

# SPECIES OF *TRICONIA* OF THE *CONIFERA*-SUBGROUP (COPEPODA, ONCAEIDAE) FROM KOREAN WATERS, INCLUDING A NEW SPECIES

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## ABSTRACT

Three species of *Triconia* belonging to the *conifera*-subgroup are described from Korean waters (NW Pacific). A new species, *Triconia hirsuta*, was found that can be distinguished from its sibling *T. conifera* by a paired patch of long setules on the anterolateral margin of the genital double-somite in the female, and an unusual position of caudal seta II branching off at almost a right angle to the caudal ramus. Males have not been found so far. Both sexes of *T. conifera* (Giesbrecht, 1891) and *T. borealis* (Sars, 1918) from Korean waters are redescribed with the addition of morphological details and/or differences not noted in earlier descriptions. Morphological characters of Korean *T. conifera* are in close agreement with specimens described from the Mediterranean Sea and the Pacific, but differ in several parameters from *T. conifera* from the Red Sea, which is regarded as a distinct, though closely related, species requiring re-examination. Published data on the community structure and zoogeographical distribution of oncaeids of the *conifera*-type in the NW Pacific are summarized, and the remaining uncertainties concerning the distribution of species of the *conifera*-subgroup in these areas are pointed out.

KEY WORDS: Copepoda, Korea, Oncaeidae, *Triconia conifera*, zooplankton

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## INTRODUCTION

The pelagic marine copepod family Oncaeidae currently includes seven genera with a total of more than 100 species (Boxshall and Halsey, 2004). Identification of oncaeid species is difficult due to their great morphological similarity and the difficulties of handling these small-sized copepods (Böttger-Schnack, 1999). Several oncaeid species described in the last century or before, such as *Oncaea conifera* Giesbrecht, 1891, *O. notopus* Giesbrecht, 1891, *Spinoncaea ivlevi* (Shmeleva, 1966), and form variants such as those of *O. venusta* Giesbrecht, 1891 (redescribed by Farran, 1929) and *O. media* Giesbrecht, 1891 (redescribed by Sewell, 1947), have turned out upon subsequent detailed analysis to be species-complexes composed of two or even more very closely related species (Heron, 1977; Heron and Bradford-Grieve, 1995; Böttger-Schnack, 2003; Elvers et al., 2006). By comparing copepod material from the Southwest Pacific and Antarctic Ocean with newly collected material from the Gulf of Naples in the Mediterranean Sea, Heron (1977) and Heron and Bradford-Grieve (1995) separated females of *O. conifera* from six new oncaeid species based on a combination of morphological characteristics including the form of the genital double-somite and the proportional lengths of the urosomites, the conspicuousness of the dorso-posterior projection on the P2-bearing somite in lateral view, the form of the pleural areas of the P4-bearing somite in lateral view, and the proportional spine lengths on the distal endopodal segment of the second to fourth swimming legs. Böttger-Schnack (1999) established the genus *Triconia*, which is composed of all oncaeids having a large conical process on the distal margin of the endopod of swimming

legs 2-4. This genus was subdivided into 3 subgroups: the *similis*-, *conifera*-, and *dentipes*-subgroups. Females of the *conifera*-subgroup can be separated from those of the other two subgroups by the presence of a dorso-posterior projection on the second pedigerous somite. Dorsal projection is not developed in males, which makes the identification of males of *Triconia* more difficult (Böttger-Schnack, 1999). For instance, the male of *T. redacta* (Heron and Bradford-Grieve, 1995), a species of the *conifera*-subgroup, was re-assigned to *T. similis* (Sars) (= *similis*-subgroup) in a later account (Heron and Frost, 2000).

Twenty-two species of *Triconia* are known to date, described from all parts of the world's ocean, including the Arctic (Sars, 1918; Heron et al., 1984), the Southwest Pacific and the Antarctic (Heron, 1977; Heron and Bradford-Grieve, 1995), the Red Sea (Böttger-Schnack, 1999, 2000), the Northeast Pacific and coastal waters of Washington State (Heron and Frost, 2000), Japanese waters (Itoh, 1997 and unpublished data), and the East China Sea (Chen et al., 1974). The *conifera*-subgroup of *Triconia* presently includes eleven species, seven of which were recorded from the Southwest Pacific by Heron and Bradford-Grieve (1995). In the Northwestern Pacific, only one species of the *conifera*-subgroup, *T. conifera*, was described from the East China Sea (Chen et al., 1974), while three form variants of *T. conifera* have been reported from Japanese waters (Itoh, 1997, and unpublished data).

Korean waters are affected by the Tsushima Warm Current (TWC) branching off from the Kuroshio Current. The TWC, which causes high temperatures and salinities throughout the year, is affected by low-salinity surface water originating from the Yangtze River, typically during summer seasons. In the Korea Strait, the TWC splits into

two branches, one of which, the East Korea Warm Current, flows along the eastern coast of the peninsula (Cho and Kim, 2000). Recently, various ecological investigations on the pelagic copepod fauna also including species of *Triconia* have been performed in the Northwestern Pacific influenced by the TWC and/or the Kuroshio. Sampling with fine-mesh nets of 0.1 mm was performed in the subarctic region (Oyashio region) during different seasons, providing information about copepod numbers and biomass, vertical distribution patterns, and community structure down to deep-sea layers (Nishibe, 2005; Nishibe and Ikeda, 2004) as well as valuable information on life cycles and early development (Nishibe and Ikeda, 2007a, b), metabolism and elemental composition (Nishibe and Ikeda, 2008). More recently, a detailed analysis of the oncaeid copepod community in Tosa Bay, southern Japan, was provided by Nishibe et al. (2009). In Taiwan waters, the species diversity and composition of the planktonic copepod fauna with respect to intrusion of the Kuroshio Branch Current was studied by Hsieh et al. (2004) and Lee et al. (2009) based on sampling with nets of 0.2 mm mesh size.

Within the frame of a current taxonomic study of oncaeid copepods from Korean waters, seven species of *Triconia* have been recorded, three of which belong to the *conifera*-subgroup. This study describes the morphological characteristics of the three species of the *conifera*-subgroup, one of which represents a form new to science, and summarizes the present knowledge on the community structure and zoogeographical distribution of species of the *conifera*-subgroup appearing in the Northwestern Pacific. Another four species of *Triconia* found during the investigation, which belong to the *similis*-subgroup (3 species) and the *dentipes*-subgroup (1 species), are still under study and will be described elsewhere.

#### MATERIALS AND METHODS

Zooplankton samples were taken at a station located in the western channel of the Korea Strait, between the Island of Tsushima and the south coast of Korea (Station 1, total water depth 108 m) and in the East Sea of Korea (Sea of Japan, Station 2, total water depth 227 m) being affected by the Tsushima Warm Current (Fig. 1). Two different kinds of net (Conical Net: mesh size 330  $\mu$ m, mouth diameter 45 cm at Station 2; Bongo Net: mesh size 150  $\mu$ m, mouth diameter 60 cm at Station 1) were towed vertically from the bottom to the surface at each station. The western channel of the Korea Strait (Station 1) sample was collected from about 100–0 m depth, on 8 May, 17 July, 6 October 2008, and on 10 February 2009; the East Sea (Station 2) sample was collected from 180–0 m depth, on 8 October 2007 (Fig. 1). Vertical profiles of temperature and salinity were recorded using CTD (Allec co.) at each station. The specimens were fixed in 99.8% ethyl alcohol (not denatured). Species of *Triconia* were sorted out from the entire zooplankton samples. Specimens were dissected under a dissection microscope (Nikon, JP/E200) in CMC-10 aqueous mounting medium (Masters Company, Inc., Wood Dale, IL), mounted on slides, and sealed with high-quality nail-varnish. Drawings were done using a differential interference contrast microscope (Nikon AFX-II) equipped with a drawing tube. Scale bars are given in  $\mu$ m. Total body length and the ratio of prosome to urosome (excluding caudal rami) was measured in lateral view by using the traditional method, where telescoping of somites is not considered. However, for calculating the relative lengths of urosomal segments, the telescoping effect was taken into account. Females of *Triconia* were examined with a Hitachi-3000 scanning electron microscope to observe the minute surface ornamentations on the exoskeleton in more detail. Specimens were prepared by dehydration through graded ethanol, critical point dried, mounted on stubs and sputter-coated with palladium. The morphological terminology follows Huys and Boxshall

(1991). Abbreviations used in the text and figures are: ae, aesthetasc; CR, caudal rami; P1–P6, first to sixth thoracopods; exp, exopod; enp, endopod; exp(enp)-1(-2, -3), to denote the proximal (middle, distal) segment of a ramus. Type and other materials examined are deposited in the collections of the National Institute of Biological Resources (NIBR), Incheon, South Korea. Additional material examined is retained in the personal collection of R. Böttger-Schnack (RBS).

Oncaeidae was established by Wilhelm Giesbrecht in his comprehensive monograph on the pelagic copepods of the Gulf of Naples (Giesbrecht 1893 [“1892”]). Following the arguments given by Holthuis and Vervoort (2006), the actual date of publication of Giesbrecht’s monograph appears to be different (1893) from the date specified in the work (1892). According to Article 22A.2.3. of the International Code of Zoological Nomenclature, it is recommended to cite both dates with the actual date cited first, followed by the imprint date for information and enclosed in parentheses or other brackets and quotation marks.

#### SYSTEMATICS

Order Cyclopoida Burmeister, 1835  
Oncaeidae Giesbrecht, 1893 [“1892”]  
*Triconia* Böttger-Schnack, 1999  
*Triconia hirsuta* n. sp.  
(Figs. 2, 3, 4A, B)

**Material Examined.**— 13 females collected from Western Channel of Korea Strait, 34°05.97’N, 129°47.32’E, (Station 1; temperature: bottom –15°C, surface –29°C) on 8 May 2008, of which 4 females were dissected and closely examined.

**Type Material.**—Holotype: Adult female mounted on 1 glass slides using CMC-10, aqueous mounting medium (Masters Company, Inc., Wood Dale, IL), NI-BRIV0000137690.

**Paratypes:** 3 females dissected on 5 slides, NI-BRIV0000137837; 7 females in total in 1 vial, NI-BRIV0000137838. Additional paratypes from the western channel of Korea Strait (Station 1) examined: One female partly dissected, urosome on slide, remaining specimen in vial, 1 female in toto on slide (RBS).

**Female.**—Body length in lateral aspect 950–1040  $\mu$ m (mean: 995  $\mu$ m,  $n = 5$  individuals), body surface densely covered with minute refractile granulations (not figured). Prosome 1.9 times as long as urosome excluding caudal rami, 1.6 times the length including CR (Fig. 2A, B). Second pedigerous somite with conspicuous dorso-posterior projection in lateral view (Fig. 2B). Fourth pedigerous somite with elongate and pointed posterolateral corners in dorsal view, more or less round in lateral view (Fig. 2B).

Proportional lengths (%) of urosomites 13.3: 57.1: 10.2: 8.2: 11.2. Proportional lengths (%) of urosomites and caudal rami 11.9: 51.4: 9.8: 7.3: 10.1: 10.1. Genital double-somite (Figs. 2A, 4A) 1.7 times as long as maximum width in dorsal view, lateral margin rounded, posterior part tapering gradually; anterolateral margin of genital double-somite ornamented with paired patch of long, fine setules, dorsal surface with paired secretory pores at posterior third and unpaired pore at mid-region posterior to genital apertures (arrowed in Fig. 2A); paired genital apertures approximately 1/3 distance from anterior margin of dorsal surface, armed with spine, and bended process near base of spine (arrowed in Fig. 4B). Anal somite about 1.7 times

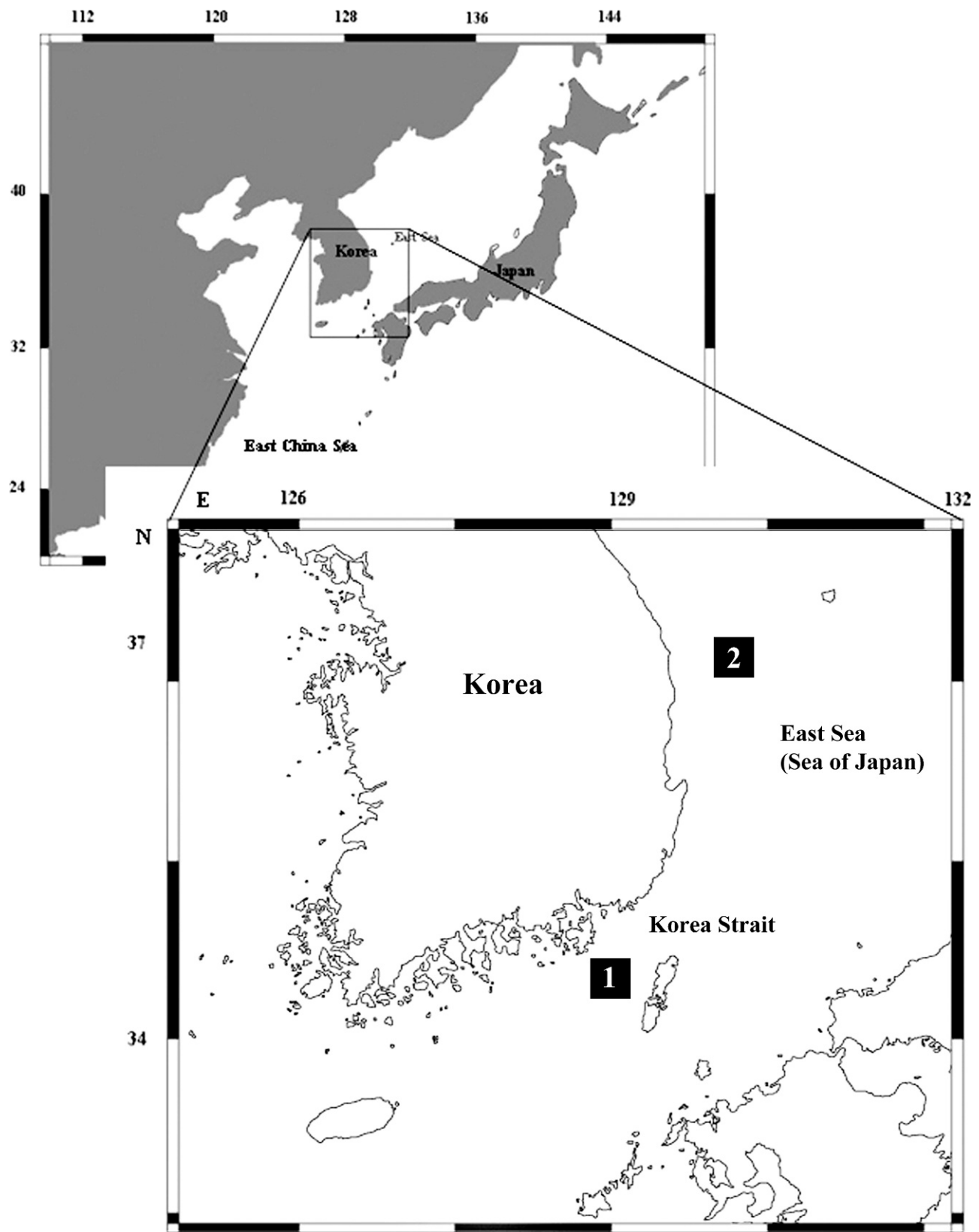


Fig. 1. Location of sampling stations of three *Triconia* species in the western channel of the Korea Strait (1) and the East Sea (Sea of Japan) (2) of Korea.

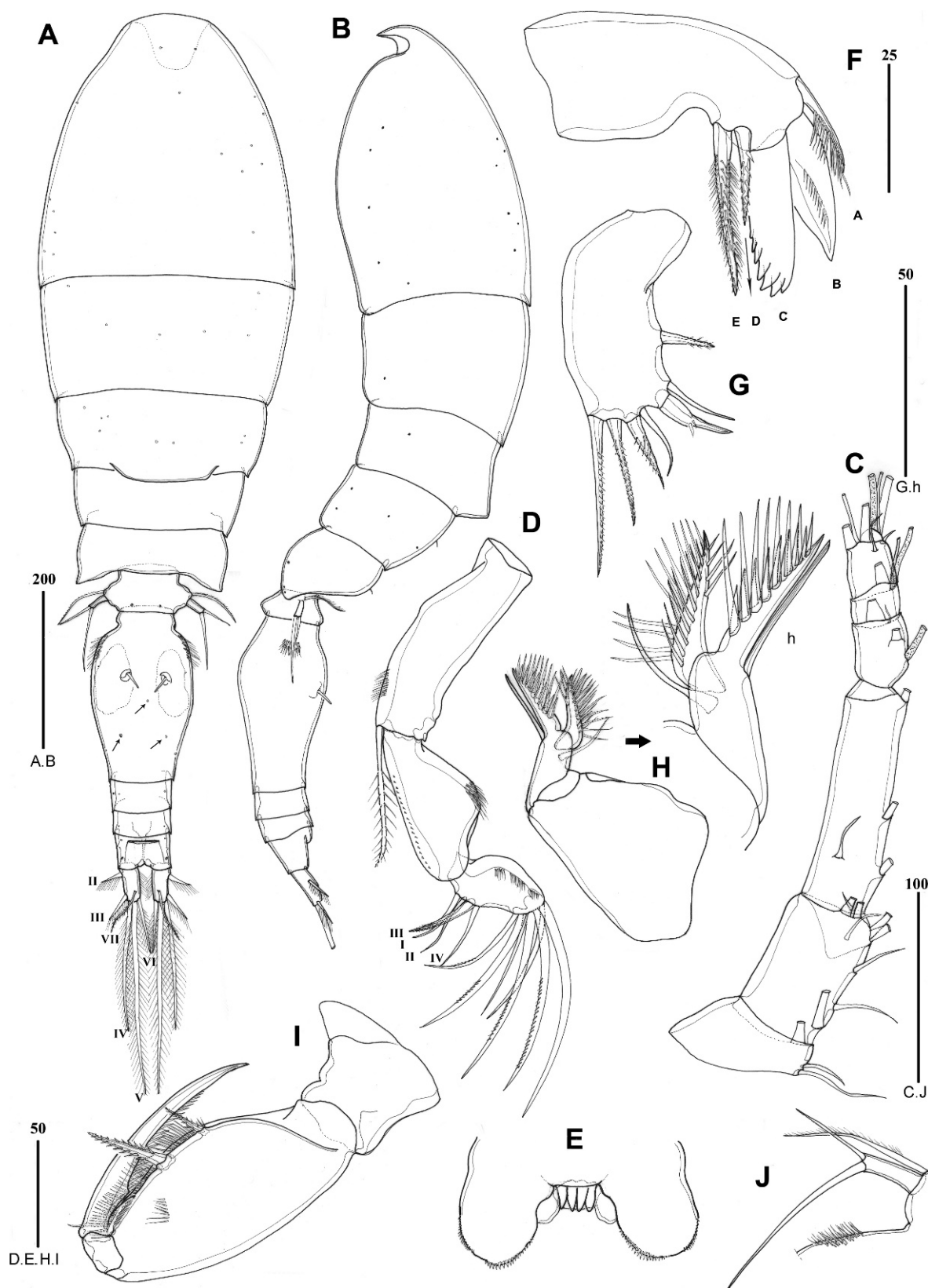


Fig. 2. *Triconia hirsuta* sp. nov., female (Holotype: B-H, J). A, habitus, dorsal view, arrows indicating secretory pores; B, habitus, lateral view; C, antennule; D, antenna, individual elements on lateral margin of second endopodal segment numbered using Roman numerals; E, labrum, posterior view; F, mandible, individual setae designated using capital letters; G, maxillule; H, maxilla [h: detail of allobasis]; I, maxilliped; J, P5.



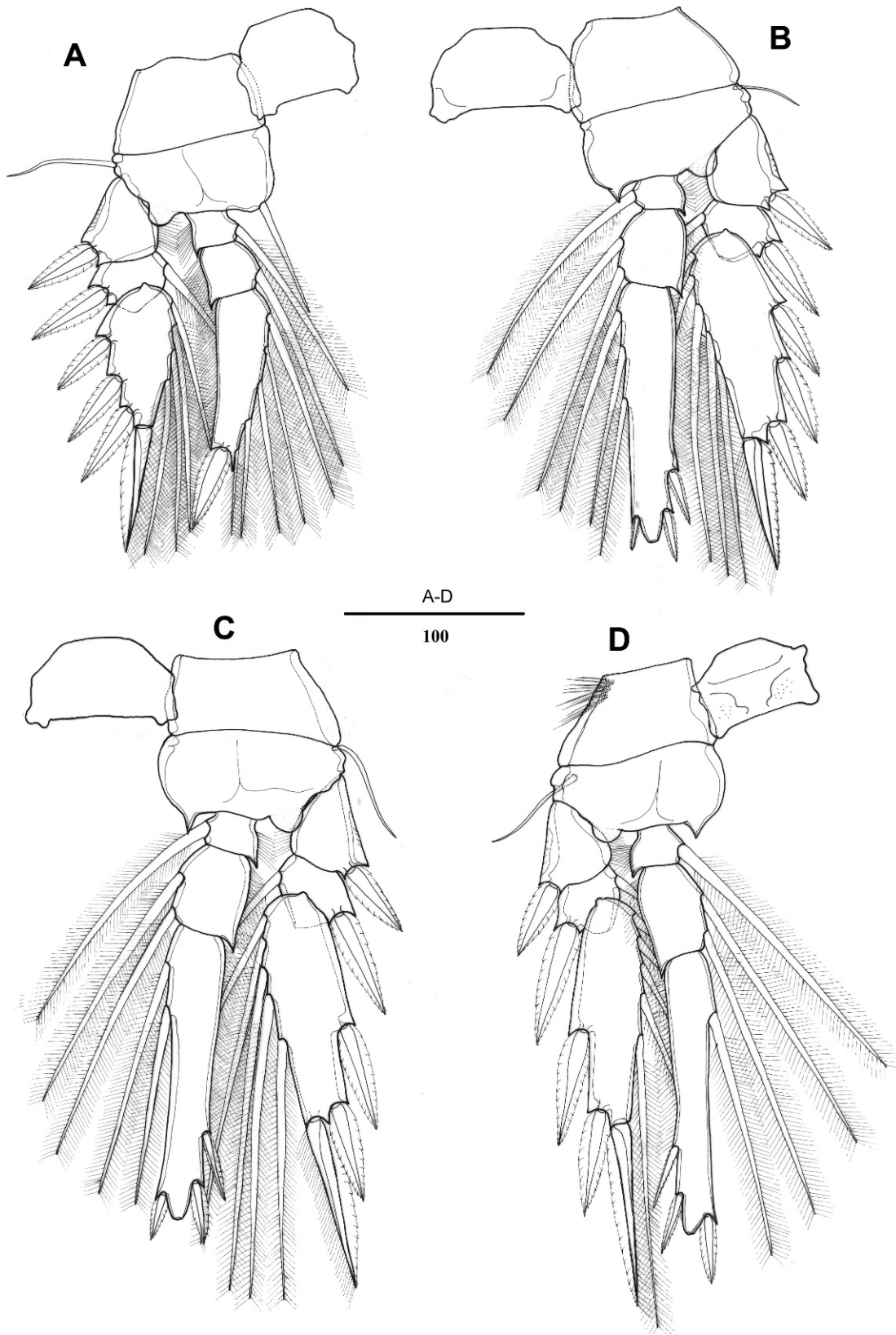


Fig. 3. *Triconia hirsuta* sp. nov., female (Holotype). A, P1, anterior view; B, P2, anterior view; C, P3, anterior view; D, P4, anterior view.

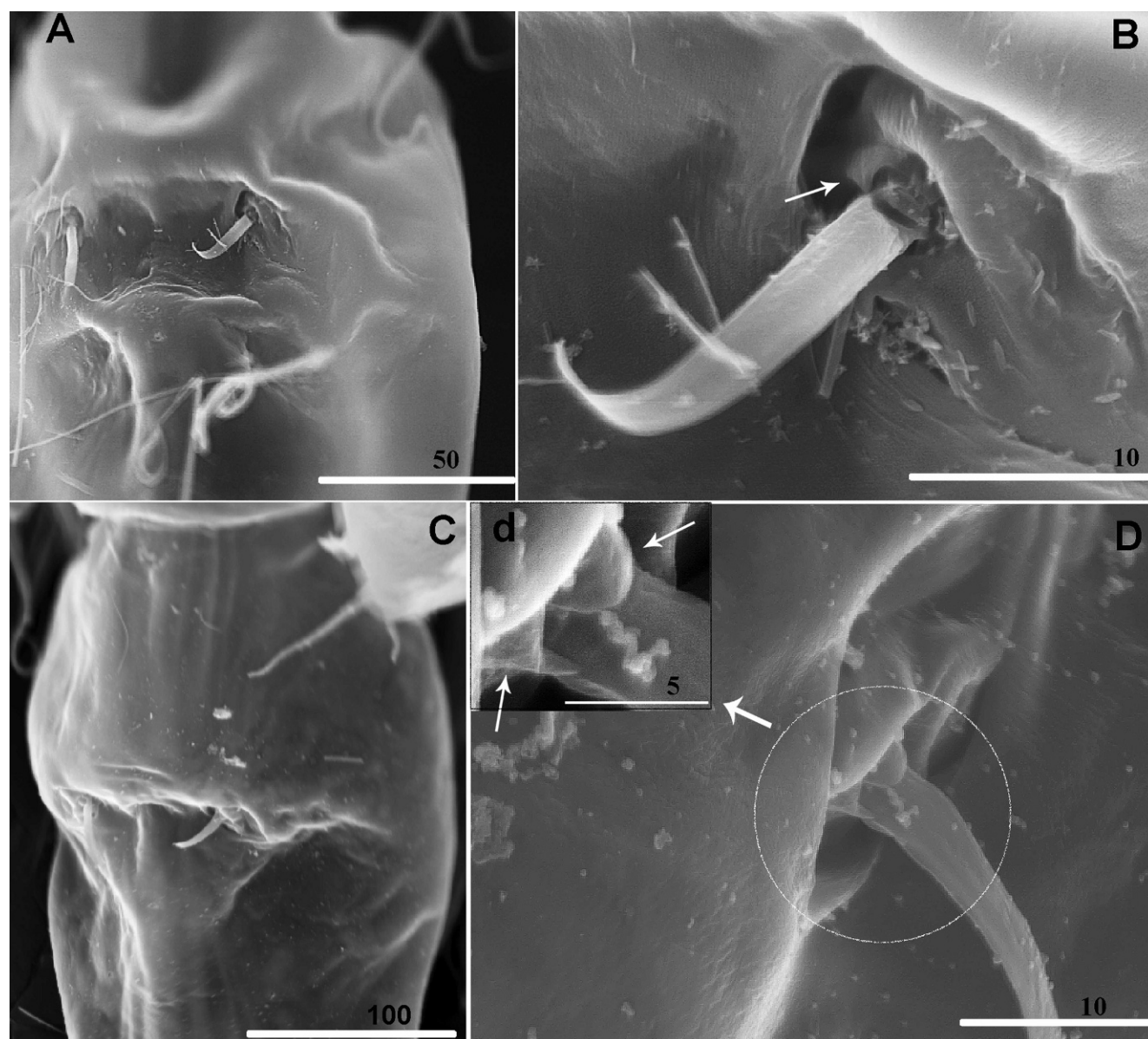


Fig. 4. SEM photographs. A, B, *Triconia hirsuta*, female; A, genital apertures; B, genital aperture, right, arrow indicating bended process near base of spine. C, D, d, *Triconia conifera*, female; C, genital apertures; D, genital aperture, right (rotated clockwise at an angle of 90 degrees); d, arrows indicating semicircular and triangular processes near base of spine on genital aperture.

wider than long. Caudal rami almost equal in length to anal somite: inner margin of CR bearing long, fine spinules; seta II articulating almost at right angle to the caudal ramus, this feature sometimes also observed in seta VII.

Antennule (Fig. 2C) 6-segmented, relative lengths (%) of segments measured along posterior non-setiferous margin 13.5: 22.5: 40.4: 10.1: 4.5: 9. Armature formula 1-[3], 2-[8], 3-[5], 4-[3 + ae], 5-[2 + ae], 6-[6 + (1 + ae)].

Antenna (Fig. 2D) 3-segmented; coxobasis ornamented with row of long, fine setules on the inner margin, armed with bipinnate seta at inner distal corner; proximal endopodal segment shorter than distal one, ornamented with row of denticles along inner margin and with protruding outer margin bearing patch of spinules; distal endopodal segment armed with 1 pectinate, spiniform seta

(III) and 3 simple setae (I, II, IV) on inner proximal margin, which are similar in length, and 5 long curved setae and 2 slender simple setae on distal margin; row of spinules along outer margin.

Labrum (Fig. 2E) distinctly bilobed, forming paired rounded posteroventral lobes with marginal teeth or denticles along outer ventral margin, and with dentiform processes along mid-ventral margin, those processes decreasing in length medially; posterior wall of medial concavity with 4 strong, sclerotized teeth; anterior face of labrum not examined.

Mandible (Fig. 2F) represented by flattened gnathobase with 5 elements: outer stout seta (A) with row of long setules; ventral blade (B) broad, bearing row of spinules on posterior surface; dorsal blade (C) strong and broad, with



several dentiform processes around distal margin and along distal third of dorsal margin; seta (D) short and pectinate; seta (E) longest and multipinnate.

Maxillule (Fig. 2G) weakly bilobed: inner lobe with 2 setae and spine, outermost spine fringed with 3 thick spinules, others setiform, innermost seta located at some distance from others; outer lobe with 4 setae, outermost one setiform, with row of minute spinules, longest; innermost one unornamented.

Maxilla (Fig. 2H) 2-segmented, comprising syncoxa and allobasis: allobasis produced distally into curved claw with two rows of very strong spinules along inner margin (Fig. 2h); outer lateral seta extending to tip of allobasis claw; proximal inner margin with simple seta and curved spine with two rows of spinules along medial margin and single row of short spinules along outer margin.

Maxilliped (Fig. 2I) 4-segmented: syncoxa unarmed; basis robust and expanded, with 2 bipinnate setae on inner margin, proximal one about half as long as distal one; row of long spinules between proximal seta and articulation with endopod and short transverse spinular row on anterior surface; proximal endopodal segment unarmed; distal endopodal segment drawn out into long, curved claw ornamented with strong pinnules along entire concave margin, accessory armature consisting of slender simple seta on outer proximal margin, and unipectinate spine basally fused to inner proximal corner of claw.

Swimming legs 1-4 biramous (Fig. 3A-D), with 3-segmented exopods and endopods, and with serrate, hyaline flanges on each spine, intercoxal sclerites well developed, without ornamentation. Terminal spine on exopod of P1 nearly equal in length to distal exopodal segment; those of P2 and P3 shorter than length of distal exopodal segment. Distal endopodal segments of P2-P4 with large conical process between outer distal and terminal spines, each projection with apical pore. Outer margin of distal endopodal segment of P1 terminating in fairly long process close to distalmost inner seta, lacking apical pore. Outer distal spine on P2 enp-3 almost equal in length to outer subdistal spine; terminal spine on P2 enp-3 hardly as long as conical process. Outer distal spine on P3 enp-3 shorter than length of outer subdistal spine. Coxa of P4 with lots of long spinules on outer margin. Armature formula of P1 to P4 as follows (Roman numerals indicate spines, Arabic numerals indicate setae):

| Leg | Coxa | Basis | Exopod          | Endopod        |
|-----|------|-------|-----------------|----------------|
| P1  | 0-0  | 1-I   | I-0;I-1;III,I,4 | 0-1;0-1;0,I,5  |
| P2  | 0-0  | 1-0   | I-0;I-1;III,I,5 | 0-1;0-2;I,II,3 |
| P3  | 0-0  | 1-0   | I-0;I-1;II,I,5  | 0-1;0-2;I,II,2 |
| P4  | 0-0  | 1-0   | I-0;I-1;II,I,5  | 0-1;0-2;I,II,1 |

P5 (Fig. 2J) with fairly long free segment, representing exopod, and plumose seta on somite, representing outer basal seta, reaching as far as tip of outer exopodal seta. Exopod about 3.0 times longer than wide, armed with 2 spiniform setae, inner one more than 2 times longer than outer one.

P6 (Fig. 2A, B) represented by external operculum closing off each genital aperture, armed with a spine.

Male.—not found

**Etymology.**—The specific name is derived from Latin *hirsutus*, meaning hirsute (hairy), and refers to the conspicuous surface ornamentation on the anterolateral margin of the genital double-somite in the female.

**Remarks.**—*Triconia hirsuta* from the western channel of Korea Strait shows all typical morphological features of the *conifera*-subgroup defined in *Triconia* Böttger-Schnack, 1999: a dorso-posterior projection on the second pedigerous somite and a conical process on the distal endopodal segments of P2 to P4. However, *T. hirsuta* can be separated from all other species of the *conifera*-subgroup by a combination of characters including: 1) the anterolateral margin of the genital double-somite being ornamented with paired patch of long fine setules; 2) the lateral margins of the genital double-somite being more rounded at mid-region; and 3) the caudal setae II articulating at a almost right angle to the caudal ramus, which sometimes is also found in seta VII. The morphology of the female genital complex is regarded as the most important character supporting the taxonomic decision of establishing the new species, because the position of the male during copulation would allow sensory interrogation of that somite complex.

Species of the *conifera*-subgroup are very close in morphology, and thus might easily be misidentified. However, due to the unique character of a hirsute surface ornamentation on the female genital double-somite, *T. hirsuta* can easily be identified without dissection of the specimens. Recently, an oncaeid of the *conifera*-type exhibiting a similar surface ornamentation on the female genital double-somite was recorded from the SE Indian Ocean, off Australia's North West Cape, which was assumed to represent a new, as yet undescribed species (McKinnon et al., 2008, as *T. conifera*). During the present study, a detailed comparison of the Australian *conifera*-type oncaeid with the Korean *T. hirsuta* confirmed that both are conspecific (R. Böttger-Schnack, unpublished data). Thus, the zoogeographical distribution of the new species is not limited to Korean waters. A thorough re-examination of all *conifera*-type oncaeids recorded from the western Pacific and eastern Indian Ocean is needed in order to clarify the existing uncertainties in the geographical distribution of species of the *conifera*-subgroup in these areas.

### *Triconia conifera* (Giesbrecht, 1891) (Figs. 4C, D, d, 5-7)

*Oncaea conifera* Giesbrecht, 1891, p. 477; Giesbrecht, 1893 ["1892"], p. 591-603, 755, 756, 774, 789, pl. 2, fig. 10, Pl. 47, figs. 4, 16, 21, 23, 28, 34-38, 42, 55, 56; Farran, 1936, p. 127, fig. 25a, d, 26a; Moulton, 1973, fig. 4Aa, e, I, fig. 4Bm, q, u; Heron and Bradford-Grieve, 1995, p. 17, 20, 21, figs. 4, 5a-h.

*Triconia conifera*: Böttger-Schnack, 1999, p. 53-60, figs. 6-8.

**Material Examined.**—Some 23 females and 5 males, collected from western channel of Korea Strait, 34°05.97'N, 129°47.32'E, (Station 1; temperature: bottom -15°C, surface -29°C) on 8 May 2008, of which 3 females and 3 males were dissected and closely examined.

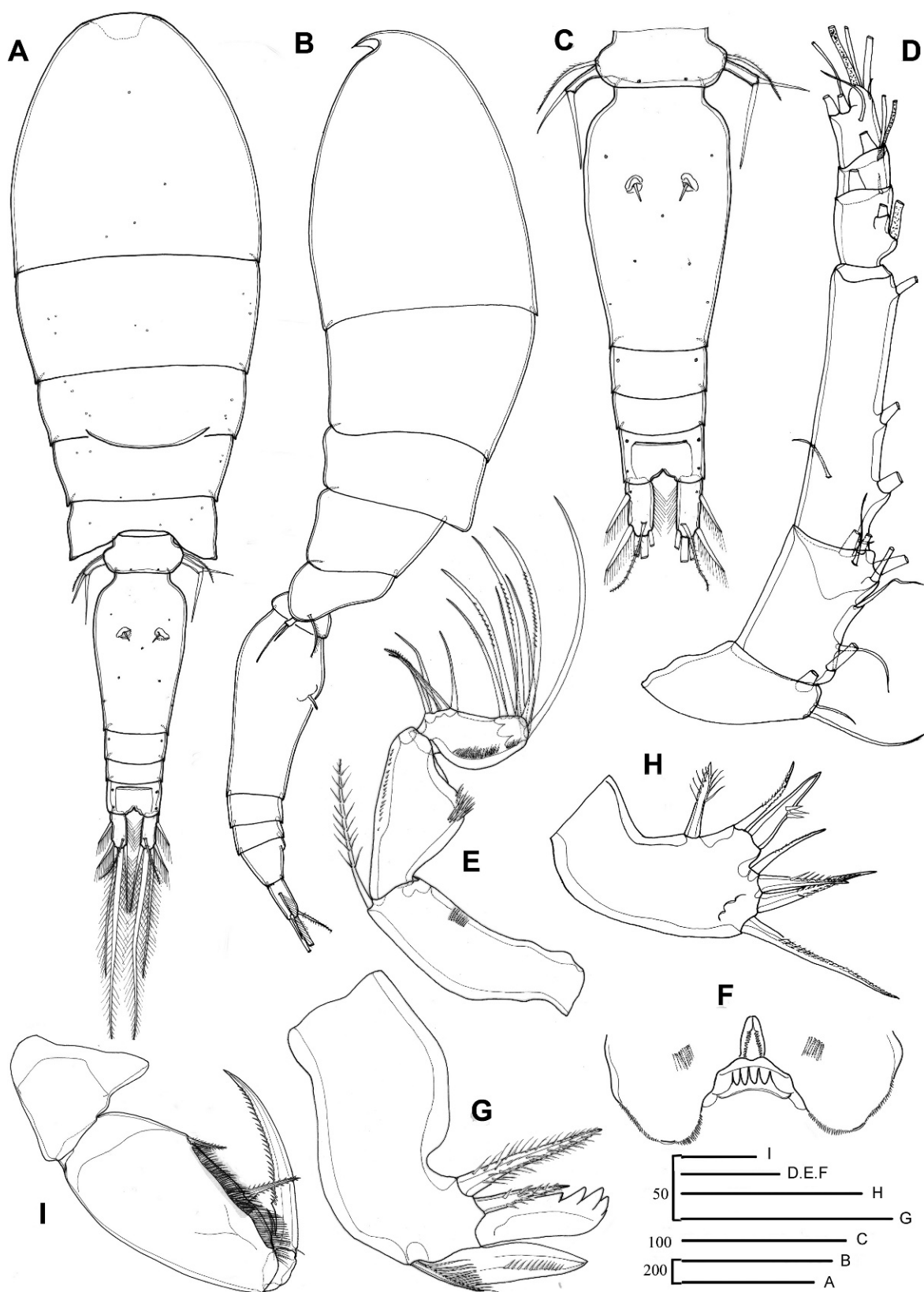


Fig. 5. *Triconia conifera* (Giesbrecht), female. A, habitus, dorsal view; B, same, lateral view; C, urosome, dorsal view; D, antennule; E, antenna; F, labrum, posterior; G, mandible; H, maxillule; I, maxilliped.



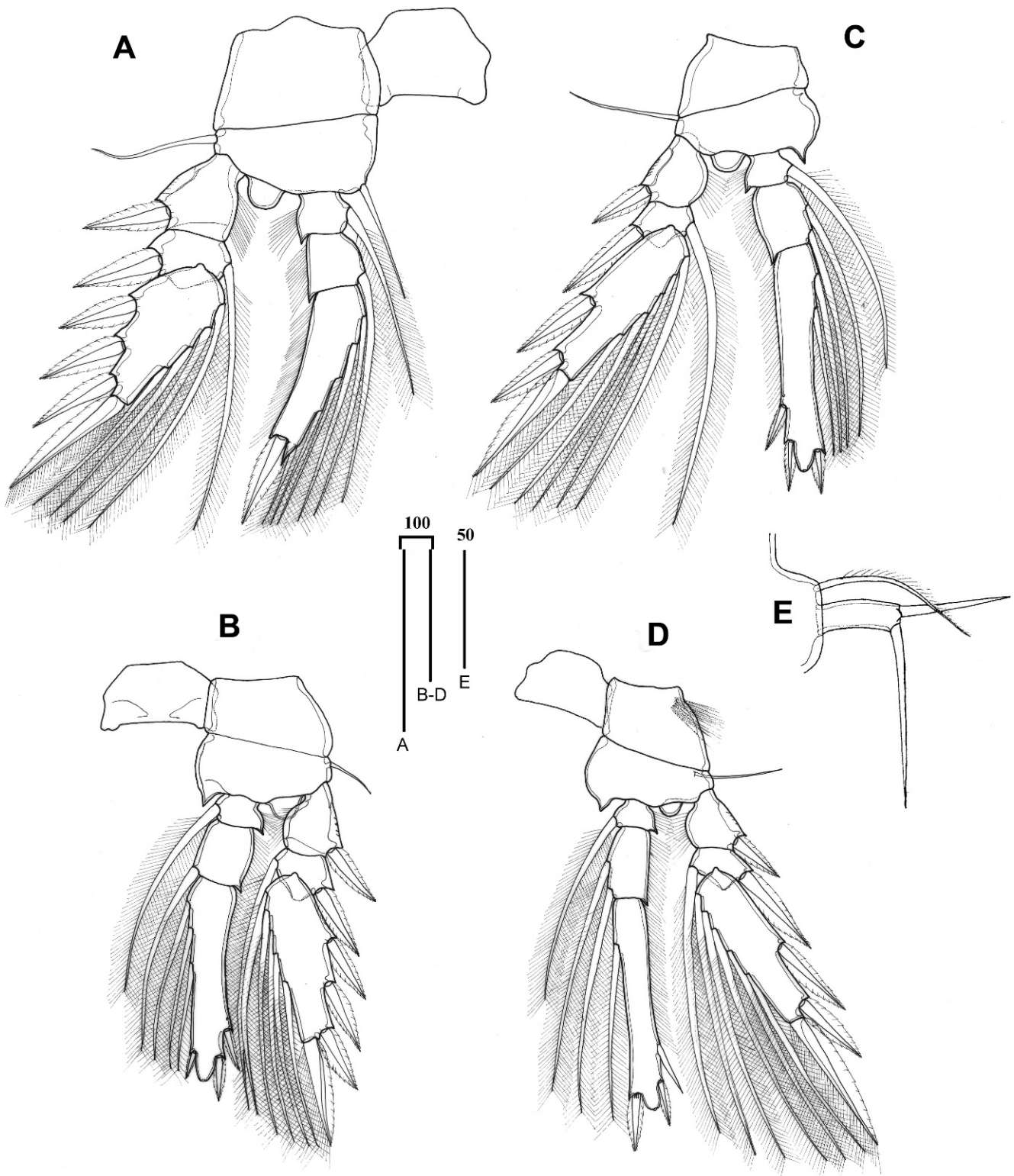


Fig. 6. *Triconia conferta* (Giesbrecht), female. A, P1, anterior view; B, P2, anterior view; C, P3, anterior view; D, P4, anterior view; E, P5.

One adult female dissected and mounted on 3 glass slides, NIBRIV0000137692. 2 females dissected on 3 glass slides, NIBRIV0000137842; 3 males dissected on 5 glass slides, NIBR0000137843; 10 females in 1 vial, NIBRIV0000137844; 2 males in 1 vial, NIBRIV0000138047.

Additional material from the western channel of Korea Strait examined: Two females in total on slides (RBS).

Female.—Body length in lateral aspect 1120–1280  $\mu\text{m}$  (mean: 1200  $\mu\text{m}$ ,  $n = 5$  individuals). Prosoma length about

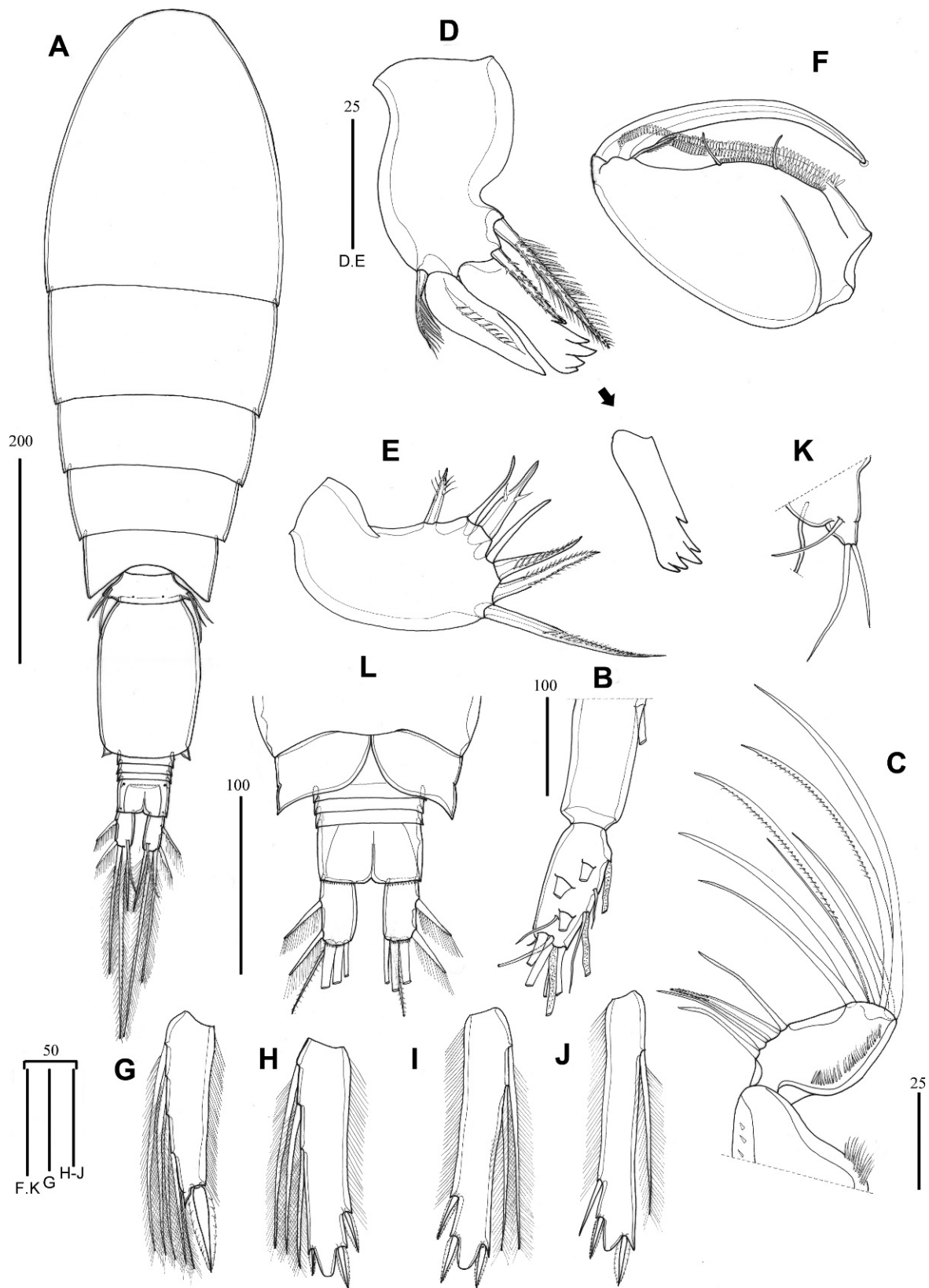


Fig. 7. *Triconia conifera* (Giesbrecht), male. A, habitus, dorsal view; B, antennule, distal segment, with most seta and aesthetascs cut short; C, antenna, distal endopodal segment; D, mandible, with dorsal blade figured separately; E, maxillule; F, maxilliped, (syncoxa not figured); G, P1 enp-3; H, P2 enp-3; I, P3 enp-3; J, P4 enp-3; K, P5; L, posterior part of genital somite (showing P6), postgenital somites, and caudal rami, ventral view.

1.7 times as long as urosome including caudal rami (Fig. 5A, B). Second pedigerous somite with conspicuous dorsoposterior projection in lateral view (Fig. 5B). Fourth pedigerous somite with rounded and slightly curved posterolateral corners (Fig. 5A). Proportional lengths (%) of urosomites 13.0: 57.6: 10.9: 7.6: 10.9. Proportional lengths (%) of urosomites and caudal rami 11.4: 50: 10: 7.1: 10: 11.4. Genital double-somite (Figs. 4C, 5A) 1.8 times as long as maximum width in dorsal view, anterolateral margin round, posterior part tapering gradually. Paired genital apertures approximately 2/5 distance from anterior margin of dorsal surface; armature represented by long spine, and semicircular process and triangular process on base of the spine (arrowed in Fig. 4D, d). Anal somite about 1.6 times wider than long (Fig. 5C). Caudal ramus almost as long as anal somite, inner margin ornamented with fringe of long, fine spinules (Fig. 5C).

Antennule (Fig. 5D) 6-segmented, relative lengths (%) of segments measured along posterior non-setiferous margin 15.5: 20.2: 41.3: 10.9: 4.6: 7.5. Armature formula as for *T. hirsuta*.

Antenna (Fig. 5E) similar to that of *T. hirsuta*, coxobasis furnished with row of fine spinules on outer margin.

Labrum (Fig. 5F) distinctly bilobed, with minute denticles along outer ventral margin and dentiform processes of graduated length along mid-ventral margin; posterior wall of medial concavity with 4 strong, sclerotized teeth; anterior face of labrum not examined.

Mandible (Fig. 5G) as in *T. hirsuta*, except for dorsal blade (C) with fewer dentiform processes (5) along distal margin.

Maxillule (Fig. 5H) similar to that of *T. hirsuta*, except innermost seta of inner lobe longer and stouter than that of *T. hirsuta*; outer lobe outermost seta with short spinules, longer than other setae.

Maxilla (not figured) as in *T. hirsuta*.

Maxilliped (Fig. 5I) similar to that of *T. hirsuta*, except for proximal seta being two third as long as distal one.

Swimming legs 1-4 (Fig. 6A-D) with armature and ornamentation as in *T. hirsuta*. Proportional spine lengths on distal endopodal segments of all legs similar to those of *T. hirsuta*, except for terminal spine on P2 exp-3 slightly longer, being always as long as distal conical projection, and outer distal and terminal spines on P3 exp-3 being relatively longer than in *T. hirsuta*.

P5 (Fig. 6E) with plumose outer basal seta, not reaching as far as tip of outer exopodal seta, and free exopod segment similar in proportional length to that of *T. hirsuta*. Exopod armed with 2 setae, inner one about 1.7 times as long as the outer one.

P6 (Fig. 4D, d, 5A-C) represented by external operculum closing off each genital aperture, armed with long spine and two small processes.

Male.—Body length measured in lateral aspect 720-793  $\mu\text{m}$  (mean: 756.5  $\mu\text{m}$ ,  $n = 5$  individuals). Sexual dimorphism evident in antennule, maxilliped, endopods of P2-P4, P6, and urosomal segmentation. Proportional lengths (%) of urosomites excluding caudal rami 11.7: 64.9: 2.6: 3.9: 2.6: 14.3. Proportional lengths (%) of urosomites including caudal rami 10.2: 56.8: 2.3: 3.4: 2.3: 12.5: 12.5. Length to

width ratio of caudal rami and proportional lengths of caudal setae as in female (Fig. 7A).

Antennule (Fig. 7B) 4-segmented; distal segment corresponding to fused fourth to sixth segments of female. Armature formula: 1-[3], 2-[8], 3-[4], 4-[11 + 2ae + (1 + ae)].

Antenna (Fig. 7C) as in female.

Mandible (Fig. 7D), maxillule (7E), maxilla (not figured) as in female.

Maxilliped (Fig. 7F) 3-segmented, comprising syncoxa (not figured), basis, and 1-segmented endopod: syncoxa without ornamentation; basis robust, expanded, posterior surface with 3 rows of short spinules of increasing length along inner margin, 2 small simple setae within longitudinal cleft; endopodal claw with unornamented concave margin; short unipectinate spine fused to inner base and small lamella at tip.

Swimming legs (Fig. 7G-J) with armature as in female. P2-P4 exp-3 with slightly shorter spines, and terminal spines of P3-P4 exp-3 also relatively shorter than those of female.

P5 (Fig. 7K) with exopod not delimited from first urosomal somite and shorter than in female, both exopodal setae slightly differing in length, with inner seta naked and much shorter than in female, outer basal seta short and naked.

P6 (Fig. 7L) represented by posterolateral flap closing off genital aperture on either side; posterolateral corners slightly protruding laterally.

Remarks.—The morphological characteristics of *T. confifera* from Korean waters agree in almost every respect with the descriptions of the species from the Mediterranean Sea and the Southwest Pacific as reported by Giesbrecht (1893 ["1892"]) and Heron and Bradford-Grieve (1995). The only notable difference was found in the proportional length of the spine on the second exopodal segment of P3, which reaches as far as the insertion point of the proximal spine of the third exopodal segment (cf. Fig. 6C), while in the re-description of *T. confifera* from the Gulf of Naples in the Mediterranean Sea by Heron and Bradford-Grieve (1995: fig. 5C), the spine is described as being shorter, not reaching the insertion point of the proximal spine on P3 exp-3. In the original description of the species by Giesbrecht (1893 ["1892"]), on the other hand, a detailed description of the exopod of P3 is lacking. In the identification key of oncaeid species constructed by Heron and Bradford-Grieve, this character is used amongst others to differentiate *T. confifera* from the closely related *T. quadrata* Heron and Bradford, 1995. To relieve this lack about the proportional spine length of the exopod of P3 in *T. confifera*, an undissected female specimen from the western Mediterranean Sea collected during recent taxonomic studies of Mediterranean oncaeids (Böttger-Schnack and Schnack, 2009) was re-examined. In this specimen the spine on P3 exp-2 reaches beyond the insertion of the proximal spine of P3 exp-3, in light of this variability being more similar to the feature described for Korean specimens than to those reported by Heron and Bradford-Grieve. Thus, the usefulness of this character to differentiate *T. confifera* from closely related species is doubted, in



particular as no sufficient information about the intraspecific variation of proportional spine lengths in *T. conifera* is available.

Böttger-Schnack (1999) described *T. conifera* from the Red Sea, which had been identified by using the identification key of Heron and Bradford-Grieve (1995), even though the author noted some slight morphological differences in the Red Sea specimens, including: 1) the proportional spine lengths on P3 exp-2; 2) the sexual dimorphism in proportional lengths of the terminal setae of P5; and 3) the endopodal spines of P2-P4. A comparison of the description of *T. conifera* sensu Böttger-Schnack (1999) with specimens from Korean waters shows the first character to be similar in specimens from both areas (but see discussion above), while the differences in the latter two characters were confirmed. In addition to these two parameters, several morphological differences not mentioned by Böttger-Schnack (1999) were noted between female specimens from the Red Sea and the genuine *T. conifera*, including: 1) the proportional lengths of the urosomites, with the two post-genital somites being relatively shorter in specimens from the Red Sea than in those of *T. conifera* from Korea; 2) the form of the female genital double-somite, with the subanterior lateral margin being distinctly contracted in specimens from Red Sea, giving a recurved appearance in dorsal view (Böttger-Schnack, 1999: fig. 5C), which is not found in specimens from Korean (cf. Fig. 5A, C) and Mediterranean waters (Heron and Bradford-Grieve, 1999: fig. 4c; R. Böttger-Schnack, personal observation); 3) the proportional spine lengths of P4 exp-3, being somewhat smaller in the Red Sea than in those from Korean and Mediterranean waters; 4) mandible blade C with fewer dentiform processes; and 5) genital apertures with long spine and one more process than specimens from the Red Sea. In the male, Red Sea specimens appear to exhibit a slightly shorter seta VII on the caudal ramus as compared to specimens from Korean waters. In conclusion, the above differences in morphological characters lead to the conclusion that specimens from the Red Sea are not conspecific with *T. conifera*, but represent a distinct, yet closely related species of the *conifera*-subgroup, which needs to be re-examined and described in more detail. Some of the morphological differences warrant further justification as they might be variable (e.g., the proportional spine lengths on the swimming legs), but the clear differences in the form of the female genital-somite and proportional lengths of urosomites strongly support this suggestion.

*Triconia borealis* (Sars, 1918)

(Figs. 8-10)

*Oncaea conifera* Sars, 1900, p. 113, pl. 32, figs. 15, 16.

*Oncaea borealis* Sars, 1918, pp. 191-193, pl. 58; Heron et al., 1984, pp. 464, 466-469, figs. 9D-G, 10, 11A-D.

**Material Examined.**—122 females and 11 males, collected from the East Sea (Sea of Japan), N 129°52.42', E 36°68.33', on 7 October 2007 (Station 2, temperature: bottom -9°C, surface -15°C), of which 3 females and 3 males were dissected and closely examined: One

adult female dissected and mounted on a glass slide, NIBRIV0000137691; 2 dissected females mounted on 3 glass slides, NIBRIV0000137839; 3 dissected males on 4 glass slides, NIBRIV0000137840; 10 undissected females in 1 vial, NIBRIV0000137841; 3 males in 1 vial, NIBRIV0000138046. Additional material from the East Sea (Sea of Japan) examined: 3 females in toto on slides, 1 female, 1 male in mating position on slide (RBS)

**Female.**—Body length in lateral aspect 564-687 µm (mean: 625.5 µm,  $n = 10$  individuals). Exoskeleton moderately sclerotized, covered with numerous granules. Prosome length 1.7 times as long as urosome including caudal rami (Fig. 8A, B). Second pedigerous somite with conspicuous dorso-posterior projection in lateral view (Fig. 8B). Fourth pedigerous somite with round posterolateral corners. Proportional lengths (%) of urosomites 11.4: 50.0: 13.6: 11.4: 13.6. Proportional lengths (%) of urosomites and caudal rami 9.7: 45.1: 12.9: 9.7: 12.9: 9.7. Genital double-somite (Fig. 8A) 1.7 times as long as maximum width (in dorsal view), about 1.3 times as long as postgenital somites combined; lateral margins of genital double-somite slightly contracted subanteriorly; posterior part tapering gradually. Paired genital apertures located at about 2/5 distance from anterior margin of genital double-somite; armature represented by long spine and 3 min spinous processes (arrowed in Fig. 10C). Anal somite about as long as wide, and longer than caudal rami, with serrate fringe along ventral posterior margin and pair of mid-ventral pores (Fig. 10E). Caudal rami 2.2 times as long as wide (Fig. 8A, I). Armature as in *T. hirsuta*; seta VI less than 2/3 as long as seta IV and about twice as long as seta V. Inner margin of ramus unornamented. Posterior margin of CR finely serrate ventrally, this ornamentation also found on lateral surface of CR at bases of seta II and III (Fig. 10E).

Antennule (Fig. 8C) 6-segmented, relative lengths (%) of segments measured along posterior non-setiferous margin 9.2: 21.5: 44.6: 10.9: 4.6: 9.2. Armature formula as for *T. hirsuta*.

Antenna (Figs. 8D, 10A) similar to that of *T. hirsuta*, ornamentation details on proximal endopodal segment showing numerous spinules along outer margin and 3 rows of denticles along inner margin as shown in Fig. 10A; distal endopodal segment shorter than proximal one, on lateral margin seta I shortest and naked, setae II, III, and IV spinulose (not discerned in Fig. 8D, but see Fig. 10A), distal margin with 5 long unipinnate setae and 2 short simple setae.

Mandible (Fig. 8E) with dorsal blade with few dentiform processes along distal two-fifth of dorsal margin, armature similar to that of *T. hirsuta*.

Maxillule (Fig. 8F) with armature similar to that of *T. hirsuta*, except for innermost seta on inner lobe being half the length of second inner seta,

Maxilla (not figured) with armature similar in number to that of *T. hirsuta*.

Maxilliped (Fig. 8G) with armature similar to that of *T. hirsuta*; proximal seta on basis about three fourth of distal one; second endopodal segment (claw) ornamented

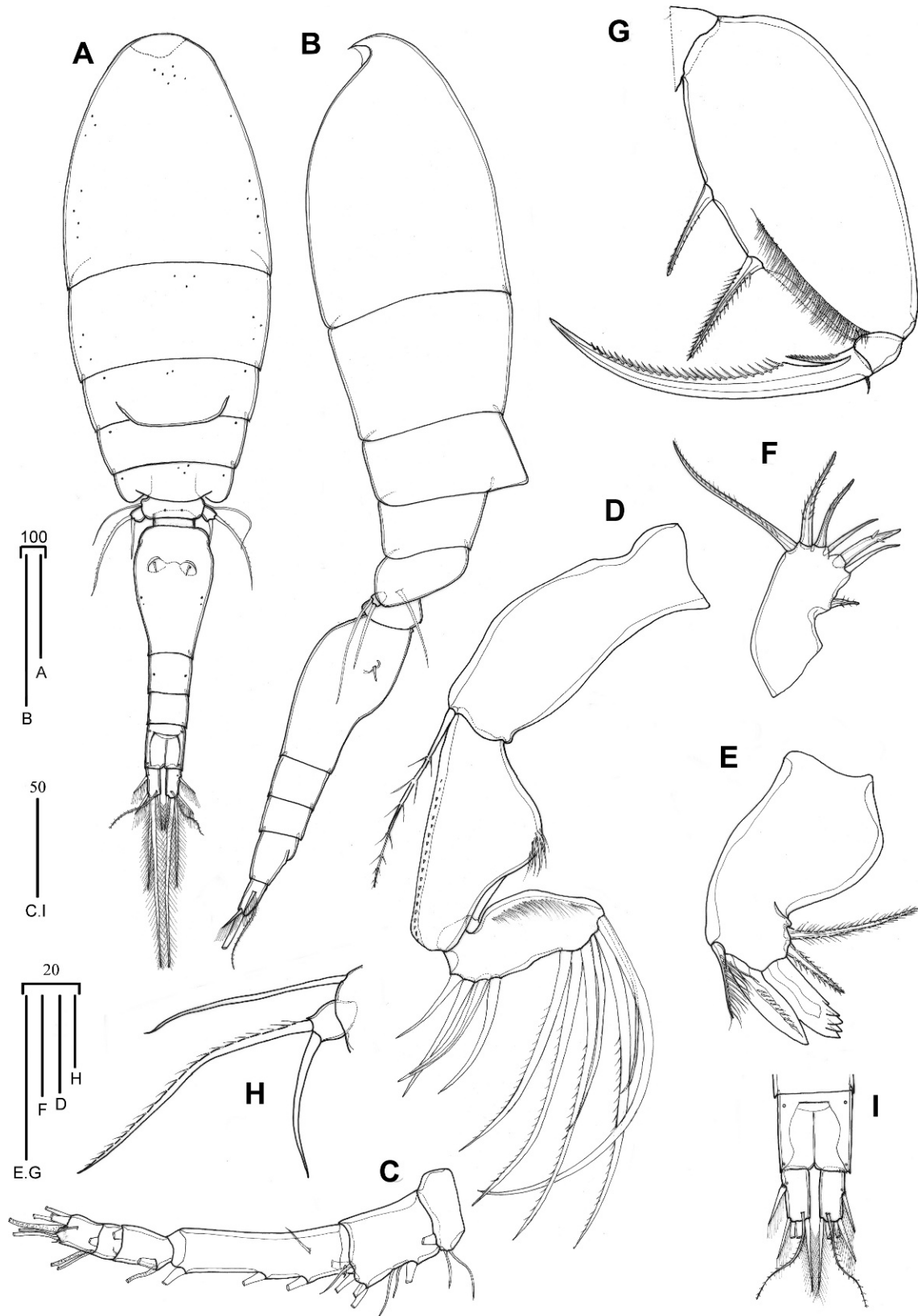


Fig. 8. *Triconia borealis* (Sars), female. A, habitus, dorsal view; B, habitus, lateral view; C, antennule; D, antenna (ornamentation on coxobasis obscured, not discerned); E, mandible; F, maxillule; G, maxilliped; H, P5; I, anal somite and caudal ramus, dorsal view, setae IV and V.

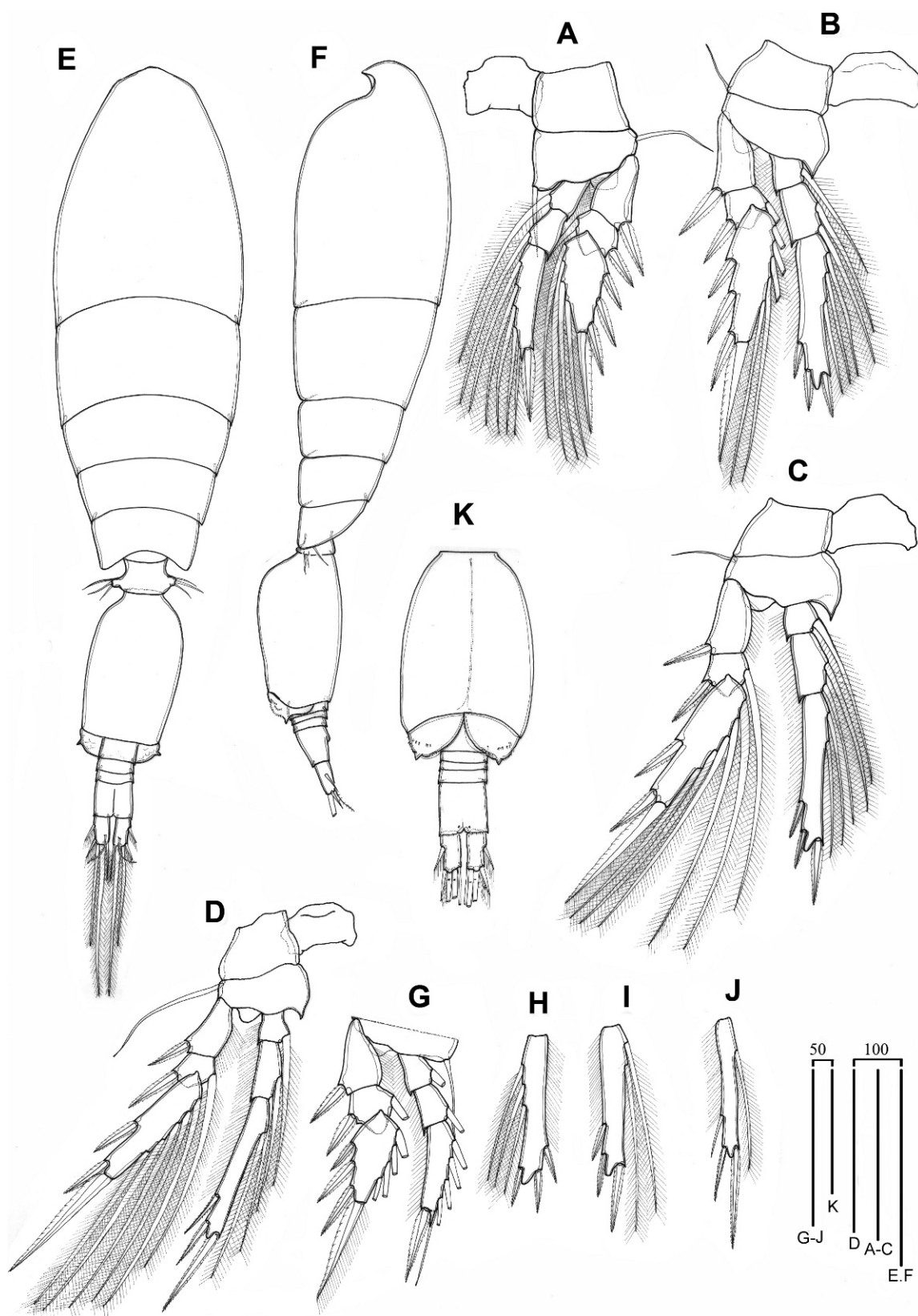


Fig. 9. *Triconia borealis* (Sars). A-D, female; A, P1, anterior view; B, P2, anterior view; C, P3, anterior view; D, P4, anterior view. E-K, Male; E, habitus, dorsal view; F, habitus, lateral view; G, P1; H, P2 enp-4; I, P3 enp-3; J, P4 enp-3; K, genital somite and caudal rami (seta not fully shown), ventral view.



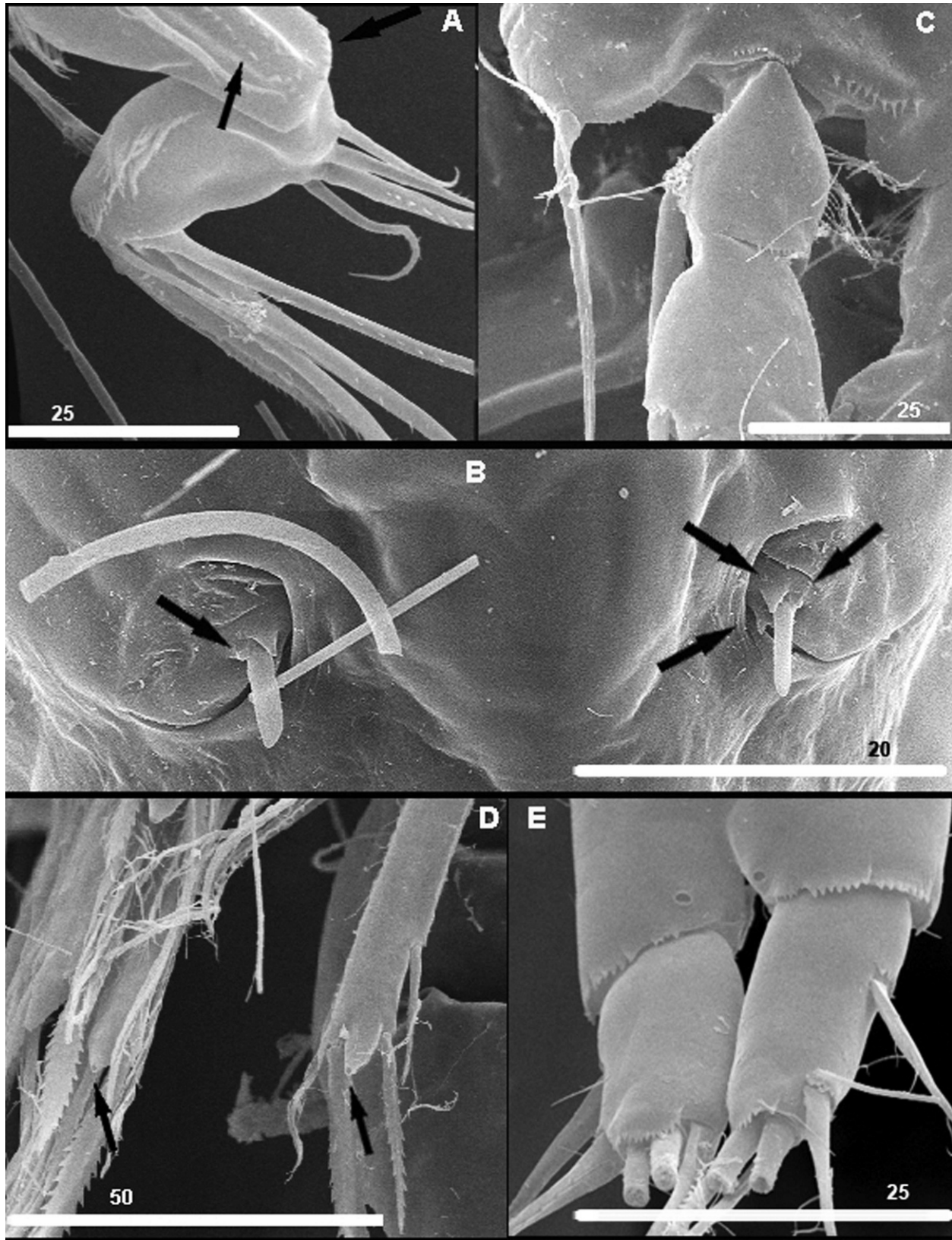


Fig. 10. SEM photographs of *Triconia borealis* (Sars), female. A, antenna, distal endopodal segment; B, genital apertures, arrows indicating spinous processes close to seta of P6; C, P1, part of basis and proximal segments of endopod, anterior view, showing inner basal seta; D, P3 and P4 enp-3, arrows indicating apical pores on conical processes; E, Caudal rami, ventral view.

with row of strong pinnules almost along entire concave margin.

Swimming legs (Figs. 8A-D, 10C, D) biramous, armature formula as in *T. hirsuta*: posterior surface of coxae and bases ornamented with rows of denticles as exemplified in Fig. 10C. Terminal spines on P1 and P3-P4 exp-3 equal in length to distal exopodal segments; that of P2 slightly shorter than distal exopodal segment. P2-P4 enp-3 with elongate conical process between outer distal and terminal spine, apical pore on process arrowed in Fig. 10D. Outer subdistal spines of P2-P4 enp-3 equal in length to outer distal spine.

P5 (Fig. 8A, H) with outer basal seta unipinnate, exopod a free segment, slightly longer than wide, armed with 2 terminal setae unequal in length, outer one long and unipinnate, inner one short and naked.

P6 (Fig. 8A, 10B) represented by operculum closing off each genital aperture; armed with long spine and 3 spinous processes (arrowed in Fig. 10B).

Male.—Body length in lateral view 380–398  $\mu\text{m}$  (mean: 389,  $n = 5$  individuals). Sexual dimorphism in antennule, maxilliped, P5–P6, setae on caudal rami, and urosomal segmentation. Prosomal length 1.8 times that of urosome excluding caudal rami (Fig. 9E, F). Proportional lengths (%) of urosomites excluding caudal rami 11.4: 63.9: 3.8: 1.9: 3.8: 15.2. Proportional lengths (%) of urosomites and caudal rami 10.2: 57.4: 3.4: 1.7: 3.4: 13.7: 10.2. Caudal rami relatively shorter than in female, and proportional lengths of caudal setae different from female: seta IV relatively longer, about 2/3 as long as seta V; and seta VI being relatively shorter, about 1/4 as long as seta V; 1/3 as long as seta IV; and seta VII about as long as seta III, shorter than in female. Rostrum not rounded, triangular in shape. Genital somite about 1.5 times as long as maximum width in dorsal view (Fig. 9E).

Antennule 4-segmented, armature formula 1-[3], 2-[8], 3-[4], 4-[11 + 2ae + (1 + ae)].

Mandible, maxillule, and maxilla as in female.

Maxilliped similar to that of *T. conifera*.

Swimming legs 1–4 (Fig. 9G–J) as in female, except proximal spine on P1 exp-3 (Fig. 9G) distinctly shorter, and the outer subdistal spine on P4 enp-3 (Fig. 9J) shorter than outer distal spine.

P5 (Fig. 9E, F) with exopod not delimited from first urosomal segment, shorter than in female, both exopodal setae slightly unequal in length, shorter than in female; outer basal seta shorter than in female.

P6 (Fig. 9E, F, K) represented by posterolateral flap closing off genital aperture on either side; covered by rows of minute denticles (Fig. 9K).

Remarks.—*Triconia borealis* from Korean waters shows the typical morphological characteristics of Norwegian *T. borealis* (cf. Sars, 1918). Heron et al. (1984) provided a detailed redescription of this species from the Arctic Ocean and the Norwegian Sea, including some important details lacking in Sars' original description: in the female 1) the seta on body near leg, and the outer terminal seta of P5 are much longer than in Sars' description; 2) the dorsal seta on the caudal rami was longer; 3) in the males, the length ratio

of prosome to urosome (excluding caudal rami) was smaller (1.8:1) than that in the description by Sars (2.15:1).

The present specimens from Korean waters agree with those of Heron et al. (1984), except for the following points in the female: 1) the length of the spine on P3 exp-1 almost equal to that of the spine on P3 exp-2, which is similar to the description by Sars (1918), but differs from that given by Heron et al. (1984), in which the spine on P3 exp-1 is longer than the one on P3 exp-2; and 2) the length of the innermost seta on the inner lobe of the maxillule is relatively shorter as compared to the female specimens described by Sars (1918) and Heron et al. (1984). In the male from Korean waters 1) the length ratio of CR seta V to seta VI (about 2.3: 1) is smaller than was reported for Arctic specimens (Heron et al., 1984: fig. 11B); and 2) the genital flaps are ornamented with minute denticles (not figured by Heron et al., 1984). Moreover, the sexual dimorphism in proportional spine lengths on the exopods and endopods as well as several other morphological details were not noted in the earlier descriptions. Among these, the presence of an apical pore on the conical process of P2–P4 enp-3 (Fig. 10D) is noteworthy, as it is typically found in oncaeids (Böttger-Schnack, 1999, 2003). Even in species exhibiting a reduced conical process on the endopods of P2 and P3, such as *Oncaea tregoubovi* Shmeleva, 1968, the apical pore can still be discerned between the outer distal and the terminal spines (Huys and Böttger-Schnack, 2008: fig. 6D, E).

Compared to specimens from arctic and subarctic waters, *T. borealis* from Korean waters are smaller by about 11–13% and 3–21% for females and males, respectively (Table 1). The smaller size of Korean specimens may be due to unfavorable environmental conditions encountered at the limit of their zoogeographical distribution. The East Sea of Korea (Station 2) represents the most southerly distribution so far recorded for this species (<http://copepodes.obs-banyuls.fr/en>), in waters marked by temperatures about 10–15°C higher (<http://portal.nfrdi.re.kr/envirodata>) than in the Arctic or Subarctic.

## DISCUSSION

### Taxonomy

Böttger-Schnack and Huys (1998) performed a preliminary phylogenetic analysis of Oncaeidae based on a total of 52 morphological characteristics, ultimately recognizing 20 species groups within the family (their Fig. 1). Most of the branches represented robust groupings and were indicated as monophyletic lineages, which may deserve generic status. The third and fourth clade included 14 oncaeid species characterized by a conical process on distal endopodal segment of P2 to P4. Subsequently, a new genus *Triconia* was established to accommodate the species of these two clades (Böttger-Schnack, 1999). *Triconia* is considered as the sister-group of *Oncaea* (Böttger-Schnack, 1999) because both genera have integumental pockets on the anterior surface of the labrum and the formation of a dorso-posterior projection on the second pedigerous somite (Böttger-Schnack, 1999, 2001). Comprehensive taxonomic studies on the species diversity of oncaeid copepods over



Table 1. Total body length (in  $\mu\text{m}$ ) of *Triconia borealis* from Korean waters with comparison to specimens from other areas. x = mean; R = Range; n = number of specimens measured; ? = not given.

|                             | Females |          |     | Males |          |     | Source              |
|-----------------------------|---------|----------|-----|-------|----------|-----|---------------------|
|                             | x       | R        | n   | x     | R        | n   |                     |
| Arctic Sea                  |         |          |     |       |          |     |                     |
| Polar Sea, north of Siberia | ~ 700   |          | ?   | ~ 400 |          | ?   | Sars (1918)         |
| Norwegian Sea (Polar front) |         | 680-840  | ?   |       | 440-480  |     | Heron et al. (1984) |
| Other areas                 |         |          |     |       |          |     |                     |
| Canadian Basin              | 720     | 640-760  | 25  | 490   | 440-560  | 28  | Heron et al. (1984) |
| NE Pacific                  |         | 640-720  | ?   | 480   |          | 1   | Heron et al. (1984) |
| Washington inland waters    |         | 680-740  | ?   |       | 480-560  | ?   | Heron et al. (1984) |
| NW Pacific                  |         |          |     |       |          |     |                     |
| Subarctic                   | 700     | $\pm 18$ | 100 | 424   | $\pm 12$ | 190 | Nishibe (2005)      |
| East Sea of Korea           | 625     | 564-687  | 10  | 389   | 380-398  | 5   | this study          |

the past years have shown that *Triconia* is one of the most speciose genera within the family (Boxshall and Halsey, 2004), and the discovery of new species in this genus shows no tendency to decline. During recent taxonomic studies on the oncaeid fauna of the Mediterranean Sea, in addition to six identified species of *Triconia*, the high number of eight additional taxa of unresolved taxonomic status were recorded (Böttger-Schnack and Schnack, 2009). Those await further examination and description.

Studies of *Triconia* in the western Pacific were carried out by Chen et al. (1974) and Itoh (1997), who both recorded four species (as *Oncaea conifera* Giesbrecht, 1981, *O. similis* Sars, 1918, *O. minuta* Giesbrecht, 1983, and *O. dentipes* Giesbrecht, 1981), representing all three subgroups of the genus. Females of *O. conifera* described by Chen et al. (1974) were distinctly smaller (0.72-0.80 mm) than elsewhere (cf. Razouls et al., 2009) whereas the size of the males (0.72-0.76 mm) was within the range of values reported from other areas. [Note: the lower range of female sizes (0.75-1.25) reported by Conway et al. (2003) in a zooplankton guide of the SW Indian Ocean is regarded as doubtful here, because those authors did not consider the most recent taxonomic data for oncaeids]. The resulting lack of any sexual size dimorphism in the specimens studied by Chen et al. (1974) is very unusual for *T. conifera* and requires re-investigation of their data, in particular as a more “typical” size dimorphism becomes obvious when re-calculating the body sizes of both sexes from their habitus drawings (their Plate 6, Figs. 6 and 10). Moreover, the description of Chen et al. (1974) also lacks many important details, such as the genital apertures on the female genital double-somite, as well as descriptions of the antennule, antenna, and mouthparts. Itoh (1997) distinguished three forms of *T. conifera* (“stocky”, “minus” and “bumped” forms) from Japanese waters, which, according to Heron and Bradford-Grieve (1995), correspond to *T. conifera*, *T. redacta*, and *T. derivata*, respectively. Itoh’s (1997: Pl. 225a-e) “stocky” form was most similar in morphology to *T. conifera* from Korean waters, although the variation in the length-to-width ratio of CR was fairly large in his specimens (1.9-2.7: 1), while in *T. conifera* from Korean waters this ratio was about 2.0: 1, showing little variation.

Hereafter, further morphological comparison and a thorough taxonomic revision of species in the *conifera*-subgroup from the western Pacific, Korean waters, the Yellow Sea, the East China Sea, and Japanese waters, is required as the species diversity of this taxon appears to be much higher than previously known from this area.

#### Community Structure and Zoogeography of species of *Triconia* of the *conifera*-subgroup in the Western North Pacific

Recently, many species of *Triconia* have been reported in the NW Pacific sampled with fine-mesh nets (Nishibe, 2005; Nishibe and Ikeda, 2004, 2007a, b, 2008; Nishibe et al., 2009), while only a small number has been recorded from waters around Taiwan (Hsieh et al., 2004; Lee et al., 2009). Nishibe and Ikeda (2004) and Nishibe (2005) studied the abundance, community structure, and vertical distribution down to ~ 2000 m depth of a total of 40 oncaeid species, including 11 species of *Triconia* at a station in the Oyashio Current region, western subarctic Pacific, which was temporarily influenced by warm-core rings of the Kuroshio Current in the upper 300 m. They recorded five species of the *conifera*-subgroup [*T. borealis*, *T. canadensis* (Heron and Frost, 2000), *T. thoresoni* (Heron and Frost, 2000), *T. redacta*, and *T. conifera*] in this area, of which the fairly small-sized *T. borealis* was by far the most abundant species on all sampling dates, being especially numerous in the upper 250 and/or 500 m depth layers. The larger *T. canadensis* and *T. thoresoni* were relatively abundant in the lower mesopelagic (250-1000 m) and bathypelagic zones (1000-2000 m), while *T. conifera* occurred in the subarctic NW Pacific area only during periods of intrusion of Kuroshio waters. More recently, Nishibe et al. (2009) examined the vertical distribution of the oncaeid copepod community down to 500 m depth in Tosa Bay, southern Japan, an area influenced by the Kuroshio Current. They recorded 13 species of *Triconia*, with the *conifera*-subgroup being represented by 4 species [*T. conifera*, *T. derivata*, *T. furcula* (Farran, 1936), and *T. redacta*]. *T. conifera* was the most abundant species among these four.

Hsieh et al. (2004) investigated the copepod diversity and composition with respect to intrusion of the Kuroshio



Branch Current (KBC) in the northern Taiwan Strait and reported only three species (*T. conifera*, *T. similis* and *T. minuta*), which co-occurred in areas representing high salinity and temperature under the influence of the KBC. No *Triconia* species except for *T. conifera* was reported in another comprehensive study (using a fine-mesh net of 100 µm) on the seasonal and spatial variations of copepod community structures in various regions of the East China Sea, including the Kuroshio Current, the northern Taiwan Strait and various coastal areas (Tseng et al., 2008). It cannot be ruled out that taxonomic difficulties in identifying the numerous species of the *conifera*-subgroup and other species of *Triconia* might at least partly be responsible for such an allegedly low species diversity of the genus in these areas.

In the present study, the three *Triconia* of the *conifera*-subgroup showed a remarkable difference in regional distribution, indicating their respective preference for different water masses: *T. conifera* and its sibling *T. hirsuta* were collected in the south coast of Korea (Korea Strait) during all seasons, affected by the KBC and the Tsushima Warm Current (TWC) (Teague et al., 2003). On the other hand, the two species did not occur in the East Sea (Sea of Japan) in October. Females of both species co-occurred during February and May and were numerically abundant in May. Also, in February ovigerous females of *T. conifera* were found and in May males and females in mating position were observed, indicating a period of reproduction. *T. borealis*, on the other hand, appeared in the East Sea (Sea of Japan) only sporadically (in October) and was not found in the south coast of Korea at all. The East Sea (Sea of Japan, Station 2) is influenced by a branch of the Liman Current, the North Korea Cold Current (NKCC), during fall to winter, when the TWC shifts eastwards to the Korea Strait (Teague et al., 2006, their Fig. 5). These two currents appear to be closely connected with the distribution of the three *Triconia*, and *T. hirsuta* is suggested to be an immigrant accompanying warm water masses.

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