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## Two new species of *Tigriopus* Norman, 1869 from Chonburi Province, Thailand (Crustacea: Copepoda: Harpacticidae)

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### Abstract

Two new species of the family Harpacticidae Dana, 1846, *Tigriopus namsaiensis* **sp. nov.** and *T. wannapaensis* **sp. nov.** were found in algal washings at Namsai and Wannapa beaches in Chonburi Province, Thailand. There are currently 14 known species in the genus, two of which, *T. thailandensis* Chullasorn, Ivanenko, Dahms, Kangtia & Yang, 2012 and *T. sirindhornae* Chullasorn, Dahms & Klangsin, 2013 were also discovered in Thailand. The genus *Tigriopus* Norman, 1869 has a worldwide distribution with nine species recorded from the Pacific Ocean (seven in the North Pacific and two in the South Pacific), four species from the Atlantic and adjacent seas, two species from the South Indian Ocean, and one species from Antarctica.

Sexual dimorphism is expressed in the antennule, antenna, P2, P5, P6, and segmentation of the urosome. *Tigriopus namsaiensis* **sp. nov.** and *T. wannapaensis* **sp. nov.** are closely related to *T. thailandensis* and *T. sirindhornae* in sharing the following characters: fewer sensilla on the prosome; antennary exopod with one seta on exp-2; P4 exp-3 with two inner setae; female P5 baseopod with five setae; male P2 exp-2 with a seta fused to the segment; and male P5 exopod with five setae.

*Tigriopus namsaiensis* **sp. nov.** closely resembles *T. thailandensis*, but the new species is characterized by four setae on the maxillulary coxa (three setae in *T. thailandensis*), the outermost seta on the female P6 is plumose (instead of the middle one), the lateral seta on the apical segment of the antennary exopod is discrete at the base (instead of fused to the segment), and the outermost seta of the male P5 exopod is plumose (instead of spinulose).

*Tigriopus wannapaensis* **sp. nov.** is very closely related to *T. sirindhornae*, but the new species differs from the latter by the following characteristics: 2-segmented mandibular exopod (3-segmented in *T. sirindhornae*); five setae on the maxillulary coxa (instead of three); all setae on female P6 are plumose (instead of two plumose and one pinnate); the lateral seta on the apical segment of the antennary exopod is fused to the segment (instead of discrete at the base); and the outermost seta on the male P5 exopod is plumose (instead of spinulose).

A dichotomous identification key to the 16 valid species of *Tigriopus* is provided.

**Key words:** Harpacticoida, identification key, morphology, Namsai Beach, taxonomy, *Ulva clathrata*, Wannapa Beach

### Introduction

Members of the harpacticoid genus *Tigriopus* Norman, 1869 (family Harpacticidae) are commonly found in coastal splash pools or intertidal pools, assuming a worldwide distribution from the tropics to Antarctica (Kim *et al.* 2003; Ki *et al.* 2009; Park *et al.* 2014). They have a good tolerance to various environmental stresses such as temperature or salinity (Itô 1970; Damgaard & Davenport 1994; Boxshall & Halsey 2004). Due to a number of promising characteristics including its significant ecological role in the marine environment, the genus *Tigriopus* has received increasing scientific attention and has already been promoted as a model organism for ecotoxicology and environmental genomics (Raisuddin *et al.* 2007).

Currently, the genus *Tigriopus* accommodates 16 valid species: *T. brevicornis* (Müller, 1776), *T. fulvus* (Fischer, 1860), *T. brachydactylus* Candeias, 1959, and *T. minutus* Božić, 1960 from the Atlantic and adjacent seas; *T. crozettensis* Soyer, Thiriot-Quévieux & Colomines, 1987 and *T. kerguelenensis* Soyer, Thiriot-Quévieux & Colomines, 1987 from the South Indian Ocean; *T. kingsejongensis* Park *et al.*, 2014 from King George Island in Antarctica; *T. raki* Bradford, 1967 (New Zealand) and *T. angulatus* Lang, 1933 (Australia and New Zealand) from the South Pacific Ocean; and *T. californicus* Baker, 1912, *T. japonicus* Mori, 1938, *T. igai* Itô, 1977, *T. thailandensis* Chullasorn, Ivanenko, Dahms, Kangtia & Yang, 2012, *T. sirindhornae* Chullasorn, Dahms & Klangsin, 2013, *T. namsaiensis* **sp. nov.** and *T. wannapaensis* **sp. nov.** from the North Pacific Ocean. Four species occur in the Gulf of Thailand, *i.e.* *T. thailandensis* from washings of the green algae *Ulva clathrata* (Roth) C. Agardh, 1811 (Chullasorn *et al.* 2012), *T. sirindhornae* from a sandy bottom (Chullasorn *et al.* 2013), *T. namsaiensis* **sp. nov.** and *T. wannapaensis* **sp. nov.** from *U. clathrata*.

In 2018, during a field trip funded by the “Cultivation and Propagation of Harpacticoid Copepods in Seaweed Habitats Project,” both sexes of two new species, *Tigriopus namsaiensis* **sp. nov.** and *T. wannapaensis* **sp. nov.** were found associated with the green algae *Ulva clathrata* at Namsai and Wannapa sandy beaches in Chonburi Province, Thailand. This paper describes both new species in detail and provides an updated identification key to the valid species currently recognized in the genus *Tigriopus*.

## Material and methods

Adult ovigerous females of *Tigriopus namsaiensis* **sp. nov.** and *T. wannapaensis* **sp. nov.** were collected in washings of green algae, *Ulva clathrata*, during low tide at Namsai sandy beach (12°36'12.72"N, 100°56'38.5"E) and Wannapa sandy beach (13°16'21.9"N, 100°55'18.4"E) in Chonburi Province, Thailand. Specimens were fixed in 6% buffered formalin, subsequently preserved in 70% ethanol and cleared in lactic acid. All measurements and dissections were made using a Leica MZ8 stereomicroscope. Drawings were made with the aid of a camera lucida mounted on a Nikon BH-2, HFX-DX compound microscope. Dissected specimens were mounted on slides in glycerol and sealed with transparent nail varnish.

The terminology of the body and appendage morphology follows Huys & Boxshall (1991) and Huys *et al.* (1996). Abbreviations used in the text are: *ae*, aesthetasc; *exp*, exopod; *enp*, endopod; *exp(enp)-1(2,3)*, proximal (middle, distal) segment of exopod (endopod); *P1–P4*, first to fourth swimming legs; and *P5–P6*, fifth to sixth leg. Total body length was measured from the anterior tip of the rostrum to the posterior margin of the caudal rami. Measurements were made with an ocular and slide micrometer. The type material of *T. namsaiensis* **sp. nov.** and *T. wannapaensis* **sp. nov.** was deposited in the collections of the National Institute of Biological Resources (NIBR), Korea.

## Systematics

### Order Harpacticoida Sars, 1903

### Family Harpacticidae Dana, 1846

### Genus *Tigriopus* Norman, 1869

#### *Tigriopus namsaiensis* **sp. nov.**

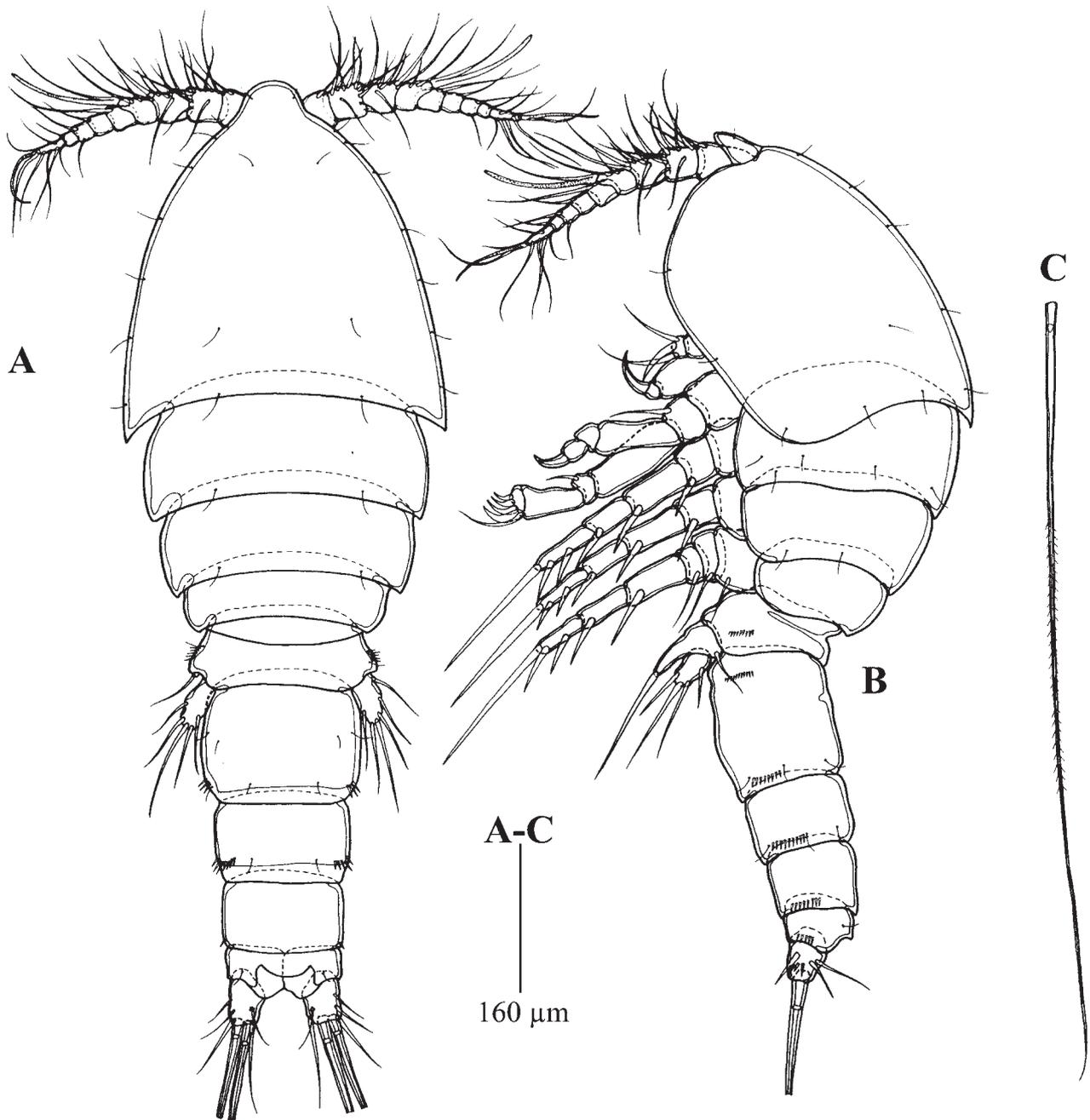
(Figs. 1–9)

**Type locality.** Associated with green algae, *Ulva clathrata* attached to a small rock at the sandy Namsai Beach in Sattahip district, Chonburi Province, Thailand (12°36'12.7"N, 100°56'38.5"E) on 6 August, 2017: collected by S. Chullasorn.

**Type material.** Adult female holotype (NIBRIV0000851927) dissected on six slides; male allotype (NIBRIV0000851928) dissected on three slides: three female and three male paratypes (NIBRIV0000851929) preserved in 95% alcohol.

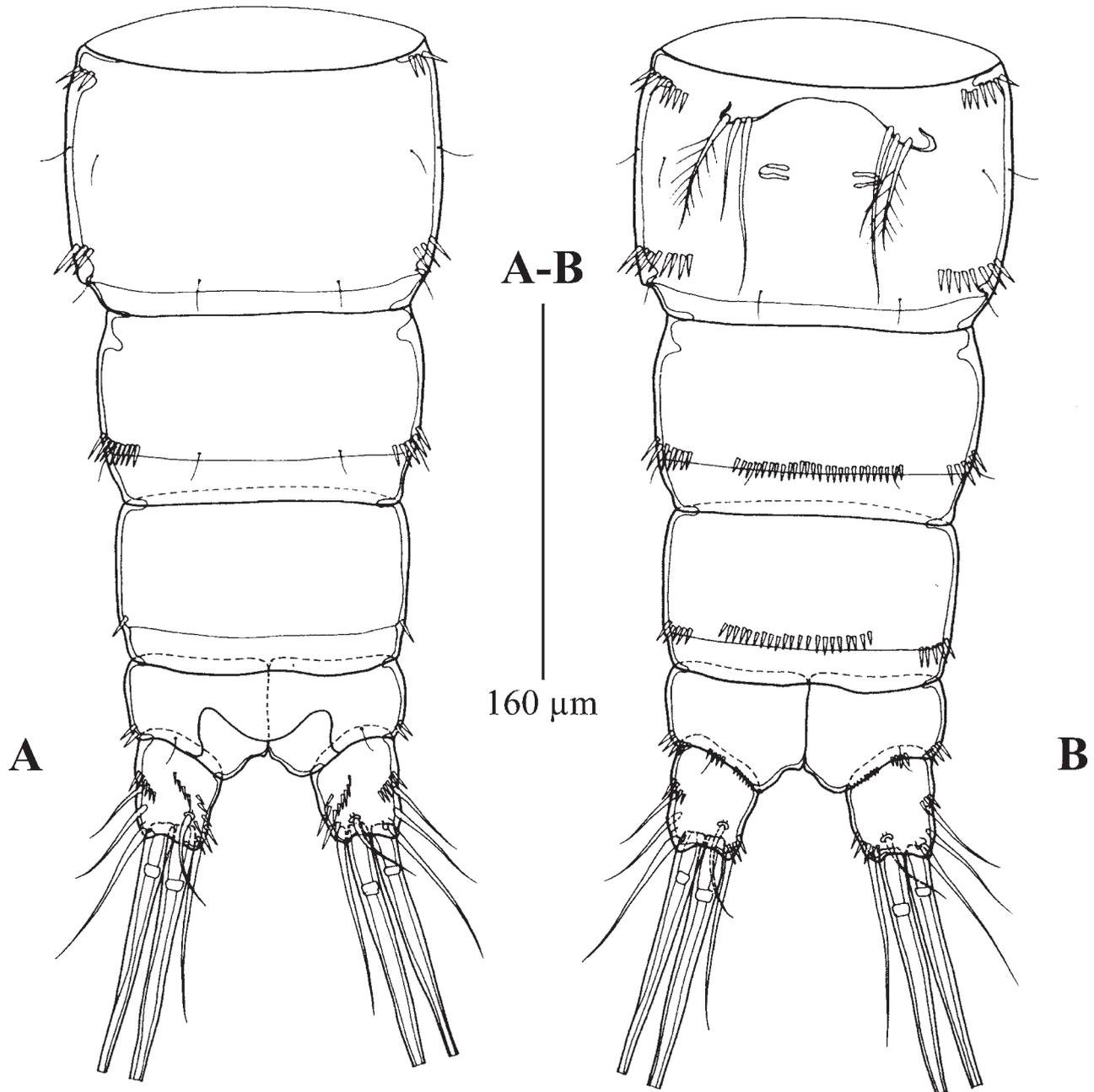
**Etymology.** The species name refers to the type locality at Namsai Beach.

**Description of female.** Total body length of holotype 959  $\mu\text{m}$  (Fig. 1A–B), measured from tip of rostrum to posterior margin of caudal ramus. Total body length of paratypes 900–1,030  $\mu\text{m}$  ( $n = 12$ , mean = 960  $\mu\text{m}$ ). Body compact, cyclopiform ornamented with few sensilla on surface. Nauplius eye not visible. Prosome 4-segmented, comprising cephalosome fused to first pedigerous somite, and three free pedigerous somites. Cephalothorax longer than three prosomites combined, posterior margin smooth. Rostrum (Fig. 3A) large, slightly longer than first segment of antennule, with two pairs of sensilla; the first pair close to the rounded tip, and the second pair at halfway the rostrum length.



**FIGURE 1.** *Tigriopus namsaiensis* sp. nov. (♀): (A) holotype, habitus, dorsal; (B) holotype, habitus, lateral; (C) caudal ramus seta V.

Urosome (Fig. 2A–B) 5-segmented, comprising P5-bearing somite, genital double-somite, two free abdominal somites, and anal somite. Genital double-somite with P6, genital field indistinct, ventrally with two genital apertures. Third and fourth urosomites with rows of spinules ventrally. Anal operculum semicircular and smooth. Caudal rami slightly longer than wide, ornamented with small spinules dorsally and ventrally. Seta I arising laterally halfway the ramus length; seta II located between seta I and seta III; seta III twice longer than seta II; seta V (Fig. 1C) 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.

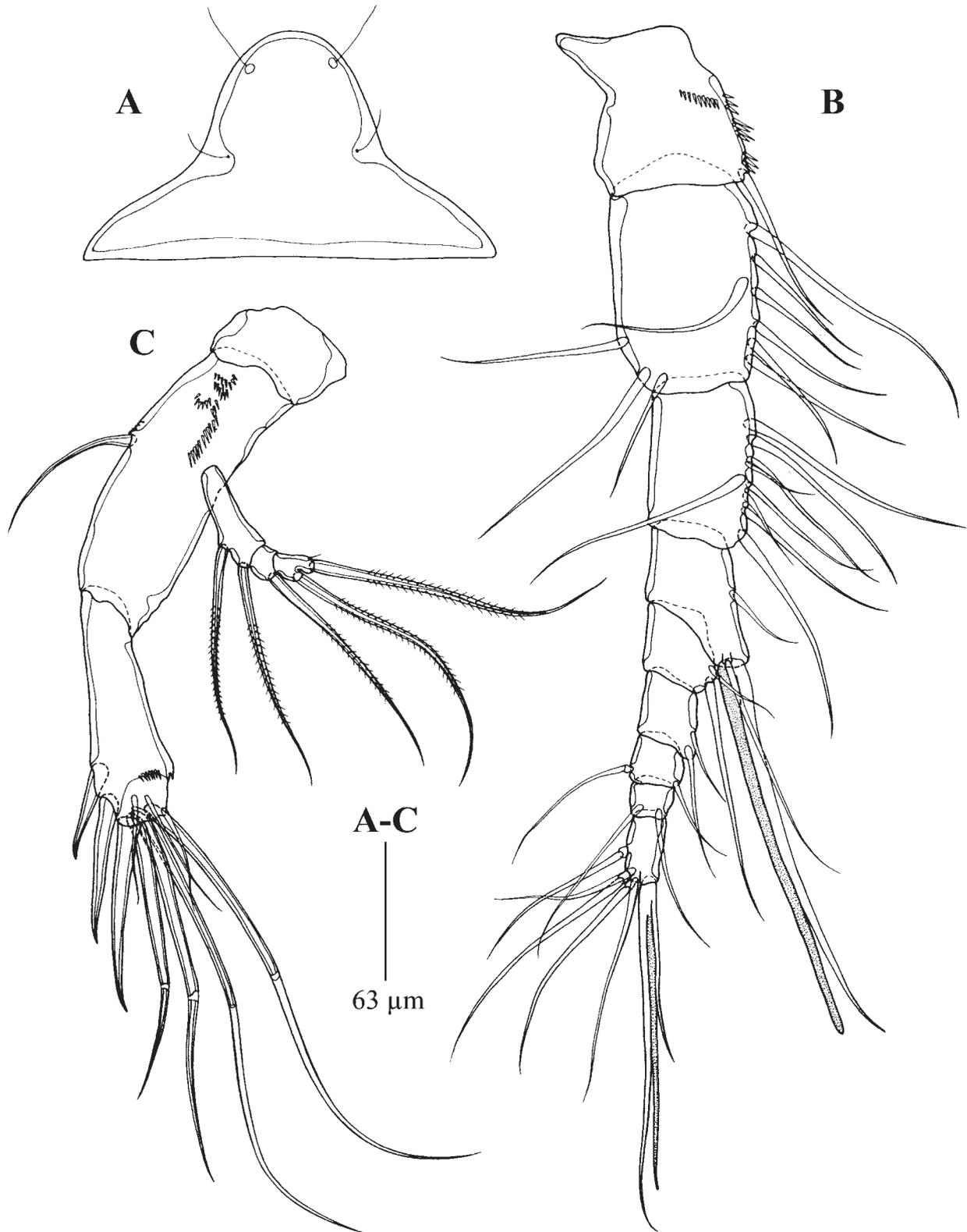


**FIGURE 2.** *Tigriopus namsaiensis* sp. nov. (♀): (A) urosome, dorsal; (B) urosome, ventral.

Antennule (Fig. 3B) 9-segmented, first segment ornamented with row of spinules on surface, second segment largest, surface of segments 2–9 smooth. Length of segments 1–2 longer than five apical segments combined. Fourth and last segment with one large and one small aesthetasc, respectively. All setae slender and naked. Armature formula: 1-(1), 2-(10), 3-(9), 4-(3 + (1 + ae), 5-(2), 6-(2), 7-(2), 8-(2), 9-(5 + acrothek). Apical acrothek consisting of aesthetasc and two setae.

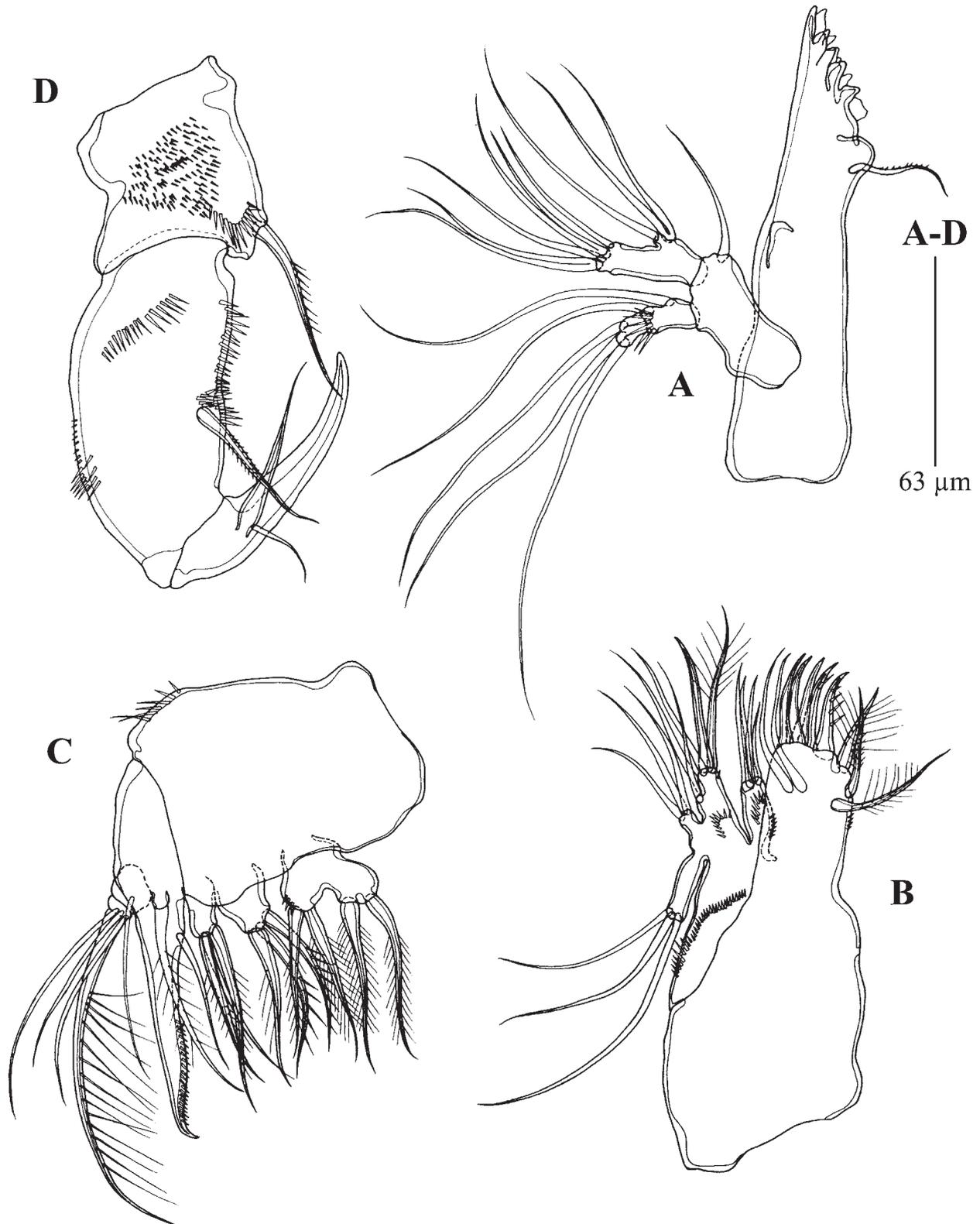
Antenna (Fig. 3C) 3-segmented, comprising coxa, allobasis, and 1-segmented endopod. Coxa short, unarmed

and unornamented. Allobasis bearing exopod, armed with one abexopodal smooth seta around middle of inner margin, furnished with rows of minute spinules on anterior surface. Exopod 3-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 pinnate seta. Free endopodal segment ornamented with row of minute spinules at outer distal corner, distal margin armed with smooth spines and setae: three spines, four small and short setae on anterior surface, and four geniculate setae.



**FIGURE 3.** *Tigriopus namsaiensis* sp. nov. (♀): (A) rostrum, dorsal; (B) right antennule, anterior; (C) left antenna anterior.

Mandible (Fig. 4A) with large and elongate coxa, without surface ornamentation, bearing well-developed gnathobase, cutting edge with nine strong teeth overlapping each other, and one pinnate seta. Basis with apical smooth seta; exopod 3-segmented, first segment with two setae and some spinules at distal edge, second segment with one seta, third segment with three setae basally; endopod 1-segmented, with three lateral inner setae (two of them fused basally), and six apical setae (two of them fused basally).



**FIGURE 4.** *Tigriopus namsaiensis* sp. nov. (♀): (A) mandible, anterior; (B) maxillule, anterior; (C) maxilla, anterior; (D) maxilliped, anterior.

Maxillule (Fig. 4B). Praecoxa without surface ornamentation, arthrite with two slender setae on surface, two plumose, spine-like, outer elements, and with five apical spines. Coxa with cylindrical endite furnished with spinules on anterior surface, with four smooth setae. Basis ornamented with spinules on anterior surface, one naked spine and four setae distally. Endopod 1-segmented with three smooth setae. Exopod 1-segmented, three times longer than wide, with three smooth setae.

Maxilla (Fig. 4C) with row of spinules distally on outer margin of syncoxa. Syncoxa with three endites (one praecoxal and two coxal); praecoxal endite bilobed, each lobe with two plumose distal setae; both coxal endites with three plumose distal setae. Basis with one smooth inner seta on a unipinnate strong claw and one plumose seta. Endopod 1-segmented with four slender setae and one plumose seta near base of the claw.

Maxilliped (Fig. 4D) comprising syncoxa, basis, and 1-segmented endopod. Syncoxa short and stout, with one unipinnate seta at inner distal corner, and many spinular rows of unequal length on anterior surface. Basis with rows of spinules on anterior surface and along outer margin, with some minute spinules at outer margin, and with median, pinnate, inner seta halfway its length. Endopod represented by smooth curved claw, about as long as basis, and with one conical process bearing one lateral and one apical seta.

All swimming legs (Figs. 5A–B; 6A–B) biramous; P1–P4 with 3-segmented exopods and endopods. Members of each leg pair connected by simple narrow intercoxal sclerite.

P1 (Fig. 5A). Praecoxa with row of spinules on anterior surface along distal margin. Coxa rectangular, ornamented with row of spinules along outer margin. Basis with one pinnate inner spine and one plumose outer spine, with three rows of spinules on anterior surface, and row of setules along inner margin. Endopod much shorter than exopod, both three-segmented. Enp-1 much longer than enp-2 and enp-3 combined, with one plumose inner seta; enp-2 shorter than last segment, unarmed; enp-3 with one strong smooth curved claw, one slender spine and one slender inner seta. Both exp-1 and exp-2 long, exp-3 short. Exp-1 with one smooth outer seta; exp-2 with one small smooth outer seta at two-thirds of outer margin, and one pinnate inner seta; exp-3 with one outwardly curved outer spine, two smooth, curved distal claws, and one smooth inner spine.

P2 (Fig. 5B). Praecoxa small and naked. Coxa ornamented with spinular rows of unequal length on anterior surface, and row of spinules along outer margin. Basis with one bipinnate outer spine, and small spinules on anterior surface. Endopod 3-segmented; enp-1 and enp-2 each with one plumose inner seta; enp-3 with one unipinnate outer spine, and three plumose setae (two distal and one inner). Exopod 3-segmented; exp-1 with one smooth outer spine and one plumose inner seta; exp-2 with one bipinnate outer spine and one plumose inner seta; exp-3 with three smooth outer spines, two plumose distal setae, and two plumose inner setae.

P3 (Fig. 6A). Coxa ornamented with spinular rows of unequal length on anterior surface, and row of spinules along outer margin. Basis smooth, with some spinules at base of slender outer seta. Endopod 3-segmented; enp-1 with one small pore on anterior surface, and one plumose inner seta; enp-2 with one plumose inner seta; enp-3 with one smooth outer spine, and three plumose setae (two median distal and one inner). Exopod 3-segmented; exp-1 and exp-2 each with one smooth outer spine and one plumose inner seta; exp-3 with three outer spines (two smooth and one unipennate), two plumose distal setae, and two plumose inner setae.

P4 (Fig. 6B). Praecoxa small and naked. Coxa with row of spinules along distal outer margin. Basis with one slender outer seta, and small spinules on anterior surface. Endopod 3-segmented; enp-1 with one plumose inner seta; enp-2 unarmed; enp-3 with one unipinnate outer spine and three plumose setae (two distal and one inner). Exopod 3-segmented; exp-1 and exp-2 each with one bipinnate outer spine and one plumose inner seta; exp-3 with one smooth outer spine, two unipinnate outer spines, two distal plumose setae, and two plumose inner setae. Exp-2 and exp-3 each with a pore on anterior surface.

Armature formula of swimming legs as follows (Arabic numbers represent setae, Roman numbers represent spines):

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

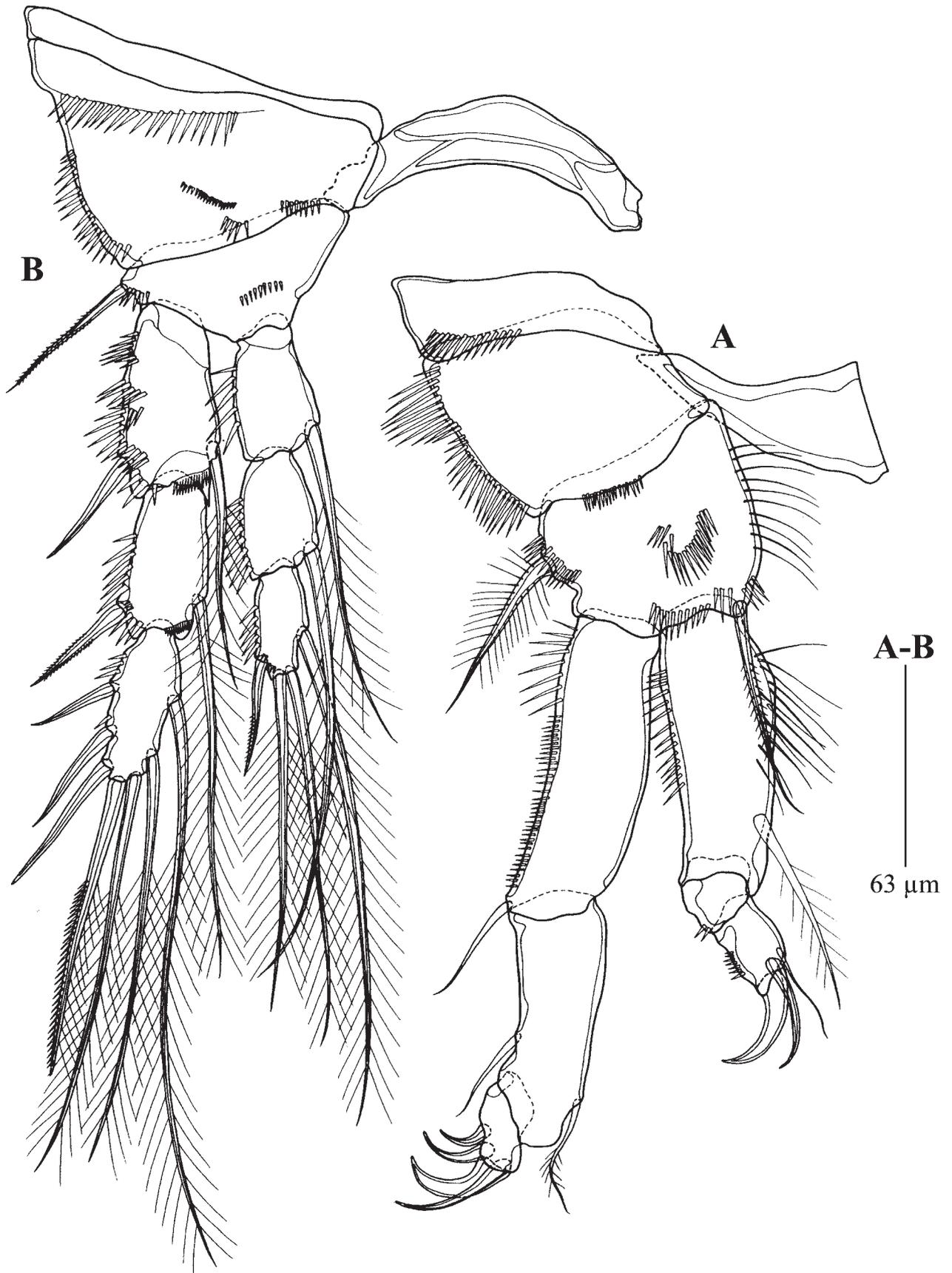
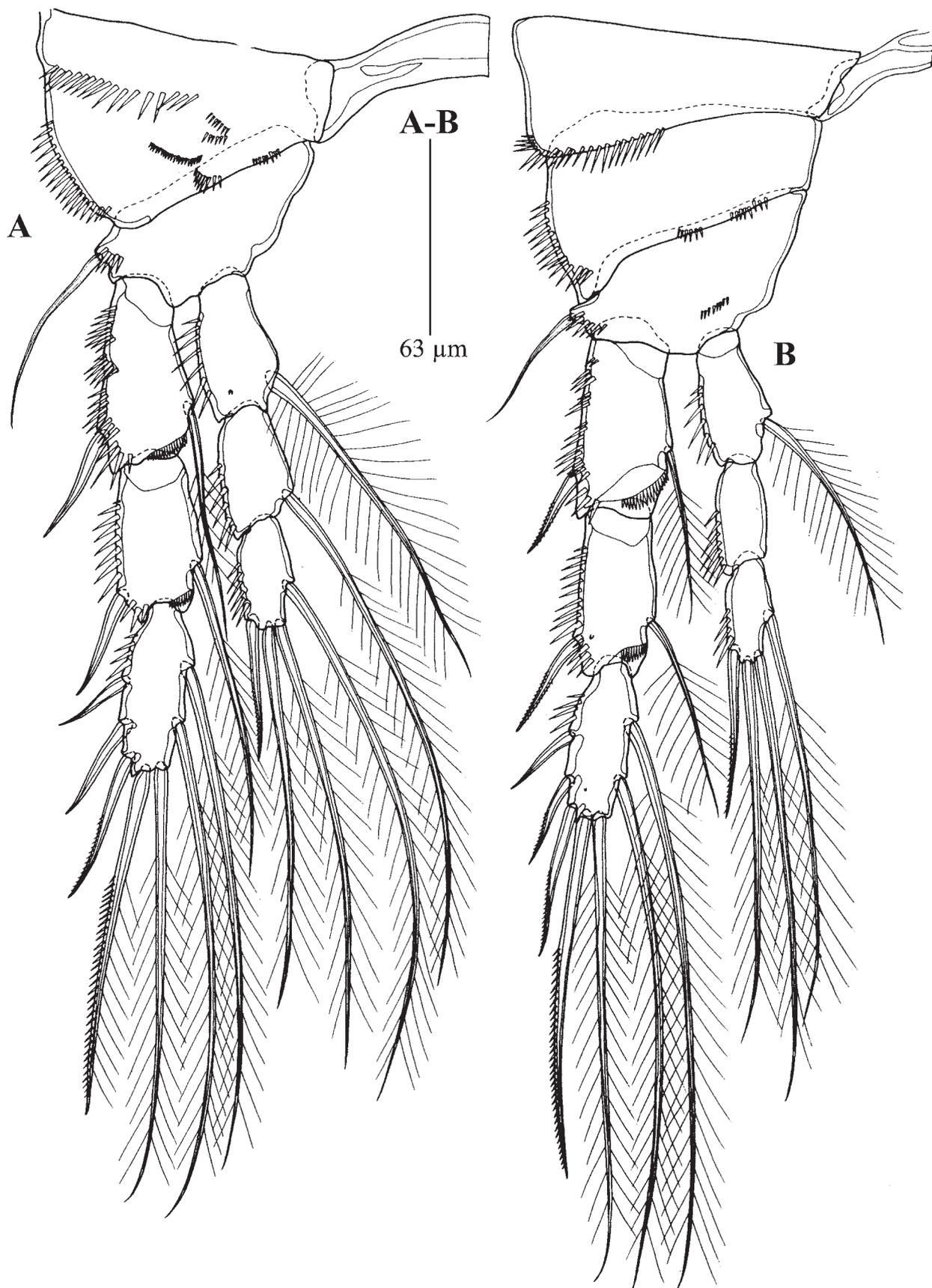
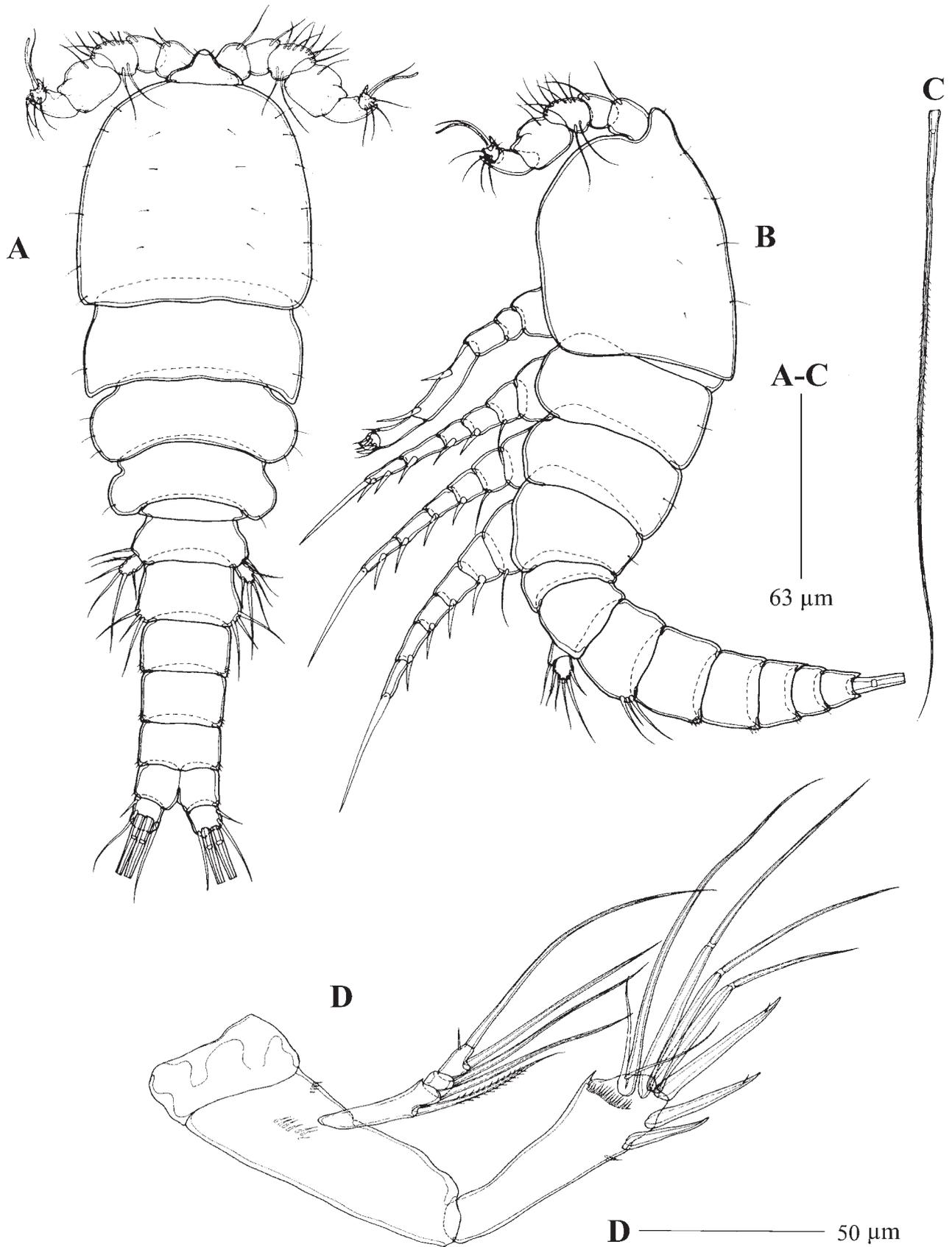


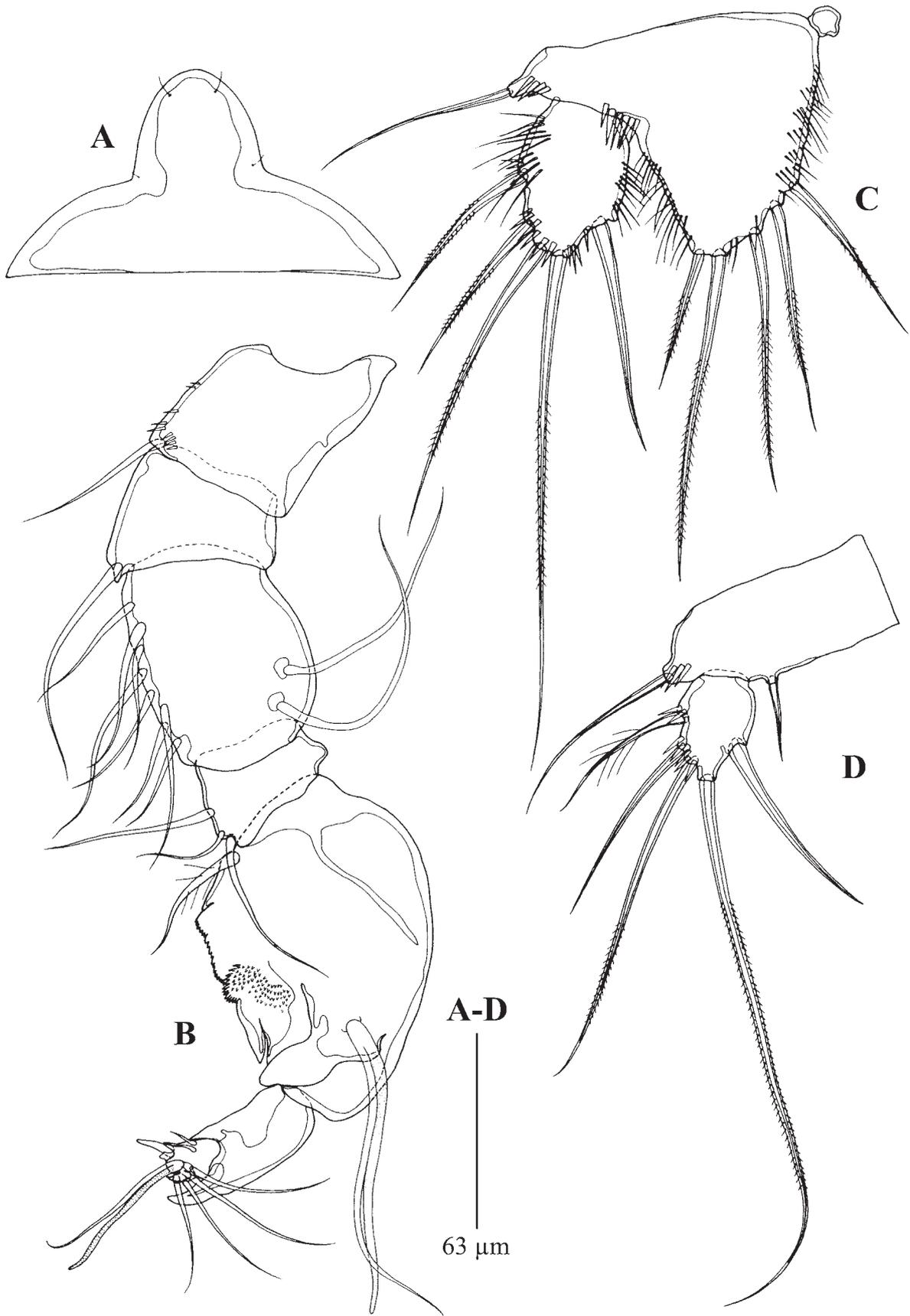
FIGURE 5. *Tigriopus namsaiensis* sp. nov. (♀): (A) P1, anterior; (B) P2, anterior.



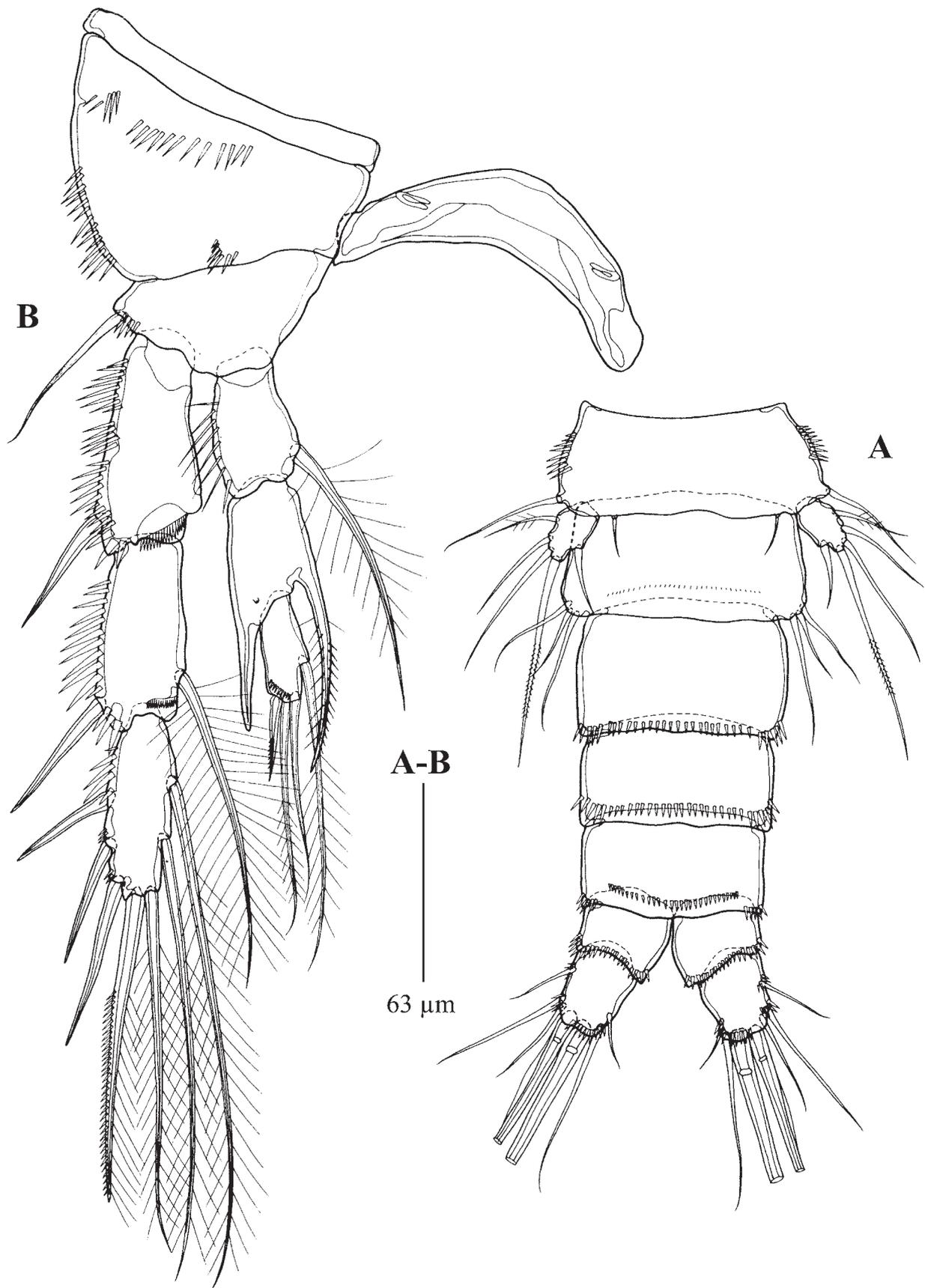
**FIGURE 6.** *Tigriopus namsaiensis* sp. nov. (♀): (A) P3, anterior; (B) P4, anterior.



**FIGURE 7.** *Tigriopus namsaiensis* sp. nov. (♂): (A) allotype, habitus, dorsal; (B) allotype, habitus, lateral; (C) caudal ramus seta V; (D) antenna, anterior.



**FIGURE 8.** *Tigriopus namsaiensis* sp. nov. (♂: A–B, D) (♀: C): (A) rostrum, dorsal; (B) left antennule, anterior; (C) P5, anterior; (D) P5, anterior.



**FIGURE 9.** *Tigriopus namsaiensis* sp. nov. (♂): (A) urosome, with P6 on both lateral sides; (B) P2, anterior.

P5 (Fig. 8C) with separate exopod and baseopod (fused basis and endopod); with spinular row along outer margin; without intercoxal sclerite and not fused medially. Exopod ovoid and small with five bipinnate setae of unequal length, second outermost longest. Baseopod with long smooth outer basal seta, and with five setae (innermost smooth, and four bipinnate outer elements), the second innermost longest.

**Description of male.** Total body length of allotype (Fig. 7A–B) 902  $\mu\text{m}$ . Total body length of paratypes 796–929  $\mu\text{m}$  ( $n = 12$ , mean = 874  $\mu\text{m}$ ). Rostrum (Fig. 8A), general body shape and size similar to those of female. Sexual dimorphism expressed in antennule, antenna, P2, P5, P6, and urosomal segmentation.

Urosome (Fig. 9A) 6-segmented, comprising P5-bearing somite, genital somite, three abdominal somites and anal somite. Third to sixth urosomites with small spinules along ventral posterior margin. Ornamentation as in female.

Antennule (Fig. 8B) subchirocer, 7-segmented, with smooth setae. First segment with small spinules on anterior surface, fourth segment shortest, fifth segment largest and globularly expanded with one plumose seta and long aesthetasc, sixth segment forming claw-like outer process, seventh segment with six setae (two short and four long) and acrothek. Armature formula: 1-(1), 2-(1), 3-(10), 4-(3), 5-(1 + (1 + ae)), 6-(0), 7-(7 + acrothek).

Antenna (Fig. 7D) similar to female condition, except for anterior edge of allobasis without abexopodal seta, and fewer spinules on anterior surface. Except for bipinnate proximal seta on exp-1 all other exopodal setae naked.

P2 (Fig. 9B). Basis with one smooth outer seta. Endopod 3-segmented and modified; enp-2 with curved spinulose inner seta almost twice as long as enp-3, and distinct spiniform outer apophysis; enp-3 small, with one unipinnate outer spine and two distal setae (one spinulose outer and one smooth inner) and one plumose outer seta. Exopod 3-segmented, as in female.

P3 and P4 as in female.

P5 (Fig. 8D) baseopod bearing one smooth basal outer seta, and one smooth (endopodal) inner seta. Exopod armed with five setae of unequal length: innermost one smooth; second inner one bipinnate and longest; apical bipinnate; outermost plumose; second outer smooth.

P6 (Fig. 9A) represented by three smooth setae, innermost longest, and middle one shortest.

### ***Tigriopus wannapaensis* sp. nov.**

(Figs. 10–18)

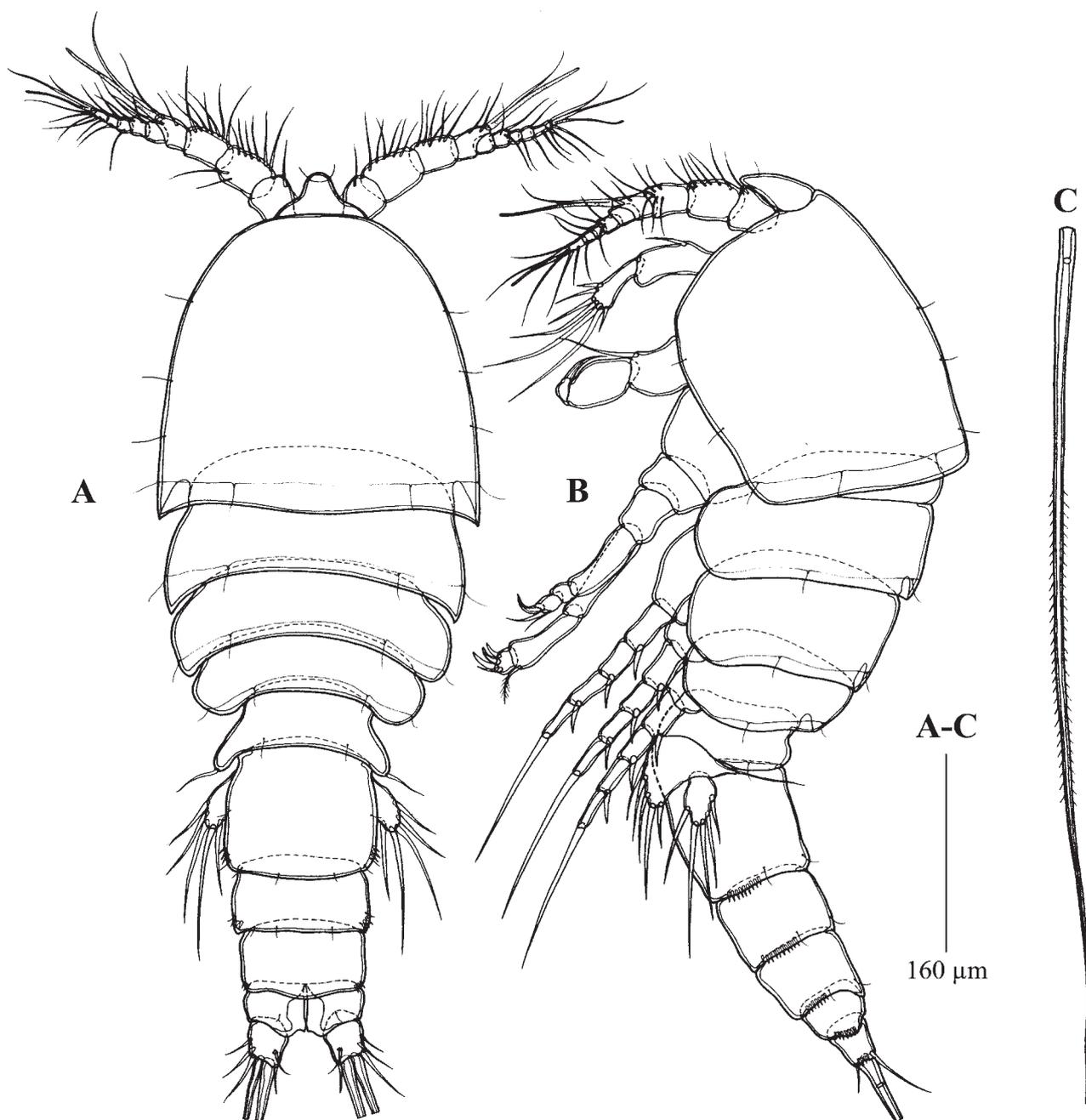
**Type locality.** Associated with slightly rotten green algae, *Ulva clathrata*, at Wannapa sandy beach in Muang district, Chonburi Province, Thailand (13°16'21.9"N, 100°55'18.4"E) on 3 June, 2017; collected by S. Chullasorn.

**Specimens examined.** Adult female holotype (NIBRIV0000851930) dissected on seven slides; male allotype (NIBRIV0000851931) dissected on three slides; three female and three male paratypes (NIBRIV0000851932) preserved in 95% alcohol.

**Etymology.** The species name refers to Wannapa Beach where the new species was found.

**Description of female.** Total body length of holotype 937  $\mu\text{m}$  (Fig. 10A–B), measured from tip of rostrum to posterior margin of caudal ramus. Total body length of paratypes 879–1,029  $\mu\text{m}$  ( $n = 12$ , mean = 957  $\mu\text{m}$ ). Body compact, cycloform ornamented with few sensilla on surface. Nauplius eye not visible. Prosome 4-segmented, comprising cephalosome fused to first pedigerous somite, and three free pedigerous somites. Cephalothorax much longer than three prosomites combined, and posterior margin smooth. Rostrum (Fig. 12A) large, slightly longer than first segment of antennule, with two pairs of sensilla; the first pair close to the rounded tip, and the second pair at halfway the rostrum length.

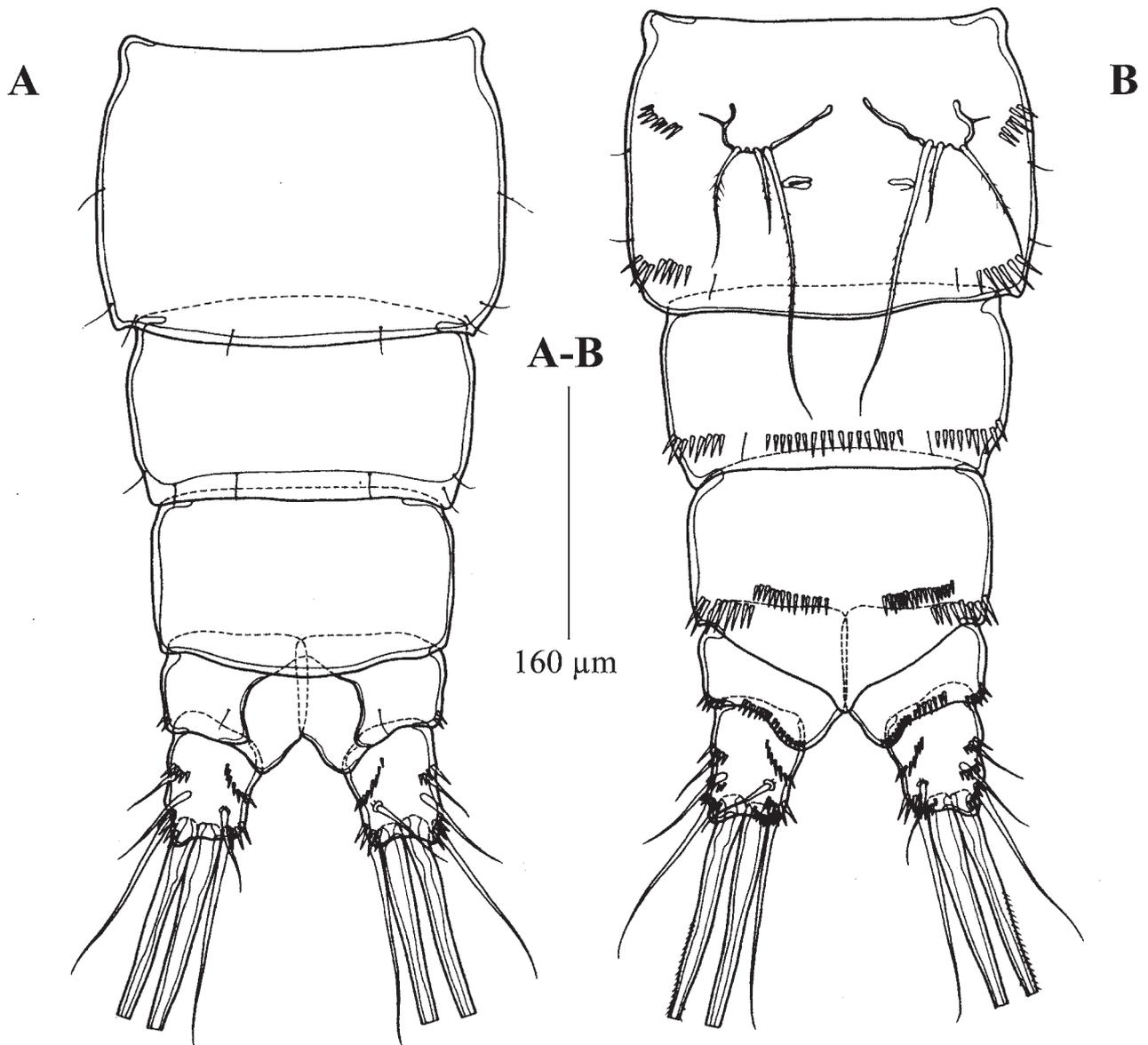
Urosome (Fig. 11A–B) 5-segmented, comprising P5-bearing somite, genital double-somite, two free abdominal somites, and anal somite. Genital double-somite with P6, genital field indistinct, ventrally with two genital apertures. Third and fourth urosomites with rows of spinules ventrally. Anal operculum semicircular and 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 twice longer than seta II; seta V (Fig. 10C) 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.



**FIGURE 10.** *Tigriopus wannapaensis* sp. nov. (♀): (A) holotype, habitus, dorsal; (B) holotype, habitus, lateral; (C) caudal ramus seta V.

Antennule (Fig. 12B) 9-segmented, first segment ornamented with rows of spinules on surface, second segment largest, surface of segments 2–9 smooth. Length of segments 1–2 longer than five apical segments combined. Fourth and last segment with one large and one small aesthetasc, respectively. All setae slender and naked. Armature formula: 1-(1), 2-(10), 3-(8), 4-(2 + (1 + ae)), 5-(2), 6-(3), 7-(2), 8-(2), 9-(5 + acrothek). Apical acrothek consisting of aesthetasc and two setae.

Antenna (Fig. 12C) three-segmented, comprising coxa, allobasis, and 1-segmented endopod. Coxa short, unarmed and unornamented. Allobasis bearing exopod, armed with one abexopodal smooth seta halfway inner margin, furnished with row of minute spinules on anterior surface. Exopod 3-segmented; first segment longest with two setae (one pinnate and one smooth), second segment short with one smooth seta, third segment with two smooth setae. Endopodal segment ornamented with row of minute spinules at outer distal corner, distal margin armed with smooth spines and setae: three spines, four slender setae on anterior surface, and four geniculate setae.



**FIGURE 11.** *Tigriopus wannapaensis* sp. nov. (♀): (A) urosome, dorsal; (B) urosome, ventral.

Mandible (Fig. 13A) with large and elongate coxa, anterior surface ornamented with one curved row of spinules, bearing well-developed gnathobase, cutting edge with eight strong overlapping teeth, and one comb-like tooth close to lateral unipinnate seta. Basis with smooth apical seta; exopod 2-segmented, first segment with two smooth setae and six spinules around distal margin, second segment with three smooth setae and two minute spines; endopod 1-segmented, with three lateral inner setae and six apical setae (four of which forming two basally fused pairs).

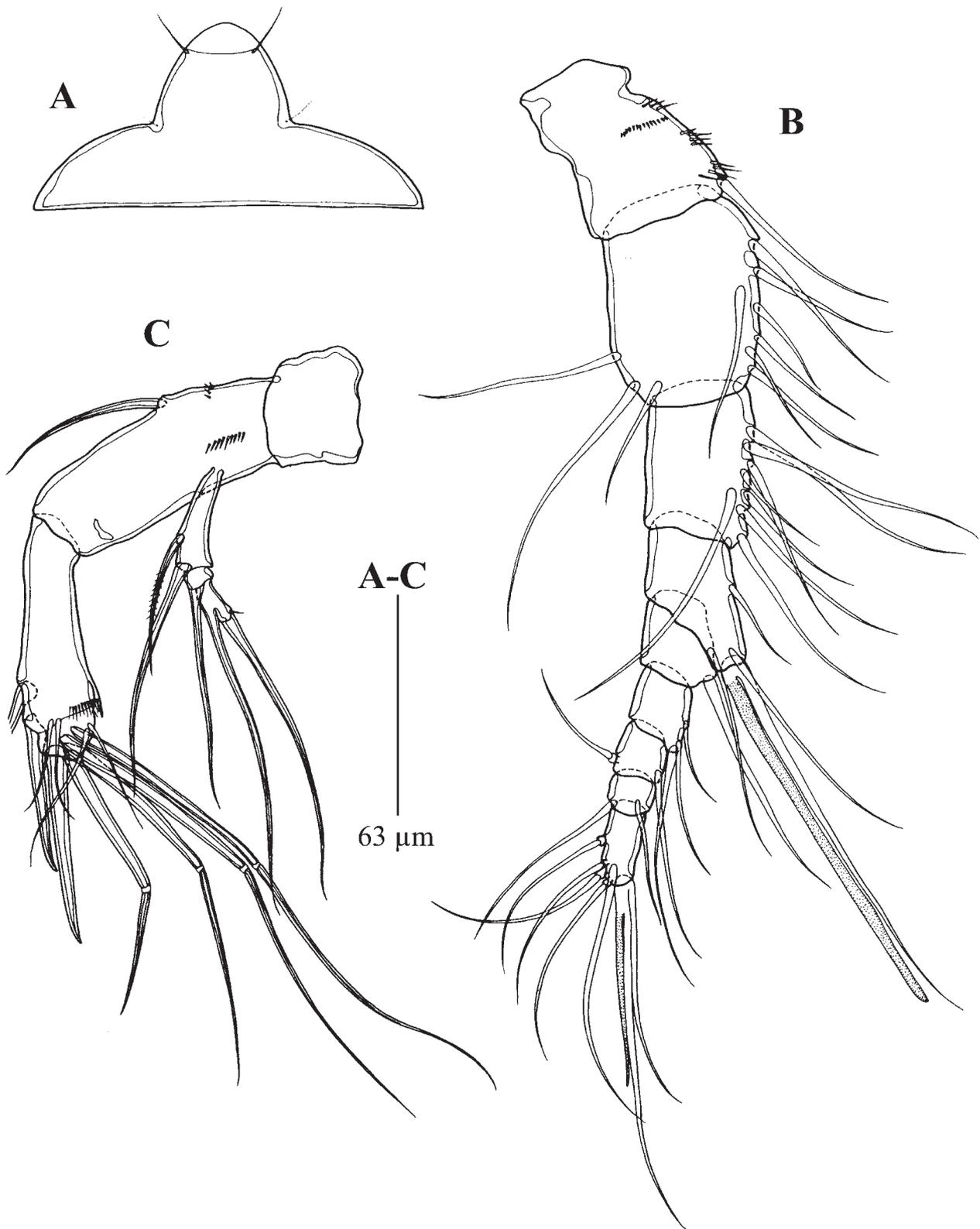
Maxillule (Fig. 13B). Praecoxa with some spinules, arthrite with two slender setae on surface, one slender seta and two plumose, spine-like outer elements, and five smooth, sharp apical spines. Coxa with cylindrical endite furnished with four smooth setae. Basis ornamented with four setae distally. Endopod 1-segmented with three smooth setae. Exopod 1-segmented, with one bipinnate spine and four smooth setae.

Maxilla (Fig. 13C) ornamented with row of spinules distally on outer margin and row of spinules on surface of syncoxa. Syncoxa with three endites (one praecoxal and two coxal); praecoxal endite bilobed, each lobe with two plumose distal setae; two coxal endites each with three spinulose distal setae. Basis furnished with one naked inner seta on a unipinnate strong claw and one plumose seta. Endopod 1-segmented with four slender setae and one plumose seta near base of claw.

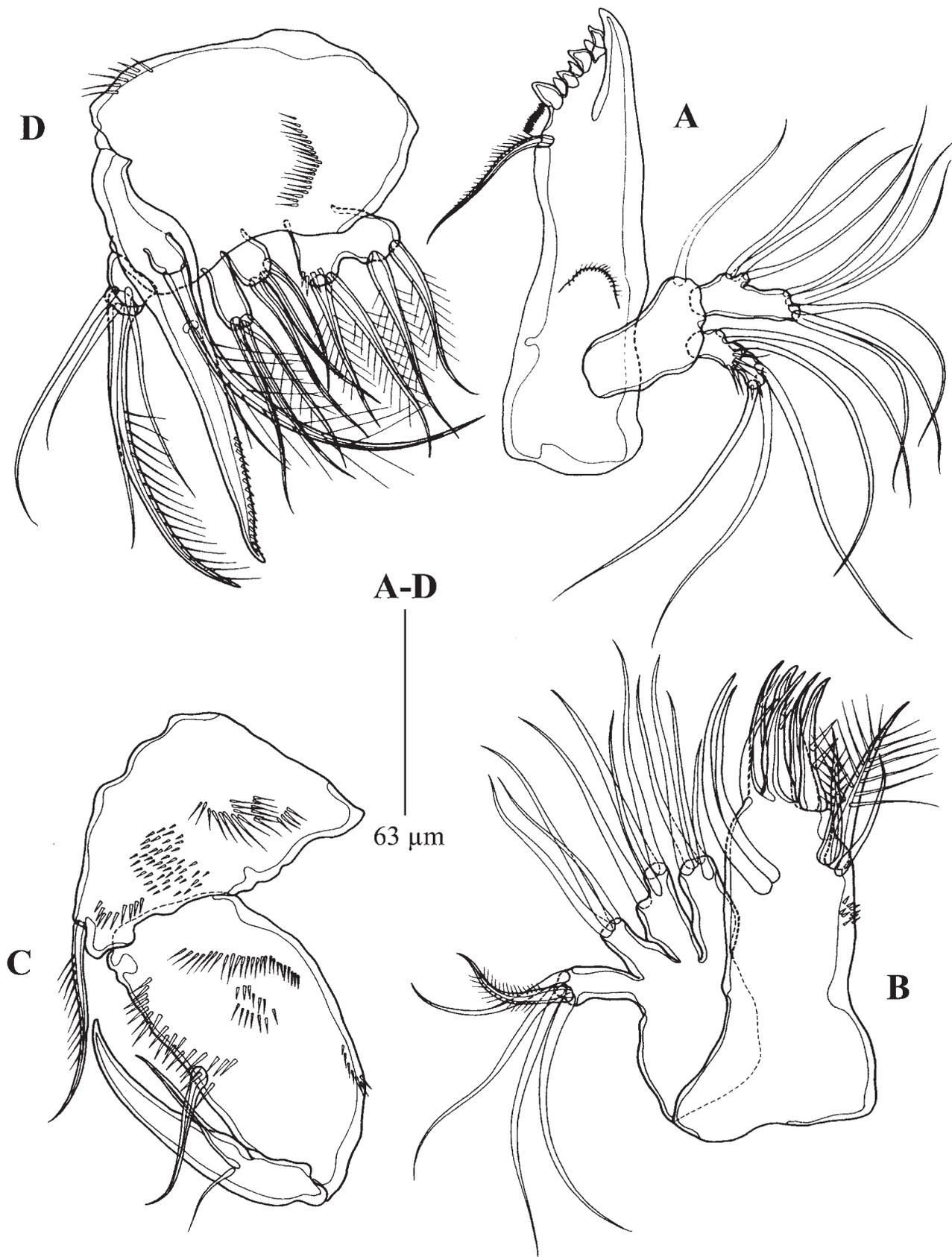
Maxilliped (Fig. 13D) comprising syncoxa, basis, and 1-segmented endopod. Syncoxa with one unipinnate seta at inner distal corner, and many spinular rows of various length on anterior surface. Basis with rows of spinules on

anterior surface and along outer margin, with some minute spinules at outer margin, and with median smooth inner seta near halfway palmar margin. Endopod represented by long smooth curved claw, almost as long as basis, and with one conical process bearing one lateral and one apical seta.

All swimming legs (Figs. 14A–B; 15A–B) biramous, P1–P4 with 3-segmented exopods and endopods. Members of each leg pair connected by simple narrow intercoxal sclerite.



**FIGURE 12.** *Tigriopus wannapaensis* sp. nov. (♀): (A) rostrum, dorsal; (B) right antennule, anterior; (C) left antenna, anterior.



**FIGURE 13.** *Tigriopus wannapaensis* sp. nov. (♀): (A) mandible, anterior; (B) maxillule, anterior; (C) maxilla, anterior; (D) maxilliped, anterior.

P1 (Fig. 14A). Praecoxa with row of spinules on anterior surface along distal margin. Coxa rectangular, ornamented with row of spinules along outer margin. Basis with one pinnate inner spine and one smooth outer spine, with two rows of spinules on anterior surface. Endopod much shorter than exopod, both 3-segmented. Enp-1 much longer than enp-2 and enp-3 combined, with one plumose inner seta; enp-2 shorter than last segment, unarmed; enp-3 with one strong smooth outwardly curved claw and two slender inner setae. Both exp-1 and exp-2 long, exp-3 short. Exp-1 with one smooth outer seta; exp-2 with one smooth outer seta at two-thirds of outer margin, and one pinnate inner seta; exp-3 with three smooth, outwardly curved, distal spines and one inner seta.

P2 (Fig. 14B). Praecoxa small and smooth. Coxa ornamented with spinular rows of unequal length on anterior surface, and row of spinules along outer margin. Basis with one bipinnate outer spine. Endopod 3-segmented; enp-1 and enp-2 each with one plumose inner seta; enp-3 with one smooth outer spine, four plumose setae (two median and two inner). Exopod 3-segmented; exp-1 with one bipinnate outer spine and one plumose inner seta; exp-2 with one smooth outer spine and one plumose inner seta; exp-3 with three smooth outer spines, two plumose distal setae and two plumose inner setae.

P3 (Fig. 15A). Coxa ornamented with spinular rows of unequal length on anterior surface, and row of spinules along outer margin. Basis with row of spinules on surface, and some spinules at base of slender outer seta. Endopod 3-segmented; enp-1 and enp-2 each with one plumose inner seta; enp-3 with one smooth outer spine, two plumose distal setae and one plumose inner seta. Exopod 3-segmented; exp-1 and exp-2 each with one bipinnate outer spine and one plumose inner seta; exp-3 with three outer bipinnate spines, two plumose distal setae, and two plumose inner setae.

P4 (Fig. 15B). Praecoxa small and smooth. Coxa with row of spinules along outer margin. Basis with some spinules at base of slender outer seta. Endopod 3-segmented; enp-1 with one plumose inner seta; enp-2 unarmed; enp-3 with one smooth outer spine, three plumose setae (two distal and one inner). Exopod 3-segmented; exp-1 and exp-2 each with one bipinnate outer spine and one plumose inner seta; exp-3 with three bipinnate outer spines, two plumose distal setae, and two plumose inner setae.

Armature formula of swimming legs as follows (Arabic numbers represent setae, Roman numbers represent spines):

	Basis	Exopod	Endopod
P1	I-I	I-0; I-1; I.II.I	0-1; 0-0; I,1,1
P2	I-0	I-1; I-1; III,2,2	0-1; 0-1; I,2,2
P3	1-0	I-1; I-1; III,2,2	0-1; 0-1; I,2,1
P4	1-0	I-1; I-1; III,2,2	0-1; 0-0; I,2,1

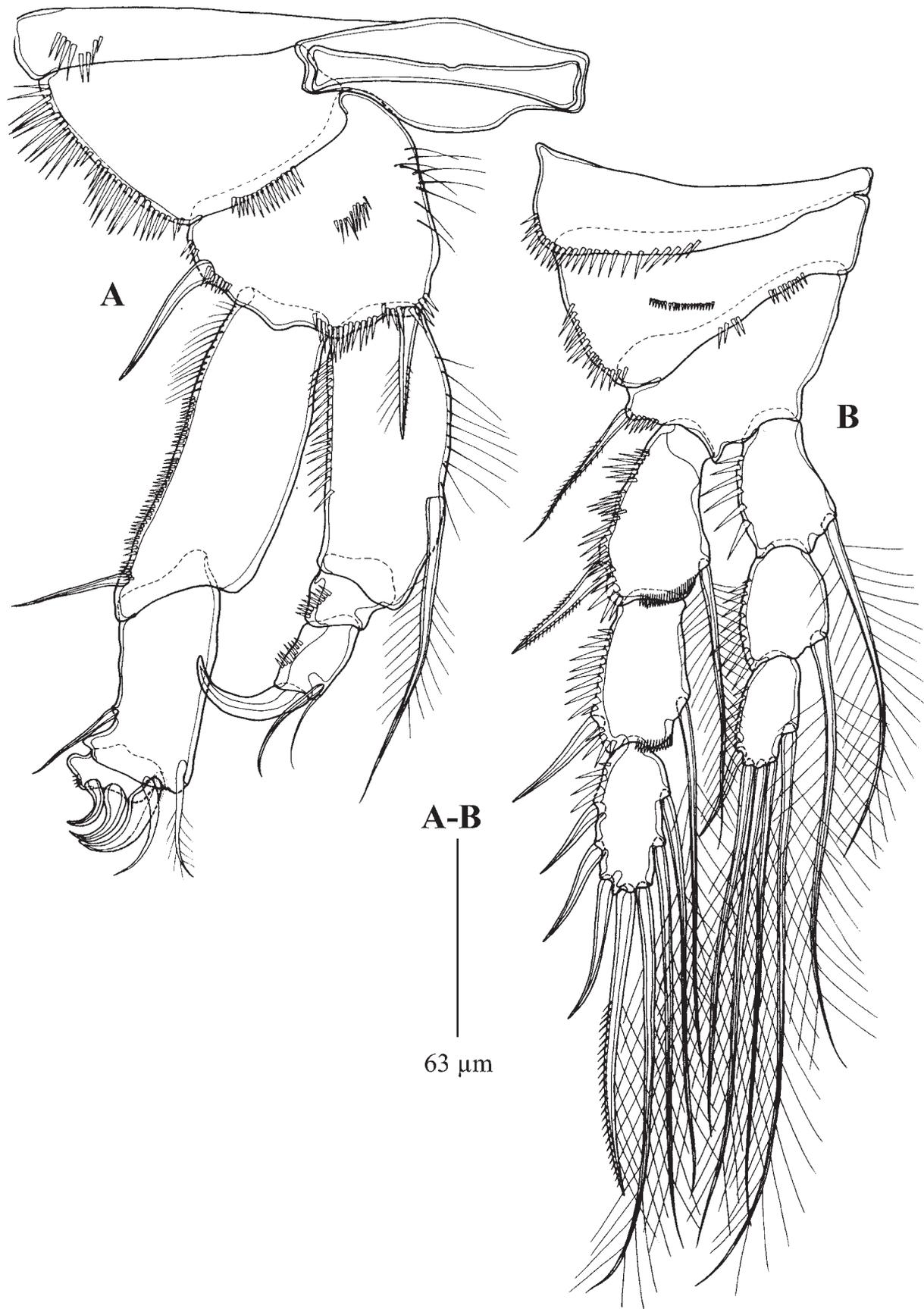
P5 (Fig. 17B) with separate exopod and baseoendopod; with spinular row along outer margin; without intercoxal sclerite and not fused medially. Exopod ovoid with smooth (innermost) seta and four bipinnate outer setae of unequal length, second outermost longest. Baseoendopod with long and smooth outer basal seta, with five bipinnate setae, second outermost longest.

**Description of male.** Total body length of allotype (Fig. 16A–B) 902  $\mu\text{m}$ . Total body length of paratypes 796–929  $\mu\text{m}$  ( $n = 12$ , mean = 874  $\mu\text{m}$ ). General body shape and size similar to those of female. Sexual dimorphism expressed in antennule, antenna, P2, P5, P6 and urosomal segmentation and ornamentation.

Urosome (Fig. 18A) 6-segmented, comprising P5-bearing somite, genital somite, three abdominal somites and anal somite. Third to sixth urosomites furnished with small spinules along ventral posterior margin. Ornamentation different from female.

Antennule (Fig. 17A) subchirocer, 8-segmented with smooth setae. First segment with small spinules on anterior inner surface, fourth segment shortest, fifth segment largest, globularly expanded, with one seta and long aesthetasc, sixth segment forming claw-like outer process, seventh segment with six setae (two short and four longer) and acrothek. Armature formula: 1-(1), 2-(1), 3-(11), 4-(6), 5-(2), 6-(8 + (1 + ae)), 7-(0), 8-(7 + acrothek). Apical acrothek consisting of basally fused aesthetasc and naked seta.

P2 (Fig. 18B). Basis with one smooth outer seta. Endopod 3-segmented and modified; enp-2 with spinulose outer seta twice as long as enp-3 and distinct spiniform outer apophysis; enp-3 small, with minute, smooth, outer spine, two spinulose distal setae, and one smooth inner seta. Exopod 3-segmented; exp-1 with one smooth outer spine and one plumose inner seta; exp-2 with one bipinnate outer spine and one plumose inner seta; exp-3 with three outer spines (two bipinnate and one smooth), two plumose distal setae and two plumose inner setae.



**FIGURE 14.** *Tigriopus wannapaensis* sp. nov. (♀): (A) P1, anterior; (B) P2, anterior.

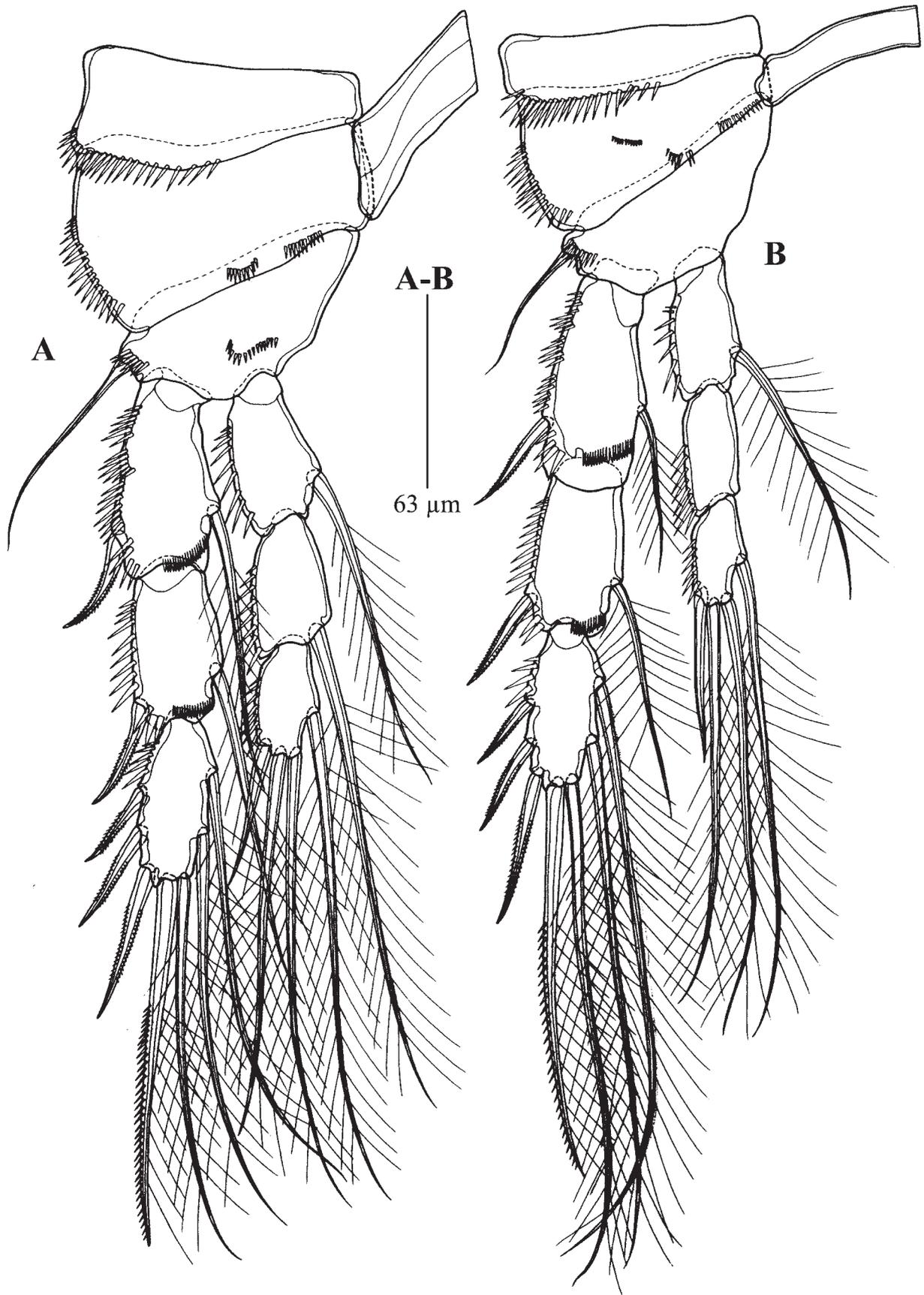
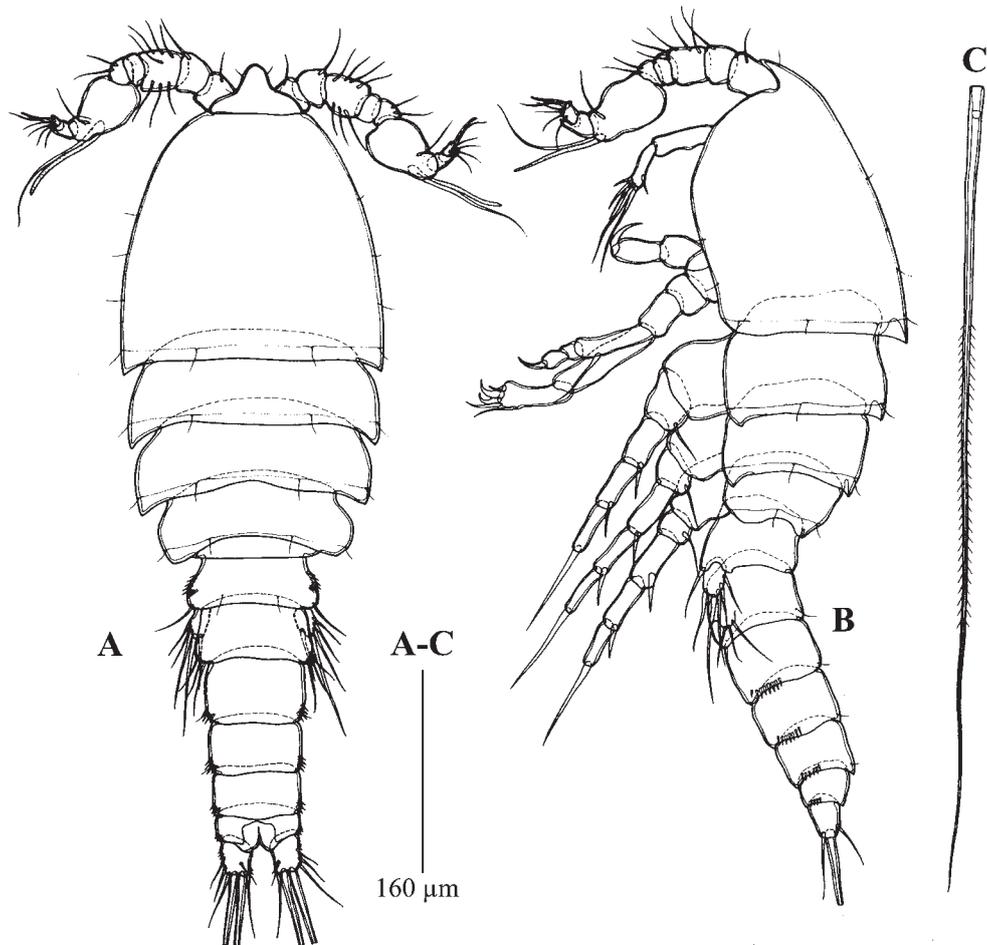
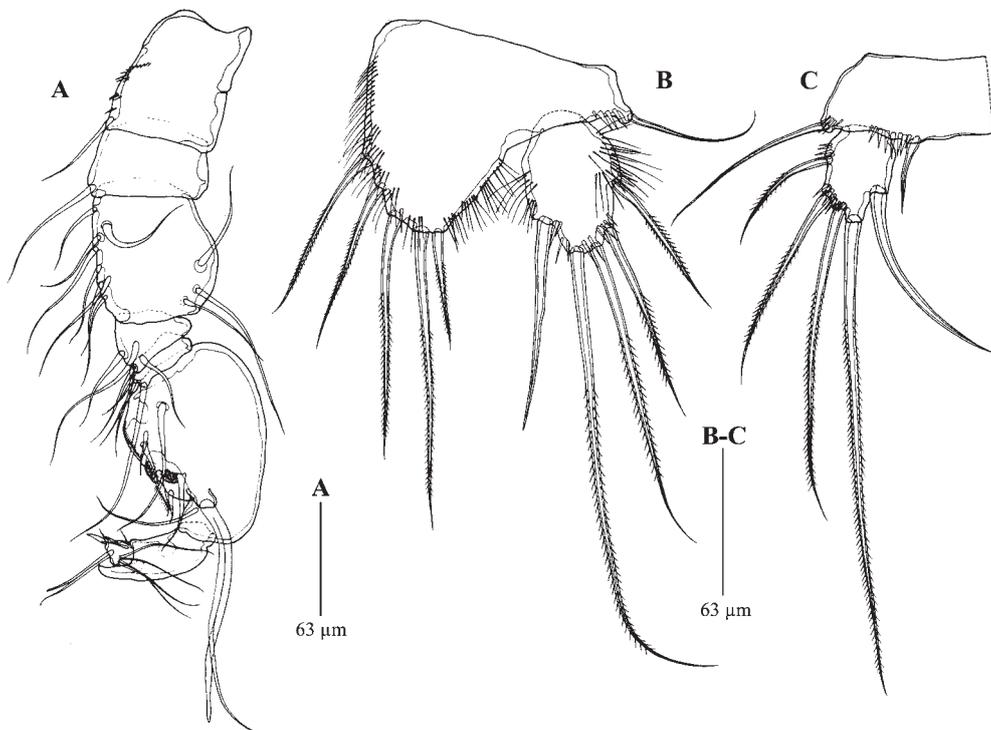


FIGURE 15. *Tigriopus wannapaensis* sp. nov. (♀): (A) P3, anterior; (B) P4, anterior.



**FIGURE 16.** *Tigriopus wannapaensis* sp. nov. (♂): (A) allotype, habitus, dorsal; (B) allotype, habitus, lateral; (C) caudal ramus seta V.



**FIGURE 17.** *Tigriopus wannapaensis* sp. nov. (♂): (A) right antennule, anterior; (B) P5, female, anterior; (C) P5, male, anterior.

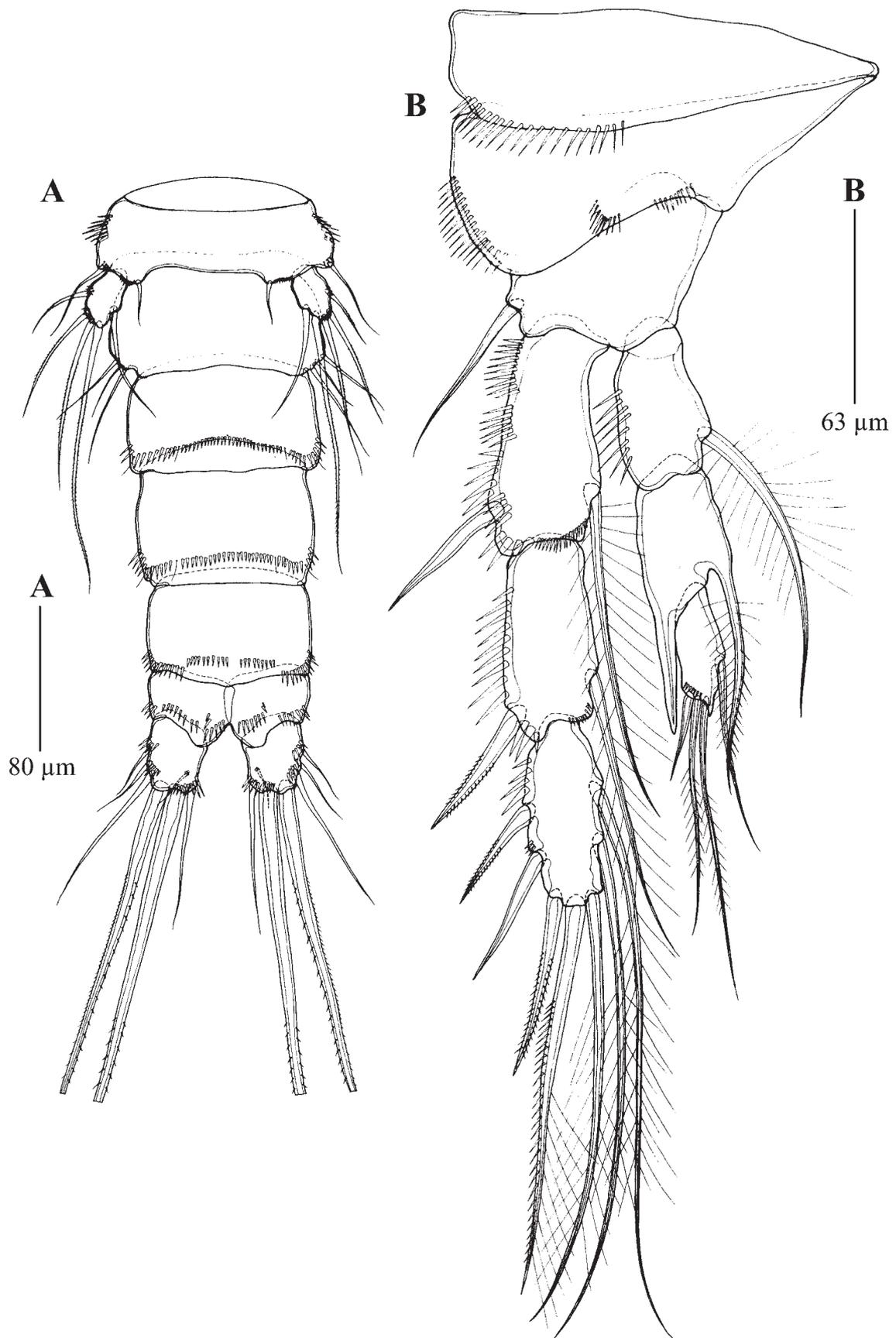


FIGURE 18. *Tigriopus wannapaensis* sp. nov. (♂): (A) urosome, with P6 on both lateral sides; (B) P2, anterior.

P5 (Figs. 17C) baseoendopod bearing one smooth basal outer seta, and one smooth inner seta. Exopod oval shaped, armed with five setae of unequal length, four of which bipinnate and innermost smooth.

P6 (Fig. 18A) represented by three smooth setae unequal length.

## Discussion

Wells (2007) emphasized that taxonomically important characters of all species of *Tigriopus* should be carefully re-examined. Such characters include the rostrum (with two pairs of sensilla) and the armature and ornamentation of the antennules, antennae, mouthparts, swimming legs and urosomites. Comprehensive analyses of closely related species based on morphological characters including minor features have been presented by Božić (1960: *T. brevicornis*, *T. fulvus* and *T. minutus*), Bradford (1967: *T. angulatus* and *T. californicus*), Carli & Fiori (1977: *T. brevicornis* and *T. fulvus*) and Itô (1988: *T. californicus* and *T. japonicus*). Recently, Park *et al.* (2014) provided a morphological comparison of 13 representatives of *Tigriopus* which greatly facilitates the identification of species in the genus.

The present two new species can be assigned with confidence to the genus *Tigriopus* based on the following suite of characters shared with their known congeners: (1) body compact, cycloform; (2) rostrum with two pairs of sensilla; (3) 9-segmented antennule in female; (4) antennary exopod 3-segmented; (5) absence of abexopodal seta on antennary allobasis in male; (6) male P2 enp-2 with distinct spiniform outer apophysis; and (7) P4 enp-2 without inner seta.

*Tigriopus namsaiensis* **sp. nov.** shows unique morphological characters which are not displayed by any of its congeners: (1) first segment of female antennule ornamented with more elaborate spinule pattern; (2) antennary allobasis with smooth abexopodal seta, exopod with five bipinnate setae in female; (3) coxa of mandible without ornamentation on anterior surface; (4) maxillule without ornamentation on praecoxal surface; (5) syncoxal endites of maxilla without ornamentation on surface; (6) basis of maxilliped with one bipinnate inner seta; (7) P3 with one small pore on anterior surface of enp-1; (8) P4 with one small pore on anterior surfaces of exp-2 and exp-3; and (9) female P5 baseoendopod with five bipinnate setae.

*Tigriopus wannapaensis* **sp. nov.** can be differentiated from other *Tigriopus* species by following combination of characters: (1) first segment of female antennule ornamented with only a few spinules; (2) antennary allobasis with smooth abexopodal seta, exopod with one bipinnate and four smooth setae in female; (3) coxa of mandible with curved row of small spinules on anterior surface; (4) maxillule with some spinules on praecoxal surface proximally; (5) syncoxa of maxilla with surface row of spinules; (6) basis of maxilliped with one smooth inner seta; (7) P3 enp-1 without pore on anterior surface; (8) P4 without pore on anterior surface of exp-2 and exp-3; and (9) P5 baseoendopod in female with five bipinnate setae.

*Tigriopus namsaiensis* **sp. nov.** differs from *T. wannapaensis* **sp. nov.** as follows: the former shows aesthetascs on the fifth and seventh segments of the male antennule; all setae on the antennary exopod are bipinnate in the female; the mandible displays a 3-segmented exopod; the maxillary exopod possesses three smooth setae; P3 enp-1 has one small pore on its anterior surface; P4 exp-2 and exp-3 both have one small pore on the anterior surface; the female P6 bears three normal setae, of which the outer one is plumose; the caudal ramus lacks setules on the inner surface; the proximal seta on exp-1 of the male antenna is much shorter than the second one; and the two outermost setae of the male P5 exopod are subequal in length, the longest distal seta extending far beyond the first abdominal somite. Conversely, *T. wannapaensis* **sp. nov.** shows aesthetascs on the sixth and eighth segments of the male antennule; the antennary exopod bears one bipinnate and four naked setae, the proximal one being very small; the mandibular exopod is 2-segmented; the maxillary exopod bears five setae; P3 enp-1 and P4 exp-2-3 lack a pore on the anterior surface; the female P6 bears three setae, of which the inner one is very long; the caudal ramus displays setules on the inner surface; the outermost seta of the male P5 exopod is much shorter than the second one, the longest distal seta extending far beyond of second abdominal somite.

The two new species from Thailand are easily distinguished from the other three austral species, *i.e.* *T. kerguelenensis* and *T. crozettensis* from the Kerguelen Islands and the Crozet Islands in the South Indian Ocean (Soyer *et al.* 1987), and *T. kingsejongensis* from King George Island, Antarctica (Park *et al.* 2014), all of which have a knob-like structure on the outer margin of male P2 enp-2 and have three inner setae on P4 exp-3. As pointed out by Park *et al.* (2014), these three species also have a ‘crescent shape’ between the first and second innermost seta

of the female P5 exopod. Our two new species are distinguishable from *T. brachydactylus* collected from Praia das Conchas of Namibe, Angola (Candeias 1959) by the presence of two lateral setae on antenna exp-2 and four setae on the P5 exopod of both sexes.

*Tigriopus namsaiensis* **sp. nov.** and *T. wannapaensis* **sp. nov.** are closely related to *T. thailandensis* and *T. sirindhornae* since they share the following characters: fewer sensilla on prosome; exp-2 of antenna with one seta; maxilliped with spinules on outer margin; P4 exp-3 with two inner setae; female P5 baseoendopod with five setae; male P2 enp-2 with the seta fused to the segment and without outer knob-like structure; male P2 apophysis with sharp tip; and male P5 exopod with five setae.

As shown in Table 1 and indicated in the key to the species below, *T. namsaiensis* **sp. nov.** closely resembles *T. thailandensis*, however the former is characterized by lateral seta on antenna exp-3 being discrete at base (*vs* fused to the segment), four setae on the maxillulary coxal endite (*vs* three), male P5 exopod with a outermost seta being plumose (*vs* spinulose), and female P6 with outer plumose seta and two bare (middle and inner) setae (*vs* middle plumose seta, one bare and one pinnate seta).

*Tigriopus wannapaensis* **sp. nov.** is very closely related to *T. sirindhornae* as presented in Table 1, the new species is different from the latter by the following characteristics: 2-segmented mandibular exopod (3-segmented in *T. sirindhornae*); five setae on the maxillulary coxa (*vs* three), all setae on female P6 plumose (*vs* two plumose and one pinnate), lateral seta on antenna exp-3 fused to segment (*vs* discrete at base), and male P5 exopod with outermost seta being plumose (*vs* spinulose).

*Tigriopus* species are known to show different segmentation patterns in the mandibular exopod. A one-segmented exopod has been reported for eight species: *T. angulatus*, *T. californicus*, *T. crozettensis*, *T. igai*, *T. kerguelensis*, *T. kingsejongensis*, *T. minutus* and *T. raki*. The two-segmented condition has been documented for five species: *T. brachydactylus*, *T. brevicornis*, *T. fulvus*, *T. japonicus* and *T. wannapaensis* **sp. nov.** Finally, three species are known to display a three-segmented exopod: *T. namsaiensis* **sp. nov.**, *T. sirindhornae* and *T. thailandensis*. Interestingly, all *Tigriopus* species from the Gulf of Thailand, except for *T. wannapaensis* **sp. nov.**, exhibit a 3-segmented mandibular exopod. The mandibular endopod has three lateral and six distal setae in *T. namsaiensis* **sp. nov.** and *T. sirindhornae*, while *T. thailandensis* has three lateral and seven distal setae.

## Key to species of the genus *Tigriopus* Norman, 1869

1. Antennary exp-2 with two setae . . . . . *T. brachydactylus*.
- Antennary exp-2 with one seta . . . . . 2.
2. P4 exp-3 with two inner setae . . . . . 3.
- P4 exp-3 with three inner setae . . . . . 7.
3. Male P2 enp-2 inner seta discrete at base. . . . . *T. japonicus*.
- Male P2 enp-2 inner seta fused to segment . . . . . 4.
4. Anal operculum with fine hairs . . . . . *T. californicus*.
- Anal operculum naked . . . . . 5.
5. Innermost seta of female P6 not extending to posterior margin of genital double-somite; mandible with 3-segmented exopod; exopod of maxillule with three setae . . . . . 6.
- Innermost seta of female P6 extending far beyond posterior margin of genital double-somite; mandible with 2-segmented exopod; exopod of maxillule with five setae . . . . . *T. wannapaensis* **sp. nov.**
- Innermost seta of female P6 extending far beyond posterior margin of genital double-somite; mandible with 3-segmented exopod; exopod of maxillule with three setae . . . . . *T. sirindhornae*.
6. Female P6 with outermost plumose seta and two bare setae; maxillulary coxa with four setae . . . . . *T. namsaiensis* **sp. nov.**
- Female P6 with middle plumose seta, one bare, and one pinnate seta; maxillulary coxa with three setae . . . . . *T. thailandensis*.
7. Female P5 endopod with four setae . . . . . 8.
- Female P5 endopod with five setae . . . . . 10.
8. Mandibular basis with one seta; maxillipedal claw prehensile and well-developed . . . . . *T. raki*.
- Mandibular basis with two setae; maxillipedal claw reduced in length. . . . . 9.
9. Male P5 endopod with one seta . . . . . *T. minutus*.
- Male P5 endopod unarmed. . . . . *T. igai*.
10. Knob on male P2 enp-2 outer margin present . . . . . 11.
- Knob on male P2 enp-2 outer margin absent . . . . . 12.
11. Anal operculum with crenate margin; male P5 exopod with five setae . . . . . *T. kingsejongensis*.
- Anal operculum with many fine hairs; P5 exopod with four setae . . . . . *T. angulatus*.
12. Mandible with 1-segmented exopod; crescent shape between 1<sup>st</sup> and 2<sup>nd</sup> innermost seta on female P5 exopod present . . . . 13.
- Mandible with 2-segmented exopod; crescent shape between 1<sup>st</sup> and 2<sup>nd</sup> innermost seta on female P5 exopod absent . . . . 14.

**TABLE 1.** Morphological characters of the *Tigriopus* species recorded from Thailand.

	<i>T. namaiensis</i> sp. nov.	<i>T. thailandensis</i>	<i>T. wannapaensis</i> sp. nov.	<i>T. sirindhornae</i>
antennary coxa	longer than in <i>T. thailandensis</i>	small	longer than in <i>T. thailandensis</i>	longer than in <i>T. thailandensis</i>
antennary basis distal surface	no ornamentation	two setular rows	no ornamentation	one setular row
antenna exp-3 lateral seta	discrete at base	fused to segment	fused to segment	s discrete at base
mandibular praecoxa	no ornamentation	one setular row	one setular row	four setular rows
maxillulary coxal endite	four setae	three setae	four setae	five setae
P1 coxa	no ornamentation	one setular row	no ornamentation	no ornamentation
P2 & P4 basis	one setular row	no ornamentation	no ornamentation	no ornamentation
P6 ♀ armature	outermost one plumose + two bare	middle one plumose + two bare	all setae plumose	two plumose + one pinnate
P5 exp ♂: longest seta extending to	end of 1st abdominal somite	end of 2 <sup>nd</sup> abdominal somite	end of 2 <sup>nd</sup> abdominal somite	2/3 of 3 <sup>rd</sup> abdominal somite
P5 exp ♂: innermost seta extending to	end of genital somite	proximal 1/5 of 1 <sup>st</sup> abdominal somite	middle of 1 <sup>st</sup> abdominal somite	middle of genital somite
P5 exp ♂: length ratio of 1 <sup>st</sup> innermost seta to 2 <sup>nd</sup> one	3.1	2.1	2.2	2.0
P5 exp ♂: outermost seta	plumose	spinulose	bipinnate	smooth

13. Female P5 exopod reaching to distal margin of baseopod (with setules on inner margin), male antennary allobasis with tiny abexopodal seta ..... *T. kerguelensis*.  
 - Female P5 exopod not reaching to distal margin of baseopod (without setules on inner margin), male antennary allobasis without abexopodal seta ..... *T. crozetensis*.
14. Surfaces of antennary allobasis and P5 exopod in female with tuft of hairs ..... *T. fulvus*.  
 - Surfaces of antennary allobasis and P5 exopod in female without tuft of hairs ..... *T. brevicornis*.

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