

Five New Species of Lichomolgid Copepods Associated with Ascidiaceans from Korea, with Proposal of Two New Genera (Crustacea, Copepoda, Lichomolgidae)

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Abstract – Five new species of the family Lichomolgidae associated with solitary ascidians are described from the east coast of Korea. Two new genera are proposed: *Protomolgus* n. gen. to incorporate *Protomolgus duplex* n. sp. and *P. singularis* n. sp., and *Dontimolgus* n. gen. to incorporate *Dontimolgus brevicaudatus* n. sp. *Protomolgus* n. gen. characteristically has a four-segmented female maxilliped and a bipartite mandible. *Dontimolgus* n. gen. possesses a large, tooth-like process on the first maxillary segment and three spines on the third exopodal segment of leg 3. Other two new species described are *Lichomolgus infirmus* n. sp. and *L. pectinatus* n. sp.

Key words – new genera, new species, Lichomolgidae, ascidians, association.

1. Introduction

The family Lichomolgidae consists of copepod associates of various marine invertebrates, and their major hosts are ascidians, mollusks, and echinoderms (Humes and Boxshall 1996). Boxshall and Halsey (2004) counted more than 110 species of 25 genera in the Lichomolgidae, not including the genus *Pteroidicola* Kim, 2003 recorded by Kim (2003) and other two genera *Parastericola* Kim, 2007 and *Lobomolgus* Ho and Kim, 2009 recorded later by Kim (2007) and Ho and Kim (2009), respectively. Kim et al (2004) transferred *Philoblenna* Izawa, 1976 and *Briarella* Bergh, 1876 from the Philoblennidae to the Lichomolgidae, and Kim (2006) synonymized *Lichomolgides* Gotto, 1954 with *Zygomolgus* Humes and Stock, 1972.

Among the hosts of the lichomolgid copepods, the ascidians serve as hosts for the copepod genera *Ascidioxynus* Humes and Stock 1972, *Debruma* Humes and Stock 1972, *Henicoxiphium* Illg and Humes 1971, *Heteranthessius* T. Scott 1904, *Lichomolgidium* Kossmann, 1877, *Lichomolgus* Thorell 1859, *Lobomolgus* Ho and Kim 2009, and *Zygomolgus* Humes and Stock 1972.

In Korea only two species in the Lichomolgidae have been recorded as associates of ascidians: *Lichomolgus nakaii* Matsuzaki and Ogawa 1989 from the solitary ascidians *Halocynthia hilgendorfi igaboja* (Oka), *H. roretzi* (von Drasche) and *Styela plicata* Herdman (Kim 1998), and *Zygomolgus dentatus* Kim 2006 from unidentified compound ascidians (Kim 2006). In the present paper we describe five new species of lichomolgid copepods associated with ascidians from Korea, three of them belonging to two new genera and the remaining two belonging to the genus *Lichomolgus*.

2. Materials and Methods

The ascidians from which the studied copepods were extracted had been collected from the shallow water of the east coast of Korea. Some ascidian samples were also obtained from fishing nets at fishery ports. The collected ascidian samples were fixed and preserved in 95% ethanol. In the laboratory the ascidians were cut into two and agitated in the water. The wash water was filtered through a fine net, and then the copepods were picked out from the filtrates.

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Before dissection and microscopic observation the copepod specimens were soaked in lactic acid for about 30 minutes. In the case of copepod material having weak exoskeleton, the specimens were soaked in 10% formalin for about 30 minutes before the soaking in lactic acid. The dissections and microscopic observations were done using reversed slide method (Humes and Gooding 1964). Drawings were made with the aid of a drawing tube equipped on microscope. Type specimens have been deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea.

3. Systematic Accounts

Family **Lichomolgidae** Kossmann, 1877

***Protomolgus* n. gen.**

Diagnosis

Body cyclopiform. Prosome consisting of cephalosome and four pedigerous somites. Urosome 5-segmented in female and 6-segmented in male. Antennule 7-segmented, with armature formula of female 3, 13, 6, 3, 4+aesthetasc, 2+aesthetasc, and 7+aesthetasc. Male antennule additionally with 2 aesthetascs on second and 1 aesthetasc on fourth segments. Antenna 4-segmented; first and second segments with 1 seta each; third segment with 3 setae in female and 4 setae in male; terminal segment with 1 strong claw and several setae. Labrum with convex posterior margin. Mandible bipartite; proximal part unarmed; distal part elongated and distally toothed; terminal lash reduced or absent. Maxillule armed with 2 apical setae. Maxilla 2-segmented; proximal segment (coxa) unarmed; distal segment (basis) with reduced lash. Maxilliped 4-segmented in both sexes. Legs 1-4 with 3-segmented rami. Leg 1 exhibiting no sexual dimorphism in armature. Leg 4 with third exopodal segment armed with 3 spines and 5 setae; endopod with armature formula 0-1, 0-1, and II. Leg 5 with free segment bearing 2 setae.

Type species

Protomolgus duplex n. sp.

Etymology

The generic name *Protomolgus* is derived from *Protos*, the Greek meaning "primary", and *-molgus*, the ending of several generic names in the Lichomolgidae. It alludes to

the primitiveness of the new genus within the family. Gender is masculine.

Remarks

Based on the possession of sexually monomorphic leg 1 and four setae on the third segment of male antenna, we place *Protomolgus* n. gen. in the family Lichomolgidae.

Within the Lichomolgidae, *Protomolgus* shares a three-segmented endopod of leg 4 and its armature formula 0-1, 0-1, and II with *Lichomolgidium* Kossmann, 1877, *Diogenella* Stock, 1968, *Diogenidium* Edwards, 1891, *Hermannella* Canu, 1891, *Modiolicola* Aurivillius, 1882, and *Pterioidicola* Kim, 2003. However, with the four-segmented female maxilliped, *Protomolgus* cannot be compared further with these genera.

The female maxilliped of the Lichomolgoidea is said to be at most three-segmented (Humes and Boxshall 1996). Kim (1998) illustrated the female maxilliped of *Nasomolgus firmus* Humes and Ho, 1967 as having an indistinct transverse line at proximal area of the third segment, and Humes and Ho (1967) also illustrated the same appendage of *N. rudis* Humes and Ho, 1967 as having an incomplete proximal articulation. Although these vestigial line and articulation may be considered as a rudimentary articulation between the third and fourth segments of female maxilliped, the other example of the distinctly four-segmented female maxilliped as in *Protomolgus* is known in *Intramolgus* Marchenkov and Boxshall, 1996 of the Intramolgoidea which is an associate of solitary ascidians in the White Sea (Marchenkov and Boxshall 1995). *Intramolgus* is not related to *Protomolgus* because it has a primitive mandible bearing a distal lash and four setal elements, a simplified leg 5 without a free segment, and different setations on swimming legs. *Nasomolgus* which belongs to the Sabelliphilidae also differs from *Protomolgus* in having a short, tapering mandible, a two-segmented endopod of leg 4, and an elongate, whip-like terminal claw on the female maxilliped.

The mandible is a very important appendage in the classification of lichomolgoid copepods (Humes and Boxshall 1996). The typical form of mandible in the Lichomolgoidea consists of a single part bearing a tapering blade. The bipartite mandible of *Protomolgus*, consisting of a short proximal and an elongate distal parts, is therefore very unusual for a lichomolgoid. Examples of the bipartite condition of the mandible are observable in some poecilostome families, such as the Chondracanthidae (see Ho 1970, p.

111). Interestingly, a molecular study done by Huys et al. (2006) reveals that the Chondracanthidae belongs to the superfamily Lichomolgoidea, near the Pseudanthessiidae. One might suspect that the distal part of the mandible of *Protomolgus* was originated from the original, articulated dorsal seta of the primitive poecilostomatoid copepods (see Huys and Boxshall 1991, p. 302). It seems uneasy for the time being to interpret the morphological nature of the mandible of *Protomolgus*. However, the characteristic form of the mandible of *Protomolgus* is certainly a diagnostic trait of this genus.

In addition to the characteristic female maxilliped and mandible, the two tape-like median terminal setae on the caudal ramus and the short distal lash of the maxilla are also considered to be significant traits typifying the new genus.

Protomolgus duplex n. sp. (Figs. 1-3)

Material examined

9♀♀, 5♂♂ collected from the *Pyura*-like solitary ascidian taken from a fishing net set at the depth of 40 m (collected along with *Lichomolgus pectinatus* n. sp. described in this paper), off Guryongpo (35°58'51"N, 129°34'02"E) on the east coast of Korea, 13 November 2009, I.-H. Kim. Holotype (♀), allotype (♂), and paratypes (5♀♀, 2♂♂) have been deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea. Dissected paratypes (3♀♀, 2♂♂) are retained in the collection of the junior author.

Description

Female. Body (Fig. 1A) rather narrow, with weak exoskeleton. Body length of dissected specimen 1.18 mm. Five other measured specimens 1.05, 1.11, 1.14, 1.15, and 1.19 mm, respectively. Prosome 658 µm long, with maximum width 425 µm. Prosomal somites gradually narrowed from anterior to posterior. Urosome (Fig. 1B) 5-segmented. Fifth pedigerous somite 135 µm wide. Genital double-somite 223×140 µm (1.59:1), with weak lateral expansion at level of genital areas and on ventral surface 2 transverse rows of spinules in anterior part and 3 patches of spinules on posterior half (Fig. 1C). Genital areas positioned dorsolaterally at area slightly anterior to midlength of somite. Three free abdominal somites 80×91, 68×73, and 63×69 µm, respectively, from anterior to posterior. First free abdominal somite with 1 transverse row of several spinules on ventral surface. Caudal ramus (Fig. 1D) 113×33 µm (3.42:1) and armed

with 6 naked setae; 2 median terminal setae expanded, tape-like and transparent.

Rostrum elongated, much longer than wide, with strongly convex posterior margin (Fig. 1E). Antennule (Fig. 1F) 288 µm long and 7-segmented, with armature formula 3, 13, 6, 3, 4+aesthetasc, 2+aesthetasc, and 7+aesthetasc; all setae naked, and aesthetascs thin. Antenna (Fig. 1G) 4-segmented, with armature formula 1, 1, 3, and 5+claw; inner setae on first 2 segments expanded, tape-like, distinctly shorter than width of each segment; second segment with spinules along outer margin; distal one of setae on third segment and 2 inner setae on terminal segment with blunt tip; terminal segment about 49×35 µm (1.40:1); terminal claw strongly curved; 2 inner setae on terminal segment shorter than terminal claw.

Labrum with convex posterior margin (Fig. 1H). Mandible (Fig. 1I) bipartite; proximal part unornamented; distal part transparent, flat, and armed with 4 larger subdistal teeth and 4 or 5 smaller distal teeth, and terminated by rudimentary terminal lash. Paragnath not recognized. Maxillule (Fig. 1J) lobe-like, with 2 naked apical setae of same size. Maxilla (Fig. 2A) 2-segmented; proximal segment large but unarmed; distal segment armed with distinct anterior seta (seta II) and rudimentary outer seta (seta I); distal lash much reduced, spiniform, with 5 denticles on convex margin. Maxilliped (Fig. 2B) 4-segmented; first segment unarmed; second segment with 2 unequal inner setae; third segment unarmed; fourth segment with 1 large seta and with or without 1 process; this process variously developed, small (Fig. 2C) or enlarged (Fig. 2D) or extremely developed and claw-like (Fig. 2E).

Legs 1-4 with 3-segmented rami. Outer seta on basis of these legs small and naked (Fig. 2F, G, I). Exopodal segments of leg 1 with elongated, acutely pointed outer processes (Fig. 2F). Distalmost seta on endopod of leg 1 naked; its nearby seta pinnate unilaterally. Armature formula of legs 1-4 as follows:

Leg 1: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,4; enp. 0-1; 0-1; I,5

Leg 2: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,5; enp. 0-1; 0-2; I,II,3

Leg 3: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,5; enp. 0-1; 0-2; I,II,2

Leg 4: coxa 0-1; basis 1-0; exp. I-0; I-1; II,I,5; enp. 0-1; 0-1; II

Leg 5 consisting of 1 small dorsal seta on fifth pedigerous somite and free segment; free segment (Fig. 2J) 120×49 µm (2.45:1), its 2 naked distal setae 42 and 39 µm. Leg 6

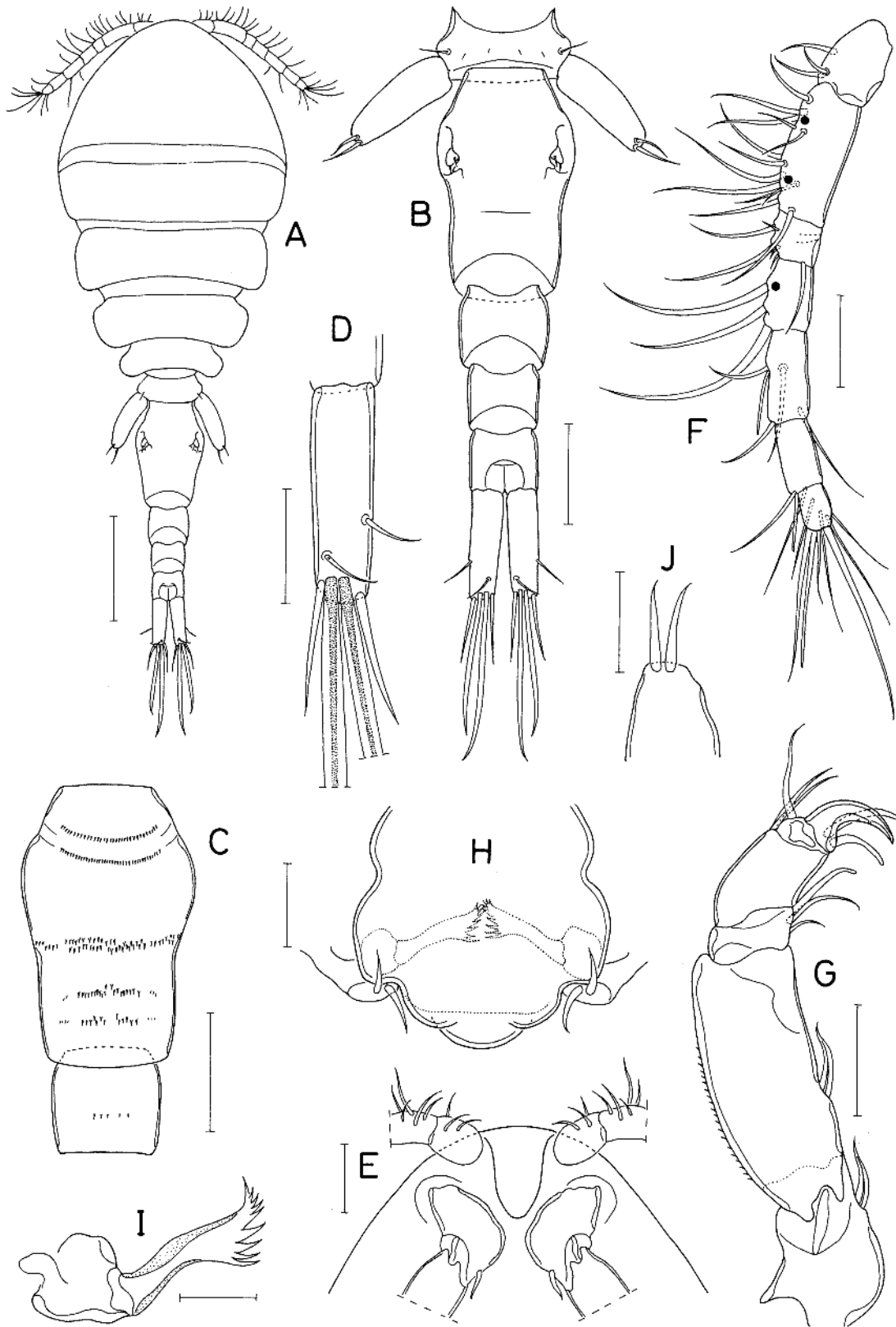


Fig. 1. *Protomolgus duplex* n. gen. n. sp., female. A, habitus, dorsal; B, urosome, dorsal; C, genital double- and first abdominal somites, ventral; D, right caudal ramus, dorsal; E, rostral area, ventral; F, antennule; G, antenna; H, labrum, mandible and maxillule; I, mandible; J, maxillule. Scales: A, 0.2 mm; B, C, 0.1 mm; D-G, 0.05 mm; H, J, 0.02 mm; I, 0.01 mm

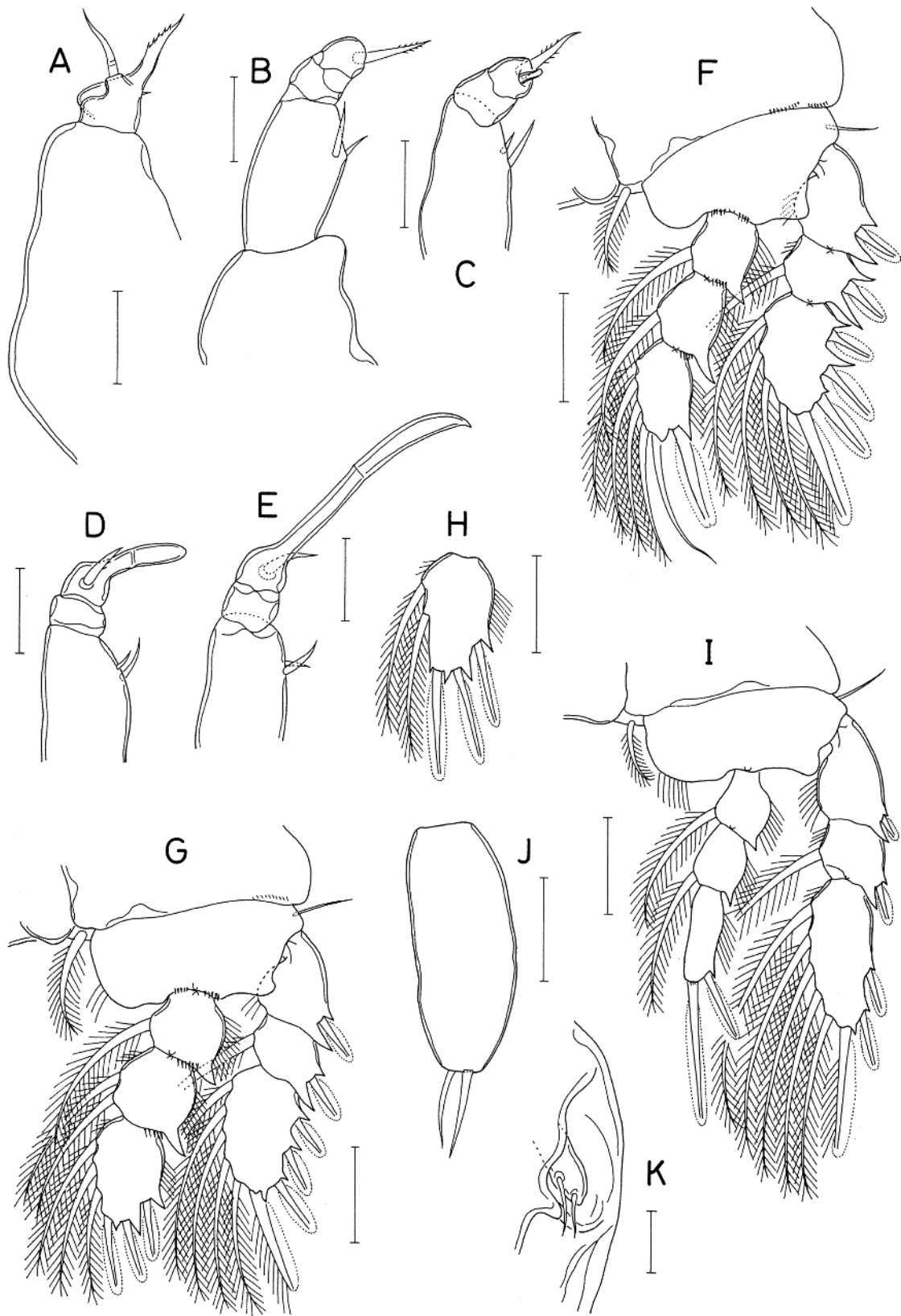


Fig. 2. *Protomolgus duplex* n. gen. n. sp., female. A, maxilla; B, maxilliped; C-E, distal part of maxillipeds; F, leg 1; G, leg 2; H, third endopodal segment of leg 3; I, leg 4; J, free segment of leg 5; K, genital area. Scales: A-E, K, 0.02 mm; F-J, 0.05 mm

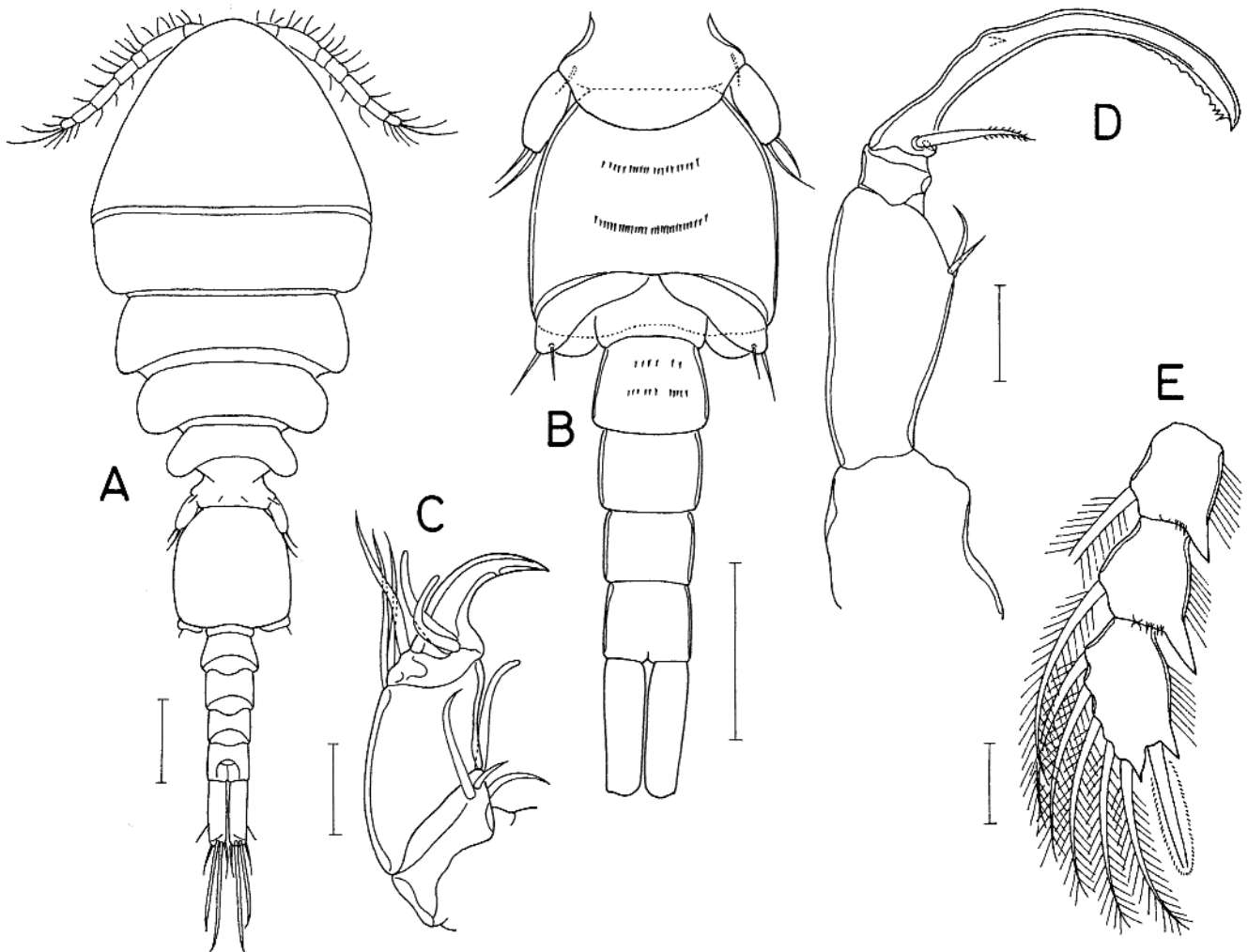


Fig. 3. *Protomolgus duplex* n. gen. n. sp., male. A, habitus, dorsal; B, urosome, ventral; C, distal part of antenna; D, maxilliped; E, endopod of leg 1. Scales: A, B, 0.1 mm; C-E, 0.02 mm

represented by 2 setae in genital area (Fig. 2K).

Male. Body (Fig. 3A) similar to that of female. Body length of dissected specimen 0.99 mm. Other 4 specimens 0.95, 0.96, 1.00, and 1.10 mm, respectively. Urosome (Fig. 3B) 6-segmented. Fifth pedigerous somite 104 μ m wide. Genital somite nearly quadrate, 144 \times 139 μ m, with 2 transverse rows of spinules on ventral surface. Four abdominal somites 48 \times 65, 46 \times 58, 41 \times 50, and 43 \times 50 μ m, respectively. First abdominal somite with 2 transverse rows of several spinules on ventral surface. Caudal ramus 77 \times 23 μ m (3.35:1).

Rostrum as in female. Antennule with 3 additional aesthetascs, 2 on second and 1 on fourth segments, at places of dots in Fig. 1F. Antenna with 1 additional seta on third segment (Fig. 3C).

Labrum, mandible, maxillule, and maxilla as in female. Maxilliped (Fig. 3D) 4-segmented; first and third segments unarmed; second segment with 2 inner setae; terminal segment as large, strongly curved claw bearing proximally 1 seta and 1 small setule and at area of 1/3 length 1 denticle.

Leg 1 with all setae pinnate on third endopodal segment; mid-terminal process on this segment pronounced and acutely pointed (Fig. 3E). Legs 2-4 as in female. Free segment of leg 5 46 μ m long. Leg 6 represented by 2 small setae on genital flap (Fig. 3B).

Etymology

The specific name *duplex* ("twofold" in Latin) refers to the presence of two rows of spinules on the anteroventral surface of the female genital double-somite.

Remarks

The variability in the development of the terminal claw of the female maxilliped revealed in *P. duplex* may be a subject of genetic researches. In some female specimens this appendage appears to be very similar to that of the male, without a sexual dimorphism.

Protomolgus singularis n. sp. (Figs. 4, 5)

Material examined

5♀, 5♂ from the solitary ascidian *Mogula manhattensis* (De Kay), at the depth of about 1 m, at Mokpo Harbor (34°47'10"N, 126°23'30"E), on 22 October 2010, by I.-H. Kim. Holotype (♀), allotype (♂), and paratypes (3♀, 3♂) have been deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea. Dissected paratypes (1♀, 1♂) are retained in the collection of the junior author.

Other material examined

1♀ (dissected) from the solitary ascidian of *Ascidia* cf. *sydneiensis* Stimpson, sublittoral, at Yangpo Port (35°52'54"N, 129°31'25"E) on the east coast of Korea, 12 August 2009, I.-H. Kim; 2♀, 1♂ (1♀, 1♂ dissected) from the solitary ascidian *Ciona intestinalis* Linnaeus, sublittoral, at Yangpo Port, 24 September 2009, I.-H. Kim.

Description

Female. Body (Fig. 4A) similar to that of preceding species, with weak exoskeleton. Body length of dissected specimen 1.14 mm. Urosome (Fig. 4B) 5-segmented. Fifth pedigerous somite 122 µm wide. Genital double-somite 193×120 µm, 1.61 times longer than wide, with weak lateral expansion at level of genital areas and 4 transverse rows (1 anterior and 3 posterior) of minute spinules on ventral surface (Fig. 4C). Genital areas positioned dorsolaterally at area slightly anterior to midlength of somite. Three free abdominal somites 66×85, 53×73, and 53×68 µm, respectively. First free abdominal somite with 1 transverse row of minute spinules on ventral surface. Anal somite with transverse row of minute spinules near base of caudal rami. Caudal ramus (Fig. 4D) 117×31 µm (3.77:1), armed with 6 naked setae; 2 mid-terminal setae expanded, tape-like; lateral margins parallel.

Rostrum not different from that of preceding species. Antennule also with same armature formula as that of preceding species. Antenna (Fig. 4E) 4-segmented, with

armature formula 1, 1, 3, and 6+claw; second segment with row of spinules along outer margin; setae on two proximal segments expanded and nearly as long as half length of second segment and distinctly longer than width of each segment; terminal segment 47×28 µm (1.68:1), its two inner distal setae longer than claw, with blunt tip (Fig. 4E).

Labrum with convex posterior margin (Fig. 4F). Mandible (Fig. 4G) bipartite; proximal part unornamented; elongate distal part transparent, flat, and armed with 4 larger subdistal and 9 smaller distal teeth, without terminal lash. Maxillule armed with 2 naked apical setae of equal size (Fig. 4F). Maxilla (Fig. 4H) 2-segmented; proximal segment large but unarmed; distal segment armed with distinct anterior seta (seta II) and rudimentary outer seta (seta I); distal lash much reduced, spiniform, with 3 or 4 minute denticles on convex margin. Maxilliped (Fig. 4I) 4-segmented; first segment unarmed; second segment with 2 unequal inner setae; third segment unarmed; fourth segment with 1 large seta and 1 small nipple-shaped process.

Legs 1–4 with 3-segmented rami. Outer seta on basis of these legs small and naked (Fig. 5A, B). Exopodal segments of leg 1 with elongated, acutely pointed outer processes (Fig. 5A). Two distal setae on endopod of leg 1 naked, distalmost one of which broader than other setae on same segment. Armature formula of legs 1–4 as that of *Protomolgus duplex*.

Leg 5 consisting of 1 small dorsal seta on fifth pedigerous somite and free segment; free segment (Fig. 5C) 135×50 µm (2.70:1), its 2 naked distal setae 43 and 33 µm. Leg 6 represented by 2 setae in genital area (Fig. 5D).

Male. Body similar to that of female. Body length of dissected specimen 0.92 mm. Urosome (Fig. 5E) 6-segmented. Fifth pedigerous somite 87 µm wide. Genital somite nearly circular, 127×132 µm, with 2 transverse rows of spinules on ventral surface. First abdominal somite also with 2 transverse rows of minute spinules on ventral surface. Caudal ramus 82×23 µm (3.57:1).

Rostrum as in female. Antennule with 3 additional aesthetascs, 2 on second and 1 on fourth segments. Antenna with 1 additional seta on third segment (Fig. 5F).

Labrum, mandible, maxillule, and maxilla as in female. Maxilliped (Fig. 3D) 4-segmented; first and third segments unarmed; second segment with 2 inner setae; terminal segment as large claw bearing proximally 1 seta, 1 small setule, and serrate tip.

Leg 1 with third endopodal segment bearing naked

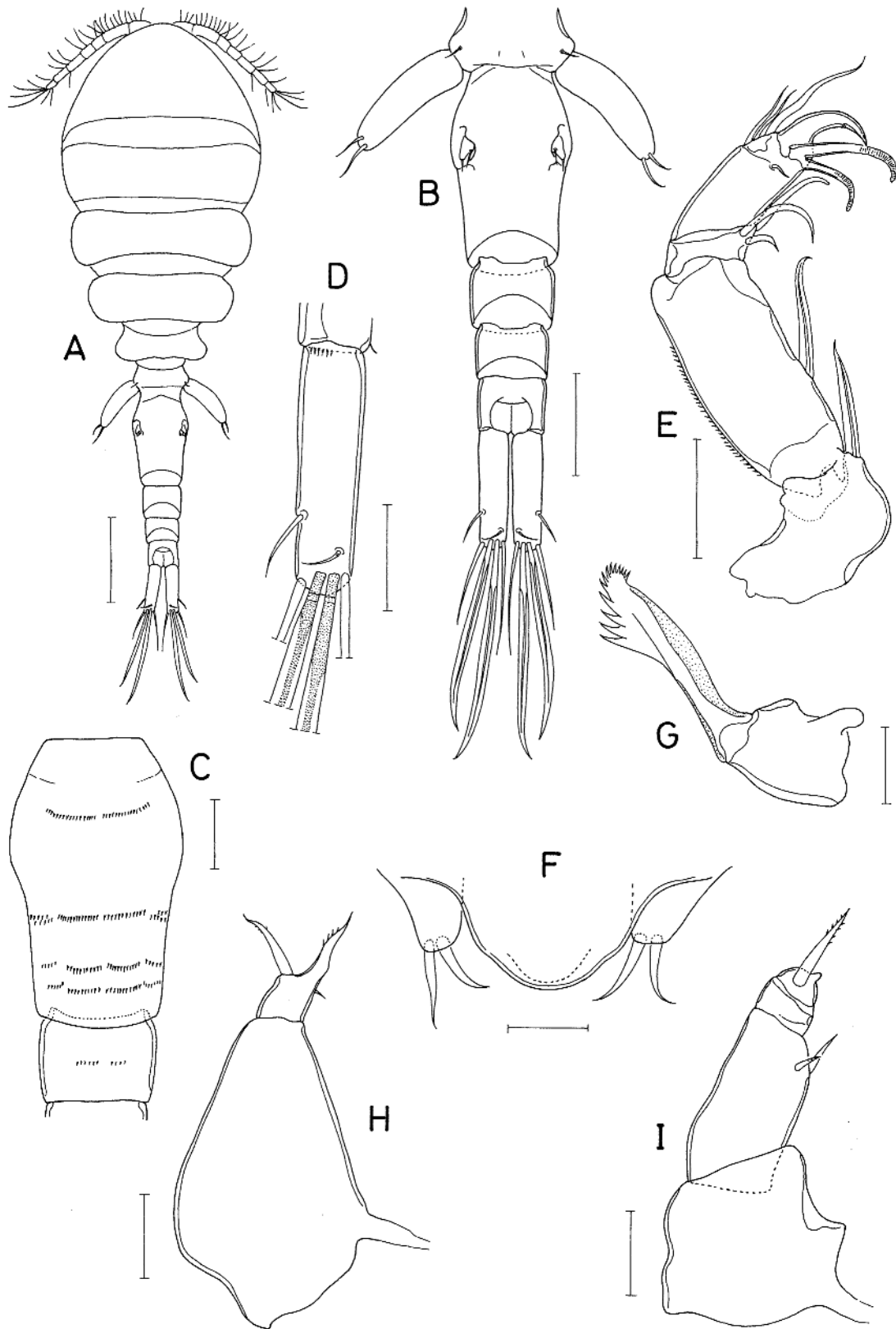


Fig. 4. *Protomolgus singularis* n. sp., female. A, habitus, dorsal; B, urosome, dorsal; C, genital double- and first abdominal somites, ventral; D, left caudal ramus, dorsal; E, antenna; F, labrum and maxillule; G, mandible; H, maxilla; I, maxilliped. Scales: A, 0.2 mm; B, 0.1 mm; C-E, 0.05 mm; F, H, I, 0.02 mm; G, 0.01 mm

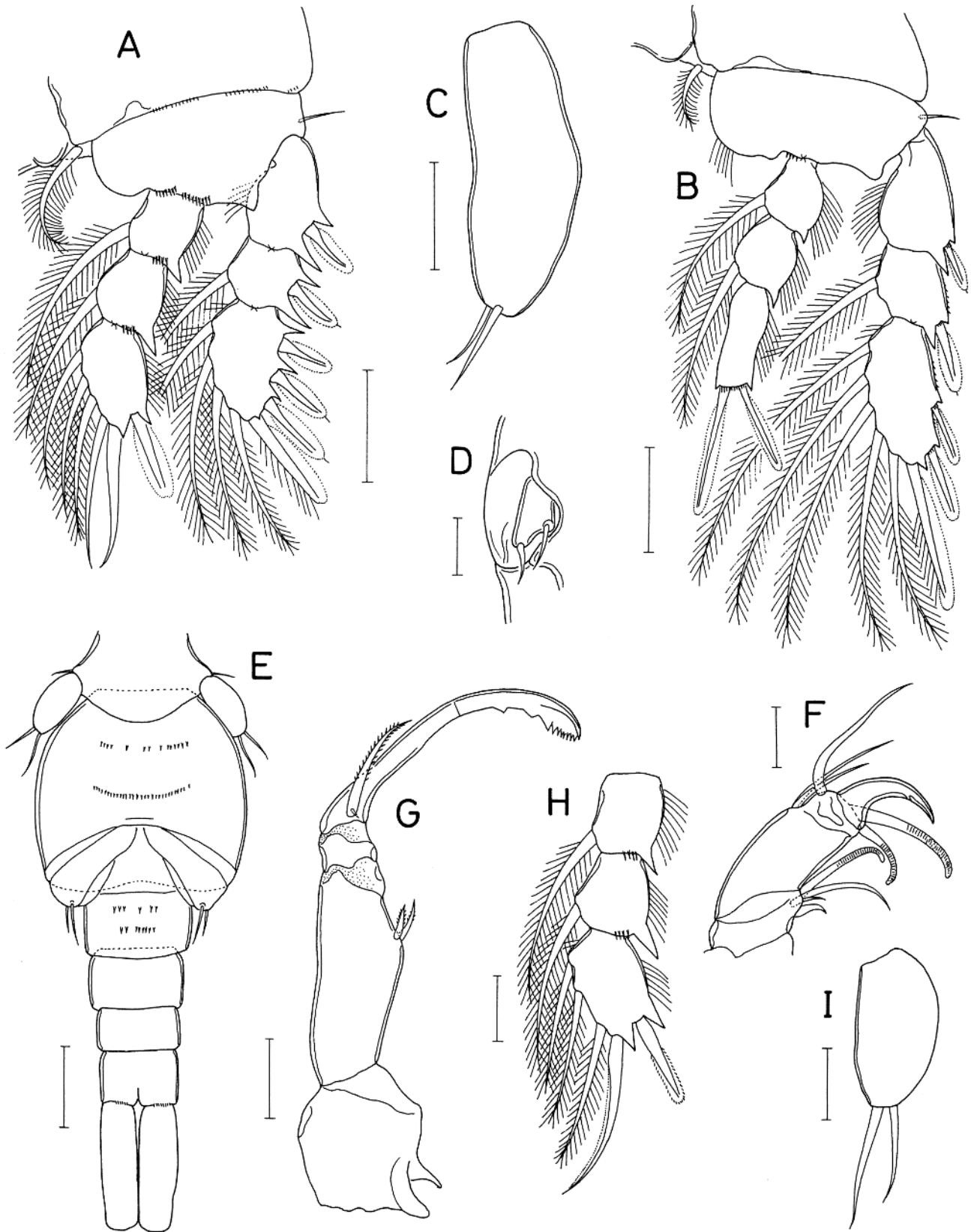


Fig. 5. *Protomolgus singularis* n. sp. Female: A, leg 1; B, leg 4; C, free segment of leg 5; D, genital area. Male: E, urosome, ventral; F, distal part of antenna; G, maxilliped; H, endopod of leg 1; I, free segment of leg 5. Scales: A-C, E, 0.05 mm; D, F-I, 0.02 mm

distalmost seta (Fig. 5H). Legs 2-4 as in female. Free segment of leg 5 $45 \times 23 \mu\text{m}$; its 2 distal setae 35 and 27 μm , respectively. Leg 6 represented by 2 small setae on genital flap (Fig. 5E).

Etymology

The specific name *singularis* ("single" in Latin) alludes to the presence of a single row of spinules on the anteroventral surface of the female genital double-somite.

Remarks

Protomolgus singularis n. sp. is very similar to *P. duplex* in the body form and other important features. Although differences between the two species are very slight, the followings are found to be consistent, reliable characters available to distinguish it from *P. duplex*: 1) the number of spinule rows on the ventral surface of the female genital-double somite: four rows in *P. singularis*, but five rows in *P. duplex*; 2) the size of the two inner distal setae on the terminal segment of the antenna: longer than the terminal claw in *P. singularis*, but shorter in *P. duplex*; 3) the size of the two inner setae on two proximal segments of antenna: longer than the width of segment in *P. singularis*, but distinctly shorter in *P. duplex*; 4) the number of the distal teeth on mandible: 13 in *P. singularis*, but 8 or 9 in *P. duplex*.

It is notable that *Mogula manhattensis* and *Ciona intestinalis*, the ascidian hosts of *P. singularis*, are invaded species of Korea. Their original distribution range is the Atlantic Ocean.

Dontimolgus n. gen.

Diagnosis

Body cycloform. Urosome 5-segmented in female and 6-segmented in male. Antennule 7-segmented, with armature formula of female 4, 13, 6, 3, 4+aesthetasc, 2+aesthetasc, and 7+aesthetasc. Male antennule with 2 additional aesthetascs on second segment. Antenna 4-segmented; first and second segments with 1 seta each; third segment with 3 setae in female and 4 setae in male; terminal segment with 1 large and 2 smaller claws. Mandible narrow, with elongated lash. Maxillule armed with 2 distal setae and 1 subdistal setiform process. Maxilla 2-segmented; proximal segment with prominent, tooth-like process. Maxilliped 3-segmented. Legs 1-3 with 3-segmented. Leg 4 with 3-segmented exopod

and 2-segmented endopod. Leg 1 exhibiting no sexual dimorphism in armature. Third exopodal segment of leg 3 with 3 spines and 5 setae (armature formula II,I,5). Leg 4 endopod with armature formula 0-1 and II. Free segment of leg 5 with 2 setae.

Type species

Dontimolgus brevicaudatus n. sp.

Etymology

The generic name *Dontimolgus* is a combination of the Greek *donti* (=tooth) and *-molgus* which is the ending of many generic names in the Lichomolgidae. It alludes to the prominent, tooth-like process on the first segment of the maxilla of the new genus.

Remarks

With a slender, evenly tapering mandible and sexually dimorphic setation on the third antennal segment, *Dontimolgus* n. gen. apparently belongs to the family Lichomolgidae, according to the definitions for families of the superfamily Lichomolgoidea given by Humes and Boxshall (1996).

The tooth-like process on the first maxillary segment seems to be the most distinctive feature of the new genus. Within the Lichomolgoidea similar process on the first maxillary segment is found in some genera such as *Andrianellus* Humes and Stock, 1972, *Humesiella* Sebastian and Pillai, 1973, *Juxtandrianellus* Humes 1995, *Parandrianellus* Humes, 1991, *Panjakus* Humes and Stock, 1972 and *Rakotoa* Humes and Stock, 1972 which are the genera of the family Anchimolgidae associated with scleractinian corals, and *Nasomolgus firmus* Humes and Ho, 1967 which is a species of the family Sabelliphilidae associated with a polychaete (Humes and Ho 1967). Although the process of the first maxillary segment is observable in these genera, no genus or species within the Lichomolgidae has been known to have a similar process on the first maxillary segment.

The establishment of *Dontimolgus* may be supported by its other diagnostic features. One of them is the possession of only three spines on the third exopodal segment of leg 3, with the armature formula II,I,5 (rather than III,I,5). Sars (1917) illustrated leg 3 of *Lichomolgus marginatus* Thorell, 1959 to have three spines on the same segment. Nevertheless, because the reduction of spine number on the third exopodal segment of leg 3 is very rare in the Lichomolgidae, we consider this feature is one of significant traits of the new

genus.

The male antennule of lichomolgid copepods generally has three additional aesthetascs, two on the second segment and one on the fourth (Humes and Stock 1973; Humes and Boxshall 1996). Therefore, the absence of an aesthetasc on the fourth segment of the male antennule also seems to be one of significant features of the new genus.

***Dontimolgus brevicaudatus* n. sp.** (Figs. 6-8)

Material examined

28♀♀, 7♂♂ collected from the solitary ascidian *Cnemidocarpa areolata* Heller, in the depth less than 10 m, off Sacheon Port (37°50'14"N, 128°52'36"E) in Kangnung, on the east coast of Korea, 3 May 2009, I.-H. Kim. Holotype (♀), allotype (♂), and paratypes (25♀♀, 5♂♂) have been deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea. Dissected paratypes (2♀, 1♂) are retained in the collection of the junior author.

Description

Female. Body (Fig. 6A) with moderately broad prosome and small urosome. Body length 930 µm (898-1010 µm), based on 5 specimens. Greatest width 238 µm. Prosome distinctly narrowed from anterior to posterior and 614 µm long. Cephalothorax 356 µm long and divided by dorsal furrow into cephalosome and first pedigerous somite. Urosome (Fig. 6B) small and 5-segmented. Fifth pedigerous somite 81 µm wide. Genital double-somite rhomboidal, 142×125 µm, widest in middle; genital area positioned dorsolaterally at place slightly posterior to midlength. Three free abdominal somites 50×63, 22×55, and 27×51 µm, respectively. Caudal ramus distinctly wider than long, 17×22 µm (0.77:1), with spinules on middle of posterior margin and 6 pinnate setae (Fig. 6C).

Rostrum (Fig. 6D) with nearly truncate posterior margin. Antennule (Fig. 6E) 232 µm long and 7-segmented, with armature formula 4, 13, 6, 3, 4+aesthetasc, 2+aesthetasc, and 7+aesthetasc; all seta naked. Antenna (Fig. 6F) 4-segmented, with armature formula 1, 1, 3, and 4+3 claws; terminal segment about 36×20 µm, with spinules on proximal half of outer margin; three terminal claws very unequal in size, consisting of elongated, largest inner one, smallest middle one, and intermediate-sized outer one.

Labrum (Fig. 6G) much wider than long, with broad median incision and membrane on posterior margin of

posterior lobes. Mandible (Fig. 6H) narrow, with elongate lash and spinules along margins of blade and lash. Maxillule (Fig. 6I) as lobe bearing 2 naked distal setae and 1 small, setiform subdistal element. Maxilla (Fig. 6J) 2-segmented; proximal segment characteristically with 1 large, tooth-like process; distal segment with large, spinulated inner seta (seta I), small, naked anterior seta (seta II), and elongated distal lash bearing large spinules on proximal half of convex margin. Maxilliped (Fig. 6K) 3-segmented; first segment unarmed; second segment with 2 small, equal setae subdistally; third segment small, with 1 spine bearing small proximal setule.

Legs 1-3 (Fig. 7A-C) with 3-segmented rami. Leg 4 (Fig. 7D) with 3-segmented exopod and 2-segmented endopod. Outer spines on second and third exopodal segments of leg 1 distinctly serrate along proximal margin. First outer spine on third exopodal segment of leg 2 distinctly smaller than other outer spine on exopod of same leg. Middle spine on third endopodal segment of legs 1 and 3 distinctly smaller than nearby spines. Distal segment of leg 4 endopod 47×16 µm; its 2 distal spines very unequal, 40 (inner) and 16 µm (outer). Armature formula of legs 1-4 as follows:

Leg 1: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,4; enp. 0-1; 0-1; I,1,4

Leg 2: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,5; enp. 0-1; 0-2; I,II,3

Leg 3: coxa 0-1; basis 1-0; exp. I-0; I-1; II,I,5; enp. 0-1; 0-2; I,II,2

Leg 4: coxa 0-1; basis 1-0; exp. I-0; I-1; II,I,5; enp. 0-1; II

Leg 5 represented by 1 dorsolateral seta on fifth pedigerous somite and free segment (Fig. 6B); free segment (Fig. 7E) 38×12 µm (3.17:1), gradually widened distally, with 2 unequal, naked distal setae of 38 and 21 µm, respectively. Leg 6 represented by 2 small setae and 1 small, spiniform process in genital area (Fig. 6B).

Male. Body shape similar to that of female. Body length of dissected specimen 850 µm. Urosome (Fig. 8A) 6-segmented. Fifth pedigerous somite 58 µm wide. Genital somite relatively large, nearly circular, and 140×147 µm. Four abdominal somites 30×52, 33×52, 27×52, and 28×52 µm, respectively. Caudal ramus 17×19 µm.

Rostrum as in female. Antennule with 2 additional aesthetascs on second segment at places of dots in Fig. 6E (no additional aesthetasc on fourth segment). Antenna with 1 additional seta (thus 4 setae) on third segment (Fig. 8B).

Mouthparts, except for maxilliped, as in female. Maxilliped

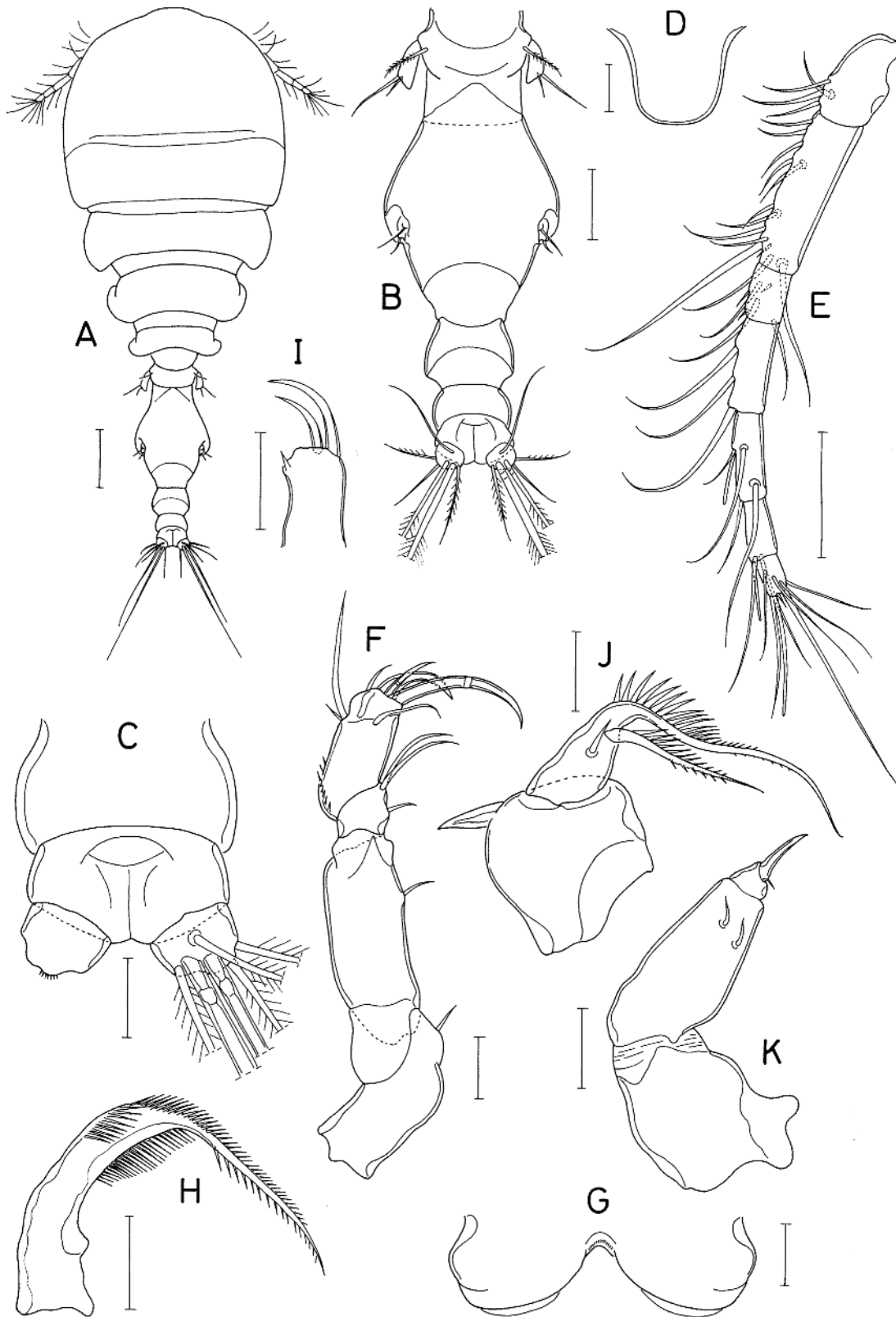


Fig. 6. *Dontimolgus brevicaudatus* n. gen. n. sp., female. A, habitus, dorsal; B, urosome, dorsal; C, distal part of urosome, dorsal; D, rostrum; E, antennule; F, antenna; G, labrum; H, mandible; I, maxillule; J, maxilla; K, maxilliped. Scales: A, 0.1 mm; B, E, 0.05 mm; C, D, F-K, 0.02 mm

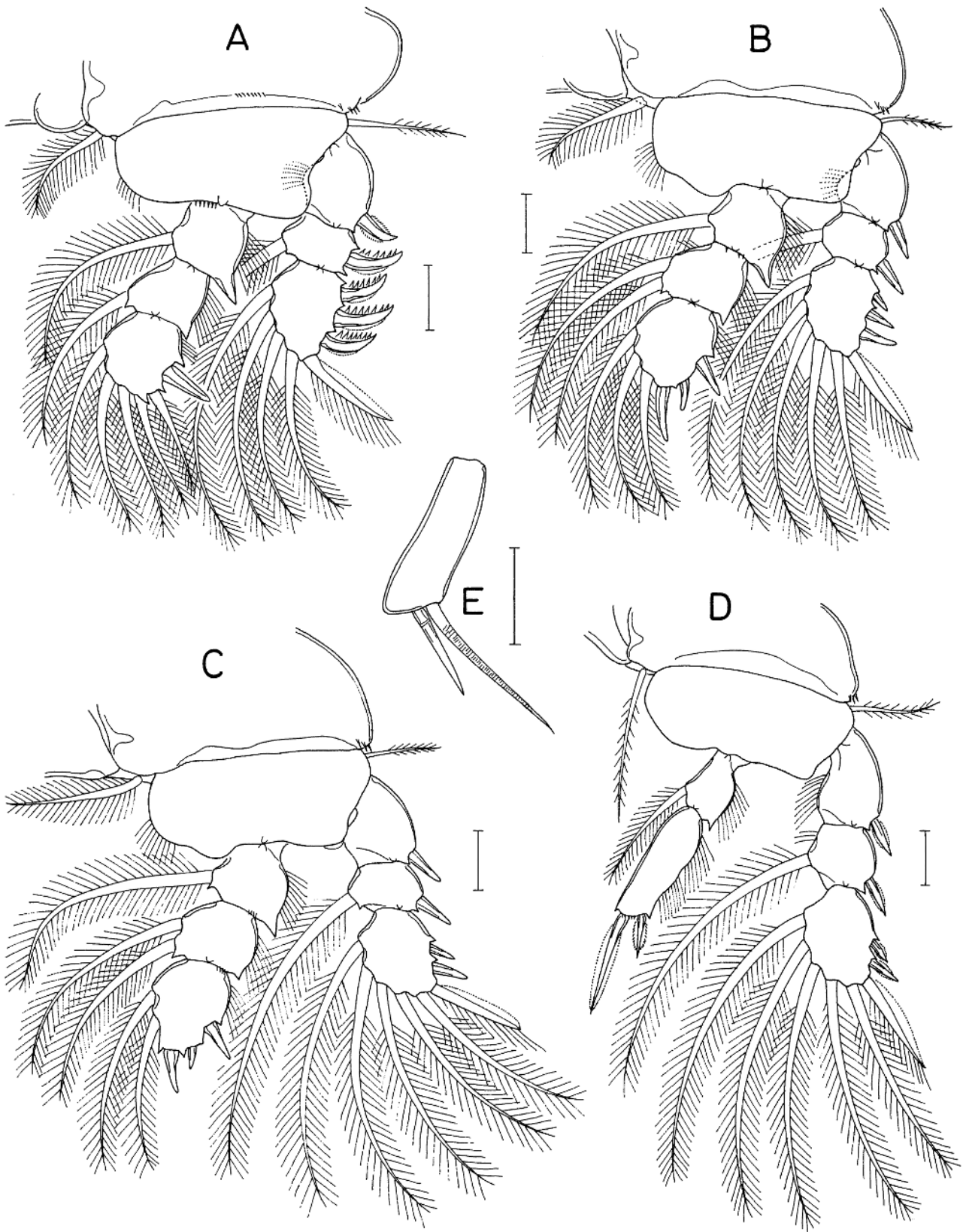


Fig. 7. *Dontimolgus brevicaudatus* n. gen. n. sp., female. A, leg 1; B, leg 2; C, leg 3; D, leg 4; E, free segment of leg 5. Scales: 0.02 mm for all

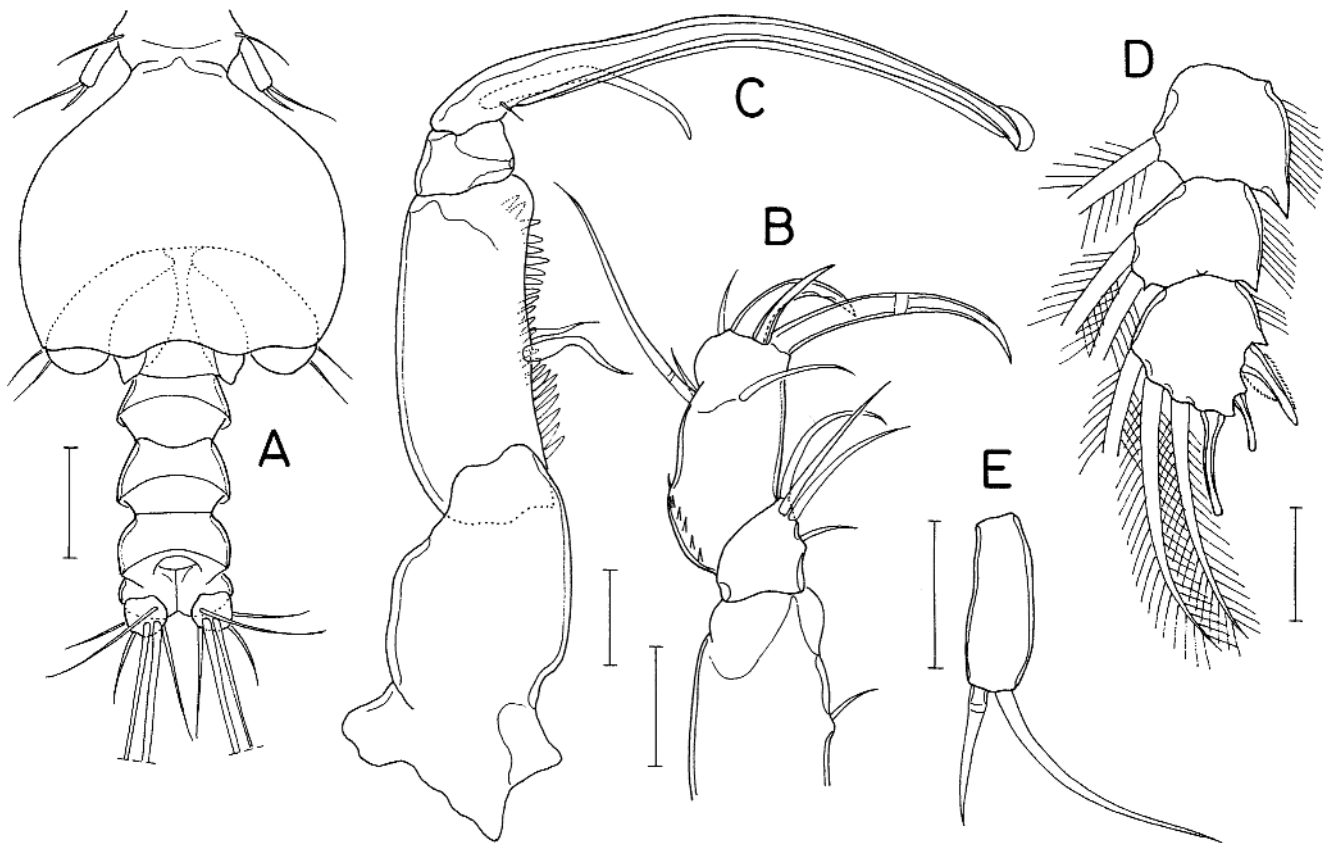


Fig. 8. *Dontimolgus brevicaudatus* n. gen. n. sp., male. A, urosome, ventral; B, distal part of antenna; C, maxilliped; D, endopod of leg 2; E, free segment of leg 5. Scales: A, 0.05 mm; B-E, 0.02 mm

(Fig. 8C) 4-segmented; first segment unarmed; second segment with 2 unequal setae and 1 longitudinal row spinules on inner margin; third segment small and unarmed; fourth segment as elongated claw bearing 1 large seta and 1 minute setule proximally.

Leg 1 as in female. Leg 2 showing slight sexual dimorphism in bearing 2 distal spines of third endopodal segment transformed to slender, rod-shaped elements (Fig. 8D). Legs 3 and 4 as in female.

Free segment of leg 5 (Fig. 8E) $24 \times 9.3 \mu\text{m}$ (2.58:1). Leg 6 represented by 2 small setae on genital flap (Fig. 8A).

Etymology

The specific name *brevicaudatus* is a combination of the Latin *brevis* (short) and *cauda* (tail). It alludes to the short caudal rami of the new species.

Genus *Lichomolgus* Thorell, 1959

Lichomolgus infirmus n. sp. (Figs. 9-11)

Material examined

7♀♀, 1♂♂ collected from the solitary ascidian *Styela plicata* Lesueur, sublittoral, at Yangpo Port ($35^{\circ}52'54''\text{N}$, $129^{\circ}31'25''\text{E}$) on the east coast of Korea, 24 September 2009, I.-H. Kim. Holotype (♀) and paratypes (5♀♀) have been deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea. Dissected paratypes (2♀♀, 1♂♂) are retained in the collection of the junior author.

Description

Female. Body (Fig. 9A) with weak exoskeleton, rather broad prosome and narrow urosome. Body length of dissected specimen 1.05 mm. Prosome $609 \times 457 \mu\text{m}$. Cephalothorax $395 \mu\text{m}$ long, divided by weak dorsal furrow into cephalosome and first pedigerous somite. Urosome (Fig. 9B) 5-segmented. Fifth pedigerous somite $102 \mu\text{m}$ wide. Genital double-somite $162 \times 125 \mu\text{m}$, with lateral expansion near genital area; margin of lateral expansion nearly linear. Genital areas broad, located dorsolaterally in

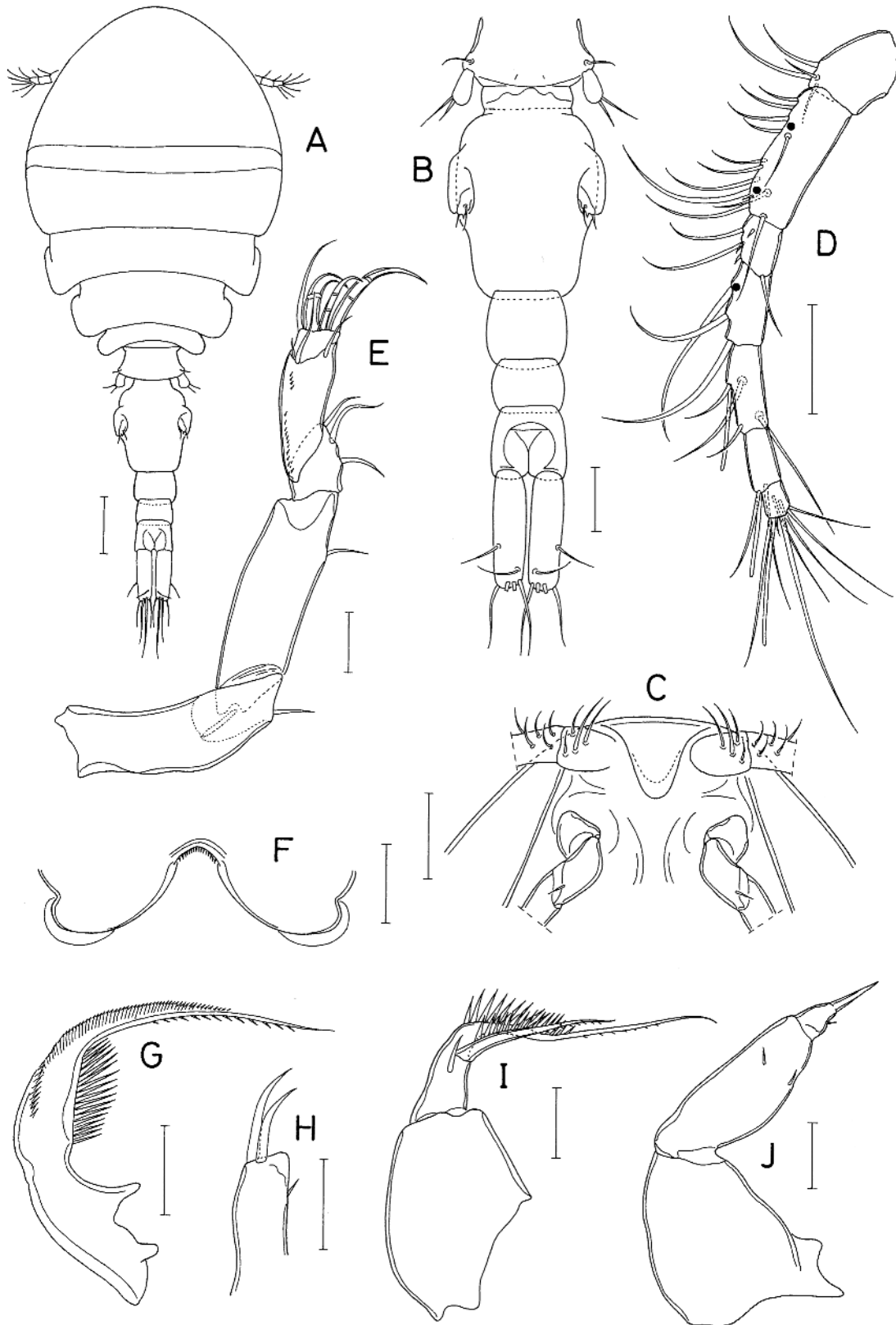


Fig. 9. *Lichomolgus infirmus* n. sp., female. A, habitus, dorsal; B, urosome, dorsal; C, rostral area, ventral; D, antennule; E, antenna; F, labrum; G, mandible; H, maxillule; I, maxilla; J, maxilliped. Scales: A, 0.1 mm; B-D, 0.05 mm; E-J, 0.02 mm

midlength of somite. Three free abdominal somites unornamented, 42×63 , 38×57 , and 52×57 μm , respectively. Caudal ramus 92×26 μm (3.54:1), armed with 6 naked setae; outer lateral seta located near $2/3$ length of ramus; largest one of caudal setae 109 μm long, slightly longer than caudal ramus.

Rostrum prominent, longer than wide, tapering, with rounded posterior apex (Fig. 9C). Antennule (Fig. 9D) 234 μm long and 7-segmented, with armature formula 4, 13, 6, 3, 4+aesthetasc, 2+aesthetasc, and 7+aesthetasc; all setae naked. Antenna (Fig. 9E) 4-segmented, with armature formula 1, 1, 3, and 4+3 claw; second segment about 66×24 μm (2.75:1); terminal segment about 44×18 μm , with minute spinules on outer side; 3 terminal claws unequal, inner one largest, middle one narrow, and outer one thick.

Labrum (Fig. 9F) short but broad, with broad median incision bearing minute spinules; posterior lobes bearing membrane along outer side. Mandible (Fig. 9G) narrow, elongated, as typical form of Lichomolgidae. Maxillule (Fig. 9H) with 2 distal setae and 1 small subdistal setule. Maxilla (Fig. 9I) 2-segmented; proximal segment unarmed; distal segment with elongated lash and armed with 2 setae (large inner and small anterior ones). Maxilliped (Fig. 9J) 3-segmented; first segment unarmed; second segment with 2 small, equal-sized setae; terminal segment small with minute lateral seta and terminated by straight spine (or process).

Legs 1-3 with 3-segmented rami (Fig. 10A, B). Leg 4 (Fig. 10D) with 3-segmented exopod and 2-segmented endopod. Distal endopodal segment of leg 4 34×38 μm , with 1 dentiform process in middle of outer margin; its 2 distal spines strongly unequal, 39 (inner) and 18 (outer) μm . Armature formula of legs 1-4 as follows:

Leg 1: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,4; enp. 0-1; 0-1; I,I,4

Leg 2: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,5; enp. 0-1; 0-2; I,II,3

Leg 3: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,5; enp. 0-1; 0-2; I,II,2

Leg 4: coxa 0-1; basis 1-0; exp. I-0; I-1; II,I,5; enp. 0-1; II

Leg 5 represented by 1 dorsolateral seta on fifth pedigerous somite and free segment (Fig. 10E); free segment broadened distally, 26×16 μm (1.63:1), with 2 naked distal setae of 35 and 24 μm , respectively. Leg 6 represented by 1 seta, 1 spinule, and small 1 dentiform process in genital area (Fig. 10E).

Male. Body (Fig. 11A) narrower than that of female. Body length of dissected specimen 729 μm . Prosome 400 μm long. Cephalothorax 255×246 μm . Urosome (Fig. 11B) 6-segmented. Genital somite 102×97 μm . Four abdominal somites 31×45 , 29×40 , 23×40 , and 35×40 μm . Caudal ramus 62×19 μm (3.26:1).

Rostrum as in female. Antennule with 3 additional setae: 2 on second and 1 on fourth segments at positions of dots in Fig. 9D. Antenna with 1 additional seta on third segment (thus 4 setae).

Mouthparts as in female, except for maxilliped. Maxilliped (Fig. 11C) 4-segmented; first and third segment unarmed; second segment with 1 longitudinal row of spinules and 2 small setae, one of these 2 setae located on protrusion in middle of inner margin; terminal segment as long, strongly curved claw bearing proximally 1 minute setule and 1 spinules-bearing seta; concave margin of terminal claw with spinules.

Legs 1-4 as those of female. Free segment of leg 5 (Fig. 11D) quadrangular, 17×10 μm , with 2 naked distal setae of 26 and 13 μm . Leg 6 represented by 2 small setae on genital flap (Fig. 11B).

Etymology

The specific name *infirmus* is a Latin meaning “weak”. It alludes to the weak exoskeleton of the new species.

Remarks

The genus *Lichomoligus* currently comprises 28 valid species. Their antennae carry various combinations of claw numbers on the terminal segment depending on species, although species of this genus associated with ascidians generally have two claws (Humes and Stock 1973). *Lichomoligus infirmus* n. sp. has three terminal claws on the antenna. However, one of these claws is so slender that one may recognize it as a seta. Thus it seems appropriate to compare the new species with congeners having two or three terminal claws on the antenna. On this basis, 11 congeners are selected to compare them with the new species: *L. albens* Thorell, 1859; *L. canui* Sars, 1917; *L. diazoniae* Gotto, 1961; *L. eganae* Gotto, 1975; *L. forficula* Thorell, 1860; *L. furcillatus* Thorell, 1860; *L. ieverisi* Thompson and Scott, 1903; *L. indicus* Ummerkutty, 1961; *L. leptodermatus* Gooding, 1957; *L. marginatus* Thorell, 1859; and *L. tridacnae* Humes, 1972. However, only two of these species, *L. eganae* and *L. ieverisi*, have a dentiform

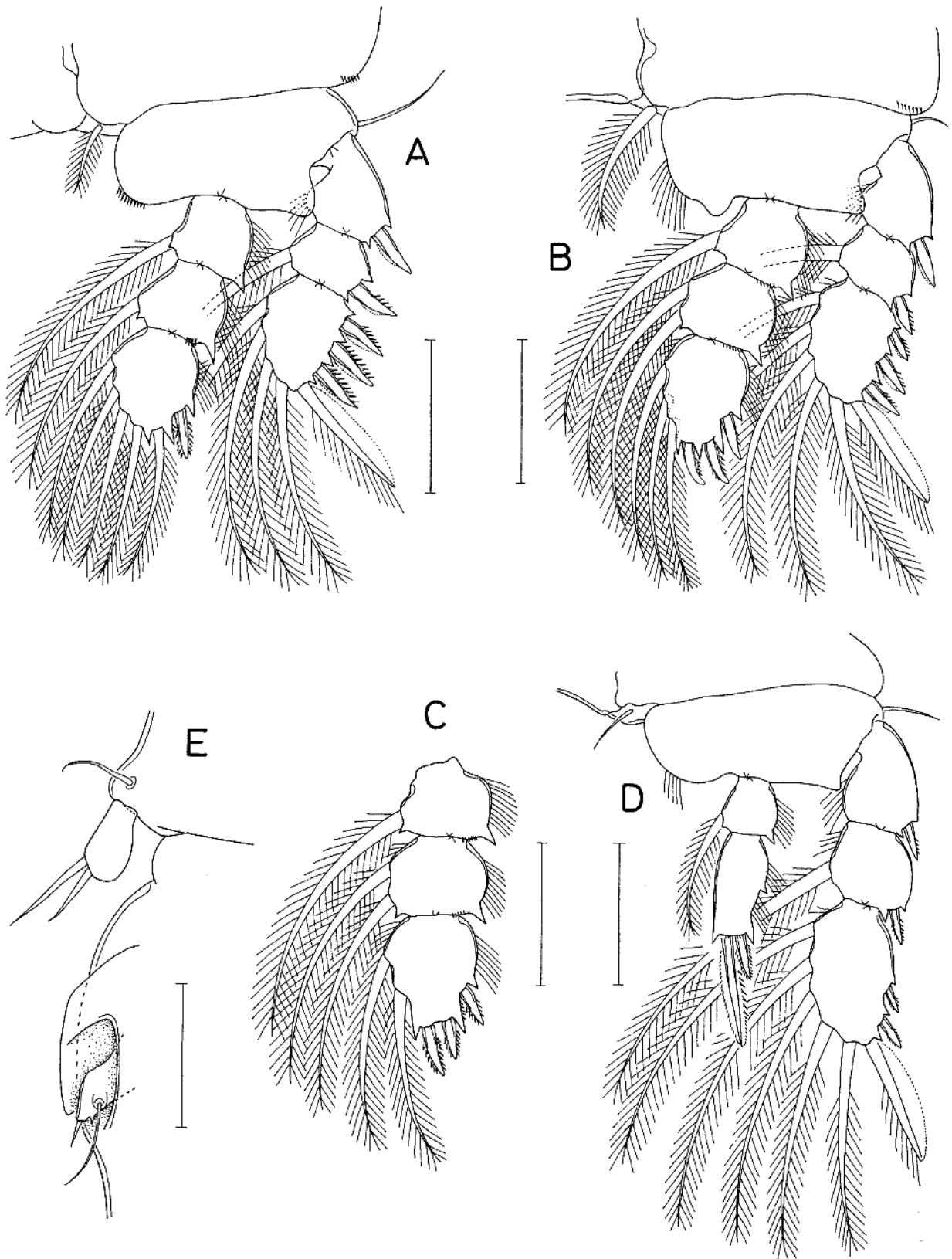


Fig. 10. *Lichomolgus infirmus* n. sp., female. A, leg 1; B, leg 2; C, endopod of leg 3; D, leg 4; E, left leg 5 and genital area, dorsal. Scales: 0.05 mm for all

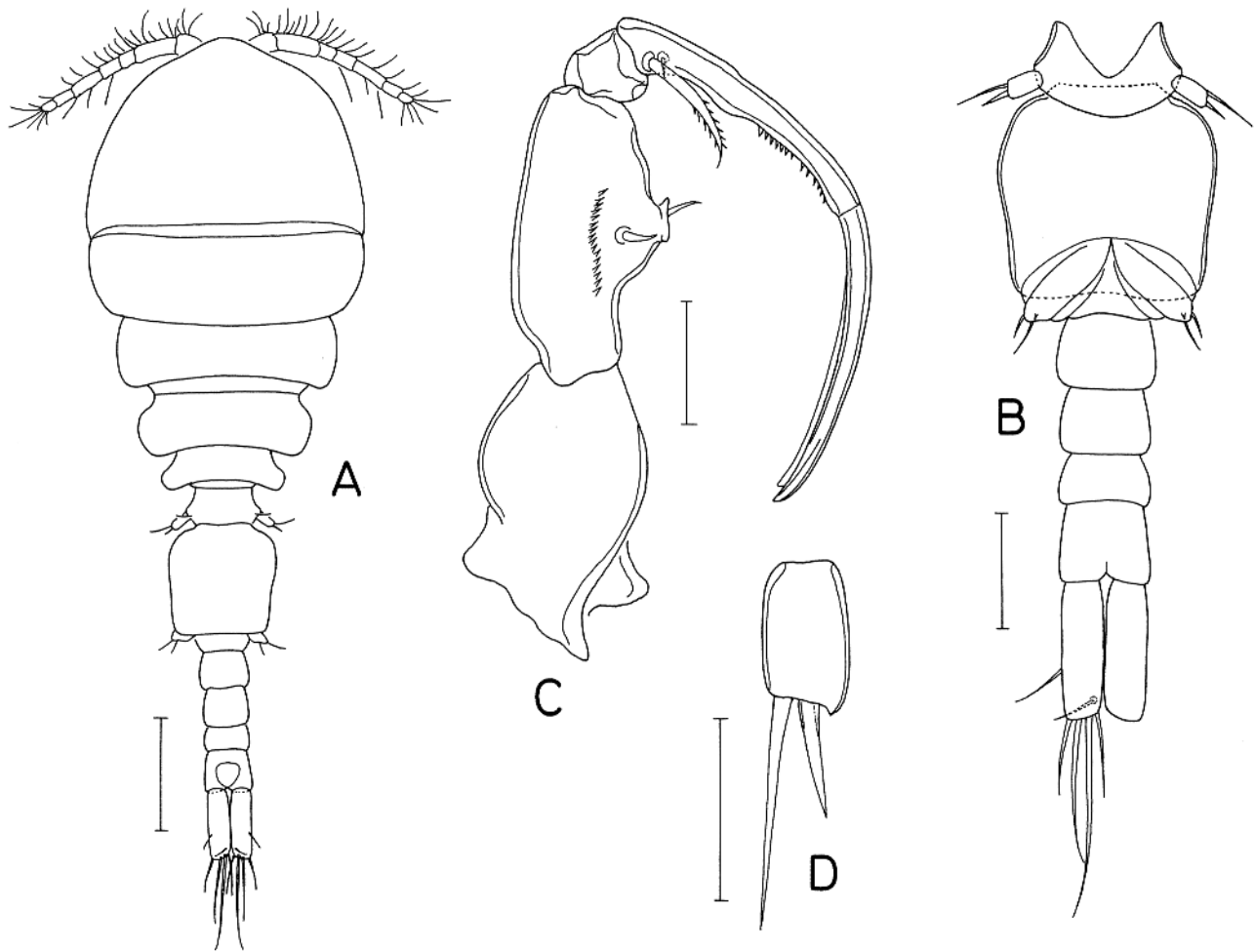


Fig. 11. *Lichomolgus infirmus* n. sp., male. A, habitus, dorsal; B, urosome, ventral; C, maxilliped; D, free segment of leg 5. Scales: A, 0.1 mm; B, 0.05 mm; C, D, 0.02 mm

process on the outer margin of the second endopodal segment of leg 4, as the new species.

Lichomolgus infirmus is easily distinguishable from the two species by the following traits possessed by the latter. *Lichomolgus eganae* is the associate of an ascidian in Australia (Gotto 1975). In this species the caudal ramus is wider than long (3.54 times as long as wide in *L. unfirmus*) and the free segment of leg 5 bears an inner process (none in *L. infirmus*). *Lichomolgus ierversi* was incompletely described originally by Thompson and Scott (1903), but later, Humes (1973) thoroughly redescribed it as the associate of a bivalve in New Caledonia. In this species the caudal ramus is elongated, 8.9 times as long as wide, the anal somite bears a pair of patches of proximal spinules (lacking in *L. infirmus*) on the ventral surface, and the free segment of leg 5 is elongated, six times as long as wide (1.63 times in *L. infirmus*).

It is notable that *Styela plicata*, the ascidian host of *L. infirmus*, is an invaded species of Korea came from the Atlantic.

Lichomolgus pectinatus n. sp. (Figs. 12-14)

Material examined

3♀, 2♂ collected from the *Pyura*-like solitary ascidian (collected along with *Protomolgus duplex* n. gen. n. sp. described above), at the depth of 40 m, off Guryongpo Port (35°58'51"N, 129°34'02"E), on the east coast of Korea, 13 November 2009, I.-H. Kim. Holotype (♀), allotype (♂), and paratype (1♀) have been deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea. Dissected paratypes (1♀, 1♂) are retained in the collection of the junior author.

Other material examined

5♀♀ (1♀ dissected) collected from the solitary ascidian *Herdmania momus* (Savigny), sublittoral, at Jeju Port (33°31'08"N, 126°31'46"E), 28 June 2010, I.-H. Kim.

Description

Female. Body (Fig. 12A) relatively narrow. Body length of dissected specimen 1.39 mm. Maximum width 489 µm. Prosome 920 µm long. Cephalothorax 500 µm long, divided by dorsal furrow into cephalosome and first pedigerous somite. Urosome (Fig. 12B) 5-segmented. Fifth pedigerous somite 129 µm wide. Genital double-somite rhomboidal, 188×152 µm, with widest area posterior to midlength of somite; genital areas large, positioned dorsolaterally at widest area of somite. Three free abdominal somites 54×71, 44×65, and 48×69 µm, respectively. Anal somite with a pair of rows of several spinules on proximal area of ventral surface (Fig. 12C). Caudal ramus broad, 42×32 µm (1.31:1), with 6 naked setae and minute spinules on posteroventral margin; lateral margins nearly parallel (Fig. 12C).

Rostrum (Fig. 13H) prominent, longer than wide, and narrowed posteriorly. Antennule (Fig. 12D) 337 µm long and 7-segmented, with armature formula 4, 13, 6, 3, 4+ aesthetasc, 2+aesthetasc, and 7+aesthetasc; all setae naked. Antenna (Fig. 12E) 4-segmented, with armature formula 1, 1, 3, and 3+4 claws; terminal segment about 73×30 µm (2.43:1), with minute spinules along outer margin; 4 terminal claws unequal, consisting of 2 long, setiform ones, 1 small but thickest one, and 1 small narrower one.

Labrum (Fig. 13G) with large posterior lobes, deep median incision, and minute spinules on posterior margin between posterior lobes; outer lateral margin of posterior lobes notched. Mandible (Fig. 12F) narrow, with elongated lash and spinules along both margins of blade and lash. Maxillule (Fig. 12G) with 2 distal setae and 1 small subdistal, setule-like process. Maxilla (Fig. 12H) 2-segmented; proximal segment unarmed; distal segment with elongated, spinulated lash and armed with spinulated inner seta (seta I) and naked anterior seta (seta II). Maxilliped (Fig. 12J) 3-segmented; first segment unarmed; second segment with 2 small, equal-sized setae; terminal segment small and terminated by spiniform process, with minute lateral setule.

Legs 1-3 with 3-segmented rami (Fig. 13A, B). Leg 4 (Fig. 13D) with 3-segmented exopod and 2-segmented endopod. Outer seta on basis of legs 1-4 small and naked; that of leg 2 much smaller than those of other legs. Inner

seta on coxa of legs 1-3 pinnate, but that of fourth leg naked. Distal endopodal segment of leg 4 80×32 µm, with 1 dentiform process on outer margin; distal corners pointed; 2 distal spines 50 (inner) and 36 µm (outer). Armature formula of legs 1-4 as follows:

Leg 1: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,4; enp. 0-1; 0-1; I,1,4

Leg 2: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,5; enp. 0-1; 0-2; I,II,3

Leg 3: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,5; enp. 0-1; 0-2; I,II,2

Leg 4: coxa 0-1; basis 1-0; exp. I-0; I-1; II,I,5; enp. 0-1; II

Leg 5 represented by 1 dorsolateral seta on fifth pedigerous somite and free segment (Fig. 12B); free segment (Fig. 12E) small, nearly rectangular, 37×24 µm (1.54:1), with slightly produced, pointed outer distal corner and distally 1 spine (32 µm) and 1 naked seta (53 µm). Leg 6 represented by 1 pinnate seta, 1 spinule, and 2 small spiniform processes (Fig. 13F).

Male. Body (Fig. 14A) very similar in shape to that of female. Body length of dissected specimen 754 µm. Urosome 6-segmented. Genital somite 113×89 µm, with rounded corners. Four abdominal somites 35×55, 33×48, 24×44, and 31×51 µm, respectively. Caudal ramus (Fig. 14B) 34×25 µm (1.36:1).

Rostrum as in female. Antennule with 3 additional aesthetascs: 2 on second and 1 on fourth segments at places of dots in Fig. 12D. Antenna with 1 additional seta (thus 4 setae) on third segment (Fig. 14C).

Mouthparts as in female, except for maxilliped. Maxilliped (Fig. 14D) 4-segmented; first segment unarmed; second segment with 2 inner setae, one of which transformed to robust, spiniform element bearing subdistal setule, and 1 longitudinal row of spinules on inner side; third segment small and unarmed; fourth segment as long, curved claw bearing proximally 1 naked seta and 1 setule.

Legs 1-4 as in female. Leg 5 (Fig. 14E) armed as in female; free segment 21×14 µm (1.50:1); distal spine 21 µm long. Leg 6 (Fig. 14F) represented by 2 small setae on genital flap.

Etymology

The specific name *pectinatus* is derived from the Latin *pecten* (=a comb). It alludes to the presence of a pair of comb-like rows of spinules on the ventral surface of the anal somite.

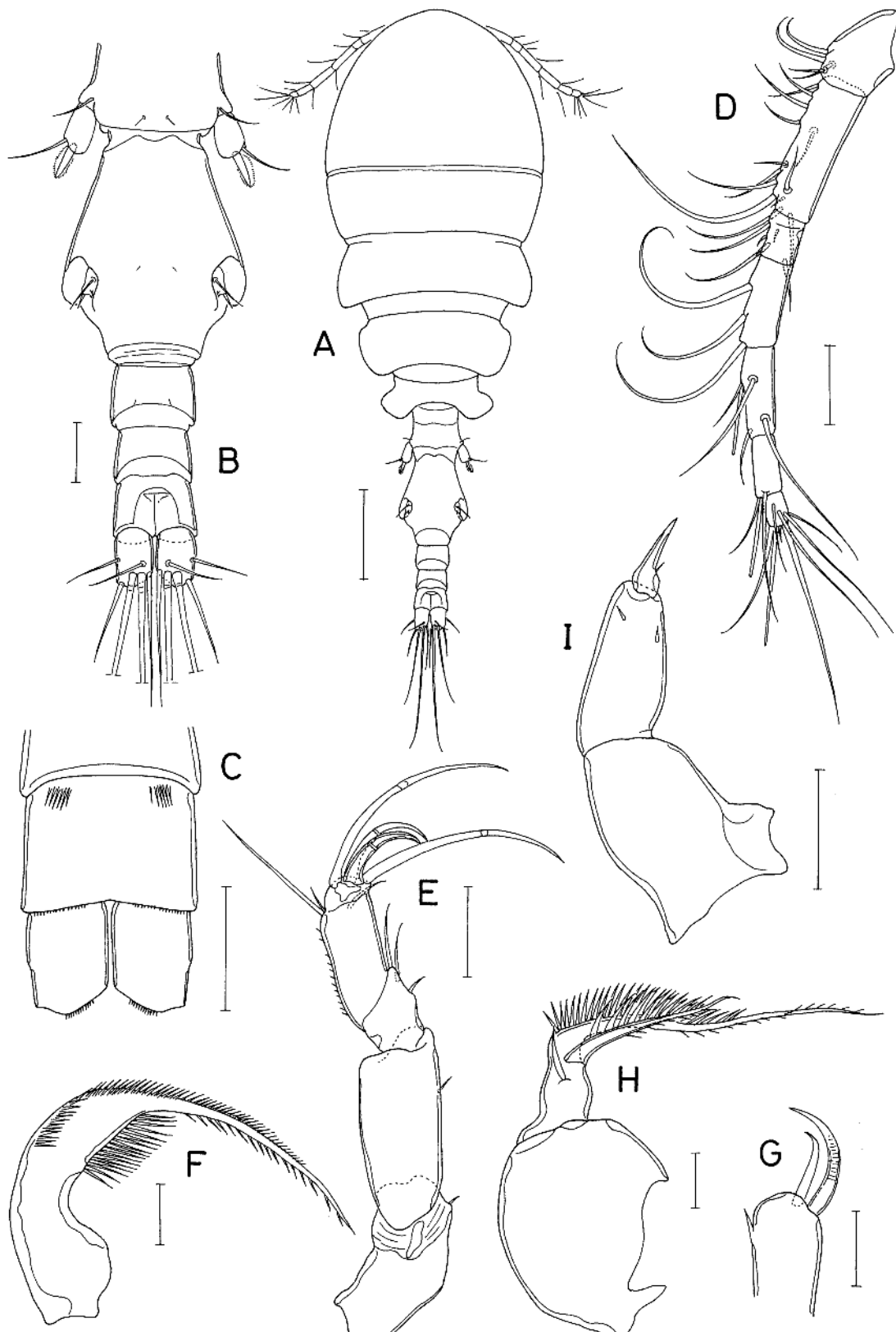


Fig. 12. *Lichomolgus pectinatus* n. sp., female. A, habitus, dorsal; B, urosome, dorsal; C, anal somite and caudal rami, ventral; D, antennule; E, antenna; F, mandible; G, maxillule; H, maxilla; I, maxilliped. Scales: A, 0.2 mm; B-E, I, 0.05 mm; F-H, 0.02 mm

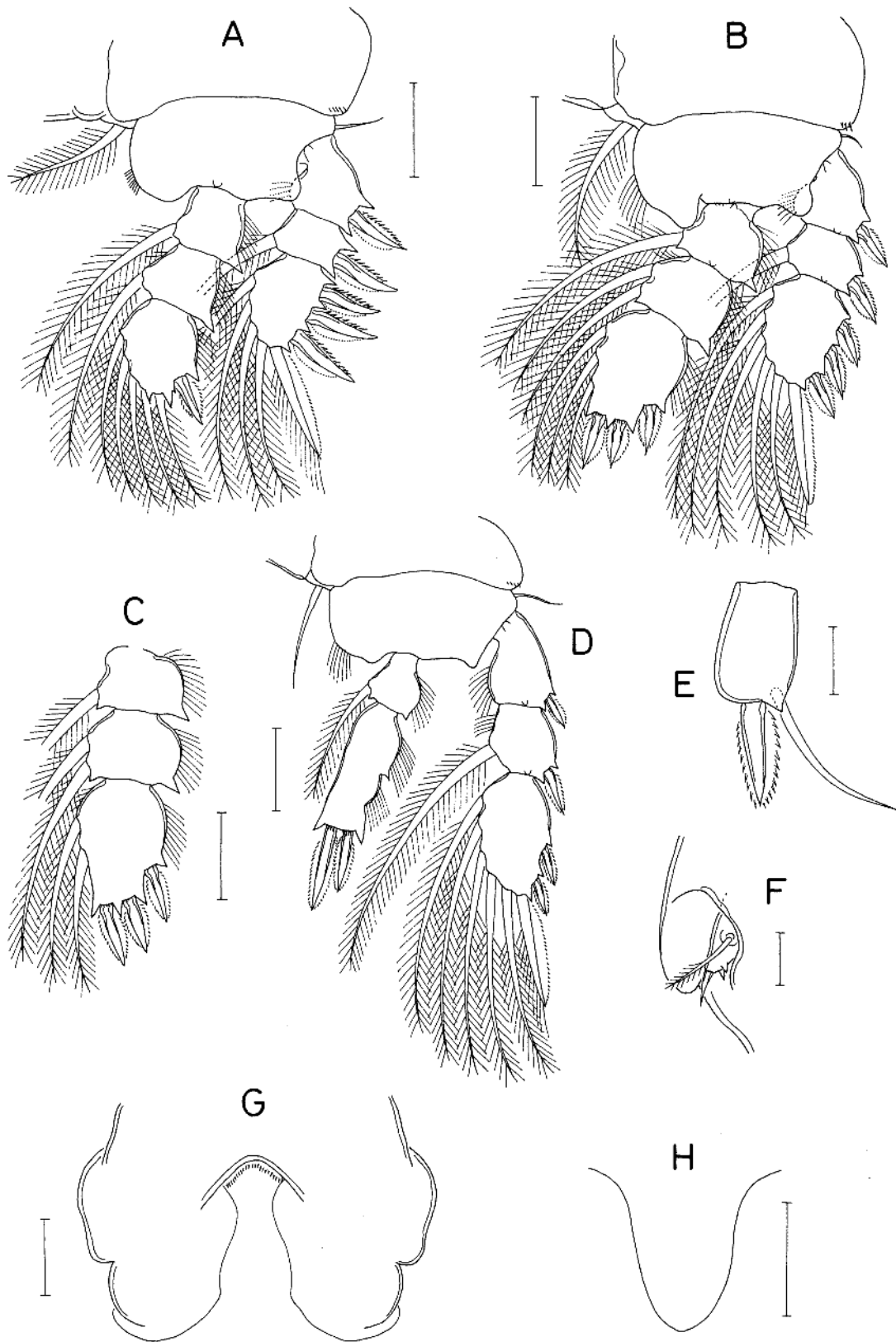


Fig. 13. *Lichomolgus pectinatus* n. sp., female. A, leg 1; B, leg 2; C, endopod of leg 3; D, leg 4; E, free segment of leg 5; F, genital area; G, labrum; H, rostrum. Scales: A-D, H, 0.05 mm; E-G, 0.02 mm

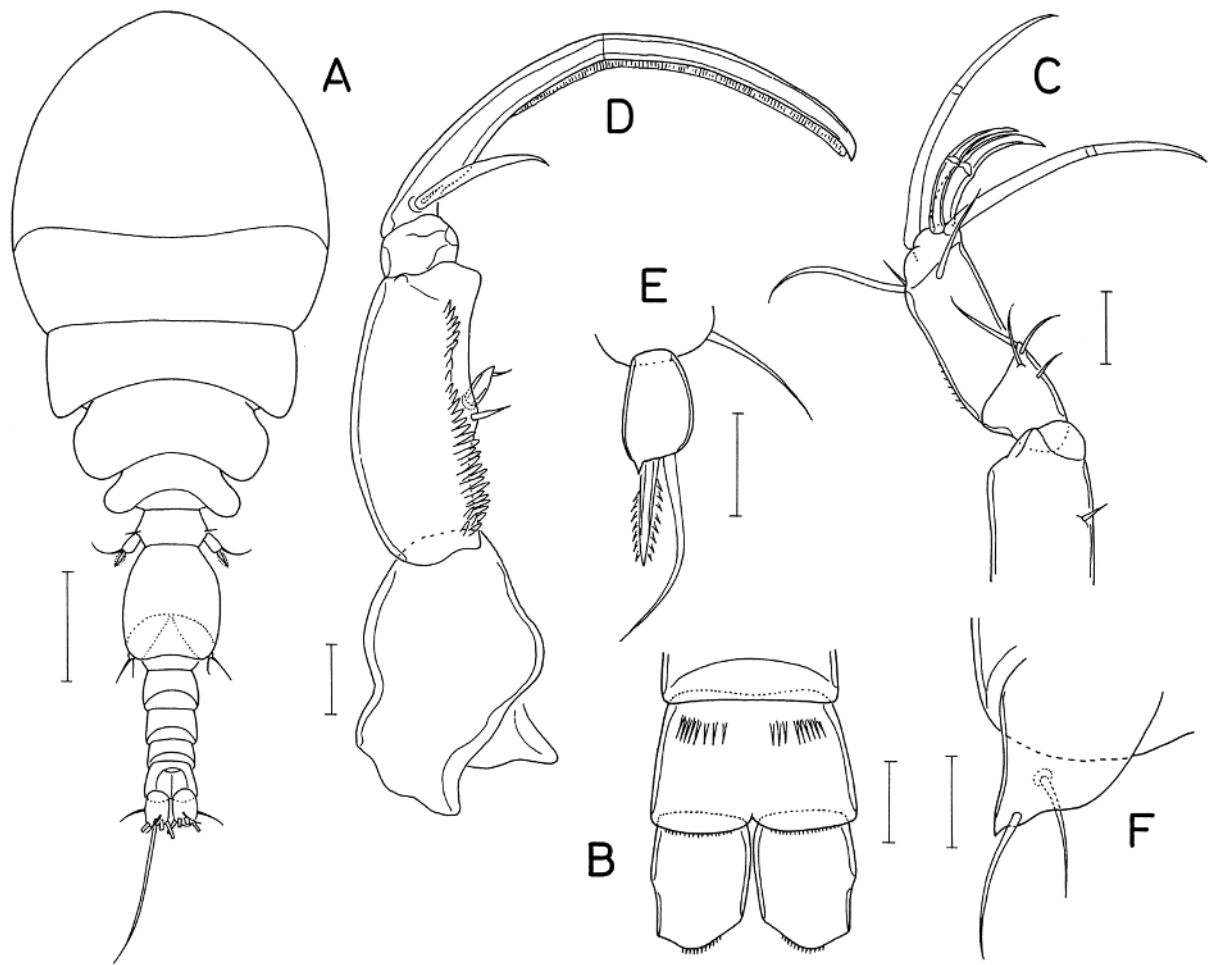


Fig. 14. *Lichomolgus pectinatus* n. sp., male. A, habitus, dorsal; B, anal somite and caudal rami, ventral; C, distal part of antenna; D, maxilliped; E, leg 5; F, leg 6. Scales: A, 0.1 mm; B, 0.2 mm; C-F, 0.02 mm

Remarks

Lichomolgus pectinatus n. sp. bears short caudal rami with the ratio of the length to width being 1.31:1. Similarly short caudal rami, in which the ratio is within a range of 1.0-2.0:1, are represented only by the two known species: *L. fusiformis* Kim, 2009 where the ratio is 1.28:1 (Kim 2009) and *L. nakaii* Matsuzaki and Ogawa, 1989 where the ratio is 1.37:1 (Kim 1998). It is interesting to note that all the three species are the associates of ascidians in the Indo-West Pacific.

Lichomolgus pectinatus differs from *L. nakaii*, because in the latter species 1) the genital double-somite of the female is widest in the middle (widest at place posterior to the middle in *L. pectinatus*); 2) the anal somite characteristically wider than the preceding somite and its ventral surface is not ornamented (with a pair of spinule rows in *L. pectinatus*); 3) the inner seta on the coxa of leg 4 is pinnate

(naked in *L. pectinatus*); and 4) the inner margin of the second segment of male maxilliped is distinctly pronounced in the middle.

A careful comparison is needed in the distinction of *L. pectinatus* from *L. fusiformis*, because the differences between these two species are very slight. They may be distinguished by the following ways: 1) the female genital double-somite of *L. pectinatus* is rhomboidal, with more distinct lateral expansion (fusiform in *L. fusiformis*); 2) the proximal spinules on the ventral surface of the anal somite is less developed in *L. pectinatus* than in *L. fusiformis*; 3) the rostrum of *L. pectinatus* is longer than wide (wider than long in *L. fusiformis*); 4) the inner seta on the coxa of leg 4 is quite large, extending over posterior margin of the basis, while it is small, not reaching the posterior margin in *L. fusiformis*; and 5) leg 6 of *L. pectinatus* is represented by one pinnate seta, one spiniform seta, and two dentiform

processes, whereas that of *L. fusiformis* is represented by one pinnate seta, one naked seta, and one dentiform process.

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