

Paracalanus orientalis n. sp. (Copepoda, Calanoida), formerly referred to as *P. parvus* in Japanese coastal waters

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Abstract: The *Paracalanus parvus* (Claus, 1863) species complex is a common marine calanoid copepod found in the world's oceans. Recent genetic analyses of its specimens from the world oceans revealed that the complex in the western North Pacific consists of three species, i.e., *P. indicus* Wolfenden, 1905, *P. tropicus* Andronov, 1977 and an undescribed species. We assign the last one to be *Paracalanus orientalis* n. sp. by comparing it with previous morphological descriptions of related species. Both sexes of the new species are fully described based on genetically identified specimens from the surface layer of the south of Japan. The new species can be reliably distinguished from *P. indicus* and *P. tropicus* by the hunchback shape of the female if it is clearly present. Among the three species, the high length:width ratio of the third exopod segment of leg 4 is also characteristic of the new species, which would be identifiable, in most cases, by having a ratio of 5.4 or more.

Key words: Copepoda, new species, *Paracalanus orientalis*, *Paracalanus parvus* species complex, western North Pacific

Introduction

The small calanoid copepod *Paracalanus parvus* (Claus, 1863) was first described off Helgoland Island in the North Sea (Claus 1863) and has been recorded from seas around the world (GBIF Secretariat 2021, Razouls et al. 2005–2021). This species is the first member of the genus, and 11 valid congeners have been created to date (Walter & Boxshall 2021). Bowman (1971) classified copepods formerly known as *Paracalanus parvus* in the southeastern United States into three species primarily by the “dorsal hump” of the female and the spinules of the genital somite; henceforth we refer to the female “dorsal hump” as “hunchback” to avoid confusion with the “cephalic dorsal hump” found in male paracalanids (Nishida 1989). These were *P. parvus*, the new species *P. quasimodo* Bowman, 1971, and the new rank *P. indicus* Wolfenden, 1905 (Bowman 1971).

Thereafter the “*P. parvus*” taxonomic problem arose in various seas, because researchers could not reliably identify “*P. parvus*” specimens in their geographic zones, probably because of individual variation in the diagnostic characteristics given by Bowman (1971). The species formerly identified as *P. parvus* is now referred to as the *P. parvus* species complex (Cornils & Held 2014). In Japan, the *P. parvus* species complex has been referred to as *P. parvus* s.l. (Ueda 1997).

Cornils & Held (2014) analyzed genetic sequences of a large number of specimens of the *Paracalanus parvus* species complex collected from all oceans. They detected 10 to 12 putative species. Hidaka et al. (2016) performed genetic analyses on the *P. parvus* complex collected in the northwestern Pacific Ocean along the 138°E line off the coast of Japan, and found three genetic groups. By comparing these groups with those analyzed by Cornils & Held (2014), they concluded that the three groups were *P. indicus*, *P. tropicus* Andronov, 1977, and an as-yet undescribed

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species. The last one was referred to as *Paracalanus* sp. A by Cornils & Held (2014) and *Paracalanus* sp. (NWP) by Hidaka et al. (2016). After a literature survey we have concluded that *Paracalanus* sp. (NWP) is not identifiable to any of the so far described and named species and therefore, assign *Paracalanus* sp. (NWP) to a new species. The present paper fully describes both sexes of the new species based on genetically identified specimens collected from the southern waters of Japan by Hidaka et al. (2016).

Materials and Methods

Specimens of the *Paracalanus parvus* species complex were sorted from samples collected at three stations (C3100, S01, C3430) during the cruises of the FRV 'Soyo-maru' (National Research Institute of Fisheries Science, Fisheries Research Agency) in 2011 and 2016. Sampling methods were as described by Hidaka et al. (2016). Those examined in this study were less damaged than others and were genetically identified using 28S LSU rRNA of the antennule. The holotype specimen is the same one illustrated as *Paracalanus* sp. (NWP) by Hidaka et al. (2016).

Morphological examination was performed by the method of Humes & Gooding (1964) using 70% glycerol under a compound microscope equipped with a camera lucida. Length and width of specimens were measured directly with an ocular micrometer or on the drawings with drawn scale bars. The body and curved urosome lengths of the male allotype in lateral view were obtained on a personal computer using the measurement software "Hakarundesu" (<https://online.onegland.net/hakarun>).

The morphological terminology follows Boxshall & Halsey (2004) and Huys & Boxshall (1991) with the exception of the following abbreviations: Exp1–Exp3 and Enp1–Enp3 denote the first–third exopod segments and the first–third endopod segments, respectively. Type specimens were deposited into the National Museum of Nature and Science, Tokyo.

Systematics

Order Calanoida Sars, 1902

Family Paracalanidae Giesbrecht, 1892

Genus *Paracalanus* Boeck, 1864

Paracalanus orientalis Itoh and Ueda, new species

(Figs 1–6)

Synonymy

Paracalanus sp. A: Cornils & Held (2014), fig. 3.

Paracalanus sp. (NWP): Hidaka et al. (2016), fig. 4, table 3.

Paracalanus intermedius: Soh & Moon (2014), p. 88, figs. 48–51; Moon et al. (2015), p. 8.

Type locality

South of Honshu, Japan, Pacific Ocean, 138°00'E, 31°00'N.

Material examined

Female holotype, dissected on 2 slides (NSMT-Cr 30657) collected at C3100 (138°00'E, 31°00'N) on 9 May 2011; male allotype, dissected on 2 slides (NSMT-Cr 30658), and 3 female paratypes in alcohol (NSMT-Cr 30659–30661), collected at S01 (137°44'E, 33°52'N) on 5 May 2011; 4 female and 9 male paratypes in alcohol (NSMT-Cr 30662–30674) collected at C3430 (138°00'E, 34°30'N) on 22 January 2016. All type materials were collected at depths of 0–200 m and identified by genetic analysis as in Hidaka et al. (2016).

Description

Female (holotype)—Body (Fig. 1A, B) length 0.87 mm. Prosome length 0.69 mm, 2.7 times width, and 3.1 times urosome. Cephalosome completely fused with first pedigerous somite; fourth and fifth pedigerous somites incompletely fused. Cephalosome hunchback shaped (Fig. 1B); rostrum with pair of long rostral filaments. Length ratios of first to fourth urosomites and caudal ramus 28 : 14 : 13 : 24 : 21. Genital double somite (Fig. 1A, C) length 0.8 times width, swollen ventrally, with cluster of minute spinules on anterior lateral surfaces and row of minute spinules along posterior margin except for ventral side; seminal receptacles almost parallel to posterior margin in lateral view. Anal somite length 0.7 times width. Caudal ramus (Fig. 1E) length 1.8 times width, with 4 long setae on distal margin and 1 short seta near distomedial corner; medial margin devoid of spinules.

Antennule (Fig. 1F) 25-segmented, extending to posterior end of caudal rami; segments 1 and 2 incompletely separated; fusion and setation patterns as follows (ancestral segment numbers in Roman numerals, ae = aesthetasc, sp = spine): 1 (I)=3, 2 (II–IV)=4+ae, 3 (V)=2+ae, 4 (VI)=2, 5 (VII)=2+ae, 6 (VIII)=1, 7 (IX)=2, 8 (X)=1+sp, 9 (XI)=2+ae, 10 (XII)=1, 11 (XIII)=1, 12 (XIV)=sp+ae, 13 (XV)=1, 14 (XVI)=1+ae, 15 (XVII)=1, 16 (XVIII)=1+ae, 17 (XIX)=1, 18 (XX)=1, 19 (XXI)=1+ae, 20 (XXII)=1, 21 (XXIII)=1, 22 (XXIV)=1+1, 23 (XXV)=1+1, 24 (XXVI)=1+1, 25 (XXVII–XXVIII)=5+ae; segments 1–10 each with row of several spinules along posterodistal margin; segments 11–23 each with longitudinal row of minute spinules.

Antenna (Fig. 1G) coxa with plumose medial seta; basis with 2 subequal setae at distomedial corner; exopod 7-segmented with 1, 3, 1, 1, 1, 1, 1+3 setae; endopod 2-segmented; Enp1 with 2 setae at two-thirds length of medial margin and spinule row near distolateral corner; Enp2 with 3 short medial, 5 subterminal and 7 terminal setae, and row of long spinules near distolateral corner.

Mandible (Fig. 1H) coxa with spinule rows on proximal part and at least 10 tooth tips on gnathobase; basis with 4 setae along medial margin, a few spinules proximal to proximalmost seta, and long row of spinules near medial margin; exopod indistinctly 5-segmented with 1, 1, 1, 1, 2 setae; endopod 2-segmented; Enp1 with 4 setae at distome-

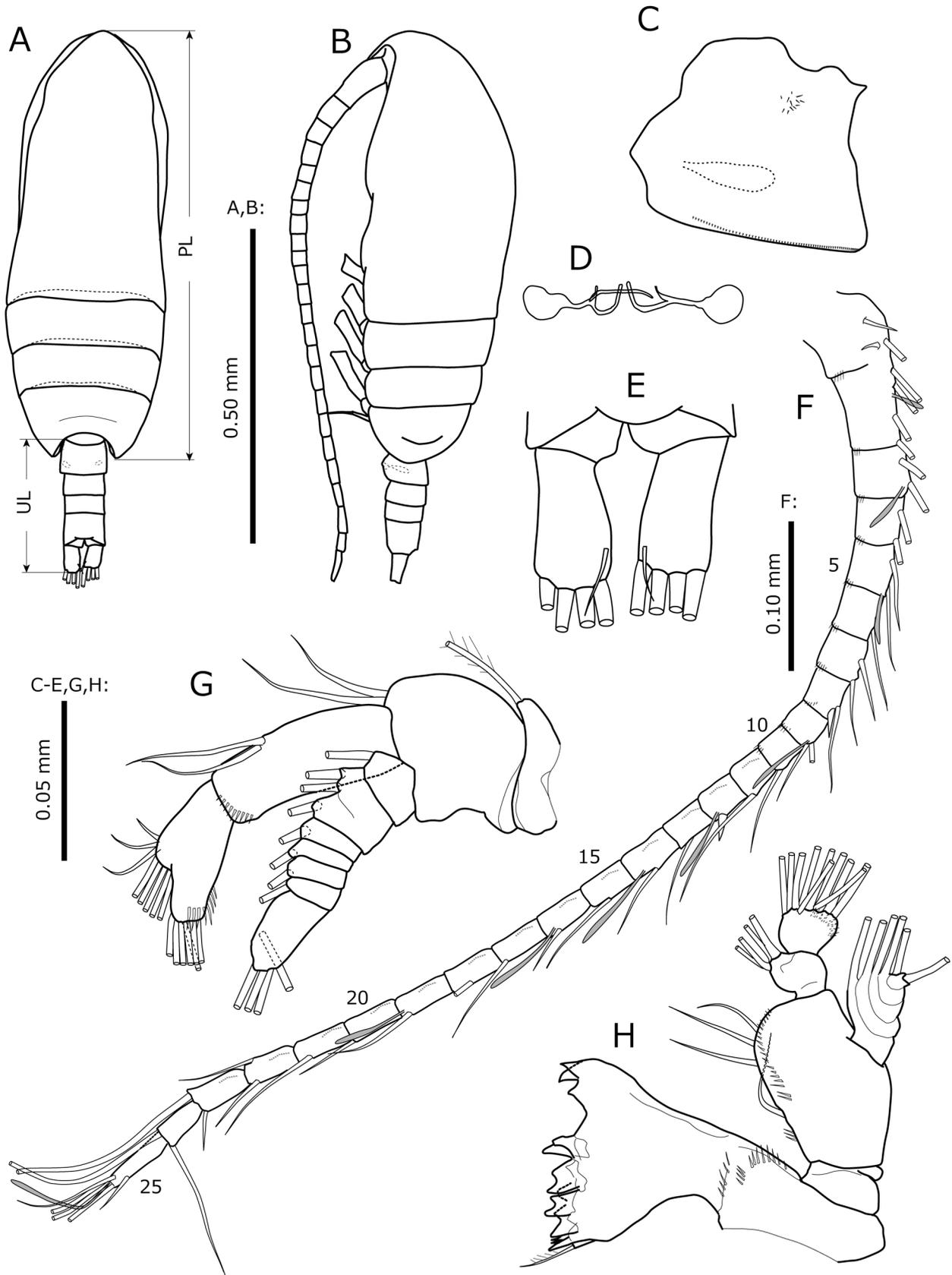


Fig. 1. *Paracalanus orientalis* n. sp., female holotype. A, habitus, dorsal; B, habitus, lateral; C, genital double somite, lateral; D, genital field, ventral; E, caudal rami, dorsal; F, antennule; G, antenna; H, mandible. Prosome (PL) and urosome (UL) lengths were measured as indicated in A.

dial corner; Enp2 with 10 terminal setae, 2 of them shorter and slightly inclined, and row of long spinules near distolateral corner.

Maxillule (Fig. 2A) praecoxal arthrite proximally with 9 elements, consisting of 4 spiniform and 1 thin setae marginally, 4 thin setae and longitudinal row of minute spinules posteriorly, and distally with 5 long spines along margin; coxal epipodite with 2 short and 7 long setae; coxal endite with 3 setae; proximal and distal basal endites each with 4 setae; endopod 3-segmented with 3, 4, 6 setae; exopod unsegmented with 11 setae marginally and row of long spinules distally.

Maxilla (Fig. 2B) praecoxa with 5 and 3 setae on proximal and distal endites, respectively; coxa with 3 setae on each of 2 endites, short seta on lateral surface, and minute spinules on distal side of each endite; basal endite with 4 setae and minute spinules on distal side; endopod 4-segmented with 1, 2, 2, 3 setae.

Maxilliped (Fig. 2C) syncoxal with indistinct 4 endites bearing 1, 2, 3, 4 setae, respectively, and cluster of spinules on each of first and fourth endites; basis slightly shorter than syncoxa, with medial margin bearing row of long spinules proximally and 3 setae distally; endopod 6-segmented with 2, 3, 4, 3, 1+3, 4 setae, lateral seta of segment 5 and lateral 2 setae of segment 6 short.

Leg 1 (Fig. 2D) endopod 2-segmented. Spine and setal formula of legs 1–4 (Fig. 2D–I) as follows.

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

Legs 1–4 coxae each with clusters of spinules or fine setules along both margins. Legs 2, 3 bases with 3, 4 conspicuous spinules, respectively, near distolateral corner on posterior surface. Legs 1–4 rami spinule pattern as in Fig. 2D–I; spinules on posterior surfaces of legs 2, 3 Enp2 very conspicuous. Legs 2–4 Exp2 with smooth lateral margins; Exp3 lateral margin between 2 lateral spines serrate in legs 2, 3 and smooth in leg 4. Leg 4 Exp3 length 5.9 times width (measurement lines indicated in Fig. 2I).

Leg 5 (Fig. 2J) 2-segmented, fused to intercoxal sclerite, with short lateral and long medial apical spines; segment 2 length 3.8 times width, as long as segment 1; long apical spine length 1.5 times segment 2, slightly curved terminally, and finely pinnate along distal 2/3 of lateral margin.

Male (allotype)—Body (Fig. 3A, B) length 0.93 mm. Prosome length 0.67 mm, 2.6 times width, and 2.3 times urosome. Genital somite (Fig. 3C) with cluster of minute spinules on anterolateral surface and gonopore on left side.

Antennule (Fig. 3D) 20-segmented, extending to fourth urosomite; armature and fusion pattern as follows: 1 (I–IV)=7+5ae, 2 (V–VIII)=7+6ae, 3 (IX–X)=4+3ae, 4 (XI)=2+2ae, 5 (XII)=1+ae, 6 (XIII)=1+ae, 7 (XIV)=1+ae, 8 (XV)=ae, 9 (XVI)=1+ae, 10 (XVII)=sp+ae, 11

(XVIII)=1+ae, 12 (XIX)=1+ae, 13=1+ae, 14 (XXI)=1+ae, 15 (XXII)=1+ae, 16 (XXIII)=1+ae, 17 (XXIV)=1+1+ae, 18 (XXV)=1+1+ae, 19 (XXVI)=1+1, 20 (XXVII–XXVIII)=4+ae.

Antenna (Fig. 3E) basis fused to coxa, with 2 setae at distomedial corner; exopod 7-segmented with 0, 0, 1, 1, 1, 1, 1 setae; endopod 2-segmented; Enp1 devoid of seta; Enp2 medially with 5 setae, proximal 2 of them short, terminally with 6 setae, and 2 spinule rows.

Mandible (Fig. 3F) without gnathobase; basis with small medial seta; exopod 5-segmented with 1, 1, 1, 1, 2 setae; endopod 2-segmented; Enp1 with medial seta; Enp2 with 8 terminal setae.

Maxillule (Fig. 3G) reduced to non-segmented appendage bearing 3 groups of 5, 7, 2 setae, last 2 setae of them short.

Maxilla (Fig. 3H, indicated by arrow) greatly reduced into small knob bearing notch at top.

Maxilliped (Fig. 3H) 5-segmented, consisting of naked syncoxa, basis with 3 medial setae, and 3-segmented endopod; Enp1 medially with 9 thin setae medially and very long thick seta laterally; Enp2 with short thin seta and long thick seta laterally; Enp3 with 2 thin setae and 1 thick seta.

Leg 1 slenderer than that of female; first lateral spine of Exp3 not beyond segment. Spinule pattern of Legs 1–4 (Fig. 4A–F) as in female except for following ornamentations: legs 2–4 Exp2 with spinule row along lateral margin; leg 3 Exp1 with spinules on posterior surface. Leg 4 Exp3 length 6.0 times width.

Left leg 5 (Fig. 4G) 5-segmented; terminal segment devoid of ornamentation, with 2 pointed apical attenuations (medial one of them probably broken at tip). Right leg 5 2-segmented; terminal segment with 2 pointed attenuations.

Etymology

The specific name “*orientalis*” (east in Latin) refers to the Orient region (East Asia) from Japan to Korea and China, which is the distribution range of this species (Cornils & Held 2014).

Variability

Bowman (1971) described the “hunchback” of the female as a characteristic feature of *Paracalanus quasimodo*. According to Hidaka et al. (2016), only a half of the female specimens of *P. orientalis* n. sp. that they examined had the prominent hunchback. As an example of the variation, the type specimens, with a prominent and a less prominent hunchback, are illustrated in Fig. 5.

Hidaka et al. (2016) described the shape and arrangement of the seminal receptacle as characteristic features to distinguish the three species of the *Paracalanus parvus* complex. However, this arrangement was found to be somewhat variable in the paratype specimens (Fig. 6). The axis of the seminal receptacle in the lateral view was perpendicular to the dorsal surface line of the somite in speci-

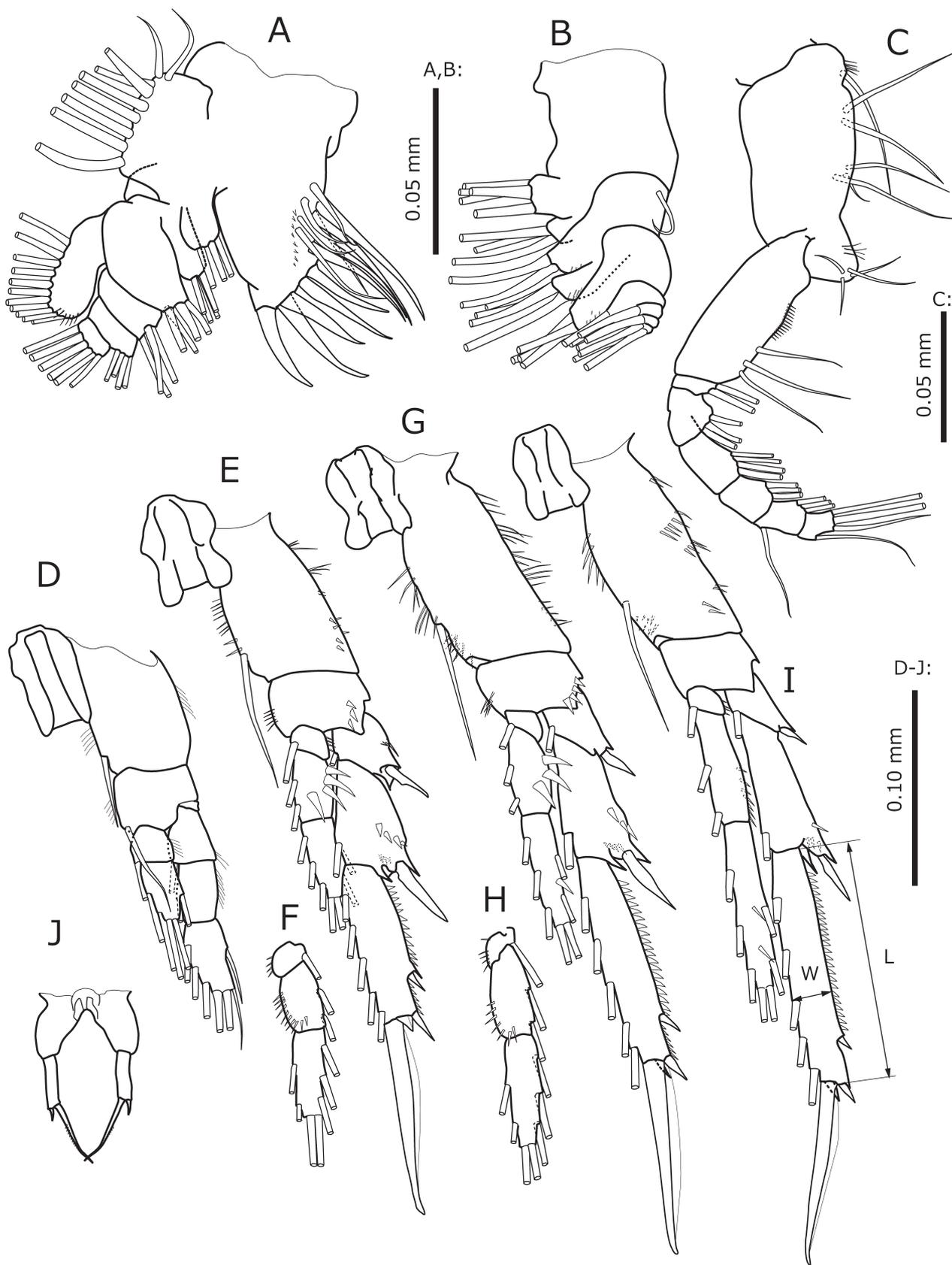


Fig. 2. *Paracalanus orientalis* n. sp., female holotype. A, maxillule; B, maxilla; C, maxilliped; D, leg 1, anterior; E, leg 2, posterior; F, endopod of leg 2, anterior; G, leg 3, posterior; H, endopod of leg 3, anterior; I, leg 4, posterior; J, leg 5.

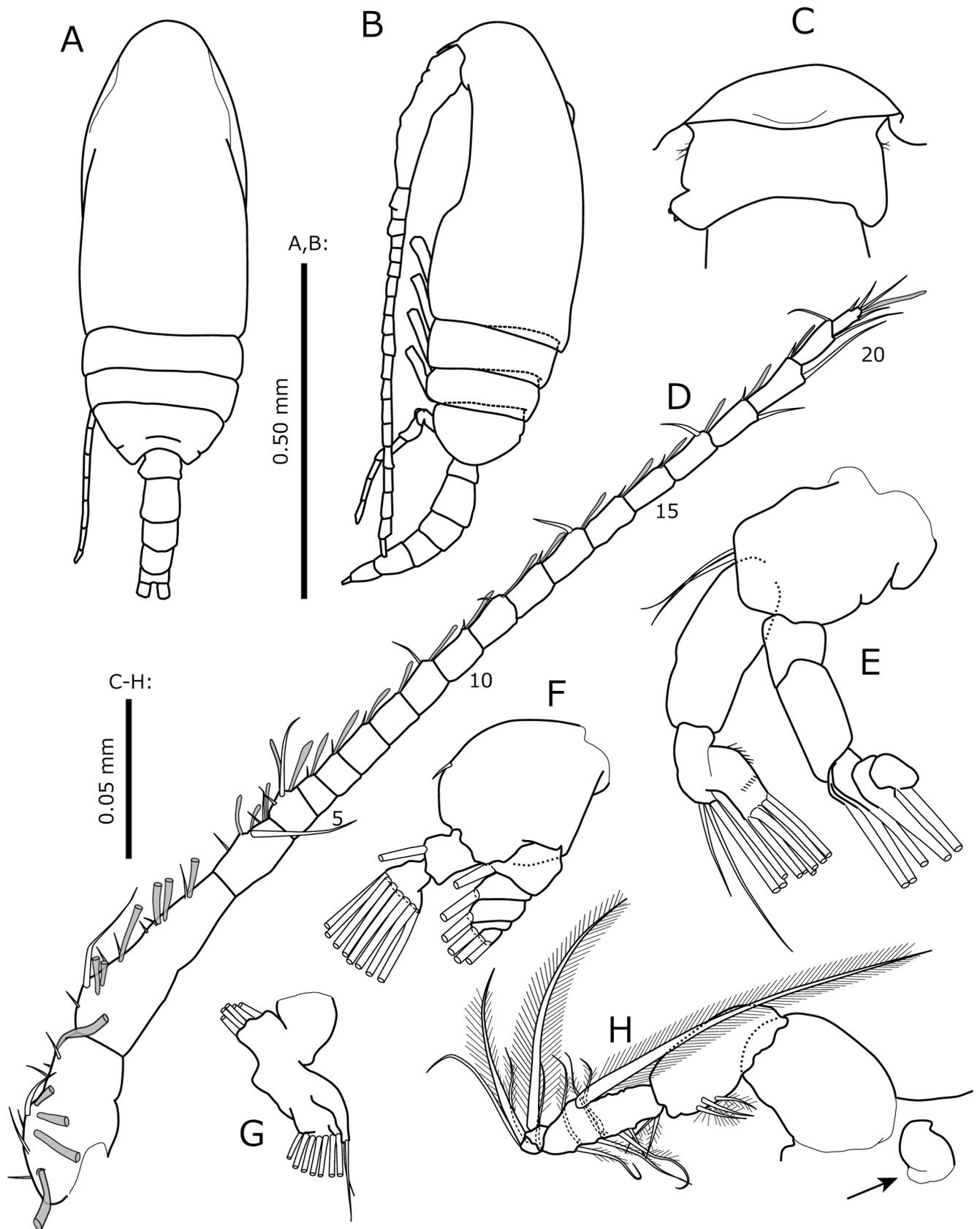


Fig. 3. *Paracalanus orientalis* n. sp., male allotype. A, habitus, dorsal; B, habitus, lateral; C, genital somite, dorsal; D, antennule; E, antenna; F, mandible; G, maxillule; H, rudimentary maxilla (indicated by arrow) and maxilliped (4 setae on proximal 2 segments of endopod were directed lateralward due to treatment on the glass slide).

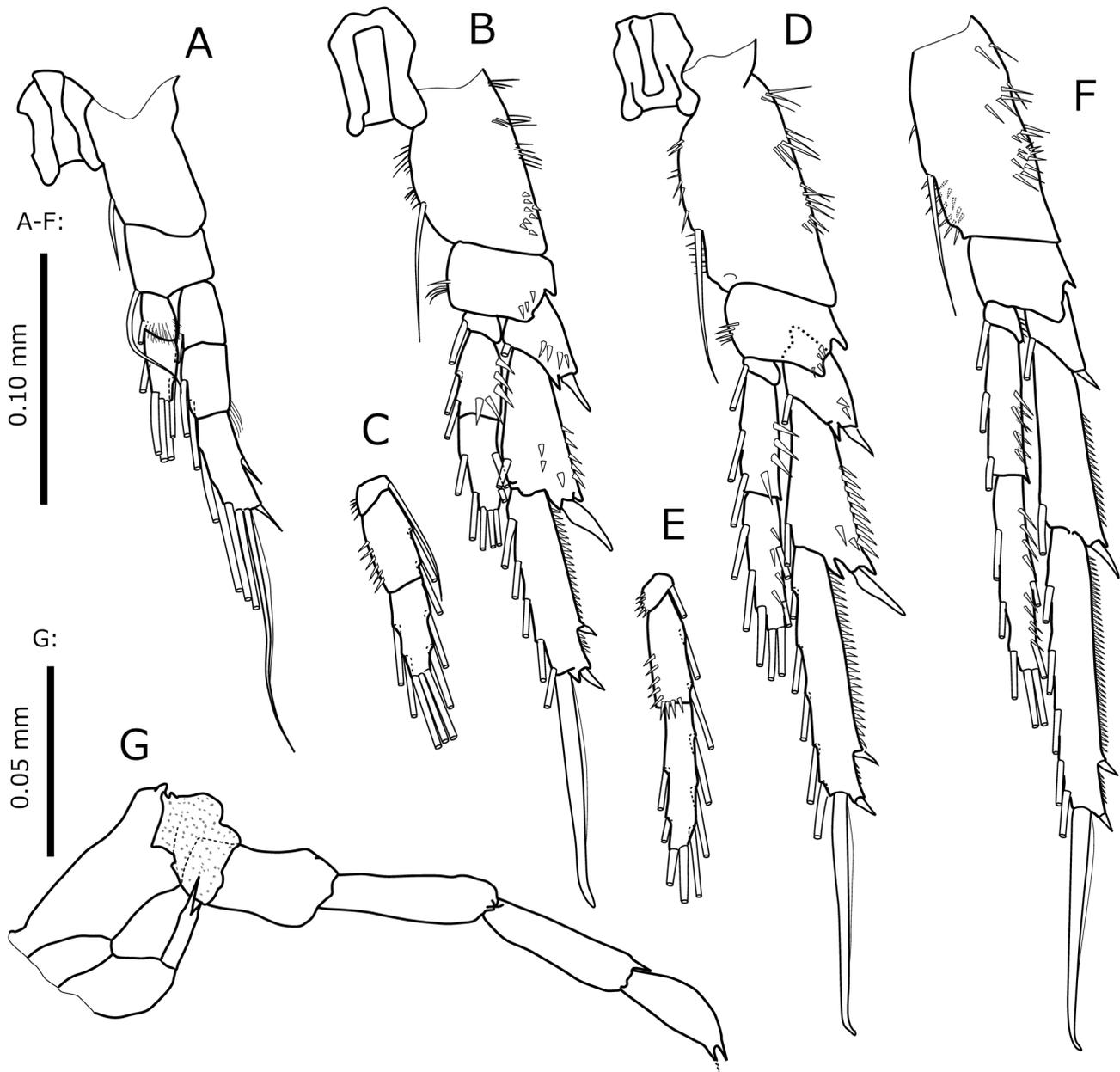


Fig. 4. *Paracalanus orientalis* n. sp., male allotype. A, leg 1, anterior; B, leg 2, posterior; C, endopod of leg 2, anterior; D, leg 3, posterior; E, endopod of leg 3, anterior; F, leg 4, posterior; G, leg 5 (joint between the first and second segments and medial terminal attenuation of the right leg were broken).

men A in Fig. 6, but was inclined in specimens B and C.

Hidaka et al. (2016) indicated that the relative length of exopod segment 3 of leg 4 was the critical morphological feature to distinguish *Paracalanus orientalis* n. sp. from coexisting congeners. In the present study, the length : width (L/W) ratio of the segment was remeasured on the 10 female specimens that were examined by Hidaka et al. (2016). The ratio varied from 5.0–6.1, with the mean 5.67 ± 0.34 SD. The variation in the male was not measured because material comprised of genetically-identified male specimens with intact leg 4 Exp3 was limited.

Discussion

The *Paracalanus parvus* species complex currently includes the following eight named species (Cornils & Held 2014, Vieira-Menezes et al. 2021): *P. brasiliensis* Vieira-Menezes et al., 2021, *P. indicus*, *P. intermedius* Shen & Bai, 1956, *P. nanus* Sars, 1925, *P. parvus* s.s., *P. quasimodo*, *P. serrulus* Shen & Lee, 1977, and *P. tropicus* Andronov, 1977. In the phylogenetic tree of the species complex by Cornils & Held (2014), *P. orientalis* n. sp. (as *Paracalanus* sp. A) belongs to a genetic clade different from those of the six species *P. nanus*, *P. quasimodo*, *P.*

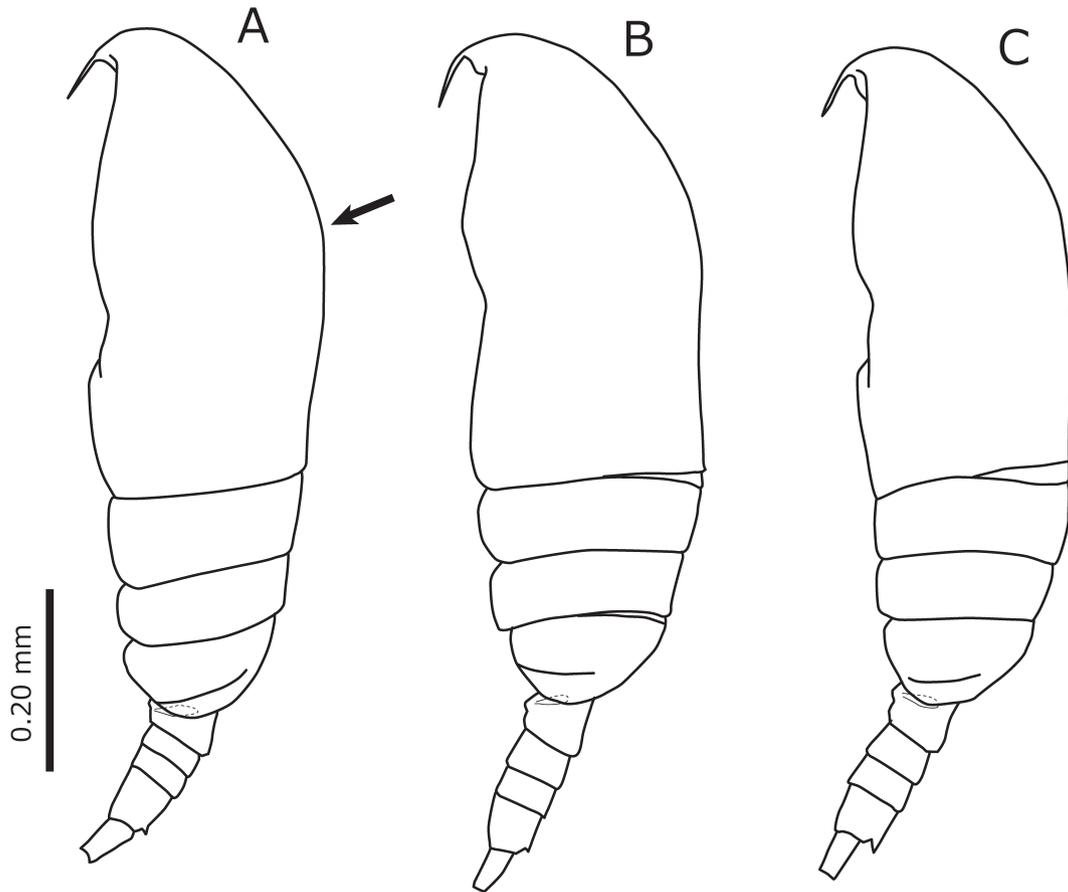


Fig. 5. *Paracalanus orientalis* n. sp., three female paratypes from S01. A–C, lateral views of the habitus (A) with prominent hunchback (shown by arrow) and (B, C) with less prominent hunchback.

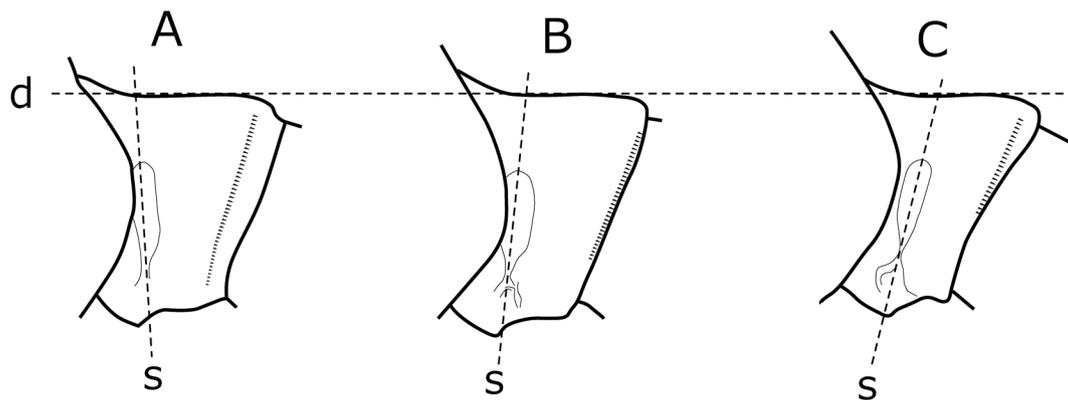


Fig. 6. Variations in the angle of the seminal receptacle of *Paracalanus orientalis* n. sp. in lateral view based on three female paratypes from S01. A–C, axes of seminal receptacles (s) were vertical (A), slightly inclined (B), and inclined (C) to the dorsal line (d) of the somite, respectively.

indicus, *P. tropicus*, *P. parvus* s.s., and *P. brasiliensis* (as *Paracalanus* sp. E), with high levels of interspecific mtCOI variations (>12% differences). This indicates that *P. orientalis* n. sp. is neither one of these six species.

Of the remaining two species, *Paracalanus serrulus* was first described from river estuaries of the southeast coast of China facing the South China Sea by Shen & Lee (1963).

According to their illustration, leg 5 of the female has a long terminal segment with a terminal spine that is shorter than the segment. Such the leg 5 is remarkably different from those of the other members of the *P. parvus* complex and rather similar to the leg 5 of *Parvocalanus scotti* (Früchtl, 1923). Furthermore, the female leg 4 of *P. serrulus* has a row of long spinules on the surface of the leg

Table 1. Distinctive characteristics of the three species formerly recorded as *Paracalanus parvus* from Japan. Values marked with * are those measured on an illustration in a reference. Mean values are in parentheses. The male of *P. tropicus* has not been recorded.

	<i>P. indicus</i>		<i>P. tropicus</i>		<i>P. orientalis</i> n. sp.	
	Female	Male	Female	Female	Male	
Body length (mm)	0.825–0.870 (0.844) ¹⁾ , 1.05 ^{*2)}		0.750–0.854 (0.794) ¹⁾ , 0.74–0.90 ³⁾		0.806–1.032 (0.903) ¹⁾ , 0.87 ⁴⁾	
Hunchback of prosome	absent		absent		usually present	
Prosome:urosoma ratio	3.33–3.39 (3.37) ¹⁾ , 3.0 ^{*2)}		3.89–4.71 (4.25) ¹⁾ , 4.0 ^{*3)}		2.76–3.64 (3.19) ¹⁾ , 3.1 ⁴⁾	
Length:width ratio of third exopod segment of leg 4	4.6 ^{*1)} , 4.8 ^{*2)}		4.3 ^{*1)}		5.1–5.9 (5.63±0.27) ⁴⁾	

¹⁾Hidaka et al. (2016), ²⁾Bradford-Grieve (1994), ³⁾Andronov (1977), ⁴⁾present study.

4 Enp2, but no spinules are present on the corresponding surface of *P. orientalis* n. sp. By these remarkable differences it is certain that *P. orientalis* n. sp. is not *P. serrulus*.

The last remaining species, *Paracalanus intermedius*, was first described from the Yellow Sea by Shen & Bai (1956) as a species smaller than co-occurring "*P. parvus*" and having intermediate morphologies between *P. parvus* and *P. aculeatus* Giesbrecht, 1888. Although there were some problems with their illustration, such as the extremely narrow leg 4 rami and the 7-segmented left leg 5 of the male, the following features of *P. intermedius* explain critical differences from *P. orientalis* n. sp. (corresponding characteristics of *P. orientalis* n. sp. in brackets): 1) leg 4 of the female lacks spinules on the posterior surface of Enp2–Enp3 [a few, but readily recognizable spinules are present on Enp3]; 2) leg 4 of the male lacks spinules on the posterior surfaces of Enp2–Enp3 [a longitudinal row of conspicuous spinules is present on both segments]. Most of the features in their table were on the spinules of the legs, indicating that they were paying attention to the spinulation pattern on the leg rami. The spinulation pattern on the legs is important for taxonomy of some paracalanid species such as *Bestiolina* (Ali et al. 2007, Ueda & Sakaguchi 2021). Besides, the size of *P. intermedius* is smaller than the co-occurring most abundant "*P. parvus*" (Shen & Bai 1956). The size and abundance of *P. intermedius* are in conflict with those of *P. orientalis* n. sp. in Japan, because the latter is the largest and the most common of the three sympatric species of the *P. parvus* complex (Hidaka et al. 2016). Accordingly, there is no doubt that *P. orientalis* n. sp. is distinct from *P. intermedius*. In conclusion, *P. orientalis* n. sp. is a distinct species from any of the seven so-far named species belonging to the *P. parvus* complex.

Soh & Moon (2014) noted that the genus *Paracalanus* in Korea consists of *P. aculeatus* Giesbrecht, 1888, *P. intermedius* and *P. indicus*. Their description of *P. intermedius* is very close to *P. orientalis* n. sp. The morphological differences between *P. orientalis* n. sp. and *P. intermedius* explained above are also the case between *P. intermedius* by Soh & Moon (2014) and *P. intermedius* s. str. by Shen & Bai (1956). Moon et al. (2015) compared the mtCOI sequences of their *P. intermedius* specimens in Korea with

those of Chinese and Japanese specimens on the GenBank database, which are correspond to *Paracalanus* sp. NWP (= *P. orientalis* n. sp.) in Hidaka et al. (2016). Moon et al. (2015) suggested that *P. intermedius* mainly occurred in Korea and around the main island of Japan. This morphological and genetic evidence indicates that "*P. intermedius*" of Soh & Moon (2014) and Moon et al. (2015) is *P. orientalis* n. sp.

Morphological characteristics of the three species formerly recorded as *Paracalanus parvus* from Japan are listed in Table 1. Hidaka et al. (2016) pointed out that morphological distinction between *Paracalanus* sp. (NWP) (= *P. orientalis* n. sp.) and *P. indicus* can be made only by the length of the leg 4 Exp3 relative to the body length. However, the two species can be more clearly separated by the L/W ratio of the leg 4 Exp3 itself. According to Hidaka et al. (2016), the mean ratio of leg 4 Exp3 length to body length in the females of *P. orientalis* n. sp. was 0.118, which is 16% and 11% higher than those of *P. indicus* (0.102) and *P. tropicus* (0.106), respectively. In contrast, the mean L/W ratio 5.63 of leg 4 Exp3 in the female of *P. orientalis* n. sp. was 23% and 31% higher than those of *P. indicus* (4.6) and *P. tropicus* (4.3), respectively. The L/W ratio in the male allotype was 6.0, which was 25% higher than that (4.8) in the male of *P. indicus* described from New Zealand by Bradford-Grieve (1994). However, some specimens may be difficult to distinguish using this ratio, because the minimum ratio 5.1 in the female of *P. orientalis* n. sp. was close to the ratio of 4.8 in *P. indicus* from New Zealand. The L/W ratio of the leg 4 Exp3 would not be a problem for identification, if the ratio is at least 5.4, which is the lower limit of the standard deviation range, i.e., the mean ratio 5.63–0.27 SD.

A more easily observable characteristic of *Paracalanus orientalis* n. sp. is the hunchback of the female, although it is unclear in some specimens. If a hunchback is clearly present, the specimen can be identified to *P. orientalis* n. sp. The female of *P. orientalis* n. sp. is distinguished from *P. tropicus* by relative length of the urosome (Hidaka et al. 2016). According to Hidaka et al. (2016), the prosome:urosoma ratio of 4.25 (ranging from 3.89–4.71) in *P. tropicus* was 33% higher than 3.19 (2.76–3.64) in *P. orientalis* n. sp.

Morphologies previously used to distinguish the species of the *Paracalanus parvus* complex have been primarily a dorsal hump (=hunchback) in the female, ornamentation of legs 2–4, and spinules on the genital somite (Bowman 1971, Bradford 1978). Since these were not considered sufficient to identify other cryptic species, other diagnostic morphologies such as spinules on cephalic appendages were needed to define their taxonomy. Comparing with *P. indicus* described by Bradford-Grieve (1994), for example, *P. orientalis* n. sp. differs by the following cephalic appendages [corresponding characteristics in *P. indicus* described by Bradford-Grieve (1994) in brackets]: the female antenna with 1 spinule row on Enp2 [without spinules]; the female mandible with 1 spinule row on Enp2 [with 2 rows]; the female maxillule with 1 spinule row on praecoxa arthrite in (a) [with 2 rows]. However, even if morphological differences from a known species are found on specimens of the *P. parvus* complex, genetic analyses are essential to create a new species. Genetic analysis should be performed not only on females but also on males, and males should be morphologically described, because males of the *P. parvus* complex have been very limitedly described.

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References

- Ali M, Al-Yamani F, Prusova I (2007) *Bestiolina arabica* sp. nov. (Copepoda, Calanoida, Paracalanidae), a new species from the northwestern Arabian Gulf. *Crustaceana* 80: 195–205.
- Andronov VN (1977) *Paracalanus tropicus* sp. n. (Copepoda, Paracalanidae) from south-east Atlantic. *Zool Zhur* 56: 154–156.
- Bowman TE (1971) The distribution of calanoid copepods off the southeastern United States between Cape Hatteras and southern Florida. *Smithsonian Contributions to Zoology* 96: 1–58.
- Boxshall JA, Halsey SH (2004) An Introduction to Copepod Diversity. The Ray Society, London, 966 pp.
- Bradford JM (1978) *Paracalanus indicus* Wolfenden and *Corycaeus aucklandicus* Kraemer, two neritic pelagic copepods from New Zealand. *J Royal Soc NZ* 8: 133–141.
- Bradford-Grieve JM (1994) The marine fauna of New Zealand: Pelagic calanoid Copepoda: Megacalanidae, Calanidae, Paracalanidae, Mecynoceridae, Eucalanidae, Spinocalanidae, Clausocalanidae. *NZ Oceanogr Inst Memoir* 102: 1–160.
- Claus C (1863) Die freilebenden Copepoden mit besonderer Berücksichtigung der Fauna Deutschland, der Nordsee und des Mittelmeeres. Leipzig 1–230, pls. 1–37.
- Cornils A, Held C (2014) Evidence of cryptic and pseudocryptic speciation in the *Paracalanus parvus* species complex (Crustacea, Copepoda, Calanoida). *Front Zool* 2014 11:19.
- GBIF Secretariat (2021) *Paracalanus parvus* (Claus, 1863). GBIF Backbone Taxonomy. Checklist dataset. Available at <https://www.gbif.org/species/10051223> (accessed on 26 July 2021)
- Hidaka K, Itoh H, Hirai J, Tsuda A (2016) Occurrence of the *Paracalanus parvus* species complex in offshore waters south of Japan and their genetic and morphological identification to species. *Plankton Benthos Res* 11: 131–143.
- Humes AG, Gooding RU (1964) A method for studying the external anatomy of copepods. *Crustaceana* 6: 238–240.
- Huys R, Boxshall GA (1991) Copepod Evolution. The Ray Society, London, 468 pp.
- Moon SY, Lee J-H, Kim DN, Park JS, Soh HY (2015) Rediscovery of *Paracalanus intermedius* Shen & Bai, 1956 (Crustacea: Copepoda: Paracalanidae) from the Northwest Pacific, with a redescription of the closely related *P. indicus* Wolfenden, 1905 from the Indian Ocean. The 6th Korea Fisheries Science Society Fisheries Resources Ecology, Division Summary of Spring Conference, Korean Society of Fisheries Science.
- Nishida, S. (1989) Distribution, structure and importance of the cephalic dorsal hump, a new sensory organ in calanoid copepods. *Mar Biol* 101: 173–185.
- Razouls C, Desreumaux N, Kouwenberg J, de Bovée F (2005–2021) Biodiversity of Marine Planktonic Copepods (morphology, geographical distribution and biological data). Sorbonne University, CNRS. Available at <https://copepodes.obs-banyuls.fr/en/fichesp.php?sp=1086> (accessed on 26 July 2021)
- Shen C., Bai S (1956) The marine Copepoda from the spawning ground of *Pneumatophorus japonicus* (Houttuyn) off Chefoo, China. *Acta Zool Sinica* 8: 177–234, pls. 1–13. (in Chinese with English summary)
- Shen C, Lee F (1963) The estuarine Copepoda of Chiekong and Zaikong Rivers, Kwai-tung Province, China. *Acta Zool Sinica* 15: 571–596. (in Chinese with English summary)
- Soh HY, Moon SY (2014) Arthropoda: Maxillopoda: Copepoda: Calanoida, Marine Planktonic Copepods III. Invertebrate Fauna of Korea, National Institute of Biological Resources, Ministry of Environment 21(34), 138 pp.
- Ueda H (1997) Family Paracalanidae. In: An Illustrated Guide to Marine Plankton in Japan (eds Chihara M, Murano M). Tokai University Press, Tokyo, pp.844–851. (in Japanese)
- Ueda H, Sakaguchi SO (2021) A new species of *Bestiolina* (Copepoda, Calanoida, Paracalanidae) and complementary description of *B. similis* (Sewell, 1914) from the Nansei Islands, Japan. *Zootaxa* 4990: 454–468.
- Vieira-Menezes FG, de Oliveira Dias C, Cornils A, Silva R, Bonecker SLC (2021) New Paracalanidae species from the central coast of Brazil: morphological description and molecular evidence. *Mar Biodivers* 51: 54.
- Walter TC, Boxshall G (2021). World of Copepods Database. *Paracalanus* Boeck, 1865. Available at <http://www.marine-species.org/copepoda/aphia.php?p=taxdetails&id=104196> (accessed on 2 November 2021)