Three Species of Ditrichocorycaeus (Copepoda, Cyclopoida, Corycaeidae) from Korean Waters, with New Identification Parameters

Article *in* Ocean Science Journal · December 2013

DOI: 10.1007/s12601-013-0036-8

CITATION
1

READS
510

3 authors:

Jinhee Wi
Research Institute for Coastal Environment and Fishery-policy
41 PUBLICATIONS **177** CITATIONS
SEE PROFILE

Tae Oh Kim
Inje University Paik Hospital
851 PUBLICATIONS **14,743** CITATIONS
SEE PROFILE

Ho Young Soh
Chonnam National University, Yeosu
172 PUBLICATIONS **1,418** CITATIONS
SEE PROFILE

Ocean Sci. J. (2013) 48(4):419-437
http://dx.doi.org/10.1007/s12601-013-0036-8

Article

Available online at http://link.springer.com

SpringerLink

Ocean Science Journal

Three Species of *Ditrichocorycaeus* (Copepoda, Cyclopoida, Corycaeidae) from Korean Waters, with New Identification Parameters

Jin Hee Wi[1], Dae Hwan Kim[2], and Ho Young Soh[1]*

[1]*Department of Environmental Oceanography, College of Fisheries and Ocean Sciences, Chonnam National University, Yeosu 550-749, Korea*
[2]*Department of Oceanography, College of Natural Sciences, Chonnam National University, Gwangju 500-757, Korea*

Received 8 September 2013; Revised 10 November 2013; Accepted 30 November 2013

Abstract – Three species of *Ditrichocorycaeus* [*D. dahli* (Tanaka, 1957), *D. lubbocki* (Giesbrecht, 1981), and *D. subtilis* (Dahl, 1912)] are first redescribed from southern area of Jeju Island, Korea. Morphological details such as mouthparts, ornamentation of genital double-somite, spine lengths of legs, and proportional lengths of caudal setae, are provided as new identification keys separating each species within *Ditrichocorycaeus* and/or each genus within Corycaeidae. In particular, the number and location of each segment on the body and antenna are re-examined and precisely defined. Also, few valid morphological characters of this genus distinguishing it from other genera are newly proposed as follows: 1) prosomes of both sexes are five-segmented; 2) basis of maxilliped with relatively longer proximal seta than in other genera.

Key words – Corycaeidae, *Ditrichocorycaeus*, taxonomy, Kuroshio Warm Current

1. Introduction

The family Corycaeidae Dana, 1852 including two genera, *Corycaeus* Dana, 1845 and *Farranula* Wilson, 1932 are marine pelagic copepods occurring typically in epipelagic zone of tropical to temperate seas (Motoda 1963; Boxshall and Halsey 2004). Of these the genus *Ditrichocorycaeus* was created by Dahl (1912) as one of the seven subgenera within the genus *Corycaeus*, but has recently been elevated to generic level (Boxshall and Halsey 2004). At present, *Ditrichocorycaeus* includes 14 valid species (http://copepodes.obs-banyuls.fr), widely distributed in warm waters of the Indo-Pacific, Atlantic, East China Sea, and Mediterranean (Farran 1911; Wilson 1942; Sewell 1947; Razouls 1974; Chen et al. 1974; Vidjak 2008).

*Corresponding author. E-mail: hysoh@chonnam.ac.kr

Ditrichocorycaeus is characterized by possession of two setae on the leg 4 endopod (Dahl 1912) and is divided into two groups by relative lengths of caudal ramus: the first group has a short caudal ramus almost equal to the anal somite and shorter than genital somite, while the second group has a has relatively long caudal ramus compared to anal and genital somites (Dahl 1912; Tanaka 1957). The genus *Ditrichicorycaeus* is the most diverse (Dahl 1912; Boxshall and Halsey 2004; Vidjak and Bojaniæ 2008) in the Corycaeidae and their small body length (< 1 mm) and very close general morphology have led to frequent taxonomic confusion (Farran 1911; Wi and Soh 2013a, b). Moreover, the taxonomic descriptions of the species in the world oceans are fragmentary and insufficient (e.g. Dahl 1912; Sewell 1947; Tanaka 1957; Chen et al. 1974; Zheng et al. 1982). For these reasons, the species within *Ditrichocorycaeus* recorded from Korean waters were just three species such as *D. affinis* (McMurrich, 1916), *D. erythraeus* (Cleve, 1904), *and D. andrewsi* (Farran, 1911) (Kang et al. 1990).

In this study, the morphological characteristics easily differentiating the species within *Ditirichocorycaeus* as well as the other genera of Corycaeidae are described in detail and discussed. Additionally, a comprehensive comparison among morphological characters of three species of *Ditrichocorycaeus* from different regions can be used as identification parameters to define new species or establish variations of Corycaeidae occurring from diverse regions.

2. Materials and Methods

Zooplankton was collected from off the south of Jeju Island,

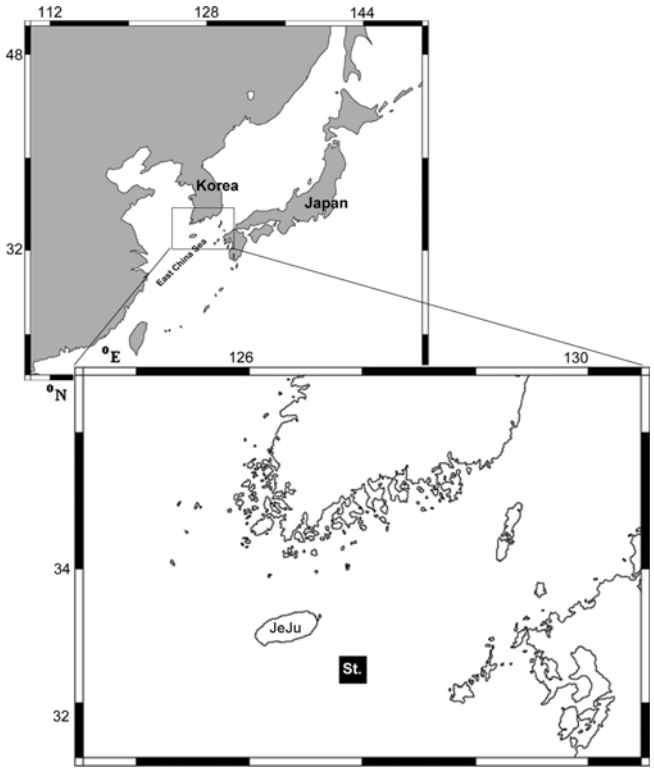

Fig. 1. Location of sampling station A, off south east of Jeju Island, Korea

Korea on 17 June 2009 (Fig. 1). A conical net (mesh size 100 μm, mouth diameter 45 cm) was towed vertically from near bottom to surface (total depth 111 m, temperature 18.0~21.5°C, salinity 34.1~34.5). The specimens were fixed in 99.9% ethanol (not denaturated). *Ditrichocorycaeus* species were sorted out from zooplankton samples. Each specimen was dissected under a dissecting microscope (Nikon, JP/E200) in CMC-10 aqueous mounting medium (Masters Co., Wood Dale, IL, USA), mounted on slides, and sealed with high-quality nail varnish. Drawings were made using a stereo-microscope (Nikon AFX-II) equipped with a drawing tube. Scale bars were given in μm. Total body length and the ratio of prosome to urosome (including caudal rami) were measured in lateral aspect, and telescoping of body somites was not considered. However, measurements of the relative lengths of different urosomites were adjusted for the telescoping effect. Measurements of length of first endopodal segment of antenna and basis of maxilliped were carried out along the outer margin. Zoogeographical distributions of *Ditrichocorycaeus* (Dahl, 1912) were determined from the web site of Razouls et al. (2013; http://copepodes.obs-banyuls.fr). The descriptive terminology follows Huys and Boxshall (1991). Abbreviations used in text and figure legend follow the conventional ones frequently used in the taxonomy of copepods: ae, aesthetasc; CR, caudal rami; P1-P6, first to sixth thoracopods; exp, exopod; enp, endopod; exp(enp)-1(-2,-3) is used to denote the proximal (middle, distal) segment of a ramus.

All voucher specimens were deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea.

Taxonomy

Order **Cyclopoida** Burmeister, 1835
Family **Corycaeidae** Dana, 1952
Genus ***Ditrichocorycaeus*** (Dahl, 1912)
Ditrichocorycaeus dahli **(**Tanaka, 1957)
(Figs. 2-4)

Corycaeus (*Ditrichocorycaeus*) *dahli* Tanaka, 1957, pl. 8, figs. 1-5; Chen et al., 1974, pl.8, figs.1-4; Zheng et al., 1982, pl.18, figs.1-7; Itoh, 1997, pl. 201, fig. 342; Al-Yamani and Prusova, 2003, p.134, figs. 51, 52.

Corycaeus tenuis: Farran, 1911, pl. 12, figs. 8, 9.

C. (*Ditrichocorycaeus*) *lubbocki*: Dahl, 1912, taf. 10, figs. 20-28.

C. (*Ditrichocorycaeus*) *africanus*: Sewell, 1947, fig. 70 A-C.

Material examined

Thirty two females and nine males were collected from off west of Jeju Island of Korea (126°5′E, 32°00′N) on 17 June 2009, of which five females and five males were dissected and closely examined; 2 females (NIBRIV0000282439) and 2 males (NIBRIV0000282440) have been deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea.

Description

Female

Body cylindrical, tapering posteriorly. Total body length in lateral view 1.11-1.15 mm (n=4), measured from anterior margin of prosome to posterior margin of CR. Urosome distinctly narrower than prosome (Fig. 2A, B).

Prosome five-segmented, comprising cephlosome and four pedigerous somites, frontal margin rounded, with two separate cuticular lenses, about 1.7 times as long as urosome including CR, 2.8 times as long as urosome length excluding CR (Fig. 2A), first pedigerous somite separated from cephalosome and 1.6 times longer than successive pedigerous somites, second pedigerous somite distinctly separated from

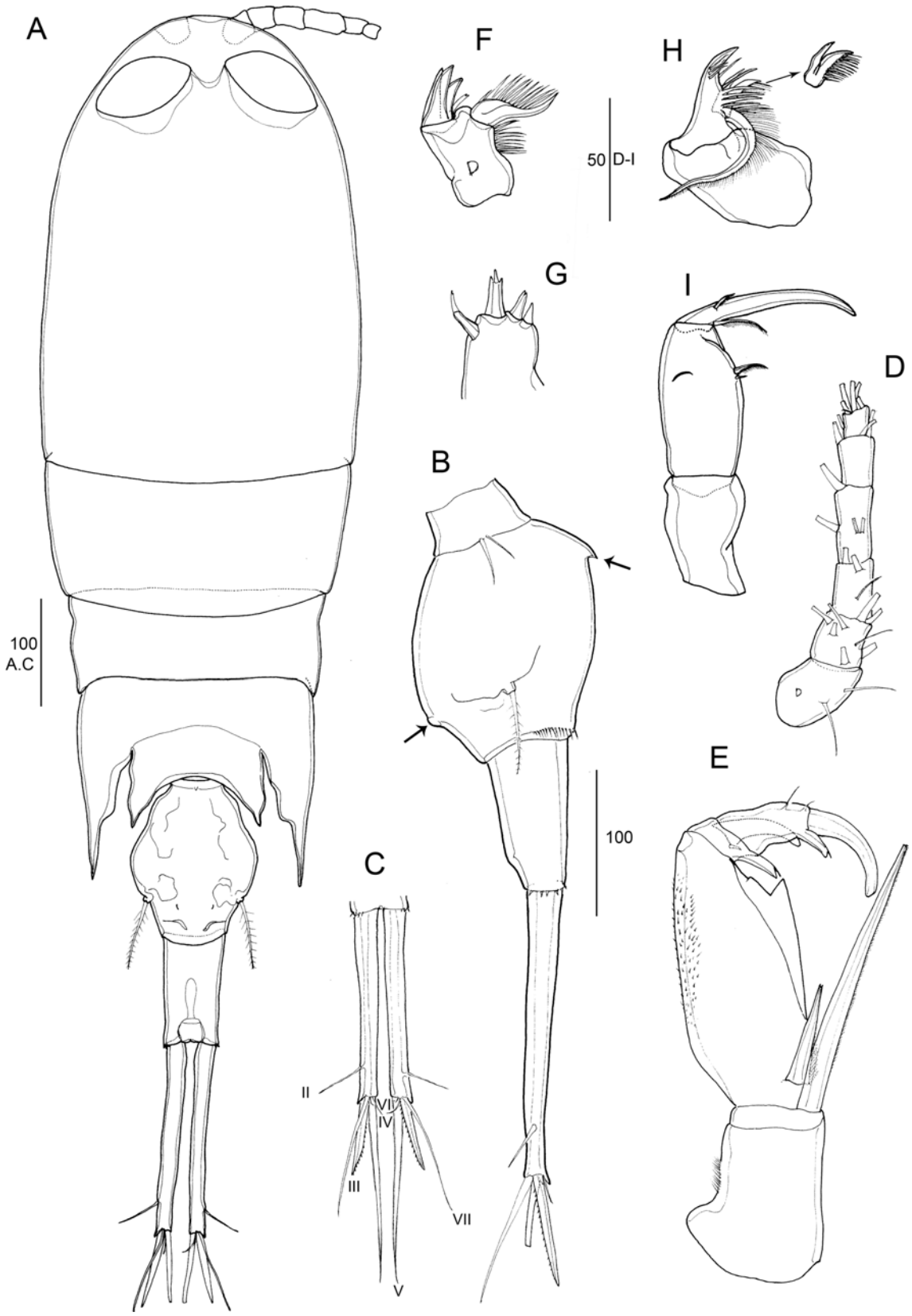

Fig. 2. *Ditrichocorycaeus dahli* female. A, habitus (dorsal view); B, urosome; C, caudal rami (caudal setae numbering using Roman numerals); D, antennule; E, antenna; F, mandible; G, maxillule; H, maxilla; I, maxilliped

previous and next somites, third and fourth pedigerous somites weakly separated along dorsal margin, both posterolateral margins extended and pointed, posterolateral margin of fourth pedigerous somite reaching to two thirds of genital double-somite and inner margins irregularly curved.

Urosome (Fig. 2A, B) three-segmented, comprising fifth pedigerous somite bearing P5 ventrolaterally, genital double-somite, and anal somite: genital double-somite reflexed and laterally swollen and 1.2 times longer than maximum width at anterior two thirds, and dorsal margin with small round process at anterior three quarters in lateral view (indicated by arrow in Fig. 2B), minute hook-like projection arising from anterior ventral margin in lateral view (indicated by arrow in Fig. 2B), distal margin ventrally fringed with spinules, genital aperture dorsolaterally located at anterior three quarters. Each operculum armed with one plumose seta; anal somite (Fig. 2A, B) slightly tapering posteriorly, with large anal opening dorsally, 1.8 times longer than wide at base and 1.4 times shorter than genital double-somite, distal margin ventrally fringed with coarse teeth.

CR (Fig. 2A-C) cylindrical, about 1.8 times longer than genital double-somite, 10.2 times longer than width at base and 1.9 times longer than anal somite, each ramus armed with six setae: short anterolateral seta II, serrated outer seta III, short and slender seta IV, inner long seta V, short terminal accessory seta VI, and dorsal seta VII located on small pedestal, seta VII about 1.6 times as long as seta III.

Antennule (Fig. 2D) short, six-segmented. Armature formula; 1-[2], 2-[8], 3-[2+ae], 6-[5+(1+ae)]. Proportional lengths (%) of segments measured along posterior non-setiferous margin 19.0: 17.5: 15.9: 23.8: 15.9: 7.9.

Antenna sexually dimorphic, four-segmented (Fig. 2E), with coxa and basis fused and endopod three-segmented; coxobasis with long strong seta at inner distal margin, outer surface partly ornamented with spinules; first enopodal segment robust, much longer than rest of endopodal segments, about 3.5 times as long as width at base, bearing short, stout seta on inner proximal margin, 3 times shorter than coxobasal seta, inner distal margin formed into two different sized teeth, proximal one distinctly and powerfully protruded and distal one weakly protruded, outer lateral margin randomly ornamented with denticles; second endopodal segment short, bearing three elements: curved spine arising from outer distal margin and small spine located near its base, and curved spine arising from inner margin with split tip; third endopodal segment cylindrical, twice as long as width at base, slightly longer than distal outer spine on second endopodal segment and armed with four elements, short curved spine arising from inner distal margin with split end, small naked setae on outer distal margin, and terminal spine drawn into curved claw, longer than outer spine on first endopodal segment.

Mandible (Fig. 2F) with two elements on gnathobase: one spine and one blade; spine broad and robust, bicuspid, with spiniform processes on ventral side, and blade forming spinuous processes, surrounded by patch of spinules around the base.

Maxillule (Fig. 2G) reduced, praecoxal arthrite bearing four articulated spinous elements: innermost one A at some distance of other elements, distal area pointed; element B broad and stout and distal margin with spinous process, almost equal to length of element A, element C short, with spinous process, twice shorter than element B, and element D shortest and naked, slightly shorter than element C. Length ratios of elements approx. 100.0:92.2:44.4:38.9.

Maxilla (Fig. 2G, H) two-segmented, allobasis as long as syncoxa: syncoxa unarmed; allobasis produced distally into curved, strong spine, with four naked setae distally, inner margin bearing two elements in different shape: one split into two branches, with comb-like spine and naked spine, other one forming long unipectinate spine, and with several spinous spine between claw and long unipinnate spine.

Maxilliped (Fig. 2I) three-segmented: syncoxa unarmed; basis robust and expanded, 2.5 times as long as width at base, with two elements along inner margin: proximal one short, located at base of distal one, distal one slightly curved and unipinnate; endopodal segment drawn out into long curved claw, unornamented and slightly longer than basis, accessory armature consisting of slender, unipinnate spine on inner proximal margin and short unipinnate spine laterally on outer proximal margin, 2.5 times shorter than inner proximal spine.

Legs 1-3 (Fig. 3A-C) comprising of coxa, basis and three-segmented rami; intercoxal sclerites well developed, forming different shape, coxa of P1 and P2 with plumose inner coxal seta, basis of P1 and P3 with round process between insertions of endopod and exopod; basis of P1 and P3 with basal outer seta, exopods distinctly longer than endopods.

Exopods of P1 to P3 fringed with long setules along inner margin of exp-1, exp-2 of P1 stout and in P2 and P3 more slender, outer spines biserrate, terminal spine with serrate outer and pinnate inner margin, distal area of terminal spine of P2 incurved and with serration. Length ratios of terminal

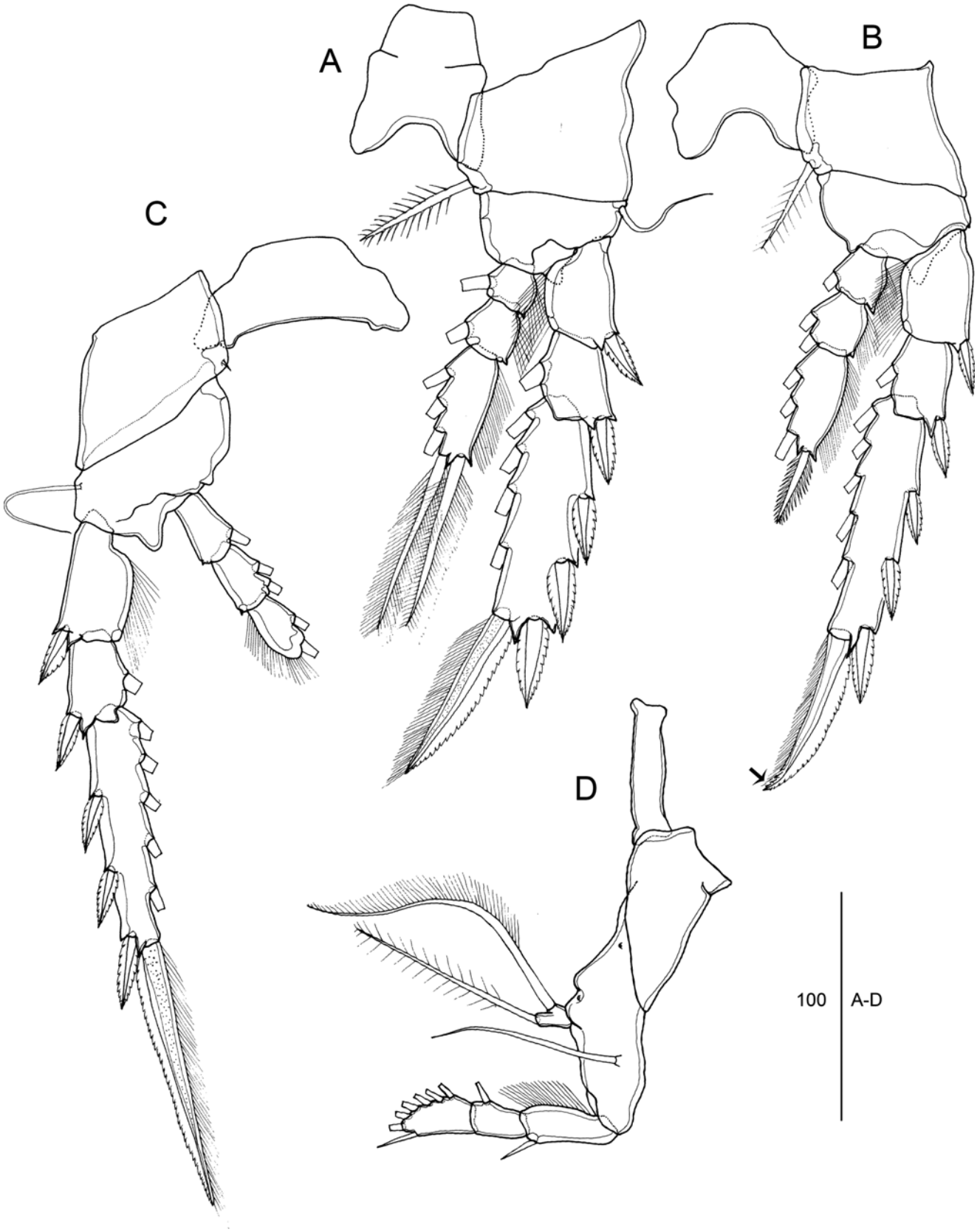

Fig. 3. *Ditrichocorycaeus dahli* female. A, P1; B, P2; C, P3; D, P4

Table 1. Armature formula of P1 to P4 in genus *Ditrichocorycaeus*

Leg	Coxa	Basis	Exopod	Endopod
P1	0-1	1-0	1-0; 1-1; III, I, 4	0-1; 0-1; 0, 1, 4
P2	0-1	0-0	1-0; 1-1; III, I, 5	0-1; 0-2; 0, 1, 3
P3	0-0	1-0	1-0; 1-1; III, I, 5	0-1; 0-2; 0, 0, 2
P4	0-0	1-0	1-0; 0-1; I, 6	-; - ; 0,1,1

Roman numerals indicate spines, Arabic numerals indicate setae

spine to distal outer spine: P1 smallest (about 1.9:1), in P2 2.3:1, and P3 largest (3.7:1); length ratios of terminal spines to exp-3, in P1 1:1.2, in P2 1:1.4, and in P3 terminal spine slightly longer.

Endopods of P1 to P3: outer margins of segments of P1 and P2 fringed with long setules, in P3 only distal segment fringed with long setules, enp-3 of P2 almost same to that of P1, and enp-3 of P3 shortest. Terminal seta on enp-3 shortest in P2, forming spiniform spine, while longest in P3.

P4 (Fig. 3D) with transversely extended, narrow intercoxal sclerite, almost rectangular in shape; coxa unarmed; basis with outer basal seta arising from the posterior surface; exopod well developed, three-segmented, bearing spinules along inner margin of exp-1, proportional length ratio of each segment 42.5: 25.0: 32.5, spine on outer distal corner of exp-1 and outer terminal spine on exp-3 almost equal in length, and exp-3 1.8 times longer than terminal spine.; endopod reduced to a knob-like segment, with two plumose terminal setae, different in length.

Armature formula of P1 to P4 as shown in Table 1.

P5 (Fig. 2B) consisting of two unequal simple setae located ventrolaterally, outer seta about 1.4 times longer than inner one.

P6 (Fig. 2A, B) represented by operculum closing off each genital aperture, with plumose seta, dorsally located at two thirds distance of genital double-somite.

Male

Total body length in lateral view 0.90-0.91 mm (n=5), measured from anterior margin of prosome to posterior margin of urosome. Urosome distinctly narrower than prosome (Fig. 4A).

Prosome five-segmented, two large contiguous cuticular lenses very close to each other on frontal area: cephalosome fused to first pedigerous somite, prosome about 1.3 times as long as urosome including CR, 2.1 times as long as urosome excluding CR (Fig. 4A); third and fourth pedigerous somites distinctly separated along the dorsal surface, with outer and inner pleural areas: outer one with extended and pointed postrolateral corners, reaching to anterior one-third of genital somite, and inner one shorter than outer one, with round margin and pointed tip.

Genital somite (Fig. 4A, B) oval, 1.6 times as long as maximum width at mid-region, ventral hook arising from anterior ventral margin prominent in lateral view, genital area ventrally formed into flaps derived from P6, each flap with long plumose seta, with small process at base, anterior surface ornamented with two rows of spinules unequal in length.

Anal somite (Fig. 4A) slightly tapering toward distal margin, 1.7 times as long as wide at base, with large opening and four secretory pores dorsally, 2.2 times shorter than genital somite.

CR 6.6 times longer than width at base (Fig. 4A), about 1.5 times longer than genital somite, and 1.4 times longer than anal somite. Armature of rami similar to that of female. Caudal seta VII 1.3 times longer than seta III.

Antennule (not figured) with segmentation and armature similar to that of female.

Antenna (Fig. 4C) sexually dimorphic, four-segmented, with coxa and basis fused and endopod three-segmented: coxobasis ornamented with patch of spinules on inner distal margin, with long strong seta on inner distal margin; first endopodal segment about 2.8 times as long as wide at base, bearing unipinnate seta on ventral proximal margin, 1.2 times shorter than coxobasal seta, inner distal margin with two large teeth-like protrusion, mid-ventral surface vertically ornamented with row of coarse teeth gradually increasing in length towards distal margin of the segment, outer lateral margin randomly ornamented with small denticles; second endopodal segment short, bearing three elements: curved stout spine arising from outer distal margin, with small spine at its base, and short curved spine arising from inner distal margin; third endopodal segment cylindrical, 2.3 times as long as wide at base, armed with outer distal naked seta and inner distal spine, slightly longer than second endopodal inner spine, and terminal spine drawn out into long claw, much longer than that of female.

Maxilliped (Fig. 4D) sexually dimorphic, four-segmented, comprising syncoxa, basis and two-segmented subchela: syncoxa without surface ornamentation, unarmed; basis robust, oval-shaped, bearing two setae unequal in length on inner margin: proximal one slender and naked, distal one ornamented with row of spinules along inner margin, 1.5

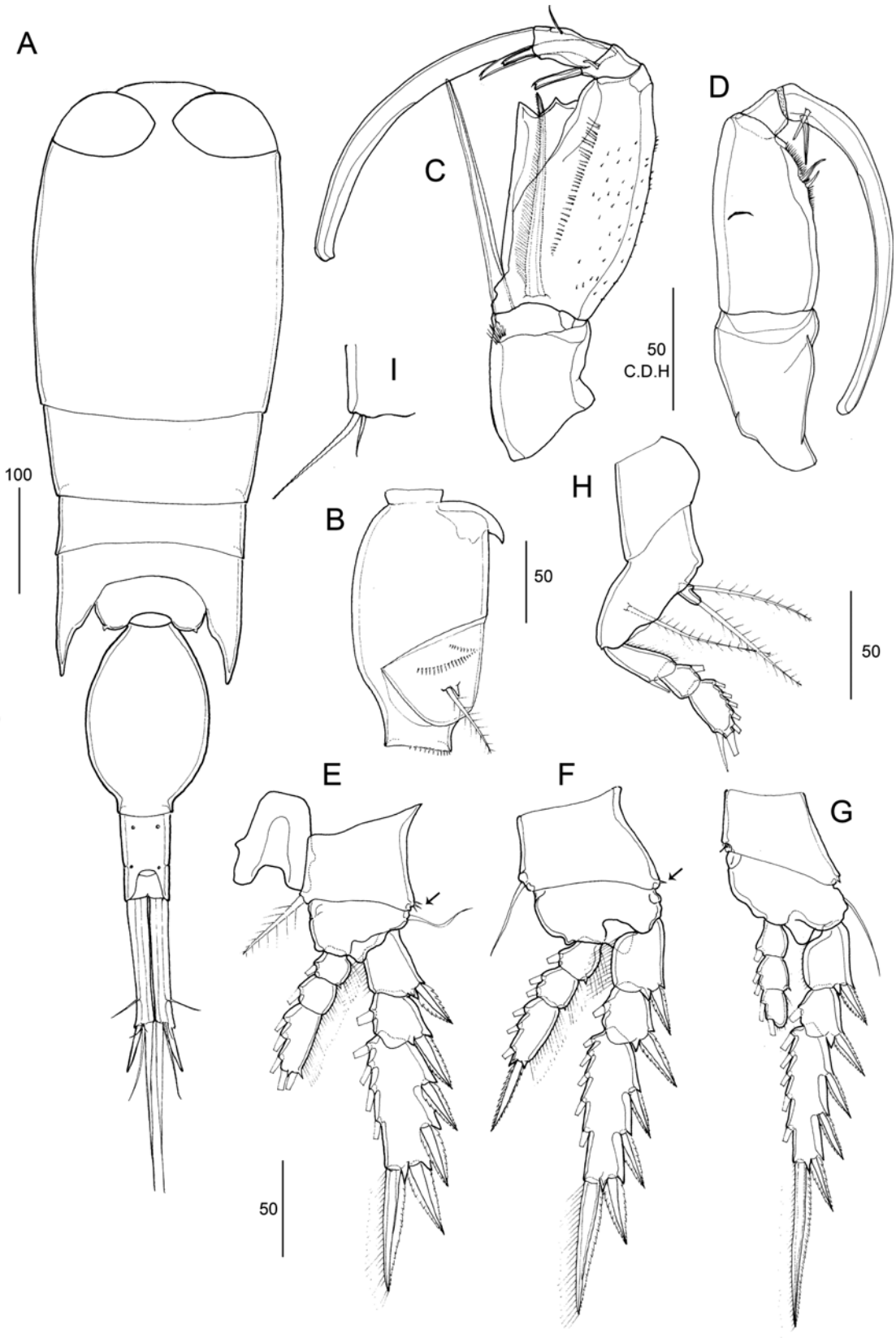

Fig. 4. *Ditrichocorycaeus dahli* male. A, habitus (dorsal); B, genital somite (lateral); C antenna; D, maxilliped; E, P1; F, P2; G, P3; H, P4; I, P5

times longer than proximal one, with fine spinules near two spinules, and outer margin recessed in mid region; subchela comprising unarmed proximal and distal endopodal segments, drawn out into long curved claw, with accessory armature consisted of unipinnate spines on lateroproximal margin and inner proximal corner of claw, respectively, inner one 1.6 times longer than lateral one.

Legs1-3 (Fig. 4E-G) segmentation and armature similar to those of female, except relative length ratios of terminal spine to outer distal spine (in P1 1.3:1, in P2 1.9:1, and in P3 3:1) and terminal spine to exp-3 (in P1 1:1.1, in P2 1:1.1, and in P3 1.2:1).

P4 (Fig. 4H) similar to that of female, except relative length of proximal spine on exp-1 to terminal spine on distal segment shorter (1.6 times) than that of female (almost equal).

P5 (Fig. 4I) similar to that of female, except for longer outer seta (2.9 times) than inner seta, as compared to that of female.

P6 (Fig. 4B) represented by genital flap closing off each genital aperture, armed with long seta, near its base with pointed process, surface ornamented with three rows of spinules.

Remarks

Ditrichocorycaeus dahli (Tanaka, 1957) has been erroneously described as *D. lubbocki* (as *Corycaeus* (*Ditrichocorycaeus*) *lubbocki* Dahl, 1912) and *D. africaus* (as *Corycaeus africanus* Sewell, 1947), but Tanaka (1957) assigned the specimen as new species by morphological differences of the proportional length of abdominal segments and caudal ramus, total lengths, and the presence of the serration along the inner anterior side of the apical spine of P2 exp-3. The female of *D. dahli* (as *Corycaeus* (*Ditrichocorycaeus*) *dahli*) described by Tanaka (1957), which was slightly smaller (1.03-1.08 mm) than Korean specimens (mean 1.15 mm) in the body length, and also the length to width ratio of CR is much larger (16:1) than Korean specimens (10.2:1), however, the shape of genital double-somite and length ratio of the terminal spine to the distal outer spine on P2 exp-3 well agreed to Korean specimens. Although P4 and caudal setae are considered as important identification keys of small cyclopoids, those of female were not described by Tanaka (1957). Chen et al. (1974) also provided details about dorsal habitus, genital somite, and antenna of both sexes and P4 of female only, of which ornamentation and segmentation of antenna were not examined; the lengths of proximal and terminal setae on P4

Table 2. A morphological comparison among three species of the genus *Ditrichocorycaeus*. PR: prosome, UR: urosome, -CR: including CR, +CR: excluding CR, GDS/GS: genital double- somite/genital somite

Species character	*Ditrichocorycaeus dahli*		*Ditrichocorycaeus lubbocki*		*Ditrichocorycaeus subtilis*	
	♀	♂	♀	♂	♀	♂
PR:UR (-CR /+CR)	2.8:1/1.7:1	2.1:1/1.3:1	2.7:1/1.5:1	1.7:1/1.2:1	2.8:1/2:1	2:1/1.6:1
GDS/GS:CR	1:1.8	1.5:1	1:1.2	1.5:1	1.6:1	2:1
GS:anal somite	1.4:1	2.2:1	2:1	2:1	1.6:1	2.3:1
CR						
Length to width	10.2:1	6.6:1	9.8:1	7.1:1	4.3:1	5.5:1
Seta III:setaVII	1:1.6	1:1.3	1:1.7	1:1.6	1:2.6	1:1
Antenna						
Length to width of 1st endopodal segment	3.5:1	2.8:1	2.5:1	2.5:1	2.5:1	2.5:1
Length ratio of coxal seta:1st endopodal seta	3:1	1:1.2	3.1:1	1:1.2	3.3:1	1:1.2
Maxilliped						
Width to length of basis	1:2.5	-	1:2.2		1:2.3	1:2.7
Length ratio of proximal seta to distal seta on basis	-	1:1.5	-	1:1.2	-	1:1.9
P1/P2/P3exp-3						
Distal segment to terminal spine	1.2:1/1.4:1/1:1	1.1:1/1.1:1/1:1.2	1.2:1/1.3:1/1:1	1.1:1/1.3:1/1:1.1	1.5:1/1.6:1/1:1	1.4:1/1.4:1/1:1.2
Terminal spine to distal outer spine	1.8:1/2.3:1/3.7	1.3:1/1.9:1/3:1	1.9:1/2.6:1/3.4:1	1.7:1/2.1:1/2.9:1	1.9:1/2.3:1/4.1:1	1.8:1/2.4:1/3.7:1
P4exp						
proximal spine to terminal spine	Almost equal	1:1.6	1:1.4	Almost equal	1:2.3	1:1.5
terminal spine to distal segment	1:1.8	1:1.8	1:1.7	1:1.3	1:2	1:2.3
GDS/GS						
Ventral process	pointed	hook-like	round	hook-like	absent	minute and pointed

exopod differedm but were almost the same as in Korean specimens. Female illustrations by Zheng et al. (1982) almost equal to those of Korean *D. dahli*, except that the lengths of endopodal setae of P4 were reverse to those of Korean specimen, and proportions of caudal setae. On the other hand, the previous illustrations of *D. dahli*, above mentioned, did not include the mouthparts, spine lengths of the legs, and proportions of the caudal setae, therefore, we provided additional identification parameters through a comprehensive comparison of the morphological details among three species of *Ditrichocorycaeus* from Korean waters, including mouthparts, in Table 2.

Ditrichocorycaeus lubbocki (Giesbrecht, 1891)

(Figs. 5-7)

Corycaeuus lubbocki Giesbrecht, 1891; 1892), fig. 57; Sewell, 1947, fig. 71; Tanaka, 1957, pl. 7, figs. 1-4; Chen et al., 1974, pl. 18, figs. 8-12; Zheng et al., 1982, fig. 90.

Corycaeus farrani: Früchtl, 1924, p.96, fig. 72.

Material examined

Fifty four females and twelve males collected from off south of Jeju Island of Korea (12°65′E, 32°00′N) on 17 June 2009, of which three females and three males were dissected and closely examined in detail; 2 females (NIBRIV0000282441) and 2 males (NIBRIV0000282442) have been deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea.

Description

Female

Body cylindrical, tapering posteriorly. Total body length in lateral view 0.98-1.03 mm (n=4), measured from anterior margin of prosome to posterior margin of CR. Urosome distinctly narrower than prosome (Fig. 5A, B).

Prosome 1.5 times longer than urosome including CR, 2.7 times longer than urosme excluding CR (Fig. 5A, B). Cephalosome 1.6 times longer than successive pedigerous somites; lateral margins of third pedigerous somite extended, reaching to anterior three-fifths distance of genital double-somite and inner margins slightly curved without flection; lateral margins of fourth pedigerous somite curved and distally pointed.

Genital double-somite (Fig. 5A-C) distally sagged (indicated by arrow in Fig. 5A, C), covering anterior margin of anal somite, 1.5 times larger than maximum width at mid area and anteroventral margin rounded, with small round process (indicated by arrow in Fig. 5C), distal margin ventrolaterally fringed with spinules, genital aperture dorsolaterally located at anterior three quarters, each operculum armed with one plumose seta.

Anal somite (Fig. 5A-C) with large anal opening dorsally, 1.4 times longer than wide at base and twice shorter than genital double-somite, distal margin ventrolaterally fringed with coarse teeth.

CR (Fig. 5A, B) similar to that of *D. dahli*. But, caudal ramus 1.2 times shorter than genital double-somite, 2.2 times longer than anal somite, and 9.8 times longer than wide at base.

Antennule (not figured) similar to that of *D. dahli*.

Antenna (Fig. 6A) similar to that of *D. dahli*. But, length to width ratio of first endopodal segment 2.5:1, first endopodal seta 3.1 times shorter than coxal seta, distal teeth-like protrusion on first endopodal segment prominently protruded, and outer distal spine on second endopodal segment extended over third endopodal segment.

Mandible (Fig. 6B), and maxilla similar to those of *D. dahli*.

Maxillule (Fig. 6C) similar to that of *D. dahli*, except for proportion lengths of each element 89.8:100.0:50.8:28.1.

Maxilliped (Fig. 6D) similar to that of *D. dahli*. But, basis 2.2 times as long as wide at base, endopodal segment drawn out into long curved claw, unornamented and 1.5 times longer than basis, accessory armature consisting of slender, unipinnate spine on inner proximal margin and unipinnate spine on outer lateroproximal margin, 3.1 times shorter than inner proximal spine.

Legs 1-3 (Fig. 6E-G) with armature and ornamentation as in *D. dahli*.

Exopods of P1 - P3: length ratios of terminal spines to distal spines, in P1 smallest (about 1.9:1), in P2 2.6:1, and P3 largest (3.4:1), length ratios of terminal spines to distal segments, in P1 1:1.2, in P2 1:1.3, and in P3 equal, and terminal spine of P2 with serration on inner distal area.

P4 (Fig. 6H) similar to that of *D. dahli*, except proportional lengths of exopodal segments 37.7: 24.6: 37.7, terminal spine on exp-3 1.4 times longer than outer distal spine on exp-1 and 1.7 times shorter than exp-3. Endopod reduced to knob-like segment, with two plumose terminal setae, different in length.

P5 (Fig. 5D) consisting of two unequal simple setae, located ventrolaterally, outer seta about twice longer than inner one in dorsal view.

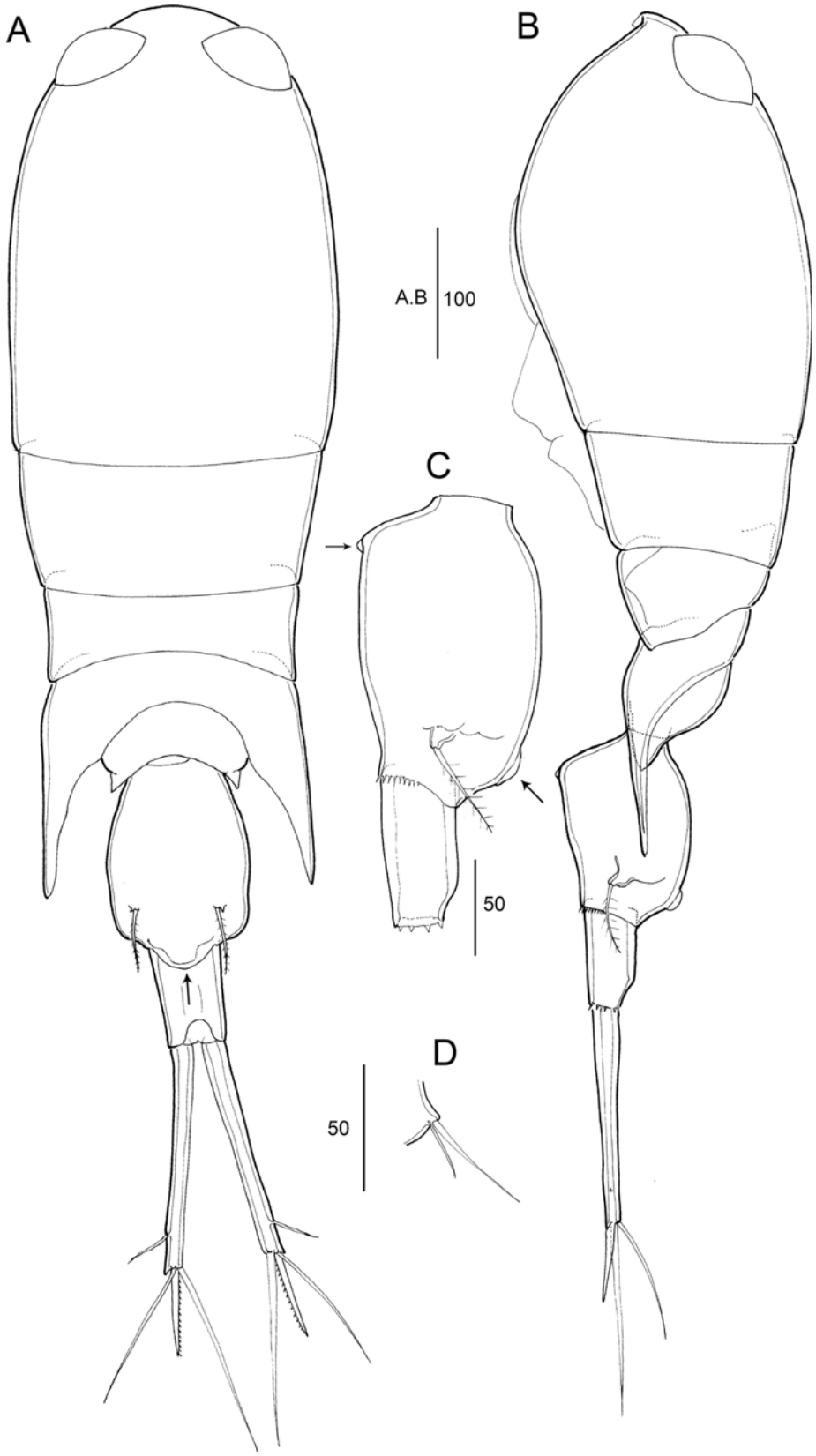

Fig. 5. *Ditrichocorycaeus lubbocki* female. A, habitus (dorsal view); B, habitus (lateral view); C, genital double-somite and anal somite (lateral view); D, P5

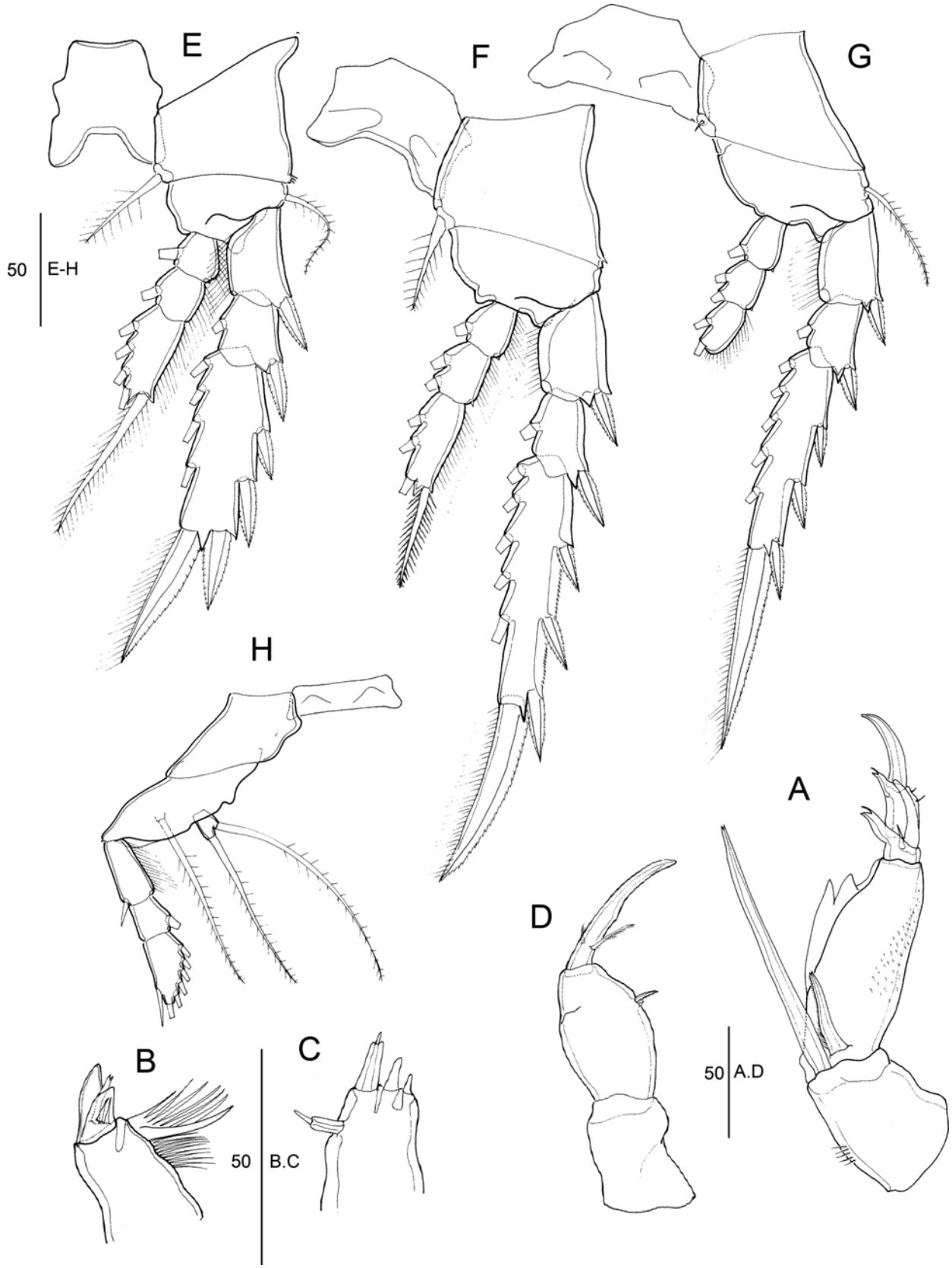

Fig. 6. *Ditrichocorycaeus lubbocki* female. A, antenna; B, mandible; C, maxillule; D, maxilliped; E, P1; F, P2; G, P3; H, P4

P6 (Fig. 5A-C) represented by operculum closing off each genital aperture, with plumose seta, dorsally located at three quarters distance of genital double-somite.

Male

Total body length in lateral view 0.80-0.82 mm (n=3), measured from anterior margin of prosome to posterior margin of urosome. Urosome distinctly narrower than prosome (Fig. 7A, B).

Prosome five-segmented (Fig. 7A, B), 1.2 times as long as urosome including CR, 1.7 times as long as urosome excluding CR, cephalosome 1.6 times longer than successive pedigerous somites. Two large contiguous cuticular lenses on frontal part closely located.

Genital somite (Fig. 7A, B) oval, 1.6 times as long as maximum width at anterior three fifths. Genital area ventrally formed into flaps derived from P6.

Anal somite (Fig. 7A, B) slightly tapered from anterior to distal margin, 1.6 times as long as wide at base, with large opening dorsally, 2.6 times shorter as long as genital somite.

CR 7.1 times longer than wide at base (Fig. 7A, B), about 1.5 times longer than genital somite, and 1.7 times longer than anal somite, caudal seta VII 1.6 times longer than seta III.

Antennule (not figured) similar to that of *D. dahli*.

Antenna (Fig. 7C) similar to that of *D. dahli*. But, first enodpodal segment 2.5 times as long as wide at base, third endopodal segment 1.8 times as long as wide at base, inner distal spine slightly shorter than inner spine on second endopodal segment, distal spine on second endopodal segment 1.9 times longer than third endopodal segment.

Maxilliped (Fig. 7D) similar to that of *D. dahli*, except basis with two setae different in length: distal one 1.2 times longer than proximal one, inner margin ornamented with row of spinules. Distal endopodal segment drawn out into long curved claw, inner proximal seta 1.8 times longer than lateroproximal seta.

Legs1-3 (Fig. 7F-H) in segmentation and armature similar to those of female. But, relative length ratio of terminal spine to distal outer spine of P1 to P3 exp different: P1 smallest (about 1.7: 1), in P2 2.1: 1, and P3 largest (2.9:1); terminal spines shorter than distal segments in P1 (1.1 times) and P2 (1.3 times), while in P3 1.1 times longer.

P4 (Fig. 7I) similar to that of female. But, terminal spine on distal exopodal segment 1.3 times shorter than exp-3 and almost equal in length of outer spine on exp-1.

P5 (not figured) similar to that of female.

P6 (Fig. 7B, E) represented by genital flap closing off each genital aperture, armed with long seta, near its base with one pointed process, surface ornamented with three rows of minute denticles.

Remarks

Females of *Ditrichocorycaeus lubbocki* agree well with Original description of *D. lubbocki* female by Giesbrecht (as *Corycäus lubbockii*, 1892) in unique shape of genital double-somite, distally swollen in dorsal view, and absence of pointed process on anteroventral margin of genital double-somite. However, the author illustrated only the lateral and dorsal habitus of *D. lubbocki* female and overlooked the small round prominence on the anteroventral margin of genital double-somite, which was expressed as different shapes in previous records. It was recorded as rounded eminence in figure by Sewell (1947) and a slightly pointed process by Chen et al. (1974) and Zheng et al. (1982).

In this study, we examined the morphological details, not mentioned in previous literatures, and suggested them as additional identification keys of *D. lubbocki* in Table 2: in female, 1) the genital double-somite has small round process on the anteroventral margin; 3) the distal margin on the first endopodal segment of the antenna forms two, well-developed teeth; 4) the second element of the maxillule is longest; in male, 5) the distal inner margin of P2 exp-3 with serration, but not curved; and 6) the ornamentation pattern on the surface of P6 with three rows of denticles.

Ditrichocorycaeus subtilis (Dahl, 1912)

(Figs. 8-10)

Corycaeus (*Ditrichocorycaeus*) *subtilis* Dahl, 1912, taf. 8, figs. 9-16; Tanaka, 1957, pl. 7, figs. 1-4; 1960, pl. 36, figs. 1-3; Chen et al., 1974, pl.18, figs. 8-12.

Material examined

Thirty four females and twelve males collected from off south of Jeju Island of Korea (12°65′E, 32°00′N) on 17 June 2009, of which three females and three males were dissected and closely examined in detail; 2 females (NIBRIV0000282443) and 2 males (NIBRIV0000282444) have been deposited in the National Institute of Biological Resources (NIBR), Incheon, Korea.

Description

Female

Body cylindrical, tapering posteriorly. Total body length

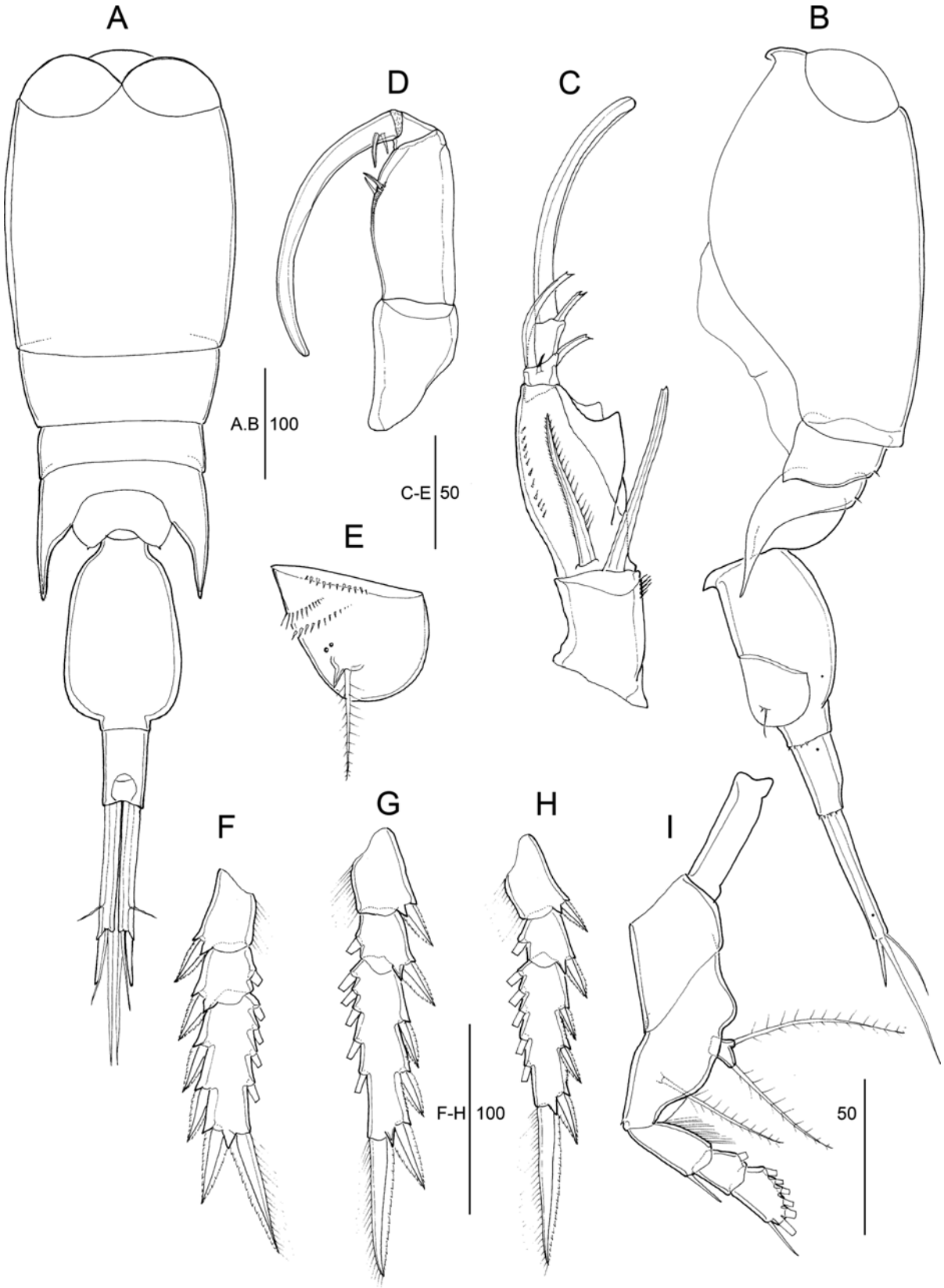

Fig. 7. *Ditrichocorycaeus lubbocki* male. A, habitus (dorsal view); B, habitus (lateral view); C, antenna; D, maxilliped; E, P6; F, P1 exp; G, P2 exp; H, P3 exp; I, P4; I, P4

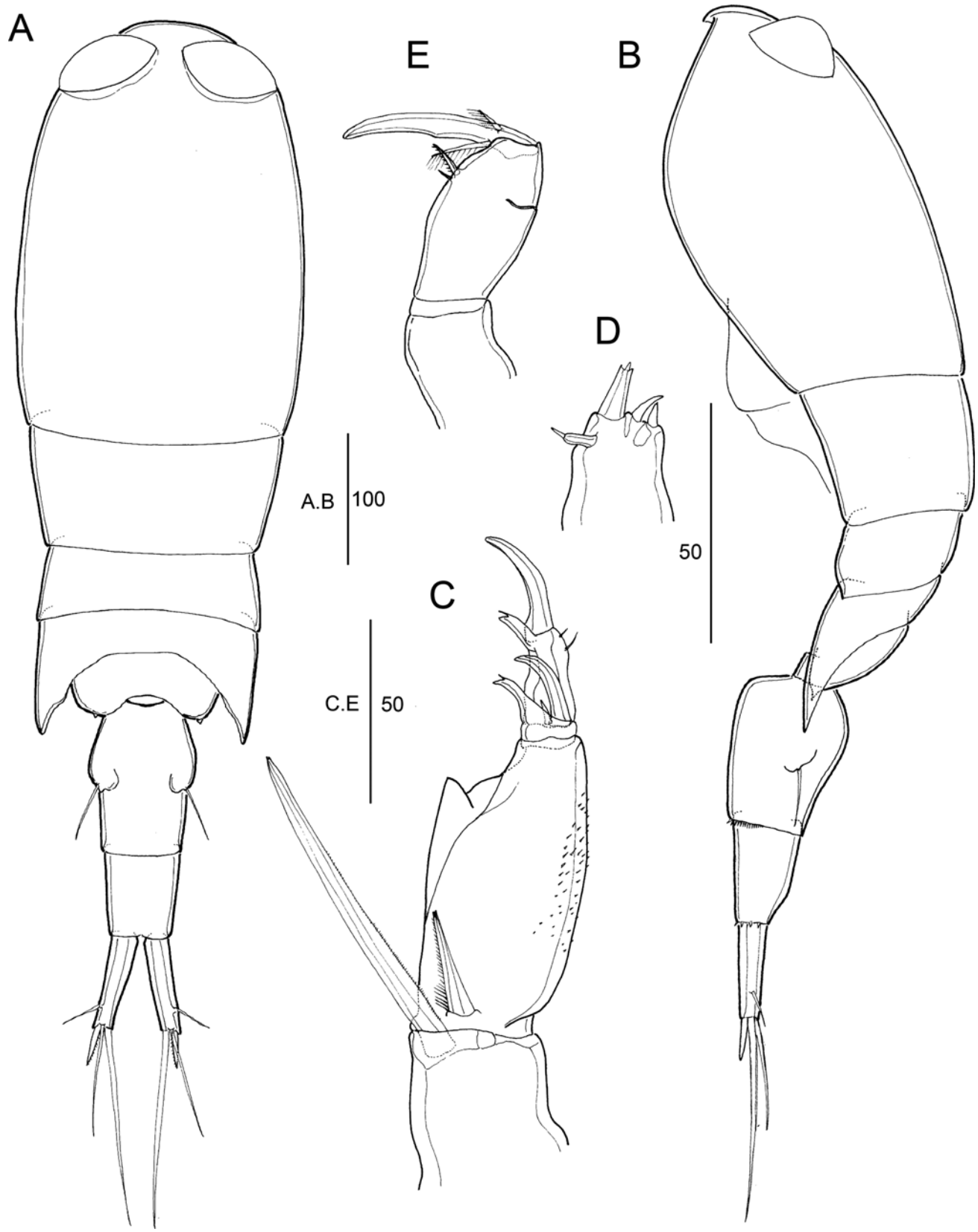

Fig. 8. *Ditrichocorycaeus subtilis* female. A, habitus (dorsal view); B, habitus (lateral view); C, antenna; D, maxillule; E, maxilliped

in lateral view 0.78-0.80 mm (n=3), measured from anterior margin of prosome to posterior margin of CR. Urosome distinctly narrower than prosome (Fig. 8A, B).

Prosome twice longer than urosome including CR, 2.8 times longer than urosome excluding CR (Fig. 8A, B), two large separate cuticular lenses, located at some distance between both, posterolateral corners of third pedigerous somite extended to anterior one-third of genital double-somite. Genital double-somite (Fig. 8A, B) 1.4 times larger than maximum width, anterior ventral margin just rounded in lateral view without process, distal margin ventrally fringed with spinules, genital aperture dorsolaterally located at mid region, each operculum armed with one plumose seta.

Anal somite (Fig. 8A, B) slightly tapering posteriorly, with large anal opening dorsally, 1.5 times longer than wide at base and 1.6 times shorter than genital double-somite, ventral surface ornamented with minute spinules and distal margin fringed with coarse teeth.

CR (Fig. 8A, B) much shorter than that of *D. dahli*, 1.6 times longer than genital double-somite, 4.3 times longer than wide at base, seta VII about 2.6 times as long as seta III.

Antennule (not figured) similar to that of *D. dahli*.

Antenna (Fig. 8C) similar to that of *D. dahli*. But, first endopodal segment 2.5 times longer than wide at base, coxobasal seta 3.3 times longer than first endopodal seta, distal part with one tooth-like protrusion; distal outer spine on second endopodal segment not reaching to distal margin of third endopodal segment.

Mandible and maxilla (not figured) similar to that of *D. dahli*.

Maxillule (Fig. 8D) similar to that of *D. dahli*. But, proportional lengths of each element 81.8:100.0:63.6:36.4.

Maxilliped (Fig. 8E) similar to that of *D. dahli*. But, basis 2.3 times as long as wide at base, endopodal segment unornamented and slightly longer than basis, accessory armature consisting of slender, unipinnate spine on lateral proximal margin 2.1 times shorter than inner proximal spine.

Legs (Fig. 9A-C) similar to *D. dahli*. Exopods of P1-3 relative length ratios of terminal spine to distal outer spine different: in P1 1.9:1, in P2 2.3:1, and P3 largest (4.1:1), length ratios of terminal spines to distal segments, in P1 1:1.5, in P2 1.6:1, and in P3 almost equal. In P2 distal inner margin of exp-3 terminal spine not serrated.

P4 (Fig. 9D) similar to that of *D. dahli*, but proportional length ratio of each segment 44:20:36, terminal spine on exp-3 terminal spine 2.3 times longer than distal spine on exp-1 and twice shorter than exp-3.

P6 (Fig. 8A, B) dorsally located at half distance of genital double-somite.

Male

Total body length in lateral view 0.730-0.734 mm (n=5), measured from anterior margin of prosome to posterior margin of CR. Urosome distinctly narrower than prosome (Fig. 10A).

Prosome five-segmented: cephalosome fused with first pedigerous somite, prosome about 1.6 times as long as urosome including CR, 2.1 times as long as urosome excluding CR (Fig. 10A), two large contiguous cuticular lenses closely located on frontal part. Genital somite (Fig. 10A, B) 1.8 times as long as maximum width at half distance.

Anal somite (Fig. 10A) 1.6 times as long as wide at base, with large opening dorsally, 2.3 times shorter than genital somite.

CR (Fig. 10A) 5.5 times longer than wide at base and twice as short as genital somite, and 1.2 times longer than anal somite. Caudal seta VII and seta III almost equal in length.

Antennule (not figured) with segmentation and armature similar to that of *C. dahli*.

Antenna (Fig.10C) similar to *D. dahli*, but first endopodal segment about twice as long as maximum width, 1.3 times shorter than coxobasal seta, third endopodal segment twice as long as wide at base, inner distal spine shorter than second endopodal inner spine, distal long spine on second endopodal segment 1.2 times longer than third endopodal segment.

Maxilliped (Fig. 10D) four-segmented: basis bearing two setae unequal in length on inner palmar margin, distal one 1.9 times longer than proximal one, distal endopodal segment with accessory armature consisting of unipinnate spines on inner and lateral proximal corner, respectively: inner one about 1.3 times longer than lateral one.

Exp-3 of P1 - P3 (Fig. 10E-G): length ratios of terminal spines to distal outer spines, P1 smallest (about 1.8:1), in P2 2.4:1, and P3 largest (3.7:1), length ratios of terminal spines to distal segments, in P1 1:1.4, in P2 1.4:1, and in P3 1.2:1.

P4 (Fig. 10H) similar to that of female, but exp-3 2.3 times longer than terminal spine on exp-3 and 1.5 times longer than exp-1 proximal spine on exp-1.

P5 (Fig. 10B) similar to that of female.

P6 (Fig. 10B) represented by genital flap closing off each genital aperture, armed with long seta, near its base with one pointed process, surface ornamented with row of denticles.

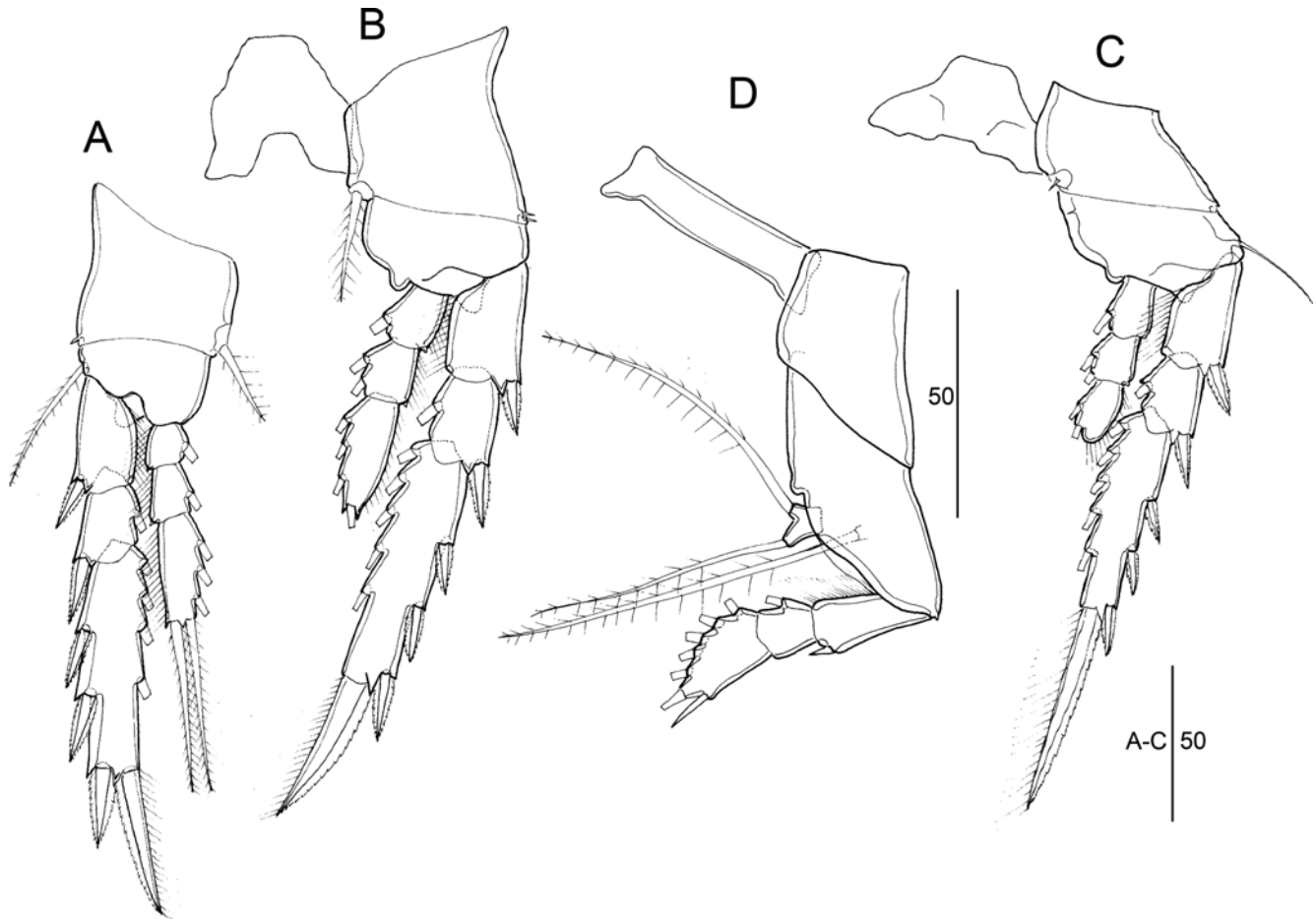

Fig. 9. *Ditrichocorycaeus subtilis* female. A, P1; B, P2; C, P3; D, P4

Remarks

The female of *Ditrichocorycaeus subtilis* from the Korean waters agrees with the original description by Dahl (as *Corycaeus* (*Ditirichocorycaeus*) *subtilis*, 1912) from the Indo-Pacific in general morphology, characterized by following characters of the third pedigerous somite forming wing-like expansions reaching to quarter distance of the genital double-somite and the anteroventral margin without the ventral process in lateral view. However, the caudal seta III is much longer than Korean specimen and the proximal exopodal spine of P4 also was illustrated as same length to the terminal exopodal spine, while in Korean specimens terminal exopodal spine is much longer. The description was very similar to specimens from the East China Sea/Yellow Sea (Chen et al. 1974). On the other hand, Tanaka (1957)'s *D. subtilis* is very similar to Dahl (1912)'s specimen morphological characteristics of longer CR than anal somite, inner margin of terminal spine on P2 exp-3 with serration, and relatively smaller length ratio of coxal seta to first endopodal seta (2.3:1) as compared to Korean specimen (3.3:1). However, the morphological characteristics of the male of Dahl (1912) were almost the same as the Korean specimen. Further studies to examine seasonal and/or geographical variation on morphology of *D. subtilis* are required.

Dahl (1912) proposed identification keys to divide the species of *Ditrichocorycaeus* such as ventral hook of the genital double-somite of the female, the form of the anal somite, and the lateral prolongation of the third pedigerous somite and confirmed that the genus could be separated into two species groups by the relative length of the caudal ramus. Of the species examined in the present study *D. subtilis* (Dahl, 1912) belongs to the first group and *D. dahli* (Tanaka, 1957) and *D. lubbocki* (Giesbrecht, 1891) belong to the second group, respectively. In order to confirm differences in morphological details between two groups, in the present study, we compared comprehensive morphological

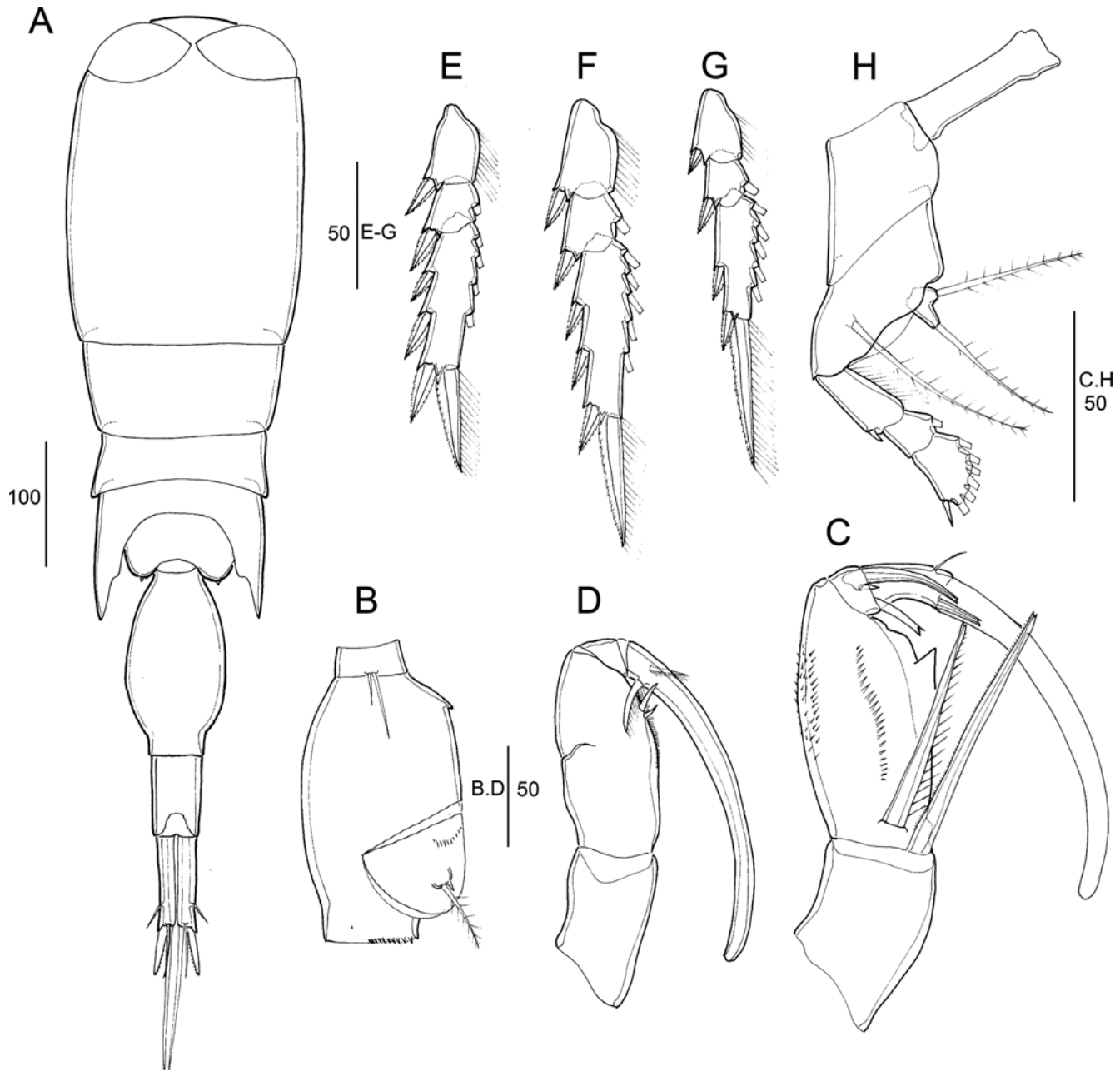

Fig. 10. *Ditrichocorycaeus subtilis* male. A, habitus (dorsal); B, genital somite (lateral); C, antenna; D, maxilliped; E, P1 exp; F, P2 exp; G, P3 exp; H, P4

features of *D. subtilis*, *D. dahli*, *and D. lubbocki* (Table 2): in both sexes, 1) the caudal ramus is relatively short; 2) the proportions in the spines of P1-3 exp-3; 3) the proximal spine of the P4 exopod is much shorter than the distal spine compared with other species; in female, 4) the length ratio of caudal seta III to VII is much larger; 5) the first endopodal segment of the antenna is distally with one protrusion, while *D. dahli* and *D. lubbocki* present two protrusion; 6) in the maxilliped, the length ratio of proximal and distal setae on the basis is the largest of three species; in male, 7) the anteroventral process of the genital somite is very small; 8) the caudal setae III and VII are almost equal in length; 9) the distal outer spine on the second endopodal segment of the antenna does not reach to the distal margin of the third endopodal segment.

3. Disscusion

Taxonomy

Fourteen species of *Ditrichocorycaeus* have so far been described from the world oceans and more similar morphological features and deficient identification keys led to frequent taxonomic confusion (Tanaka 1957; Vidjak and Bojaniæ 2008). Tanaka (1957) compared the proportional lengths of abdominal segments, CR, and the absence/presence of the ventral hook of genital double-somite/somite to discover morphological differences between nine species of *Ditrichocorycaeus*. As a result the author confirmed the specimens named as *D. lubbocki* by Dahl (1912), *D. tenuis* by Farran (1911), and *D. africanus* by Sewell (1947) to be a new species, and then assigned it as *D. dahli* (as *Corycaeus* (*Ditrichocorycaeus*) *dahli*). However, it is difficult to identify, because the species are almost equal in proportional lengths of urosomites and CR, and the size and the shape of the genital double-somite. Due to this, representative species of the genus, *D. affinis* has mostly been studied in Korean waters and the adjacent regions (e.g. the East China Sea, Japanese waters), however, the ecological and taxonomic records for *D. dahli* and *D. lubbocki* barely exist. In addition, the morphological details of ornamentation and segmentation of body and the appendages were probably not considered as essential identification points in previous studies. In particular, the segmentation of prosome of *Ditrichocorycaeus* was expressed differently in earlier studies and/or by even same author (Giesbrecht 1892; Dahl 1912; Tanaka 1957). Some of the authors described to be a cephalosome and the first pedigerous were combined, but those in others were separated forming 4- or 5-segmented prosome. The prosome was verified as being 5-segmented in the present study.

To resolve the taxonomic problem of a certain species from different geographic regions being described as a cosmopolitan species (e.g. *D. affinis* in Korean waters) without considering their morphological variations or/and differences, recent trend of taxonomic studies need to present more morphological details, such as mouthparts, spines of legs, ornamentation on genital double-somite/somite, and length ratios of caudal setae (Wi and Soh 2013a, b). In the present study, we have provided additional morphological characters to identify each species within *Ditirichocorycaeus* which have not been noticed or provided in the previous literatures: in both sexes, (1) the proportional lengths of caudal seta III to VII; (2) the proportions of each elements of maxillule; (3) in P1 to P3 exp-3, each length ratio of terminal spine to distal segment and to outer distal spine; (4) in P4 exp-3, the length ratios of terminal spine to proximal spine and to distal segment; in male, (5) the size and shape of the distal protrusion of the first endopodal segment of the antenna; (6) the length ratio of the basal setae of the maxilliped.

4. Conclusions

Three species of *Ditrichocorycaeus* could readily be distinguished based on a comprehensive comparison of morphological details provided on in this study. The identification parameters can be used for confirmation of new species and morphological variations within of this genus from various regions. Therefore previously recorded species of *Ditrichocorycaeus* should be re-examined by region, and the results provided will serve as more reliable information for ecological research purposes with regard to species diversity, occurrence of characteristics, and indicator species of various environments.

Acknowledgements

I wish to thank Dr. B.A. Venmathi Maran (KIOST) for useful comments on the manuscript. This study was supported by "Long-term change of structure and function in marine ecosystems of Korea" funded by the Ministry of Land, Transport and Maritime Affairs, Korea.

References

Böttger-Schnack R, Machida RJ (2010) Comparison of morphological and molecular traits for species identification and taxonomic grouping of oncaeid copepods. Hydrobiologia **666**:111-125

Boxshall GA, Halsey SH (2004) An Introduction to Copepod Diversity. The Ray Soc London, 966 p

Chen QC, Zhang SZ, Zhu CS (1974) On planktonic copepods of the Yellow Sea and the East China Sea. 2. Cyclopoida and Harpacticoida. Stud Mar Sin **9**:64-66

Dahl M (1912) Die Copepoden der Plankton-Expedition I. Die Corycaeinen. Mit Berücksichtigung aller bekannten Arten *Ergebn.* Plankton-Exped **2G f1**:1-136

Farran GP (1911) Plankton from Christmas Island, Indian Ocean. I. On Copepoda of the family Corycaeidae. Proc Zool Soc Lond **1911**:282-296

Früchtl F (1924) Die Cladoceren und Copepoden Fauna des Aru-Archipels. Mit Beiträgen zur Kenntnis der strukturellen Anomalien indo-pazifischer Plankton-Copepoden. Arb Zool Inst Univ

Innsbruck **2**:1-114

Giesbrecht W (1891) Elenco dei Copepodi pelagic raccolti dal tenente di vascello Gaetano Chierchia durante il viaggio della R. Corvetta, Vettor Pisani negli anni 1882-1885, e dal tenente di vascello Francesco Orsini nel Mar Rosso, nel 1884. Atti Accad Naz Lincei **4**(7):659-671

Giesbrecht W (1892) Systematik und Faunistik der pelagischen Copepoden des Golfes von Neapel und der angrenzenden Meeres-abschnitte. Fauna Flora Golf Neapel **19**:1-831

Hsiao SH, Fang TH, Shih CT, Hwang JS (2011) Effects of the Kuroshio Current on Copepod Assemblages in Taiwan. Zool Stud **50**(4):475-490

Hsieh CH, Chiu TS, Shih CT (2004) Copepod diversity and composition as indicators of intrusion of the Kuroshio Branch Current into the Northern Taiwan Strait in Spring 2000. Zool Stud **43**:393-403

Huys R, Boxshall GA (1991) Copepod Evolution. The Ray Society, London, 468 p

Kang YS, Huh SH, Lee SS (1990) Taxonomy and Distribution of Corycaeidae (Copepoda: Cyclopoida) in the Korean Waters in Summer. J Oceanol Soc Korea **25**(2):49-61

Lee CY, Liu DC, Su WC (2009) Seasonal and spatial variations in the planktonic copepod community of Ilan Bay and adjacent Kuroshio waters off northeastern Taiwan. Zool Stud **48**:151-161

Motoda S (1963) *Corycaeus* and *Farranula* (Copepoda, Cyclopoida) in Hawaiian waters. Pub Seto Mar Biol Lab **11**(2):209-262

Nagai N, Tadokoro K, Kuroda K, Sugimoto T (2006) Occurrence characteristics of chaetognath species along the PM transect in the Japan Sea during 1972-2002. J Oceanogr **62**:597-606

Nagai N, Tadokoro K, Kuroda K, Sugimoto T (2008) Chaetognath species-specic responses to climate regime shifts in the Tsushima Warm Current of the Japan Sea. Plank Benth Res **3**(2):86-95

Razouls C (1974) Les Corycaeidae (Copepoda, Cyclopoidea) de la region de Benguela (Golfe Du Lion). Vie Millieu **24**:83-113

Razouls C, de Bovée F, Kouwenberg J, Desreumaux N (2013) Diversity and Geographic Distribution of Marine Planktonic Copepods. http://copepodes.obs-banyuls.fr/en. Accessed 26 Nov 2013

Sewell RBS (1947) The free-swimming planktonic copepod: Systematic account. British Muse John Murray Exped Sci Rep **8**(1):1-303

Tanaka O (1957) On Copepoda of the family Corycaeidae in Japanese waters. J Fac Agric Kyushu Univ **11**:77-97

Tang X, Wang F, Chen Y, Li M (2009) Warming trend in northern East China Sea in recent four decades. Chinese J Oceanol Limnol **27**(2):185-191

Vidjak O, Bojaniæ N (2008) Redescription of *Ditrichocorycaeus minimus indicus* M. Dahl, 1912 (Copepoda: Cyclopoida, Corycaeidae) from the Adriatic Sea. J Plank Res **30**:233-240

Wi JH, Soh HY (2013a) Two *Farranula* (Copepoda, Cyclopoida, Corycaeidae) species from Korean waters. J Nat Hist **47**(5-12):289-312

Wi JH, Soh HY (2013b) A new species of *Farranula* (Copepoda, Cyclopoida, Corycaeidae) and a redescription of *Farranula carinata* from off Jeju Island, Korea. J Mar Biol Assoc UK **93**(7):1813-1824

Wilson CB (1942) The copepods of the plankton gathered during the last cruise of the Carnegie. J P Ault Carnegie Inst Wash Publ **536**:1-237

Zheng Z, Li S, Li SJ, Chen B (1982) Marine planktonic copepods in Chinese waters. Shanghai Sci Tech Press, Shanghai, 151 p (in Chinese)