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The Hyperbenthic Calanoid Copepod *Paramisophria* from Okinawa, South Japan

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ABSTRACT—Two species of the genus *Paramisophria* T. Scott, 1897 (Copepoda: Calanoida: Arietellidae), one of which is new to science, were collected from near the bottom off Zamami and Kume Islands, Okinawa, South Japan and described here. The finding of *Paramisophria japonica* n. sp. synonymizes the two closely related genera *Paramisophria* and *Parapseudocyclops* Campaner, 1977, and the valid name of genus is *Paramisophria,* based on the principle of priority. This new species has the most plesiomorphic characters of the genus as follows: 22-segmented antenna 1 of female; inner lobe of maxilla 1 with five spines and one process; endopod of maxilla 1 bearing three setae; endopod of leg 5 of female having two plumose setae apically.

INTRODUCTION

Although most calanoid copepods are generally thought to be pelagic, many species of hyperbenthic calanoids, however, have been collected from lower intertidal zone to depths over 1800 m [1–13].

In Japan, one of the authors (SO) has intensively been investigating shallow water hyperbenthic calanoid copepods [2–6], and recently obtained numerous hyperbenthic species belonging to the families Aetideidae, Arietellidae, Pseudocyclopidae, Pseudocyclopiidae and Stephidae from the Nansei Islands, South Japan. During the course of the taxonomic study, two species which have morphological characters unique to the genus *Parapseudocyclops* Campaner, 1977 (Arietellidae), have been found first time in the Indo-Pacific region. One of them is new to science and both adult females and males were collected. The monotypic genus *Parapseudocyclops* accommodates *P. giselae* Campaner, of which only two adult females were collected from the Brazilian continental shelf [1]. By the record of the new species from Japan, the relationship between *Parapseudocyclops* and the closely related *Paramisophria* T. Scott, 1897 is reconsidered.

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MATERIALS AND METHODS

The specimens were collected off Kume Island (Stn. 1, 26°17.9′N, 126°54.2′E, 170 m, sandy bottom, 23 May 1989) and Zamami Island (Stn. 2, 26°15.9′N, 127°21.4′E, 120 m, sandy bottom, 23 May 1989), Okinawa by an originally designed sledge-net (mouth area: 1450 mm in length ×326 mm in width; last net mesh size: 0.33 mm). The sledge-net was towed along the bottom at a speed of two knots by the T/RV Toyoshio-maru of Hiroshima University for about five min. The distance between the sledge-net and the bottom was measured by a remote-sensing system (Furuno-denki, Color net recorder CN-8). The specimens were fixed in 10% neutralized formalin/sea-water immediately after capture. The ventral side of the genital segment of the new species was observed with a SEM (Jeol JSM-T20). Contents in prosomal guts of 10 adult females of the new species were examined with a differential interference microscope. The detailed procedure for gut content analysis was shown in the previous work [16].

All the type specimens and one dissected specimen of another species are deposited in the US National Museum of Natural History, USNM Smithsonian Institution, Washington, D.C., U.S.A.

Paramisophria japonica n. sp.
(Figs. 1–5)

Types. Holotype: ♀, collected at Stn. 2 (26°15.9′N, 127°21.4′E, 23 May 1989), dissected and mounted on glass slides, USNM 250568; Paratypes: 2♀♀ and 3♂♂, collected at Stn. 2, dissected and mounted on glass slides; 3♀♀ and 3♂♂, taken at Stn. 2, whole specimens, USNM 250569.

Body length. Female. Stn. 1 (one individual): 1.99 mm. Stn. 2 (21 individuals): range (r)=1.85–2.08 mm; mean±standard deviation (m±s.d.)=1.95±0.05 mm. Male. Stn. 1 (one individual): 1.62 mm. Stn. 2 (seven individuals): r=1.41–1.64 mm; m±s.d.=1.56±0.08 mm.

Description. Female (holotype). Body (Fig. 1–A, B) compact and robust, 1.98 mm long; cephalosome and pediger 1 separated; pedigers 4 and 5 fused. Prosome nearly symmetrical in dorsal view. Rostrum (Fig. 1–C) with a pair of subterminal filaments. Each side of pediger 5 with pointed dorsolateral process and round lamellous medial and ventrolateral lobes, former lobe reaching two-

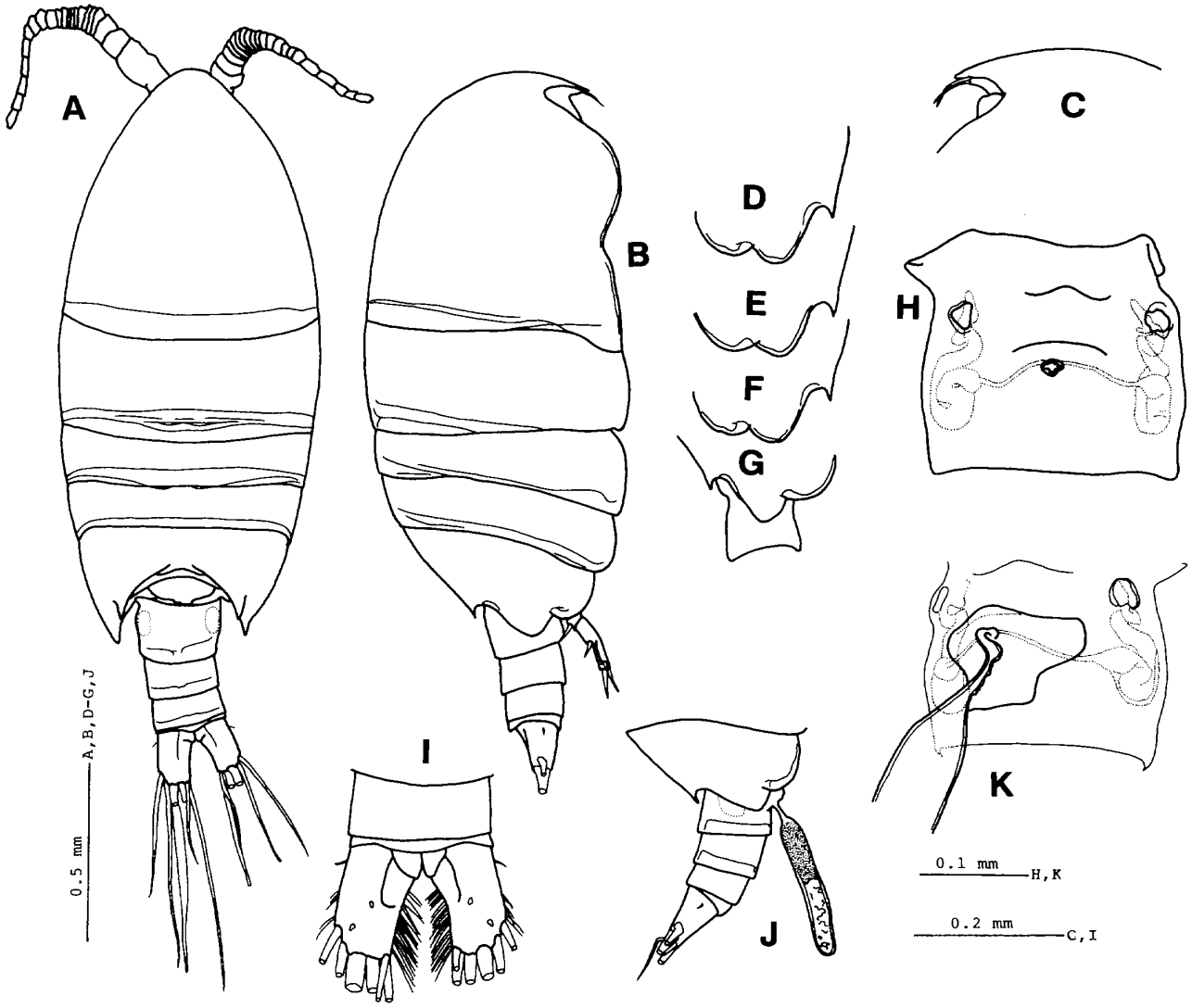

FIG. 1. *Paramisophria japonica* n. sp. Female (holotype: A, B, D, H, I; paratypes: C, E-G, J, K). A. Habitus, dorsal view; B. Habitus, lateral view; C. Rostrum, lateral view; D-F. Pediger 5, left lateral view; G. Pediger 5, right lateral view; H. Genital segment, ventral view; I. Anal segment and caudal rami, dorsal view; J. Urosome with spermatophore, lateral view; K. Genital segment with spermatophore, ventral view.

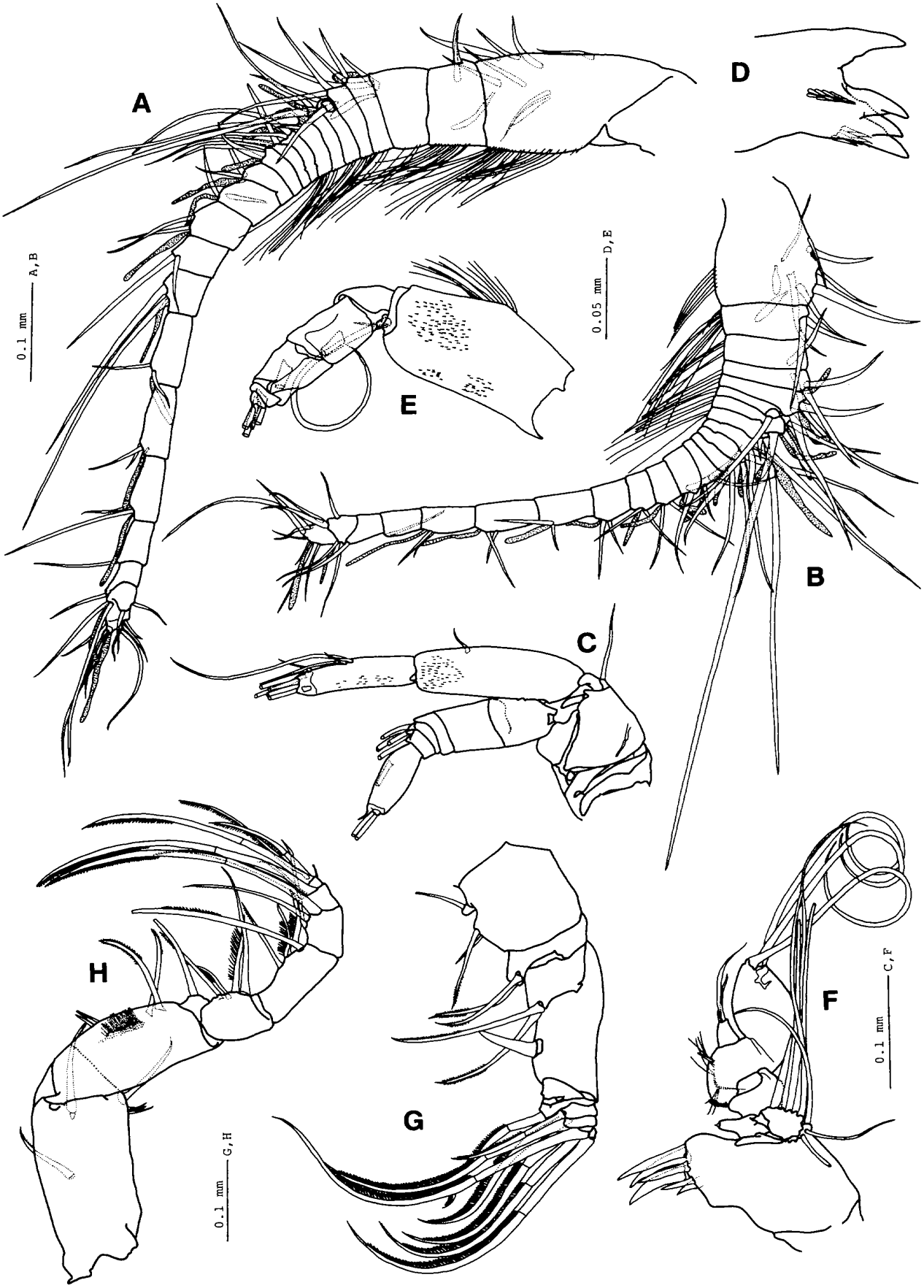

FIG. 2. *Paramisophria japonica* n. sp. Female (holotype). A. Left antenna 1; B. Right antenna 1; C. Antenna 2; D. Mandibular cutting edge; E. Mandibular palp; F. Maxilla 1; G. Maxilla 2; H. Maxilliped.

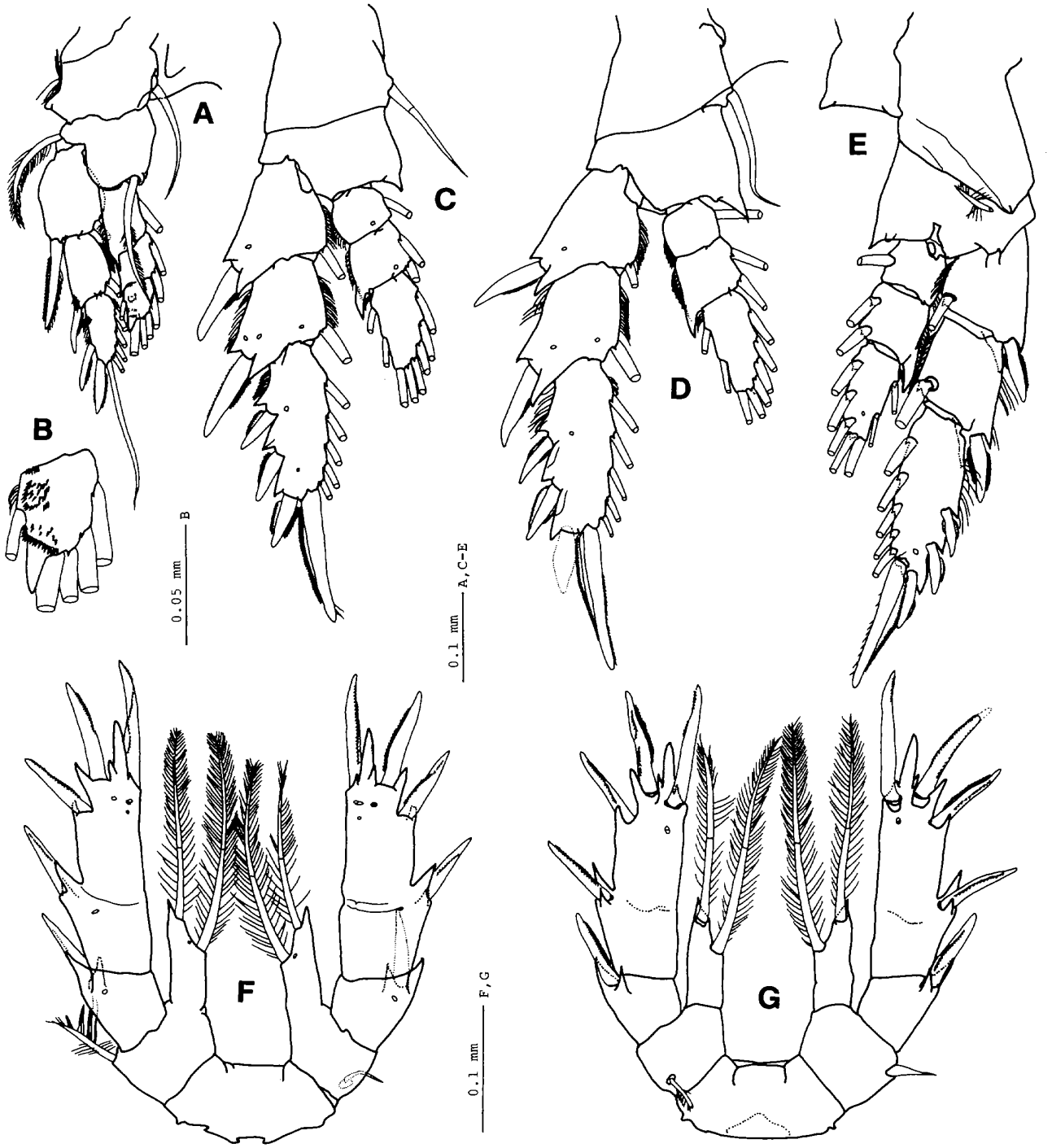

FIG. 3. *Paramisophria japonica* n. sp. Female (holotype: A-F; paratype: G). A. Leg 1, anterior face; B. Terminal segment of endopod of leg 1, anterior face; C. Leg 2, anterior face; D. Leg 3, anterior face; E. Leg 4, posterior face; F. Leg 5, anterior face; G. Leg 5, posterior face.

thirds the length of genital segment (Fig. 1–A, B). Urosome 4-segmented, one-third the length of prosome. Genital segment (Fig. 1–H) with a pair of ventrolateral gonopores anteriorly; two small copulatory openings located closely together at middle part of ventral surface (see Fig. 5–A, B, C) and connecting with sigmoid seminal receptacle of each side through fine tube. Anal segment (Fig. 1–I) small. Caudal ramus (Fig. 1–I) with four terminal and one subterminal setae and one dorsal inner setule. Left antenna 1 (Fig. 2–A) longer than right (Fig. 2–B); both antennae 1 22-segmented; segments 3–19 each furnished with two setae and one aesthetasc, segment 7 bearing

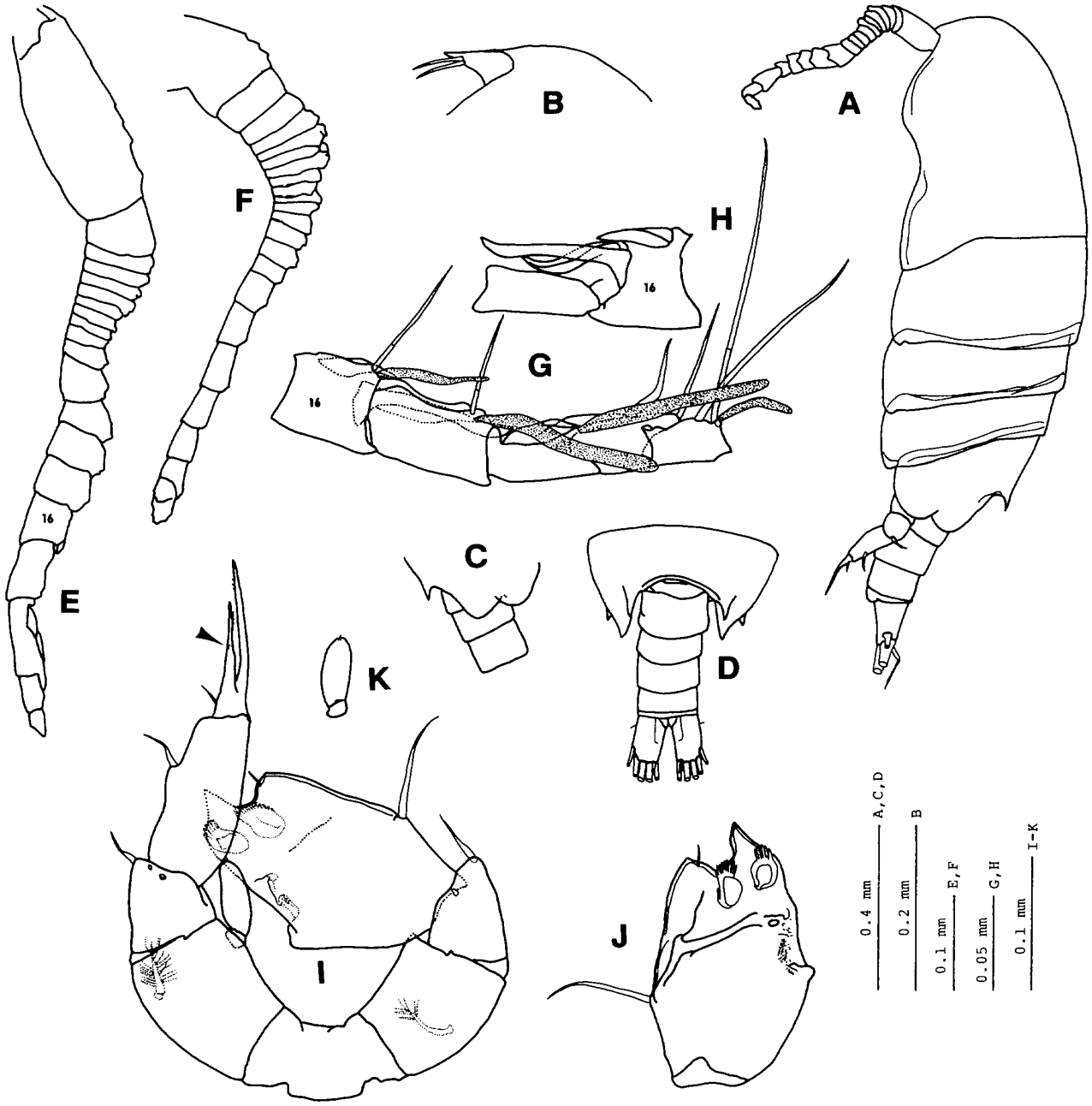

FIG. 4. *Paramisophria japonica* n. sp. Male (a paratype: A-I; another paratype: J, K). A. Habitus, lateral view; B. Rostrum, lateral view; C. Pediger 5, right lateral view; D. Pediger 5 and urosome, dorsal view; E. Left antenna 1, all setae omitted; F. Right antenna 1, all setae omitted; G. Segments 16–20 of left antenna 1, dorsal view; H. Segments 16 and 17 of left antenna 1, ventral view; I. Leg 5, anterior face, short, thick spinule on outer process indicated by arrowhead; J. Terminal segments of right leg 5, posterior face; K. Endopod of left leg 5.

extremely long seta; terminal segment with 10 setae and three aesthetascs; segments 1–8 possessing long hairs along posterior margin. Antenna 2 (Fig. 2–C): endopod 2-segmented, slightly longer than exopod; apical segment shorter than proximal one, bearing three setae of unequal lengths at midst length of inner margin; exopod consisting of six segments, proximal two segments incompletely fused, terminal segment with one medial seta, and two setae and one minute setule terminally. Mandibular gnathobase (Fig. 2–D) with three teeth, dorsalmost bifurcate, and two patches of dagger-like spinules. Mandibular palp (Fig. 2–E): 1-segmented rudimentary endopod bearing two setae of unequal lengths terminally; exopod 5-semented, each of proximal four segments having

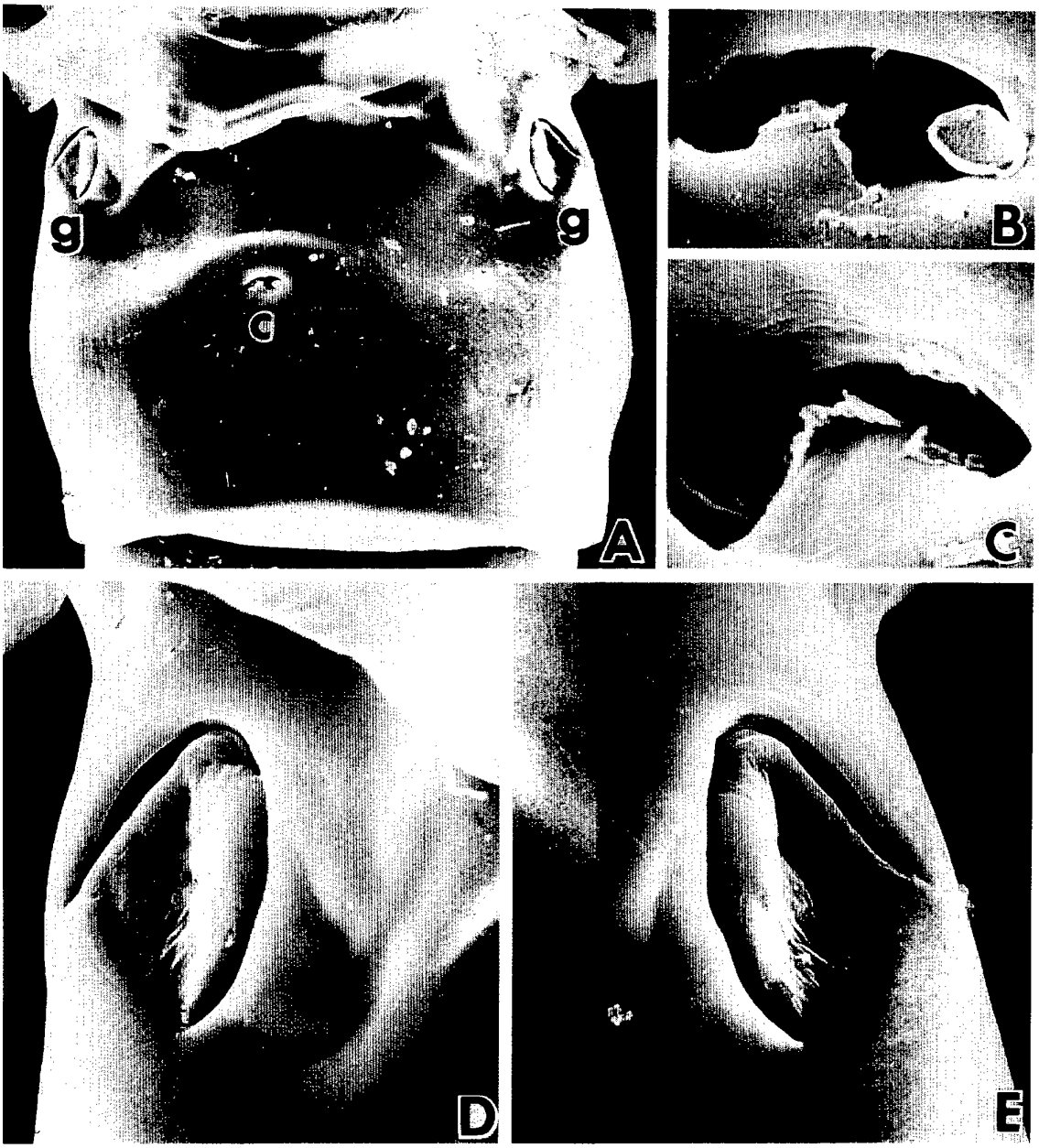

FIG. 5. *Paramisophria japonica* n. sp. SEM-microphotographs of genital segment of female. A. Genital segment, ventral view, gonopore (g), copulatory pore (c), ×619; B, C. Copulatory pores, ×6188 (B), ×8840 (C); D. Right gonopore, ×2652; E. Left gonopore, ×2652.

one seta; apical segment with two setae. Maxilla 1 (Fig. 2–F): first inner lobe (gnathobase) with five spines and one process; second inner lobe with rudimentary minute setule on tip; first outer lobe bearing eight setae; inner margin of basipod 2 bearing two rows of hairs and one minute middle seta; endopod 1-segmented, bulbous, and having three terminal setae of unequal lengths; exopod fused, with basipod segment 2, bearing three plumose setae terminally. Maxilla 2 (Fig. 2–G) stout, with six weakly developed inner lobes; fifth inner lobe furnished with one naked strong spine; endopod segments bearing seven large pectinate setae. Maxilliped (Fig. 2–H): basipod segments elongated; segment 1 being at right angle to segment 2; endopod 5-segmented, segments 1, 2, and 3, 4 bearing four and three inner setae, respectively; terminal segment having four setae. Legs 1–4 each with 3-segmented endo- and exopods. Leg 1 (Fig. 3–A, B): basipod segment 1 produced outwards into subterminal blunt process, segment 2 finely serrated along base of endopod, and bearing

medial outer seta and inner seta near base of endopod; endopod segments 2 and 3 produced outwards into terminal acute process. Legs 2 and 3 (Fig. 3–C, D) similar in structure, acute inner terminal process longer in latter than in former; endopod segment 2 produced outwards into acute terminal process, near base of which a small prominence is present. Leg 4 (Fig. 3–E) furnished with small plumose seta on posterior face of basipod segment 2. Leg 5 (Fig. 3–F): basipod segments 1 fused to intercoxal plate to form a common base; basipod segment 2 completely fused with endopod segment; endopod produced terminally and bearing two plumose setae, one terminal and one subterminal; exopod segment 1 and basipod segment 1 separate; exopod segments 2 and 3 fused incompletely, and its fusion line clearly visible on anterior face; exopod segment 3 bearing two terminal and one subterminal large serrate spines; terminal process with two minute prominences at its base.

Male (a paratype: Fig. 4–A–I; another paratype; Fig. 4–J, K). Body (Fig. 4–A) slenderer than in female, 1.56 mm long. Rostrum (Fig. 4–B) with two subterminal filaments as in female. Pediger 5 (Fig. 4–C, D) reaching middle of urosome segment 2. Urosome (Fig. 4–D) 5-segmented; segment 5 small. Left antenna 1 (Fig. 4–E, G, H) geniculate, 21-segmented; segments 18 and 19 incompletely fused; segment 16 (Fig. 4–G, H) with cuticular ridge along anterior margin, and bearing large spine anteroterminally; segment 17 furnished with cleft along anterior margin, and cuticular ridge along proximal half anterior margin; segment 18 (Fig. 4–G) also having two cuticular ridges along anterior margin; segment 19 (Fig. 4–G) with anterior terminal end produced into a blunt process which reaches middle length of next segment. Right antenna 1 (Fig. 4–F) 22-segmented, shorter than left. Mouthparts and legs 1–4 similar to those of the female. Leg 5 (Fig. 4–I, J, K): basipod segments 1 fused to form a common base. Right leg: basipod segment 2 produced at inner terminal end; exopod segment 1 triangular, bearing small outer naked seta at apex; exopod segments 2 and 3 incompletely fused, expanded like a fan, and jointed with preceding segment at an angle of about 60°; middle inner margin of this fused segment bluntly produced inwards and bearing patches of minute hairs on posterior face; two subterminal crest-like cuticular structures present on posterior face, inner one with six prominences, outer one with 9–12 prominences; two triangular lamellous projections present terminally, outer one with a small setule. Left leg: basipod segment 2 broad, with 1-segmented bulbous endopod and short plumose seta near outer terminal end on posterior face; exopod segment 1 triangular, bearing small outer naked seta terminally; exopod segment 2 located on inner side of segment 1, elongated, furnished with outer middle naked seta; exopod segment 3 small, with two stout pectinate processes of unequal lengths and minute outer setule; outer process bearing minute projection directed slightly outwards (indicated by arrowhead in Fig. 4–I).

Structure of female genital segment. An SEM-examination of the female genital segment revealed that the gonopore (Fig. 5–A, D, E) has an operculum with its anterior part open, and that the copulatory pores (Fig. 5–B, C) open closely in a shallow common hole located centrally on the ventral side. A paratypic female has a sausage-like spermatophore on the ventral side of its genital segment, which covers the copulatory pores (Fig. 1–J, K).

Variation. Dorsolateral lobe and dorsal process of pediger 5 (Fig. 1–B, D, E, F, G) are slightly variable in shape: smoothly rounded (Fig. 1–B, D, E, F) or bluntly pointed lobe (Fig. 1–G); sharpness in dorsal process. A fusion line between the endopod and basipod 2 of leg 5 is not visible from both sides in the holotypic female (Fig. 3–F), whereas it is clearly visible on the posterior surface in a paratypic female (Fig. 3–G). In right leg 5 of male, the outer lamellous projection on the terminal segment is triangular in one paratype and smoothly rounded in another paratype.

Examination of gut contents. Half the individuals preyed on benthic cyclopoid or harpacticoid copepodids. One female fed on a chaetognath. Four individuals had empty guts. The gut-content

analysis indicated that *P. japonica* is a strong carnivore feeding mainly on epibenthic organisms.

Remarks on new synonymy. The genus *Paramisophria* was established and briefly defined by Scott [15]. Later, the definition of the genus was given more exactly by Sars [7], and partly revised by Krishnaswamy [9]. The revised generic definition of *Paramisophria* is as follows: rostrum with two filaments; pediger 5 with two conspicuous subdorsal projections; antenna 1 21-segmented; inner corner of basipod 2 of legs 2–4 produced, and endo- and exopods 3-segmented; legs 5 of female and male 3- and 5-segmented, respectively; basipod 2 of female leg 5 with inner projection; basipod 2 of leg 5 of male with or without endopod; right and left terminal segments of leg 5 of male spatulate and unguiform, respectively.

The following definition of the closely related genus *Parapseudocyclops* is given based on only two adult females of the monotypic *P. giselae* [1]: rostrum with one filament; left antenna 1 22-segmented; maxilla 1 with six spines on first inner lobe, one seta on second inner lobe, three setae on endopod and nine setae on first outer lobe; both endo- and exopods of leg 5 coalesced with basipod 2; endopod with two long setae; exopod with three lateral and two terminal spines.

Although Campaner [1] didn't mention morphological differences between two genera *Paramisophria* and *Parapseudocyclops* in detail, he might have thought that the most important characteristic to distinguish between these two genera was the structure of leg 5 of adult female: in *Paramisophria,* exopode separate from basipod 2, and endopod with or without one seta, while in *Parapseudocyclops,* both endo- and exopods fused with basipod 2, and endopod bearing two setae [1, 14]. Although Sars [7] and Krishnaswamy [9] did not mention in their definition of the genus *Paramisophria,* the structure of maxilla 1 and maxilla 2 of *Paramisophria* is also distinguishable from that of *Parapseudocyclops* in: maxilla 1 having four or five spines and one process on first inner lobe, no seta on second inner lobe, two setae on endopod and eight setae on first outer lobe; maxilla 2 with only one seta on first inner lobe [4, 6, 7, 9–12]. The characteristics of antenna 1, maxilla 1 and maxilla 2 of *Parapseudocyclops* are in plesiomorphic state compared with those of *Paramisophria* by Sars [7]: reduction generally occurs in *Paramisophria.*

The present new species has parts of the above diagnostic characters of both *Paramisophria* and *Parapseudocyclops*: endopod of leg 5 of female separates from basipod 2, and has two setae on it; maxilla 1 bears five spines and one process on the first inner lobe and three setae on its endopod, and eight setae on its outer lobe; one seta on the second inner lobe of maxilla 1 is rudimentary; there is only one seta on the first inner lobe of maxilla 2. These characters which are unsuitable to the diagnosis of the genus *Parapseudocyclops* belong to those of the genus *Paramisophria.* Previously known species of the genus *Paramisophria* have an endopod of leg 5 of female with none (*P. platysoma* Ohtsuka & Mitsuzumi, 1990) or one seta (*P. cluthae* T. Scott, 1897; *P. spooneri* Krishnaswamy, 1959; *P. cluthae* sensu Tanaka; *P. ammophila* Fosshagen, 1968; *P. itoi* Ohtsuka, 1985; *P. variabilis* McKinnon & Kimmerer, 1985), and a maxilla 1 with four or five spines and one process on the first inner lobe [4, 6, 7, 9–12, 15]. A reexamination of *Paramisophria* species collected from Raunefjorden, Norway by Fosshagen [11], however, revealed that this species has five spines and one process on the first inner lobe and rudimental small setule on the second inner lobe of maxilla 1, and one seta on endopod of leg 5 of female, and that the genus *Paramisophria* shares morphological characters with the genus *Parapseudocyclops.* In male, the present new species is morphologically similar to congeneric species except the crest-like cuticular structure of terminal segment of right leg 5 unique to the new species. Therefore, we have come to a conclusion that the genus *Parapseudocyclops* should be synonymous with the genus *Paramisophria.* Accoring to the rule of priority (International Code of Zoological Nomenclature, Article 23), *Paramisophria* is a valid name.

Comparisons. The genus *Paramisophria* accommodates 11 species including the present newly described species, seven species in the Indo-Pacific region and four species in the Atlantic [1, 4, 6–12, 15; Greenwood personal communication]. *P.*

japonica and *P. giselae* are in the most plesiomorphic state among congeneric species in the Indo-Pacific region and the Atlantic, respectively, because these two species have such characters combined as 22-segmented antenna 1, leg 5 of female with two setae on endopod, and maxilla 1 with five spines and one process on the first inner lobe, one seta on the second inner lobe and three setae on endopod, while counterparts of other congeneric species are in an apomorphic state: 20- or 21-segmented antenna 1; endopod of leg 5 of female with or without a seta; maxilla 1 with four or five spines and one process on gnathobase, one or no seta on second inner lobe and two setae on endopod.

P. japonica is most similar to *P. giselae* in having a 22-segmented antenna 1, two setae on endopod of female leg 5, and five spines and one process on first inner lobe and three setae on endopod of maxilla 1. However, the new species is distinguished from *P. giselae* in the following characters: (1) rostrum with two filaments; (2) pedigers 2 and 3 not produced on posteroventral ends; (3) dorsolateral lobe of pediger 5 not as produced as in *P. giselae*; (4) genital segment of female wider than long. In addition, the appendages of the new species are different from those of *P. giselae*: (1) dense hairy row along posterior margin of left antenna 1 present on segments 1–8 in *P. japonica,* and on segments 1–11 in *P. giselae*; (2) six segments of exopod of antenna 2 in *P. japonica,* and seven in *P. giselae*; (3) rudimentary 1-segmented mandibular endopod present in *P. japonica* and absent in *P. giselae*; (4) dorsalmost mandibular tooth divided into two tips in *P. japonica,* but undivided in *P. giselae*; (5) seta on second inner lobe of maxilla 1 reduced in *P. japonica,* but developed in *P. giselae*; (6) the number of setae on outer lobe of maxilla 1 is eight in *P. japonica,* and nine in *P. giselae*; (7) first inner lobe of maxilla 2 bearing one seta in *P. japonica,* and two in *P. giselae*; (8) setal number of endopod segments 1 and 5 of maxilliped are respectively four and four in *P. japonica,* and two and three in *P. giselae*; (9) inner terminal end of basipod segment 2 of leg 3 with only one pointed tip in *P. japonica* and two in *P. giselae*; (10) basipod segment 2 and exopod segment 1, and exopod segments 1 and 2 of leg 5 of female separate in *P. japonica,* and fused in *P. giselae.*

Although Campaner [1] mentioned that *P. giselae* has only one rostral filament, another filament might have been detached during collection or dissection, because arietellids usually bear two rostral filaments [7]. In Campaner's description [1] (see p. 816, Fig. 19), one seta on the posterior surface of exopod segment 1 of leg 4 is illustrated, but this is not mentioned in the text. Considering other arietellids and the unlikely position of this seta, this may be incorrectly described.

These two plesiomorphic species, *P. japonica* and *P. giselae* might be mainly distributed at a depth of 100 to 200 m on continental shelves, while other congeneric species have a wide distribution, from lower intertidal zone (*P. platysoma*) to 240 m depth (*P. cluthae* from Raunefjorden, Norway) [1, 4, 6, 9–12, 17]. The species- and habitat-relationships in the genus *Paramisophria* will be revealed by a cladistic analysis in a forthcoming paper.

The genus *Rhapidophorus* Edwards, 1891 is monotypic, comprising *R. wilsoni* Edwards of which only the male is known [11, 14, 18], and is suggested to be related to the genera *Paramisophria* and *Parapseudocyclops* [1, 11, 18]. Campaner [1] mentioned that "until the male of *Parapseudocyclops* is found or until the species *R. wilsoni* is reencountered, it is better to maintain the genera apart". Edwards [18] incompletely described only left leg 5 but not right leg 5. Comparing the legs 5 of the males of *R. wilsoni* and *P. japonica,* their terminal segments are different: in *R. wilsoni* the segment has only one seta, while in *P. japonica* the segment bears two stout processes and a minute setule. The terminal segment of *R. wilsoni* is more similar to that of genus *Metacalanus* in the Arietellidae rather than to that of *P. japonica* [2, 14].

Paramisophria sp.
(Fig. 6)

Body length. Copepodid IV stage, female. Stn. 1 (26°17.9′N, 126°54.2′E, 23 May 1989) (two individuals): 2.05 mm, dissected; 1.87 mm, whole specimen. The specimen collected at Stn. 1 is

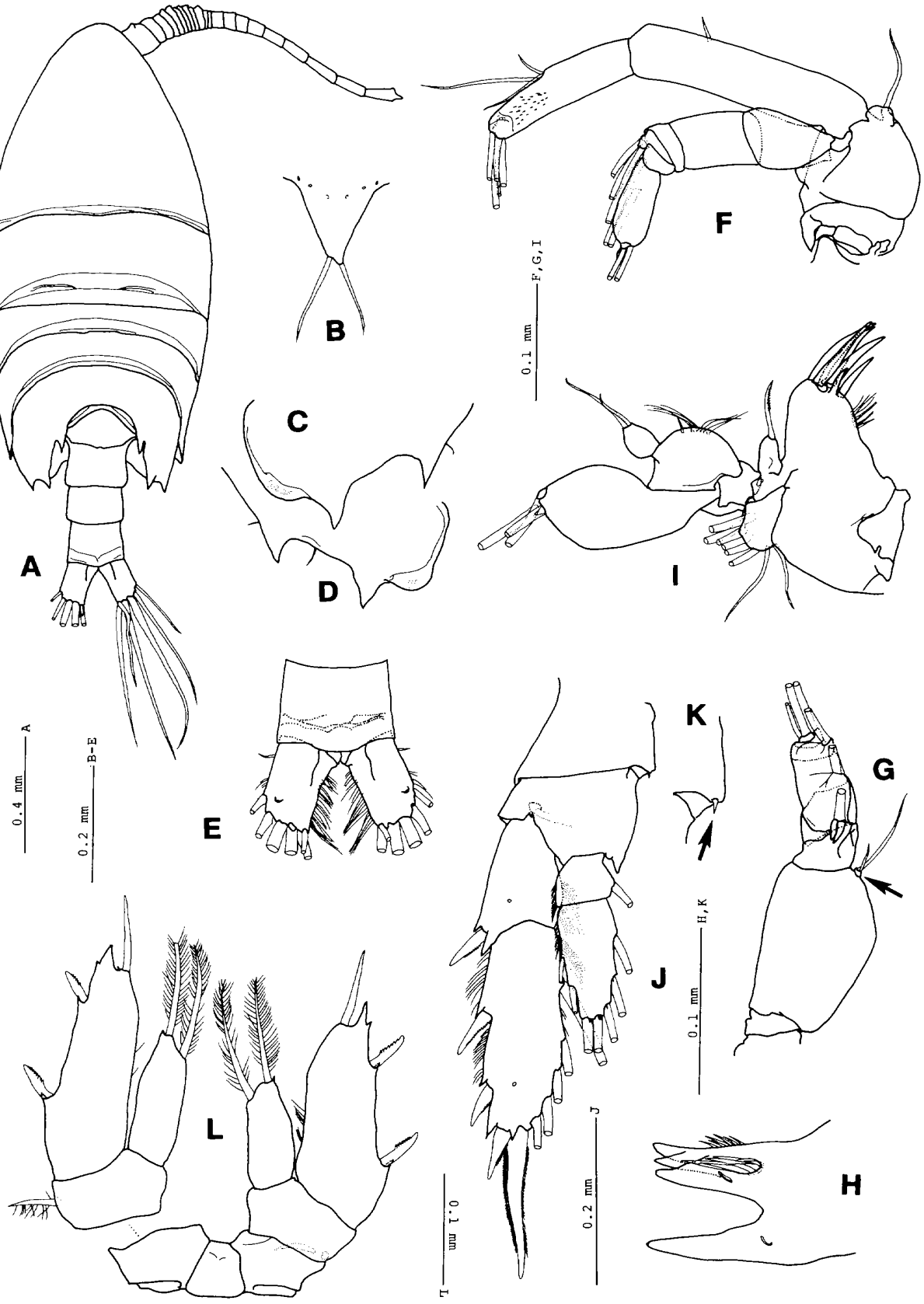

FIG. 6. *Paramisophria* sp. Copepodid IV female. A. Habitus, dorsal view; B. Rostrum, dorsal view; C. Pediger 5, left lateral view; D. Pediger 5, right lateral view; E. Segment 3 of urosome and caudal rami, dorsal view; F. Antenna 2; G. Mandibular palp, rudimentary endopod indicated by arrow; H. Mandibular cutting edge; I. Maxilla 1; J. Leg 4, anterior face; K. Inner terminal end of basipod 1 of leg 4, minute setule indicated by arrow; L. Leg 5, anterior face.

deposited in the US National Museum of Natural History, USNM Smithsonian Institution, Washington, D.C., U.S.A.

Description. (copepodid IV stage female). Body (Fig. 6–A) robust, yellowish in colour. Rostrum (Fig. 6–B) bearing one pair of filaments, left one located terminally, right one subterminally. Each side of pediger 5 (Fig. 6–C, D) with dorsolateral and medial pointed processes, and round ventrolateral lamellous plate. Urosome 3-segmented, segments 1–3 nearly equal in length. Caudal ramus (Fig. 6–E) with one inner dorsal, one subterminal outer and four terminal setae, and minute proximal outer setule. Antenna 1 22-segmented, relatively long, reaching distal end of pediger 1; left antenna 1 slightly longer than right antenna 1. Antenna 2 (Fig. 6–F) similar to that of *Paramisophria japonica*: exopod segments 1 and 2 partly fused. Mandibular cutting edge (Fig. 6–H): diastema deeper than in *P. japonica,* bearing three teeth, dorsalmost tooth bifurcated at tip; two patches of spinules present near bases of second and third teeth. Mandibular palp (Fig. 6–G) with rudimentary 1-segmented endopod bearing two setae of unequal lengths on tip (indicated by arrow); exopod with five incompletely fused segments. Maxilla 1 (Fig. 6–I); first inner lobe with five stout spines and one acute process; second inner lobe with pectinate seta; endopod 1-segmented, bulbous, bearing two small setae of unequal lengths; first outer lobe with eight setae. Legs 1–4 each with 2-segmented endo- and exopods; leg 4 (Fig. 6–J, K) with basipod segment 1 bearing minute setule on inner distal end (indicated by arrow in Fig. 6–K). Leg 5 (Fig. 6–L): basipod segment 1 separate from intercoxal plate; basipod segment 2 separate from endo- and exopods; endopod possessing two plumose setae, one terminal and one subterminal: exopod 1-segmented, bearing two lateral and one terminal spines.

Remarks. Since the specimen examined is a copepodid IV female, we only give a description here without naming it as a new species. This copepodid IV is different from the adult female *P. japonica* in the following characters: antenna 1 long, reaching beyond end of pediger 1; pediger 5 with two pointed processes, one lateral and one dorsolateral; mandibular cutting edge more acute; second inner lobe of maxilla 1 with serrate seta; basipod 1 of leg 4 with fine, short setule at inner distal end; right and left basipods 1 of leg 5 separate from intercoxal plate, endopod completely separate from basipod 2. These characteristic states of the maxilla 1, and legs 4, 5 may be developmental stage-specific ones, and the reduction of the seta on the second inner lobe of maxilla 1 and the fusion of segments of leg 5 may occur in its adult stage.

The body of this species has a yellow tinge, by which this species is readily distinguishable from *P. japonica.* As suggested for the hyperbenthic calanoid copepod *Pseudocyclops* (Pseudocyclopidae) [5], characteristics such as relatively large-sized body and long antenna 1 may indicate that this species is more pelagic than *P. japonica.*

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