

Discovery of the rarely known genus *Psammophilocyclops* (Cyclopidae Cyclopinae) from a water purification plant in South Korea

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A genuine interstitial cyclopoid species belonging to the genus *Psammophilocyclops* Fryer, 1956 is recorded from the filtration basin of a water treatment plant, South Korea. The genus *Psammophilocyclops* is very rarely found, and only three species have been recognized as yet: *P. boccaroi* Fryer, 1956 from Africa, *P. trispinosus* Shen et Tai, 1964 and *P. bispinosus* Shen et Tai, 1964 from China. The present new species differs from the congeneric species by the character combination of 11-segmented antennule in female, four-segmented maxilliped with 2,1,1,2 setation, the spine formula of 3,3,3,3, and setal arrangement of 3,3,5,3 on the distal endopodal segments of legs 1–4. Description and taxonomic accounts of the new species are presented with a revised generic diagnosis and a key to the species hitherto known in the genus.

Keywords: Cyclopoida; freshwater Copepoda; psammobiont; subterranean; taxonomy

Introduction

Recently, the senior author (JL) participated in a research project on the biological environment at the slow filtration sand basin at a water treatment plant in Yecheon County, South Korea, during the period from May 2007 to September 2008. A few psammobenthic copepod species, *Epaetophanes richardi* Mrázek, 1893, *Microcyclops rubellus* (Lilljeborg, 1901) and *Parastenocaris* sp. were frequently observed after the formation of algal biofilm at the upper part of the sand filtration basin. Along with them, some minute cyclopids were obtained by rinsing the sands and from water discharge, which turned out to be a new species belonging to the rarely known genus *Psammophilocyclops* Fryer, 1956.

In the genus *Psammophilocyclops*, only three species are currently recognized: *P. boccaroi* Fryer, 1956 from Africa, *P. trispinosus* Shen et Tai, 1964 and *P. bispinosus* Shen et Tai, 1964 from China. They are seemingly hypogean, considering that all the members were reported from the interstitial waters of lakeside or riverside sand beaches, and that they usually co-occurred with *Parastenocaris* harpacticoids, one of the representative interstitial copepods (see Lee and Chang, 2009: 169).

The continental cyclopoid copepod fauna of Korea comprises a total of 59 species of 20 genera in three families (Chang 2009), of which three subterranean species were recorded from Korea as new to science: *Acanthocyclops tokchockensis* Kim and Chang, 1991 from wells (Kim and Chang 1991), *Ochridacyclops coreensis* Chang, 2004 from springs (Lee et al., 2004)

and *A. fonticulus* Lee and Chang, 2007 from wells and springs (Lee and Chang 2007). In the interstitial freshwaters of Korea were reported only a few *Diacyclops* species, *D. disjunctus* (Thalwitzer, 1927), *D. languidoides* (Lilljeborg, 1901) and *D. suoensis* Ito, 1954 (Kim and Chang 1989; Chang et al. 1998; Chang and Min, 2005; Chang, 2009).

In this study, we describe a new interstitial species of the genus *Psammophilocyclops* from South Korea, with detailed illustrations. Moreover, as the true identity of the rarely found genus has not been clarified yet, we provide a revised generic diagnosis with a key to the species hitherto known in the genus.

Materials and methods

Samplings were carried out at the slow filtration sand basin at the Yecheon Water Treatment Plant in Yecheon County, South Korea, monthly during the period from May 2007 to September 2008. Copepods were collected by filtering about 1 liter of sands through nylon mesh with 64 µm aperture from the three filtration basins of the plant. The filtered copepods were fixed in 5% buffered formalin.

Specimens were dissected using tungsten needles sharpened by electrolysis, and mounted in lactophenol on a Cobb slide, after treatment in a solution of 5% glycerin / 95% ethanol for 1–2 days. The mounted specimens were observed using a differential interference contrast microscope (Olympus BX-51) equipped with Nomarski optics. All drawings were made with the aid of a camera lucida. Measurements were conducted

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using a digital camera for microscope (Cool SNAP 5.0M, Roper Scientific Co., USA) and the calibration software QCapture Pro (ver. 5.0, Media Cybernetics Inc., USA).

Type specimens are deposited in the National Institute of Biological Resources, Korea (NIBR), and in the Department of Biological Science, Daegu University (DB).

The abbreviations enp 1-2 or exp 1-2 are used in the text and figure legend to denote the first to second endopodal or exopodal segment of each leg.

Systematic accounts

Family Cyclopidae Dana, 1846

Subfamily Cyclopinae Kiefer, 1927

Genus *Psammophilocyclops* Fryer, 1956

Diagnosis. Body minute, 350–450 μm long, excluding caudal seta; slightly flattened dorsoventrally, with distinct demarcation between prosome and urosome. Cephalothorax incorporating first pedigerous somite. Rostrum not developed. Genital somite and first abdominal somite fused to form genital double-somite in female; anterior part generally swollen laterally, lacking a chitinous lateral projection. Seminal receptacle made up of broad and short anterior robe and well developed posterior lobe. Anal operculum convex, generally with smooth posterior margin, but sometimes semicircular in some species, rarely with serrated posterior margin. Caudal rami truncate and not so elongate, 2–3 times as long as wide, armed with six caudal setae.

Antennule 10- or 11-segmented; last segment with an aesthetasc, lacking distinguishable hyaline lamella. Antenna 4-segmented; coxobasis without outer distal seta representing exopod. Mandibular palp reduced to one naked seta on small projection. Maxilliped comprising syncoxa, basis and 2-segmented endopod basically, with 2,1,2,3 setation, but often segmentation and setation reduced.

Legs 1–4, both endopods and exopods 2-segmented, with spine formula of 3,3,3,3 or 2,2,2,2, and seta formula of 5,5,5,4. Basis of leg 1 bearing one spiniform seta inner distally. Legs 1–4, inner coxal seta basically present, but often defected according to species; enp 1 each bearing an inner seta; enp 2 basically with setal arrangement of 4,4,4,3, or with setation reduced. Leg 4 enp 2 typically with 1,I,2 formula.

Leg 5 completely incorporated into fifth pedigerous somite, represented by one lateral seta and two inner apical setae in both sexes.

Sexual dimorphism known in genital somite, antennule and leg 6. Male leg 6 with three setal elements. In the present new species, sexual dimorphism also shown in the shape of anal operculum and distal spine on leg 3 enp 2.

Free-living cyclopoids, found in the beaches and a sand basin in the water purification plant: interstitial waters of lakeside beach (Fryer, 1956); riverside beach (Shen and Tai, 1964); streamside sand basin in the water purification plant (this study).

Type species: *Psammophilocyclops boccaroi* Fryer, 1956. Other species: *P. trispinosus* Shen et Tai, 1964; *P. bispinosus* Shen et Tai, 1964; *P. paucisetosus* n. sp.

Psammophilocyclops paucisetosus n. sp. (Figures 1–5)

Material examined. Holotype: ♀ (NIBRINV0000243263), Yecheon Water Treatment Plant, Yecheon (36°39'59.91"N, 128°27'36.56"E"), 23 May 2008, J.G. Park. Holotype was dissected and mounted on glycerin. Allotype: ♂ (NIBRINV0000243264), dissected and mounted on glycerin, same locality, 27 Dec. 2007, J.G. Park. Paratypes: 2♂♂ (DB20034), undissected and preserved in 80% ethanol, same locality, 14 Sep. 2007, J.G. Park; ♂ (DB20035), undissected and preserved in 80% ethanol, same locality, 27 Dec. 2007, J.G. Park. Additional material: 2♀♀ (copepodites), same locality, 14 Sep. 2007, J.G. Park; 1♀ (copepodite), same locality, 26 Oct. 2007, J.G. Park.

Holotype female. Body (Figure 1A) minute, 412 μm long, excluding caudal setae, greatest width 138 μm in the middle of cephalothorax; slightly flattened dorsoventrally. Prosome oblong-oval, much longer than urosome (1.42 times). Cephalothorax protruding anteriorly, about 1.7 times longer than next three prosomites combined; chitinous lines present on dorsal and lateral surface, running transversely along posterior margin of cephalothorax and winding up to lateral margin; innumerable pits and 20–24 sensilla scattered on whole dorsal and lateral surfaces (Figure 1A, B). Second prosomite with 1 longitudinal cuticular ridge laterally, with paired sensilla dorsolaterally. Third prosomite with rough and rugged posterior margin. Posterolateral corners of third and fourth prosomites slightly produced posterolaterally. First urosomite (fifth pedigerous somite) with ventrolateral corner strongly produced (Figure 1B).

Genital somite and first abdominal somite fused to form genital double-somite, remaining chitinous suture line laterally; somewhat flattened dorsoventrally; much (about 1.5 times) wider than long (58.6 μm long, 87.5

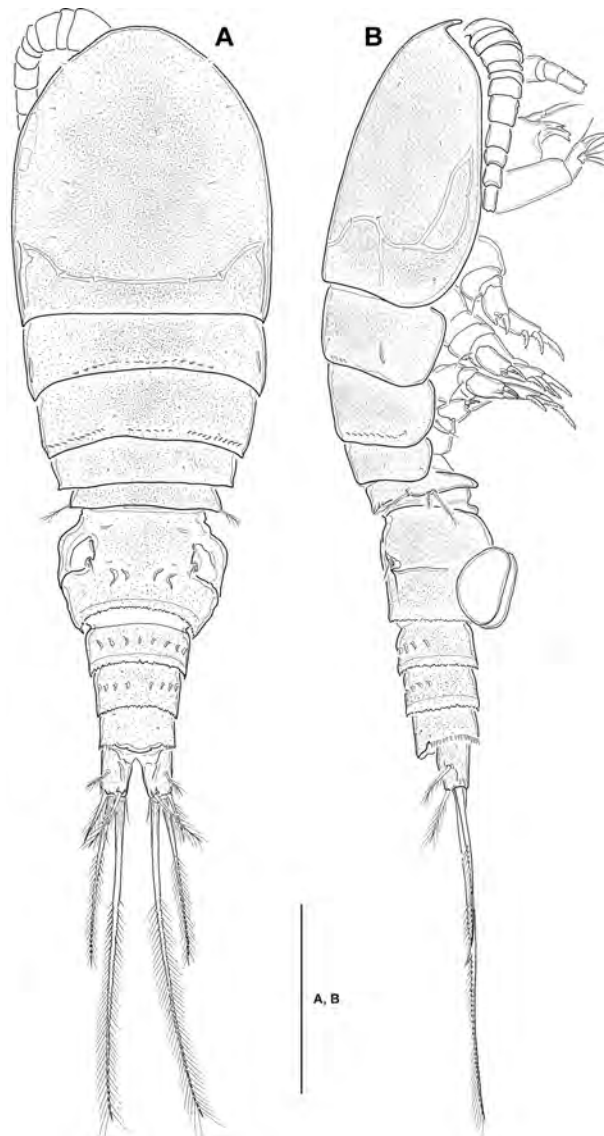


Figure 1. *Psammophilocyclops paucisetosus* n. sp., female (holotype). A, habitus, dorsal; B, habitus, lateral (with paired spermatophores attached). Scale bar = 100 μ m.

μ m wide) (Figure 1A); both sides swollen laterally, but lateral margin rather smooth without chitinous projection; dorsolateral surface depressed widely and heavily sclerotised with wrinkles and one slender plumose seta and one small conical projection representing leg 6 (Figure 1A, 1B, 2I); two pairs of cuticle furrows, each engraved to form a dugout, at hind region of mid-dorsal surface. Seminal receptacle made up of two wide lobes in the shape of a pot with lid, posterior lobe well developed, nearly semicircular with slight posteromedial depression (Figure 2A). Third and fourth urosomites ornamented with one row of eight cuticle furrows dorsally. Posterior margins of abdominal somites strongly crenated, except anal somite bearing a spinule

row on both dorsal and ventral sides. Anal operculum slightly convex; posterior margin round and smooth, except one notch at each side (Figure 2B).

Caudal rami (Figure 2B) nearly parallel or slightly divergent, 1.91 times as long as wide; weak dorsal rib curving inward, running up to dorsal caudal seta; lateral margins smooth. Lateral caudal seta located at almost halfway point of lateral margin of ramus, inserted slightly dorsolaterally, without spinules around its base. Outer caudal seta plumose, flanking one spinule just ahead of its base; nearly as long as caudal ramus, 1.9 times as long as inner caudal seta. Inner terminal caudal seta not swollen at its base, with fracture plane, about 1.9 times longer

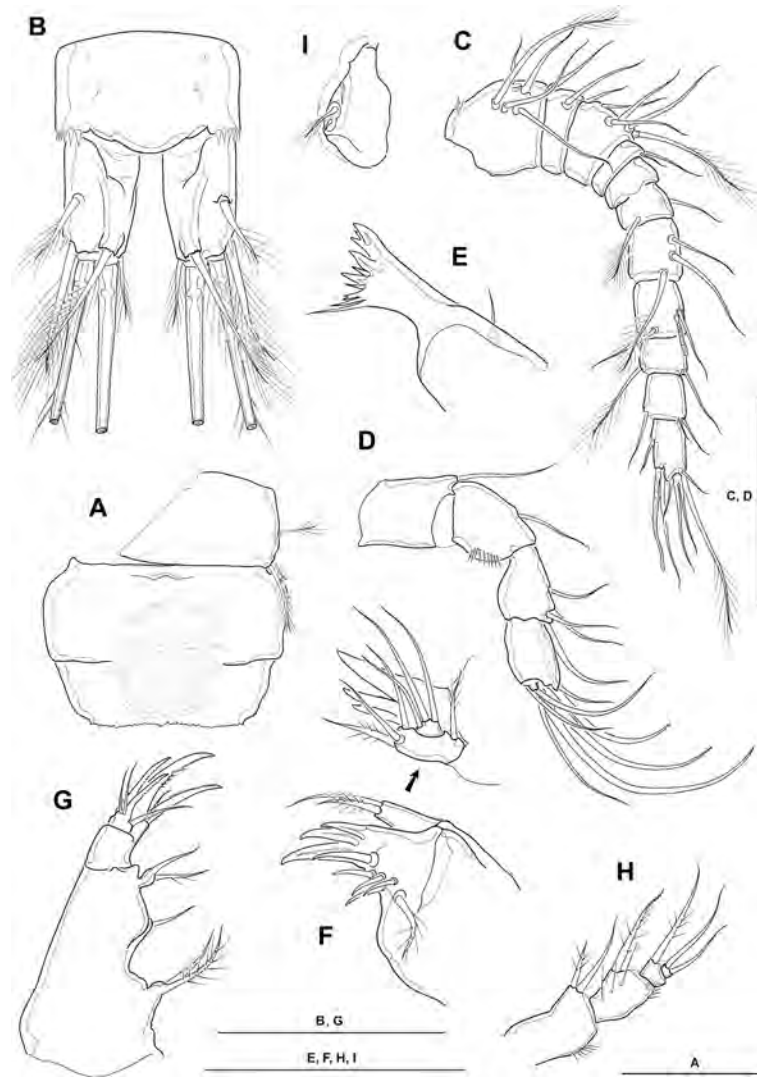


Figure 2. *Psammophilocyclops paucisetosus* n. sp., female (holotype). A, genital double-somite and leg 5, ventral; B, anal somite and caudal rami, dorsal; C, antennule; D, antenna, caudal; E, mandible; F, maxillule, posterior (with palp in anterior view); G, maxilla; H, maxilliped; I, leg 6. Scale bars = 30 µm (B–G) and 50 µm (A, H).

than outer terminal seta, and 0.42 times as long as whole body length. Dorsal caudal seta slightly longer than caudal ramus, about 1.2 times longer than outer caudal seta.

Antennule (Figure 2C) 11-segmented, its tip slightly not reaching to posterior third of cephalothorax. Segments 2, 4 and 5 relatively short; segments 1, 3, 7 and 8 stout and long. Anterodistal seta on segment 5 completely lacking. Segments 7 and 11 each with one aesthetasc. Last segment without distinguishable hyaline lamella, about 1.5 times longer than penultimate segment. Setal formula: 6, 2, 5, 2, 0, 2, 3, 2+1 aesthetasc, 2, 3, 7+1 aesthetasc.

Antenna (Figure 2D) 4-segmented, comprising coxobasis and three-segmented endopod. Coxobasis bearing one inner distal seta, lacking outer distal seta

representing exopod. First endopodal segment bearing one inner seta with one spinule row at outer distal corner. Second endopodal segment with five setae in total along inner distal margin. Third endopodal segment armed with seven setae around distal area.

Mandible (Figure 2E), coxa with well-developed gnathobase, armed with eight or nine teeth and one naked seta posteriorly. Palp very reduced, represented by one naked seta on small projection.

Maxillule (Figure 2F) with praecoxal arthrite bearing nine elements, of which the proximal-most one is plumose. Palp two-segmented; coxobasis bearing one strong spinulose and two slender naked setae inner distally, plus one outer plumose seta representing exopod; distal segment, representing endopod, with three long setae.

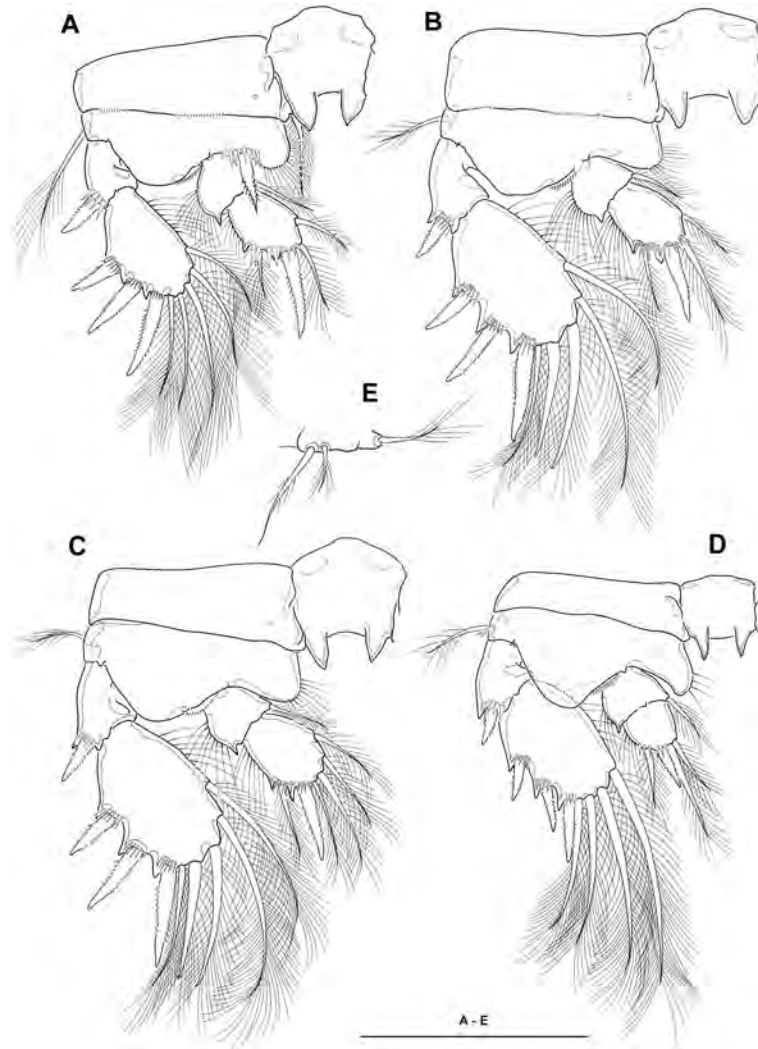


Figure 3. *Psammophilocyclops paucisetosus* n. sp., female (holotype). A–D, legs 1–4, caudal; E, leg 5, ventrolateral. Scale bar = 50 μ m.

Maxilla (Figure 2G) 3-segmented. Praecoxa and coxa completely fused; praecoxal endite with two setae, one of which pinnate; coxa with one naked seta representing proximal endite and one bisetose lobe representing distal endite. Basis forming two strong dentate claws with one naked seta. First endopodal segment bearing two spinulose setae. Endopod 1-segmented, carrying five elements of one basal, two spiniform and two slender setae.

Maxilliped (Figure 2H) 4-segmented. Syncoxa with two setae representing endite. Basis ornamented with three setules along outer margin, bearing one long pinnate seta. First endopodal segment armed with one strong pinnate seta; second endopodal segment with two naked setae.

Legs 1–4 (Figure 3A–D), both endopods and exopods 2-segmented. Seta/spine armature of legs 1–4

as follows (Roman numerals indicate number of spines, and Arabic numerals indicate number of setae):

	Coxa	Basis	Exopod	Endopod
Leg 1	0-1	1-1	I-0; III,5	0-1; 1,I,2
Leg 2	0-0	1-0	I-0; III,5	0-1; 1,I,2
Leg 3	0-0	1-0	I-0; III,5	0-1; 1,I,4
Leg 4	0-0	1-0	I-0; III,4	0-1; 1,I,2

Intercoxal sclerites (couplers) of legs 1–4 each with paired lateral lobes strongly produced distally and smooth distal margin; both anterior and posterior surfaces smooth without transverse spinule or setule row. Inner coxal seta present in leg 1, while absent in legs 2–4. Bases of legs 1–4 produced inner distally, with

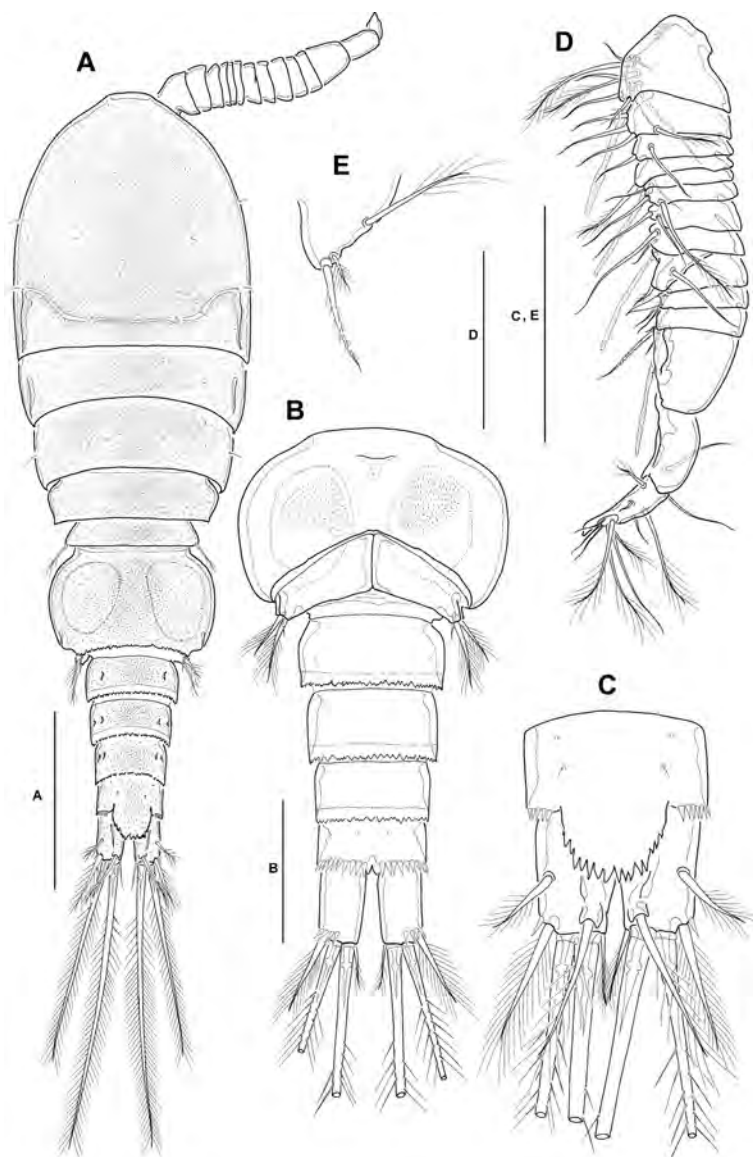


Figure 4. *Psammophilocyclops paucisetosus* n. sp., male (allotype). A, habitus, dorsal; B, urosome with leg 6, ventral; C, anal somite and caudal rami, dorsal; D, antennule E, leg 5, ventrolateral. Scale bars = 30 μm (B–G) and 50 μm (A, H).

setule row along inner distal margin. Basis of leg 1 bearing one stout and short spiniform seta inner distally, not reaching to middle of leg 1 enp 2. Enp 1 of legs 1–4 each with one inner seta. Exp 2 of legs 1–4 strikingly enlarged, each armed with three spines (spine formula 3,3,3,3), and with five setae on legs 1–3 and four setae on leg 4 (setal formula 5,5,5,4). Enp 2 of legs 1–4 with 3,3,5,3 setae. Leg 4 enp 2 relatively small, about 0.9 times as long as wide, bearing only one spine, nearly as long as enp 2.

Leg 5 (Figure 1B, 2A, 3E) completely incorporated into fifth pedigerous somite, represented by one lateral seta and two inner apical setae; two inner setae inserted close together, innermost one nearly 3 times longer than

outer one. Leg 6 (Figure 2I) represented by one plumose seta and one minute spinule on small cuticular projection in dorsolateral part of genital double-somite.

Male. Sexual dimorphism shown in genital somite, anal operculum, antennule, leg 3 enp 2, and leg 6. Genital somite swollen laterally (Figure 4A, B), about 1.6 times wider than long, posterior margin serrated dorsally; in ventral view, paired genital opercular plates oblong, each with three setae in total (two plumose setae posterolaterally and one minute vestigial seta posterodorsally), representing leg 6. Next three urosomites with posterior margins serrated both dorsally and ventrally. Anal somite with spinules along posterior

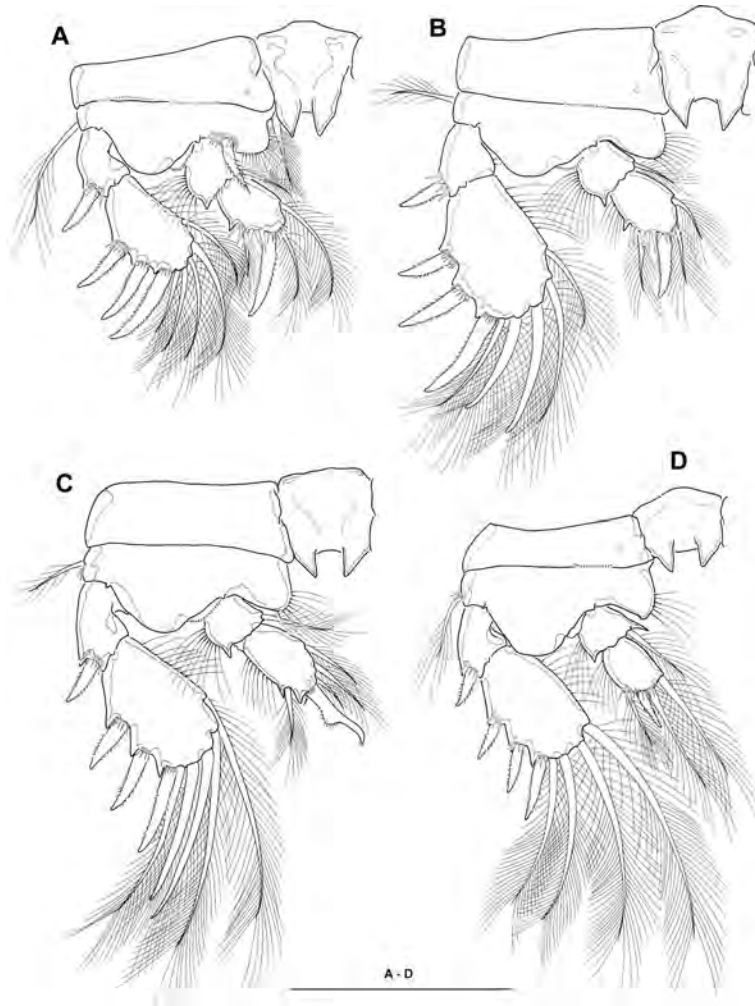


Figure 5. *Psammophilocyclops paucisetosus* n. sp., male (allotype). A–D, legs 1–4, caudal. Scale bar = 50 μ m.

margin, 5–7 spinules dorsally, 9 or 10 spinules ventrally. Anal operculum (Figure 4C) nearly semicircular, with posterior margin strongly serrated. Caudal rami (Figure 4C) 2.15 times as long as wide, slightly longer than in female; ratio between caudal setae similar to those in female. Antennule (Figure 4D) geniculate, indistinctly 14-segmented; articulation between segments 12 and 13; segments 1, 4, 8, 12 each bearing one aesthetasc. Leg 1 (Figure 5A) similar to that of female, including inner seta on basis. Leg 3 enp 2 (Figure 5C), bearing one short, slender seta issuing from base of distal spine; distal spine modified with hooked tip and swollen mid-lateral margin, armed with spinules along outer margin.

Etymology. The proposed specific name, *paucisetosus* (*paucus*, *L.* meaning ‘few’; *setosus*, *L.* meaning ‘of seta’), refers to ‘bearing fewer setae’ on enp 2 of legs 1–2 as well as the absence of inner coxal seta on legs 2–4 in the present new species.

Remarks. Since Fryer (1956) established a new genus *Psammophilocyclops* for a new species, *P. boccaroi*, from sandy beaches of Lake Nyasa (now called Lake Malawi), southeastern Africa, only two species have been additionally recorded in the genus: *P. trispinosus* Shen et Tai, 1964 and *P. bispinosus* Shen et Tai, 1964, both from riverside beaches at Kwangtung, southern China. Shen and Tai (1964) regarded *Psammophilocyclops* as being allied to the genera *Goniocyclops* Kiefer, 1955, *Psammocyclops* Kiefer, 1955 and *Cochlocyclops* Kiefer, 1955 in sharing the character combination of 11- or 10-segmented antennule, semicircular (or triangular) shape of anal operculum, two-segmented endopods and exopods of legs 1–4, and leg 5 completely incorporated into fifth pedigerous somite with two apical setal elements (see Shen and Tai, 1964: 376, Table 7; Tai and Chen, 1979: 402). The present new species apparently does not belong to the allied genera above but to

Table 1. Character comparison between four known species of *Psammophilocyclops*.

	<i>P. boccaroi</i>	<i>P. trispinosus</i>	<i>P. bispinosus</i>	<i>P. paucisetosus</i> n. sp.
Antennule, segments, ♀	11	10	10	11
Maxilliped, segments (setal armature)	3 (1,1,3)	4 (2,1,1,3)	3 (1,1,3)	4 (2,1,1,2)
Legs 1–4 exp 2, spine formula	3,3,3,3	3,3,3,3	2,2,2,2	3,3,3,3
Legs 1–4 exp 2, setal formula	5,5,5,4	5,5,5,4	5,5,5,4	5,5,5,4
Legs 1–4 enp 2, setal formula	4,4,4,3	4,4,4,3	3,4,4,3	3,3,5,3
Legs 1–4, inner coxal seta	1,?,?,1	1,1,1,0	1,1,1,1	1,0,0,0
Leg 4 enp 2, length/width ratio	1.3	1.7	1.4	~1
Anal operculum	Angular with straight margin	Semicircular	Semicircular	♀: round; ♂: semicircular (serrated)
Caudal ramus, length/width ratio, ♀	2.0–2.2	2.6–2.7	2.5	1.9
Locality and habitat	Lake Niasa, Rhodesia; lakeside beach (Fryer, 1956)	Kwangtung, China; riverside beach (Shen and Tai, 1964)	Kwangtung, China; riverside beach (Shen and Tai, 1964)	Yecheon, Korea; water filtration sand basin (this study)

Psammophilocyclops in showing the spine formula of 3,3,3,3 (while 2,3,3,2 in *Goniocyclops*, and 3,3,3,2 in *Psammocyclops* and *Cochlocyclops*).

As shown in Table 1, the reduction in the setal and/or spine armature of legs and in the segmentation and setation of maxilliped occurs widely in the members of the genus *Psammophilocyclops*, supposedly resulting from the interstitial or hypogean habit. Especially, the tendency to reduction appears evidently in the number of setae on the distal endopodal segment of legs 1–2 and inner coxal seta of legs 2–4 as well as the segmentation and setation of maxilliped. *Psammophilocyclops paucisetosus* n. sp., as suggested in the specific name, is most characteristic in showing the reduction in the setal armature, that is, only three setae on legs 1–2 enp 2 and the absence of inner coxal seta on legs 2–4.

Psammophilocyclops paucisetosus n. sp. shares the combination of characters of 11-segmented antennules, spine formula (3,3,3,3) and relatively shorter caudal rami (around 2 times as long as wide) with *P. boccaroi*. However, *P. boccaroi* differs from the new species by 3-segmented maxilliped and the angular shape of anal operculum with straight posterior margin (vs. round in female and semicircular in male of the new species).

Psammophilocyclops trispinosus is allied with *P. paucisetosus* in sharing the same spine formula and 4-segmented maxilliped; however, the former differs from the latter by setation of 2,1,2,3 on maxilliped

(vs. 2,1,2,2), 10-segmented antennules and relatively elongate caudal rami.

The other Chinese congener, *P. bispinosus*, apparently differs from the new species by the spine formula of 2,2,2,2, 10-segmented antennule, 3-segmented maxilliped and elongate caudal rami.

In *P. boccaroi*, the arrangement of two exopodal setae of leg 5 was described as inner seta being short and outer one long, in contrast with long inner seta and short outer seta in the three Asian species including this new species. If the difference is not caused simply by inadequate observation with incorrect positioning of the minute specimen in *P. boccaroi*, it could be a genuine interspecific discrepancy between the species groups from two continents.

Another remarkable characteristic of the new species is the semicircular anal operculum with serrated posterior margin shown only in male specimens. The feature is strongly reminiscent of the triangular anal operculum with serrated lateral margins of *Itocyclops yezoensis* Reid and Ishida, 2000, which has been reported from cavern waters, springs and driven wells in Japan, Alaska and Korea (Ito, 1953, 1954; Ishida, 1992, 2002; Reid and Ishida, 2000; Lee et al., 2004), and still remains as the monotypic species of the genus. In *I. yezoensis*, the shape of anal operculum is known as rather variable in length and in the shape of lateral margins from heavily crenate to weakly undulate (Lee et al., 2004). As this study is based on only two female specimens including a juvenile and several males, it cannot be fully ascertained whether the characteristic is

a real sexual dimorphic character or not, and whether it would be variable or consistent, especially in the female.

A key to the species of genus *Psammophilocyclops*

- 1. Spine formula (number of spines on legs 1–4 exp 2)
 2,2,2,2 *P. bispinosus*
 - Spine formula 3,3,3,3 2

- 2. Maxilliped 3-segmented; inner coxal seta on leg 4 present *P. boccaroi*
 - Maxilliped 4-segmented; inner coxal seta on leg 4 lacking 3

- 3. Legs 1–2 enp 2 with four setae; inner coxal seta on legs 2–3 present; caudal rami more than 2.5 times as long as wide; antennule 10-segmented *P. trispinosus*
 - Legs 1–2 enp 2 with three setae; inner coxal seta on legs 2–3 lacking; caudal rami less than 2 times as long as wide; antennule 11-segmented *P. paucisetosus* n. sp.

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