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Three new species of the demersal calanoid copepod *Pseudocyclops* from Phuket, Thailand

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Abstract: Both sexes of three new species of the demersal calanoid copepods, *Pseudocyclops ornaticauda, P. ensiger* and *P. minutus*, are described from Phuket, Thailand. *Pseudocyclops ornaticauda* comprises a distinct species group with *P. lepidotus* from southern Japan, whereas *P. ensiger* is closely related to an Australian species, *P. kulai*. *Pseudocyclops minutus* is similar to *P. crassiremis* from Norway and *P. bahamensis* and *P. oliveri* from the Bahamas, suggesting that these species may show a full Tethyan track. Taxonomic and zoogeographical notes are provided. A gut content analysis revealed that *Pseudocyclops* mainly fed on both pelagic and benthic microalgae.

Key words: *Pseudocyclops*, demersal, Calanoida, Phuket

Introduction

Shallow-water demersal calanoid copepods have been well known in the northeastern Atlantic (Sars 1903, 1921), the Caribbean (Bowman & Gonzalez 1961; Fosshagen 1968a, b, 1970, 1973), Australian (Othman & Greenwood 1988, 1989, 1994) and Japanese waters (Ohtsuka 1984, 1985, 1992; Ohtsuka & Hiromi 1987; Barr & Ohtsuka 1989; Ohtsuka & Mitsuzumi 1990; Ohtsuka et al. 1991, 1994). However these calanoids have never been intensively studied in Thailand. In December 1997 we had an opportunity to collect shallow-water demersal copepods in the Andaman Sea and the Gulf of Thailand, using SCUBA, and found three new species of *Pseudocyclops* from Phuket, described below. The genus *Pseudocyclops* has a worldwide distribution from temperate to tropical shallow waters, and accomodates 30 species until now (Table 1). Among them 10 species have so far been recorded in the Indian Ocean including the Red Sea and Suez Canal (Haridas et al. 1994). We discuss the taxonomy, zoogeography and feeding ecology of the genus *Pseudocyclops*.

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Materials and Methods

Copepods were collected from Hi and Aew Islands off Phuket with hand-nets (diameter 30 cm; mesh size 0.1 mm) using SCUBA on 19 December 1997. The nets were towed along coral sandy bottoms. Sediment was stirred in sea water several times and the supernatant was filtered with the same nets. Copepods were fixed in 10% neutralized formalin/sea water immediately after capture. The genital double-somites and legs 5 of two of the new species of *Pseudocyclops* were examined with scanning electron microscope (SEM, JEOL T-20). Gut contents of five adult females of the most abundant new species described below were also examined with SEM.

The type specimens are deposited in the Phuket Marine Biological Center (PMBC) and the Natural History Museum and Institute, Chiba (CBM ZC). Terminology follows Huys & Boxshall (1991).

Family Pseudocyclopidae Giesbrecht, 1893
Genus *Pseudocyclops* Brady, 1872
***Pseudocyclops ornaticauda* new species (Figs 1–3)**

Material examined

Four adult females and 2 adult males from water off Hi Island, Phuket, 9 m depth, 19 December 1997.

Table 1. Body length and distribution of *Pseudocyclops* species.

Species	Body length (mm) ♀	Body length (mm) ♂	Distribution	Sources[a]
P. crassiremis Brady, 1872	0.86	0.65–0.80	England, Scotland, Norway	(1)
P. obtusatus Brady & Robertson, 1873	0.8	0.7	Northeastern Atlantic,	(1)
			Mediterranean, Indian Ocean	(1)
P. umbricatus Giesbrecht, 1893	0.60–0.65	0.54	Mediterranean, Suez Canal, Mauritania	(1, 2)
P. magnus Esterly, 1911	1.1	—	Bermuda,	(1)
	0.60–0.68	0.59–0.62	Barbados	(1)
P. latens Gurney, 1927	0.63	—	Suez Canal	(1)
P. latisetosus Sewell, 1932	—	0.78	Indian Ocean	(1)
P. simplex Sewell, 1932	0.5	0.72	Indian Ocean	(1)
P. australis Nicholls, 1944	0.78	—	South Australia	(1)
P. reductus Nicholls, 1944	0.50–0.60	—	Red Sea	(1)
P. gohari Noodt, 1958	0.95	1.0	Red Sea	(1)
P. cokeri Bowman & González, 1961	0.5–0.6	0.45–0.55	Puerto Rico, Bahamas	(1, 3)
P. paulus Bowman & González, 1961	0.40–0.42	0.37–0.43	Puerto Rico	(1)
P. rostratus Bowman & González, 1961	0.72–0.76	0.72	Puerto Rico, Bahamas	(1, 3)
P. rubrocinctus Bowman & González, 1961	0.55–0.62	0.50	Puerto Rico, Bahamas	(1, 3)
P. pacificus Vervoort, 1964	—	0.69	Caroline Islands	(1)
P. xiphophorus Wells, 1967	0.72–0.76	0.68–0.73	Mozambique	(4)
P. bahamensis Fosshagen, 1968	0.60–0.73	0.59–0.67	Bahamas	(3)
P. lerneri Fosshagen, 1968	0.61–0.68	0.54	Bahamas	(3)
P. mathewsoni Fosshagen, 1968	0.86–1.18	0.91–0.98	Bahamas	(3)
P. oliveri Fosshagen, 1968	0.61–0.65	—	Bahamas	(3)
P. spinulosus Fosshagen, 1968	0.45–0.71	—	Bahamas	(3)
P. steinitzi Por, 1968	0.66–0.70	0.59–0.62	Red Sea	(5)
P. bilobatus Dawson, 1977	0.73	0.65	California	(6)
P. arguinensis Andronov, 1986	0.62–0.71	0.52–0.59	Mauritania	(2)
P. pumilis Andronov, 1986	0.42–0.46	0.37–0.41	Mauritania	(2)
P. mirus Andronov, 1986	0.49	0.44	Mauritania	(2)
P. lepidotus Barr & Ohtsuka, 1989	0.90	0.73	Nansei Islands	(7)
P. kulai Othman & Greenwood, 1989	0.85–0.90	0.77	Gulf of Carpentaria	(8)
P. minya Othman & Greenwood, 1989	—	0.62	Gulf of Carpentaria	(8)
P. lakshmi Haridas, Madhupratap & Ohtsuka, 1994	0.86–0.95	0.81–0.85[b] 0.85–0.95[b]	Laccadives	(9)
P. ornaticauda n.sp.	0.88–0.96	0.82–0.91	Phuket	(10)
P. ensiger n.sp.	0.80–0.86	0.65–0.85	Phuket	(10)
P. minutus n.sp.	0.48–0.51	0.45–0.47	Phuket	(10)

[a](1): Vervoort (1964); (2) Andronov (1986); (3) Fosshagen (1968a); (4) Wells (1967); (5) Por (1968); (6) Dawson (1977); (7) Barr & Ohtsuka (1989); (8) Othman & Greenwood (1989); (9) Haridas et al. (1994); (10) present study. [b]Two morphs recognized only in male.

Types

Holotype: 1 adult female, dissected and mounted on glass slides, (CBM ZC-4546). Paratypes: 1 adult male, dissected and mounted on glass slides (CBM ZC-4547); 1 adult female and male, whole specimens (CBM ZC-4548); 1 adult female and male, whole specimens (PMBC 14334).

Body length

Female, range=0.89–0.96 mm (mean±SD: 0.91±0.04 mm, n=4); male, 0.82–0.91 mm (0.86±0.05 mm, n=3).

Female (holotype)

Body (Fig. 1A, B) compact; prosome oval viewed dorsally. Cephalosome separate from first pedigerous somite, protruded ventrally into strongly produced rostrum (Fig. 1C). Second and third pedigerous somites produced into acutely pointed process at ventrolateral corner (Fig. 1B). Fourth pedigerous somite expanded ventrolaterally, reaching beyond posterior end of next somite. Fifth pedigerous somite with pair of acute processes dorsolaterally. Urosome (Fig. 1D, E) 4-segmented, covered by foliaceous scale-like structures, which easily detach; genital double-somite slightly asymmetrical, with posteroventral ridge on left side; gonopore (indicated by large arrowheads) and copula-

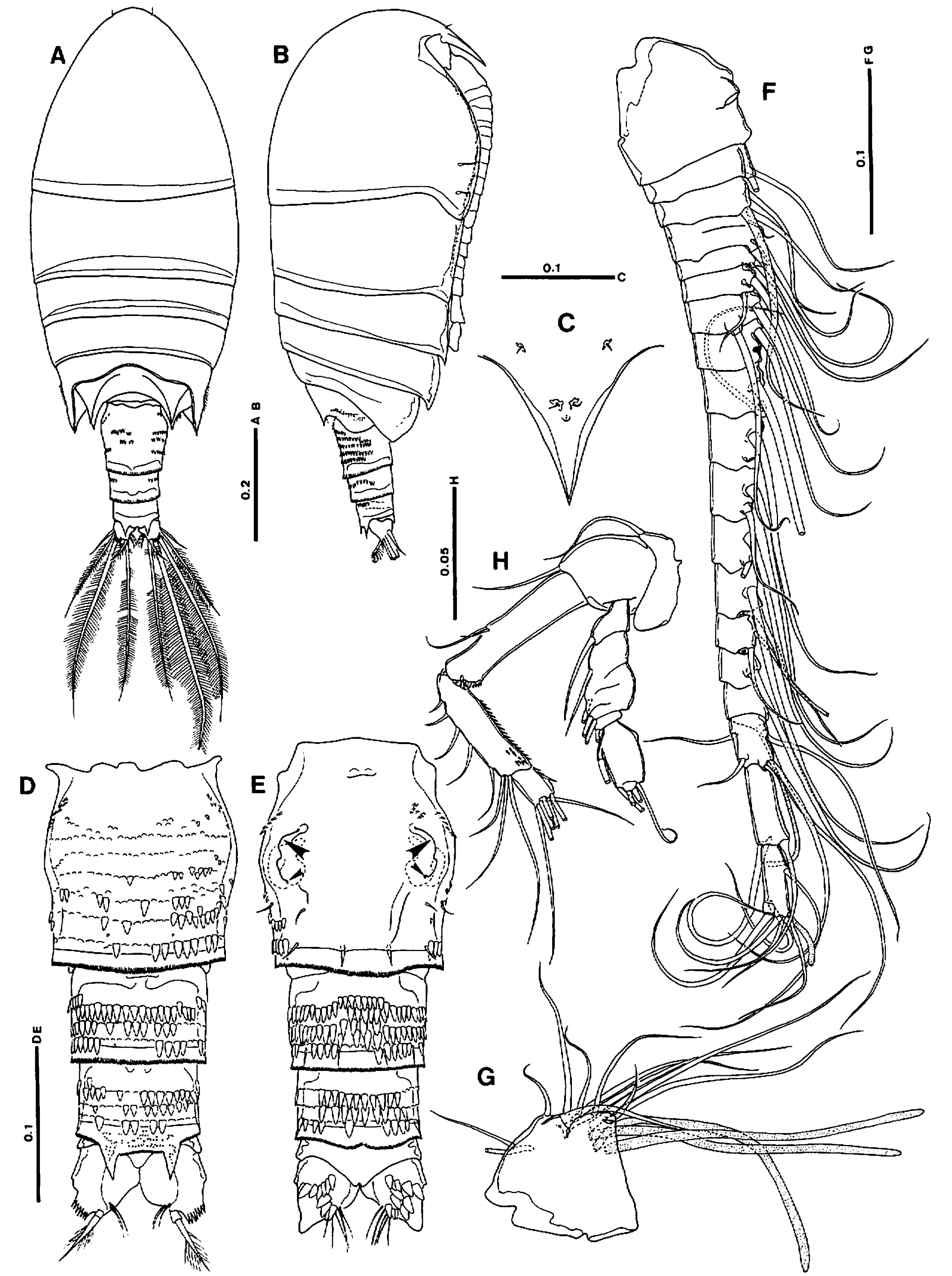

Fig. 1. *Pseudocyclops ornaticauda*, n.sp. Female (holotype). **A**. Habitus, dorsal. **B**. Habitus, lateral. **C**. Rostrum. **D**. Urosome, dorsal. **E**. Urosome, ventral; gonopores and copulatory pores indicated by large and small arrowheads, respectively. **F**. Antennule; elements on first segment omitted. **G**. First segment of antennule. **H**. Antenna. Scale bars in mm.

tory pore (by small arrowheads) opening in common longitudinal slit (Fig. 1E); third urosomal somite with 2 triangular processes dorsally (Fig. 1D); anal somite almost telescoped into penultimate somite; caudal ramus with serrate posterior margin dorsally and blunt posterior process ventrally, ramus bearing scales on ventroposterior surface; seta II spiniform, seta V longest.

Antennule (Fig. 1F, G) with 19 free segments, reaching beyond middle of second pedigerous somite; armature element as follows: 1 (I–VII), 13+3 long aesthetascs; 2 (VIII), 2; 3 (IX), 2; 4 (X–XI), 4; 5 (XII), 2; 6 (XIII), 2; 7 (XIV), 2; 8 (XV), 2 (1 seta missing in Fig. 2F); 9 (XVI), 2; 10 (XVII), 2 (1 seta missing in Fig. 2F); 11 (XVIII), 2; 12 (XIX), 2; 13 (XX), 2; 14 (XXI), 2; 15 (XXII), 1; 16 (XXIII), 1; 17 (XXIV–XXV), 2+2+aesthetasc; 18 (XXVI), 1+1; 19 (XXVII–XXVIII), 6+aesthetasc; fourth compound segment with suture visible. Antenna (Fig. 1H) and mandible (Fig. 2A) almost same as those of *Pseudocyclops lepidotus* (Barr & Ohtsuka 1989) except for 4 setae at inner distal corner on first endopod segment of mandible. Maxillule (Fig. 2B–D) with 6 heavily chitinized spiniform, 2 spinulose, 2 slender and 4 posterior setae on praecoxal arthrite; coxal epipodite bearing 9 setae, 5 proximal of which slender; basal exite with 1 fine seta; coxal and 2 basal endites bearing 3, 4 and 4 setae, respectively; exopod lobate, with 10 setae; endopod 2-segmented, first segment elongate, bearing 8 setae along inner margin, second segment with 7 setae terminally. Maxilla (Fig. 2E) and maxilliped (Fig. 2F) with armature as in *P. lepidotus*. Legs 1–5 all with 3-segmented rami, entirely covered by minute prominences on anterior and posterior surfaces except for intercoxal sclerite. Seta and spine formula of legs 1–5 identical with those of *P. lepidotus*. Leg 1 (Fig. 2G) with inner basal process curved distally; process distal to base of outer spine of second exopod segment serrated at tip. Legs 2 (Fig. 2H) and 3 (Fig. 2I) similar except for 2 and 3 outer spines on third exopod segment, respectively. Leg 4 (Fig. 3A) with outer basal seta.

Leg 5 (Fig. 3B) with transverse row of minute prominences on intercoxal sclerite; basis with acute process between both rami; first endopod segment produced outwards into large bifurcated process; third exopod segment with 2 outer, 1 terminal and 1 inner spine.

Male (paratypes)

Body (Fig. 3C) similar to that of female; ventrolateral posterior corners of second and third pedigerous somites sharply pointed as in female (Fig. 3D); ventrolateral flap of fourth pedigerous somite reaching middle of second urosomal somite. Genital to fourth urosomal somites covered by scales as in female (Fig. 3E); fourth urosomal somite with triangular processes posterodorsally as in female; fifth urosomal somite telescoped into preceding somite.

Right geniculate antennule (Fig. 3F) 18-segmented; armature as follows: 1 (I–VII), 13+3 large aesthetascs; 2 (VIII), 2; 3 (IX), 2; 4 (X), 2 (one of which rudimentary); 5 (XI), 2; 6 (XII), 2; 7 (XIII), 2; 8 (XIV), 2; 9 (XV), 2; 10 (XVI), 2; 11 (XVII), 2; 12 (XVIII), 2; 13 (XIX), 1+process; 14 (XX), 1+process; 15 (XXI-XXIII), 1+2 processes; 16 (XXIV–XXV), 2+2+aesthetasc; 17 (XXVI), 1+1; 18 (XXVII–XXVIII), 6+aesthetasc; 16th segment produced distally, reaching posterior end of penultimate segment. Mouthparts and legs 1–4 as in female.

Leg 5 (Fig. 3G–L) complex, with coxa and basis completely fused on left leg and separate on right. Left leg (Fig. 3G) with elongate process (Fig. 3H) on anterior surface of protopod tapering distally; exopod 2-segmented, first segment bearing large spine and acutely pointed process, second segment complex, bearing 4 lobes, innermost of which spatulate with inner serrate margin (Fig. 3I); second outermost lobe bilobed at tip, with minute granules and fine setules near tip and seta at base; outermost lobe with curved tip and basal seta; endopod bearing 5 plumose setae. Right leg (Fig. 3J) with unisegmented rami; endopod swollen subproximally, bearing setules subterminally; exopod with outer flanged spine and 3 long curved spines; innermost and middle (Fig. 3L) spines recurved, the latter with spiniform seta at base, outermost spine (Fig. 3K) smoothly curved inwards, with round process proximally.

Remarks

The new species is most closely related to *P. lepidotus* from the northwestern Pacific in: (1) fifth pedigerous somite with paired dorsolateral processes; (2) the presence of foliaceous scales on the urosome; (3) relatively long antennules consisting of 19 free segments in female; (4) the presence of an inner basal seta of leg 1; (5) the armature and structure of legs 5 of both sexes. Since a combination of these characters is unique among congeners, these two species comprise a distinct species group which is distributed in the Indo–West Pacific tropical/subtropical regions. The above-mentioned unique characteristics are shared also with an undescribed species from Guam and the Philippines (Barr & Ohtsuka 1989), to which the new species may be closely related.

The new species is distinguishable from *P. lepidotus* by the following characters: (1) in both sexes the fourth pedigerous somite bears a more posteriorly produced ventrolateral flap; (2) in both sexes the inner basal process of leg 1 is curved at tip; (3) in the male right leg 5 the innermost lobe of the second exopod segment with serrate margin is more slender; (4) in the male left leg 5 the unisegmented endopod is expanded along the outer margin.

Huys & Boxshall (1991) mentioned that the distal and proximal fusion of antennular segments of the genus *Pseudocyclops* prevents the precise recognition of their homologies. However, the basic pattern proposed by them can be applied to *P. ornaticauda* with the maximum number of antennular segments in the genus.

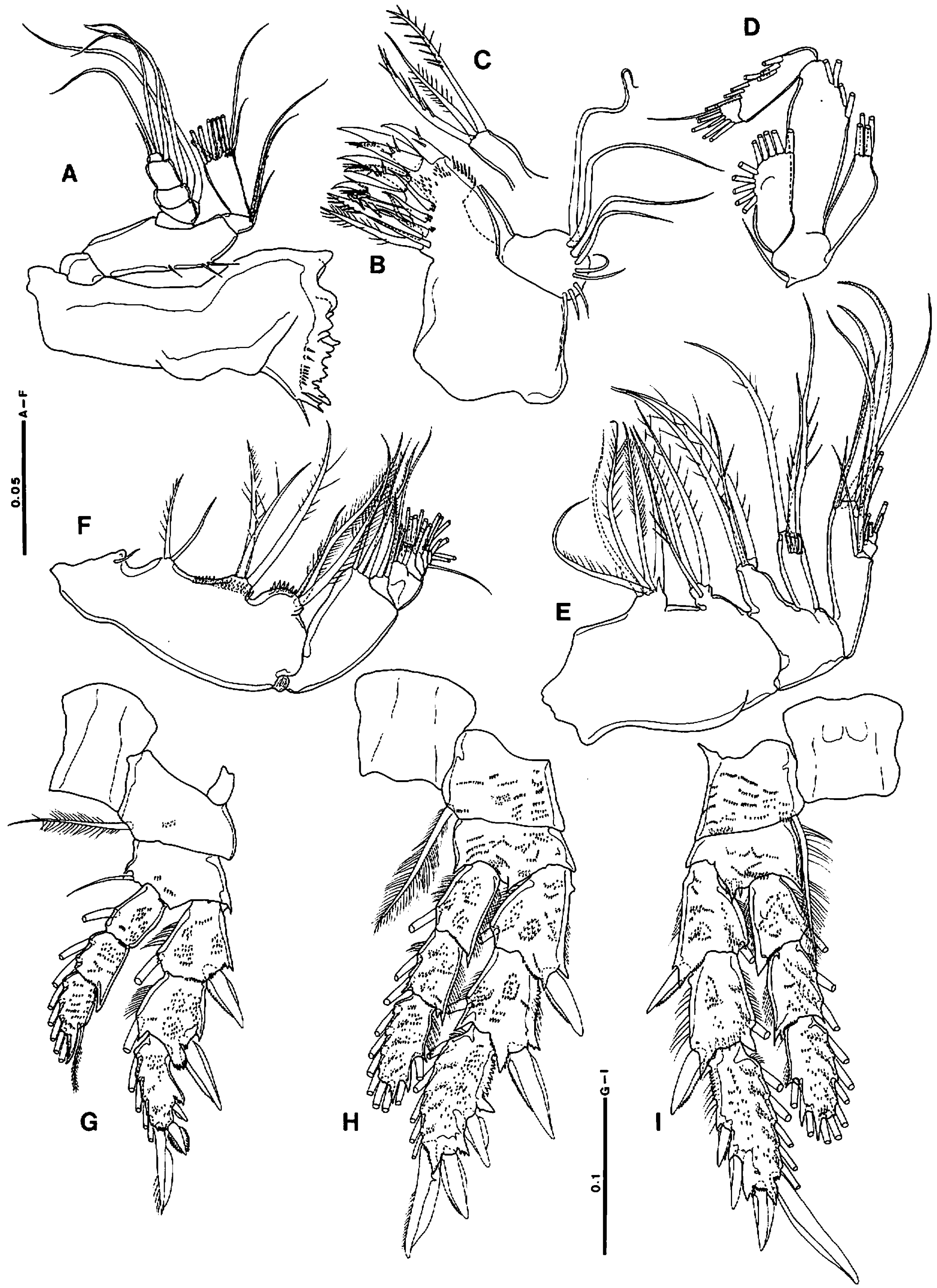

Fig. 2. *Pseudocyclops ornaticauda*, n.sp. Female (holotype). **A.** Mandible. **B.** Praecoxal arthrite and coxal exite of maxillule. **C.** Coxal endite of maxillule. **D.** Basis and rami of maxillule. **E.** Maxilla. **F.** Maxilliped. **G.** Leg 1, anterior. **H.** Leg 2, anterior. **I.** Leg 3, anterior. Scale bars in mm.

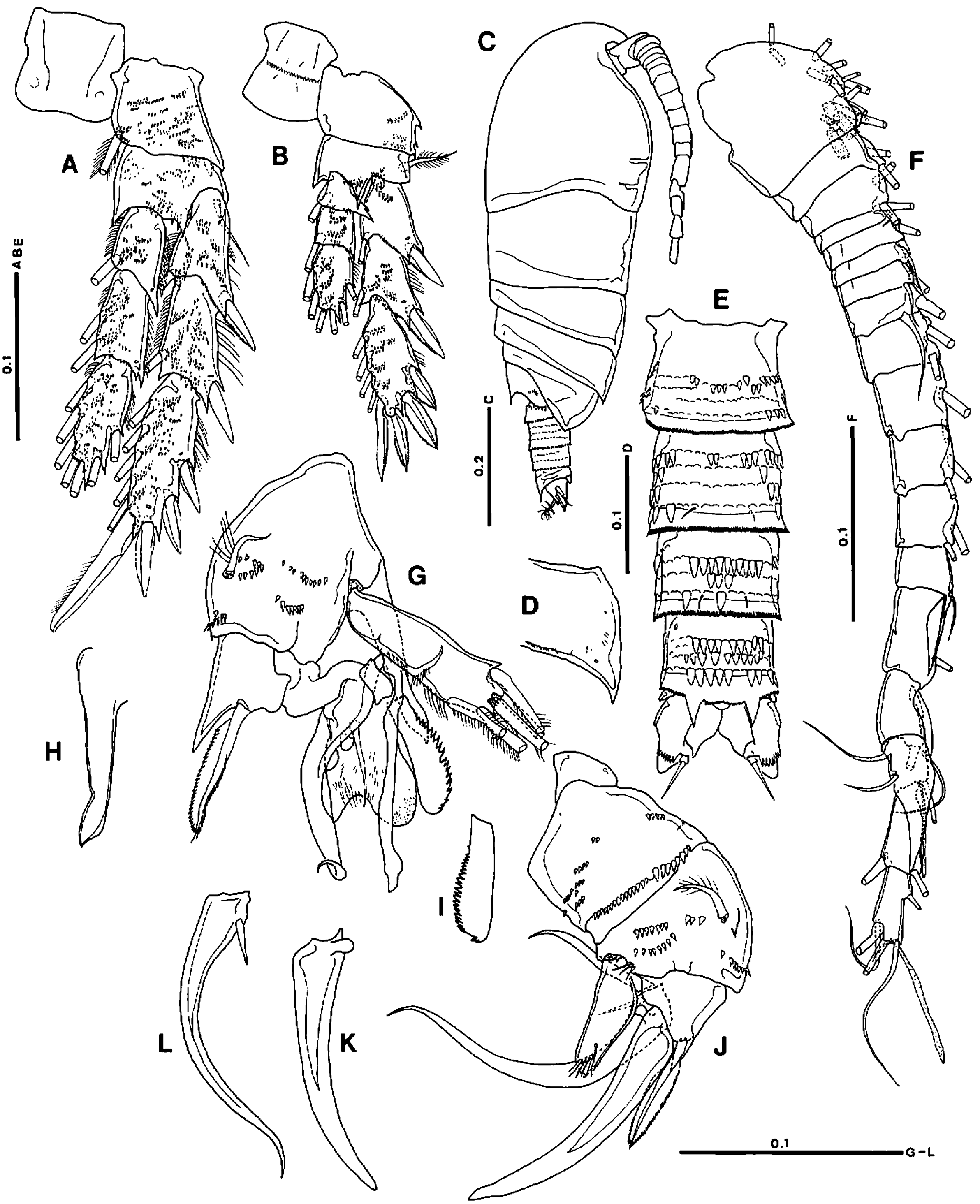

Fig. 3. *Pseudocyclops ornaticauda*, n.sp. Female (A, B, holotype) and male (C–L, paratypes). **A**. Leg 4, anterior. **B**. Leg 5, anterior. **C**. Habitus, lateral. **D**. Ventrolateral corner of pediger 3. **E**. Urosome, dorsal. **F**. Right antennule. **G**. Left leg 5, posterior. **H**. Process of protopod of left leg 5, anterior. **I**. Terminal lobe of second exopod segment of left leg 5. **J**. Right leg 5, posterior. **K**. Outer spine of exopod of right leg 5. **L**. Inner spine of exopod segment of right leg 5. Scale bars in mm.

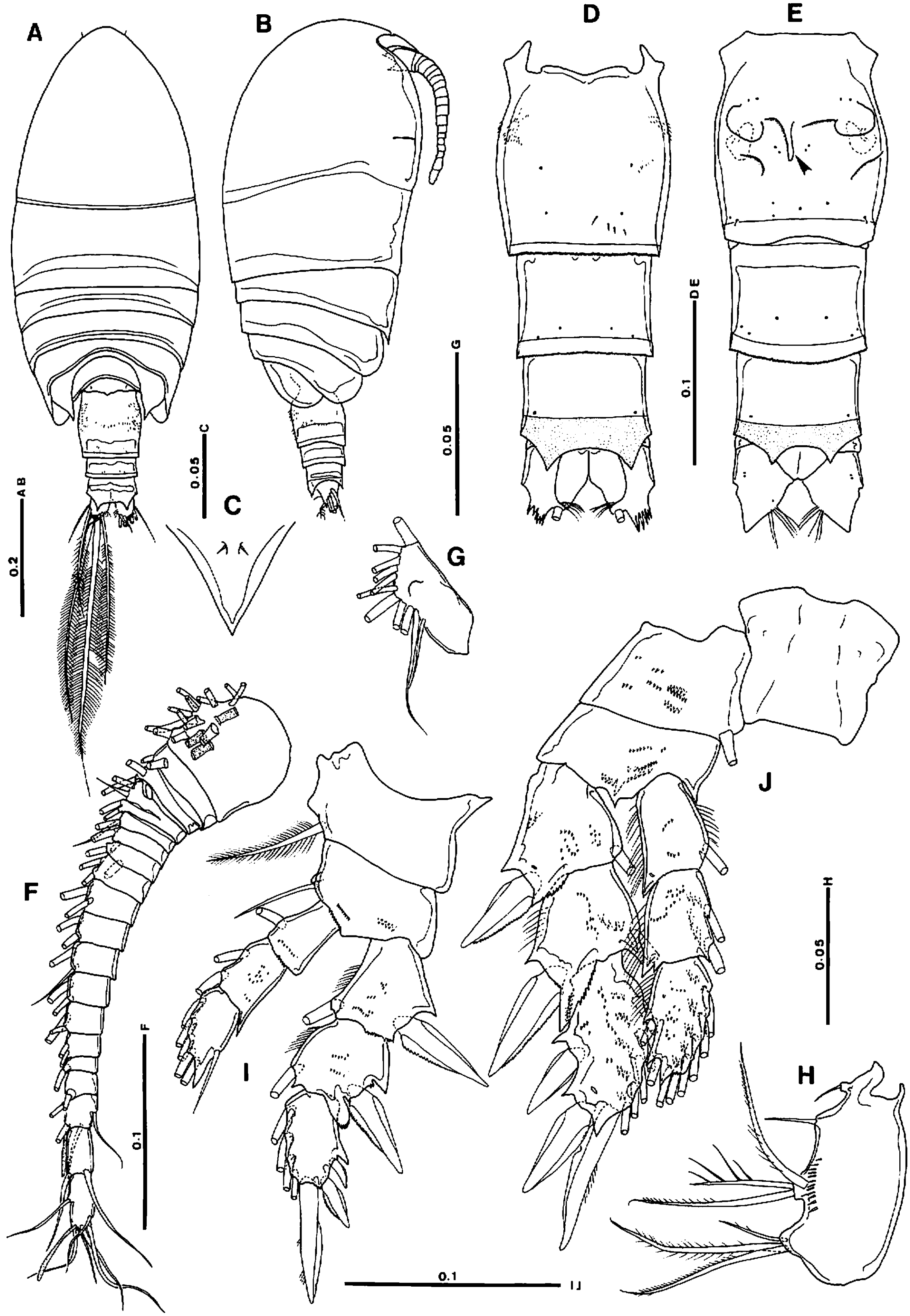

Fig. 4. *Pseudocyclops ensiger*, n.sp. Female (holotype). **A**. Habitus, dorsal. **B**. Habitus, lateral. **C**. Rostrum. **D**. Urosome, dorsal. **E**. Urosome, ventral; longitudinal sword-like ridge arrowed. **F**. Antennule. **G**. Exopod of maxillule. **H**. Syncoxa of maxilliped. **I**. Leg 1, anterior. **J**. Leg 2, anterior. Scale bars in mm.

Ethymology

The specific name *ornaticauda* (Latin "*ornatus*", decorated and "*cauda*", tail) refers to the urosome covered by scale-like structures.

Pseudocyclops ensiger new species (Figs 4–8)

Material examined

Twenty-two adult females and 40 adult males from Aew Island, Phuket, 9–13 m depth, 19 December 1997; 2 adult females and 4 adult males from Hi Island, Phuket, 9 m depth, 19 December 1997.

Types

Holotype: 1 adult female, dissected and mounted on glass slides, collected from Aew Island (CBM ZC-4549). Paratypes: 3 adult males, dissected and mounted on glass slides, collected from Aew Island (CBM ZC-4550–4552); 10 adult females and 10 adult males, whole specimens, collected from Aew Island (CBM ZC-4553, 4554); 11 adult females and 11 adult males, whole specimens, collected from Aew Island (PMBC 14335).

Body length

Aew Island: female, 0.80–0.86 mm (0.83±0.02 mm, n=22); male, 0.65–0.80 mm (0.73±0.03 mm, n=38). Hi Island: female, 0.80, 0.83 mm; male, 0.70–0.85 mm (0.79±0.07 mm, n=4).

Female (holotype)

Body (Fig. 4A, B) oval in dorsal view; cephalosome almost fused with first pedigerous somite (see Fig. 5A); rostrum moderately produced ventrally (Fig. 4C); first and second pedigerous somites with ventrolateral posterior corner produced into acute process; fourth and fifth pedigerous somites separate; fourth pedigerous somite produced posteriorly, reaching end of fifth one; fifth pedigerous somite with smoothly curved posterior margin. Urosome (Fig. 4D, E) with genital double-somite slightly asymmetrical in ventral view, patches of minute prominences present posterodorsally and anterolaterally (see also Fig. 5B); ventral surface with paired genital flaps and longitudinal sword-like ridge (see Fig. 5C, D, arrowed) anteriorly; depressions present at midlength, semicircular on right side and obliquely long on left (see Fig. 5C). Third urosomal somite with paired triangular processes both dorsally and ventrally; anal somite almost telescoped into penultimate somite; caudal rami and setae as in *Pseudocyclops ornaticauda* except for ventral scales.

Antennule (Fig. 4F) with 19 free segments, reaching near posterior margin of cephalosome; fusion pattern and armature the same as in *P. ornaticauda*. Mouthpart appendages similar to those of *P. ornaticauda* excepting the following points: exopod of maxillule bearing 11 setae along outer margin (Fig. 4G); second syncoxal endite of maxilliped bearing only single seta (Fig. 4H).

Fig. 5. SEM photomicrographs of *Pseudocyclops ensiger*, n.sp. Female. **A.** Habitus, lateral; suture between cephalosome and pediger 1 arrowed. **B.** Genital double-somite, dorsal. **C.** Urosome, ventral; longitudinal sword-like ridge arrowed. **D.** Longitudinal sword-like ridge on genital double-somite arrowed. Scale bars = 100 μm (A); 20 μm (B, C); 10 μm (D).

Legs 1–4 (Figs. 4I, J, 6A) with segmentation and armature elements as in *P. ornaticauda* except for the presence of outer spine on basis of leg 3 (Fig. 6A); minute prominences on rami more sparesely distributed than in *P. ornaticauda* (see Fig. 2G–I). Leg 1 (Fig. 4I) with basis bearing small round process at base of inner seta. Leg 2 (Fig. 4J) with process on outer terminal corner of second exopod segment nearly reaching base of proximal spine of next segment.

Leg 5 (Fig. 6B) with segmentation and armature element as in *P. ornaticauda*, but outer terminal process of basis more strongly produced and bifurcated at tip.

Male (paratypes)

Body (Fig. 6C) similar to that of female; rostrum not articulated at base. Urosome (Fig. 6D) with genital somite more coarsely serrated along posterior margin than second

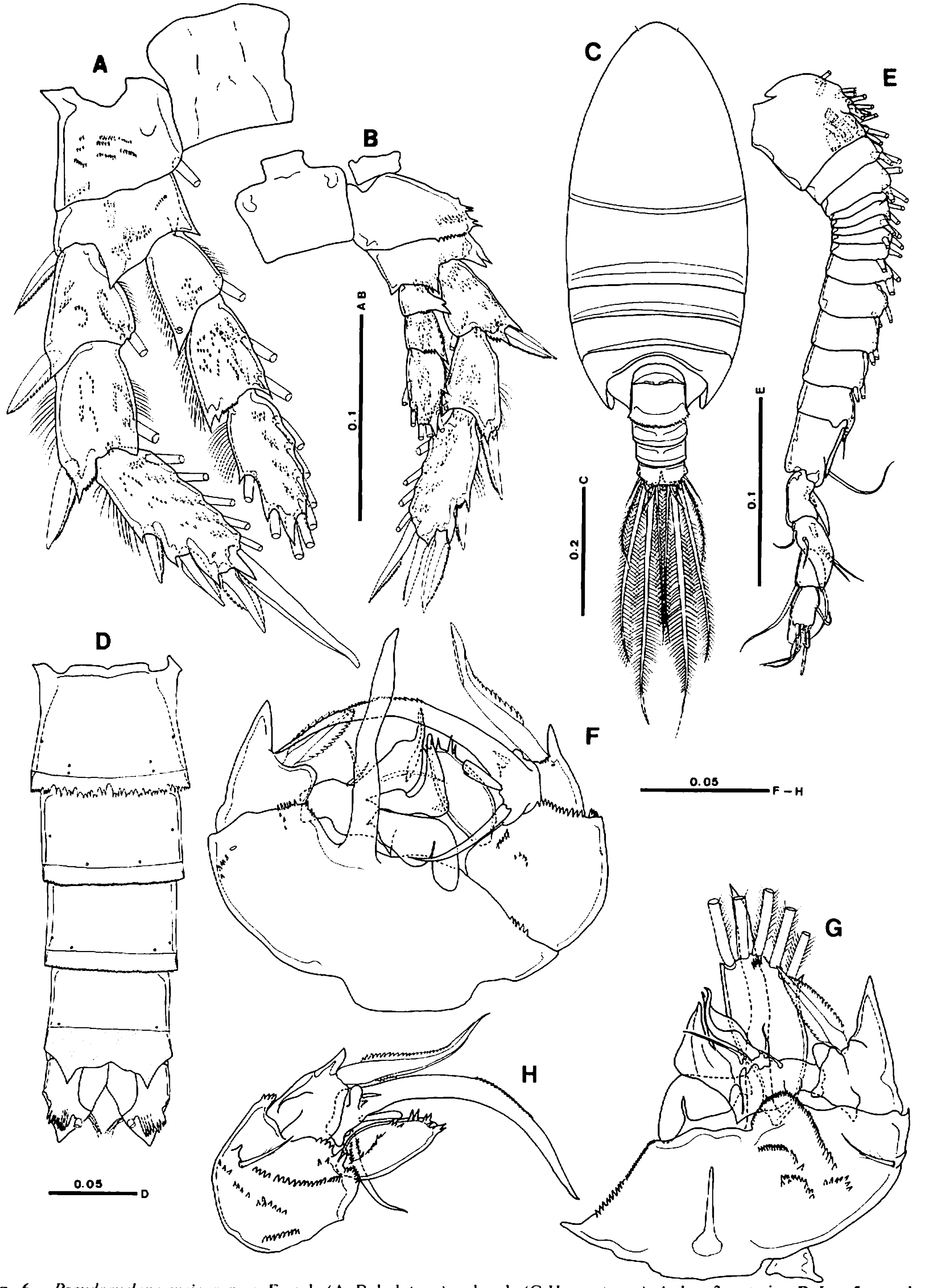

Fig. 6. *Pseudocyclops ensiger*, n.sp. Female (A, B, holotype) and male (C-H, paratypes). **A.** Leg 3, anterior. **B.** Leg 5, anterior. **C.** Habitus, dorsal. **D.** Urosome, dorsal. **E.** Right antennule. **F.** Leg 5, anterior. **G.** Fused coxae and left leg 5, posterior. **H.** Right leg 5, posterior. Scale bars in mm.

Fig. 7. SEM photomicrographs of leg 5 of *Pseudocyclops ensiger*, n.sp. Male. **A**. Leg 5, anterior. **B**. Terminal portion of second exopod segment of left leg 5. **C**. Leg 5, posterior. **D**. Right endopod, posterior; elements arrowed. Scale bars=20 μm (A, C); 10 μm (B, D).

and third urosomal somites; fourth urosomal somite with pair of triangular processes dorsally and ventrally.

Right geniculate antennule (Fig. 6E) 18-segmented, with armature as in *P. ornaticauda*.

Leg 5 (Fig. 6F–H; see also Fig. 7) complex, with both coxae and intercoxal sclerite fused to form common base; in left leg coxa and basis also coalescent to form protopod. Left leg (Fig. 6F, G) with protopod bearing smoothly curved distal lobe on posterior surface marginated by row of acute prominences (see Fig. 7C), and elongate sinuated process on anterior surface (see Fig. 7A); exopod 2-segmented, first segment with strong outer process and bipinnate spine, second segment with triangular process and 3 long elements at inner midlength (see Fig. 7D, arrowed) and 4 lobes terminally, innermost of which bilobed (see Fig. 7B). Endopod 1-segmented, bearing 5 plumose setae terminally.

Right leg (Fig. 6F, H) with 1-segmented rami; exopod with outer bipinnate spine twice as long as comparable spine on left side, and an inner, smoothly curved large spine with serrated outer subterminal margin; this spine bearing a round process, triangular minute prominence, and 3 articulated elements basally (Fig. 6H); endopod unarmed, furnished with prominences distally and proximally (see Fig. 7D).

Remarks

The new species closely resembles *Pseudocyclops kulai* Othman & Greenwood, 1989 from the Gulf of Carpentaria, Australia in: (1) the penultimate urosomal somite with a dorsal pair of triangular processes in both sexes (misidentified as anal somite in Othman and Greenwood (1989)); (2) the number of free antennular segments which are 19 in female and 18 in male (right geniculate antennule); (3) the presence of only one seta on the second syncoxal endite of the maxilliped; (4) the presence of an outer spine on the basis of leg 3 instead of seta; (5) 3-segmented endopod of the female leg 5 with 6 setae on the third exopod segment; (6) the structure of the male leg 5 (the complete fusion of both coxae; the shape of both endopods; the extremely

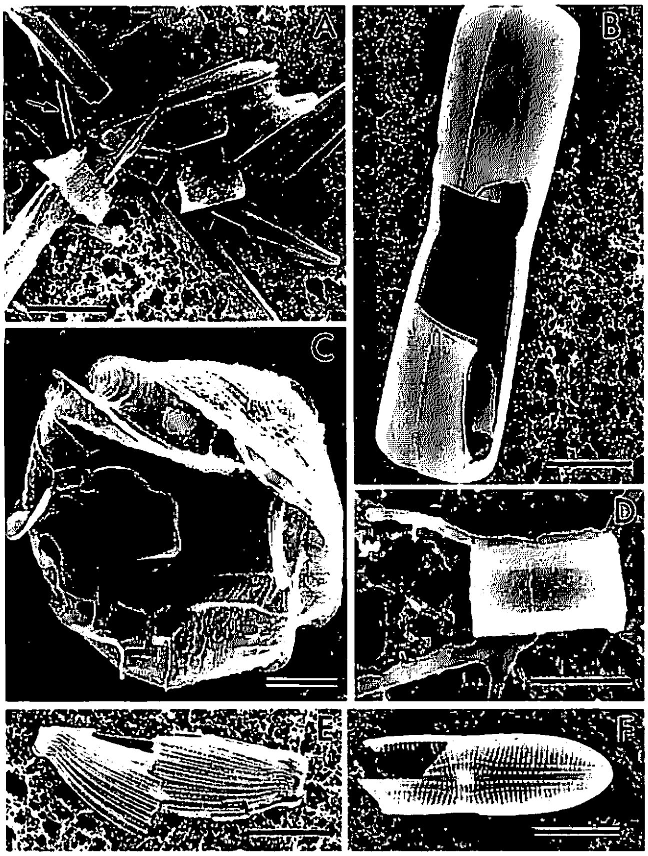

Fig. 8. SEM photomicrographs of gut contents of females of *Pseudocyclops ensiger*, n.sp. **A.** Fragments of *Nitzschia* (?) sp. and *Chaetoceros* spine (arrowed). **B.** Possibly benthic pennate diatom. **C.** Unidentified dinoflagellate. **D.** *Chaetoceros* valve. **E.** *Amphora* sp. **F.** *Diploneis* sp. Scale bars=10 μm (A, B, E, F); 5 μm (C, D).

elongate outer spine on the right exopod segment; the structure of the inner spine of the right exopod; the presence of the triangular process at the inner middle point in the left second exopod segment). However, this new species is easily distinguished from *P. kulai* by the structure of the second exopod segment of the male left leg 5 and the endopod of the female leg 5 reaching beyond the terminal end of the second exopod segment.

Pseudocyclops ensiger shares synapomorphies found in the male leg 5 (the complete fusion of both coxae; the extremely elongate outer spine on the right exopod segment; the triangular process at the inner middle point of the left second exopod segment) with *P. kulai*, which suggests that these two species comprise a species group.

Etymology

The specific name *ensiger* (Latin "*ensiger*", sword-bearing) of the new species refers to the ventral longitudinal sword-like ridge of the genital double-somite of the female.

Gut contents

In Fig. 8 gut contents of the adult females of the new species are depicted. Not only benthic pennate diatoms (Fig. 8B, E, F) but also pelagic microalgae such as a centric diatom *Chaetoceros* sp. (Fig. 8A, arrowed, 8D) and dinoflagellates (Fig. 8C) were found in the guts. The largest dimensions of almost intact microalgae found in the guts ranged approximately from 20 to 60 μm.

Pseudocyclops minutus new species (Figs 9, 10)

Material examined

Eight adult females and 3 adult males from Aew Island, Phuket, 9–13 m depth, 19 December 1997; one adult female from Hi Island, Phuket, 9 m depth, 19 December 1997.

Types

Holotype: 1 adult female, dissected and mounted on glass slides, collected from Aew Island (CBM ZC-4555). Paratypes: 1 adult male, dissected and mounted on glass slides, collected from Aew Island (CBM ZC-4556); 4 adult females and 1 adult male, whole specimens, collected from Aew Island (CBM ZC-4557); 4 adult females and 1 adult male, whole specimens, collected from Aew Island (PMBC 14336).

Body length

Aew Island: female, 0.48–0.51 mm (0.50±0.01 mm, n=8); male, 0.45–0.47 mm (0.46±0.01 mm, n=3). Hi Island: female, 0.51 mm.

Female (holotype)

Body (Fig. 9A) small; rostrum pointed; cephalosome and first pedigerous somite partly fused; fourth and fifth pedigerous somites almost fused with suture visible ventrolaterally. Urosome (Fig. 9B, C) 4-segmented with anal somite completely telescoped into penultimate somite; genital double-somite symmetrical, with pair of gonopores located posterior to ventral midlength (see Fig. 10A); penultimate somite produced posterodorsally, covering caudal rami partially; caudal rami each with 4 or 5 dorsoposterior serrations and ventral acutely pointed process; seta I not recognizable; seta II spiniform, seta V naked, longest.

Antennule (Fig. 9D) 17-segmented; fusion and armature on proximal 4 segments not clearly identified due to small size and dense distribution of elements; armature on distal 13 segments except for completely fused segment XXII–XXIII (14th segment) as in *P. ornaticauda*. Mouthpart appendages not observed except for syncoxa of maxilliped. Maxilliped syncoxa (Fig. 9E) with 1, 2, 3, and 3 setae on first to fourth endites, respectively.

Legs 1–4 (Fig. 9F–I) with prominences more sparsely distributed on both rami than in two new species described above. Leg 1 (Fig. 9F) with basis acutely produced at inner midlength; inner basal seta absent. Leg 2 (Fig. 9G) with

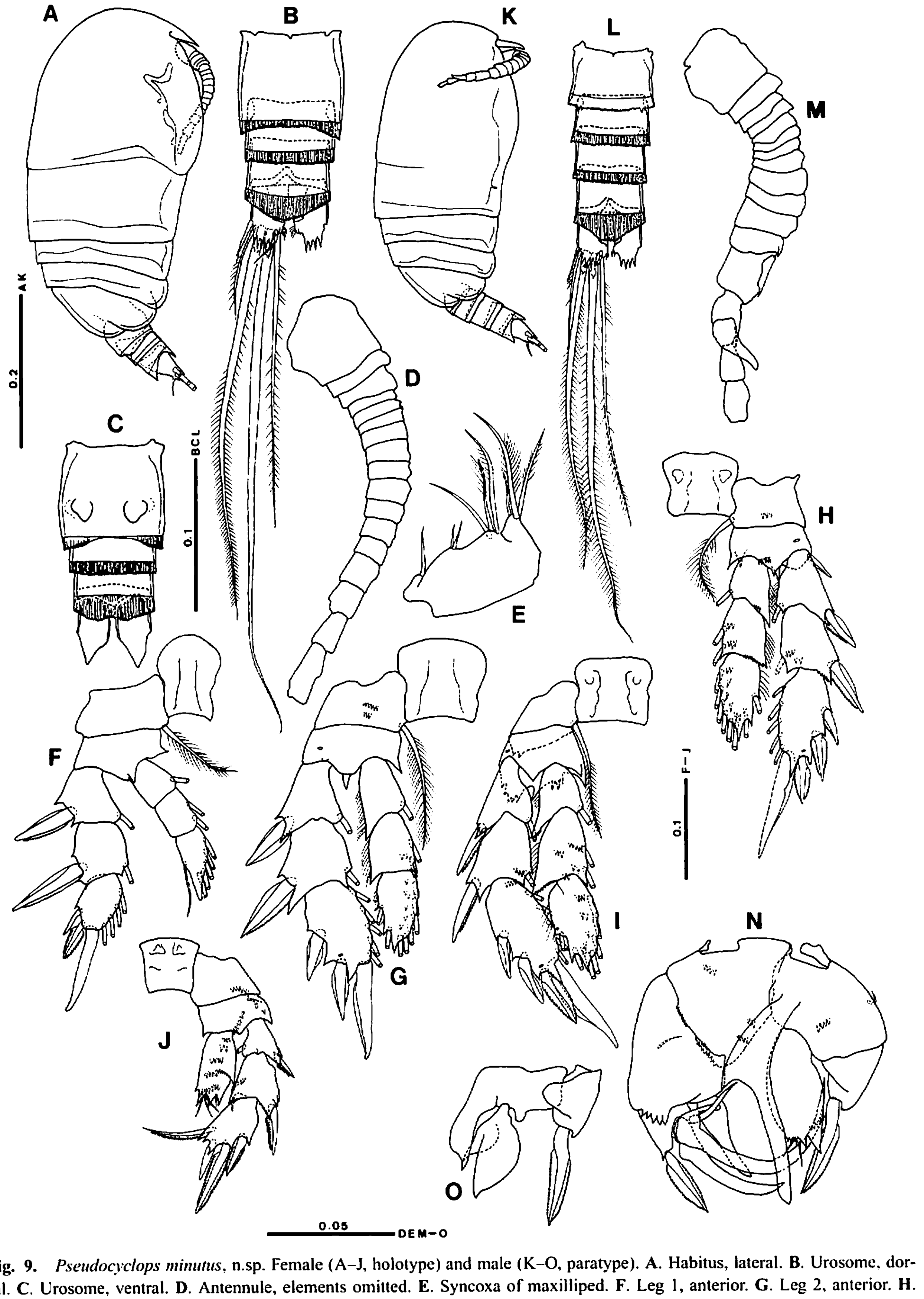

Fig. 9. *Pseudocyclops minutus*, n.sp. Female (A–J, holotype) and male (K–O, paratype). **A.** Habitus, lateral. **B.** Urosome, dorsal. **C.** Urosome, ventral. **D.** Antennule, elements omitted. **E.** Syncoxa of maxilliped. **F.** Leg 1, anterior. **G.** Leg 2, anterior. **H.** Leg 3, anterior. **I.** Leg 4, anterior. **J.** Leg 5, anterior. **K.** Habitus, lateral. **L.** Urosome, dorsal. **M.** Right antennule, elements omitted. **N.** Leg 5, anterior; second exopod segment of left leg omitted. **O.** Exopod of left leg 5. Scale bars in mm.

Fig. 10. SEM photomicrographs of *Pseudocyclops minutus*, n.sp. Female (A) and male (B). **A.** Urosome, ventral; genital openings arrowed. **B.** Terminal portion of leg 5, posterior. Scale bars=20 μm (A); 10 μm (B).

acute process on posterior surface of basis. Leg 3 (Fig. 9H) with outer basal spine instead of seta. Leg 4 (Fig. 9I) with strong serrations on posterior margin of basis.

Leg 5 (Fig. 9J) with 3-segmented exopod and 1-segmented endopod; coxa and basis bearing row of prominences on posterior surface; basis with outer seta. Exopod with first segment bearing outer spine and inner seta; second segment with rudimentary inner seta distally and outer spine; third segment bearing minute inner seta proximally and 4 spines distally. Endopod with 4 fine setae and 4 acute processes terminally, and 1 pointed process at outer midlength.

Male (paratypes)

Body (Fig. 9K) similar to that of female, but rostrum articulated at base. Urosome (Fig. 9L) more slender than that of female; caudal seta V plumose.

Right geniculate antennule (Fig. 9M) 17-segmented; fusion and armature only partly identified because of small size and densely distributed elements; fusion pattern on distal 10 segments as in *P. ornaticauda*, based on their elements. Leg 5 (Fig. 9N, O; see Fig. 10B) with both coxae incompletely fused. Left leg with bifurcate basal process arising from anterior surface; exopod 2-segmented, first segment with outer flanged spine, second segment with 2 lobes terminally, outer one bilobed; endopod 1-segmented, with 2 fine setae terminally. Right leg with posterior serrated margin on anterior surface of basis; exopod 1-segmented, with outer flanged spine and 2 inner large curved spines; innermost spine bearing cylindrical process and jointed element proximally; endopod 1-segmented, unarmed, tapering distally.

Remarks

The new species is similar to *Pseudocyclops crassiremis* Brady, 1872, *P. rostratus* Bowman & Gonzalez, 1961, *P. paulus* Bowman & Gonzalez, 1961, *P. bahamensis* Fosshagen, 1968, *P. spinulosus* Fosshagen, 1968, and *P. oliveri* Fosshagen, 1968 in having an unisegmented endopod of leg 5 in female. However the new species is most closely related to *P. crassiremis* (both sexes known) from Norway and *P. bahamensis* (both sexes) and *P. oliveri* (only female) from the Bahamas in: (1) the fusion of the fourth and fifth pedigerous somites; (2) 17-segmented antennules; (3) the presence of an outer basal spine of leg 3 (not present in *P. crassiremis* described by Sars, 1921); (4) the very similar armature of the exopod of female leg 5; (5) the articulated rostrum in male (*P. crassiremis* and *P. bahamensis*); (6) the relatively complex process on the left protopod of male leg 5; (7) the shape of the right endopod of male leg 5. The absence of an outer spine on the basis of leg 3 of *P. crassiremis* described by Sars (1921) may be missing. However, the new species can be distinguished from these three species by: (1) the number of setae on the endopod of female leg 5 (4 in *P. minutus* and *P. bahamensis*; 1 in *P. crassiremis*; none in *P. oliveri*); (2) the number of setae on the third exopod segment of female leg 5 (1 in *P. minutus* and *P. crassiremis*; 2 in *P. bahamensis*; 3 in *P. oliveri*); (3) the structure of the male leg 5 (the shape of the left basal process and exopods on both sides; the number of terminal setae on the left endopod).

Pseudocyclops minutus shares synapomorphies such as reduced segmentation and setation in the female leg 5 and fusion of the last two pedigerous somites together with *P. crassiremis*, *P. bahamensis* and *P. oliveri*. Therefore these three species can be assigned to a species groups irrespective of their wide distributions. Such a wide distribution pattern may correspond to a full Tethyan track (cf. Stock 1993).

Etymology

The specific name *minutus* (Latin "*minutus*", minute) of the new species refers to the small-sized body of the new species.

Gut contents

The paratypes had a gut packed with pennate diatoms and amorphous matter, some of which also involved dinoflagellates as well as in *Pseudocyclops ensiger*.

Discussion

Taxonomy and zoogeography

The genus *Pseudocyclops* is demersal in shallow waters, but some species have been found in plankton samples, in particular, during the night time when they perform diel migrations (Esterly 1911; Gurney 1927; Sewell 1932; Vervoort 1964; Yeatman 1975; Dawson 1977; Othman & Greenwood 1989; Haridas et al. 1994). Very often only a single sex, based on one or a few specimens from plankton hauls, has been described. This has caused several taxonomic problems, some of which are discussed below.

(1) *Pseudocyclops latens* has been treated as a junior synonym of *P. magnus* by Nicholls (1944b) and Yeatman (1975). We, however, agree with Vervoort's (1964) separation of these two taxa in consideration of their distribution and morphology. The former was described from the Suez Canal while the latter is known originally from Bermuda. We believe that although species groups showing a full Tethyan track are broadly distributed in the world oceans, each member of the species groups has a relatively restricted distribution. Secondly there are distinct morphological discrepancies in the body length, caudal rami, and leg 5. (2) There is a possibility that *P. magnus* described from Barbados by Yeatman (1975) may be another species. However the conclusion must be pending because of Esterly's (1911) poor original description of only a single female. (3) Both sexes of *P. simplex* were described by Sewell (1932). However, the male (0.72 mm) is much larger than the female (0.5 mm), which leads us to doubt that both specimens are assignable to the same species.

Thirty three species of the genus *Pseudocyclops*, including the present three new species, have hitherto been found in tropical to temperate waters (see Table 1). However, previous poor descriptions make it difficult to assign all species to species groups. In the present study three distinct species groups are recognized: *lepidotus*-group (*P. lepidotus*, *P. ornaticuada*); *kulai*-group (*P. kulai*, *P. ensiger*); *crassiremis*-group (*P. crassiremis*, *P. bahamensis*, *P. oliveri*, *P. minutus*). In addition there is another species group clearly recognized in the genus: *magnus*-species group (*P. magnus*, *P. latens*, *P. xiphophorus*, *P. bilobatus*). The *magnus*-group shares synapomorphies as follows: (1) the absence of exopodal setae along the inner margin of the female leg 5; (2) the unarmed proximal endopod segment(s) of the female leg 5 with acutely pointed inner and outer processes; (3) the distal endopod segment of the female leg 5 with one or two setae and an acute process terminally; (4) the female genital double-somite with a pair of posteriorly directed processes (in *P. magnus*, *P. latens*, *P. xiphophorus*, and, probably, *P. bilobatus*); (5) the second caudal seta from the inner side spatulate in female (only in *P. magnus*, *P. xiphophorus* and *P. bilobatus*).

The *lepidotus*- and *kulai*-groups have many primitive characters as follows: (1) the separation between the cephalosome and the first pedigerous somite; (2) the separation between the fourth and fifth pedigerous somites; (3) the antennule bearing 19 free segments in female and 18 in male (right); (4) 2 setae present on the second endite of maxilliped syncoxa; (5) the presence of an inner basal seta of leg 1; (6) 3-segmented rami of the female leg 5 with the maximum elements among congeners; (7) 5 setae on the left endopod of the male leg 5; (8) the separation of both coxae of the male leg 5. In contrast the *crassiremis*- and *magnus*-group are furnished with the following advanced features: (1) the fusion between the fourth and fifth pedigerous somites; (2) the male rostrum articulated at the base (formation of pseudorostrum: see Huys & Boxshall 1991); (3) the number of antennule segments of both sexes is 16–17; (4) the absence of an inner basal seta of leg 1; (5) the endopod of the female leg 5 consisting of 1 or 2 free segments; (6) no developed setae on the left endopod of the male leg 5.

The distribution of the genus *Pseudocyclops* evidently shows a full Tethyan track (cf. Stock 1993). As suggested by Ohtsuka et al. (1998), many taxa of shallow-water demersal platycopioids and calanoids have such a distributional pattern. Stock (1993) has suggested that these taxa must have existed ever since the Tethyan Sea (ca. 120–20 MYA). However, the species groups of *Pseudocyclops* have their own distributional pattern. Interestingly the *lepidotus*- and *kulai*-groups, with many primitive characters, are restricted to tropical/subtropical waters in the Indo-West Pacific. The *crassiremis*- and *magnus*-groups, which retain more advanced character states in the body and appendages, are circumglobally distributed.

Feeding ecology

The feeding ecology of *Pseudocyclops* has been documented by Bowman & Gonzalez (1961) and Fosshagen (1968a). Ciliates and pennate diatoms were found in the guts of species from Puerto Rico and the Bahamas, respectively. Although Bowman & González (1961) suggested different food preference among congeners, Fosshagen (1968a) pointed out that food items in the guts only reflect what is most available in the different habitats because of the close similarity of the mouthparts of congeners. *Pseudocyclops* is essentially a particle-feeder, based on the structure of the mouthparts. In addition, the body size may be important in accessing available food particles. Since the largest species is approximately three times as large as the smallest one (see Table 1), the maximum size of available food particles may differ greatly (cf. Berggreen et al. 1988).

The present study showed that both benthic and pelagic microalgae are utilized as food by *Pseudocyclops*. Since some of pelagic dinoflagellates were found in the posterior parts of guts of *P. minutus*, these could have been fed in the ambient waters. Another benthic calanoid copepod, *Stephos*, also feeds on both benthic and pelagic microalgae (Ohtsuka & Hiromi 1987). Both types of microalgae may be taken in the hyperbenthos. However, if *P. ensiger* and *P. minutus* exhibit a diel migration as do other congeners, pelagic microalgae may be ingested in the water column during the night time.

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