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Four rare harpacticoid copepods from shallow littoral habitats in South Korea

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Abstract

In natural sciences single observations are sometimes ignored and often excluded from datasets as outliers. Taxonomists refrain from reporting new records or describing new species after single specimens for obvious reasons of inability to explore sexual dimorphism and intraspecific variability. Here I report on four such harpacticoids from four different families, all collected from marine algal beds (0.5–1.5 m) in South Korea in 2013. Three of them are new species: *Diarthrodes jindoensis* **sp. nov.** (family Dactylopusiidae), *Paralaophonte (P.) naroensis* **sp. nov.** (family Laophontidae), and *Xouthous naroensis* **sp. nov.** (family Pseudotachidiidae). The fourth species, *Delavalia oblonga* (Lang, 1965) (family Miraciidae), is recorded for the first time from the Western Pacific, being described originally from California. One can only speculate about the reasons these harpacticoids were not found again after a decade of intensive fieldwork all around Korea, but not reporting them would be a misrepresentation of biodiversity.

Key words: algal beds, diversity, new species, single specimens, taxonomy

Introduction

Harpacticoida is the second most diverse copepod order (after Cyclopoida), with 53 valid families and more than 4,000 described species (Wells, 2007; Walter and Boxshall, 2022). Very few are parasitic or commensal (Huys, 2016). About one quarter live exclusively in freshwater habitats (Huys *et al.*, 1996). They are overwhelmingly benthic crustaceans, and in marine habitats they are abundant all the way from the interstitial of sandy beaches (Giere, 1993) to abyssal depths (Ahnert and Schriever, 2001). Research on harpacticoid taxonomy started relatively late in Korea (Yeatman, 1983; Ho and Hong, 1988), compared to other parts of the world, and especially Europe (Müller, 1776; Sars, 1903; Lang, 1948). In the subsequent three decades, intensive efforts have produced even some monographic works on both freshwater (Chang, 2009) and marine (Lee *et al.*, 2012) harpacticoids here. However, utilization of novel taxonomic methods, such as survey of cuticular organs (Karanovic and Cho, 2012, 2016; Karanovic and Lee, 2012; Karanovic and Kim 2014a), partial DNA analysis (Karanovic and Kim, 2014b; Karanovic *et al.*, 2014, 2015; Kim *et al.*, 2014; Vakati *et al.* 2019), landmark-based geometric morphometrics (Karanovic *et al.* 2018), as well as surveys of marginal habitats (Karanovic and Lee, 2016; Karanovic, 2017, 2021), have resulted in numerous recent additions to the Korean harpacticoid fauna, with a surprisingly high endemic component. Recent discoveries include a world record for the number of syntopic copepod congeners (Karanovic, 2020), second members of two genera that were considered monotypic for a very long time (Karanovic and Cho, 2018), and range extensions for species previously known only from the Eastern Pacific (Karanovic, 2019). As the current paper illustrates, we are yet a long way away from understanding the full extent of harpacticoid diversity in this part of the world.

Material and methods

Specimens were collected by gently sweeping a hand-net (mesh size 30 µm) through and over algal growth, while disturbing sandy and gravely bottom by feet. The depth varied from knee-deep to chest-deep. All samples were immediately fixed in 99 % ethanol; they were subsequently sorted in the laboratory also in 99 % ethanol, using an

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Olympus SZX12 dissecting microscope with PLAPO objectives and magnification of up to 200 times. Locality data are given in the species diagnoses below and holotypes are deposited in the National Institute of Biological Resources (NIBR), in Inchon, South Korea. Each specimen was dissected and mounted on a single microscope slide, in a drop of Faure's medium that was prepared according to Stock and von Vaupel Klein (1996), and dried at room temperature. Habitus was destroyed during dissection and was not recorded unfortunately. Line drawings of the urosome and appendages were prepared using a drawing tube attached to a Leica DMLS brightfield compound microscope, equipped with C-planachromatic objectives. The terminology for morphological characters follows Huys and Boxshall (1991), except for the numbering of setae on the caudal rami (their terminology is here based on their relative position) and small differences in the spelling of some appendages (antennula, mandibula, maxillula instead of antennule, mandible, maxillule), as in other crustacean groups (see Karanovic, 2019, 2020). Armature formulae of the swimming legs are as in Lang (1948).

Results and discussion

***Delavalia oblonga* (Lang, 1965)**
(Fig. 1)

Specimen examined. Adult female dissected on one microscope slide (NIBR-DSEVIV0000004075) from South Korea, South Cost, Jindo Island, Jukrim-ri, small harbour, shallow littoral, sandy bottom and algal beds, 34°22.770'N 126°15.994'E, 15 August 2013, collected by T. Karanovic.

Female diagnosis. Integument thin, transparent, mostly smooth. Genital double-somite about as long as wide. Anal somite (Fig. 1A) deeply clefted, with single pair of ventral pores, large spinules along dorso-lateral margin, and slender spinules along ventro-median margin. Caudal rami (Fig. 1A) slightly longer than wide, slightly shorter than anal somite, with three ventral pores each; principal setae with breaking planes and all other setae smooth and slender. Antennula (Fig. 1B) short and eight-segmented, ultimate segment about 1.7 times as long as penultimate segment. Exopod of antenna (Fig. 1C) very slender, three-segmented, with armature formula 1.1.4; third segment about as long as first two segments combined. Maxilliped (Fig. 1D) straight, three-segmented but ultimate segment really minute, armature formula 3.2.2. First swimming leg (Fig. 1E) with three-segmented exopod and two-segmented and slightly geniculate endopod of similar length; second endopodal segment twice as long as first endopodal segment. Second swimming leg (Fig. 1F) with three-segmented endopod and exopod, also of similar length; third endopodal segment about as long as second endopodal segment and slightly longer than third exopodal segment. Third swimming leg (Fig. 1G, H) similar to second swimming leg, but with slightly shorter endopod; third endopodal segment slightly longer than second endopodal segment. Fourth swimming leg (Fig. 1I, J) similar to second swimming leg, but with much shorter endopod; third endopodal segment slightly longer than second endopodal segment. Armature formula of swimming legs (first to fourth, exopod/endopod): 0.1.022/1.211; 0.1.223/1.2.121; 1.1.323/1.1.321; 1.1.323/1.1.221. Fifth leg (Fig. 1K) with elongated exopod, twice as long as wide, armed with five setae, with short spinules along inner margin and long spinules along outer margin; endopodal lobe very short, with only four strong setae and a large gap between outermost endopodal seta and exopod.

Remarks. This species was originally described as *Stenhelia (Delavalia) oblonga* Lang, 1965 from mudflats in Dillon Beach, California, and this is its second record ever. My specimen agrees well with those illustrated by Lang (1965). The only difference worth noting is the absence of an inner seta on the first exopodal segment of the second swimming leg (Fig. 1F). However, it is possible that Lang (1965) misinterpreted a long and slender spinula (or a few spinulae clumped together) as a seta, as the inner margin of that segment in his illustrations lacks a notch normally associated with a seta, and clearly visible in those of the third and fourth legs (compare his fig. 137b with figs. 137c and 137d). The shape and armature of the fifth leg, as well as the ornamentation of the urosome and caudal rami, are remarkably similar between the two populations, and they are usually better indicators of conspecificity in harpacticoids than small variations in the armature of swimming legs (see Lang, 1965; Karanovic, 1999, 2006).

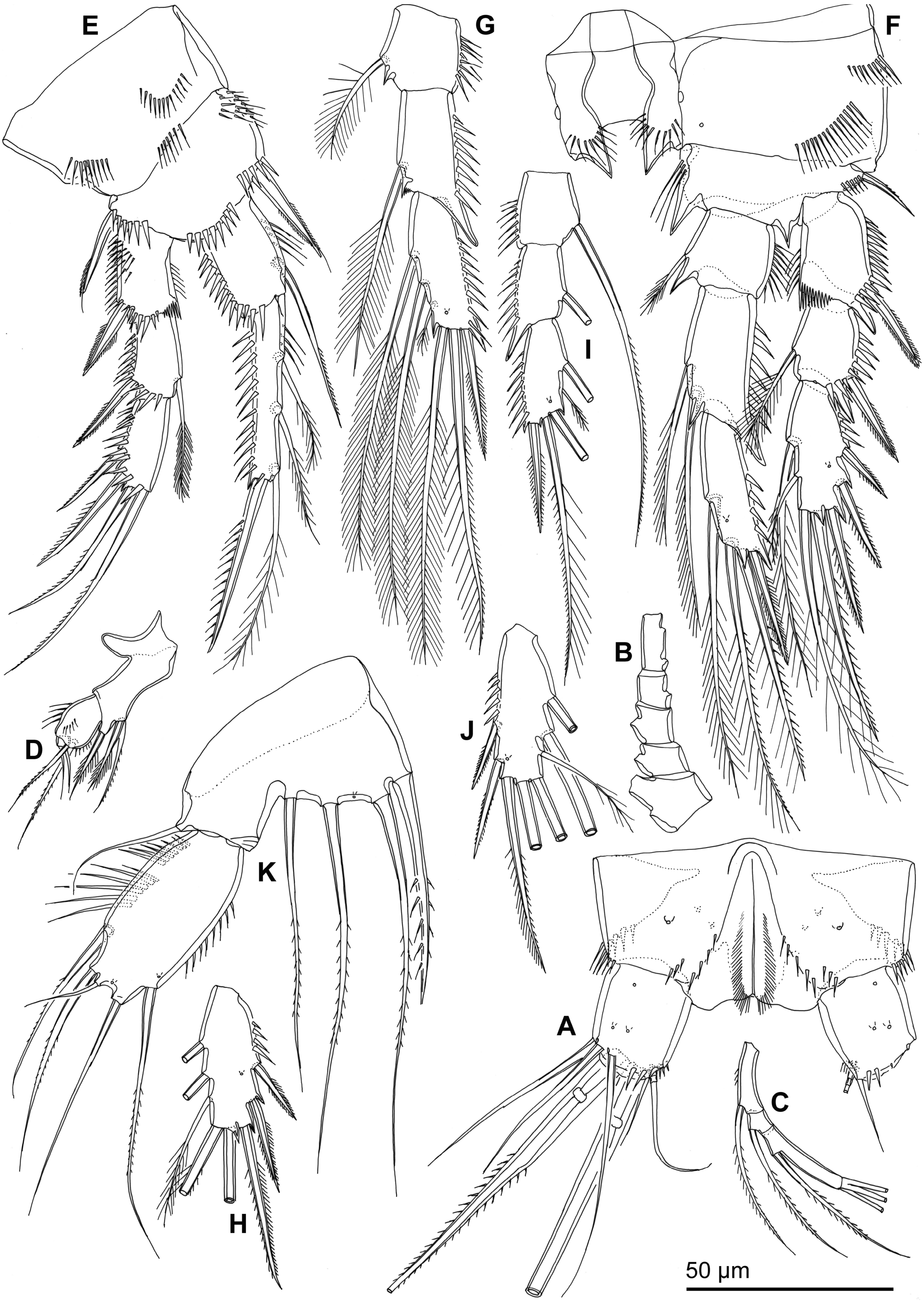

FIGURE 1. *Delavalia oblonga* (Lang, 1965), adult female: A, anal somite and caudal rami, ventral; B, last five segments of antennula without armature; C, exopod of antenna; D, maxilliped; E, first swimming leg; F, second swimming leg; G, endopod of third swimming leg; H, third exopodal segment of third swimming leg; I, endopod of fourth swimming leg; J, third exopodal segment of fourth swimming leg; K, fifth leg.

The genus *Delavalia* Brady, 1868 is the most speciose and morphologically diverse of all stenheliins (Karanovic and Kim, 2014b), currently containing 54 valid species globally (Gómez, 2021; Walter and Boxshall, 2022). It was upgraded from the subgenus level by Mu and Huys (2002), but it was postulated to be either paraphyletic (Willen, 2002) or polyphyletic (Mu and Huys, 2002). Its polyphyly was demonstrated with a phylogenetic analysis based on molecular markers by Karanovic and Kim (2014b), who described three new genera and six new species from the highly industrialized Gwangyang Bay in South Korea. Amazingly, this is the first record of a stenheliin copepod outside of Gwangyang Bay, and the first record of the genus *Delavalia s. str.* in Korea.

Diarthrodes jindoensis **sp. nov.**
(Fig. 2)

Type locality. South Korea, South Cost, Jindo Island, Jukrim-ri, small harbour, shallow littoral, sandy bottom and algal beds, 34°22.770'N 126°15.994'E, 15 August 2013, collected by T. Karanovic.

Holotype. Adult female dissected on one microscope slide (NIBR-DSEVIV0000004076).

Etymology. The species is named after its type locality, Jindo Island. The name is an adjective in genitive singular, made with the Latin suffix "-ensis", and is thus in agreement with the gender of the (masculine) generic name.

Female diagnosis. Integument relatively thick but transparent. Female genital double somite wider than long, with two prominent, kidney-shaped spermatophores. Preanal somite (Fig. 2A) with interrupted ventral row of spinules. Anal somite (Fig. 2A) short, with two pairs of ventral pores, and with robust ventral spinules at base of caudal rami. Caudal rami (Fig. 2A) very short, less than half as long as wide, with deeply imbedded central principal setae (both with breaking planes), short and slender innermost apical seta, one strong and two slender outer setae. Antennula (Fig. 2B) six-segmented, with third segment longest, which about as long as three subsequent segments. Exopod of antenna (Fig. 2C) slender, two-segmented, with three setae on first segment and two setae on second segment; first segment about 1.3 times as long as second segment. First swimming leg (Fig. 2D) with two-segmented and short exopod; endopod three-segmented, long and geniculate; first endopodal segment about five times as long as wide and 2.4 times as long as entire exopod. Second swimming leg (Fig. 2E) with three segmented exopod and endopod, endopod only slightly shorter than exopod; third exopodal segment about 1.9 times as long as wide and 1.3 times as long as third endopodal segment. Third swimming leg (Fig. 2F, G) also with three segmented exopod and endopod, but endopod significantly shorter than exopod; third exopodal segment about 2.4 times as long as wide and 1.3 times as long as third endopodal segment. Fourth swimming leg (Fig. 2H, I) with three-segmented exopod and endopod, but endopod shorter than exopod even more than in third leg; third exopodal segment about 2.4 times as long as wide and 1.6 times as long as third endopodal segment. Armature formula of swimming legs (first to fourth, exopod/endopod): 0.123/1.0.011; 1.1.223/1.2.221; 1.1.323/1.2.321; 1.1.323/1.1.221. Fifth leg (Fig. 2J) with oval exopod armed with five setae, central seta shortest; endopodal lobe trapezoidal, armed with five strong and closely spaced setae.

Remarks. There are currently 44 valid species in the genus *Diarthrodes* Thompson, 1883 (Walter and Boxshall, 2022), distributed all around the world and mostly living in shallow littoral habitats (Suárez-Morales & Fuentes-Reines, 2018). Gómez *et al.* (2008) divided the genus into seven species-groups, based on the segmentation of antennal exopod and both rami of the first swimming leg, and Huys (2016) provided a dichotomous key to species for the group VII. The Korean new species belongs to the group V, and it is most similar to the Mexican *D. hexasetosus* Gómez, Chertoprud and Morales-Serna, 2008. The two even share details of urosomal ornamentation, caudal rami shape and ornamentation, as well as the armature of the antennal exopod and the ultimate exopodal segment of the first swimming leg (Gómez *et al.* 2008). However, the new species can be distinguished by a six-segmented antennula, slenderer second exopodal segment of antenna, absence of a minute seta on the third endopodal segment of the first swimming leg, and a wider exopod of the fifth leg. Five other members of this group (see Gómez *et al.*, 2008) differ even more markedly from the new species (see Lang, 1948). This is the first record of the genus *Diarthrodes* in South Korea.

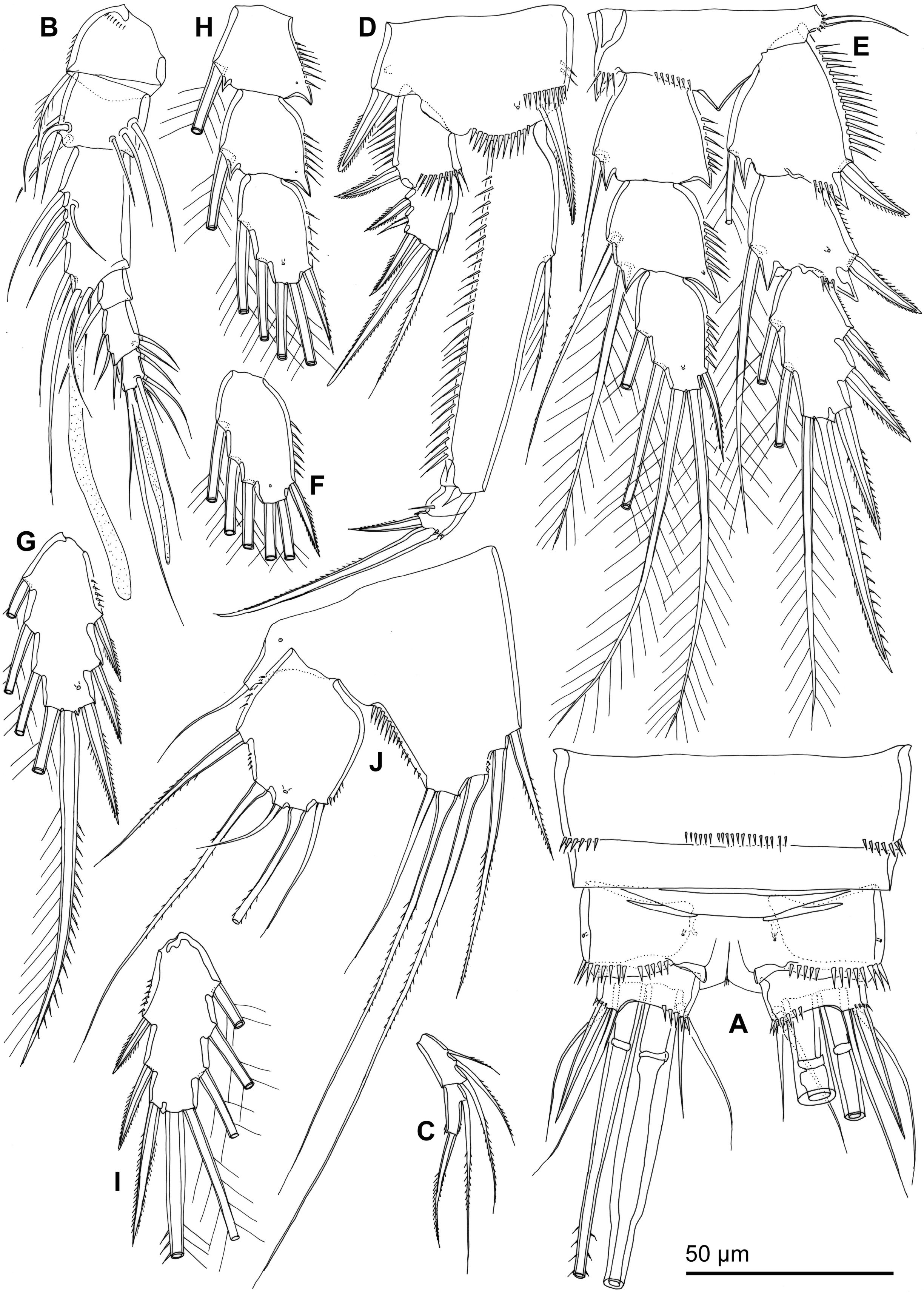

FIGURE 2. *Diarthrodes jindoensis* **sp. nov.**, holotype female: A, last two urosomal somites and caudal rami, ventral; B, antennula; C, exopod of antenna; D, first swimming leg; E, second swimming leg; F, third endopodal segment of third swimming leg; G, third exopodal segment of third swimming leg; H, endopod of fourth swimming leg; I, third exopodal segment of fourth swimming leg; J, fifth leg.

***Xouthous naroensis* sp. nov.**
(Fig. 3)

Type locality. South Korea, East Cost, Naro Space Centre, shallow littoral, sandy bottom and algal beds, 34°27.348'N 127°31.216'E, 18 August 2013, collected by T. Karanovic.

Holotype. Adult female dissected on one microscope slide (NIBR-DSEVIV0000004072).

Etymology. The species is named after its type locality, Naro Space Centre. The name is an adjective in genitive singular, made with the Latin suffix "-ensis", and is thus in agreement with the gender of the (masculine) generic name.

Female diagnosis. Very round habitus, dorsoventrally compressed, with extremely thick and not very transparent integument. Urosomites (Fig. 3A) with finely serrated distal margin along ventral surface, which also frilled, and with large spinules dorsolaterally. Pseudoperculum (Fig. 3B) large, with six major teeth. Anal somite (Fig. 3A) with single pair of ventral pores and extremely long spinules along ventral margin, which about as long as caudal rami. Antennula (Fig. 3C) seven-segmented, ultimate segment shorter than two preceding segments combined. Exopod of mandibula (Fig. 3D) 2.8 times as long as wide, with two strong lateral setae and three slender apical setae. Maxilliped (Fig. 3E) three-segmented, geniculate, with armature formula 1.1.2. First swimming leg (Fig. 3F) with three-segmented exopod and two-segmented geniculate endopod; first endopodal segment 2.1 times as long as wide and nearly 1.4 times as long as entire exopod; second endopodal segment minute, slightly wider than long. Second swimming leg (Fig. 3G) with three-segmented endopod and exopod; endopod about 1.3 times as long as exopod and also significantly wider; third endopodal segment about 1.9 times as long as wide. Third swimming leg (Fig. 3H) with three-segmented endopod and exopod of about same length; third endopodal segment nearly 2.5 times as long as wide. Fourth swimming leg (Fig. 3I) with three-segmented endopod and exopod; endopod slightly shorter than exopod. Armature formula of swimming legs (first to fourth, exopod/endopod): 0.1.023/1.211; 1.1.223/1.2.221; 1.1.323/1.1.321; 1.1.323/1.1.221. Fifth leg (Fig. 3J) with wide endopodal lobe that reaching to about midlength of exopod, armed with five medium-long robust setae, innermost one with long whip; second endopodal seta from outer side nearly 1.4 times as long as exopod; exopod relatively large and conical, about 1.8 times as long as wide, with five strong setae; second exopodal seta from inner side longest, about 0.85 times as long as exopod.

Remarks. This species is very similar to the Korean endemic *Xouthous yeonghooni* Song, Lee, Lee and Kim 2020 (see Song *et al.* 2020), as well as to the Californian population of a supposedly widely distributed *X. purpurocinctum* (Norman & Scott T., 1905) (see Lang 1965). Song *et al.* (2020) report that *X. yeonghooni* is very common all around Korea, but provided no record of its variability. Additionally, they mentioned several times similarities between *X. yeonghooni* and the population of *X. purpurocinctum* that was redescribed by Lang (1965) from California, but never any differences! My specimen is morphologically more similar to the Californian specimens illustrated by Lang (1965) than to the Korean specimens illustrated by Song *et al.* (2020). Therefore, I conclude that this is probably a species-complex, and that there must be more than one species in Korea. Multiple closely related harpacticoid congeners along the Korean coast have been demonstrated with molecular markers several times already (Karanovic and Kim, 2014b; Karanovic *et al.*, 2018; Vakati *et al.*, 2019). Major differences between *X. naroensis* **sp. nov.** and *X. yeonghooni* are in the body shape (rounder in *X. naroensis*), length of the second endopodal segment of the first swimming leg (much shorter in *X. naroensis*), length of setae on the female fifth leg endopod (longer in *X. naroensis*, including innermost seta with a long whip, which is a unique character), and length of spinules along ventral posterior margin of the anal somite (almost as long as caudal rami in *X. naroensis*, vs. shorter than outer spinules in *X. yeonghooni*). Major differences between *X. naroensis* and *X. purpurocinctum* are in the number of setae on the first segment of maxilliped (one vs. two), length of the second endopodal segment of the first swimming leg (shorter in *X. naroensis*), and details of the fifth leg (with a larger exopod and a whip on the innermost endopodal seta in *X. naroensis*); unfortunately, Lang (1965) did not provide details of urosomal ornamentation, so those cannot be compared. Song *et al.* (2020) correctly pointed out that *X. laticaudatus* (Thompson & Scott A., 1903) that was reported by Kim (2014) from Korea does not even belong to this genus.

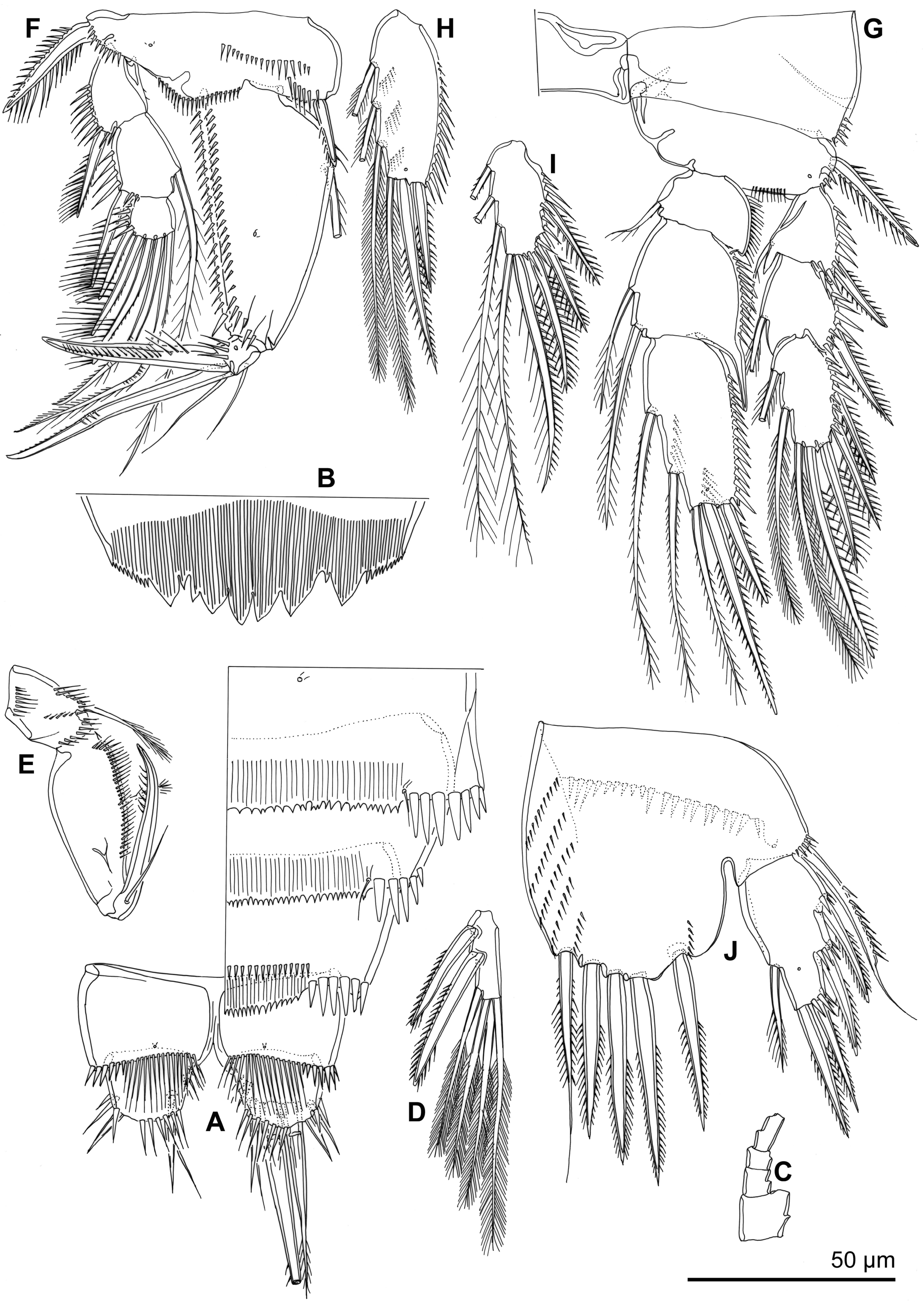

FIGURE 3. *Xouthous naroensis* **sp. nov.**, holotype female: A, urosome and caudal rami, ventral; B, pseudoperculum of penultimate urosomite, dorsal; C, last four segment of antennula without armature; D, exopod of mandibula; E, maxilliped; F, first swimming leg; G, second swimming leg; H, third endopodal segment of third swimming leg; I, third exopodal segment of fourth swimming leg; J, fifth leg.

***Paralaophonte (P.) naroensis* sp. nov.**
(Fig. 4)

Type locality. South Korea, East Cost, Naro Space Centre, shallow littoral, sandy bottom and algal beds, 34°27.348'N 127°31.216'E, 18 August 2013, collected by T. Karanovic.

Holotype. Adult male dissected on one microscope slide (NIBR-DSEVIV0000004083).

Etymology. The species is named after its type locality, Naro Space Centre. The name is an adjective in genitive singular, made with the Latin suffix "-ensis", and is thus in agreement with the gender of the (masculine) generic name.

Male diagnosis. Habitus slender and cylindrical, with thin integument covered by large spinules on urosomites (Fig. 4A). Anal operculum (Fig. 4A, B) short, convex, not reaching posterior margin of anal somite, with 18 small spinules. Caudal rami (Fig. 4A) slightly longer than wide, and slightly tapering towards posterior end; innermost terminal seta slender and shorter than caudal ramus, principal terminal setae strong but without breaking planes. Antennula (Fig. 4C) with small beak on second segment. Exopod of antenna (Fig. 4D) one-segmented, twice as long as wide, with lateral row of spinules and four apical setae. Mandibular palp (Fig. 4E) one-segmented, unornamented, with four setae. Maxilliped (Fig. 4F) three-segmented, geniculate, with armature formula 2.0.2. First swimming leg (Fig. 4G) with large and geniculate, two-segmented endopod and smaller, three-segmented exopod; first endopodal segment more than seven times as long as wide and about twice as long as entire exopod. Second swimming leg (Fig. 4H) with long and three-segmented exopod and about half as long as two-segmented endopod; distal inner seta on the second endopodal segment characteristically transformed. Third swimming leg (Fig. 4I) with three-segmented exopod and endopod, but exopod much stronger and nearly twice as long as endopod; inner setae on exopod minute, while all apical and outer setae on third exopodal segment strong, nearly smooth, and deeply inserted; second endopodal segment with outer-distal apophysis, which about 1.8 times as long as third endopodal segment. Fourth swimming leg (Fig. 4J, K) with slender three-segmented exopod, and half as long two-segmented endopod. Armature formula of swimming legs (first to fourth, exopod/endopod): 0.0.022/0.011; 0.1.123/0.220; 0.1.122/0.0.220; 0.1.223/0.121. Fifth legs (Fig. 4L) fused medially, with single strong seta on almost flat endopodal lobe, and with five setae on ovoid exopod. Sixth leg (Fig. 4M) with inner spine and slightly longer outer slender seta.

Remarks. *Parapaophonte naroensis* **sp. nov.** is most similar to *P. obscura* Vervoort, 1962, decribed from New Caledonia by Vervoort (1962) and reported from South Korea by Kim (2013). However, Kim (2013) did not provide any illustrations, so it will never be clear if he indeed found *P. obscura*, was observing *P. naroensis*, or was observing something completely different. He described the second segment of antennula as "fairly long", which is in contrast to our specimen (see Fig. 4C), using the same wording as Vervoort (1962)! Because of these and other problems (see above and Song *et al.*, 2020), I propose that the works of Kim (2013, 2014) should be taken with caution until his collection could be re-examined. The New Caledonian species differs from *P. naroensis* by a much longer apophysis on the second endopodal segment of the third leg (which reaches the tip of exopod), exopod of the fifth leg with only four setae (vs. five in *P. naroensis*), longer second segment of the antennula, shorter third exopodal segment of the fourth swimming leg, much shorter setae on the third endopodal segment of the third leg, slightly shorter second endopodal segment of the first leg, and much longer outer seta on the sixth leg (see Vervoort, 1962). The new Korean species is somewhat similar to *P. congenera* (Sars, 1908), reported and beautifully illustrated from Korea by Lee *et al.* (2012), but the latter has much longer caudal rami, much stronger inner setae (and two instead of one) on the third exopodal segment of the third leg, no slender seta on the fifth leg exopod, as well as a much shorter apophysis on the second endopodal segment of the third leg (which only reaches the tip of endopod). Lee *et al.* (2012) claimed that this species is one of the most common laophontids in Korea, which I can confirm from numerus samplings (unpublished data). Unfortunately, its congener *P. naroensis* seems to be one of the rarest.

The genus *Paralaophonte* Lang, 1948 today contains 54 valid species globally, 42 of which belong to the nominotypical subgenus (Walter and Boxshall, 2022). *Paralaophonte lunata* (Willey, 1930) has a similar third exopodal segment of the third leg, as well as a similar fifth leg, but differs from the new species by longer caudal rami and a shorter apophysis on the third leg endopod (see Lang, 1948). *Paralaophonte septemarticulata* Chislenko, 1978 also shows some similarities, but it was described only after females so comparisons are limited; it has a shorter third exopodal segment of the fourth swimming leg than *P. naroensis*, longer innermost terminal setae on the caudal rami, and the caudal rami are also more widely spaced (Chislenko, 1978). All other species show more obvious and more numerous differences.

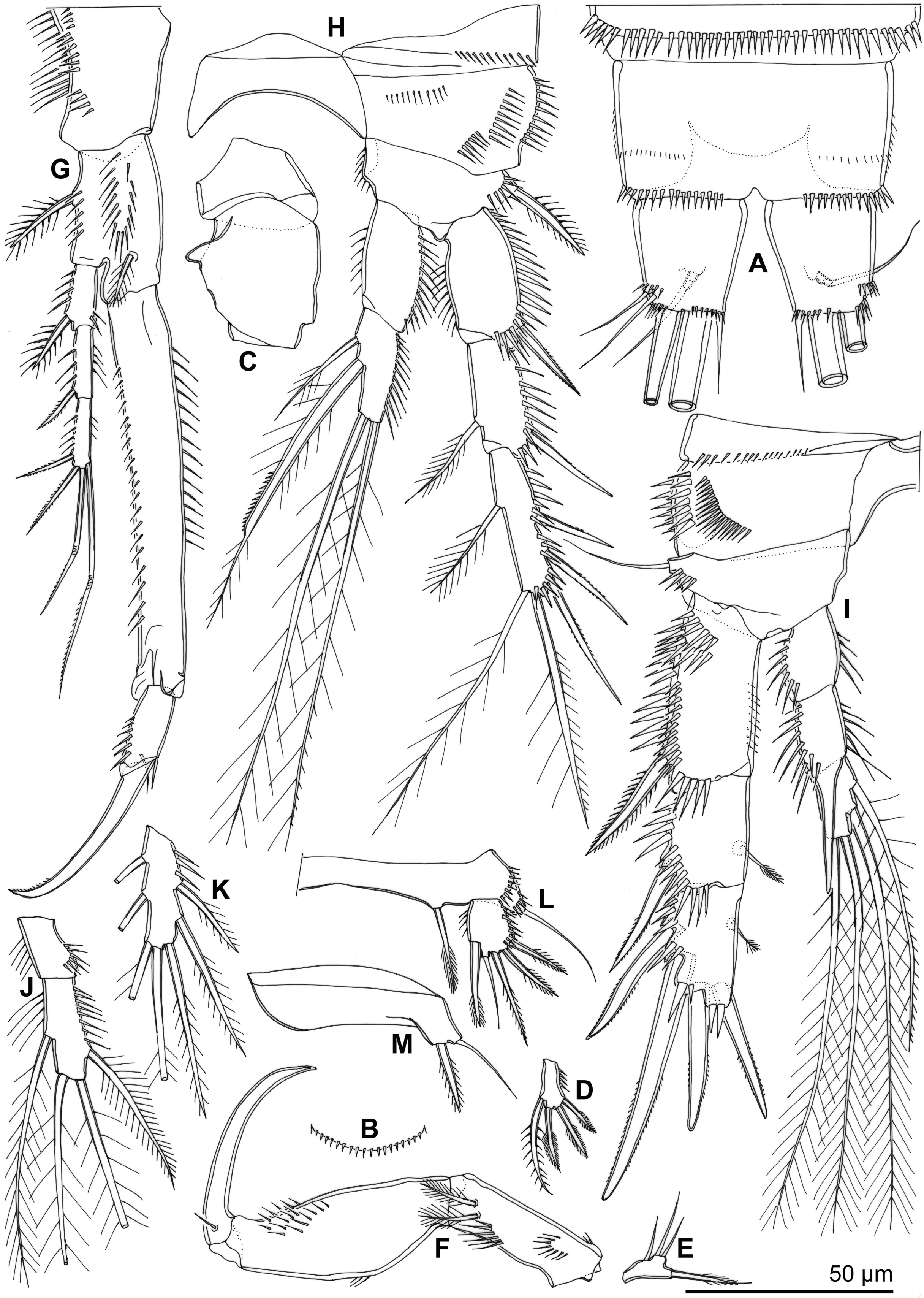

FIGURE 4. *Paralaophonte (P.) naroensis* **sp. nov.**, holotype male; A, anal somite and caudal rami, ventral; B, anal operculum, dorsal; C, first two segments of antennula without armature; D, exopod of antenna; E, mandibular palp; F, maxilliped; G, first swimming leg; H, second swimming leg; I, third swimming leg; J, endopod of fourth swimming leg; K, third exopodal segment of fourth swimming leg; L, fifth leg; M, sixth leg.

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