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A new species of Tigriopus (Copepoda: Harpacticoida: Harpacticidae) from Thailand with a key to the species of the genus

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A new species of *Tigriopus* (Copepoda: Harpacticoida: Harpacticidae) from Thailand with a key to the species of the genus

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A new species of the genus *Tigriopus* Norman, 1869 is described from Thailand. *Tigriopus sirindhornae* sp. nov. resembles other species in having cyclopidiform shape, nine-segmented A1 in female, A2 allobasis with three-segmented exp, male lacking an abexopodal seta, male P2 enp II with distinct outer spiniform apophysis, both baseoendopod and exp of female P5 with five setae. The new species can be distinguished by having fewer sensillae; two-segmented mandibular exp; Mx1 praecoxa more spinulose, Mx2 with spinules on three syncoxal endites, and Mxp with spinules on outer margin. Additional characters related to the female P5 and P1 and the male A1 and P2 are also helpful to distinguish this species from its congeners. An identification key for the 13 known species of *Tigriopus* is also provided.

<http://www.zoobank.org/urn:lsid:zoobank.org:pub:ABA4C14F-E484-4883-8191-F7ECECC7A3D3>

Keywords: taxonomy; harpacticoids; Thailand; key to species; external morphology

Introduction

We provide here a morphological description of a new harpacticoid copepod species belonging to the genus *Tigriopus* Norman, 1869, which consists presently of 12 valid species (Boxshall and Halsey 2004; Wells 2007; Chullasorn et al. 2012). Besides the new species from Thailand, the following species of *Tigriopus* are known so far: *T. thailandensis* Chullasorn, Ivanenko, Dahms, Kangtia and Yang, 2012 described from Bangsaen Beach in Thailand, *T. angulatus* (Lang, 1933) from New Zealand, *T. brachydactylus* (Candeias, 1959) from northern Europe, *T. brevicornis* (Müller, 1776) from Spain, *T. californicus* (Baker, 1912) from North America, *T. crozettensis* Soyer, Thiriot-Quievreux and Colomines, 1987 and *T. kerguelenensis* Soyer, Thiriot-Quievreux and Colomines, 1987 from the South Indian Ocean, *T. fulvus* (Fischer, 1860) from the Mediterranean Sea, *T. igai* (Itô, 1977) and *T. japonicus* (Mori, 1938) from Japan, the latter redescribed by Itô (1970), *T. minutus* Bozic, 1960 from Senegal, and *T. raki* (Bradford, 1967) from New Zealand. Lang (1948) treated *T. fulvus* as a synonym of *T. brevicornis*, but Bozic (1960) recognized them as distinct species. *Tigriopus minutus* is similar to *T. brachydactylus*, particularly in the female setal armature of P5. The lack of outer seta on the exp 2 of P1 in *T. brachydactylus* seems to be an artefact, because all other *Tigriopus* species have this seta, including the new species from Thailand.

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Species of *Tigriopus* have been studied from different disciplines, and there are surveys on ecology (Dethier 1980), life history (Koga 1970), internal and external anatomy (Itô 1973), reproductive chemical ecology (Kelly and Snell 1998) and adaptive genetics (Burton et al. 1999). Other studies focus on its genomics (Machida et al. 2002; Jung et al. 2006; Kim et al. 2003; Lee 2003; Lee et al. 2005), medicine-related genetics (Kim et al. 2004) and its population genetics (Edmands and Burton 1998; Edmands 1999). Raisuddin et al. (2007) reviewed its ecotoxicology. Representatives of *Tigriopus* inhabit splash pools (McAllen 1998, 1999) and show a remarkable adaptation to changes in salinity, temperature and oxygen (McAllen and Block 1997; McAllen 1998, 1999). The description of the new species of *Tigriopus* is based on the examination of adult females and males collected at a sandy beach of the Rayong Province, in Thailand. A key to the known species of the genus is also provided.

Material and methods

Adult specimens of a previously undescribed species of *Tigriopus* were collected during low-tide at a sandy beach located off the Eastern Marine Fisheries Development Centre, Ban Phe, Rayong Province, Thailand (12°37' N, 102°20' E). In addition, different developmental stages of this species were washed out from thalli of the brown alga *Padina* sp.

Specimens were fixed in 5% formaldehyde and suspended in W15 (embedding medium Carl Zeiss Co.). Before dissection, the habitus of the specimens was drawn from whole mounts and total body length measurements were made from individuals mounted in W15. Dissected parts were mounted on slides in glycerine. Broken glass fibres were added to prevent the animal and appendages from being compressed by the coverslip and to facilitate rotation and manipulation, so allowing observation from all angles. All drawings were prepared using a camera lucida on a Nikon HFX-DX compound microscope at a magnification of 1000 ×. Measurements were made with an ocular micrometer. Scale bars in illustrations are in micrometers. No colour pattern was discernible. The references for the morphological description of this species were Lang (1948), Itô (1977), Huys and Boxshall (1991), and Chullasorn et al. (2012). Abbreviations used are as follows: R, rostrum; A1, antennule; A2, antenna; Md, mandible; Mx1, maxillule; Mx2, maxilla; Mxp, maxilliped; P1–P4, first to fourth swimming legs; P5, leg 5; P6, leg 6; enp I, II, III, endopod I, II, III; exp I, II, III, exopod I, II, III; ae, aesthetasc; Uro 4, 5, 6, urosomite 4, 5, 6.

Systematics

Family **HARPACTICIDAE** Dana, 1846

Genus *Tigriopus* Norman, 1869

Tigriopus sirindhornae sp. nov.

(Figures 1–12)

Type specimens

One female holotype (USNM1156995) dissected on eight slides, and one male allotype (USNM-1156996) dissected on seven slides, plus 10 female and 10 male

undissected paratypes (USNM-1156997) preserved in 95% alcohol were deposited in the Department of Invertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, DC, USA.

Type locality

Tigriopus sirindhornae sp. nov. was recovered from the brown alga *Padina* sp. at Ban Phe, Rayong Province in Thailand (12°37' N, 102°20' E).

Etymology

The species was named after Her Royal Highness Princess Maha Chakri Sirindhorn of Thailand.

Descriptions

Female. Total length of holotype female, 1.12 mm; total length of paratype female, 0.94 mm ($n = 12$, mean = 0.96 mm); measured from tip of rostrum to posterior margin of caudal ramus. Body (Figure 1A,B) compact, cyclopiform ornamented with few sensillae on surface. Prosome four-segmented, comprising cephalosome and three free pedigerous somites. Cephalosome slightly shorter than three prosomites combined. Rostrum large, almost as long as first segment of antennule, with two pairs of sensilla on each side; the first pair close to the rounded tip, and the second pair at midlength as in Figure 3A.

Urosome (Figure 2B, C) five-segmented, comprising P5 bearing-somite, genital double-somite, and three free abdominal somites. Genital double-somite with P6, genital field indistinct, ventrally with two small copulatory apertures, and with two oblique outer and inner spinular rows. Abdominal somites with rows of spinules dorsally and ventrally. Third urosomite (distal half of genital double-somite) with two pairs of sensillae: one pair on posterior half, one pair in opposite distal corner. Fourth and fifth urosomites with one pair of sensilla each at opposite corners. Anal operculum semicircular, smooth. Caudal rami slightly longer than wide, ornamented with small spinules dorsally and ventrally. Seta I arising laterally at midlength; seta II located between seta I and seta III; seta III two times longer than seta II; seta V (Figure 3C) longest, much longer than urosomal length; seta IV shorter than seta V; seta VI as long as seta III, located at inner distal corner; seta VII shortest located close to insertion point of seta V.

Antennule (Figure 3B): nine-segmented; surface of second to ninth segments smooth. Length of two proximal segments longer than five apical segments combined. Fourth and last segment with one large and one small aesthetasc, respectively. Armature formula: 1-(1), 2-(10), 3-(9), 4-(4 + ae), 5-(1), 6-(4), 7-(2), 8-(2), 9-(5 + acrothek). Acrothek consisting of aesthetasc and two setae.

Antenna (Figure 3C): coxa bearing short row of minute spinules close to base of allobasis. Allobasis bearing exopod, armed with one abexopodal pinnate seta at middle of inner edge, furnished with rows of minute spinules on anterior surface. Exopod three-segmented; first segment longest with two pinnate setae, second segment short with one pinnate seta, third segment short with one lateral pinnate and one apical

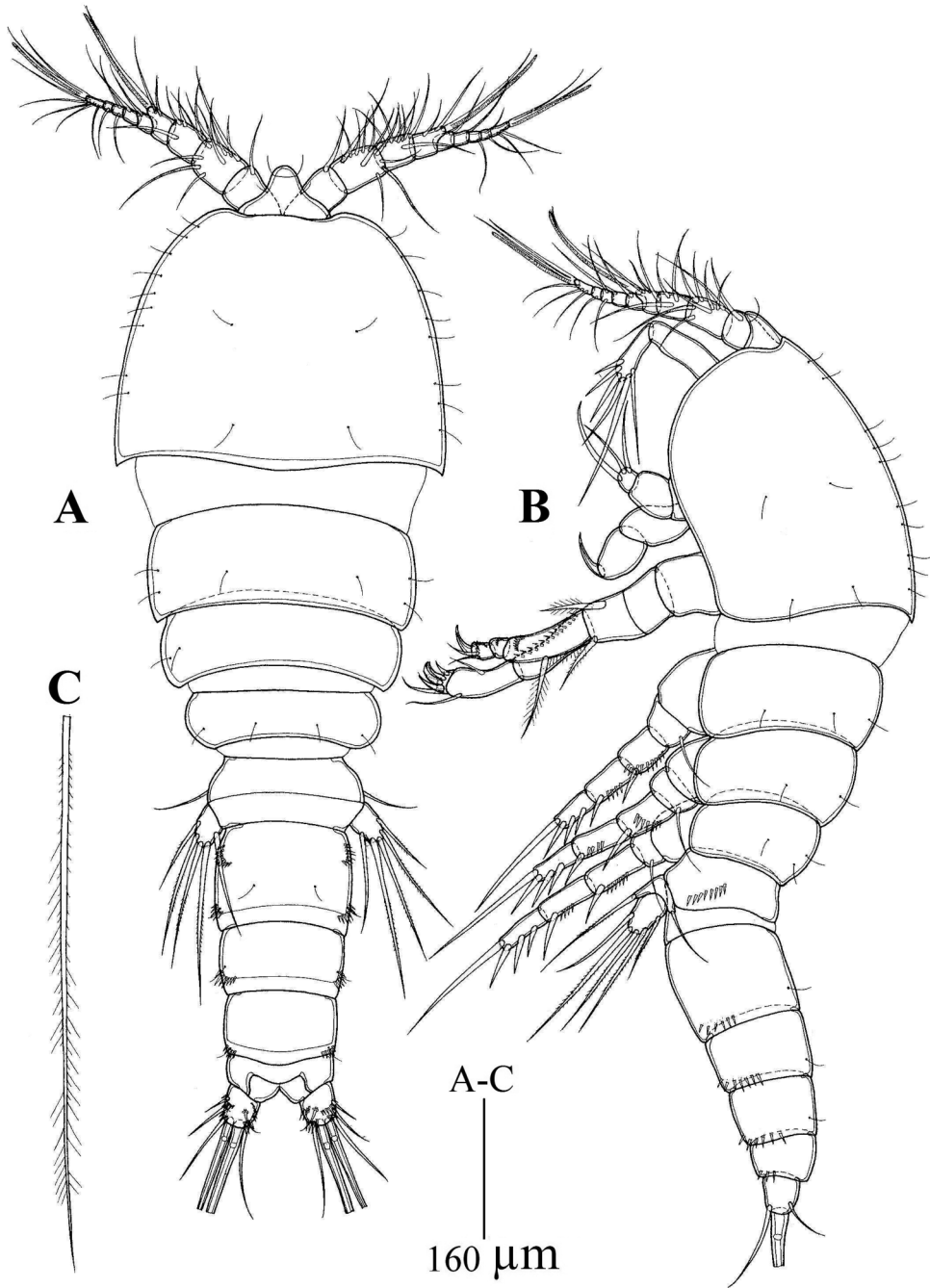


Figure 1. *Tigriopus sirindhornae* sp. nov., female. (A) Habitus, dorsal view; (B) habitus, lateral view; (C) caudal seta V.

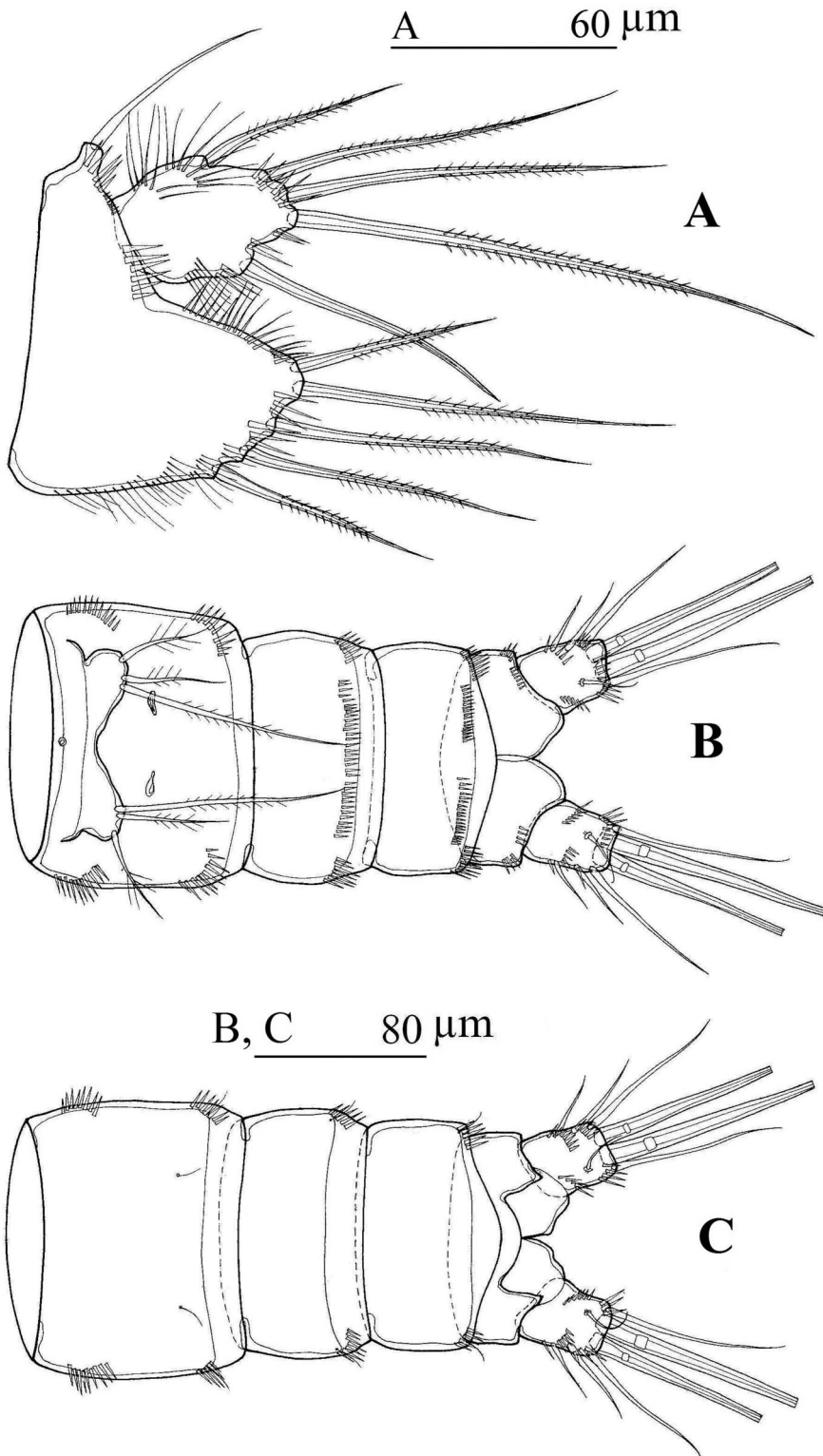


Figure 2. *Tigriopus sirindhornae* sp. nov., female. (A) P5; (B) urosome, ventral view; (C) urosome, dorsal view.

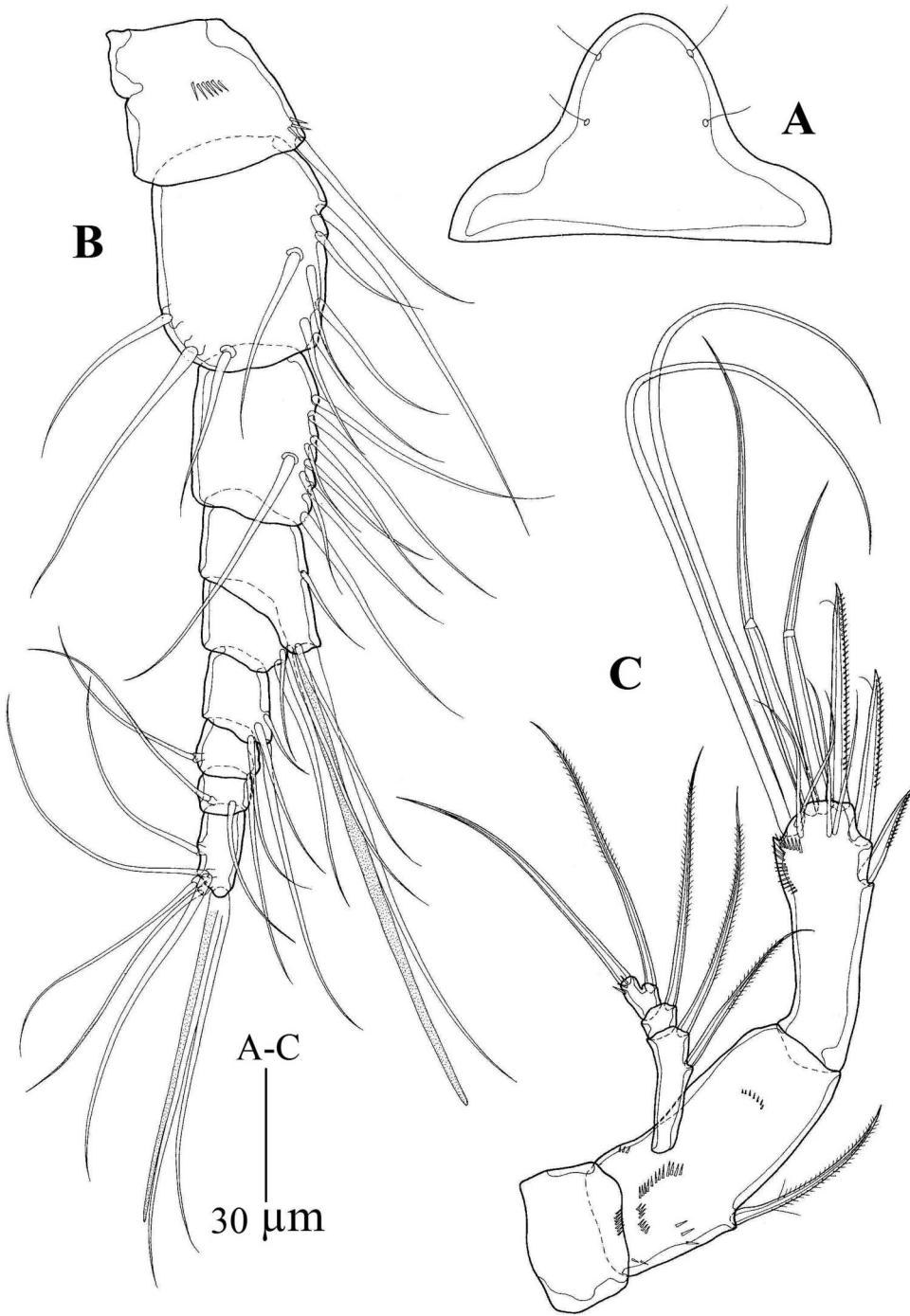


Figure 3. *Tigriopus sirindhornae* sp. nov., female. (A) rostrum, dorsal view; (B) right antennule, anterior view; (C) left antenna, anterior view.

smooth seta. Free endopodal segment ornamented with row of minute spinules at outer distal corner, with three pinnate spines, two pairs of small and short setae on anterior surface, two apical geniculate setae, and two long smooth setae arising from outer distal corner.

Mandible (Figure 4A, B): coxa well developed with arched spinular row at midlength of anterior surface. Cutting edge with five strong spines and one row of minute spinules, and pinnate seta. Basis with apical smooth seta; exopod three-segmented, first segment with two setae and some spinules at distal edge, second segment with one seta, third segment with two setae fused basally; endopod one-segmented, with three lateral inner setae (two of them fused basally), and six apical setae (two of them fused basally).

Maxillule (Figure 4C–F): praecoxa ornamented with rows of spinules, arthrite with two slender setae and one outer plumose spine-like element, with four naked and five pinnate apical spines. Coxa furnished with spinules on anterior surface, with three inner smooth setae and two pinnate spines. Basis with one pinnate spine and two setae distally, one seta laterally, and two subdistal setae (two juxtaposed). Exopod and endopod reduced, with three smooth setae each.

Maxilla (Figure 5A–E): syncoxa with rows of spinules on outer corner and three endites: one praecoxal and two coxal; praecoxal endite bilobular, each lobe with two distal plumose setae; two coxal endites with three distal spinulose setae each. Basis with one inner bare seta on a strong pectinate claw and two strong, remarkably plumose setae, and four slender bare setae near base of claw.

Maxilliped (Figure 5F): syncoxa and basis well developed. Syncoxa with one spinulose seta at inner distal corner, and spinule rows on anterior surface. Basis with rows of spinules on anterior surface and some minute spinules at outer margin, with inner median pinnate seta. Endopod with one large pinnate claw, and with one conical process bearing one lateral and one apical setae.

P1 (Figure 6A): praecoxa naked, coxa with spinular ornamentation pattern as shown. Basis with one inner pinnate seta and outer plumose element. Endopod much shorter than exopod, both three-segmented. Endopod I much longer than enp II and enp III combined, with one spine-like inner plumose seta; enp II shorter than last segment without seta; enp III with one strong outwardly curved claw-like smooth seta, one spine-like and one inner slender setae. Both exp I and exp II long, exp III reduced. Exopod I with one smooth outer seta; exp II with one smooth seta at two-thirds of outer margin, and one inner spinulose seta; exp III with two median distal claw-like setae, one inner and two outer spine-like setae.

P2–P3 (Figures 6B, 7A): coxa with rows of spinules. Basis bare, with one pinnate outer seta. Endopod three-segmented; enp I and enp II with one inner plumose seta each; enp III with one outer pinnate spine-like seta, three plumose setae: two median distal and one outer. Exopod three-segmented; exp I and exp II with outer pinnate spine each, and inner plumose seta; exp III with three outer pinnate spines, two plumose setae apically, and two inner plumose setae.

P4 (Figure 7B): as P2 and P3, except for enp II without inner seta.

Armature formula of P1–P4 is shown in Table 1.

P5 (Figure 2A): baseopod large, with spinular row along outer margin, with one outer basal smooth seta and five spinulose setae of unequal length on endopodal

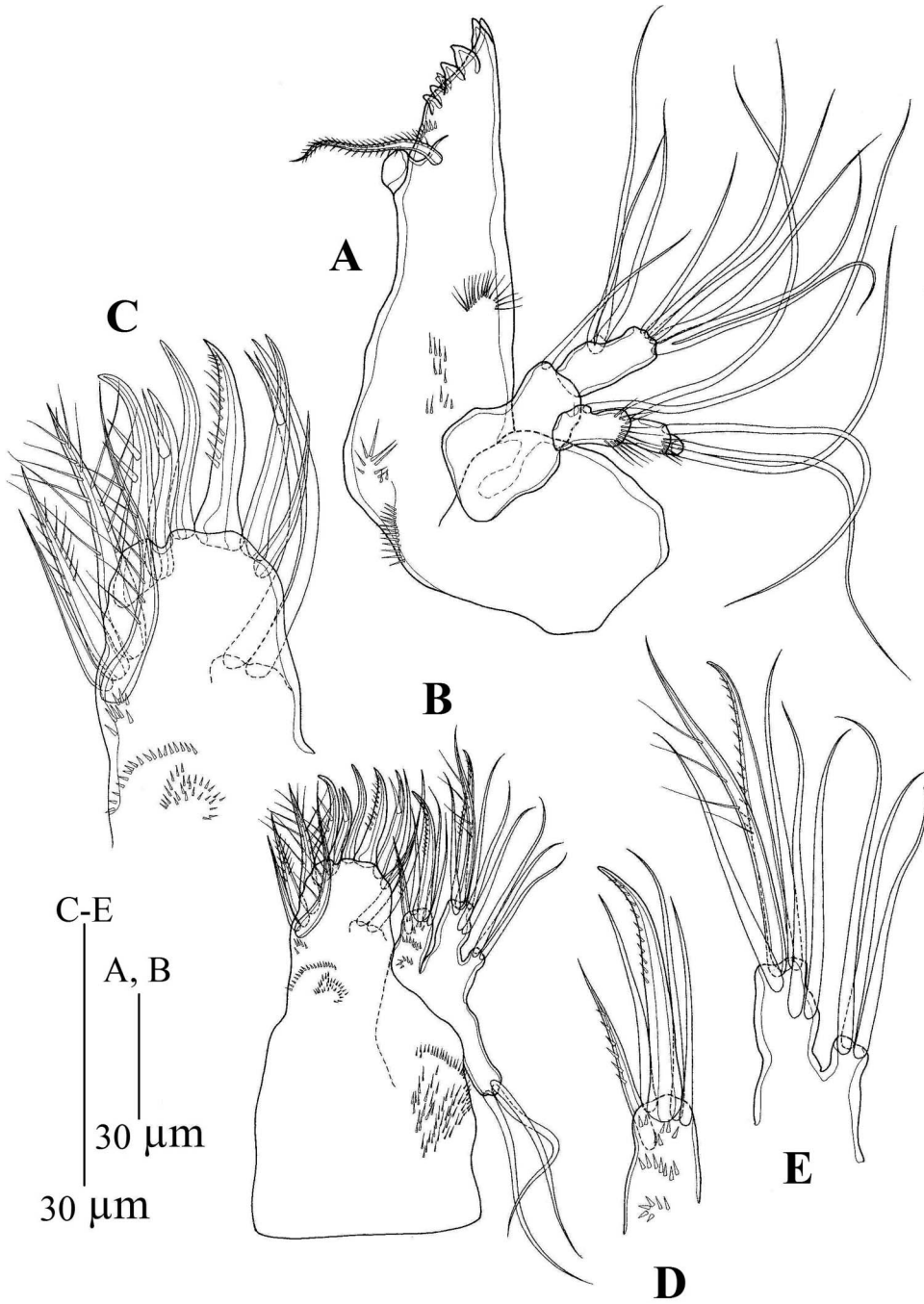


Figure 4. *Tigriopus sirindhornae* sp. nov., female. (A) Mandible, anterior view; (B) maxillule, anterior view; (C) praecoxal arthritis; (D) coxa; (E) basis and endopod.

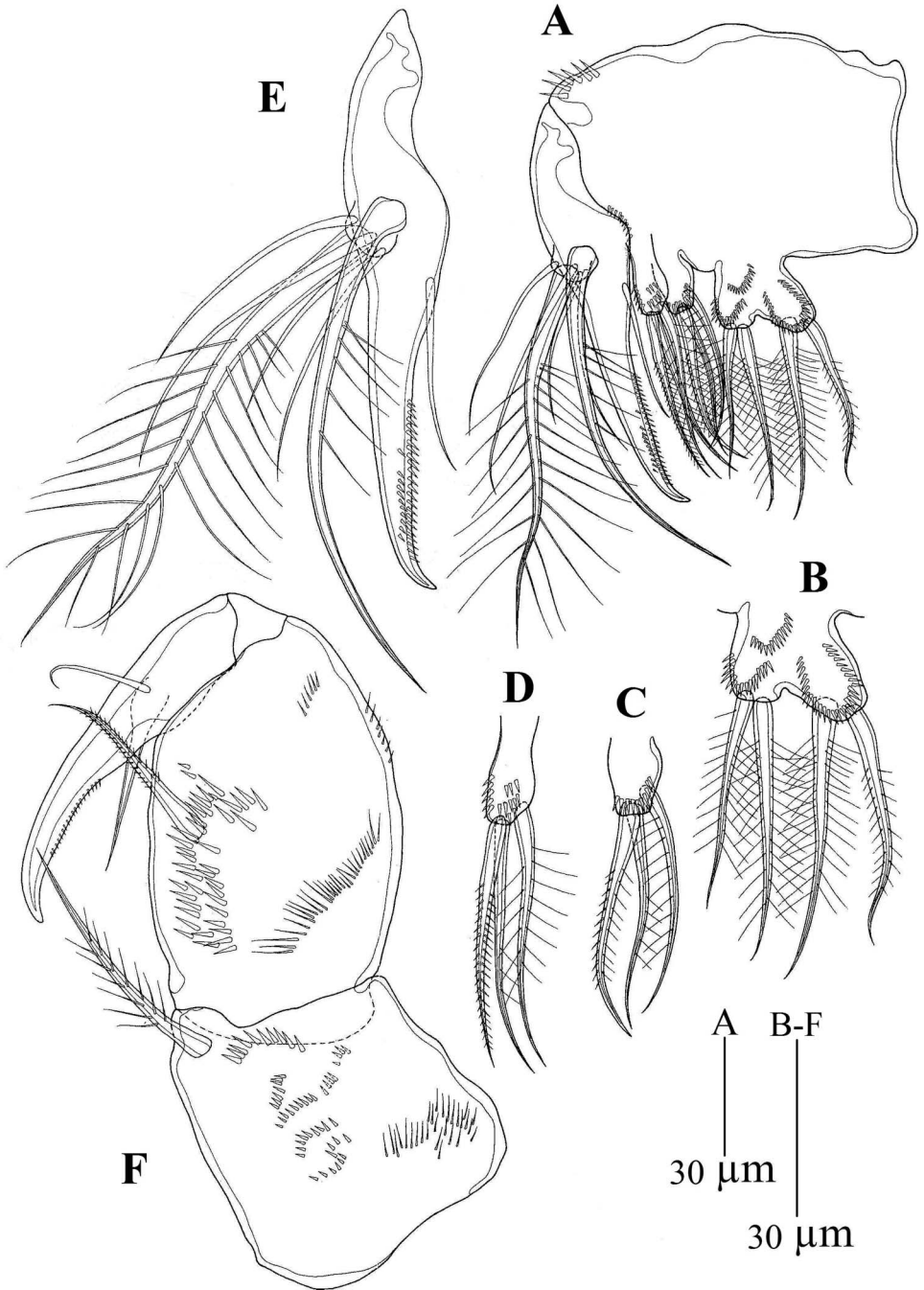


Figure 5. *Tigriopus sirindhornae* sp. nov., female. (A) Maxilla, posterior view; (B) praecoxal endite; (C, D) coxal endites; (E) basis; (F) maxilliped, anterior view.

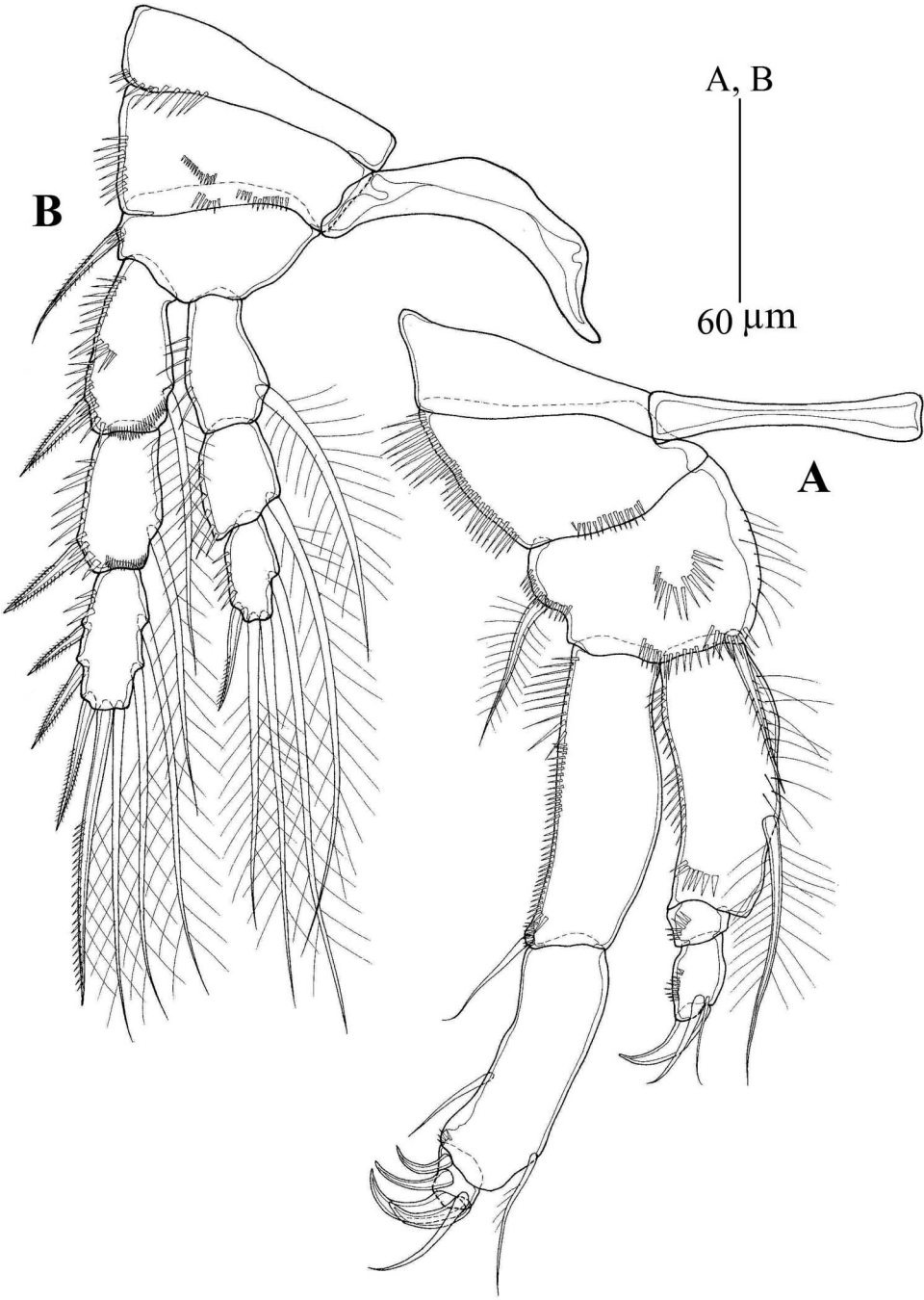


Figure 6. *Tigriopus sirindhornae* sp. nov., female. (A) Right P1; (B) right P2, posterior view.

lobe, second outermost being longest. Anterior face of exopod covered with longer-sized spinules, with four outer spinulose and one innermost smooth seta, the second innermost longest.

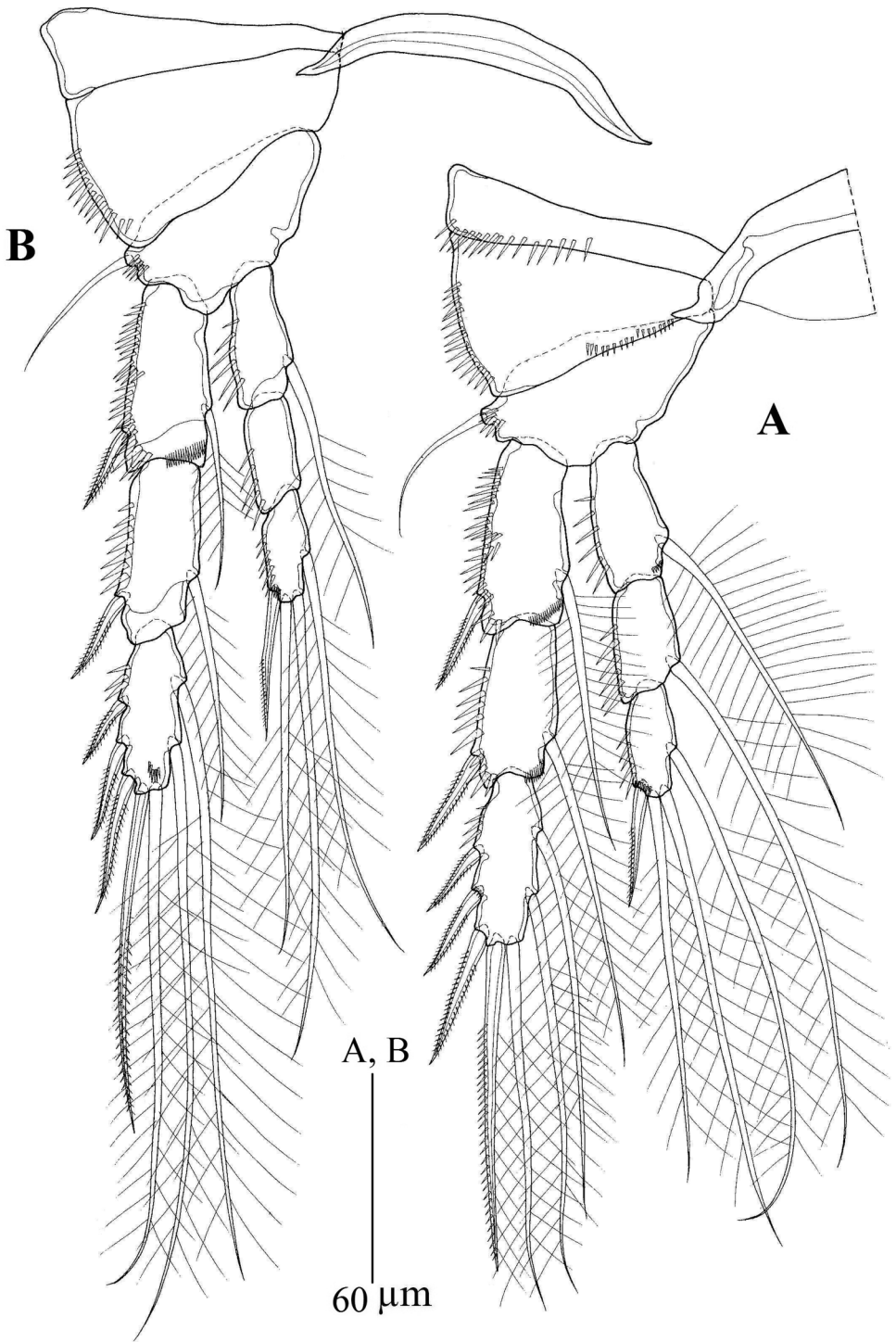


Figure 7. *Tigriopus sirindhornae* sp. nov., female. (A) Right P3; (B) right P4, posterior view.

Table 1. Armature formula of P1–P4 of female *Tigriopus sirindhornae* sp. nov.

	Exopod	Endopod
P1	1-0;1,1;V-1	1-0;0-0;2,I
P2	I-1; I-1, III,2,2	1-0;1-0;1,2,I
P3	I-1; I-1; III, 2,2	1-0;1-0;1,2,I
P4	I-1; I-1; III,2,2	1-0;0-0;1,2,I

Arabic numbers represent setae, Roman numerals represent spines.

Male. Total length of allotype, 0.92 mm (Figure 8A, B), total length of paratype, 1.0 mm ($n = 12$, mean = 0.90 mm) measured from tip of rostrum to posterior margin of caudal ramus. Body surface as in female but having more sensillae. General body shape and size similar to female. Sexual dimorphism expressed in A1, A2, P2, P5, P6 and urosomites.

Urosome (Figure 9A, B): six-segmented, comprising P5 bearing-somite, genital somite, three abdominal and anal somites. In ventral view, Uro3 to Uro6 furnished with small spinules at posterior margin. Armature and ornamentation as in female.

Antennule (Figure 10A, B): subchirocer, seven-segmented. First segment with small spinules on anterior inner surface, fifth one shortest, sixth one globularly expanded with long aesthetasc, seventh one developing claw-like outer process. Armature formula: 1-(1), 2-(1), 3-(11), 4-(6), 5-(12 + ae), 6-(0), 7-(7 + ae).

Antenna (Figure 10C): as in female, except for anterior edge of allobasis without seta.

P1 (Figure 11A): as in female, except for basis with longer inner seta.

P2 (Figure 11B): basis with one outer smooth seta. Endopod three-segmented as long as exp I and exp II lengths combined; first segment with one inner plumose seta; second segment with inner curved spinulose seta twice as long as exp III, with distinct outer spiniform apophysis; third segment reduced, with one inner plumose seta, two distal plumose setae and one outer apical spine. Exopod three-segmented, as in female.

P3 and P4 (Figure 12A, B): as in female.

P5 (Figure 9A, B): both baseoendopods confluent, with one inner short endopodal seta and long slender outer seta. Exopod twice as long as wide, with five smooth unequal setae; apical, innermost seta longest, about 3.5 times as long as exopod.

P6 (Figure 9A, B): represented by three setae, innermost longer than outermost, middle one shortest.

Remarks

Wells (2007) reported difficulties in finding characters useful to separate the females of species of *Tigriopus*. The taxonomy and correct identification of specimens of this genus is not an easy task as one has to pay attention to subtle details such as the number of sensilla on the rostrum; all species of *Tigriopus* have two pairs of rostral sensillae, if carefully examined. Other taxonomically important characters include also the armature and ornamentation of A1, A2, mouthparts, appendages and urosomites.

Tigriopus sirindhornae sp. nov. shares the same generic characters with its known congeners: (1) body compact, cycloform; (2) rostrum with two pairs of sensillae;

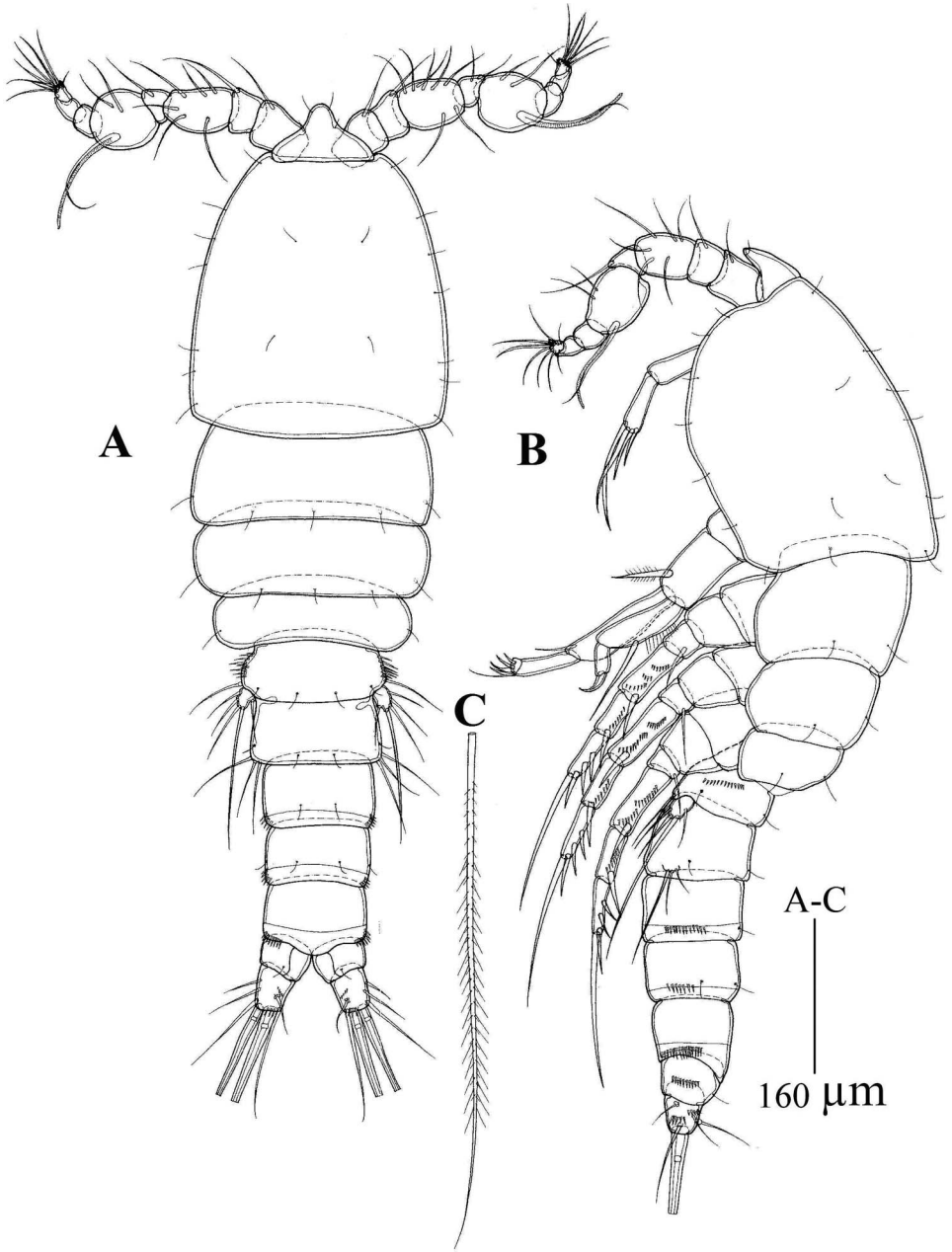


Figure 8. *Tigriopus sirindhornae* sp. nov., male. (A) Habitus, dorsal view; (B) habitus, lateral view; (C) caudal seta V.

(3) nine-segmented antennule in female; (4) A2 exopod three-segmented; (5) absence of abexopodal seta on allobasis of antenna in male; and (6) with distinct outer spiniform apophysis on male P2 enp II.

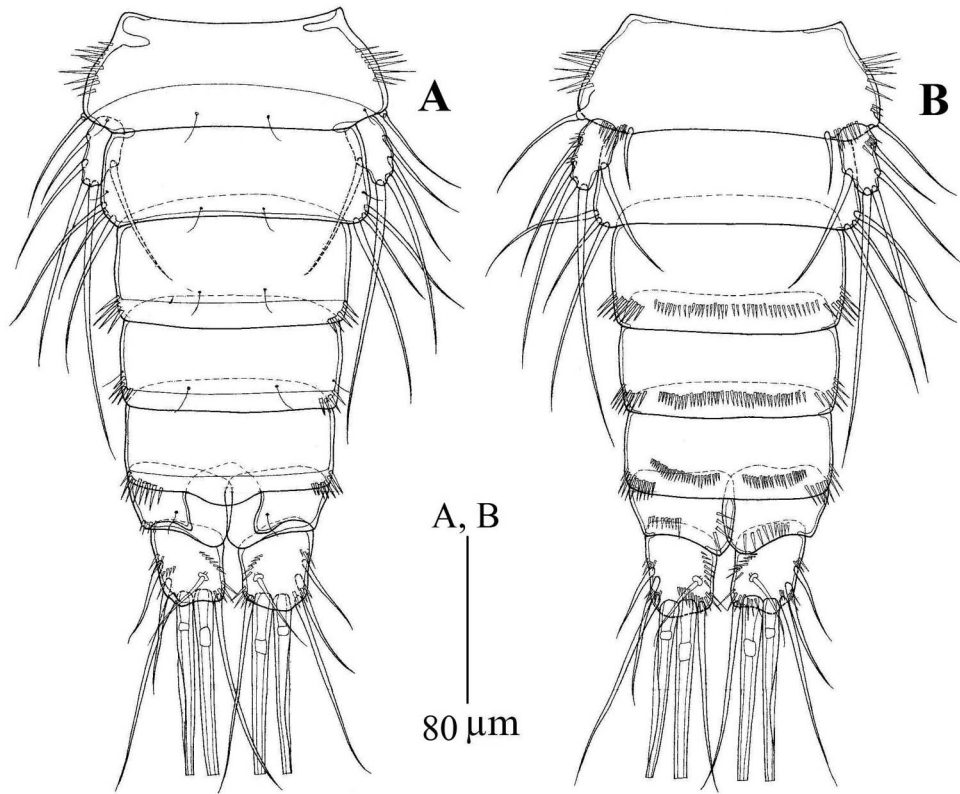


Figure 9. *Tigriopus sirindhornae* sp. nov., male. (A) Urosome, dorsal view; (B) urosome, ventral view.

Females of *T. sirindhornae* are unique in combining the following characters: (1) whole body with relatively fewer sensillae; (2) first segment of A1 ornamented with fewer spinules; (3) mandible with more spinules on coxal surface, only one seta on the mandibular basis and three-segmented exp; (4) maxillule with more spinules on praecoxal surface, arthrite with four bare and five spinulose spines on inner edge; (5) maxilla with three syncoxal endites ornamented with dense minute spinules; (6) basis of mxp with one inner median pinnate seta, enp with one large pinnate claw; (7) praecoxa of P1 bare, exp II without surface ornamentation, exp III with four curved outwardly smooth spine-like setae apically; (8) exopod of P5 with four outer spinulose and one innermost smooth seta.

Tigriopus sirindhornae females share with their closest relatives, *T. thailandensis* and *T. japonicus*, the following characters: the presence of two inner setae on P4 exp III, whereas other congeners bear three setae. The endopod of A2 is more slender and elongate in *T. sirindhornae* and *T. thailandensis* than it is in *T. japonicus*; there are fewer small spinules on the first segment of A1 of *T. sirindhornae* than in *T. thailandensis*, whereas spinules are absent on *T. japonicus*. In both males and females of *T. sirindhornae*, the P1 exp III bears five setae, two median distal claw-like setae, one inner and two outer spine-like setae, whereas *T. thailandensis* bears five claw-like

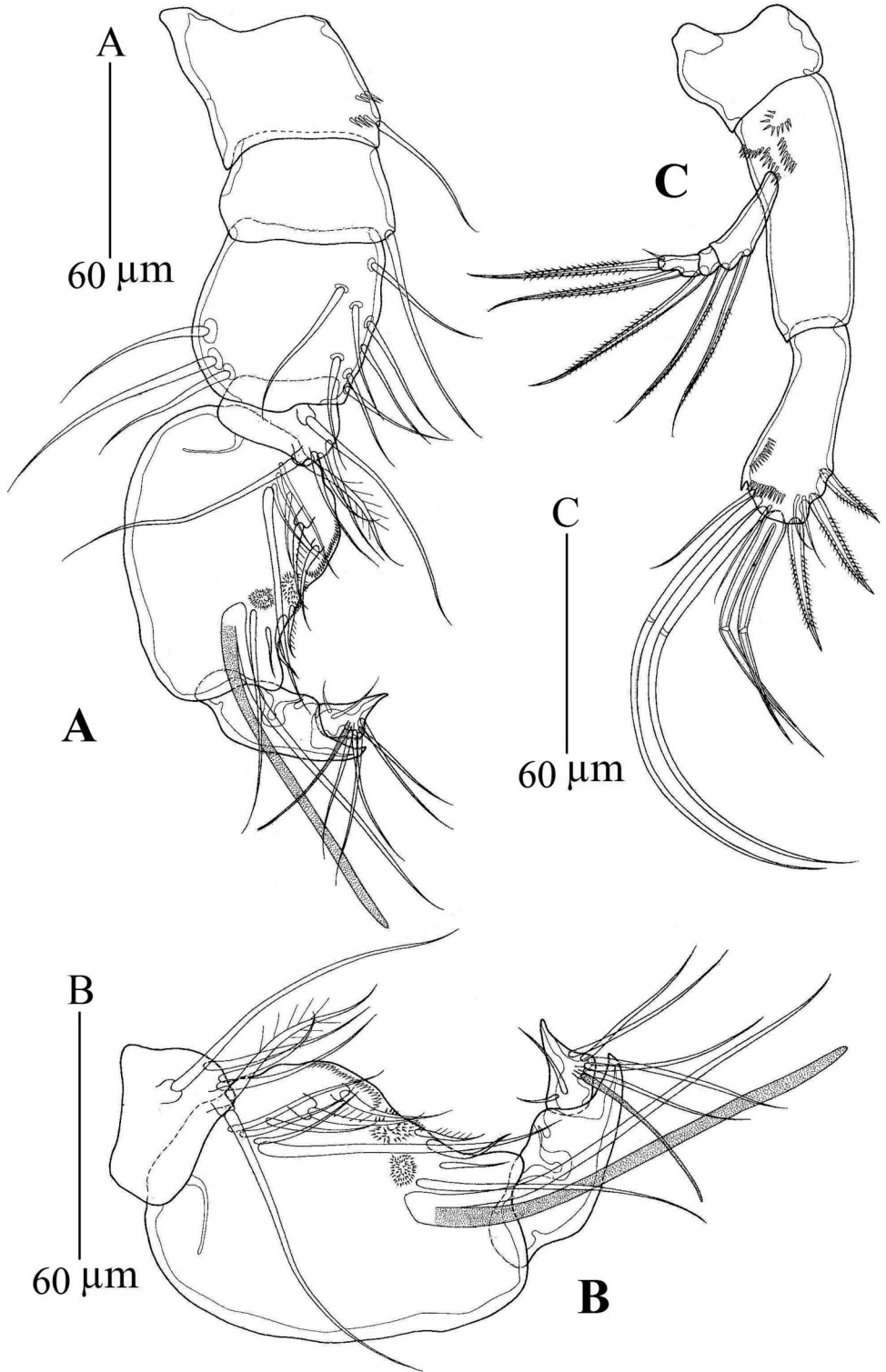


Figure 10. *Tigriopus sirindhornae* sp. nov., male. (A) Right antennule, anterior view; (B) A1 distal part; (C) right antenna, anterior view.

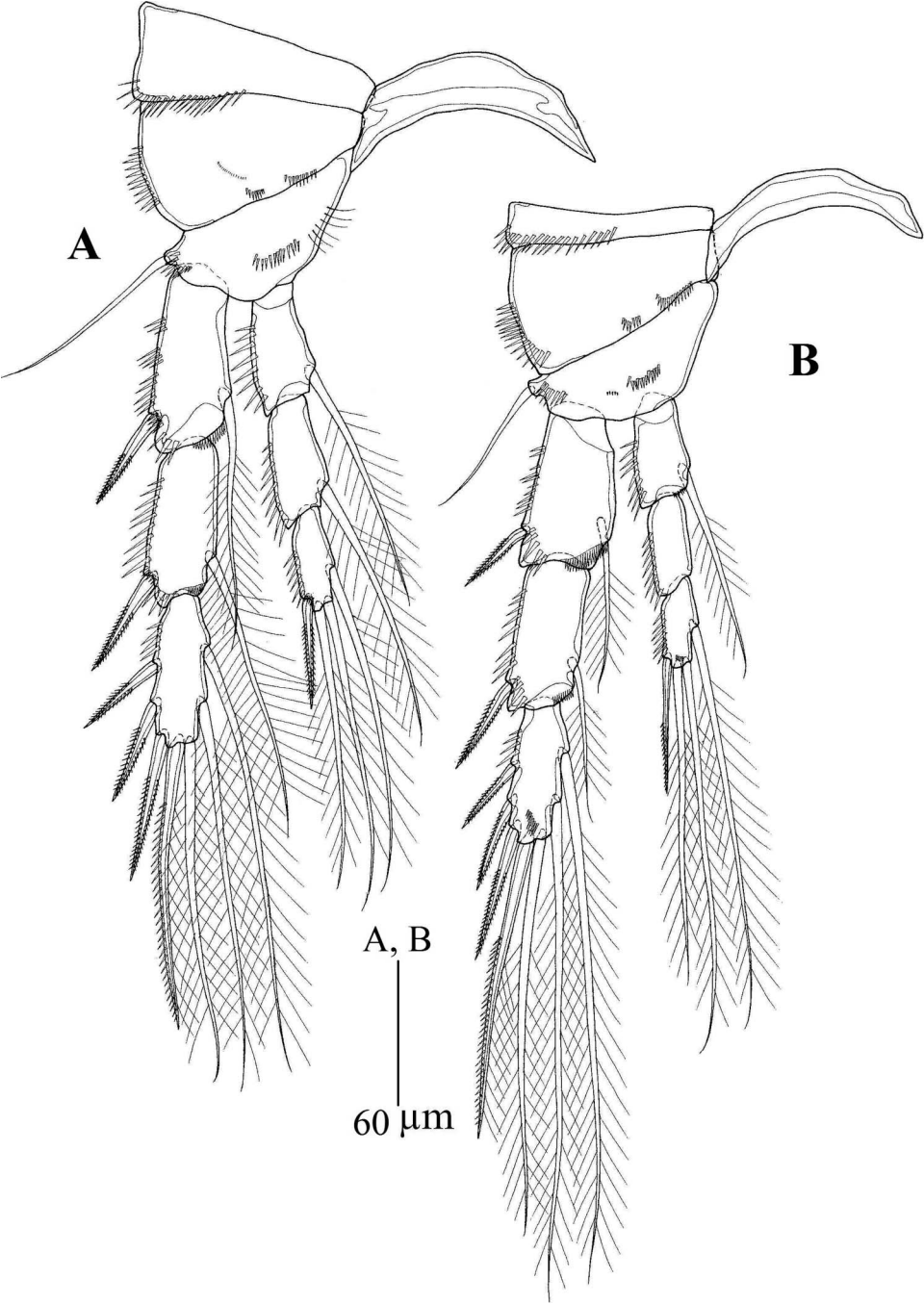


Figure 11. *Tigriopus sirindhornae* sp. nov., male. (A) Right P1; (B) right P2, posterior view.

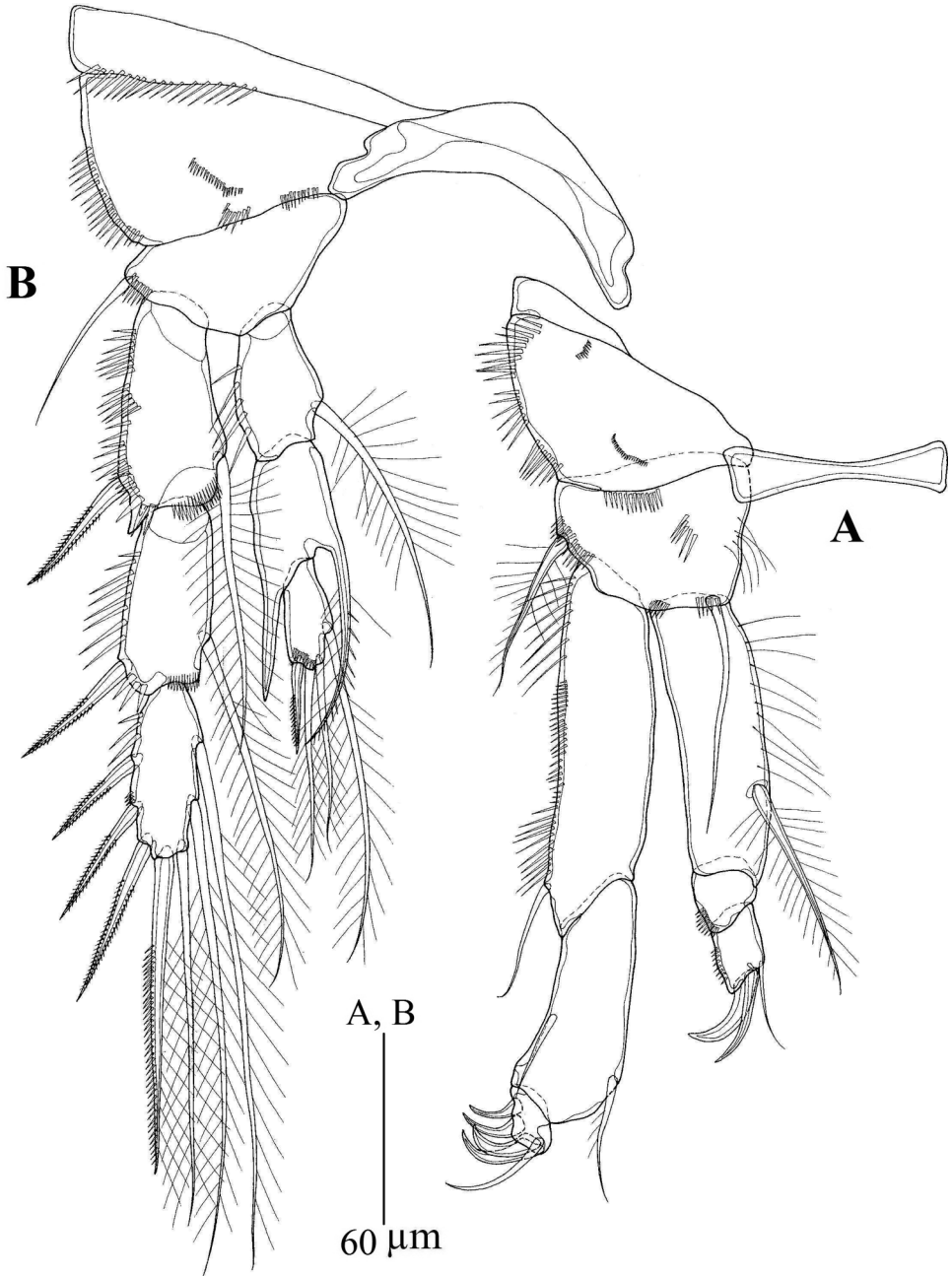


Figure 12. *Tigriopus sirindhornae* sp. nov., male. (A) Right P3; (B) right P4, posterior view.

setae, with the outermost one being slender, and *T. japonicus* has three setae, with the outermost seta being stout. In *T. sirindhornae* and *T. thailandensis* the P1 enp I bears strong spiniform spinules along its distal rim, whereas only tiny spinules are present in *T. japonicus* (Mori 1938; Chullasorn et al. 2012).

Table 2. Worldwide zoogeographic distribution of *Tigriopus* Norman, 1869.

Species	Locality	Source
1. <i>T. angulatus</i> Lang, 1933	New Zealand	Lang (1933)
2. <i>T. brachydactylus</i> Candeias, 1959	Northern Europe	Candeias (1959)
3. <i>T. brevicornis</i> Müller, 1776	Atlantic coast of Spain	Müller (1776)
4. <i>T. californicus</i> Baker, 1912	North America	Baker, 1912
5. <i>T. crozettensis</i> Soyer et al., 1987	Crozet Islands, South India Ocean	Soyer et al. (1987)
6. <i>T. fulvus</i> Fischer, 1860	Mediterranean Sea	Fischer, (1860)
7. <i>T. igai</i> Itô, 1977	Bonin Islands, Japan	Itô (1977)
8. <i>T. japonicus</i> Mori, 1938	Shimoda, Japan	Mori (1938)
9. <i>T. kerguelenensis</i> Soyer et al., 1987	Kerguelen Islands, South Indian Ocean	Soyer et al. (1987)
10. <i>T. minutus</i> Bozic, 1960	Goree, Senegal	Bozic (1960)
11. <i>T. raki</i> Bradford, 1967	New Zealand	Bradford (1967)
12. <i>T. thailandensis</i> Chullasorn et al. 2012	Bangsaen, Thailand	Chullasorn et al. (2012)
13. <i>T. sirindhornae</i> sp. nov.	Rayong, Thailand	Present study

Tigriopus sirindhornae differs from its only other Thailand congener, *T. thailandensis*, as follows: whole body of *T. sirindhornae* with fewer sensillae; posterior margin of cephalothorax smooth; A1 of female with large aesthetasc on fourth and acrothek on terminal segments; exopod II of P1, praecoxa, coxa and basis of P4 without surface ornamentation. In addition, there are differences in body ornamentation, details of oral appendages, structure of the genital field, and armature formula of appendages.

The discovery of the new species *T. sirindhornae* increases the number of recognized species in the genus *Tigriopus* to 13 (Table 2). The present key is modified from Bradford (1967) and Itô (1969), and is an aid to the identification of species of *Tigriopus* (the key will work best if both female and male specimens are available).

Key to species of *Tigriopus*

1. P5 exp with five setae in both female and male 2
P5 exp with five setae in female and four setae in male 3
2. P5 exp with five setae in male; anal operculum with finely hairs
..... *T. californicus*
P5 exp with five setae in male; anal operculum is naked *T. brevicornis*
3. P5 exp with four setae in male; P4 exp III with two inner setae ... *T. japonicus*
P5 exp with four setae in male; P4 exp III with three inner setae 4
4. Baseoendopod of P5 without inner seta in male *T. igai*
Baseoendopod of P5 with one inner seta in male 5
5. P6 with two setae in both female and male *T. raki*
P6 with three setae in both female and male 6

6. P1 exp II without outer seta 7
 P1 exp II with one outer seta 8
7. First endopodal segment of Mxp thickset and not excavated
 *T. brachydactylus*
 First endopodal segment of Mxp slender and oval in shape *T. minutus*
8. Mandibular basis with one seta 9
 Mandibular basis with two setae *T. fulvus*
9. Caudal rami without rows of spinules on dorsal surface *T. angulatus*
 Caudal rami with rows of spinules on dorsal surface 10
10. Anal somite and operculum with fine hair-like elements on dorsal surface ...
 11
 Anal somite and operculum not as above 12
11. Tip of apophysis of male P2 rounded *T. kerguelenensis*
 Tip of apophysis of male P2 sharp *T. crozettensis*
12. P1 exp II, P4 praecoxa, coxa and basis with surface ornamentation
 *T. thailandensis*
 P1 exp II, P4 praecoxa, coxa and basis without surface ornamentation
 *T. Sirindhornae*

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