

Two New Species of *Tropocyclops prasinus* Group (Copepoda: Cyclopidae) from South Korea

Ji Min Lee¹ and Cheon Young Chang^{2,*}

¹Institute of Basic Science, Daegu University; ²Department of Biological Science, Daegu University, Gyeongsan 712-714, Korea

Abstract: A taxonomic study on the genus *Tropocyclops* has been accomplished as a part of the series of studies on the freshwater cyclopoid copepods in South Korea. As a result, the *Tropocyclops prasinus*, hitherto known from Korea in many reports and papers, turns out to be a species complex of three sibling species: *T. prasinus* (Fischer, 1860), *T. ishidae* n. sp., and *T. setulifer* n. sp. This paper deals with description of two of these new species with taxonomic accounts on their inter- or intraspecific morphological discrepancies.

Keywords: Taxonomy, Copepoda, Cyclopoida, Cyclopidae, *Tropocyclops*, new species, Korea

Genus *Tropocyclops* Kiefer, 1927 is one of the representative freshwater cyclopoid copepods, comprising 20 species in the family Cyclopidae. Among the *Tropocyclops* species, *T. prasinus* (Fischer, 1860) is famous worldwide, and had been considered cosmopolitan. The species is common and frequently found generally in the eutrophicated lentic warm waters, however, its occurrence extends to nearly all types of habitats including ponds, reservoirs, lakes, swamps, rivers, streams, mountain waters, ground waters and brackish waters.

In South Korea, only one species has been recorded in a few papers and limnological reports under the name of '*T. prasinus*'. Kim and Chang (1989) first dealt with the species taxonomically in their faunistic study on the freshwater cyclopoid copepods from Korea. Yoon et al. (1995) reported the species at several wetlands of Jindo Island. Chang et al. (1998) reported '*T. prasinus*' from 19 mountain waters such as streamside bogs and marshes in South Korea. However, the '*T. prasinus*' in the above papers or reports might have been misidentified, for their identifications were based on the so-called old 'macrocharacters' that Van de Velde

(1984) mentioned when he dealt with *Mesocyclops* species complex. Therefore, the true *Tropoclops* fauna in Korea has remained entirely unclear.

In Japan, the late Dr. T. Ishida proposed the possibility that the *T. prasinus* s. lat. might be mixed up with more than three cryptic species in Japan, although he could not determine them as distinct species (Ishida, 2002).

During communications with the late Dr. T. Ishida, the senior author (CYC) and he concluded that the most urgent and prerequisite task is to confirm the true identity of European *T. prasinus* s. str., then to determine whether the genuine *T. prasinus* exists in East Asia, and if so, finally to identify the species among the cryptic species from Korea and Japan.

As a part of the series of studies on the freshwater cyclopoid copepods from South Korea, the authors re-examined all the *Tropocyclops* specimens stocked in the Department of Biological Science, Daegu University since 1990. Recently, the senior author (CYC) obtained the voucher specimens of *T. prasinus* from France and Germany. As a result, the '*T. prasinus*', hitherto known from Korea through many reports and papers, turned out to be a species complex of *T. prasinus* (Fischer) and two new sibling species.

Following the taxonomic revision on *Mesocyclops* (Lee, Jeon and Chang, 2005) and *Eucyclops* (Lee, Min and Chang, 2005) from Korea, this paper presents the description of two new *Tropocyclops* species from Korea with the taxonomic accounts on the interspecific morphological differences.

MATERIALS AND METHODS

Samplings were made with a plankton net of 63 µm mesh aperture from various freshwater bodies in South Korea. Copepods were fixed and stored in 4% buffered formalin or 95% ethanol. Specimens were dissected and mounted in lactophenol on H-S slide (Shirayama et al., 1993), a recent

*To whom correspondence should be addressed.
Tel: 82-53-850-6454; Fax: 82-53-850-6459
E-mail: cychang@daegu.ac.kr

variation of Cobb slide, after treatment in a solution of 5% glycerin - 95% ethyl alcohol for 1-2 days. Dissection was performed using two needles made from 0.25 mm diameter tungsten wire by electrolysis (Huys and Boxshall, 1991; Huys et al., 1996). Mounted specimens were observed under a differential interference contrast microscope (Olympus BX51) with Nomarski optics. Figures were prepared with the aid of a camera lucida. Measurements were made with a digital camera for microscope (Cool SNAP 5.0M, Roper Scientific Co., USA) and a calibration software QCapture Pro (ver. 5.0, Media Cybernetics Inc., USA).

Type specimens have been deposited in the National Institute of Biological Resources, Incheon (NIBR), Korea.

Abbreviations used in the text and figures follow the conventional ones frequently used in the taxonomy of freshwater cyclopoid copepods: A1, antennule; A2, antenna; Fu, caudal rami (furcal branches); L/W, length to width ratio; P1-P5, legs (pereopods) 1-5; enp 1-3 or exp 1-3, the first to third endopodal or exopodal segments of each leg.

DESCRIPTION

Family Cyclopidae Sars, 1913
Subfamily Eucyclopinae Kiefer, 1927
Genus *Tropocyclops* Kiefer, 1927
Tropocyclops ishidae n. sp. (Figs. 1, 2)

Synonym

Tropocyclops prasinus (Fischer, 1860) *sensu* Kim and Chang, 1989, p. 235, fig. 4 (partim).

Tropocyclops sp. 1 Ishida, 2002, p. 49, fig. 15a-h; Chang and Min, 2005, p. 53, fig. 28A-E.

Type. *Holotype*: ♀ (NIBRIV0000100005), Yeonji Res., Daegu Univ., Gyeongsan, 28 Sep. 2007, *leg.* C.Y. Chang, J.M. Lee and H.J. Yoon. *Paratypes*: 3 ♀♀, 1 ♂, collection details same as in holotype. Holotype and allotype (NIBRIV0000100006) are deposited in NIBR. Other 3 female and 2 male paratypes (DB10013-1~5) were dissected and mounted in glycerin on H-S slide and kept in the senior author's research collection at the Department of Biological Science, Daegu University (DB).

Additional material examined. 2 ♀♀, Gungae (bog), Yangyang, 11 Oct. 2005 (H.W. Lim); 1 ♂, Wicheon Str., Gunwi, 7 Jan. 2007 (C.Y. Chang); 4 ♀♀ (ovi.), 1, Geumho R., Geumho, Yeongcheon, 6 Feb. 2007 (J.M. Lee, H.J. Yoon and S.W. Lee); 1 ♂, Taehwa R., Ulsan, 3 Oct. 2004 (J.M. Jeon); 4 ♀♀ (3 ovi.), 1 ♂, Gunsangje Res., Jinan, 13 Aug. 2003 (C.Y. Chang); 2 ♀♀, 1 ♂, Saokdo Is. (estuary of a streamlet), Sinan, 17 Jun. 2006 (H.W. Lim); 1 ♀, Songdang-ri (stream-side puddle), Jeju Is., 26 Jan. 2004 (C.Y. Chang and J.M. Lee).

Female. Body (Fig. 1A) relatively small, 0.64-0.72 mm (mean 0.68 mm, sd = 0.4, N = 21) long, excluding caudal seta; somewhat slender, greatest width about 31% of body length at posterior margin of cephalothorax; tinged with dark blue-green. Prosoma ellipsoidal, 1.7 times longer than urosome; widest at posterior margin of cephalothorax, and gradually tapering behind. Rostrum reduced. Cephalothorax somewhat protruding anteriorly, about 1.6 times longer than next three thoracic somites combined. Fifth pedigerous somite with hairs laterally. Genital somite 1.25 times longer than wide, anterior part a little swollen laterally (Fig. 1B). Anterior part of seminal receptacle 'T'-shaped with both wings bent posteriorly in the middle; Posterior part narrower than anterior part. Posterior margins of all urosomites with weakly crenulate hyaline fringes; posterolateral margin of anal somite with 7-8 spinules dorsally. Anal operculum rather strongly convex, smooth on its posterior margin (Fig. 1C, arrow).

Caudal rami (Fig. 1C) about 2.7 times (ranging 2.6-2.7) as long as wide, without hairs along inner (medial) margin. Lateral seta inserted dorsolaterally at about middle of lateral margin of ramus; lateral margin not interrupted by minute spinules. Outer caudal seta (caudal seta III) stout, a little shorter than caudal ramus. Inner caudal seta (caudal seta IV) 1.5 -1.6 times longer than outer caudal seta. Dorsal caudal seta (caudal seta VII) slender, plumose, slightly (1.1 times) longer than inner caudal seta, and about 1.4 times longer than caudal ramus.

A1 (Fig. 1D) slender, not reaching posterior margin of prosoma, consisting of 12 segments, distal 3 segments with narrow but apparent hyaline membrane. Segment 8 elongate; segments 5 and 6 short.

A2 consisting of 4 segments; exopod represented by 1 long seta at outer distal corner of basis. Frontal face of A2 basis nearly smooth distally (Fig. 1E); caudal face ornamented with 1 transverse spinule row and group of minute spinules on inner distal corner; lacking spinules at outer distal corner near base of outer seta (Fig. 1F). Maxillular palp (Fig. 1G), basis bearing 3 apical setae including 1 pinnate seta, with minute spinules along ventral and inner margins; endopod 1-segmented, armed with 3 long plumose or pinnate setae; exopod represented by a single plumose seta on outer surface of basis. Mandible, maxilla and maxilliped shown as typical shape of genus *Tropocyclops*.

P1-P4 (Fig. 2A-D), biramous, both exopods and endopods 3-segmented. Spine formula (number of spines on exp 3 of legs 1-4) 3,4,4,3. Seta formula (number of setae on exp 3 of legs 1-4) 5,5,5,5. Spine/seta armature of P2-P4 as follows (Arabic numerals representing setae, while Roman numerals indicating spines):

P1 coxa 0-1 basis 1-1 exp I-1; I-1; II,I+1,4
enp 0-1; 0-2; I,I+1,3

P2 coxa 0-1 basis 1-0 exp I-1; I-1; III,I+1,4

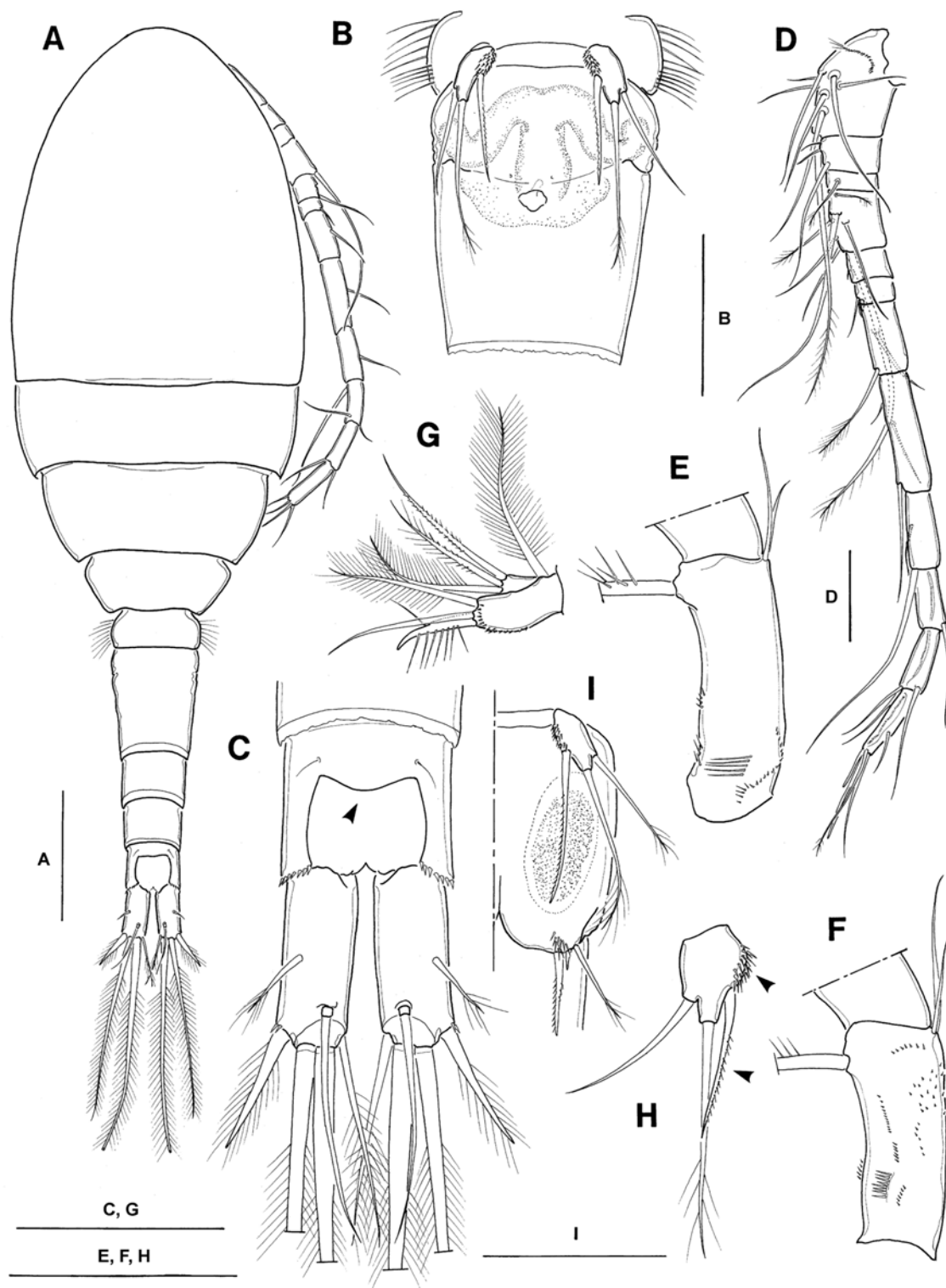


Fig. 1. *Tropocyclops ishidai* n. sp. A-H, female: A, habitus, dorsal; B, genital somite and P5, ventral; C, anal somite and Fu, dorsal; D, A1; E, A2 basis, frontal; F, A2 basis, caudal; G, maxillular palp; H, P5. I, male P5 and P6. Scale bars = 0.1 mm (A) and 0.05 mm (B-I).

enp 0-1; 0-2; 1,I+1,3
 P3 coxa 0-1 basis 1-0 exp I-1; I-1; III,I+1,4
 enp 0-1; 0-2; 1,I+1,3

P4 coxa 0-1 basis 1-0 exp I-1; I-1; II,I+1,4
 enp 0-1; 0-2; 1,II,2
 P1, basis with 1 inner seta exceeding enp 2 (Fig. 2A);

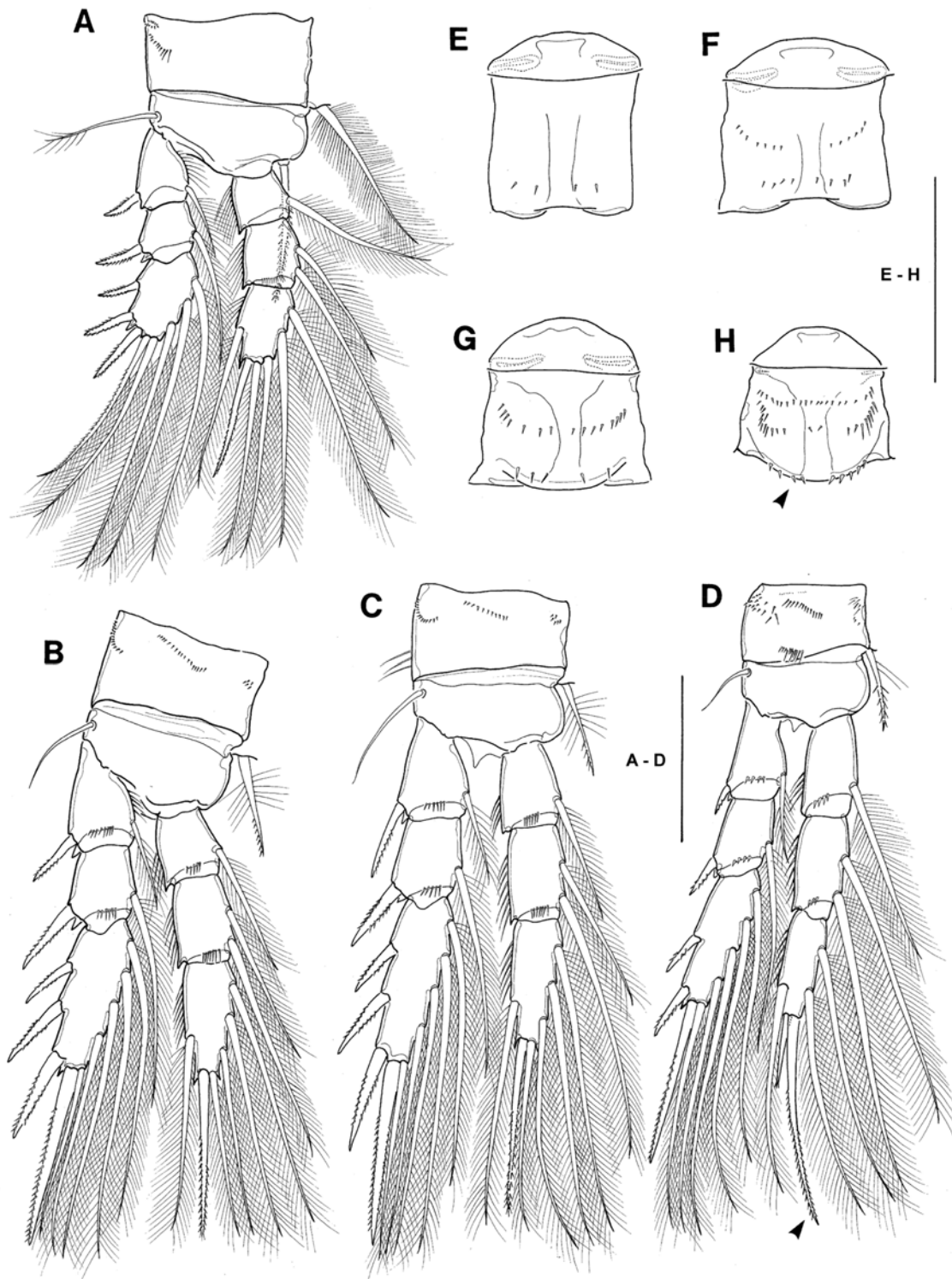


Fig. 2. *Tropocyclops ishidae* n. sp., female. A-D, P1-P4; E-H, couplers of P1-P4. Scale bars = 0.05 mm.

coupler (intercoxal sclerite) with 2 naked lateral lobes, caudal face with 4-6 spinules near posterior margin (Fig. 2E). P2 coupler (Fig. 2F) ornamented with 8-10 spinules along posterior margin and a row of 14-16 spinules in the middle of caudal face; posterior margin naked. P3 coupler

(Fig. 2G) showing similar pattern as in P2 coupler except distal spinules arranged sparsely, locating more marginally, and proximal row of spinules stronger. P4 coupler, posterior margin typically convex, rounded, with 8-9 minute spinules or denticles (shown as granules under a light microscope

Table 1. Character comparison of three sibling species of *Tropocyclops* from Korea

	<i>T. prasinus</i>	<i>T. ishidae</i>	<i>T. setulifer</i>
P4 coupler ornamentation	fine setules	denticles	short setules
Length ratio of 2 spines on P4 enp 3	2.2-2.6	~3.0	2.0-2.4
Fu L/W	2.7-3.0	~2.7	<2.5
Spinule patch on P5	absent	present	absent
Length ratio of P5 spine/P5 in female	~1.4	~1.7	~3.0
Spinule row on A2 basis, caudal	absent (or faint)	absent	present
Anal operculum	not convex	convex	not convex

with low resolution power) (Fig. 2H, arrow); caudal face ornamented with 1 oblique row of 8-10 setules laterally and 1 transverse row of 20-24 spinules proximally. P4 enp 3 about 2.9 times as long as wide (ranging 2.63-3.0); enp 3 about 1.4 times longer than outer apical spines; inner spine elongate (Fig. 2D, arrow), 2.7-3 times as long as outer spine, and about 2 times longer than enp 3.

P5 1-segmented, nearly pentagonal; inner surface hirsute, furnished with dense minute spinules (Fig. 1H, upper arrow); bearing 1 innermost spine and 2 setae, inner seta (Fig. 1H, lower arrow) about 1.7 times longer than P5 segment (ranging 1.54-1.80), and nearly as long as outermost seta.

Male. Body 0.53 mm long. Fu 2.4 times as long as wide; dorsal caudal seta longer than Fu and inner caudal seta. Inner spine of P5 relatively longer than in female, 2.5 times longer than P5 segment (Fig. 1I). P6 represented by small protuberance on distolateral corner of genital plate with 1 long innermost spine, 1 short median spine and 1 outermost seta with group of spinules anterior to inner spine.

Habitat. Mainly inhabiting debris-rich ponds, swamps, bogs and puddles, especially abundant in aquatic plants.

Etymology. The specific name *ishidae* is taken in honor of the late Dr. Teruo Ishida, who suggested the existence of *Tropocyclops prasinus* species complex in the East Asia and first recognized this species as presumably new.

Remarks. Ishida (2002) proposed the diagnostic characters of his "*Tropocyclops* sp. 1" as follows: (1) granular ornamentation on the posterior margin of P4 coupler; (2) the L/W ratio of Fu about 2.7, with lateral seta situated at about middle of lateral margin of Fu; (3) the long inner spine of P4 enp 3 (about 3 times longer than outer spine); (4) spinular patch widely distributed on the inner proximal surface of P5. In sharing the character combination above, the present species must be conspecific with *Tropocyclops* sp. 1 *sensu* Ishida, 2002. After detailed examination of both the Korean specimens and the Japanese specimens Dr. Ishida had kindly sent, the following features also turned

out to be consistent and significant (*see* Table 1): (1) inner spine of P5 relatively shorter in female (inner seta about 1.7 times longer than P5, while about 3 in *T. setulifer*, and about 1.4 in *T. prasinus* s. str.); (2) a spinule row absent at outer distal corner of caudal face of A2 (well developed in *T. setulifer*, and absent or faint in *T. prasinus* s. str.); (3) anal operculum convex, protruding posteriorly (not convex and nearly straight in both *T. setulifer* and *T. prasinus* s. str.). The Korean specimens showed a minor discrepancy from the Japanese specimens in having a longer dorsal caudal seta (usually longer than caudal ramus, while a little shorter in the Japanese specimens examined).

This species is most common among the three species of *T. prasinus* complex in Korea. Considering its habitat type and occurrence frequency, most of the previous records from Korea of "*T. prasinus*" are presumed as misidentification of this species.

Tropocyclops setulifer n. sp. (Figs. 3, 4)

Synonym

Tropocyclops sp. 2: Chang and Min, 2005, p. 53, fig. 28F-G.

Type. *Holotype*: ♀ (NIBRIV0000100007), Seongryu-gul Cave, Uljin, 17 Feb. 2005, *leg.* W.-R. Kim and Y.-G. Choi. *Paratypes*: 2♀♀, 1♂, Jungmun Valley (stream), Jeju Is., 12 Jan. 2007, *leg.* C.Y. Chang and J.M. Lee. Holotype and allotype (NIBRIV0000100008) are deposited in NIBR. Other 2 female paratypes (DB10014-1, 10014-2) were dissected and mounted in glycerin on H-S slide, and kept in the senior author's research collection at the Department of Biological Science, Daegu University (DB).

Additional material examined. 2♀♀, Gomgol Valley (spring), Seoraksan Mt., 27 Apr. 1994 (S.M. Yoon); 1♂, Mulgol-gul Cave, Samcheok, 18 Feb. 2005 (Y.G. Choi and W.R. Kim); 4♀♀, 1♂, Mureung Valley, Donghae, 29 Jun. 1995 (C.Y. Chang); 1♀, Juwangsan Mt. (stream-side bog), Cheongsong, 10 Apr. 1995 (C.Y. Chang); 1♀, Seongryu-gul Cave, Uljin, 13 Jun. 2004 (Y.G. Choi and W.R. Kim); 1

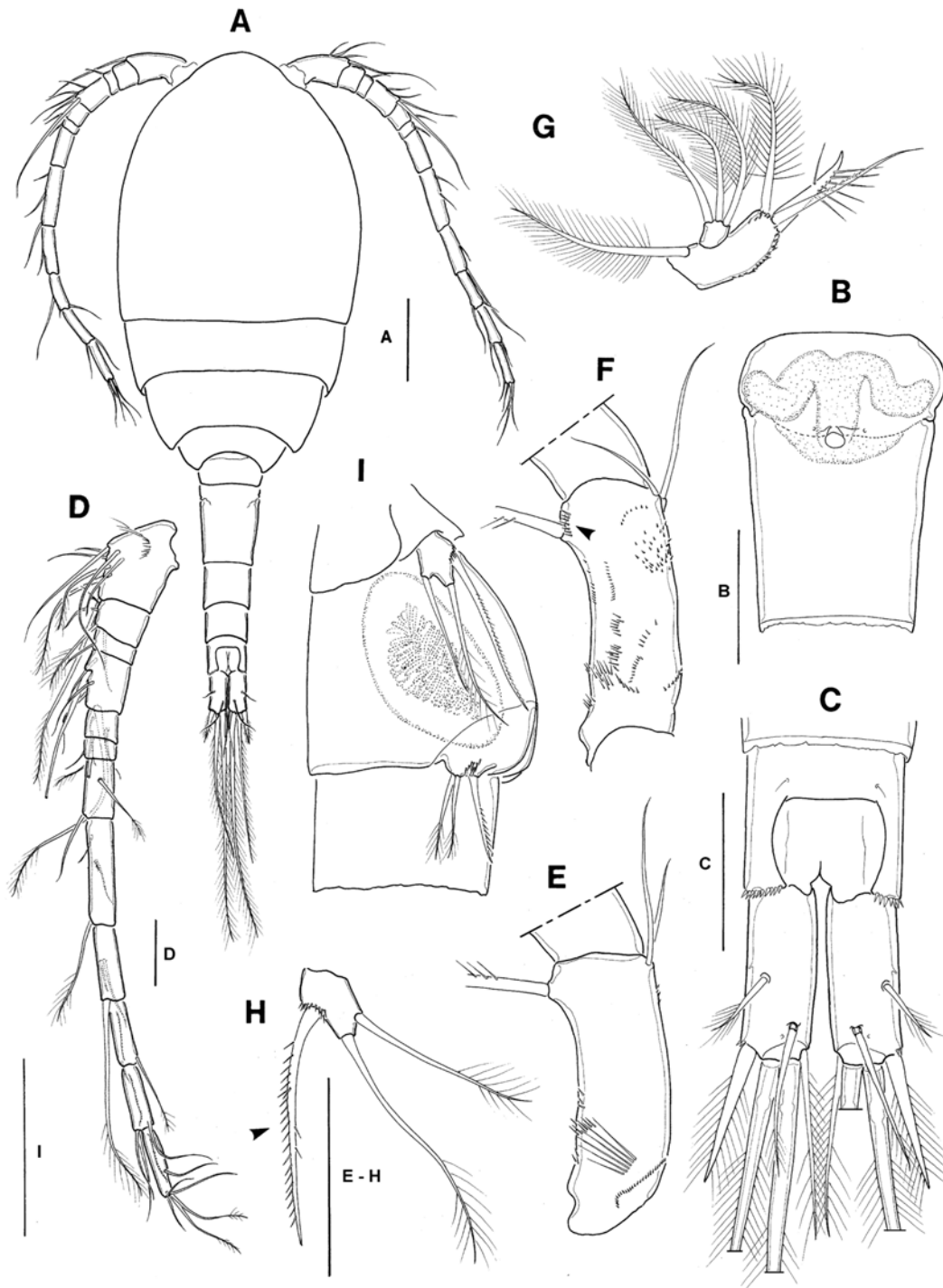


Fig. 3. *Tropocyclops setulifer* n. sp. A-H, female: A, habitus, dorsal; B, genital somite, ventral; C, anal somite and Fu, dorsal; D, A1; E, A2 basis, frontal; F, A2 basis, caudal; G, maxillular palp; H, P5. I, male P5, P6 and genital somite, lateral. Scale bars = 0.1 mm (A) and 0.05 mm (B-I).

♀ (ovi.), Daegok-ri (well), Gyeongju, 1 Jun. 2007 (P.G. Choi); 3 ♀♀, Suryeom-ri (trickle), Gyeongju, 18 Apr. 2005 (H.W. Lim and J.M. Jeon); 2 ♂♂, Ssanggyesa Temple (spring), 17 Oct. 2004 (H.W. Lim and J.M. Jeon).

Female. Body (Fig. 3A) 0.65-0.78 mm long (mean 0.72

mm, sd = 0.06, N = 18) excluding caudal seta. Prosome oval, much broader than urosome, greatest width 36% of body length at middle of cephalothorax, and tapering behind. Rostrum reduced. Cephalothorax somewhat protruding anteriorly, about 1.75 times longer than next 3 thoracic somites combined. Genital somite 1.4 times longer than

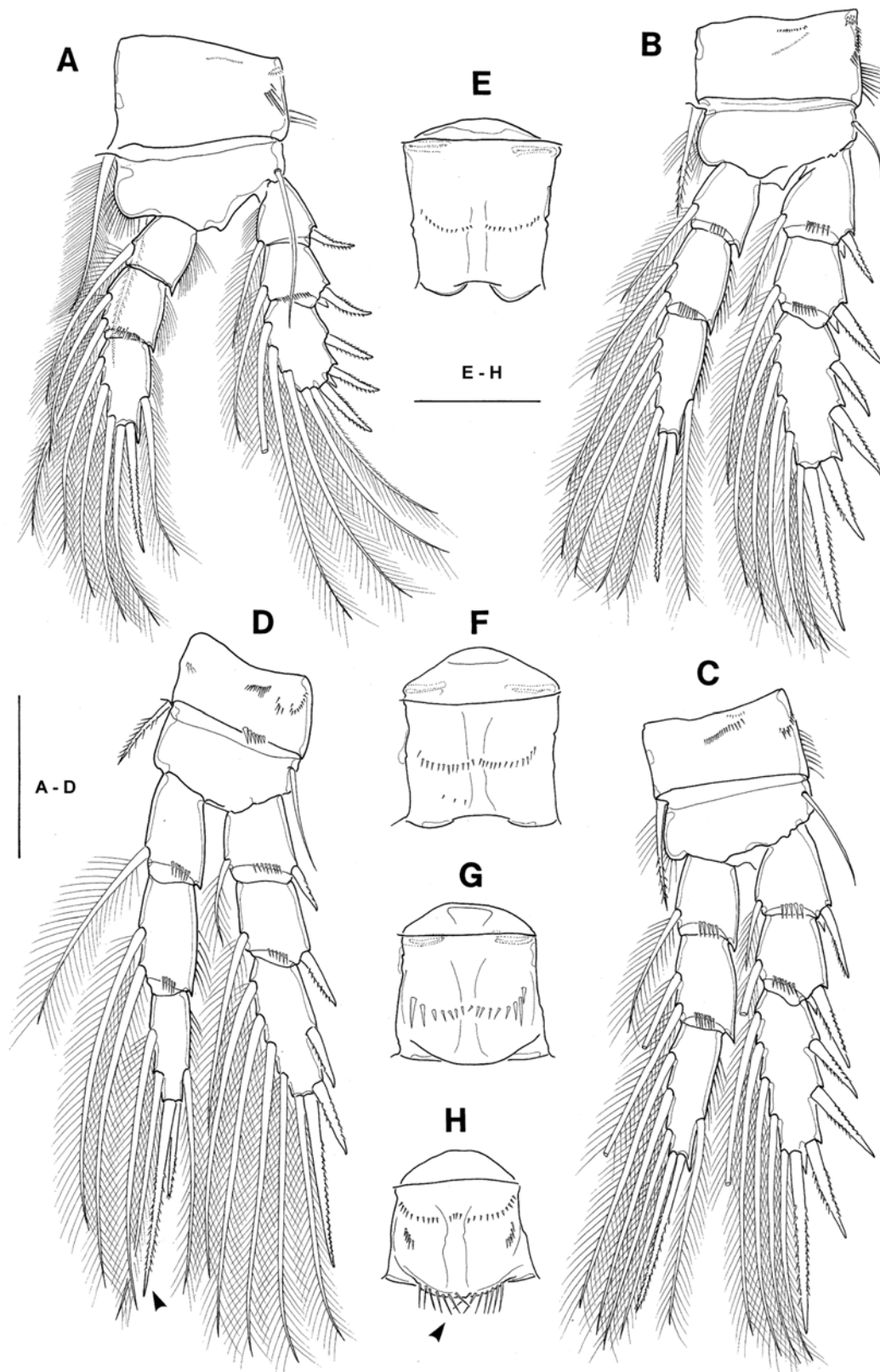


Fig. 4. *Tropocyclops setulifer* n. sp., female. A-D, P1-P4; E-H, couplers of P1-P4. Scale bars = 0.05 mm.

wide, anterior part a little swollen laterally (Fig. 3B). Upper part of seminal receptacle 'T'-shaped with long, bent

wings. Posterior margins of all urosomites with weakly crenulate hyaline fringes; dorsoposterior margin of anal

somite with 7-9 spinules. Anal operculum not convex and rather straight, smooth on its posterior margin.

Fu (Fig. 3C) slightly divergent to each other; a little shorter than in the preceding species, about 2.4 times (ranging 2.3-2.6) as long as wide, without hairs along inner (medial) margin. Lateral seta inserted dorsolaterally at about middle of lateral margin of ramus, a little shorter than width of ramus itself; lateral margin not interrupted by minute spinules. Outer caudal seta (caudal seta III) stout, 0.9 times as long as caudal ramus. Inner caudal seta (caudal seta IV) 1.3 -1.4 times longer than outer caudal seta. Dorsal caudal seta (caudal seta VII) slender, slightly shorter than caudal ramus, and a little longer than outer caudal seta.

A1 (Fig. 3D) slender, elongate, nearly reaching posterior border of prosome, consisting of 12 segments. Segment 8 elongate; segments 5 and 6 short. Last 3 segments with narrow hyaline membrane, relatively weaker than in preceding species.

A2 consisting of 4 segments, (coxo) basis and 3-segmented endopod; exopod represented by 1 long seta at outerodistal corner of basis. Frontal face of A2 basis nearly smooth distally (Fig. 3E); caudal face ornamented with patch of spinules on inner distal corner, and 1 spinule row (Fig. 3F, arrow) at outer distal corner near base of outer seta. Maxillular palp (Fig. 3G), basis bearing 3 apical setae including 1 pinnate seta, with minute spinules along ventral and inner margins; endopod 1-segmented, armed with 3 long plumose setae; exopod represented by single plumose seta on outer surface of basis.

P1-P4 (Fig. 4A-D), biramous, both exopods and endopods 3-segmented. Spine formula (number of spines on exp 3 of legs 1-4) 3,4,4,3. Seta formula (number of setae on exp 3 of legs 1-4) 5,5,5,5. Spine/seta armature of P1-P4 same as in the preceding species. P1 coupler (intercoxal sclerite) with 2 naked lateral lobes; posterior margin smooth; a transverse row of 20-24 weak spinules present in the middle of caudal face. Distomedial corner of basis of P1 with 1 pinnate seta, its tip highly exceeding posterior margin of enp 2. P2 coupler (Fig. 4F) ornamented with 3-6 spinules along posterior margin and 1 row of 24-26 spinules in the middle of caudal face; posterior margin naked. P3 coupler (Fig. 4G) with 1 row of 15-18 spinules in posterior half of caudal face, spinules becoming larger and sharpened laterally; posterior margin gently convex, naked in caudal view. P4 coupler, posterior margin rounded, with 7 pairs of short and sharp setules medially (Fig. 4H, arrow); caudal face ornamented with 1 oblique row of 5-6 spinules laterally and 1 transverse row of 24-26 spinules in proximal part. P4 enp 3 about 2.8 times as long as wide; enp 3 a little (1.1 times) longer than outer spine; inner spine nearly 2 times longer than enp 3, about 2.2 times (ranging 2.0-2.4) as long as outer spine (Fig. 4D, arrow).

P5 (Fig. 3H) 1-segmented, nearly pentagonal; inner proximal surface not hirsute, only with spinule array along base of innermost spine; bearing 1 innermost spine and 2 setae, inner spine (Fig. 3H, arrow) about 3 times longer (ranging 2.7-3.5) than P5, and about 1.3 times longer than outermost seta.

Male. Body 0.6 mm long, slenderer than female. P5, inner spine elongate, more than 3 times as long as P5 itself, longer than both apical and outermost setae. P6 represented by small protuberance on distolateral corner of genital plate with innermost spine and 2 outer plumose setae, their lengths similar to each other. Other characters, including caudal rami, couplers of P3-P4, and length of inner spine on P4 enp 3 nearly the same as in female holotype.

Habitat. Mostly collected from mountain streamlets, trickles, springs and caves; supposedly favoring relatively colder and more oligosaprobic waters, compared with *T. prasinus* s. str. and *T. ishidae*, and often occurring from subterranean waters including wells, springs, and cave waters.

Etymology. The specific name (*setulifer*, Latin) means “bearing setules”, taken from the character state of the P4 coupler, furnished with setules along posterior margin.

Remarks. This new species is clearly differentiated from the two sibling species, *T. prasinus* and *T. ishidae*, by the character combination of the ornamentation of P4 coupler (6-7 pairs of short setules arranged on the medial part of posterior margin), relatively shorter Fu (L/W ratio less than 2.5), the length ratio (about 2.2) of two apical spines of P4 enp 3, elongate inner spine of female P5 (length ratio of inner spine to P5 segment about 3), and the presence of spinule row on outer distal corner of caudal face of A2 basis, as shown in the character comparison table (Table 1). Among these characters, P4 coupler ornamentation and length ratio between P5 and its spine in female are the most diagnostic characters of this species. The spinule row on A2 basis is also consistent and discriminative, but its existence is difficult to confirm unless dissected. This species shows rather shorter Fu (L/W generally a little less than 2.5) than in other congeners. However, some individuals have relatively longer Fu (L/W 2.6), near those of other two sibling species.

Considering the characters above, *T. setulifer* n. sp. is evidently much similar to *Tropocyclops* sp. 2 *sensu* Ishida, 2002. Based on his figures (Ishida, 2002, Fig. 15k-l), P2-P3 couplers show the marginal setules on or near posterior margin, while this new species lacks the marginal setules on P2-P3 couplers. Upon re-examination of the three Japanese specimens he sent, the marginal ornamentation of P2 coupler seems to have been inadequately illustrated. They are not marginal setules on caudal face but hairs

situated on the posterior part of frontal face. As for the P3 coupler, among the three specimens, two have the strong marginal setules as in Dr. Ishida's figure, while one has the smooth margin as in *T. setulifer*. Another discrepancy is very short dorsal caudal seta as shown in Dr. Ishida's figure (Ishida, 2002, Fig. 15i), that is, a little shorter than even outer caudal seta. In *T. setulifer* specimens examined, the dorsal caudal seta is usually much longer than outer caudal seta, and only a little shorter than Fu and inner seta. Whether the discrepancies are genuine differences between two distinct species or geographical differences resulting from allopatric distribution is still unclear. The taxonomic status of *Tropocyclops* sp. 2 *sensu* Ishida, 2002, therefore, remains as *species inquirenda* pending more detailed re-examination.

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