edge. Seta and spine formula as shown in Table 3.

Leg 5 (Fig. 9A) symmetrical; coxa unarmed, completely fused with intercoxal sclerite; basis with plumose outer seta; endopod 1-segmented, slightly curved inward and shorter than 1/3 of exopod, distal half serrate along outer margin; exopod represented by long, curved segment with small outer spine at mid-length, terminal end with both margins serrate.

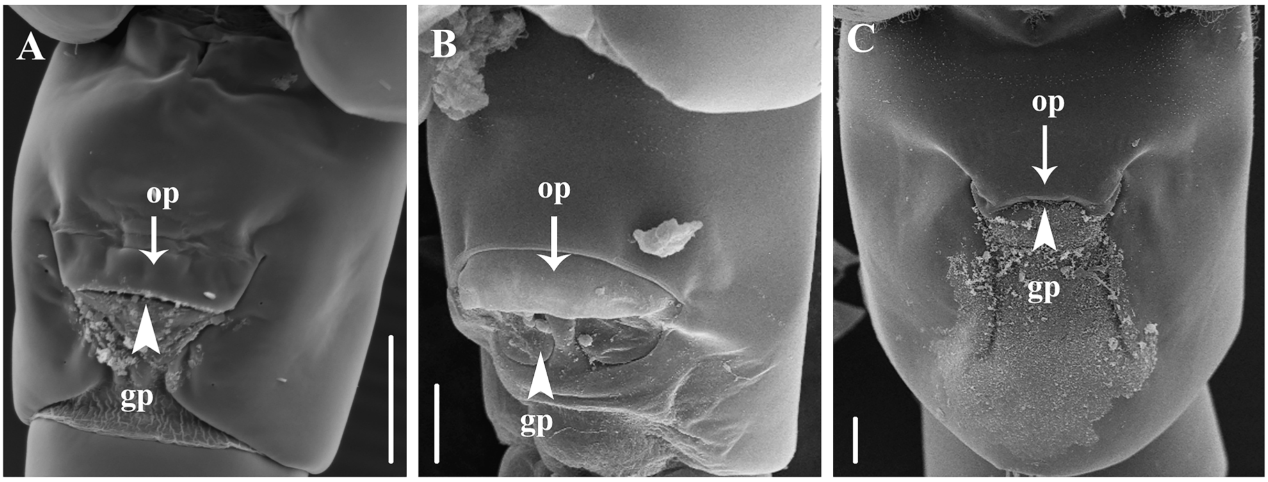

Fig. 10. SEM micrographs of genital double-somites of females of *Acartiella*, ventral side. A, *A. kempi*; B, *A. nicolae*; C, *A. sinensis*. Scale bars: A, 20 µm; B−C: 10 µm. Abbreviations: gp, gonoporal plate; op, opercular pad.

Male. Total length 1.10–1.23 mm (1.15±0.04 mm, N=6); prosome length 0.71–0.76 mm (0.73±0.01 mm); prosome width 0.23–0.24 mm (0.23±0.004 mm).

Body (Fig. 9B, C) symmetrical; urosomite 5-segmented; caudal rami each with five plumose setae and one small seta.

Right antennule (Fig. 9D) geniculate, incompletely 20-segmented; segments 2–4 and 6–7 partly fused in dorsal view, segments 12–14 having rows parallel of small spines along length of segments. Armature elements as follows: 1=1, 2=(2–4)=4+ae, 3=1, 4=3+2+ae, 5=1, 6–7=(1 spiniform element)+ae, 8=(1 spiniform element), 9=(1 spiniform element), 10=2+ae, 11=1, 12=1+ae, 13=1, 14=1, 15=(1 process), 16=2+(1 process), 17=1+(1 spiniform element)+(1 process), 18=3+(1 spiniform element), 19=2+(1 spiniform element), 20=4+ae.

Legs 5 (Fig. 9E) asymmetrical and uniramous; both coxae fused. Right leg with single outer seta on basis; endopod completely fused with basis and expressed as triangular inner process on proximal to mid-length region; exopod 2-segmented, first segment about twice as long as wide, proximal end with prominent process bearing small seta at mid-length, irregularly sinuate along inner margin; second segment abruptly curved inward, tapering distally, with small seta near terminal end and superficially serrate seta terminally. Left leg with thickened basis completely fused with endopod, bearing prominent triangular process smoothly curved to hook-like tip, inner margin irregularly sinuate; exopod 2-segmented, first segment with small seta sub-terminally; second segment with hirsute region at proximal end, small, thick seta at middle of inner margin, and three terminal spines of unequal length.

Remarks. This species was originally described by Shen and Lee (1963) based on specimens collected from the northern Luichow Peninsula, East China Sea, where the body lengths of females and males were reported to be 1.38 and 1.23 mm, respectively. Further specimens described from the South China Sea ranged from 1.30 to 1.40 mm and 1.10 to 1.17 mm for females and males, respectively (Chen and Zhang 1965); specimens introduced from China to the San Francisco Estuary, California, ranged from 1.27 to 1.64 mm and 1.17 to 1.34 mm for females and males, respectively (Orsi and Ohtsuka 1999). The specimens of both sexes examined in the present study were similar to those from the South China Sea (Chen and Zhang 1965).

The description of the female genital structure in the present study corresponds well with the observations of Barthélémy (1999), who studied the genital structures of six species of *Acartiella* but not *A. kempi* (see Fig. 10C).

Distribution. This species has so far been recorded from the East China Sea (Shen and Lee 1963; Shang *et al.* 2007), the South China Sea (Chen and Zhang 1965), the Taiwan Strait (Zheng *et al.* 1982), the upper Gulf of Thailand (Suwanrumpha 1987; Pinkaew 2003), and Thale-Noi, southern Gulf of Thailand (Pholpunthin 1997). A non-indigenous population was accidentally introduced via ballast water into San Francisco Bay, California, USA, where it became established prior to 1993 (Orsi and Ohtsuka 1999). *Acartiella sinensis* was found to be abundant in brackish water of 18–21.8‰ in the East and South China Sea (Shen and Lee 1963; Shang *et al.* 2007). In Thailand, the species was found to occur in waters of around 31.3°C and around 5.0‰ in July, 2012 (present study). In San Francisco Bay, the maximum abundance of this species was recorded in waters of 2.5–8.6‰ (Orsi and Ohtsuka 1999).

Discussion

The genus *Acartiella* currently consists of 11 species that are restricted to the brackish waters of tropical and subtropical Asian regions (Boxshall and Halsey 2004; Razouls *et al.* 2014) (see Fig.1). The present study extends the distribution of the genus in Thailand waters. Nine species of the genus have a limited distribution in the Indian Ocean (Sewell 1919; Tranter and Abraham 1971), while two species, *A. nicolae* and *A. sinensis*, occur exclusively in the brackish waters of the West Pacific (Shen and Lee 1963; Chen and Zhang 1965; Zheng *et al.* 1982; Dussart 1985; Suwanrumpha 1987; Pholpunthin 1997; Pinkaew 2003; Mulyadi 2004; Shang *et al*. 2007; present study). In addition to *A. kempi*, which is redescribed here, the following eight congeners occur in the coastal regions of the Indian Ocean: *A. faoensis* Khalaf, 1991 from the Persian Gulf (Khalaf 1991; Ali *et al*. 2009; Peyghan *et al*. 2011; Razouls *et al*. 2014); *A. gravelyi* Sewell, 1919 from Cochin Backwater, India (Sewell 1919, 1932; Wellershaus 1969); *A. keralensis* Wellershaus, 1969 from Cochin Backwater, India (Wellershaus 1969); *A. major* Sewell, 1919 from Chilka Lake, India (Sewell 1919; Wellershaus 1969); *A. minor* Sewell, 1919 from Chilka Lake, India (Sewell 1919; Wellershaus 1969); *A. natalensis* Connell and Grindly, 1974 from South African estuaries (Connell and Grindly 1974); *A. sewelli* Steur, 1934 from the Sittoung River and north-east of Yangon (Rangoon), Myanmar (Steur 1934; Wellershaus 1969); and *A. tortaniformis* Sewell, 1912 from the Hooghly River in India, the Chittagong River in Bangladesh, the Bay of Bengal, and the Yangon River, Myanmar (Sewell 1912, 1932; Steuer 1923; Wellershaus 1969).

The 11 species of *Acartiella* can be classified into the following three groups. Group I: restricted to the brackish waters of the West Pacific, comprising two members, *A. nicolae* and *A. sinensis*. Group II: restricted to the coastal and estuarine waters of the Andaman Sea, Myanmar, Gulf of Mannar, Bay of Bengal, and the Arabian Sea in the Indian Ocean, consisting of eight species, *A. gravelyi*, *A. kempi*, *A. keralensis*, *A. major*, *A. minor*, *A. sewelli*, *A. tortaniformis*, and *A. faoensis*. Group III: restricted to the estuarine waters of southeastern Africa: *A. natalensis*. Two other genera of calanoid copepods occurring in the Indo-West Pacific, *Labidocera* and *Pseudodiaptomus*, show the same biogeographical groupings as *Acartiella* (Walter *et al*. 2002; Mulyadi 2002; Srinui *et al*. 2012; Hirabayashi and Ohtsuka 2014), but no species of *Acartiella* has a broad distribution in the Indo-West Pacific, unlike certain species of *Labidocera* and *Pseudodiaptomus* (Fleminger 1986; Walter *et al*. 2002; Hirabayashi and Ohtsuka 2014). This suggests that *Acartiella* is a more brackish water taxon than a coastal one and is less influenced by current systems for dispersal than the latter genera. The observed allopatric distributions seem to have been established by vicariant events since the Tethys Sea closed in the Late Oligocene or Early Miocene (Fleminger 1986; Briggs 1999; Ohtsuka and Reid 1998; Williams and Duda 2008).

Some species groups of brackish water and coastal calanoid copepods clearly exhibit parapatric distributions in the Indian and West Pacific Oceans as is also seen in *Acartiella* (Flemniger 1986; Walter *et al*. 2002; Hirabayashi and Ohtsuka 2014). Parapatric taxa have continuous ranges across a wide geographic region and, although they do not overlap significantly, they are immediately adjacent to each other; they may come into contact with one another in a narrow contact zone and compete for common resources there, but specific behaviors prevent interbreeding. The large landmass known as "Sundaland" represented a significant barrier between the Pacific and Indian Oceans for coastal organisms during the Pleistocene. It may have caused the separation of an originally widespread Indo-West Pacific ancestral population into the current parapatric Indian and West Pacific populations (see Fleminger 1986). Such a parapatric distribution of Indo-West Pacific calanoids can be seen in the *Labidocera pectinata* species group (Indian *L. pectinata* Thompson and Scott, 1903 and West-Pacific *L. rotunda* Mori, 1929) (Fleminger 1986); the *L. gangetica* species group (Indian *L. gangetica* Sewell, 1934 and West-Pacific *L. sinilobata* Shen and Lee, 1963) (Hirabayashi and Ohtsuka 2014); Types II and III of the *lobus*, *hyalinus*, and *ramosus* species groups of the genus *Pseudodiaptomus* (see Walter *et al*. 2002); and Groups I and II of *Acartiella* (present study). It is likely that these pairs co-evolved under the same vicariant events during the Pleistocene. More comprehensive, molecular studies on the Indo-West Pacific copepods are required to understand this process.

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