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Article *in* Proceedings of the Biological Society of Washington · January 2015

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On the occurrence of a new species of benthic copepod, *Zaus wonchoelleei* (Harpacticoida, Harpacticidae), in a macroalgal habitat from Tongyong, Korea

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Abstract.—The marine phytal zone has received little attention as yet as a habitat of associated and symbiotic crustaceans, particularly copepods. We describe here the female and male of a new harpacticoid copepod species *Zaus wonchoelleei* from the green alga *Ulva* sp. attached to aquaculture floats at Tongyeong Marine Living Resources Research and Conservation Center, Gyeongsangnamdo, Korea. The new species is closely related to *Z. unisetosus* recorded from Japan and Korea and *Z. goodsiri* by having one inner seta on leg 2 endopod but can be easily distinguished by the combination of the following characters: leg 2 enp-3 with only 1 inner seta, setation of leg 5 exopod, segmentation of antennule, and sexual dimorphism of leg 2 endopod. The detailed taxonomic description of the new species, *Z. wonchoelleei*, addresses the similarity and/or distinctiveness of species in the genus *Zaus* and contributes to the discussion of characters found useful to justify the separation of closely related species reported or being documented elsewhere.

Keywords: benthic copepod, Harpacticidae, Korea, macroalgal habitat, *Zaus*

Copepods are abundant and widely distributed in plankton and the benthos (Boxshall & Halsey 2004). They are ecologically important in terms of energy and matter cycling for aquatic food webs and the structuring of biogeochemical cycles in aquatic systems (Dahms et al. 2011b, 2012). In recent years, there has been a substantial increase in studies related to copepod phylogeny (Huys et al. 2006, Ferrari et al. 2011, Song et al. 2011), geographic distribution (Chullasorn et al. 2011, Karanovic et al. 2013), ecology (Tseng et al. 2011, Lee et al. 2012a), biology (Lee et al. 2011), and genomics (Ki et al. 2009), as well as in biochemical and molecular responses following exposure to physical and chemical environmental disturbances (Dahms et al. 2011a, Wu et al. 2011). This is less so for the group of benthic copepods that commonly belong

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to the meiofauna (Mantha et al. 2012a, b). Smaller invertebrates are known as phytal meiofauna if they live associated with seaweed (Hicks 1977, 1980; Coull et al. 1983, Johnson & Scheibling 1987). Particularly little attention has been paid as yet to copepods associated with seaweed (Ho & Hong 1988, Song et al. 2010) or even parasitic taxa that infest macroalgal thalli (Song et al. 2007). The mass production of macroalgae contributes to carbon sequestration, providing food for phytal-based food webs and combating against global warming. Besides being seafood for human consumption, macroalgae provide promising products for the cosmetic and pharmaceutical industries, and biomass for the production of biofuel (Ibañez & Cifuentes 2013, Horincar et al. 2014). The mass production of macroalgae likely contributes to carbon sequestration. Thus, ecological studies of phytal animals would be of significance to mariculture of macroalgae worldwide (Kang 1981, Schmidt & Scheibling 2006, Lee et al. 2012b).

The genus *Zaus* Goodsir, 1845, presently comprising 13 species (Wells 2007), is adapted to the particular habitat of macroalgal thalli by a dorsoventrally depressed body that makes them better able to withstand the surge and shock of wave action and hydrodynamic exposure in their littoral and usually rocky environment. The taxonomic status of the genus *Zaus* is particularly unresolved. This uncertain status prevented Karl Lang (1965) from providing an identification key for the group. Our objective in the present study is to describe the morphology of a new species belonging to *Zaus* and to add to the phylogenetic discussion of this genus inhabiting a phytal environment in the coastal ocean.

Materials and Methods

Adults of *Zaus wonchoelleei*, belonging to *Zaus* Goodsir, 1845, were collected by Hans-Uwe Dahms, Bancherd Sornsupharp, and Hyung-Uk Park from the green alga *Ulva* sp. attached to aquaculture floats at Tongyeong Marine Research Center, Gyeongsangnamdo, Korea, on 1 Nov 2011. Adult specimens (ovigerous females and males) were retrieved by washing seaweed in a bucket. The residue containing all developmental stages of *Z. wonchoelleei* was rinsed and decanted over a 50 μm-mesh screen into smaller bowls for fixation and transport of live individuals to the laboratory. Some specimens were fixed in 5% formaldehyde. Dissected somites and appendages were mounted on slides in glycerin. The coloration was described based upon observations of live specimens. Before dissection, the habitus was drawn from whole mounts, and total length measurements were made from specimens mounted in Zeiss W15 medium. As there was no asymmetry in the two appendages of the same somite, only one (of each type of appendage) is shown. Drawings were made with the aid of a camera lucida. The main references for a morphological description of the genus are provided by Lang (1948, 1965), Itô (1980), Huys et al. (1996), and Boxshall & Halsey (2004).

Results

Family Harpacticidae Dana, 1846
Genus *Zaus* Goodsir, 1845
Zaus wonchoelleei, new species
Figs. 1–12

Type locality.—Tongyeong Marine Living Resources Research & Conservation Center (Korea Institute of Ocean Science and Technology), Gyeongsangnamdo, Korea (34°46.12′N, 128°22.59′E).

Type material.—Holotype, female preserved in ethanol (NIBRIV 0000261534); 1 Nov 2011, coll. H.-U. Dahms, Bancherd Sornsupharp, and Hyung-Uk Park from the green alga *Ulva* sp. attached to aquaculture floats at above institute, as

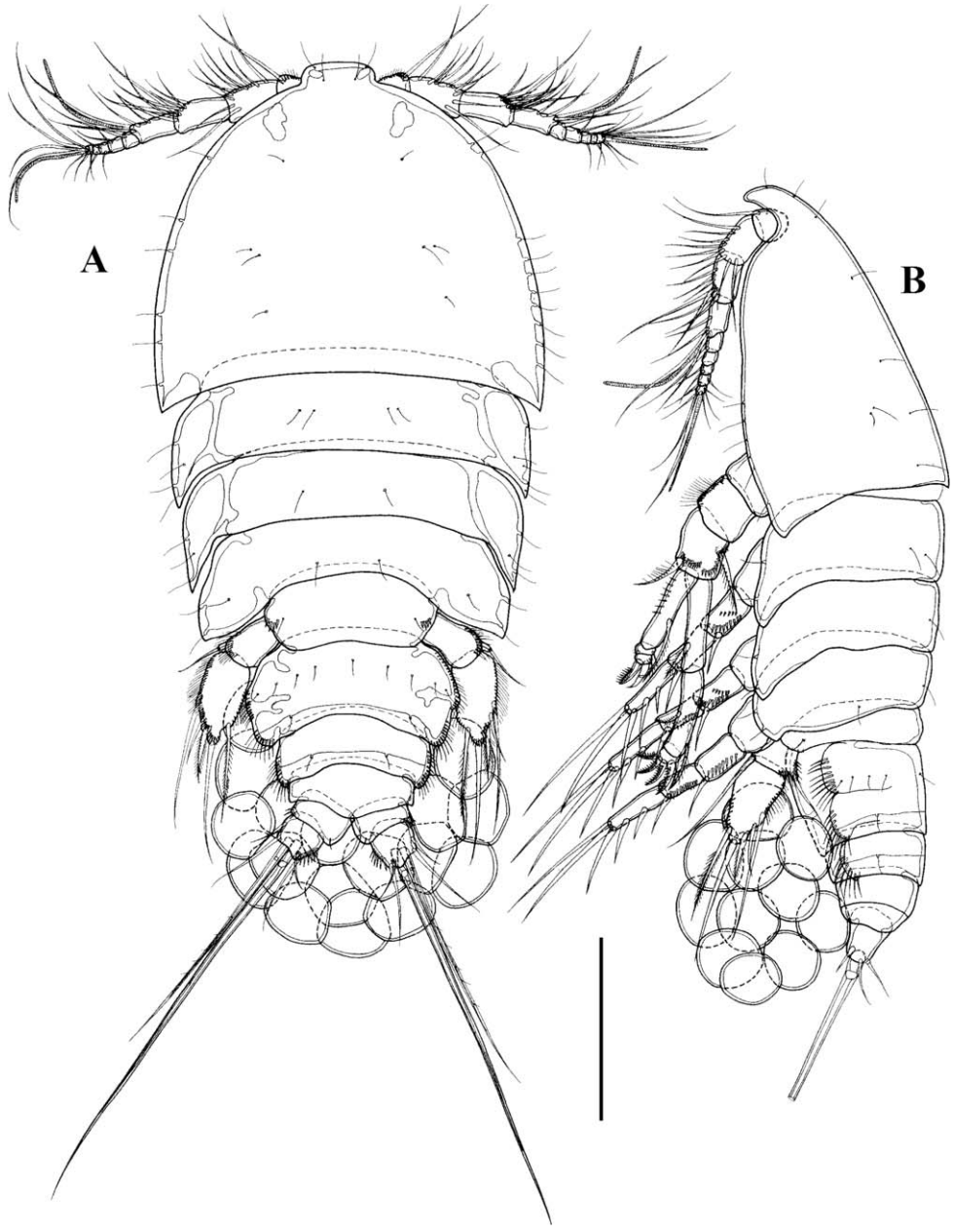

Fig. 1. *Zaus wonchoelleei*. Female. A, habitus, dorsal view; B, habitus, lateral view. Scale bar: 160 μm.

type locality. Allotype: undissected male in ethanol (NIBRIV 0000261535), sampling data as in holotype. Paratypes: 4 females and 1 male preserved in ethanol (NIBRIV 0000261536). One female and one male illustrated and dissected on 10 and 9 slides (NIBRIV 0000261537–0000261538), respectively. Sampling data as in holotype. Type specimens are deposited at the National Institute of Biological Resources (NIBR), Incheon, Korea.

Description of female.—Body length measured from tip of rostrum to posterior margin of caudal rami: 704 μm. Cepha-

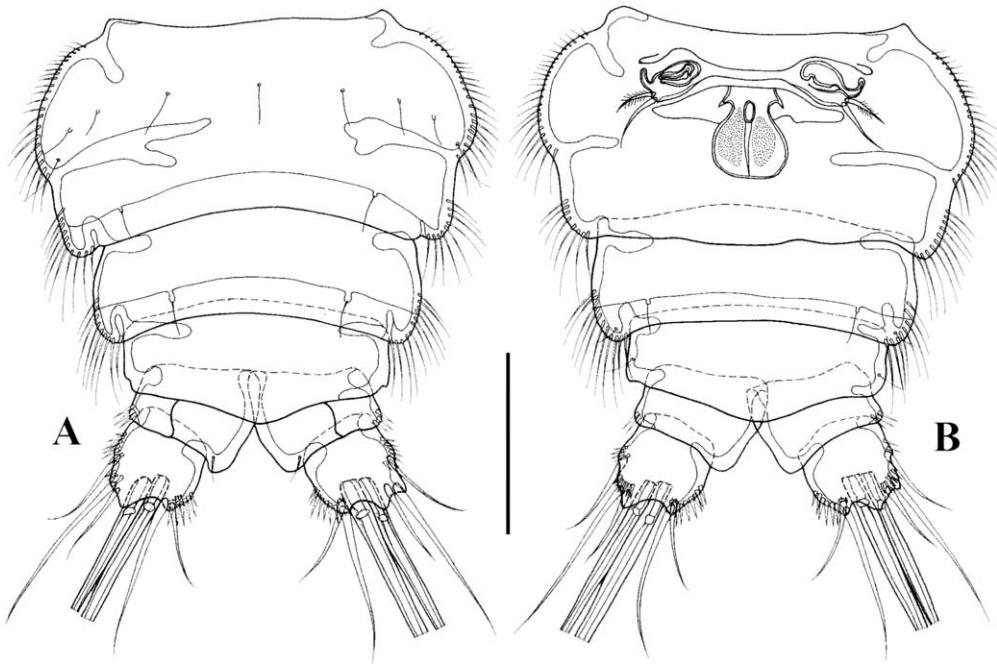

Fig. 2. *Zaus wonchoelleei*. Female. A, urosome, dorsal view; B, urosome, ventral view. Scale bar: 80 μm.

losome and pedigerous somites with numerous integumental sensilla as illustrated (Fig. 1A, B). Rostrum (Fig. 3C) trapezoidal, about 1.31 times wider than long, with middorsal pore near proximal margin and pair of sensilla on distal corners. Pedigerous somites without distinct hyaline frills or spinular rows (Fig. 1B). All urosomites without middorsal spinules, except for genital double-somite and first abdominal somites (Fig. 1A). Genital double-somite with 2 spinule rows laterally (Figs. 1A, 2A, B). First abdominal somite with a spinular row laterally. Second abdominal somite without ornamentation. Anal somite with spinules on distal corner and a setule row on inner distal surface, and with vestigial anal operculum, largely concealed under hyaline frill of penultimate somite (Figs. 2A, 7C). Caudal rami (Fig. 2A, B) slightly longer than wide, with 7 setae: seta I small, surrounded by spinules; seta II located near seta III at outer distal corner; setae IV and V well developed, with fracture planes and fused at base; seta VI on inner distal corner; seta VII tri-articulate at base (Fig. 1B).

Antennule (Fig. 3A) 9-segmented: segment 1 small, with 2 spinular rows on anterior margin and on the surface proximally; segment 3 longest; segment 4 slightly produced at anterior distal corner and with a slender aesthetasc terminally. Setal formula as follows: 1-[1], 2-[9 + 2 tiny], 3-[10], 4-[4 + (1+ae)], 5-[2], 6-[3], 7-[1], 8-[2], 9-[8 + acrothek]. Apical acrothek consisting of 2 bare setae and one aesthetasc.

Antenna (Fig. 3B) comprising coxa, allobasis, 2-segmented exopod, and 1-segmented endopod. Coxa unarmed. Allobasis slightly longer than endopod, with spinular row on proximal surface, and abexopodal seta at midlength. Endopod with transverse row of large spinules; lateral armature consisting of 4 bare setae; apical armature comprising 4 geniculate setae and 3 strong pinnate spines. Exopod with 2 long bipinnate setae on exp-1; exp-2 as long as exp-1, 2 bipinnate setae laterally,

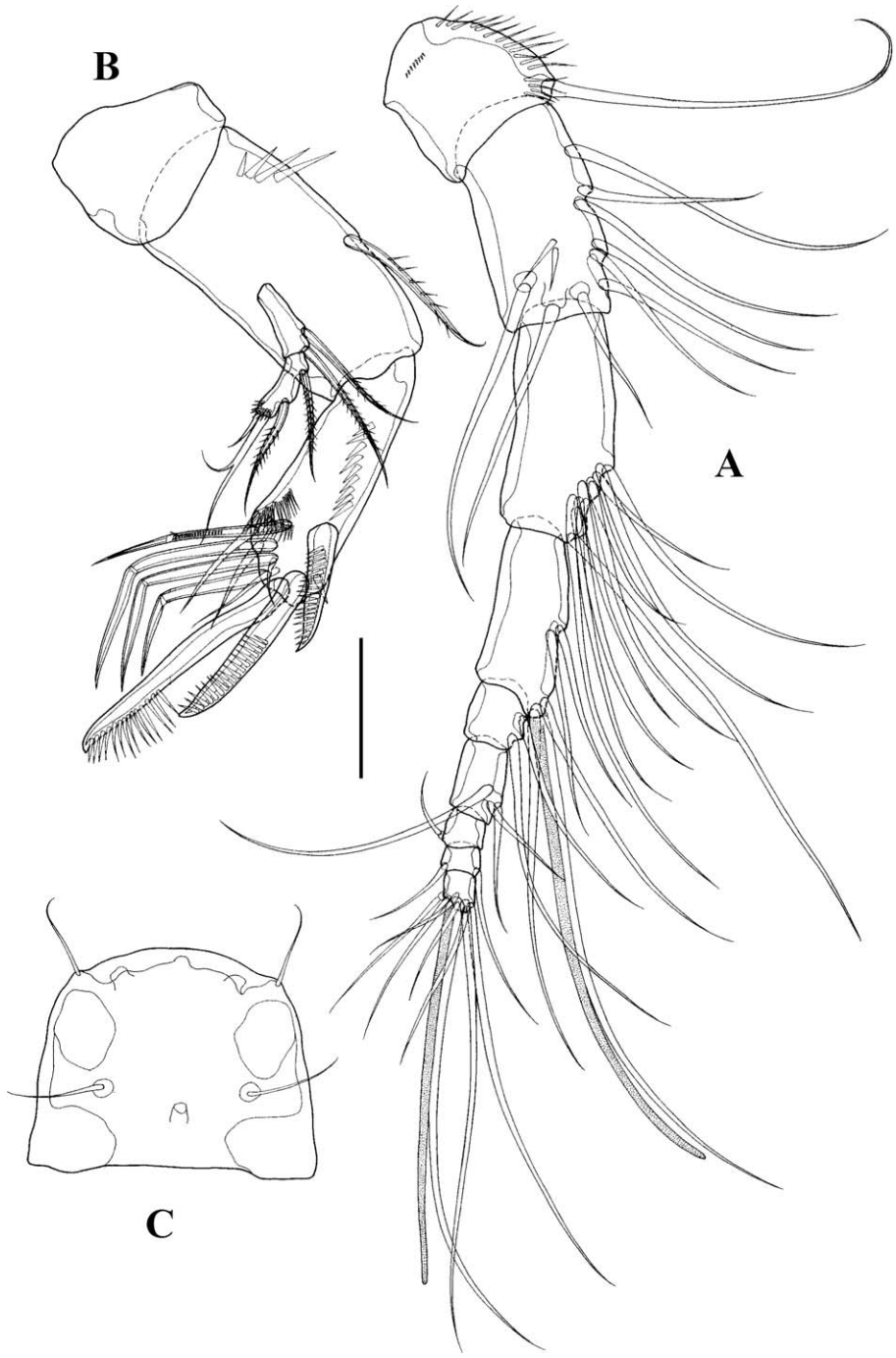

Fig. 3. *Zaus wonchoelleei*. Female. A, antennule; B, antenna; C, rostrum, dorsal. Scale bar: 32 μm.

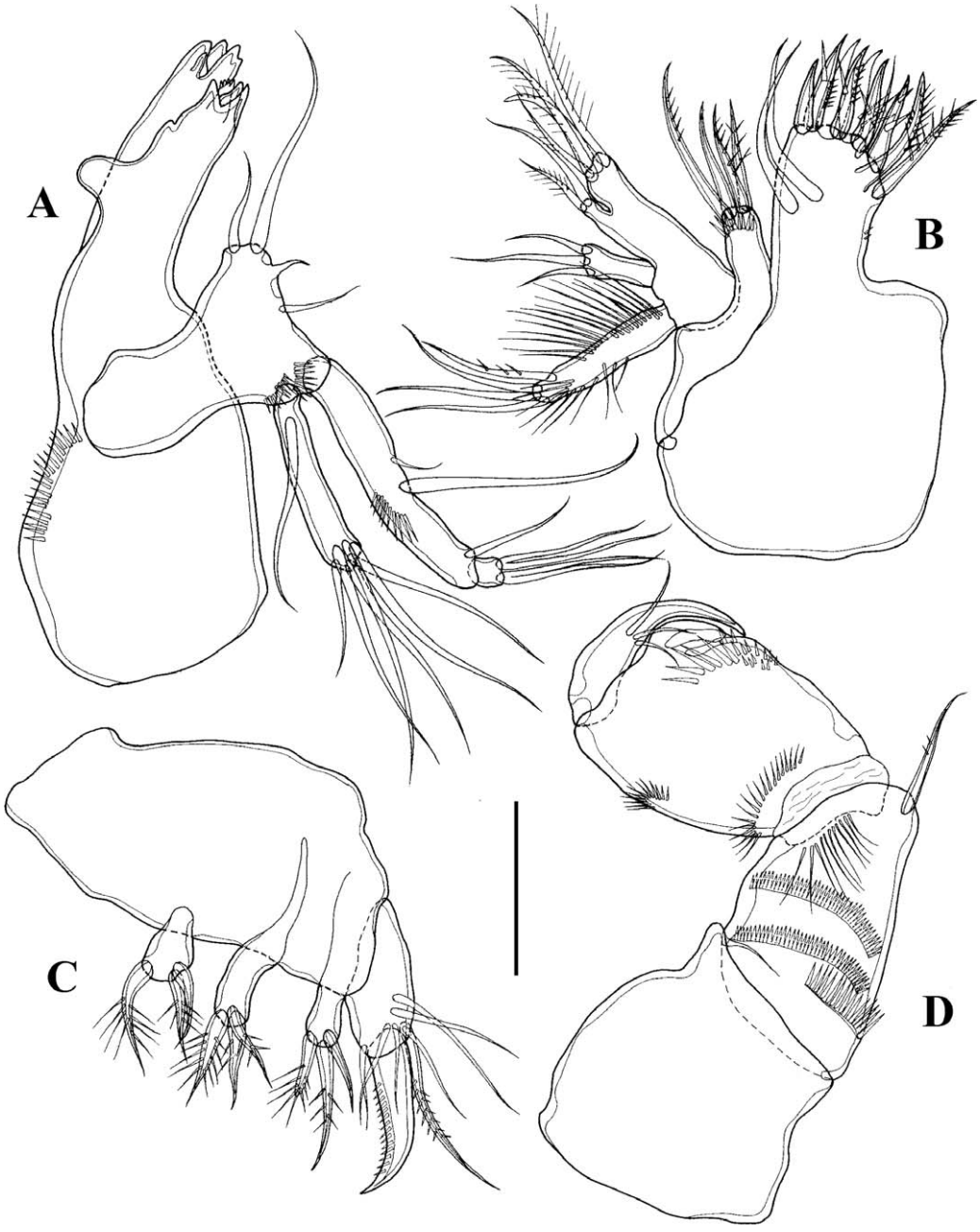

Fig. 4. *Zaus wonchoelleei*. Female. A, mandible; B, maxillule; C, maxilla; D, maxilliped; A–D, anterior view. Scale bar: 32 μm.

1 small bare seta and 1 long bifurcated seta distally.

Mandible (Fig. 4A) with robust gnathobase provided with series of multicuspidate teeth. Palp comprising basis and 2-segmented endopod and 1-segmented exopod. Basis with 2 spinular rows distally and bearing 4 setae. Endopod much longer than exopod; enp-1 with 1 spinular row on surface and bearing 2 lateral and 1

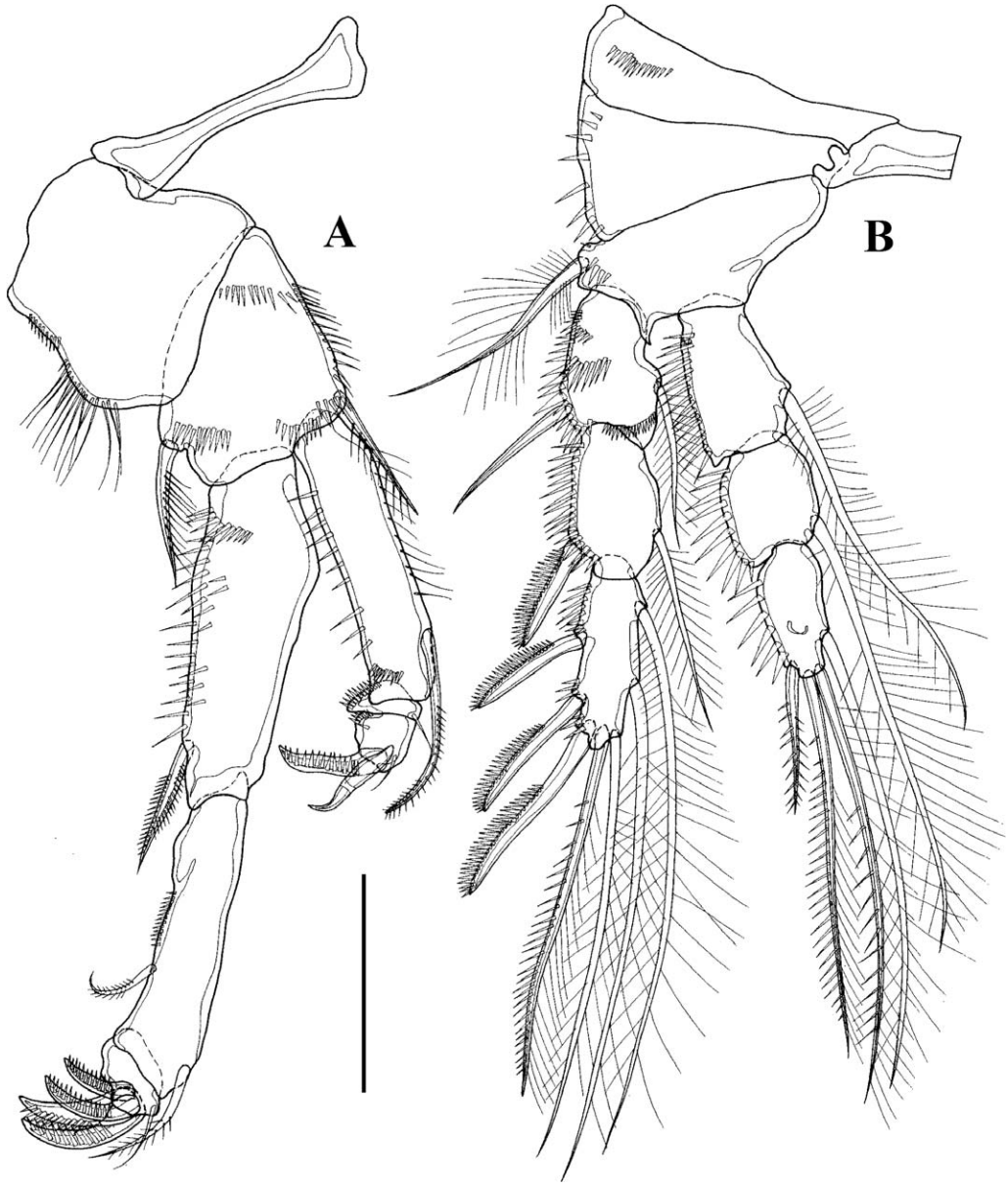

Fig. 5. *Zaus wonchoelleei*. Female. A, right P1; B, right P2, anterior view. Scale bar: 63 μm.

subdistal setae; enp-2 very small, with 4 apical setae having two pairs of basally fused setae. Exopod with 1 lateral seta and 6 apical setae.

Maxillule (Fig. 4B) with arthrite bearing 2 setae on anterior surface, 2 minute spinules around inner margin and 9 ornamented spines and 1 seta around distal margin. Coxal endite with spinular row subdistally, bearing 4 distal setae. Basis bilobed, with 2 setae on outer lobe and 4 distal setae on inner lobe. Exopod elongate, ornamented with long setules on both margins, and with 1 pinnate and 3 bare setae distally. Endopod much shorter than exopod, with 3 bare distal setae.

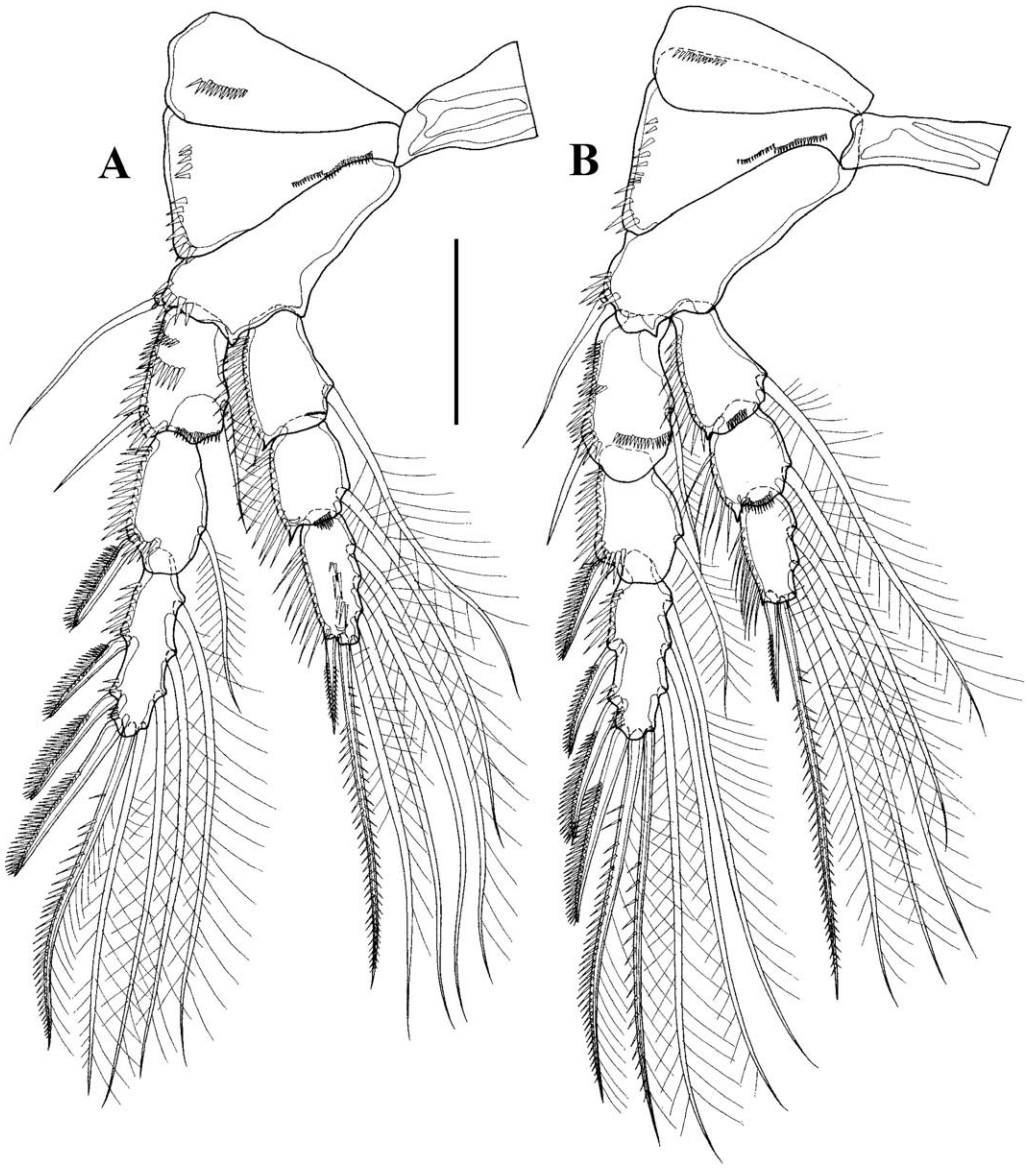

Fig. 6. *Zaus wonchoelleei*. Female. A, right P3; B, right P4, anterior view. Scale bar: 63 μm.

Maxilla (Fig. 4C). Syncoxa without ornamentation, and with 3 endites; each endite with 3 ornamented spines on distal lobe. Allobasis drawn out into pectinate claw; accessory armature consisting of 4 bare setae and 1 bipinnate anterior seta. Endopod represented by 2 long setae on its distal surface.

Maxilliped (Fig. 4D). Subchelate, well developed. Praecoxa large, without ornamentation. Syncoxa with 3 spinular rows on anterior surface and 1 long setule line distally, and bearing 1 pinnate seta subdistally. Basis with 2 spinular rows on anterior surface and 1 spinular cluster subdistally. Endopod shorter than basis, drawn out into strong, curved claw, accessory armature consisting of 3 bare setae.

P1 (Fig. 5A). Intercoxal sclerite bare. Coxa with minute spinules and long setule

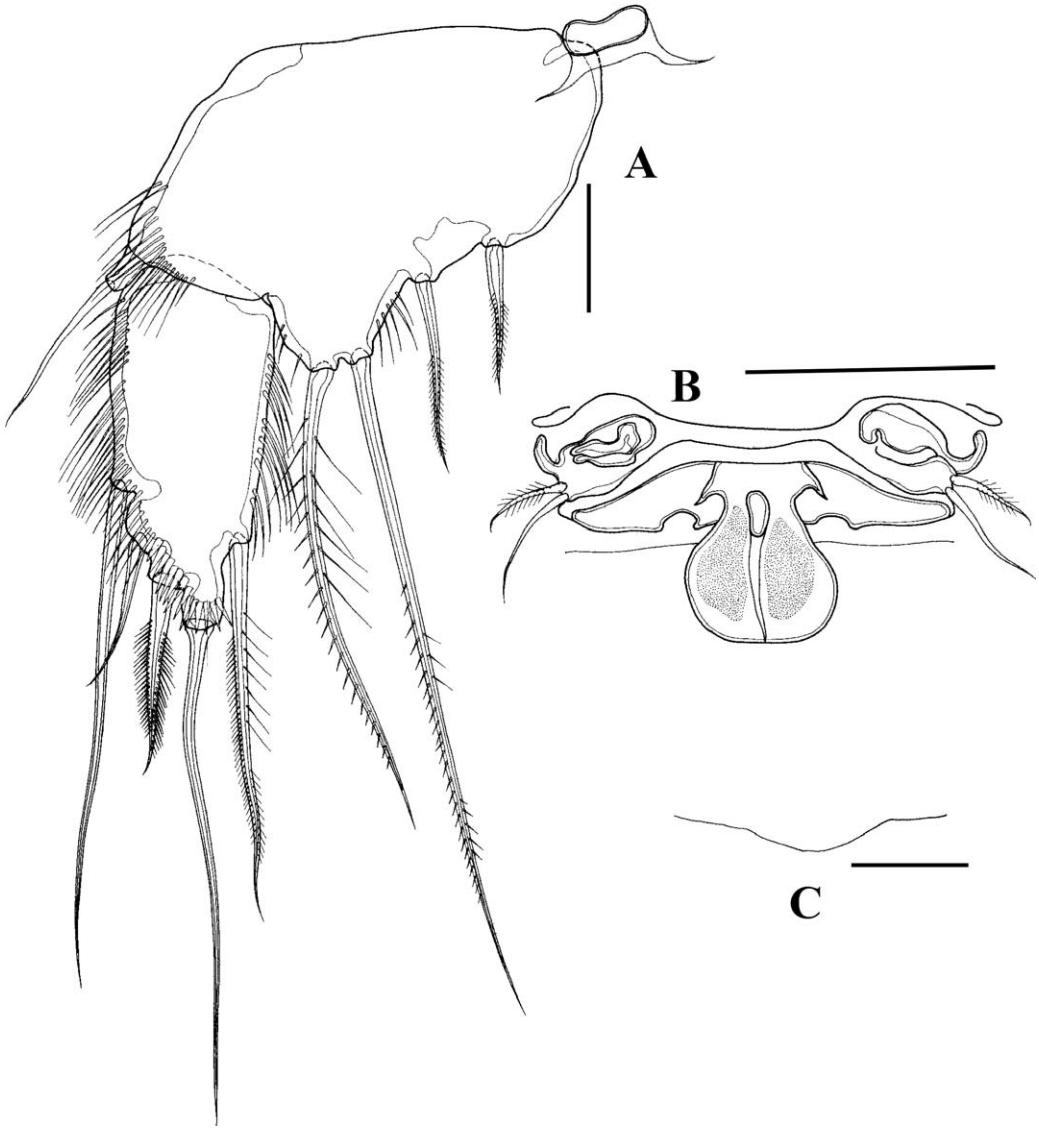

Fig. 7. *Zaus wonchoelleei*. Female. A, right P5; B, genital field; C, anal operculum. Scale bars (μm): A, 32; B, 63; C, 30.

line along outer margin. Basis with 3 surface spinular rows anteriorly and 1 setule row along inner margin; additional spinules present around base of inner spine; outer spine stout and pinnate; inner spine slender and pinnate. Exopod 3-segmented; exp-1 slightly longer than exp-2, with spinules on anterior outer surface and outer margin, and with subdistal outer bipinnate spine; exp-2 with minute spinular row along outer margin, and with inner and outer bipinnate setae; exp-3 represented by small sclerite partly embedded in membranous proximal part of exp-2, with 1 bare seta and 4 non-geniculate claws, all claws minutely bipinnate. Endopod slightly shorter than exp-1, 3-segmented; enp-1 elongate, with spinules along inner, outer, and distal margins, inner seta bipinnate and reaching beyond

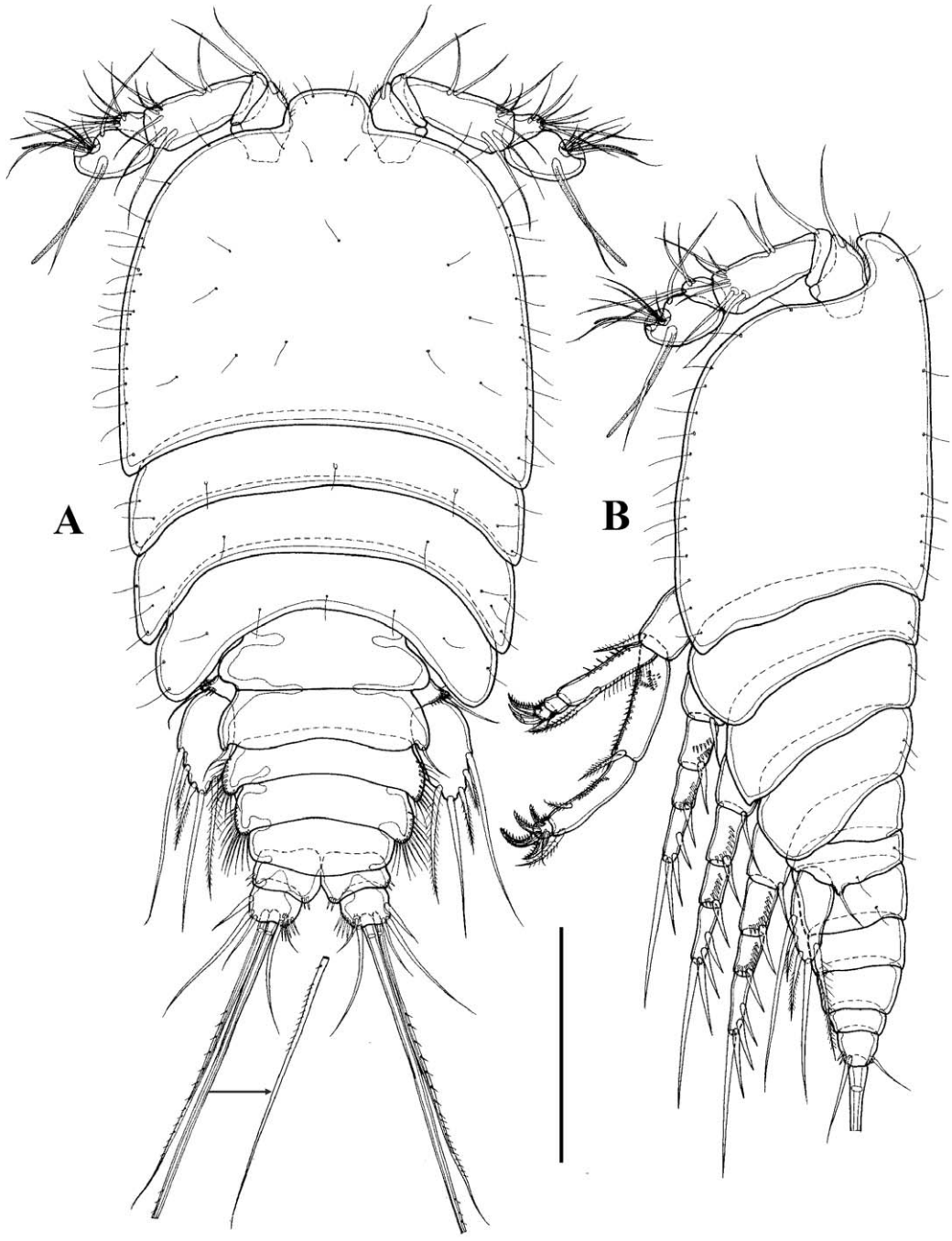

Fig. 8. *Zaus wonchoelleei*. Male. A, habitus, dorsal view; B, habitus, lateral view. Scale bar: 160 μm.

distal margin of endopod; enp-2 small with setules on outer surface and with 1 inner tiny seta; enp-3 rounded with 1 geniculate spine, 1 stout spine bearing two parallel rows of delicate spinules, and 1 tiny bare seta.

P2–P4 (Figs. 5B, 6A, B) with wide intercoxal sclerites lacking ornamentation.

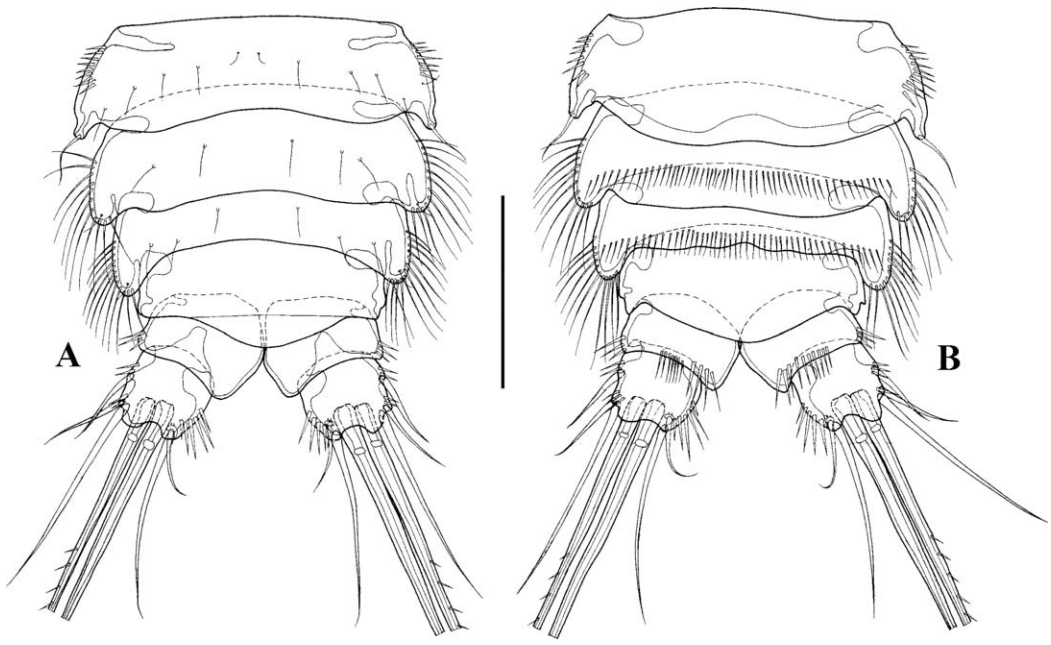

Fig. 9. *Zaus wonchoelleei*. Male. A, urosome, dorsal view; B, urosome, ventral view. Scale bar: 80 μm.

Praecoxae with setular row on anterior surface. Coxae with several spinules along outer margin, and 1 minute setule row distally, except P2. Bases much wider than long, each with 1 bare seta having additional spinules around its base (P2 with plumose seta). Each leg consisting of 3-segmented exopod and endopod; armature formulae of P2–P4 as follows:

	Exopod	Endopod
P2	1, 1, 223	1, 1, 121
P3	1, 1, 323	1, 1, 321
P4	1, 1, 323	1, 1, 221

P5 (Fig. 7A) not fused to supporting somite; rami separate. Baseoendopod wider than long, with bare seta on cylindrical process, with long setules distally and few setules on outer margin of outermost seta and on inner margin of second outer seta, and with 2 long and 2 short bipinnate setae in total. Exopod elongate with many setules on inner, outer and distal margins, with 3 bare setae and 2 bipinnate setae.

P6 (Fig. 7B) represented by 1 pinnate and 1 bare seta. Copulatory pore in anterior half of genital double-somite.

Description of male.—Total body length: 569 μm. Morphology of male as in female, except for the following characters. Prosome (Fig. 8A, B) 4-segmented as in female. Cephalothorax with few integumental sensilla on surface as illustrated; lateral and posterior margins as in female. Rostrum (Fig. 10A) with flattened apex and more rounded lateral margins compared to those of female. Urosome (Fig. 9A, B) 6-segmented, comprising P5-bearing somite (not shown in Fig. 9), genital somite, and 4 abdominal somites. Posterior margin of all somites with smooth line dorsally; first, second and fourth abdominal segments with posterior spinular row ventrally; caudal rami (Fig. 9A, B) with all 7 setae similar to those of female.

Antennule (Fig. 10B) subchirocer and 8-segmented: segment 1 large and swollen, with 3 clusters of spinules anteriorly, and with 1 bare seta on distal corner; segment 2

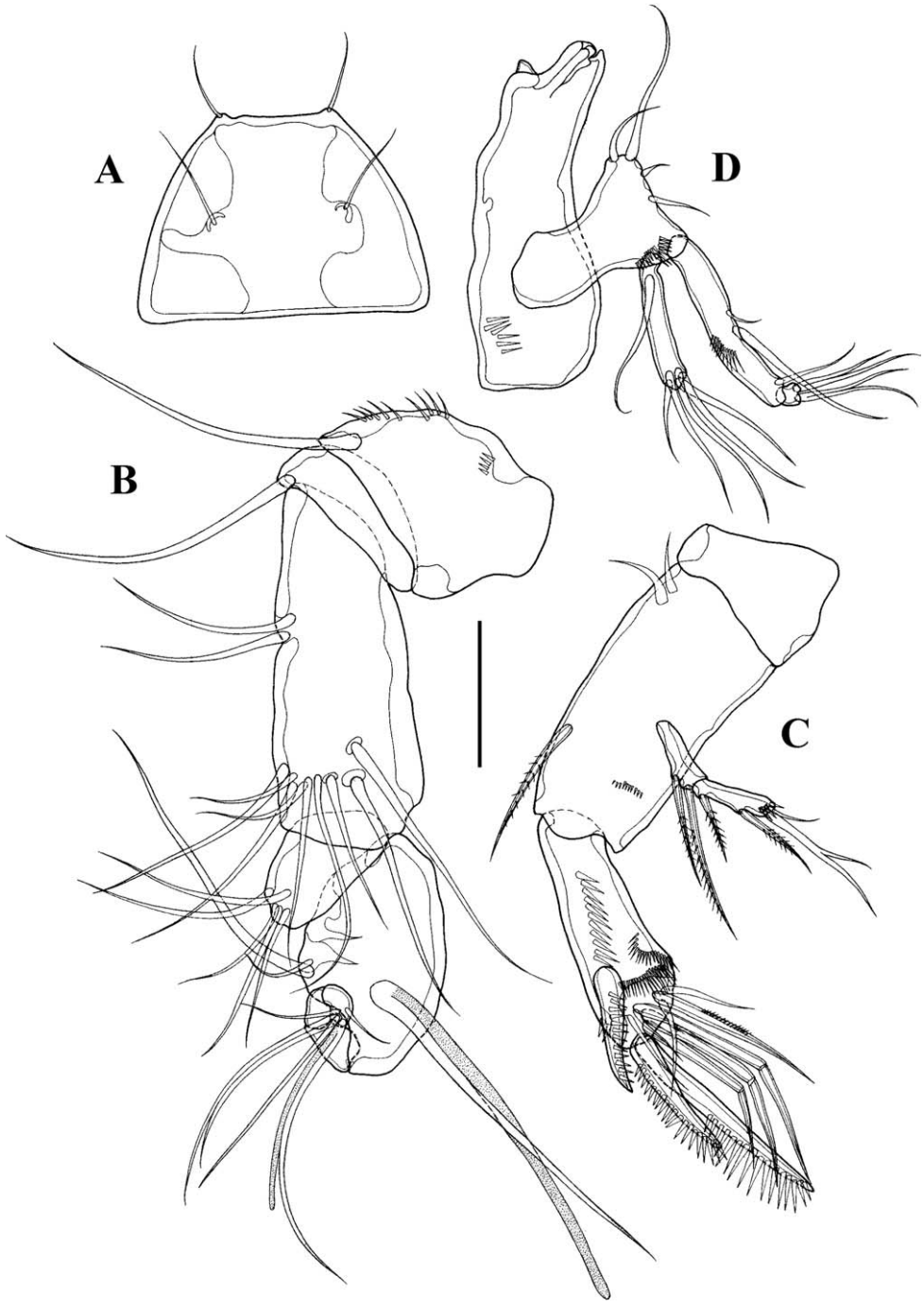

Fig. 10. *Zaus wonchoelleei*. Male. A, rostrum, dorsal view; B, left antennule; C, left antenna; D, right mandible; B–D, anterior view. Scale bar: 32 μm.

Fig. 11. *Zaus wonchoelleei*. Male. A, right P1; B, right P5, posterior view. Scale bar: 63 μm.

small with 1 bare seta; segment 3 longest and widened distally, with 2 lateral setae and 9 setae subdistally; segment 4 with 5 setae on protruded lobe; segment 5 modified and swollen with 1 long and 1 minute seta on inner surface, 1 long seta and aesthetasc on middle surface; segments 6 and 7 lacking ornamentation; segment 8

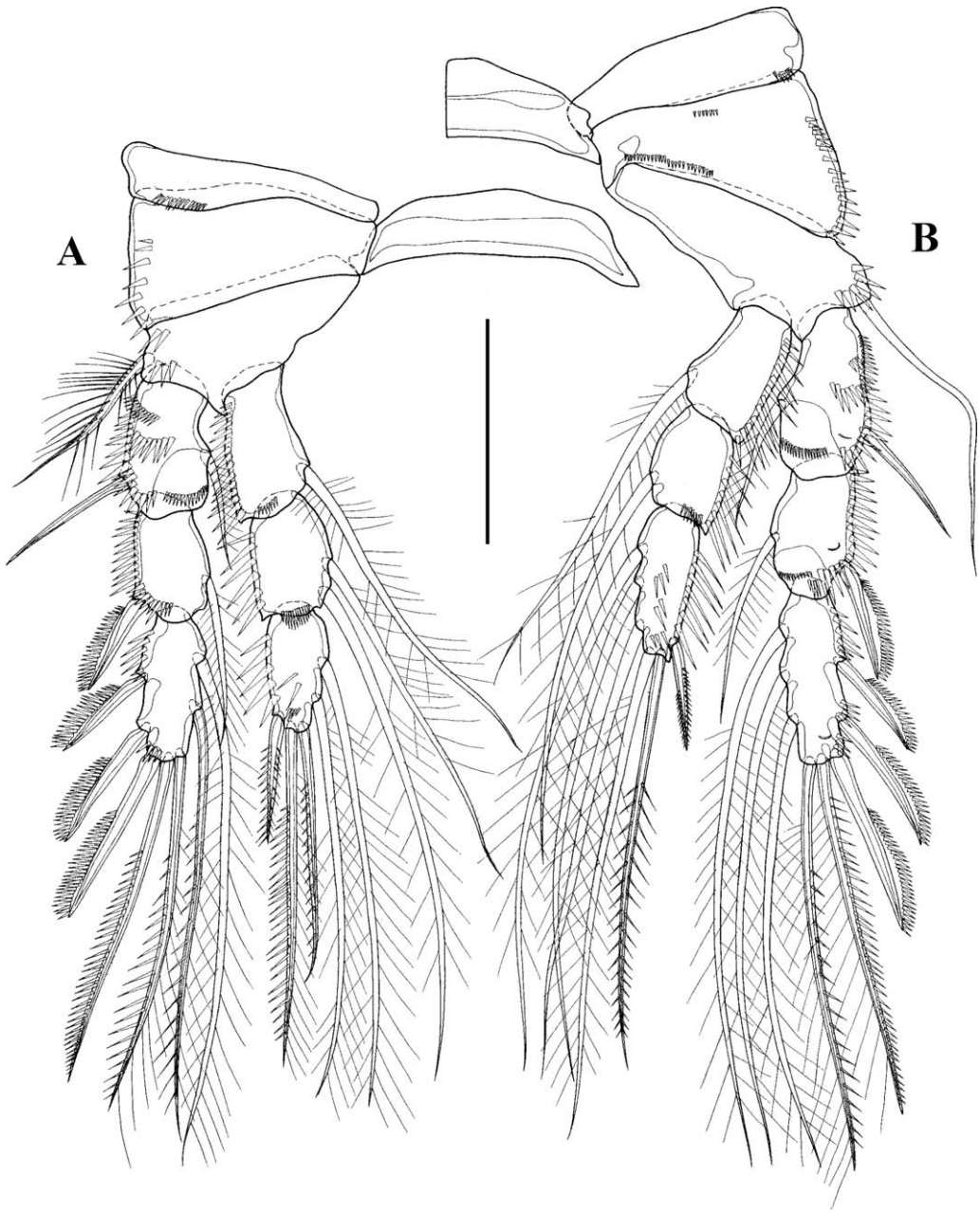

Fig. 12. *Zaus wonchoelleei*. Male. A, right P2; B, right P3, posterior view. Scale bar: 63 μm.

small with 3 setae and acrothek. Apical acrothek consisting of 2 bare setae and aesthetasc.

Antenna (Fig. 10C) similar to that of female, except for minor discrepancies; allobasis with only 2 setules on inner proximal surface, minute setular row distally, and with abexopodal seta on third segment distally.

Mandible (Fig. 10D) similar to that of female, except for less strongly developed cuspidate teeth than in female, and exopod

with 1 lateral seta and 5 distal setae (6 in female).

P1 (Fig. 11A). Coxa with 2 spinular rows along outer margin and minute spinular row proximally. Basis as in female; exopod 3-segmented; exp-1 as long as endopod, with spinular row on outer margin, proximal surface as illustrated; exp-2 as in female; exp-3 with outer spinules, 1 inner seta and 4 claws. Endopod as in female.

P2–P3 (Fig. 12A, B). Enp-2 of P2 with 2 inner setae; enp-3 with setules on anterior surface and with 2 inner setae. Coxa of P3 with spinular rows on proximal and distal surface, and on outer margin; exp-2 slightly swollen with spinular row on distal surface.

P5 (Fig. 11B) not fused to supporting somite; rami separate. Baseoendopod small with bare seta on cylindrical process and ornamented with long setules. Exopod oval with long setules on inner and outer margins, 3 spinular rows on posterior surface, and with 2 bare setae and 3 bipinnate setae.

Etymology.—The new species is named after Dr. Wonchoel Lee (Hanyang University, Korea), for his significant contributions to Korean copepod research.

Differential diagnosis.—The new species is different from all other described representatives of *Zaus* in the following characters: the antennule (A1) fifth segment is shorter than the sixth segment. P1 exp-1 has a swollen inner portion proximally, endopod consisting of 3 segments, enp-3 has a geniculate spine, 1 stout spine bearing two parallel rows of delicate spinules, and 1 tiny bare seta. P2 enp-2 has 1 inner seta, enp-3 has 1 inner, 2 distal and 1 outer setae. Female P5 exp is elongate, and its outermost seta is bare. Male P5 exp is elongate, and its long distal seta is bare.

Discussion

The taxonomy within the genus *Zaus* has remained uncertain due to inadequately described species as well as uncertain biogeographic records (see revision by Lang [1965]). Itô (1980) emphasized this especially with respect to the species *Z. aurelii* Poppe, 1884, *Z. caeruleus* Campbell, 1929, *Z. intermedius* Nicholls, 1939, *Z. serratus* Monk, 1941, and *Z. schaeferi* Klie, 1949. Itô (1974) redescribed *Z. intermedius*, and *Z. aurelii*. Itô (1974) stated that *Z. aurelii* sensu Willey (1923) is likely a synonym of *Z. intermedius* Nicholls, 1939, as well as *Z. caeruleus* Campbell, 1929. *Zaus serratus* Monk, 1941 resembled *Z. aurelii* but differed in some characters (Itô 1980). There was neither a report nor a proposed synonymy of *Z. aurelii* since its original description by Poppe (1884) (for discussion, see Itô 1980). As Nicholls (1942) stated in an initial review of the taxon *Zaus*, the segmentation of the leg 1 endopod (2- or 3-segmented) and the shape and armature of the fifth leg provide the best characters that differentiate the species. In the case of the leg 1 endopod, Lang (1965) concluded after very thorough studies that the leg 1 endopod is probably 2-segmented in all species. He claimed that the middle segment is a lamella at the end of the first segment, and it is of the same nature as the triangular prominence at the end of the first exopodite segment. Itô (1974), however, described 3-segmented endopods in all representatives of *Zaus* that he studied. It was not easy to define the middle one of 3 segments in several species. However, Itô (1974) convincingly demonstrated by comparison with a copepodid V stage that a 3-segmented state is derived from the distal segment and not from the proximal segment.

In the case of leg 5, Lang (1965) noted that some useful diagnostic characters were not sufficiently evaluated. This holds particularly for a geniculate spine on leg 1 endopod that is present in four species of the genus, namely *Z. robustus*, *Z. aurelii*, *Z. intermedius*, and *Z. hiranoi*. These four species are further characterized by setal characteristics particularly of the male (but also female) leg 5 exopodite, which was

further elaborated by Itô (1980). The terminal seta of the exopodite is entirely bare in *Z. robustus* but is somewhat spinulose in the other three species. Although the fifth (outermost) marginal seta of the segment is always naked in *Z. robustus*, *Z. aurelii*, *Z. intermedius*, and *Z. hiranoi*, the corresponding seta is sparsely spinulose in *Z. spinatus* (Itô 1974). In *Z. unisetosus* from Hokkaido, the seta in question is usually spinulose (Itô 1974), but Itô also observed a few examples with an almost bare seta. Interestingly, the first seta having long hairs was found on the exopodite of the female leg 5 of *Z. robustus*. Lang (1965) mentioned that the male leg 5 of *Z. caeruleus* Campbell, 1929 looks very similar to *Z. intermedius* in those characters discussed by Lang (1965). Shape and ornamentation of leg 5 has been regarded as the most important species character in the female. This character is not as useful in the males within the genus (Itô 1974). For this reason Itô (1974) found this character in the first pair of legs in the males to be of particular importance. Due to the lack of detailed information on species of *Zaus*, together with the absence of type specimens (Lang 1965), the validity of certain key distinctions used to characterize the species of *Zaus* remains unclear for use in the justification of closely related species.

Besides its either 2- or 3-segmented state, the apical claws of the last endopodal segment of leg 1 were illustrated by Sars (1904) as being bordered on one side with a dense comb-like series of spinules in *Z. spinatus* (Sars, 1904) and as brush-like for *Z. spinatus hopkinsi* (Lang, 1965) and *Z. biunguiferus* (Lang, 1965). Itô (1974) observed 2 parallel longitudinal rows of delicate spinules on each claw in *Z. spinatus spinatus* and *Z. unisetosus*. He further claimed that the claws of *Z. intermedius* and *Z. robustus* were appended with one row of some spinules which could be counted more easily than in the former two species. The claws in *Z. spinatus spinatus* are transformed at the margins into a thin lamella that is finely serrated along its distal part, and the serration clearly bends. In *Z. robustus* the claws have scarcely evident lamellae, but they are serrated marginally, if they are spinulose. According to Itô (1974), an obscure shallow groove arising within each base of "spinules" extends to the opposite edge of the claw in *Z. robustus*, whereas the same grooves in *Z. spinatus spinatus* are very conspicuous from the base of serration to the opposite edge. This led Itô (1974) to define the *robustus*-type and *spinatus*-type of claws.

According to Lang (1965), the presence of spine-like sensilla on the first three thoracic somites in *Z. aurelii* seems to be unique within the genus. In female antennules, the relative lengths of the fifth and sixth segments clearly differ among representatives of *Zaus*. The sixth segment is much longer than the fifth in *Z. intermedius* and *Z. robustus*. The sixth segment is somewhat longer than the fifth in the present description of *Z. wonchoelleei* (see Fig. 3) but nearly of the same length in *Z. spinatus spinatus* and *Z. unisetosus*. A thorough re-examination of other species is recommended in this respect, as also suggested by Itô (1974).

Acknowledgments

This research was supported by a grant from the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2013R1A1A2A10011073) to JSK and by a grant from the Discovery of Korean Indigenous Species Project, NIBR (National Institute of Biological Resources) given to SJS.

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Associate Editor: Janet W. Reid.