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A New Species of *Hemicyclops* (Crustacea: Copepoda: Cyclopoida) Found in Plankton at the Mouth of the Jiulong River, Southern China

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A new species of the cyclopoid copepod genus *Hemicyclops*, *H. xiamenensis*, is described from plankton sampled at the mouth of the Jiulong River, southern China. This is the second species of the genus occurring in Chinese waters. The new species is readily distinguishable from its congeners by a combination of features of the fourth pediger, female genital double-somite, caudal ramus, and appendages. Because adults of *Hemicyclops* are ordinarily associated with benthic animals, the planktonic occurrence of the new species may be interpreted as either, 1) a new mode of life involving diel migration, 2) host switching between day and night, or 3) accidental occurrence.
Key Words: Crustacea, Copepoda, *Hemicyclops*, plankton, China, Xiamen.

Introduction

The cyclopoid copepod genus *Hemicyclops* accommodates ca. 40 species from shallow waters of the world (Kim 2000; Boxshall and Halsey 2004; Mulyadi 2005). Recently, Kim (2007) transferred four species to the new genus *Goodingius*. The development and life cycle of *Hemicyclops* are well investigated (Itoh and Nishida 1991, 1995, 1997, 2007, 2008; Kim and Ho 1992; Itoh 2001). Six naupliar and the first copepodid stages are free-swimming and serve for dispersal, and then the first copepodid stage settles on the bottom; the second and subsequent copepodid stages and adults are loosely associated with benthic animals such as polychaetes, echiurans, crabs, and mud shrimps. The first copepodid stage was previously referred to as *Saphirella* based on its unique morphology and predominance in plankton (Itoh and Nishida 1991; Itoh 2001).

During our survey of brackish zooplankton at the mouth of the Jiulong River, China, in September, 2008, we found both sexes of an undescribed species of *Hemicyclops*. This is the second species of *Hemicyclops* occurring in Chinese waters, after *H. mortoni* Boxshall and Humes, 1987 from Hong Kong (Boxshall and Humes 1987). The present paper deals with the description of the new species, with re-

marks on the unusual occurrence of adults in plankton community.

Material and Methods

Copepods were collected from the surface at the mouth of the Jiulong River off Xiamen, China (24°25′56.5″N, 117°53′48.8″E, <6 m deep) at night (local time 20:35) on 20 September 2008, using a NORPAC net (diameter 45 cm; mesh size 0.3 mm). All samples were fixed with 99.5% ethanol immediately after collection, and then preserved in 70% ethanol. Copepod specimens were observed with a differential interference contrast microscope with a drawing tube. Dissected appendages were immersed with gum-chloral medium.

Type specimens are deposited in the Kitakyushu Museum of Natural History and Human History (KMNH IvR), Kitakyushu, Japan, as well as in Xiamen University, Xiamen, China (XOB). Terminology follows Huys and Boxshall (1991).

Taxonomy

Hemicyclops xiamenensis sp. nov.
(Figs 1–5)

Material examined. Holotype: 1 ♀, body length 1.14 mm, dissected and mounted on glass slides, mouth of Jiulong River (24°25′56.5″N, 117°53′48.8″E), 20 September 2008, KMNH IvR 500,424. Paratypes: 1 ♀ (body length 1.30 mm), 1 ♂ (body length 1.05 mm), dissected and mounted on glass slides, same data as holotype, KMNH IvR 500,425 and 500,426, respectively; 16 ♀ ♀ (body length 1.06–1.31 mm), 4 ♂♂ (body length 1.09–1.24 mm), whole specimens, same data as holotype, 14 ♀ ♀ and 2 ♂♂ of them are deposited in KMNH (KMNH IvR 500,427 and 500,428, respectively) and 2 ♀ ♀ and 2 ♂♂ in XOB (XOB-PC7-10).

Size. Female 1.06–1.31 mm (mean±s.d. 1.21±0.07 mm, N=18); male 1.05–1.24 mm (1.14±0.07 mm, N=5).

Description. *Female*. Body (Fig. 1A) with plump prosome; cephalosome completely coalesced with first pedigerous somite; second pedigerous somite widest of all free somites in dorsal view; fourth pedigerous somite shallowly incised along posterior margin; fifth pedigerous somite abruptly narrower than preceding somites. Urosome composed of fifth pedigerous somite, genital double-somite, 2 free abdominal somites, and anal somite. Genital double-somite (Fig. 1A, B) expanded dorsolaterally in anterior half; paired gonopores located ventrolaterally at about one third length. Anal somite (Fig. 1C) furnished ventrally with row of minute spinules along posterior margin; caudal rami symmetrical, with seta I reduced, II and III naked, and VII located at inner dorsodistal corner.

Antennule (Fig. 1D) 7-segmented, with segmental length ratio of 1.0:1.0:0.5:1.3:0.8:0.8:0.7; armature elements as follows, 1st=4, 2nd=15, 3rd=6, 4th=3, 5th=4+ae, 6th=2+ae, 7th=7+ae. Antenna (Fig. 1E) 4-segmented, with exopod completely absent; coxobasis bearing distal seta; endopod 3-segmented, first segment with minute seta at midlength, second segment with row of spinules along inner margin

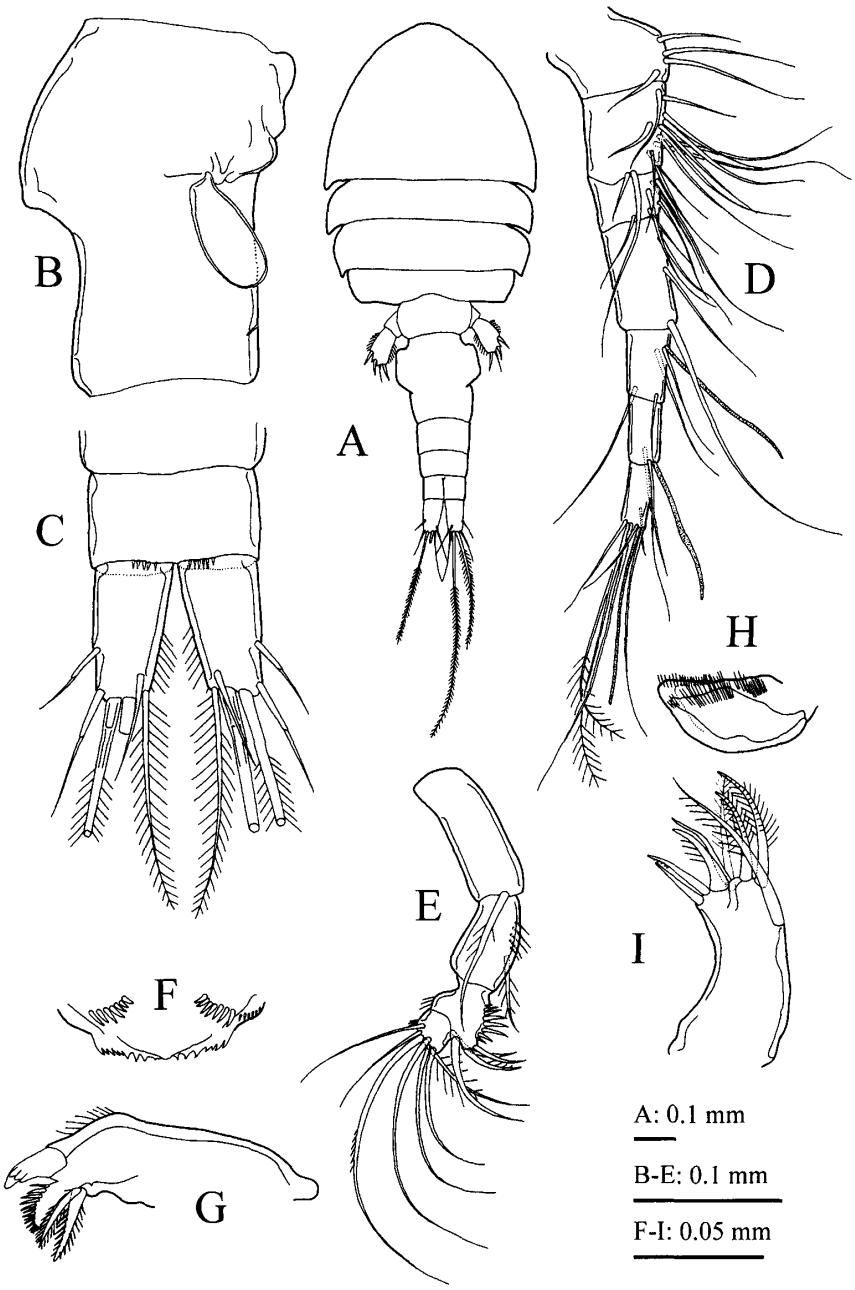

Fig. 1. *Hemicyclops xiamenensis* sp. nov., holotype, female (KMNH IvR 500,424). A, Habitus, dorsal; B, genital double-somite, right lateral; C, anal somite and caudal rami, ventral; D, antennule; E, antenna; F, labrum, ventral; G, mandible, anterior; H, paragnath, ventral; I, maxillule, posterior.

and 2 subdistal and 2 distal setae, third segment small, with 7 setae distally. Labrum (Fig. 1F) ornamented with paired rows of spinules at midlength and serration along posterior margin. Mandible (Fig. 1G) with 1 serrate and 1 spinulose spine and 2 spinulose setae. Paragnath (Fig. 1H) semicircular, with tuft of hairs on ventral side. Maxillule (Fig. 1I) bilobed, proximal lobe (=praecoxal arthrite) with 5 setae and distal lobe (=palp) with 3 setae. Maxilla (Fig. 2A) stout, 2-segmented;

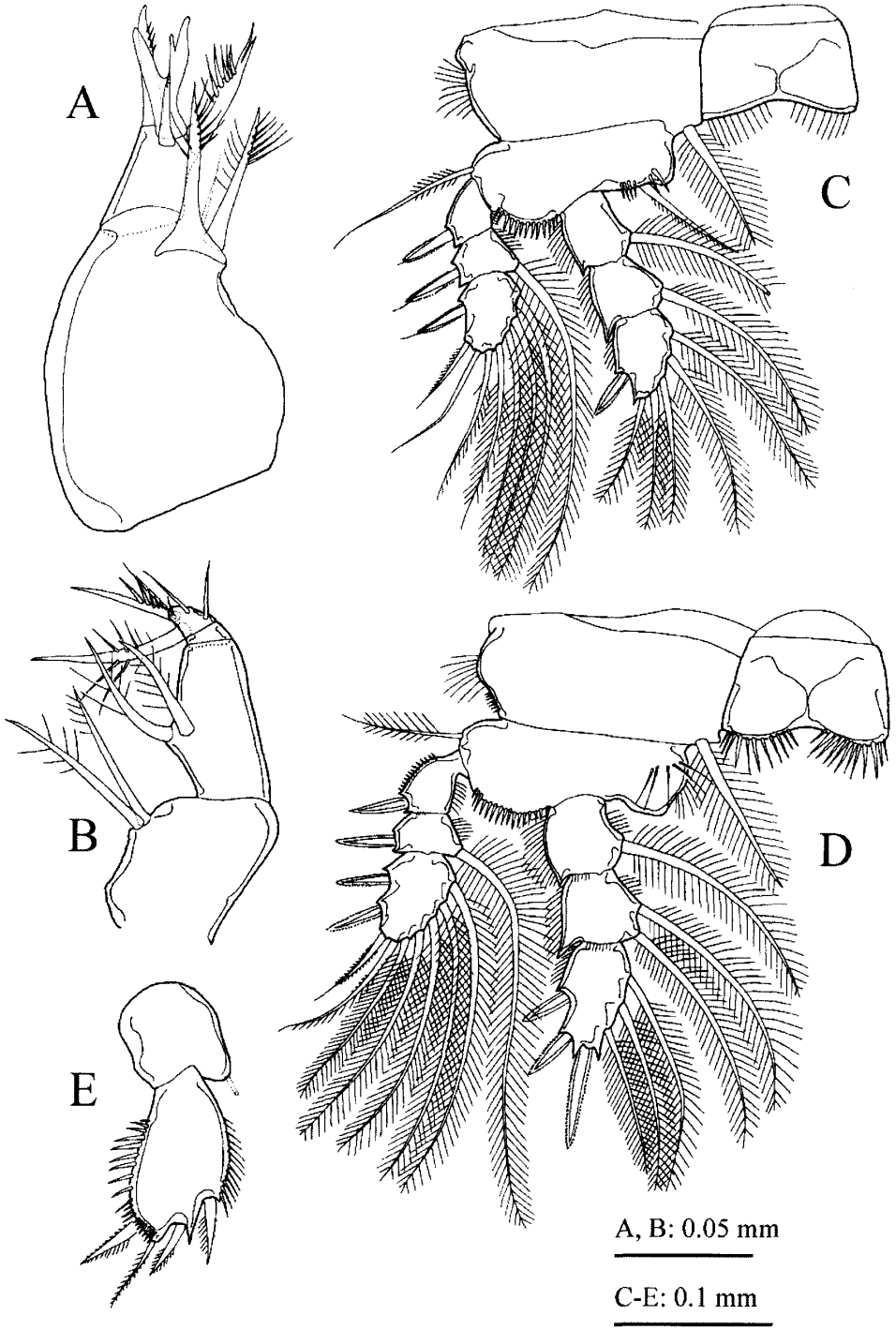

Fig. 2. *Hemicyclops xiamenensis* sp. nov., holotype, female (KMNH IvR 500,424). A, Maxilla, anterior; B, maxilliped, posterior; C, leg 1, anterior; D, leg 2, anterior; E, leg 5, posterior.

proximal segment (=syncoxa) with 2 bipinnate setae and simple seta distally; distal segment (=basis) bearing 2 barbed and 2 spinulose setae at tip. Maxilliped (Fig. 2B) 4-segmented; first (=syncoxa) and second (=basis) segments each with 2 spinulose setae at midlength; endopod 2-segmented, first segment unarmed, second seg-

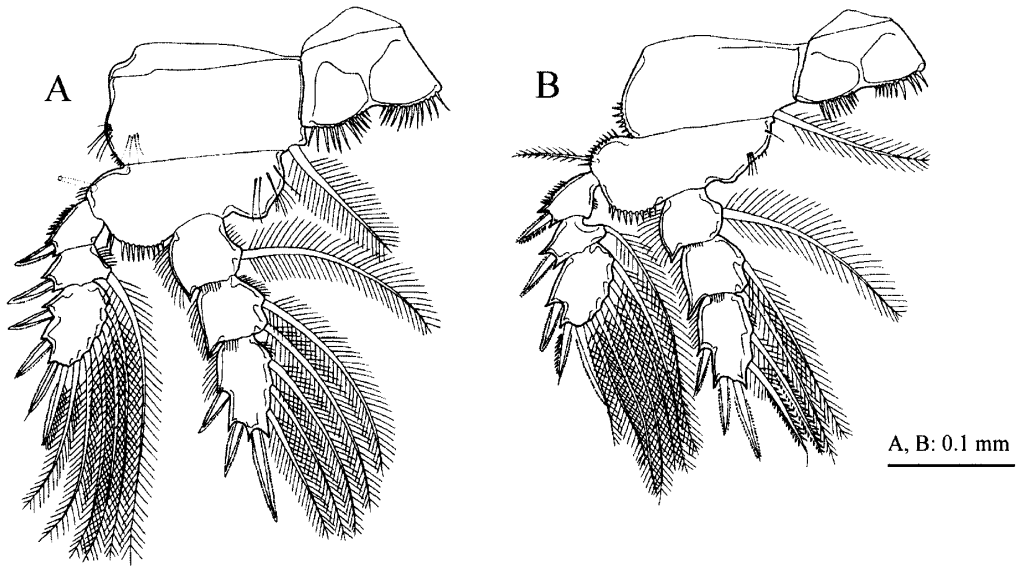

Fig. 3. *Hemicyclops xiamenensis* sp. nov., holotype, female (KMNH IvR 500,424). A, Leg 3, anterior; B, leg 4, anterior.

Table 1. Spine (Roman numerals) and seta formula of legs 1–4 of *Hemicyclops xiamenensis* sp. nov.

Leg	Coxa	Basis	Exopod	Endopod
1	0-1	1-I	I-0; I-1; I, 7	0-1; 0-1; I-5
2	0-1	1-0	I-0; I-1; II, 7	0-1; 0-2; III, 3
3	0-1	1-0	I-0; I-1; II, 7	0-1; 0-2; III, 3
4	0-1	1-0	I-0; I-1; I, 7	0-1; 0-2; III, 2

ment with 2 spinulose and 3 fine setae.

Legs 1–4 (Figs 2C, D, 3A, B) with 3-segmented rami; seta and spine formula depicted in Table 1; intercoxal sclerite furnished with paired rows of fine hairs along posterior margin in leg 1 (Fig. 2C) and with spinule rows in legs 2–4 (Figs 2D, 3A, B); coxa fringed with tuft of hairs on outer proximal (legs 1 and 2) and distal (leg 3) margins or with outer row of spinules along distal half (leg 4); basis with row of spinules along distal margin between rami; distal margin of first and second endopodal segments fringed with row of minute prominences and produced distally into acutely pointed process at outer corner. Leg 1 (Fig. 2C) with inwardly protruded basis bearing rows of short spinules near base of inner seta. Legs 2 (Fig. 2D) and 3 (Fig. 3A) bearing row of long hairs along inner margin. Leg 4 (Fig. 3B) with basis not strongly expanded inward as in preceding legs; second exopodal segment constricted proximally.

Leg 5 (Fig. 2E) 2-segmented; first segment bearing fine dorsal seta; second segment foliaceous, having 1 inner and 2 outer pinnate spines and terminal seta, inner and outer margins with spinules along almost entire length. Leg 6 represented by unarmed genital operculum, with relatively small spermatophore in holotype (Fig. 1B).

Male. Body (Fig. 4A) similar to but more slender than that of female; urosome consisting of fifth pedigerous somite, genital somite, 3 free abdominal somites, and anal somite, with length ratio of 1.0 : 1.6 : 0.9 : 0.8 : 0.5 : 0.5.

Antennule (Fig. 4C) non-geniculate, 7-segmented; ratio of segmental lengths 1.0 : 1.3 : 0.8 : 1.7 : 1.0 : 1.0 : 1.0; setal formula as follows, 1st=4, 2nd=15, 3rd=7, 4th=3, 5th=4+ae, 6th=2+ae, 7th=7+ae.

Maxilla and maxilliped showing distinct sexual dimorphism. Maxilla (Fig. 4D) 2-segmented; syncoxa with 3 fine setae of unequal length distally; basis bearing 3 stout spiniform elements and fine seta terminally. Maxilliped (Fig. 5A) well developed, 4-segmented; syncoxa with single seta at midlength; basis expanded medially, bearing fine inner seta and rows of minute spinules along inner margin; first endopodal segment small, unarmed; second endopodal segment drawn into claw, latter smoothly curved inward, slightly longer than basis, with fine seta proximally.

Leg 1 (Fig. 5B) differing from that of female in absence of inner basal seta. Legs 2–4 as in female.

Leg 5 (Fig. 4B) unisegmented, lobate with 2 outer and 1 distal spines, with spinules on both outer and inner margins. Leg 6 (Fig. 4B) represented by foliaceous genital flap with 2 outer spines of unequal length.

Etymology. The new specific name is after the type locality, Xiamen, China.

Discussion

Comparison

Recently Kim (2000) pointed out heterogeneity among 36 species of *Hemicyclops* occurring in the world, and he subsequently erected (Kim 2007) a new genus *Goodingius* to accommodate four species that can be distinguished by the number of urosomites and by the segmentation, armature, and sexual dimorphism of the appendages. True members of *Hemicyclops* are characterized by 1) five-segmented female urosome, 2) antennule with four setae on the first segment and one aesthetasc on the fifth segment, 3) mandible furnished with four distinct elements distally, 4) maxilla and leg 1 showing sexual dimorphism, 5) an inner coxal seta on leg 4, and 6) three spines and two setae on the third endopodal segment.

The present new species is unambiguously assignable to *Hemicyclops* rather than *Goodingius*, and is most closely related to *H. japonicus* Itoh and Nishida, 1993 (*q.v.*) from Japan in sharing the following features: 1) genital double-somite of female longer than wide; 2) second and third urosomites of female relatively short and smoothly tapering distally; 3) caudal rami relatively short, less than twice as long as wide; and 4) similar armature of distal segment of leg 5 of both sexes. However, the new species is readily distinguishable from *H. japonicus* in the following respects: 1) genital double-somite of female expanded anterodorsally in its anterior half (vs flattened dorsally, constricted at anterior third, and with lateral pair of hooks at proximal third in *H. japonicus*); 2) third pediger rounded posterolaterally in dorsal view (vs pointed); 3) fourth pedigers of female and male about 2.0 and 3.2 times as wide as long, respectively (vs 4.9 and 5.3 times, respectively); 4) third segment of antenna (first endopodal segment) not very produced at outer distal corner (vs reaching midlength of fourth segment); 5) labrum serrated along posterior mar-

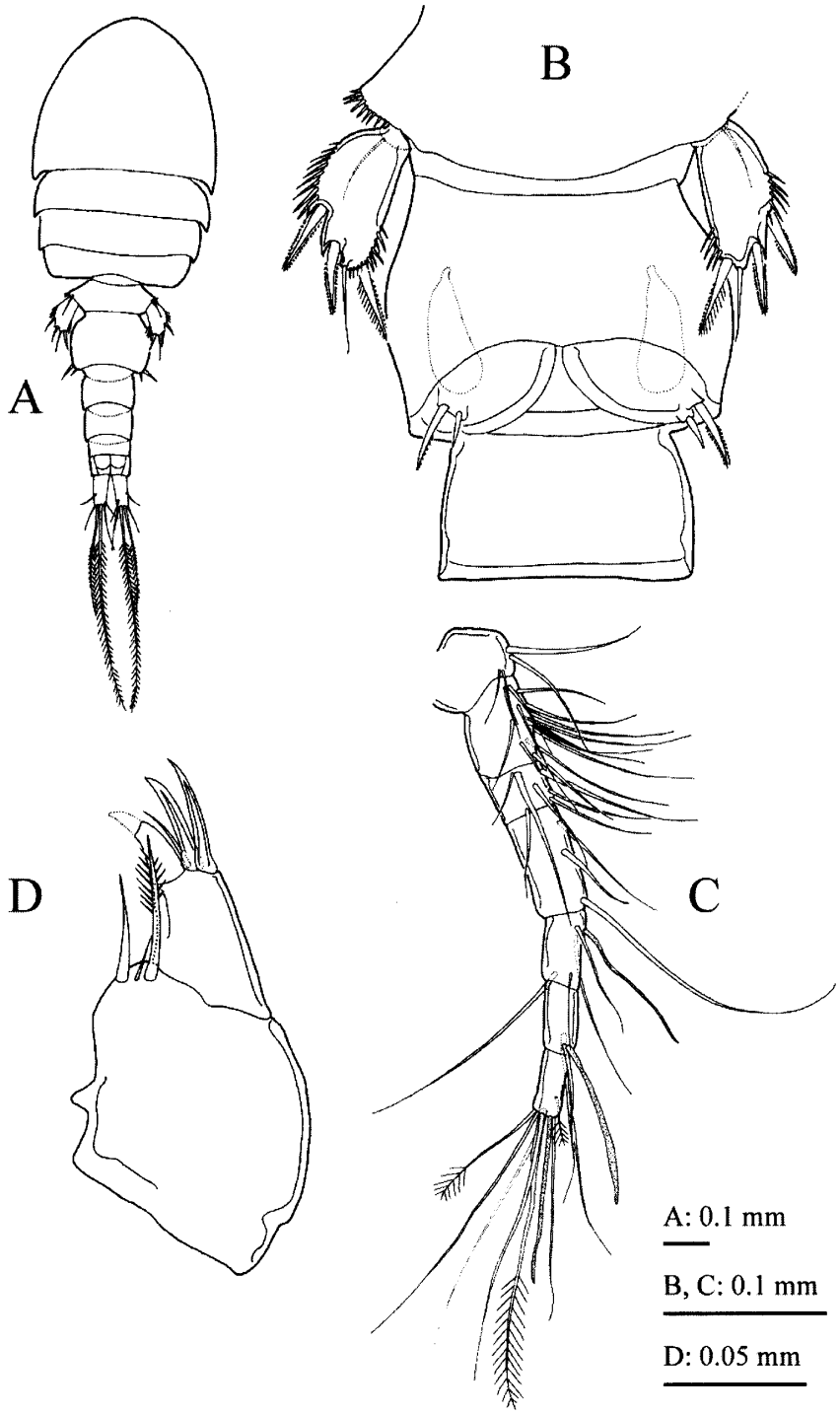

Fig. 4. *Hemicyclops xiamenensis* sp. nov., paratype, male (KMNH IvR 500,426). A, Habitus, dorsal; B, first to third urosomites, ventral; C, antennule; D, maxilla, anterior.

gin (vs smooth); 6) maxillule smooth along outer margin (vs with three prominences); 7) second segment of maxilla lacking strongly sclerotised, ramified spines (vs such spines present); 8) first segment of leg 5 in females lacking transverse row of spinules (vs such spinules present); 9) leg 5 in males reaching at most to mi-

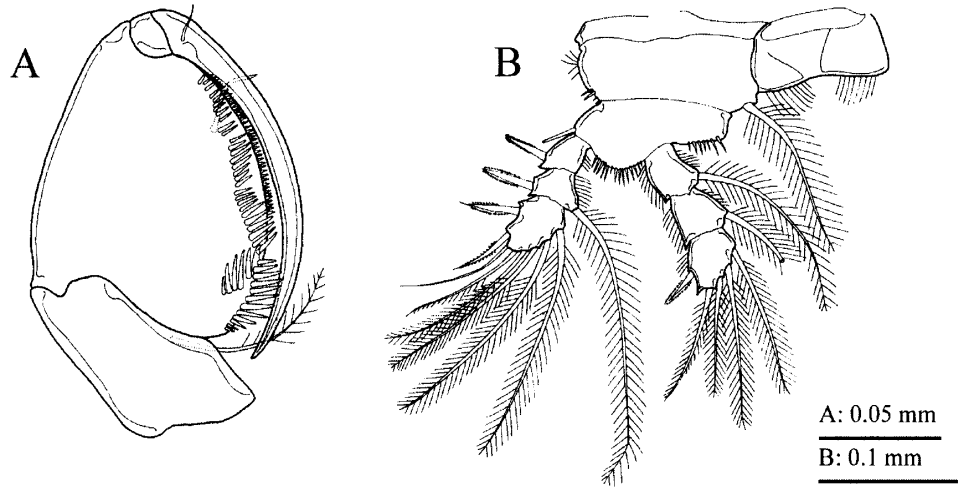

Fig. 5. *Hemicyclops xiamenensis* sp. nov., paratype, male (KMNH IvR 500,426). A, Maxilliped, anterior; B, leg 1, anterior.

dlength of genital somite (vs beyond genital somite); and 10) leg 6 in males furnished with 2 elements (vs 1 element).

In addition to *Hemicyclops xiamenensis* and *H. japonicus*, the following six species of *Hemicyclops* have so far been recorded from East Asia: *H. mortoni* Boxshall and Humes, 1987 (Hong Kong), *H. gomsoensis* Ho and Kim, 1991 (Yellow Sea; Tokyo Bay, Japan), *H. saxatilis* Ho and Kim, 1991 (Yellow Sea), *H. spinulosus* Itoh and Nishida, 1998 (Tokyo Bay), *H. ventriplanus* Kim, 2000 (Yellow Sea), and *H. tanakai* Itoh and Nishida, 2002 (Tokyo Bay).

Life cycle

The development and life history of the genus *Hemicyclops* have been intensively addressed by Itoh and Nishida (1991, 1995, 1997, 2007, 2008), Kim and Ho (1992), and Itoh (2001). According to these studies, the six naupliar and first copepodid stages are free-swimming suspension-feeders. The first copepodid stage settles on the bottom and starts a benthic mode of life. The second to sixth (=adult) copepodid stages are loosely associated mainly with benthic animals such as polychaetes, echiurans, crabs, and mud shrimps, and rarely with sponges, hard corals, bivalves, and hermit crabs (Boxshall and Humes 1987; Ho and Kim 1991; Humes 1995; Kim 2000; Itoh 2001; Itoh and Nishida 2007, 2008). These benthic stages have been isolated from the body surface of benthic animals and from their burrows. Itoh and Nishida (2007) reported that the gut contents of adults of *Hemicyclops gomsoensis* found in benthic burrows were composed of diatoms, dinoflagellates, copepod nauplii, and detrital material, which suggests that it does not depend nutritionally on the host. The mouthparts of the second to fifth copepodid stages and adults of all congeners essentially resemble those of *H. gomsoensis*, implying a similar feeding habit (see Ho and Kim 1991; Itoh and Nishida 1995; Itoh 2001). Therefore the association is most likely a matter of commensalism rather than parasitism.

The life history of two sympatric species, *Hemicyclops gomsoensis* and *H. spinulosus*, has been well compared in Tokyo Bay, Japan, by Itoh and Nishida (2007,

2008). These two species clearly exhibit different population dynamics and reproductive strategies, due to their different host-specificities. Benthic stages of the former are associated with the ocypodid crab *Macrophthalmus japonicus* (De Haan, 1835) and the mud shrimp *Upogebia major* (De Haan, 1841), and attain larger population size than do those of *H. spinulosus*. In contrast, the latter has an association with *M. japonicus* and the polychaete *Tylorrhynchus heterochaetus* (Quartrefages, 1865), and exhibits an adaptation to somewhat narrow habitat spaces and lower densities than in *H. gomsoensis*. In addition, flushing by increased river flow causes more severe population decreases in *H. gomsoensis*, due to its lesser tolerance to low salinity (Itoh and Nishida 2008).

The present occurrence of adults of *Hemicyclops xiamenensis* in the plankton community at night is mysterious in contrast to the above-mentioned, usual benthic mode of life of the genus. The salinity of the surface waters varied widely, from 1.2 to 20.0‰. Over half of the adult females examined (55.6%, N=18) carried paired egg-sacs and/or spermatophores on the genital double-somite. Several explanations for this phenomenon may be suggested: 1) a new mode of life involving diel migration of adults between the bottom and the water column and/or association with pelagic or nektonic animals instead of benthic ones; 2) host switching; 3) accidental occurrence, e.g., due to flooding. The last two seem unlikely, because no copepodid stages were collected along with the adults; however, smaller copepodids could have passed readily through the plankton net mesh of 0.3 mm. In the case of *H. japonicus*, with an adult body length nearly the same as that of the new species, body lengths of the first to fifth copepodid stages range from 0.61 (first) to 1.04 mm (fifth female) (Itoh and Nishida 1995). The first possibility, a diel vertical migration, may be the most likely, although such a phenomenon has never been reported in *Hemicyclops*. Recently, a dual mode of life between hosts and water column has been proposed for adults of some species of the families Ergasilidae and Caligidae, both of which have been regarded as parasites mainly on fish (Ohtsuka *et al.* 2004; Venmathi Maran and Ohtsuka 2008). These adults are suggested to spend alternate periods as plankters and symbionts. The present occurrence of pelagic adults of *H. xiamenensis* may be similar. However, this should be investigated by means of laboratory experiments.

Acknowledgements

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