

## Two new species of the genus *Heteropsyllus* (Crustacea, Copepoda, Harpacticoida) from Jeju Island, Korea and Devon, England

EUN-JUNG NAM & WONCHOEL LEE

Biodiversity Laboratory, Department of Life Science, College of Natural Science, Hanyang University, Seoul, Korea

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### Abstract

During a study of the harpacticoid copepods from off Jeju Island, in the South Sea of Korea, a new species of the genus *Heteropsyllus* was discovered. *Heteropsyllus coreanus* sp. nov. differs from its congeners in the following combination of characters: a pointed apex of rostrum; areolated ornamentation of the cephalothorax; a single basal seta on the maxillule and the shape of the fifth thoracopod in the female. This is the first record of the genus *Heteropsyllus* from Asia. The second new species is described from specimens in the Norman collection in the Natural History Museum, London (NHM). *Heteropsyllus celticus* sp. nov. was originally identified as *H. curticaudatus* by Norman, however this new species is distinguishable from *H. curticaudatus* T. Scott (1894) by having reticulated ornamentation on the cephalothorax, a strong seta on the proximal endite of the maxilla, only one seta on the exopod of the mandibular palp, and a different armature formula of the swimming legs. This study reveals that the mouthpart structures of *Heteropsyllus* can be important in identifying the species of this genus, and should be re-examined in all other species of *Heteropsyllus*.

**Keywords:** *Canthocamptidae*, *Celtic Sea*, *Copepoda*, *Harpacticoida*, *Heteropsyllus*, *Korea*, *new species*

### Introduction

T. Scott (1894) created the genus *Heteropsyllus* in the family Cletodidae to accommodate *H. curticaudatus*, the type species of the genus, and currently the genus includes 12 species and is *incertae sedis* (Bodin 1997). *Heteropsyllus curticaudatus* was first reported from off Musselburgh and Aberdour in Scotland. Since then, *H. curticaudatus* has been reported by Norman and T. Scott (1906), T. Scott (1906), A. Scott (1908), and Lang (1936b). Pesta (1927) also reported the species as *H. curticaudatum* from the North Sea.

Sars (1911) reported *Mesochra exigua* from Norway and put the species in the family Canthocamptidae; Lang (1936b) verified that the species was a synonym of *Heteropsyllus*

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Correspondence: Wonchoel Lee, Biodiversity Laboratory, Department of Life Science, College of Natural Science, Hanyang University, Seoul 133-791, Korea. Email: wlee@hanyang.ac.kr

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*exiguus*. Subsequently, Sars (1920) created the genus *Cletomesochra* to accommodate *C. major*, *C. nana*, and *C. rostrata* in the family Canthocamptidae from Norway, but Lang (1936a, 1936b) showed that the generic name also was a synonym of *Heteropsyllus*. Therefore each species name was changed to *H. major* and *H. nannus* (Lang, 1936b), and *H. rostratus* (Lang, 1936a). Since Lang's monograph (1948), seven species and *incertae sedis* have been added: *H. rostratus similis* Smirnov, 1946, *H. masculus* Kunz, 1971, *H. meridionalis* Soyer, 1975, *H. confluens* Soyer, 1975, *H. nunni* Coull, 1975, and *H. pseudonunni* Coull and Palmer, 1980.

Coull (1975) synonymized *H. dimorphus*, reported by Por (1959), with *H. major*. Recently, Schriever (1983) reported *H. serratus* from the Iceland-Faroe-Ridge and Por (1986) provisionally placed the species in *incertae sedis* of the family Canthocamptidae. Finally, Por (1986) allocated the genus *Heteropsyllus* to a subfamily in the family Canthocamptidae.

Among the samples from off Jeju Island, South Sea of Korea, a species of *Heteropsyllus* was identified as *H. curticaudatus*; however, certain differences were present between the Korean specimen of *H. curticaudatus* and the original description. To confirm the differences, the specimens collected by Norman were borrowed from the Natural History Museum, London (NHM). After a detailed observation, it was revealed that the specimens from NHM were also different from the original *H. curticaudatus* in the characters of the reticulated ornamentations on the cephalic shield, exopod setation and segmentation of mandibular palp, and armature formula of swimming legs.

In this study, two new species, *Heteropsyllus coreanus* sp. nov. from off Jeju Island, South Sea of Korea and *H. celticus* sp. nov. from Norman's collection are described and a key to the species of the genus is presented.

## Materials and methods

The specimens of *Heteropsyllus coreanus* sp. nov. were collected from seven stations off Jeju Island, South Sea of Korea from 24 September to 3 October 2002 (Figure 1).

Sediments were collected by a box corer at each station and five replicates were taken from each box corer. Sediments were subsampled using a 2.7 cm (internal) diameter syringe from the box corer. Three replicates were used for the analysis of meiofauna, one was used for total organic matter (TOM) and sediment analysis, and the last replicate was used for the analysis of heavy metals. Meiofauna was extracted from sediments by Ludox-AM method (Burgess 2001). Harpacticoids were sorted out and counted under a dissecting microscope, and stored in 70% ethanol.

*Heteropsyllus celticus* sp. nov. was originally labelled as *H. curticaudatus* in Norman's collection (1911.11.8.45151–165) of the Natural History Museum, London (NHM). The species was originally collected from Salcombe, Devon, UK in 1875.

Specimens were dissected in lactic acid and mounted on slides using lactophenol as mounting medium. Preparations were sealed with transparent nail varnish. All drawings were made with an Olympus BX51<sup>®</sup> or a Zeiss Axioskop<sup>®</sup> differential interference contrast microscope equipped with a camera lucida. *Heteropsyllus coreanus* sp. nov. was also examined by scanning electron microscopy (SEM; Philips XL30). Specimens were dehydrated through a graded acetone series and dried using a critical-point dryer, the dried specimens were mounted on stubs and coated with gold using an ion sputter.

The descriptive terminology proposed by Huys et al. (1996) was adopted. Abbreviations used in the text and figures are as follows: A1, antennule; A2, antenna; ae, aesthetasc; exp,

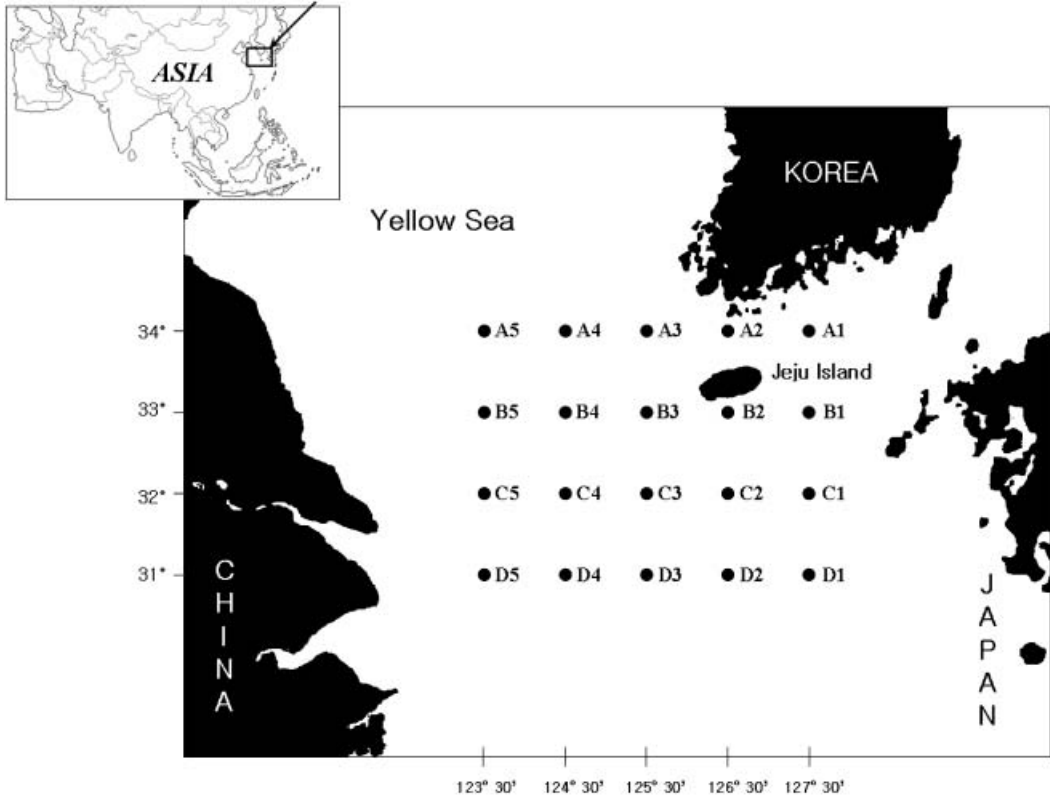


Figure 1. The sampling stations around Jeju Island, the South Sea of Korea.

exopod; enp, endopod; P1–P6, first to sixth thoracopod; exp(enp)-1(2,3) to denote the proximal (middle, distal) segment of a ramus. Type series are deposited in the Natural History Museum, London (NHM).

## Systematics

Family CANTHOCAMPTIDAE Sars, 1906

Genus *Heteropsyllus* T. Scott, 1894

*Heteropsyllus coreanus* sp. nov.

(Figures 2–8)

### *Type locality*

Station A5 (34°N, 123°30'E); off Jeju Island, South Sea of Korea (Figure 1).

### *Material examined*

(1) The Natural History Museum, London. Holotype: 1♀ (NHM 2006-349) dissected on nine slides. Paratypes: 1♀ (NHM 2006-350) dissected on seven slides, 1♂ (NHM 2006-351) dissected on seven slides, 1♂ (NHM 2006-352) dissected on four slides, 5♀♀ and 1♂

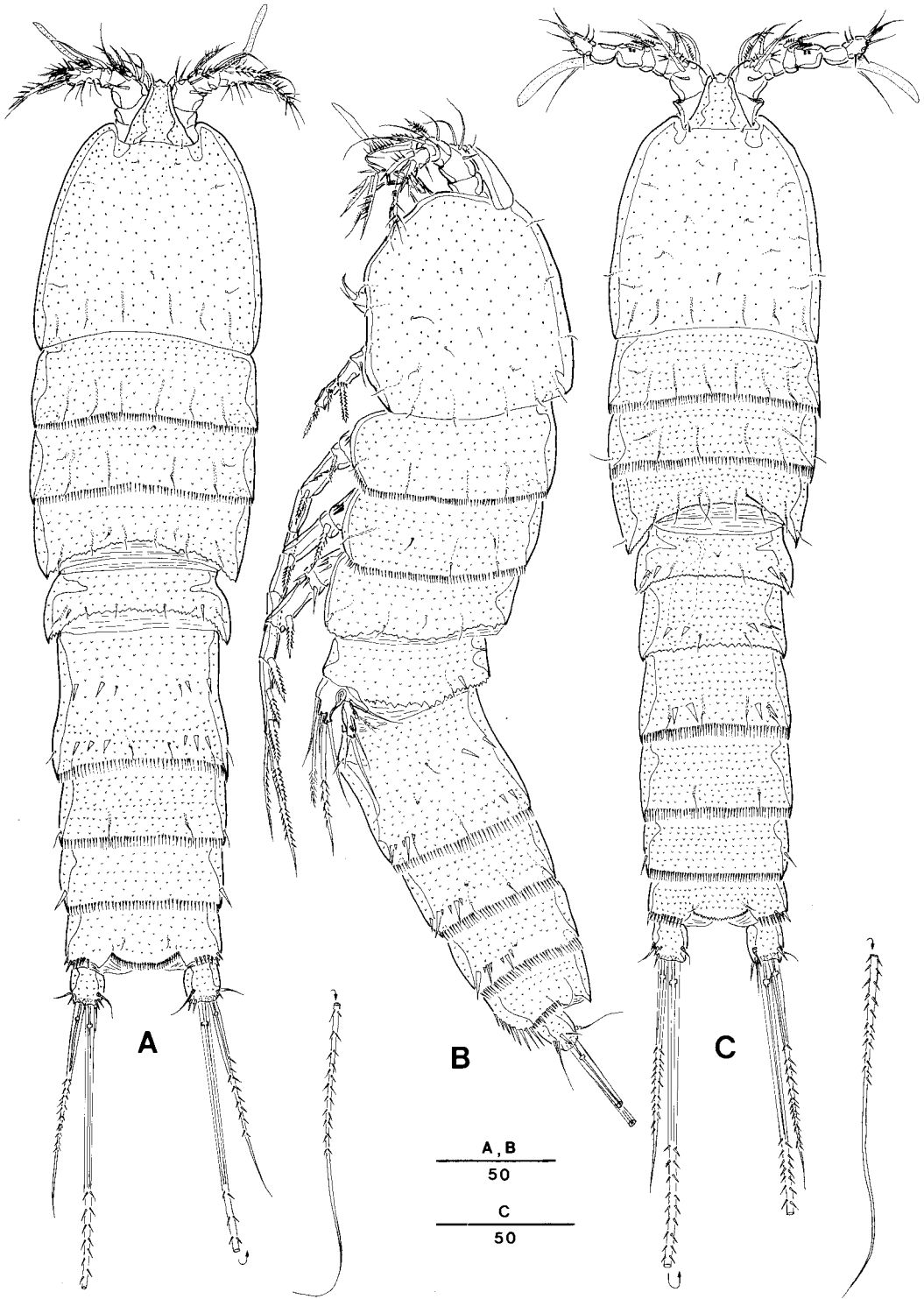


Figure 2. *Heteropsyllus coreanus* sp. nov. (A) Female, habitus, dorsal; (B) female, habitus, lateral; (C) male, habitus, dorsal. Scale bars in  $\mu\text{m}$ .

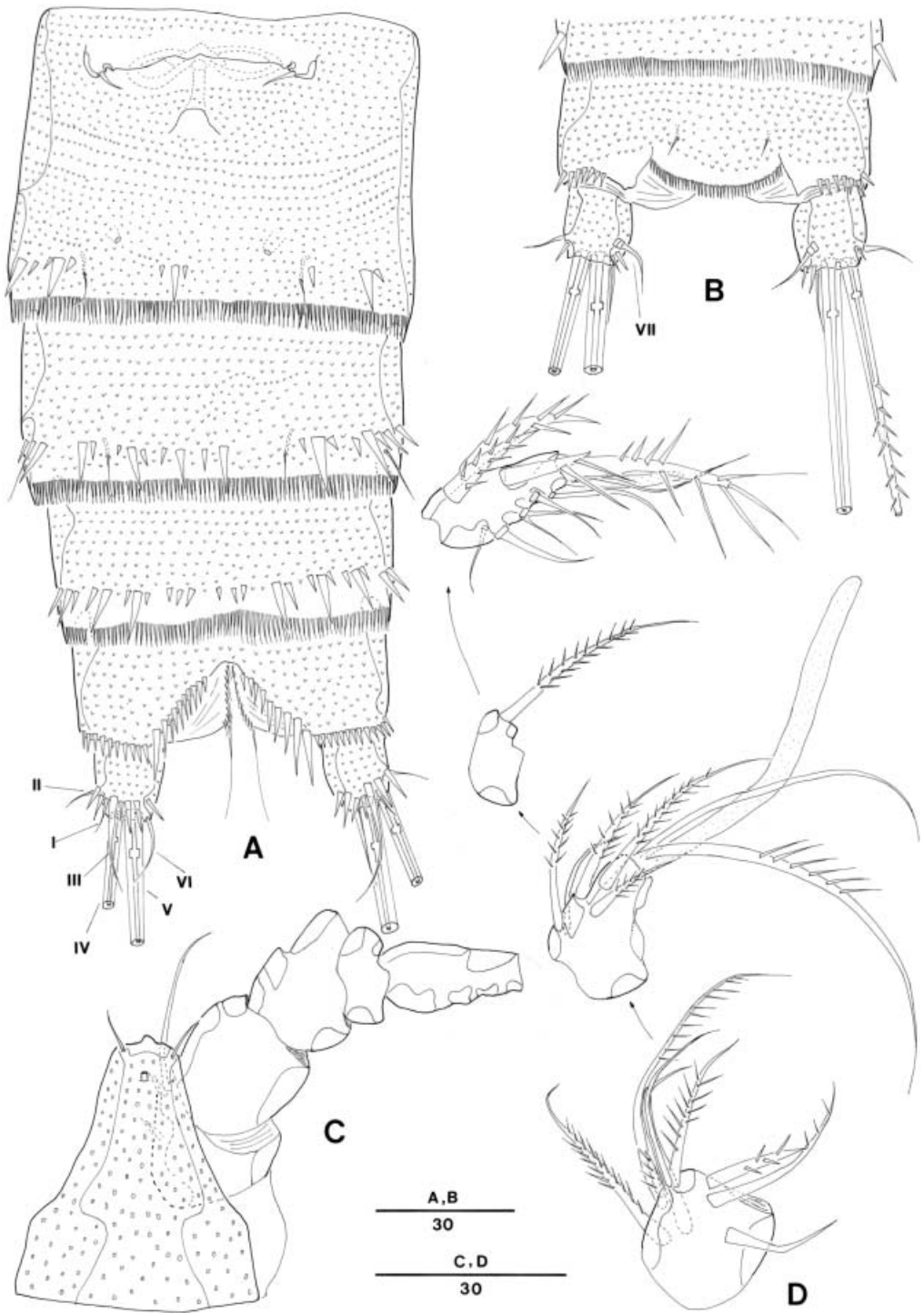


Figure 3. *Heteropsyllus coreanus* sp. nov., female. (A) Urosome (except for somite-bearing P5), ventral; (B) anal somite and caudal rami, dorsal; (C) rostrum and antennule (armature omitted from segments 2–5); (D) antennular segments 2–5. Scale bars in  $\mu\text{m}$ .

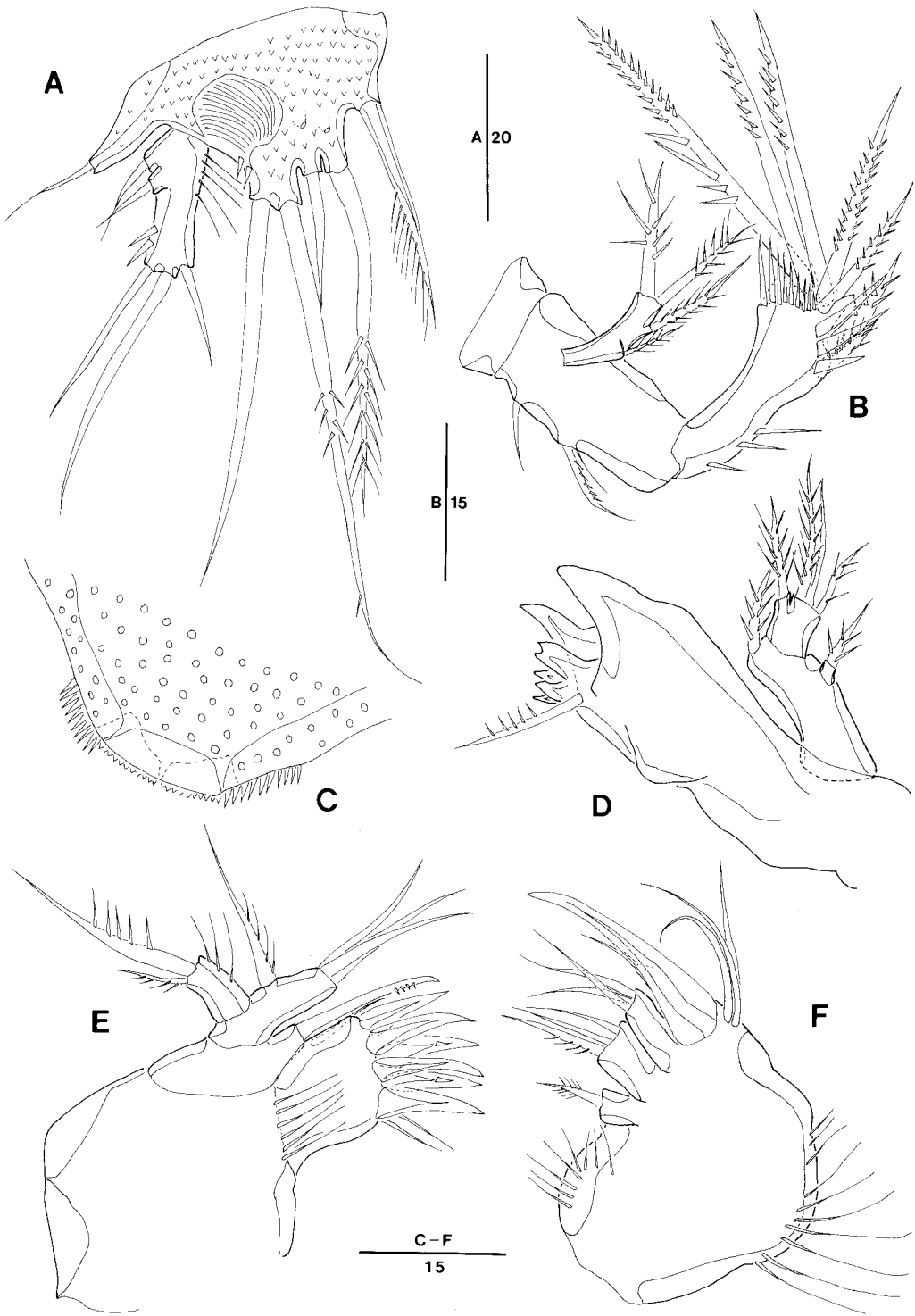


Figure 4. *Heteropsyllus coreanus* sp. nov., female. (A) P5; (B) antenna; (C) labrum; (D) mandible; (E) maxillule; (F) maxilla. Scale bars in  $\mu\text{m}$ .

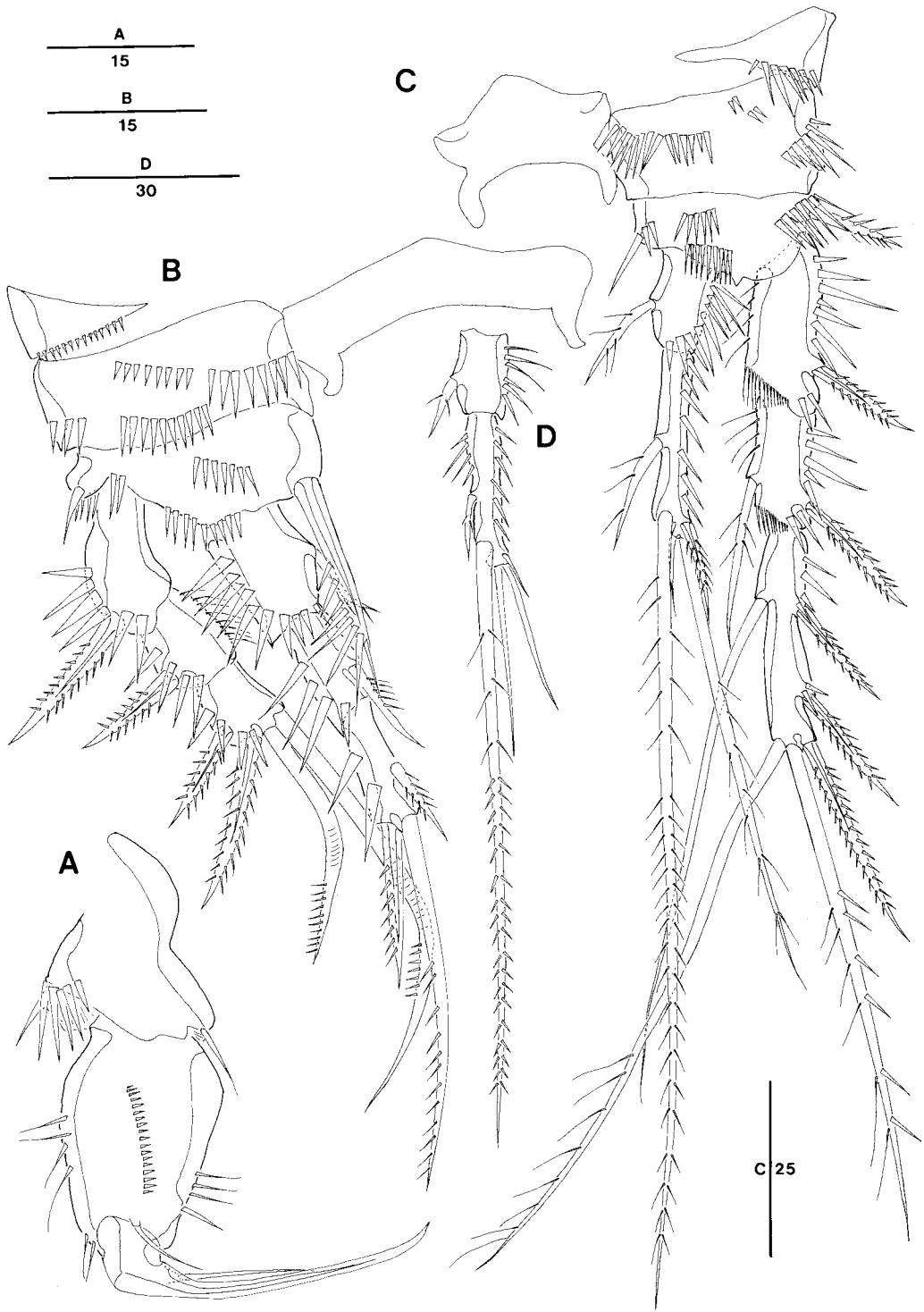


Figure 5. *Heteropsyllus coreanus* sp. nov. (A) Female, maxilliped; (B) female, P1; (C) female, P2; (D) male, P2 enp. Scale bars in  $\mu\text{m}$ .

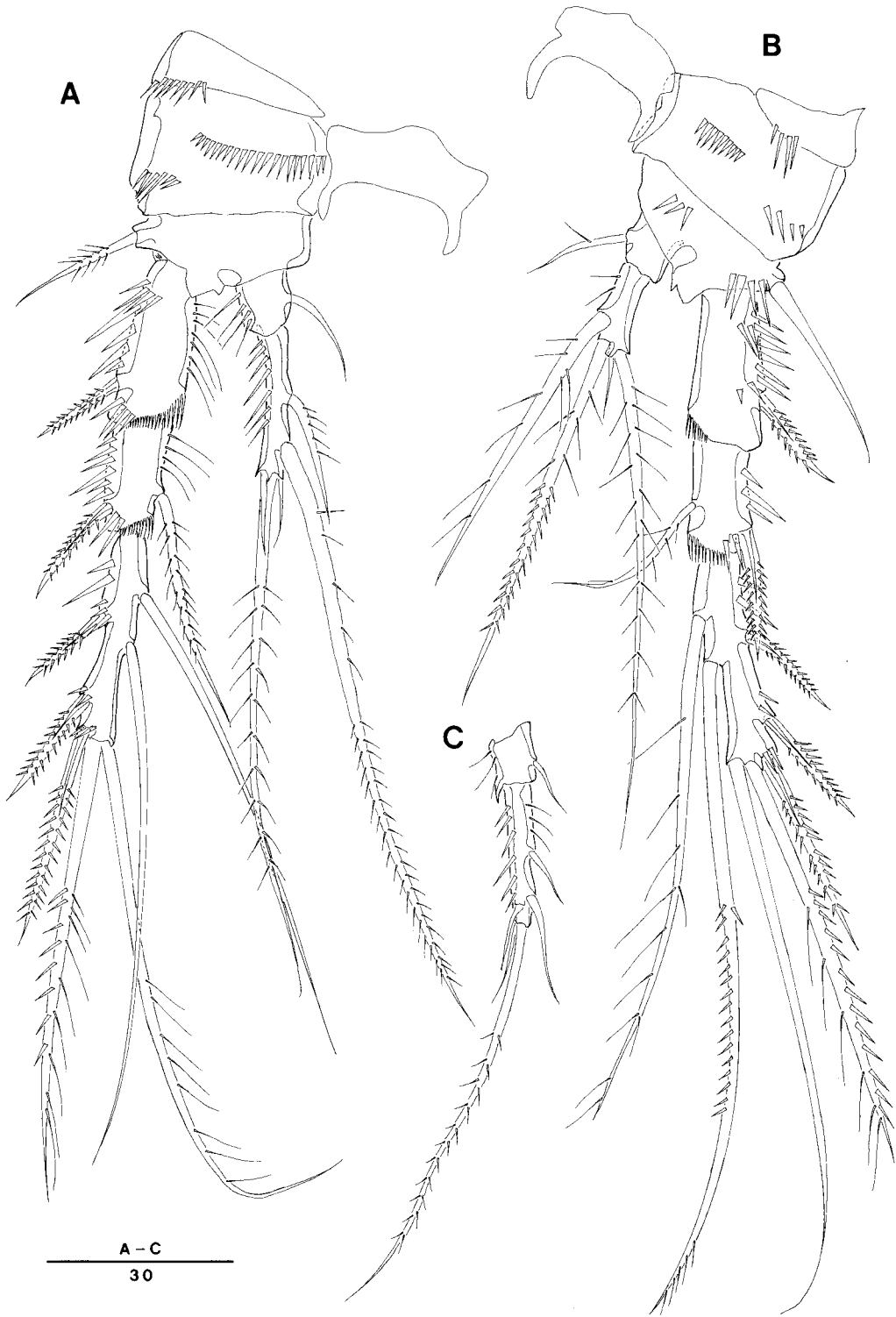


Figure 6. *Heteropsyllus coreanus* sp. nov. (A) Female, P3; (B) female, P4; (C) male, P3 enp. Scale bar in  $\mu\text{m}$ .



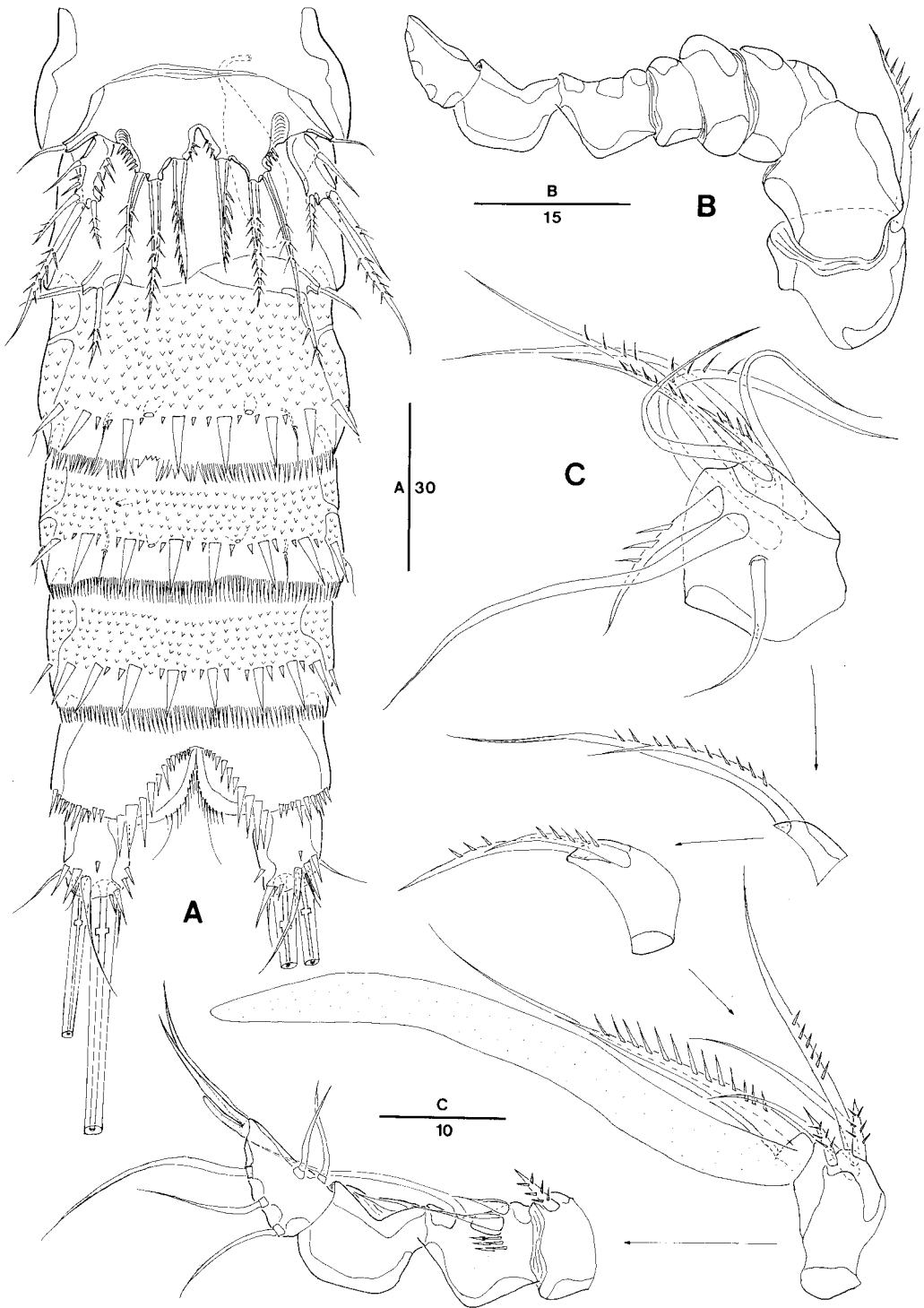


Figure 7. *Heteropsyllus coreanus* sp. nov., male. (A) Urosome, ventral; (B) antennule (armature omitted from segments 2–9); (C) antennular segments 2–9. Scale bars in  $\mu\text{m}$ .

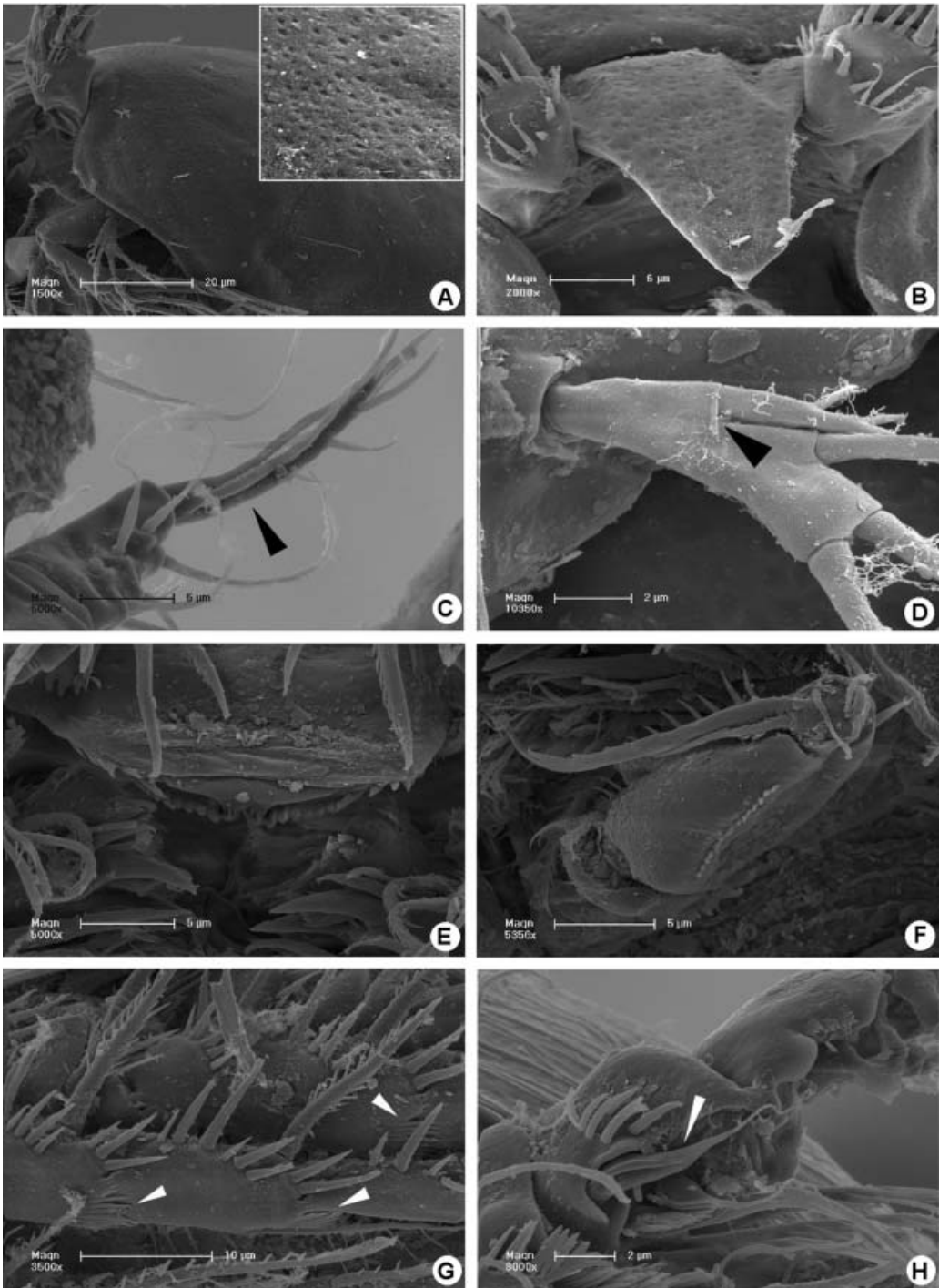


Figure 8. Scanning electron microphotographs of *Heteropsyllus coreanus* sp. nov. (A–G) Female: (A) areolated surface of cephalothorax (enlarged image in box); (B) rostrum, dorsal; (C) apical segment of antennule (acrothek arrowed); (D) antennary exopod (median wrinkle arrowed); (E) labrum; (F) maxilliped; (G) hyaline frills of P2–P3 (arrowed). (H) Male, geniculation of antennule (modified seta arrowed).

(NHM 2006-353-358) in 70% ethanol; 2♀♀ and 2♂♂ on SEM stub. (2) Hanyang University, Seoul. Paratypes: 7♀♀ and 1♂ in 70% ethanol. All samples are from the surrounding waters of the type locality: 1♀ from A3, 8♀♀ from A5, 3♀♀ from B1, 1♀ from B3, 3♀♀ from D5, 1♂ from A1, 1♂ from A2, 2♂♂ from B1, 1♂ from C1, and 1♂ from C4, coll. E. J. Nam and Y. H. Song, between 24 September and 3 October 2002.

### *Etymology*

The species name, *coreanus*, refers to its type locality, Republic of Korea.

### *Description*

*Female.* Total body length 403 µm ( $n=11$ , range 362–459 µm; measured from anterior margin of cephalic shield to posterior margin of caudal rami). Body subcylindrical. Largest width 98 µm, measured at posterior margin of cephalic shield. Cephalothorax surface distinctly pitted. Other somites covered with tiny denticles and first three urosomites with spinules dorsally and ventrally as illustrated in Figure 2A, B.

Prosome (Figure 2A, B) four-segmented, comprising cephalothorax (bearing first pedigerous somite) and three free pedigerous somites. Cephalothorax areolated (Figure 8A) with few sensilla and smooth posterior margin. Pleural areas of cephalic shield rounded, well developed and posterolateral angles rounded. Second and third prosomites with hyaline frills and last prosomites with hind margin serrulate.

Rostrum developed, defined at base (Figures 2A, B, 3C, 8B) and pointed anterior apex. Dorsal surface areolated as in cephalothorax, with pair of sensilla near anterior margin and with tube-pore near apex.

Urosome (Figures 2A, 3A, B) five-segmented, comprising P5-bearing somite, genital double-somite and three free abdominal somites. First urosomite with hind margin serrulate and other urosomites with hyaline frills.

Genital double-somite completely fused, dorsal surface with row of spinules in middle of segment indicating original segmentation. Genital field (Figure 3A) located rather proximally and with large copulatory pore located in median depression. Gonopores fused medially forming single genital slit covered on both sides by opercula derived from sixth legs. P6 with small protuberance bearing short naked seta.

Anal somite (Figure 3B) with well-developed operculum with spinulous posterior margin and flanked by pair of sensilla.

Caudal rami (Figure 3A, B) as long as broad, with seven setae; seta I minute and ventral to seta II, and situated more distally than latter; seta II as long as seta I and located laterally; seta III more than twice as long as seta II and located ventrally; seta IV and V bare proximally and bipinnate distally, latter more than twice as long as former; seta VI slightly shorter than seta III and located on distal inner corner; seta VII bare, close to outer margin in middle and triarticulate.

Antennule (Figures 3C, D, 8C) five-segmented, segment 1 with inner margin ornamented with few spinules. Armature formula: 1-[1 plumose], 2-[3 bare+4 plumose+2 spinulose], 3-[2 bare+4 plumose+(1+ae)], 4-[1 plumose], 5-[6 bare+3 large spinulose+1 acrothek]. Aesthetasc on segment 3 large and fused to long spinulose seta; apical acrothek consisting of well-developed aesthetasc fused basally to one slender and one strong bipinnate setae.

Antenna (Figures 4B, 8D) three-segmented, comprising coxa, allobasis, and free one-segmented endopod. Allobasis with one bare seta proximally and one plumose seta

medially. Exopod one-segmented with four plumose setae; two setae laterally and others apically. Free endopodal segment with strong spinules along inner proximal margin and with two lateral spines and five apical setae and spines.

Labrum with areolated ornamentation on anterior surface as in Figures 4C, 8E.

Mandible (Figure 4D) with large coxa bearing well-developed gnathobase; cutting edge with six major blunt teeth overlapping each other; accessory seta plumose. Mandibular palp well developed. Basis with one plumose seta. Endopod one-segmented with one bare and three plumose setae; one laterally and others apically. Exopod small and one-segmented with one plumose seta.

Maxillule (Figure 4E): arthrite with one posterior seta, six strong spines claw-like with spinule medially and two slender setae at posterior corner. Coxa with cylindrical endite bearing one strong seta claw-like. Basis with one plumose seta laterally and three bare setae apically. Endopod with two setae apically. Exopod absent.

Maxilla (Figure 4F): syncoxa with three endites; proximal praecoxal endite with one small plumose seta; middle and distal coxal endites with three setae, respectively. Allobasis produced into strong claw with three bare setae on anterior surface and one bare seta on posterior surface.

Maxilliped (Figures 5A, 8F) comprising syncoxa, basis, and one-segmented endopod. Syncoxa and basis with spinules on outer margin. Basis with row of spinules on middle and setules on margin. Endopodal segment produced into strong claw with two additional setae.

Swimming legs 1–4 biramous, P1 with three-segmented exopod and endopod. P2–P4 with three-segmented exopod and two-segmented endopod, and each ramus ornamented with setules and spinules along inner and outer margins as figured.

P1 (Figure 5B): praecoxa with spinules on distal margin. Coxa wider than long and rectangular. Basis with one short bare outer seta and one strong spinulose seta on inner distal corner. Endopod three-segmented, each segment subequal in length; enp-1 with one small seta on middle of inner margin; enp-2 with one pinnate inner seta; enp-3 with one pinnate inner seta, one plumose distal seta and one pinnate outer seta. Exopod three-segmented and extending beyond middle of enp-2; exp-3 with two geniculate distal setae and two strong spinulose outer spines; innermost distal seta longer than next.

P2 (Figure 5C): praecoxa small. Coxa with few rows of spinules proximally. Basis with plumose outer seta and spinules on inner margin. Endopod two-segmented and enp-2 1.5 times longer than enp-1, reaching almost to end of exp-2; enp-1 with one plumose seta; enp-2 with two plumose inner setae (distal inner seta much longer than exp), two distal setae (innermost distal seta reduced and bare, and next seta plumose) and one short pinnate outer seta. Exopod three-segmented; first two segments with hair-like setules along inner margin and hyaline frills on inner distal margin (Figure 8G); exp-3 longest; exp-2 with one plumose seta; exp-3 with one bare inner seta, two plumose distal setae and three pinnate outer spines.

P3 (Figure 6A): praecoxa with spinules on distal margin. Coxa with row of spinules proximally. Basis with long plumose outer seta. Endopod two-segmented and enp-2 twice longer than enp-1, reaching almost to middle of exp-2; enp-1 with one long bare seta; enp-2 with two plumose inner setae (distal inner seta much longer than exp), two distal setae (innermost distal seta reduced and bare, and next seta plumose) and one short bare outer seta. Exopod three-segmented; first two segments with hair-like setules and hyaline frills on inner distal margin and exp-3 longest; exp-2 with one plumose seta; exp-3 with two bare inner setae, two plumose distal setae and three pinnate outer spines.

P4 (Figure 6B): praecoxa small and with spinules on distal margin. Coxa with few rows of spinules. Basis with one long outer seta and spinules on inner margin. Endopod two-segmented; enp-2 longer than enp-1; enp-1 with one plumose inner seta; enp-2 with two plumose inner and two distal setae (innermost seta reduced and bare, and next seta plumose). Exopod three-segmented; first two segments with hyaline frills on inner distal margin; exp-3 longest; exp-2 with one plumose seta; exp-3 with two plumose inner setae, two plumose distal setae (innermost seta bare) and three spinulose outer spines.

Armature formula as follows:

Thoracopod	Exopod	Endopod
P2	0.1.123	1.221
P3	0.1.223	1.221
P4	0.1.223	1.220

P5 (Figure 4A): both legs separated. Baseoendopod wider than long and covered with dense denticles; circular wrinkled area present near proximal area of exopod. Endopod with five setae; innermost seta unipinnate, middle seta shortest, outermost seta bare and each seta set on peduncles, respectively. Exopod 2.5 times longer than wide and with five bare setae; two setae on outer margin closely located to each other. Outer basal seta bare.

*Male.* Male smaller and more slender than female. Body length 292  $\mu\text{m}$  ( $n=6$ , range 258–306  $\mu\text{m}$  measured from anterior margin of cephalic shield to posterior margin of caudal rami). Greatest width 72  $\mu\text{m}$ , measured at posterior margin of cephalic shield. Cephalothorax surface distinctly areolated. Other somites covered with tiny denticles as illustrated in Figure 2C.

Prosome (Figure 2C) four-segmented, comprising cephalothorax (bearing first pedigerous somite) and three free pedigerous somites. Cephalothorax narrower than in female and with smooth posterior margin. Second and third prosomites with posterior hyaline frills and last prosomite without defined hyaline frills and with serrulated posterior margin. Rostrum same as in female.

Urosome (Figures 2C, 7A) six-segmented, comprising P5-bearing somite, genital somite, and four free abdominal somites. All urosomites with pattern of surface ornamentation consisting of dense denticles dorsally and ventrally. First two urosomites with serrulated hind margin and other with hyaline frills. Sexual dimorphism in A1, P2 enp, P3 enp, P5, and genital field.

Antennule (Figures 7B, C, 8H) nine-segmented and subchirocer with geniculation between segments 7 and 8. Segment 2 largest. Segment 3 represented by small sclerite. Segment 7 with spinules on dorsal surface. Armature formula: 1-[1 pinnate], 2-[4 bare+2 spinulose+3 plumose], 3-[2 pinnate], 4-[2 pinnate], 5-[3 bare+2 spinulose+1 pinnate+(1+ae)], 6-[1 spinulose], 7-[1 bare+2 modified], 8-[1 modified], 9-[5 bare+acrothek]. Modified setae on segments 7 and 8 swollen and split into two folds proximally. Apical acrothek consisting of minute aesthetasc and two naked setae.

P2 enp (Figure 5D) with few differences from that of female; enp-1 with plumose seta; enp-2 with two plumose inner setae (proximal short and distal very long), two bare distal setae, and one short and bare outer seta.

P3 enp (Figure 6C) two-segmented and enp-2 longer than enp-1; enp-1 with one bare inner seta; enp-2 with two bare inner setae, two distal setae (inner seta plumose and outer distal seta short) and one short apophysis on anterior lateral margin.

P5 (Figure 7A): both legs fused; baseoendopod and exopod defined. Baseoendopod with three pinnate setae and wrinkled circular area near proximal region of exopod. Exopod with four setae; outermost seta bare and other setae pinnate. Outer basal seta bare.

Sixth legs (Figure 7A) asymmetrical, each represented by small plate with two setae; outer seta bare and inner seta pinnate.

### Ecology

This species inhabits wide ranges of depth (35~139 m), temperature (10.3~25.0°C) and salinity (32.0~34.5 psu). The species was discovered from a layer of only 0-1cm at all stations where it occurred. TOM ranged from 1.61 to 5.14% at the stations and the sediment composition was primarily muddy sand except for stations A5 and D5 (Table I).

### *Heteropsyllus celticus* sp. nov.

(Figures 9–14)

### Type locality

Salcombe, Devon, UK.

### Material examined

Holotype: 1♀ dissected on 10 slides (NHM 1911.11.8.45151). Paratypes: 1♂ dissected on three slides (NHM 1911.11.8.45152), and 3♀♀ dissected on slides and 1♀ in 70% ethanol.

### Etymology

The species name, *celticus*, refers its type locality, close to the Celtic Sea.

### Description

*Female*. Total body length 418 µm measured from anterior margin of cephalic shield to posterior margin of caudal rami. Body subcylindrical. Largest width 105 µm, measured at

Table I. Environmental factors from the stations where *Heteropsyllus coreanus* sp. nov. occurred.

Station	Depth (m)	Temperature (°C)	Salinity (psu)	TOM (%) <sup>a</sup>	Sediment type <sup>b</sup> (granule:sand:mud) (%)
A1	74	15.2	34.0	5.14	mS (0:86.26:13.74)
A2	49	18.3	32.0	1.70	gmS (19.01:58.70:22.29)
A3	75	13.0	32.8	3.07	MS (0:60.08:39.92)
A5	66	10.3	33.0	4.11	sM (0:36.63:63.35)
B1	130	17.0	34.6	2.67	S (0:96.85:3.15)
B3	92	13.3	33.1	2.63	Unknown
C1	139	14.4	34.5	1.61	S (0:98.57:1.43)
C4	35	25.0	32.2	2.90	mS (0:82.24:17.76)
D5	50	22.3	34.0	2.59	S (0:91.46:8.54)

<sup>a</sup>Total organic matter: ratio of weight loss for the original weight of the sediment after burning for 2 h at 550°C;

<sup>b</sup>sediment type: S, sand; mS, muddy sand; gmS, slightly gravelly muddy sand; sM, sandy mud.

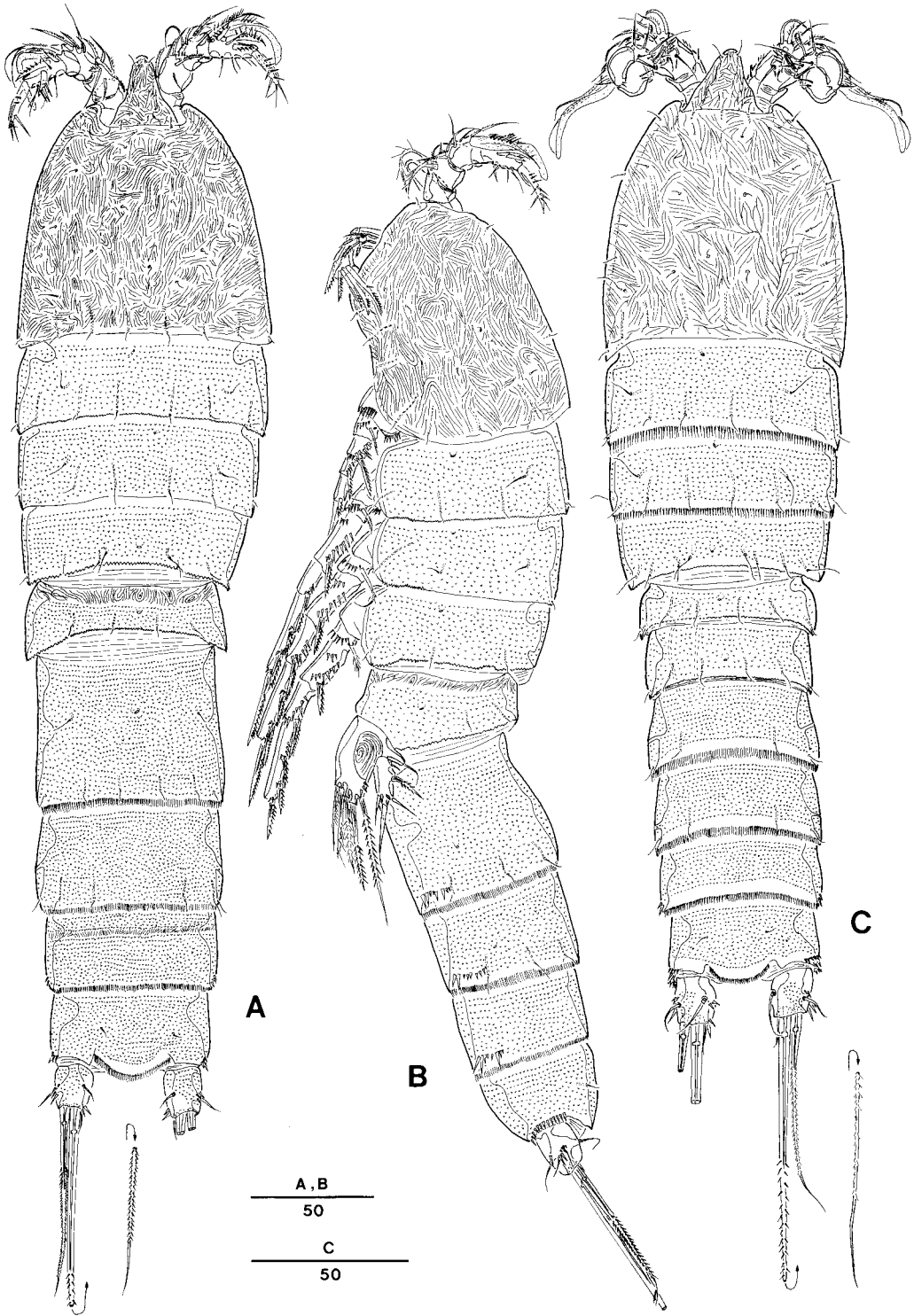


Figure 9. *Heteropsyllus celticus* sp. nov. (A) Female, habitus, dorsal; (B) female, habitus, lateral; (C) male, habitus, dorsal. Scale bars in  $\mu\text{m}$ .

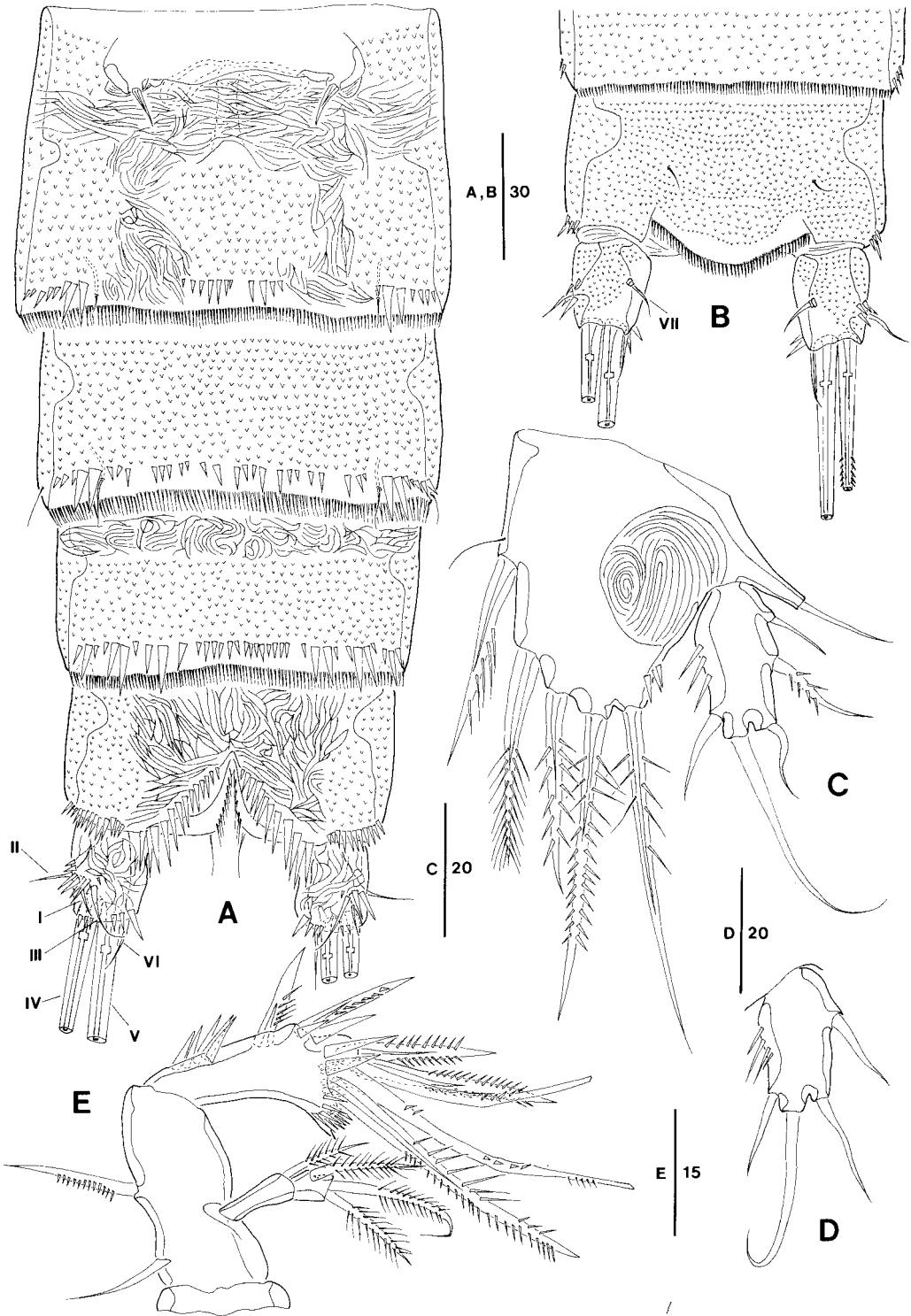


Figure 10. *Heteropsyllus celticus* sp. nov., female. (A) Urosome (except for somite-bearing P5), ventral; (B) anal somite and caudal rami, dorsal; (C) P5; (D) P5 exp (aberrant); (E) antenna. Scale bars in  $\mu\text{m}$ .



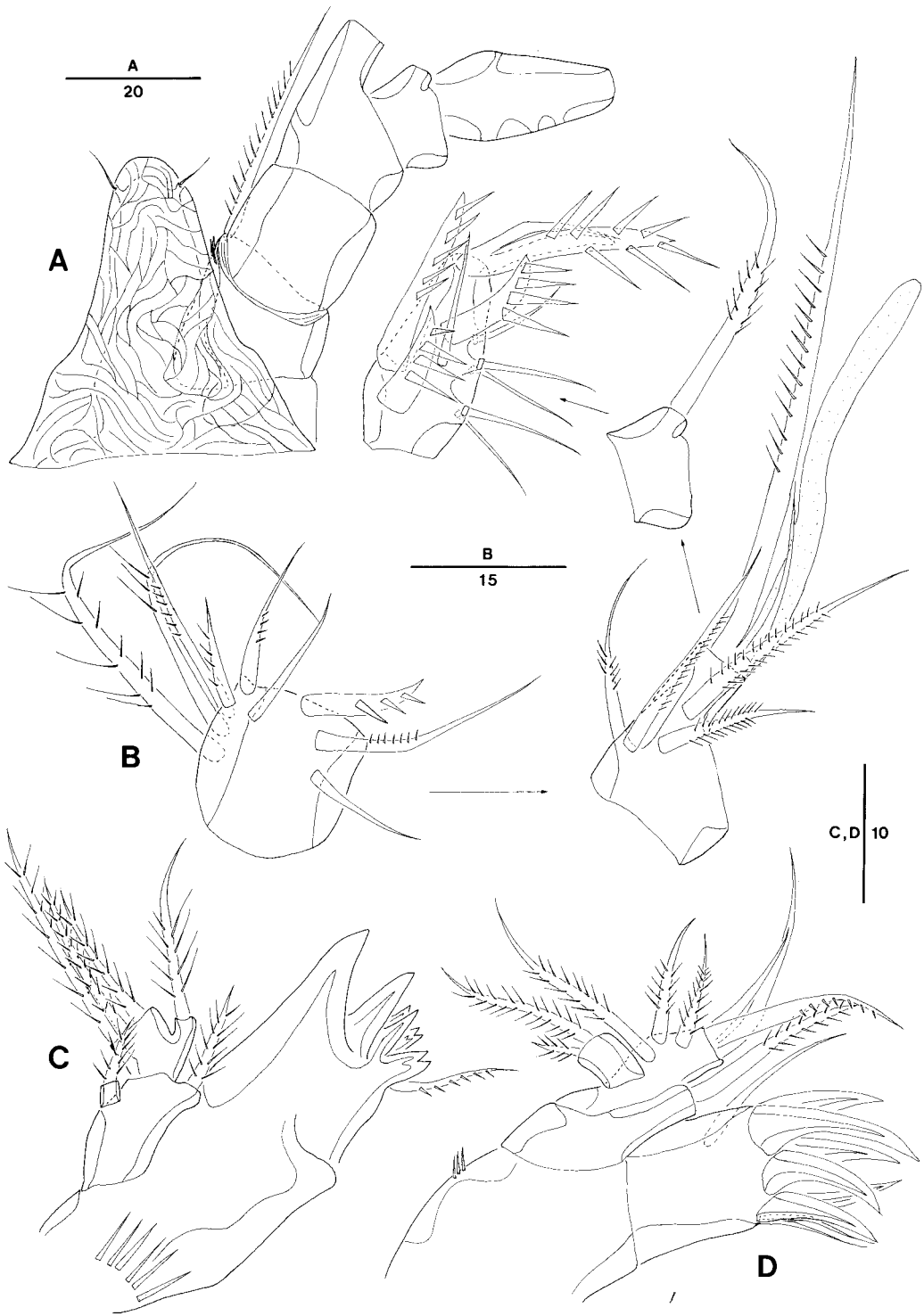


Figure 11. *Heteropsyllus celticus* sp. nov., female. (A) Rostrum and antennule (armature omitted from segments 2–5); (B) antennular segments 2–5; (C) mandible; (D) maxillule. Scale bars in µm.

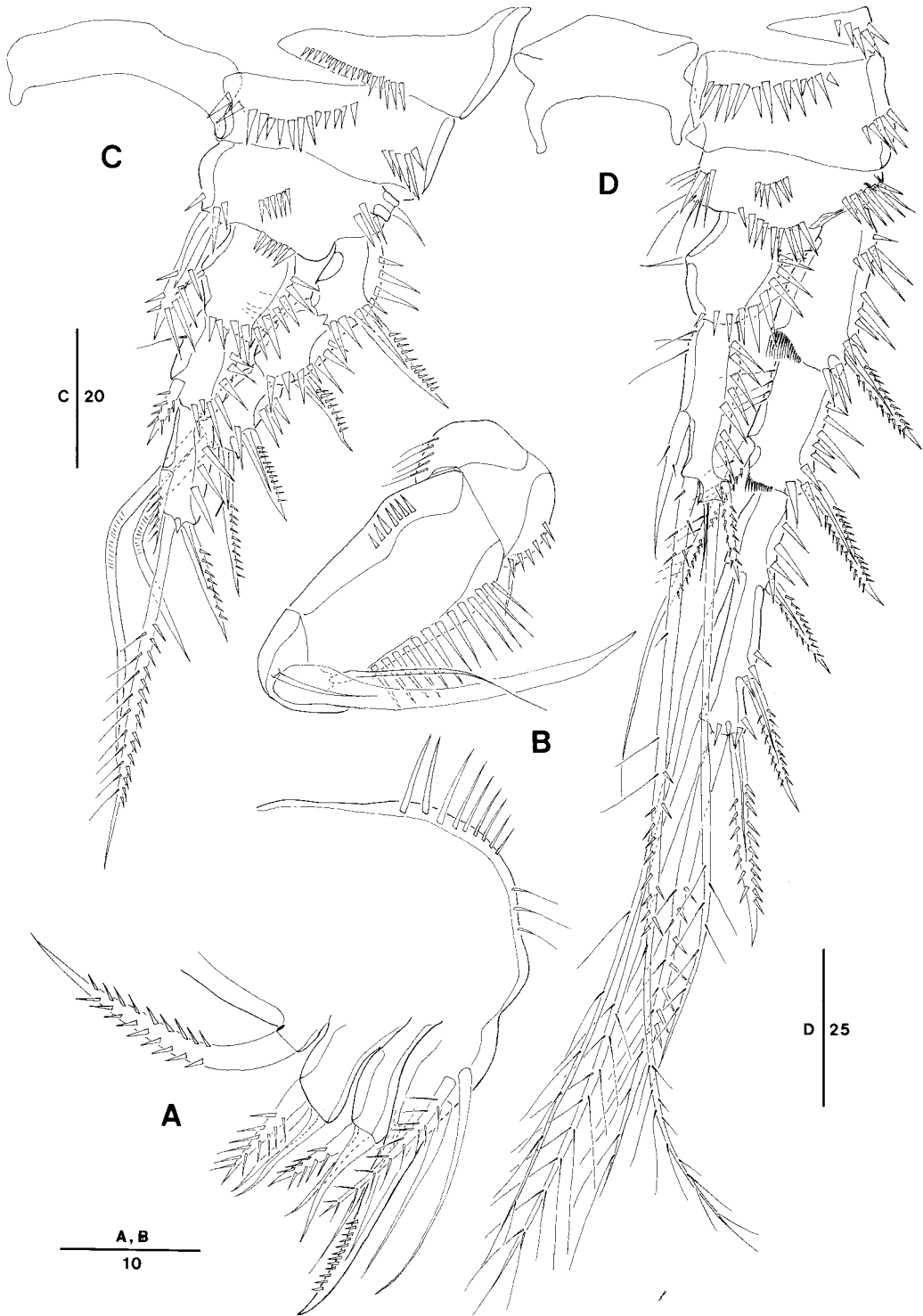


Figure 12. *Heteropsyllus celticus* sp. nov., female. (A) Maxilla; (B) maxilliped; (C) P1; (D) P2. Scale bars in  $\mu\text{m}$ .

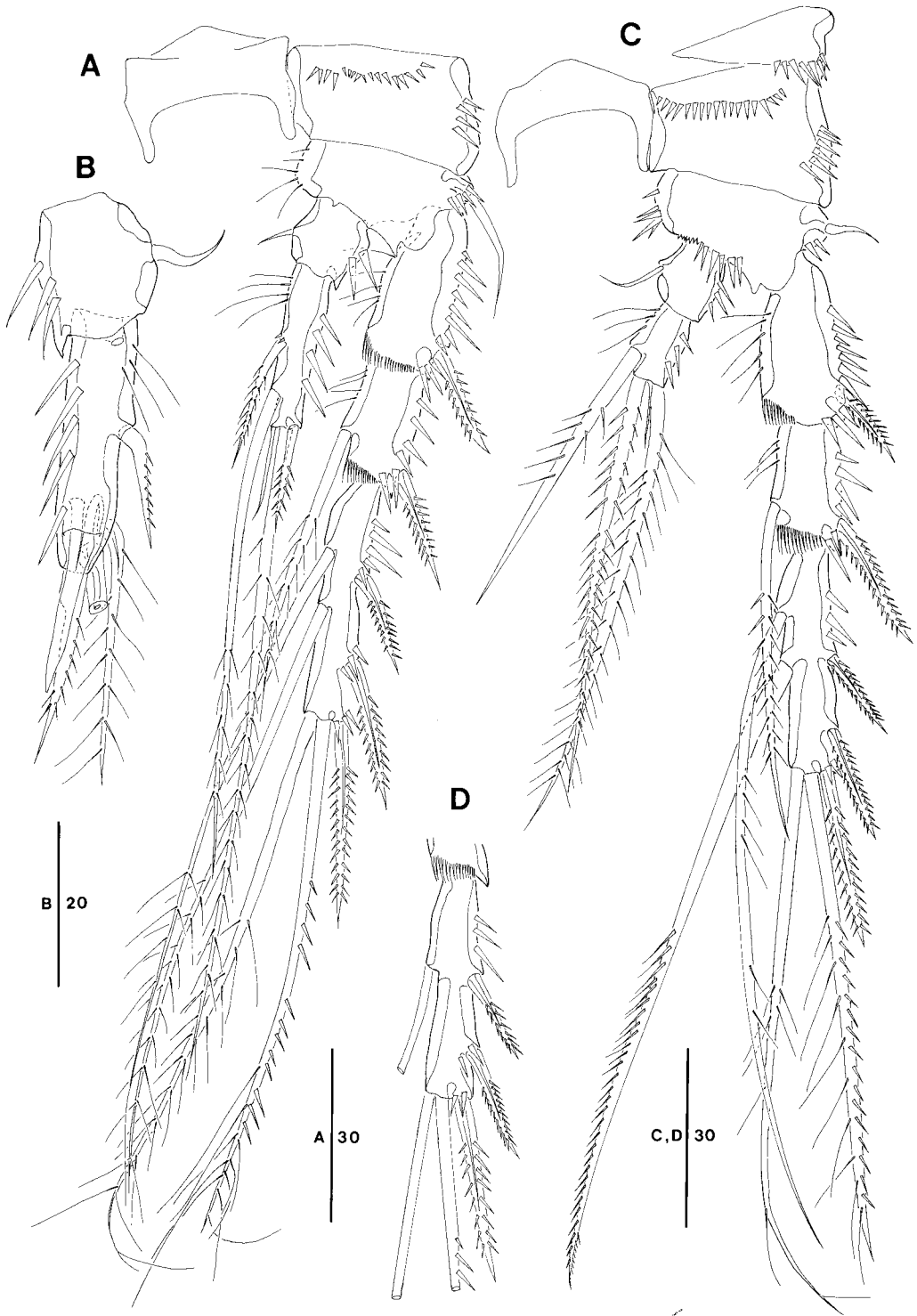


Figure 13. *Heteropsyllus celticus* sp. nov. (A) Female, P3; (B) male, P3 enp; (C) female, P4; (D) female, P4 exp-3 (aberrant). Scale bars in  $\mu\text{m}$ .

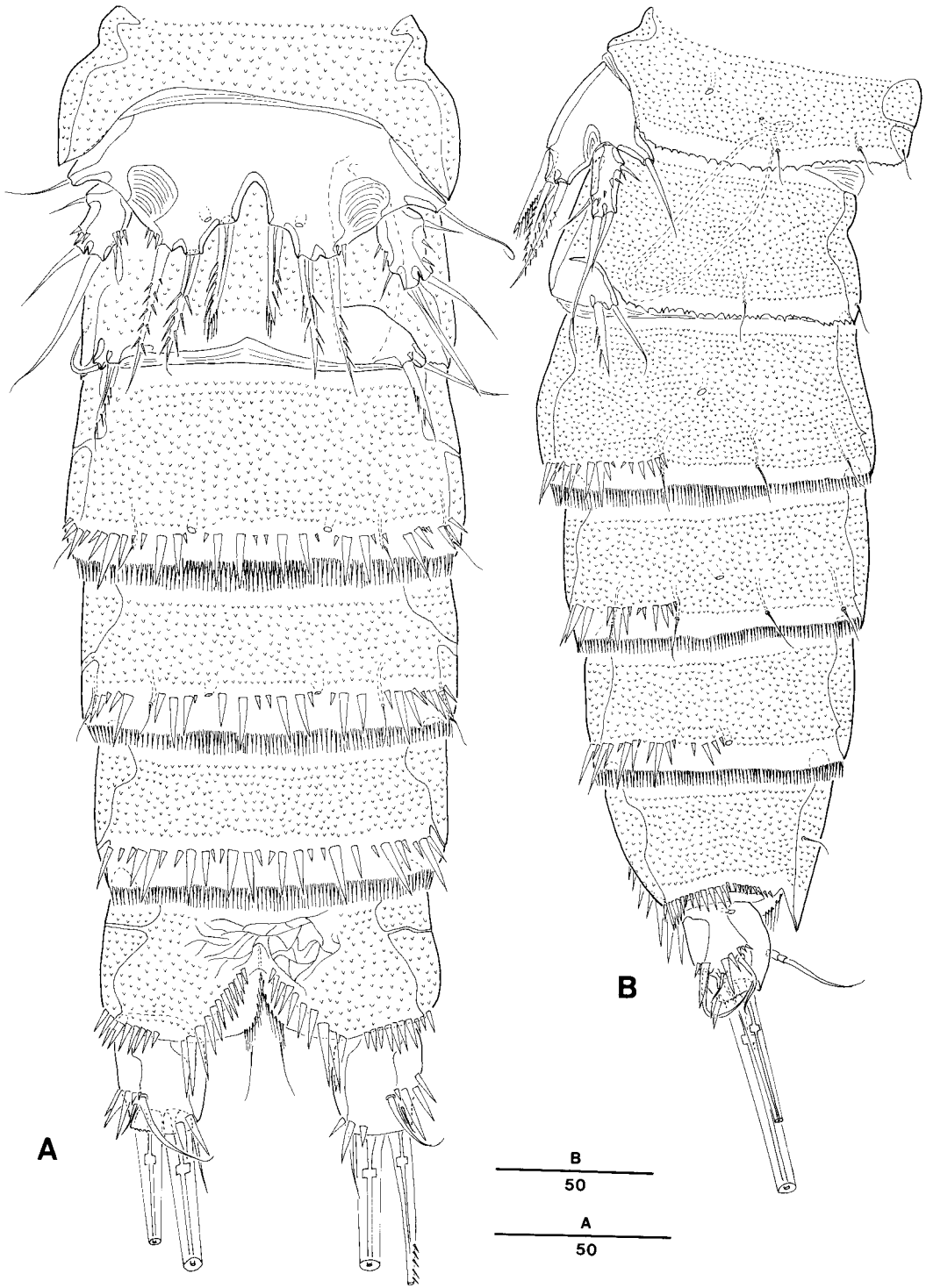


Figure 14. *Heteropsyllus celticus* sp. nov., male. (A) Urosome, ventral; (B) urosome, lateral. Scale bars in  $\mu\text{m}$ .

posterior margin of cephalic shield. Body surface covered with tiny denticles as illustrated in Figure 9A, B, except for cephalothorax and some parts of body.

Prosoma (Figure 9A, B) four-segmented, comprising cephalothorax (bearing first pedigerous somite) and three free pedigerous somites. Cephalothorax with ornamentations consisting of reticulation and few sensilla as illustrated in Figure 9A, B, smooth posterior margin and posterolateral pleural areas rounded and well developed. From second to fourth prosomites without defined hyaline frills, and with serrulated hind margin.

Rostrum well developed, defined at base (Figures 9A, B, 11A) and dorsal surface with reticulation as in cephalothorax and pair of sensilla near anterior margin.

Urosoma (Figures 9A, 10A, B) five-segmented, comprising P5-bearing somite, genital double-somite and three free abdominal somites. Urosomites with surface ornamentation consisting of dense denticles and some reticulated area; urosomites 2–4 with ventral row of spinules on posterior margin and denticulate hyaline frills.

Genital double-somite completely fused dorso-ventrally. Genital field (Figure 10A) located rather proximally and with large copulatory pore located in median depression. Gonopores fused medially forming single genital slit covered on both sides by opercula derived from sixth legs. P6 with small protuberance bearing one short naked seta. Ventral surface of genital double somite covered with reticulation or dense denticles.

Anal somite (Figure 10B) with well-developed operculum with spinulous posterior margin and flanked by pair of sensillae.

Caudal rami (Figure 10A, B) 1.5 times as long as broad, with seven setae; seta I minute and ventral to seta II, and situated more distally than latter; seta II about 1.5 times longer than seta I and located laterally; seta III 1.5 times longer than seta II and located ventrally; seta IV and V bare proximally and bipinnate distally, and seta V 1.5 times longer than seta IV; seta VI as long as seta III and located on inner distal corner; seta VII bare, close to outer margin on middle and tri-articulated.

Antennule (Figure 11A, B) five-segmented, segment 1 with inner margin ornamented with few spinules. Armature formula: 1-[1 plumose], 2-[2 bare+6 plumose+1 spinulose], 3-[1 bare+4 plumose+(1+ae)], 4-[1 plumose], 5-[6 bare+3 large spinulose+1 acrothek]. Aesthetasc on segment 3 large and geniculate fused to long spinulose seta; apical acrothek consisting of well-developed aesthetasc fused basally to one slender and one strong bipinnate seta.

Antenna (Figure 10E) comprising coxa, allobasis, free one-segmented endopod, and two-segmented exopod. Allobasis with two setae; one bare seta proximally close to coxa and one plumose seta on mid-lateral margin, and with groove along insertion of exopod. Exopod two-segmented; exp-1 with one plumose seta posterodistally, exp-2 with one plumose seta posteromedially and two plumose setae distally. Free endopodal segment with strong spinules along inner proximal margin and with two lateral spines, and five apical setae and spines.

Mandible (Figure 11C) with large coxa bearing well-developed gnathobase; cutting edge with six major blunt teeth overlapping each other; accessory seta spinulose. Mandibular palp well developed. Basis with one plumose seta. Endopod with one lateral and three apical plumose setae. Exopod small and one-segmented with one plumose seta.

Maxillule (Figure 11D); arthrite with one posterior seta, six strong spine-like claws with spinules medially and two slender setae at posterior corner. Coxa with cylindrical endite bearing one plumose seta. Basis with three plumose setae laterally, and one strong pinnate and two slender setae terminally. Endopod with two setae apically. Exopod absent.

Maxilla (Figure 12A): syncoxa with three endites; proximal praecoxal endite with one well-developed pinnate seta; middle and distal praecoxal endite with three setae (innermost seta pinnate and outermost seta wide proximally). Allobasis produced into strong claw with one pinnate and two bare setae on anterior surface, and one bare seta on posterior surface.

Maxilliped (Figure 12B) comprising syncoxa, basis, and one-segmented endopod. Syncoxa and basis with setules and spinules on outer lateral and inner margin. Endopodal segment produced into strong claw with two additional setae.

Swimming legs 1–4 biramous, P1 with three-segmented exopod and endopod. P2–P4 with three-segmented exopod and two-segmented endopod, and each ramus ornamented with setules and spinules on inner and outer margins as figured. Armature formulae as in *H. coreanus* sp. nov.

P1 (Figure 12C): praecoxa with spinules on distal margin. Coxa wider than long. Basis with one short bare outer seta and one strong spinulose seta on inner distal corner. Endopod three-segmented and each segment subequal in length; enp-1 with one small seta on middle of inner margin; enp-2 with one inner pinnate seta; enp-3 with one pinnate inner seta, one plumose distal seta and one spinulose outer spine. Exopod three-segmented and reaching almost end of enp-2; exp-3 with two geniculate distal setae and two spinulose outer spines; innermost distal seta longest.

P2–P3 (Figures 12D, 13A): praecoxa small. Coxa with row of spinules proximally. Basis with small (P2) or long (P3) naked outer seta and hair-like setules on inner margin. Endopod two-segmented, enp-2 about 1.5 times longer than enp-1, reaching almost to end of exp-2 and with hair-like setules on inner margin; enp-1 with one bare seta; enp-2 with two plumose inner setae (distal inner seta of P2 much longer than exp and that of P3 as long as exp), two distal setae (innermost distal seta reduced and bare) and one spinulose outer spine. Exopod three-segmented, first two segments with hair-like setules and hyaline frills on inner distal margin, and exp-3 longest; exp-2 with one plumose inner seta; exp-3 with one plumose inner seta (P2) or two plumose inner setae (P3), two plumose distal setae and three spinulose outer spines.

P4 (Figure 13C): praecoxa with spinules on distal margin. Coxa with row of spinules proximally. Basis with one short outer seta and spinules on inner margin. Endopod two-segmented and each segment subequal in length; enp-1 with one bare inner seta; enp-2 with two plumose inner and two distal setae (innermost seta reduced and bare). Exopod same as that of P3.

P5 (Figure 10C): both legs separated; exopod and baseoendopod defined. Baseoendopod as long as broad, with wrinkled circular area near proximal margin of exopod, and with five pinnate setae; innermost seta unipinnate and outermost seta longest. Exopod twice as long as wide and with five setae; distal outer seta pinnate.

*Male.* Body smaller and more slender than in female (Figure 9C). Body length 297  $\mu\text{m}$  measured from anterior margin of cephalic shield to posterior margin of caudal rami. Greatest width 78  $\mu\text{m}$ , measured at posterior margin of cephalic shield. Sexual dimorphism in A1, P3 enp, P5, and genital field. Whole body surface covered with tiny denticles except for reticulated cephalothorax.

Prosome (Figure 9C) four-segmented, comprising cephalothorax (bearing first pedigerous somite) and three free pedigerous somites. Cephalothorax narrower than in female and with smooth posterior margin. Second and third prosomites with posterior hyaline frills. Last prosomite without defined hyaline frill and with serrulated hind margin. Rostrum same as in female.

Urosome (Figures 9C, 14A, B) six-segmented, comprising P5-bearing somite, genital somite, and four free abdominal somites. All urosomites with surface ornamentation consisting of dense denticles dorsally and ventrally. First two urosomites with serrulated hind margin and others with hyaline frills.

Antennule nine-segmented (not figured) and subchirocer with geniculation between segments 7 and 8. Segment 2 largest. Segment 3 represented by small sclerite. Segment 7 with spinules on dorsal surface. Modified setae on segments 7 and 8 swollen and split into two folds proximally. Apical acrothek consisting of minute aesthetasc and two naked setae. Armature formula same as in *H. coreanus* sp. nov.

P3 enp (Figure 13B) two-segmented and enp-2 longer than enp-1; enp-1 with one short bare seta on inner margin; enp-2 with two plumose inner, two distal setae (outer distal seta wide proximally) and one apophysis on anterior side.

P5 (Figure 14A, B): both legs fused medially; baseoendopod and exopod defined. Baseoendopod with three pinnate setae and circular wrinkled area near proximal margin of exopod. Exopod with four bare setae. Outer basal seta bare.

Sixth legs (Figure 14A, B) asymmetrical, each represented by small plate with two setae; outer seta bare and inner seta pinnate.

## Discussion

Both new species certainly belong to *Heteropsyllus*, with several diagnostic characters for the genus including a well-defined rostrum, the three-segmented P1 enp, two-segmented P2–P4 enp, five-segmented female antennule, the short caudal ramus, and the first endopodal segments of P2–P4 always with an inner seta.

The differences between *Heteropsyllus celticus* sp. nov. from Norman's collection and *H. curticaudatus* were revealed after careful observations of the specimens. *Heteropsyllus curticaudatus* has two setae on the one-segmented exopod and a long seta on the basis of the mandibular palp, a long inner seta on enp-1 and only three setae on enp-2 of P4. *Heteropsyllus celticus* sp. nov. might be closely related to *H. major* rather than to *H. curticaudatus* by the rounded rostrum apex and armature formula of P2–P4. Although *H. celticus* sp. nov. is closely related to *H. major*, this species can be distinguished by the body ornamentation, mandibular palp, maxilla, basal outer seta and enp-1 inner seta of P1–P4, and P5, as indicated by the following character states: (1) the rostrum and cephalothorax are covered with reticulation and other parts of the body are covered with tiny denticles; (2) in the mandibular palp, the basal seta is shorter than in *H. major*, and the one-segmented exopod has only one seta; (3) maxilla has one strong seta on the proximal endite; (4) the basal outer setae of P1–P4 except for P3 are shorter than in *H. major*; (5) enp-1 of P1–P4 have a small inner seta; (6) P5 baseoendopod of female is as long as wide.

Variations of the setal numbers on the P4 endopod (Figure 13D) and P5 exopod (Figure 10D) in *H. celticus* sp. nov. were observed in one specimen. Normally, P4 endopod is armed with two inner setae and P5 exopod with five setae, however, only one seta was present on the P4 endopod and four setae on the P5 exopod in the abnormal specimen.

*Heteropsyllus coreanus* sp. nov. is most closely related to *H. celticus* sp. nov. sharing similar characters in the mouthparts including one-segmented exopod with one plumose seta of mandibular palp, and seta formula of swimming legs. However, *H. coreanus* sp. nov. is easily distinguished by the following character states: (1) the rostrum and cephalothorax are covered with distinct areolation, and first three urosomites have a few spinules dorsally; (2) the rostrum apex is pointed; (3) the antenna has a one-segmented exopod; (4) the maxillule

has only one plumose seta laterally on basis; (5) the P5 baseoendopod of the female is about twice wider than long and has a short middle seta, two setae on the outer margin are located lower than the others; (6) the P5 exopod is 2.5 times longer than wide and two setae on the outer margin are located very close to each other; (7) tip of P5 baseoendopod of male extends beyond to the middle of exopod.

The antennary exopod in *H. coreanus* sp. nov. is only one-segmented with four plumose setae. It appears two-segmented under the optical microscope but can be recognized as one-segmented with a median wrinkle under the SEM (Figure 8D).

So far reports of species of *Heteropsyllus* have been limited only to Europe and North America (Table II). *Heteropsyllus coreanus* sp. nov. is the first record from Asia for the genus.

The exopod of the mandibular palp is an important character of the genus *Heteropsyllus*. The species within the genus can be classified into three groups with the exopod of the mandibular palp (A) one-segmented, (B) with vestigial segment, and (C) none (Table III) except for two species for which the characters of mandibular exopod are unknown, *H. rostratus similis* (Smirnov, 1946) and *H. masculus* (Kunz, 1971). The first group (A) in turn can be classified in three subgroups by the setal number on the exopod as in Table III. Oligomerization in segmentation and in setation of the appendages is an obvious tendency in copepod evolution (Huys and Boxshall 1991) and the segmentation of the mandibular palp can be one of the key characters to establish the new genera, for instance the family Normanellidae (Lee and Huys 1999). The reduction of exopods and seta numbers on the mandibular palp is only part of the diversification shown in *Heteropsyllus*. Even the two closely related species, *H. coreanus* sp. nov. and *H. celticus* sp. nov., display striking differences in their mouthparts: (1) *H. coreanus* sp. nov. has one-segmented antennary exopod having a surface wrinkle indicating the original segmentation (Figures 4B, 8D; two-segmented in *H. celticus* sp. nov., Figure 10E); (2) maxillule ornamented with only one plumose seta laterally on basis in *H. coreanus* sp. nov. (Figure 4E; three in *H. celticus* sp.

Table II. List of *Heteropsyllus* species and their reported localities.

Species	Distribution
<i>H. curticaudatus</i>	Scotland—Musselburgh and Aberdour in Firth of Forth (Scott 1894, 1906) England—Salcombe, Duke Buoy, Jenny Cliff Bay, Chequer Buoy in Devon (Norman and Scott 1906), between Piel and Ormas Head in Liverpool Bay (Scott 1908)
<i>H. exiguus</i>	Norway—Farsund (Sars 1911)
<i>H. major</i>	Norway—Hvalör (Sars 1920) Sweden—Gullmarfjord (Lang 1948) France—La Rochelle (Bodin 1970) Germany—Beltsee (Kunz 1971) Bulgaria (Apostolov and Marinov 1988)
<i>H. nanus</i>	Norway—Risör (Sars 1920) Sweden—Gullmarfjord (Lang 1948)
<i>H. rostratus</i>	Norway—König-Kal-Land, Bremer Sund (Lang 1936a), Risör (Sars 1920), Koster fjord, Nord Koster (Por 1964)
<i>H. rostratus similis</i>	Arctic Ocean (Smirnov 1946)
<i>H. masculus</i>	Germany—Helgoland (Kunz 1971)
<i>H. meridionalis</i>	France (Soyer 1975)
<i>H. confluens</i>	France (Soyer 1975)
<i>H. nummi</i>	USA—South Carolina (Coull 1975)
<i>H. pseudonummi</i>	USA—Chesapeake Bay, Maryland (Coull and Palmer 1980)
<i>H. celticus</i> sp. nov.	England—Salcombe in Devon (Norman and Scott 1906; present study)
<i>H. coreanus</i> sp. nov.	Korea—off Jeju Island, the South Sea of Korea (present study)



Table III. Five groups based on the seta numbers of exopod and its segmentation in the mandibular palp of the genus *Heteropsyllus*.

Exopod segment	No. of setae	Species	Reference
(A) One-segmented	3	<i>H. rostratus</i>	Sars (1920)
		<i>H. nunni</i>	Coull (1975)
		<i>H. meridionalis</i>	Soyer (1975)
	2	<i>H. curticaudatus</i>	Scott (1894)
		<i>H. exiguus</i>	Sars (1911)
	1	<i>H. nanus</i>	Sars (1920)
		<i>H. confluens</i>	Soyer (1975)
<i>H. coreanus</i> sp. nov.		Present study	
(B) Vestigial segment	2	<i>H. celticus</i> sp. nov.	Present study
		<i>H. pseudonunni</i>	Coull and Palmer (1980)
(C) None		<i>H. major</i>	Sars (1920)

The characters of the mandibular exopod are unknown in *H. rostratus similes* and *H. masculus*.

nov., Figure 11D); (3) small and short seta on the precoxal endite in maxilla of *H. coreanus* sp. nov. (Figure 4F; well-developed and large bipinnate seta in *H. celticus* sp. nov., Figure 12A); and (4) a short row of spinules on inner lateral margin of maxilliped in *H. coreanus* sp. nov. (Figures 5A, 8F; a long row of spinules on lateral margin in *H. celticus* sp. nov., Figure 12B). It is easily expected that the differences in the mouthpart structures in the genus *Heteropsyllus* are enormous, considering the above comparison in two closely related species and the diversity of the mandibular palp of the genus (Table III). However, as Soyer (1975) distinguished his two new species mainly depending on setal formula of swimming legs, the previous studies on *Heteropsyllus* did not focus on mouthpart structures (Coull and Palmer 1980). Our information on the characters of mouthparts in the genus is premature at the moment. It would be interesting to investigate the phylogenetic lineage within *Heteropsyllus* after detailed observation and confirmation of the mouthpart structures of all its constituent species in a future study.

Key to the species of the genus *Heteropsyllus* (modified from Coull and Palmer 1980)

- 1. P1 exp-2 with and P4 enp-1 without inner seta . . . . . 2
- P1 exp-2 without and P4 enp-1 with inner seta . . . . . 3
- 2. Enp-1 of P1–P3 with inner seta . . . . . *H. pseudonunni* Coull and Palmer
- Enp-1 of P1–P3 without inner seta . . . . . *H. nunni* Coull
- 3. Terminal exopodal segment of P1 with four setae. . . . . 4
- Terminal exopodal segment of P1 with five setae . . . . . 10
- 4. A2 exp one-segmented . . . . . 5
- A2 exp two-segmented . . . . . 7
- 5. P1 enp-1 with inner seta . . . . . *H. coreanus* sp. nov.
- P1 enp-1 without inner seta . . . . . 6
- 6. P5 baseoendopod and exopod separated . . . . . *H. serratus* Schriever *incertae sedis*
- P5 baseoendopod and exopod fused . . . . . *H. confluens* Soyer

7. Terminal exopodal segment of A2 with three setae . . . . . 8  
 – Terminal exopodal segment of A2 with four setae . . . . . *H. nanus* (Sars)
8. Terminal endopodal segment of P4 with three setae . . . . . *H. curticaudatus* T. Scott  
 – Terminal endopodal segment of P4 with four setae . . . . . 9
9. Exopod of mandibular palp completely absent . . . . . *H. major* (Sars)  
 – Exopod of mandibular palp one-segmented with one seta . . . . . *H. celticus* sp. nov.
10. Last endopodal segment of P2 with five setae . . . . . 11  
 – Last endopodal segment of P2 with four setae. . . . . 12
11. P1 enp-3 twice as long as enp-2; syncoxa of Mxp with two setae at inner distal corner . . . . . *H. exiguus* (Sars)  
 – P2 enp-3 equal in length to enp-2; syncoxa of Mxp with one seta at inner distal corner . . . . . *H. meridionalis* Soyer
12. Rostrum pointed; P3 enp-3 with five setae. . . . . 13  
 – Rostrum rounded; P3 enp-3 with four setae . . . . . *H. masculus* Kunz
13. Baseoendopod of P5♀ with four setae . . . . . *H. rostratus* (Sars)  
 – Baseoendopod of P5♀ with five setae. . . . . *H. rostratus similis* Smirnov

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