

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/271418443>

# A new species of Centropages (Copepoda: Calanoida: Centropagidae) from the central Red Sea based on morphological and molecular evidence

Article in *Zootaxa* · January 2015

DOI: 10.11646/zootaxa.3911.3.6

CITATIONS

3

READS

390

2 authors, including:



Mohsen El-Sherbiny

King Abdulaziz University

80 PUBLICATIONS 484 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Biofouling community recruitment and succession on aquaculture cages deployed in Red Sea [View project](#)



Nutrient gradients in the Red Sea [View project](#)



## A new species of *Centropages* (Copepoda: Calanoida: Centropagidae) from the central Red Sea based on morphological and molecular evidence

MOHSEN M. EL-SHERBINY<sup>1,2,3</sup> & ALI M. AL-AIDAROOS<sup>1</sup>

<sup>1</sup>Department of Marine Biology, King Abdulaziz University, Jeddah 21589, Saudi Arabia

<sup>2</sup>Department of Marine Sciences, Suez Canal University, Ismailia 41522, Egypt

<sup>3</sup>Corresponding author. E-mail: oomar@kau.edu.sa

### Abstract

*Centropages mohamedi* sp. nov. (Copepoda: Calanoida) is described from specimens collected in zooplankton samples off Obhur Creek on the Saudi Arabian coast of the central Red Sea. The new species is most closely related to *C. orsinii* Giesbrecht, 1889, a species described from the Red Sea and widely distributed in the neritic waters of the Indo-West Pacific region. The new species is mainly distinguished by the female genital double somite, male antennules, male leg 4, and leg 5 of both sexes. DNA sequences of the mitochondrial cytochrome C oxidase subunit one (mtCOI) of the two species differ by 20.8%, supporting their morphology-based identification as distinct species.

**Key words:** morphology, mtCOI, Saudi Arabia, taxonomy, zooplankton

### Introduction

The Red Sea is an oligotrophic sea and can be considered an extreme environment for plankton owing to its high salinity, lack of any fresh water supply and a high evaporation rate, as well as isolation from the open ocean (Weikert 1987). During the last decade, more attention has been paid to the plankton community by shore-based laboratories in Red Sea countries, resulting in the discovery of several planktonic copepod species new to science or to the fauna of the Red Sea (e.g. El-Sherbiny & Ueda 2008a, b; El-Sherbiny 2009, 2011; El-Sherbiny & Al-Aidaros 2013, 2014; Ohtsuka *et al.* 2000). The genus *Centropages* (Family: Centropagidae) presently comprises 34 species, including 3 doubtful species (Razouls *et al.* 2014). This genus has a worldwide distribution with species being distributed across a wide range of marine environments, from low to high latitudes (Vervoort 1964; Bradford-Grieve 1999; Bradford-Grieve *et al.* 1999; Boxshall & Hasley 2004). Some coastal species are abundant, comprising a main component of copepod communities and playing important roles as food for fish (Brodsky 1950; Chen & Zhang 1965). In the Red Sea, the following nine species of the genus have hitherto been recorded (Halim, 1969; El-Sherbiny & Ueda 2008a; El-Sherbiny 2011): *Centropages aegypticus* El-Sherbiny & Ueda, 2008, *C. calaninus* Dana, 1849, *C. elongatus* Giesbrecht, 1896, *C. furcatus* (Dana, 1849), *C. gracilis* (Dana, 1849), *C. kroyeri* Giesbrecht, 1892, *C. orsinii* Giesbrecht, 1889, *C. uedai* El-Sherbiny, 2011, and *C. violaceus* (Claus, 1863). During our study of zooplankton diversity in coastal waters around Obhur Creek, near Jeddah coastal water on the Saudi Arabian coast of the Red Sea, an undescribed species of planktonic calanoid copepod of the genus *Centropages*, very closely related to *C. orsinii*, was collected. Here, we describe this new species and compare it morphologically and genetically with *C. orsinii* collected from the central Red Sea, its type locality.

### Material and methods

**Sample collection.** *Centropages* specimens of the new species were collected from the coastal waters off Obhur Creek, the central Red Sea (21°41.37'N, 39°2.13'E) on 31 May 2012, and specimens of *Centropages orsinii* were

sampled on 10 June 2013 from Obhur Creek (21° 41.398' N, 39° 3.002' E) (Fig. 1). Samples were collected by horizontal tows of a 150 µm mesh plankton net near the sea surface. Immediately after sampling, specimens for morphological examination were fixed in a 4% formalin-seawater solution; those for genetic analyses were fixed in 95% ethyl alcohol. The alcohol was changed after 1 day. Temperature and salinity in the surface water were measured using a multiparameter water quality meter (Horiba U-50). During the sampling time, the temperature and salinity off Obhur Creek were 26 °C and 39.9 respectively, and those at Obhur Creek were 25.6 °C and 39.8 respectively.

**Morphological examination.** Microscopic examination and dissections were made in polyvinyl lactophenol using bright-field and differential interference microscopes (Nikon DM 6000). For detailed observations, specimens were stained with a 0.1% Rose Bengal solution. Drawings were made with a camera lucida attached to the microscope. Terminology follows Huys & Boxshall (1991). Specimens were deposited in the collection of the National History Museum, London. For scanning electron microscopy, specimens were washed in filtered seawater, and then clean distilled water, dehydrated through an alcohol series 30–100% (ethanol) and subsequently critical-point-dried. The specimens were mounted on a stub, coated with gold palladium, and observed with a SEM Hitachi S-3500N.

**Molecular analysis.** DNA sequences were determined for portions of the mitochondrial gene cytochrome oxidase subunit one (mtCOI). Individual adult female copepods were identified under a dissecting microscope at ×250 magnification. Each individual for mtCOI analysis was placed in a capped 0.2 ml microcentrifuge tube. Individual copepods were digested in 400 µl ATL buffer (Qiagen) and 20 µl Proteinase K overnight. After digestion 400 µl of AL buffer was added and DNA extraction continued using Qiagen's Blood and Tissue kit as per the manufacturer's instructions. DNA was precipitated in 30 µl AE buffer and mtCOI amplicons were amplified using the PCR primers LCO1490 and HCO2198 (Folmer *et al.* 1994). The reaction conditions were: initial denaturation for 5 min at 95 °C, followed by 40 cycles of 94°C (1 min); 47°C (2 min); 72°C (3 min). A final extension at 72 °C for 10 min was undertaken. PCR products were purified using ExoStar (Illustra) and sequencing was carried out in an ABI 3730xl Capillary Sequencer. The machine-read sequences were compiled using Sequencing Analysis (Ver. 3.3, ABI prism) and manually checked for accuracy. Multiple-sequence alignments were made using CLUSTAL X version 2.0 (Larkin *et al.* 2007). Pairwise distance measures and phylogenetic analyses were conducted using MEGA 6 software (Tamura *et al.* 2007). Ambiguous sites were eliminated from the dataset.

## Results

### Subclass Copepoda Milne Edwards, 1830

### Order Calanoida G. O. Sars, 1903

### Family Centropagidae Giesbrecht, 1893

### Genus *Centropages* Krøyer, 1849

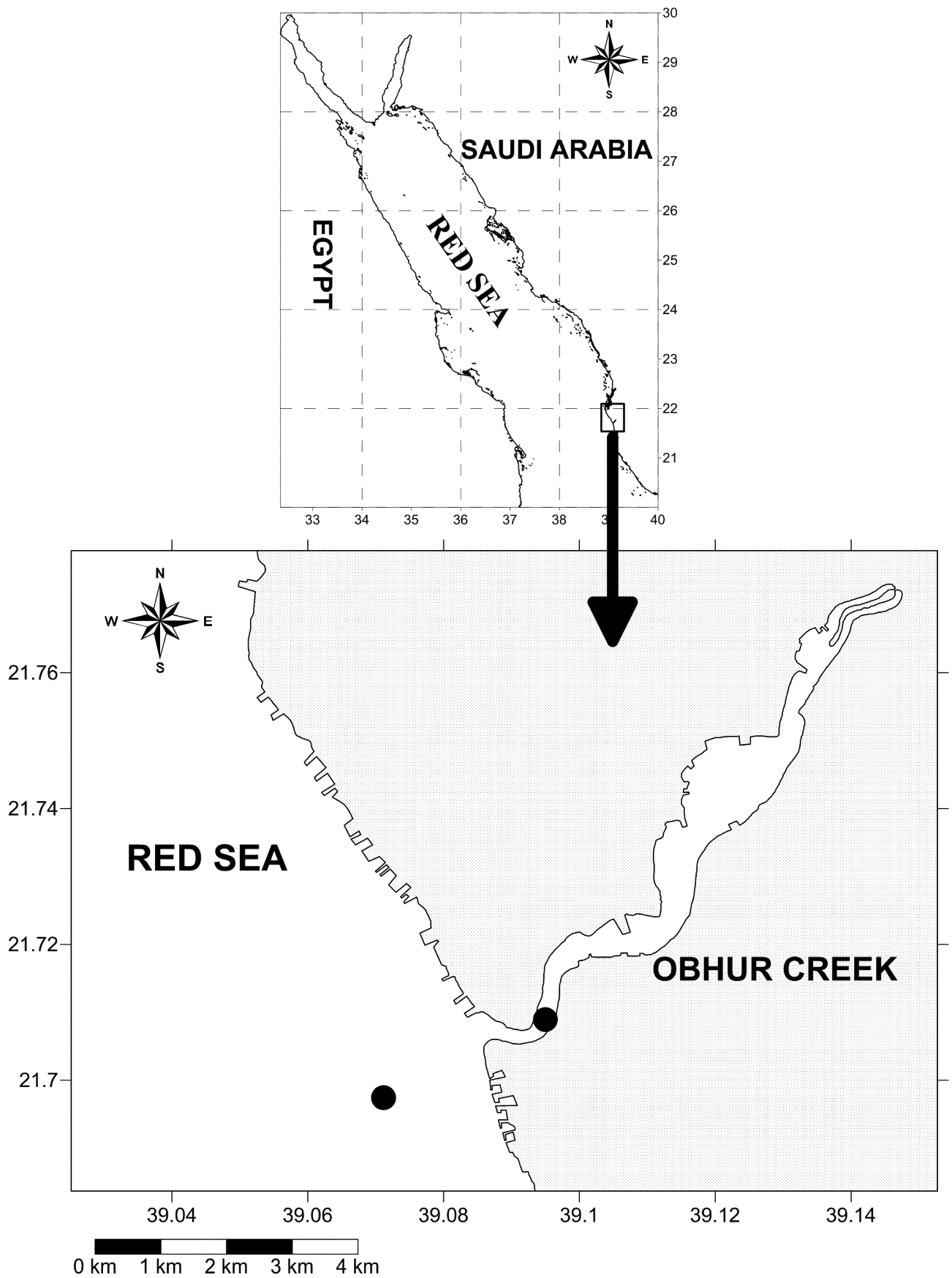
#### *Centropages mohamedi* sp. nov.

(Figs 2,4–6)

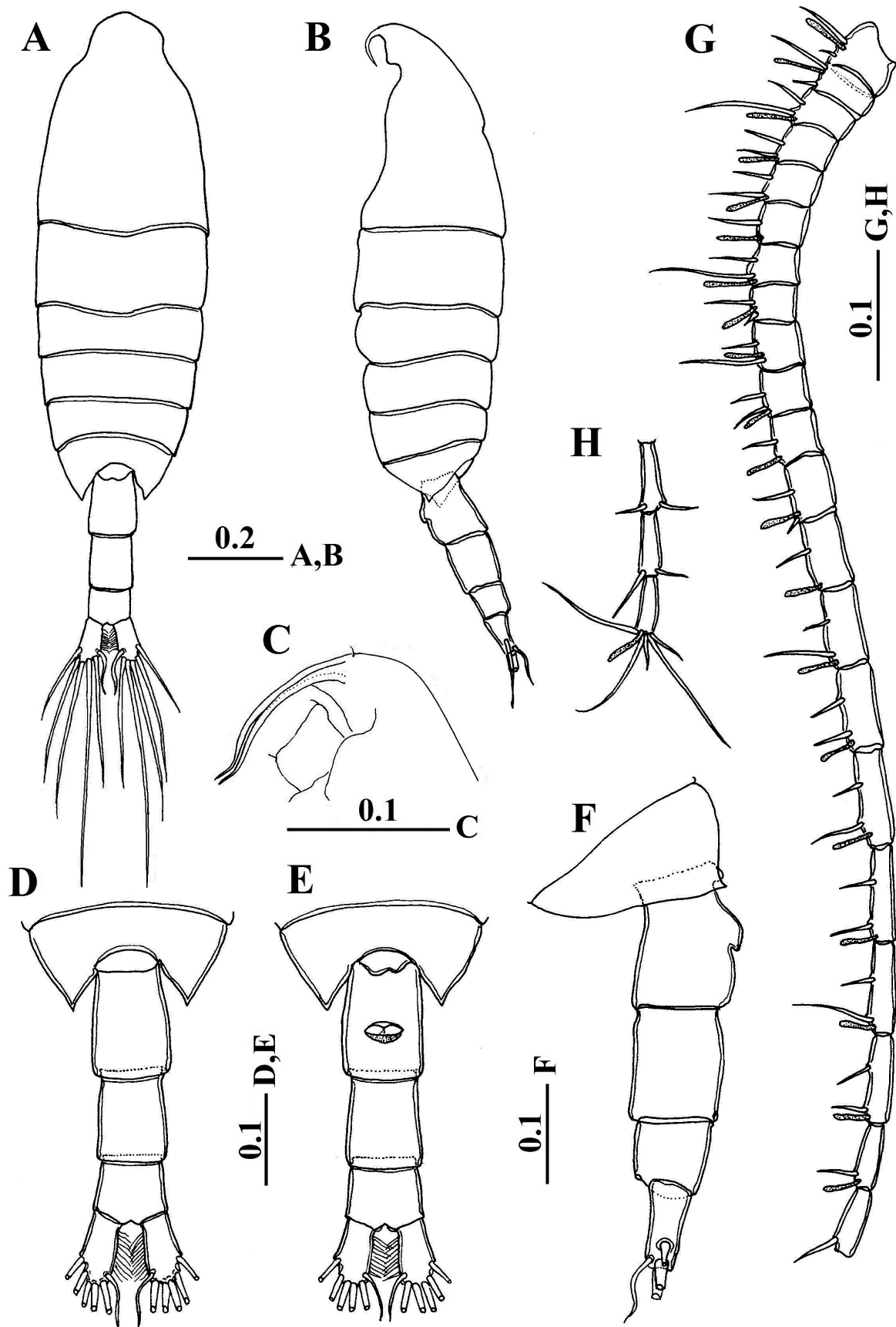
**Type material.** Holotype. Adult female, 1.39 mm, dissected and mounted on 1 glass slide with CMC-10 (Reg. No NHMUK 2014.613-622) collected at coastal water off Obhur Creek, Jeddah, central Red Sea, (21° 41.398' N, 39° 3.002' E) on 31 May 2012, 0.5 m depth.

Allotype. Adult male, 1.20 mm, partly dissected and mounted in 1 glass slide with CMC-10 (Reg. No NHMUK 2014.623-632) collected at coastal water off Obhur Creek, Jeddah, central Red Sea (21° 41.398' N, 39° 3.002' E), on 31 May 2012, 0.5 m depth.

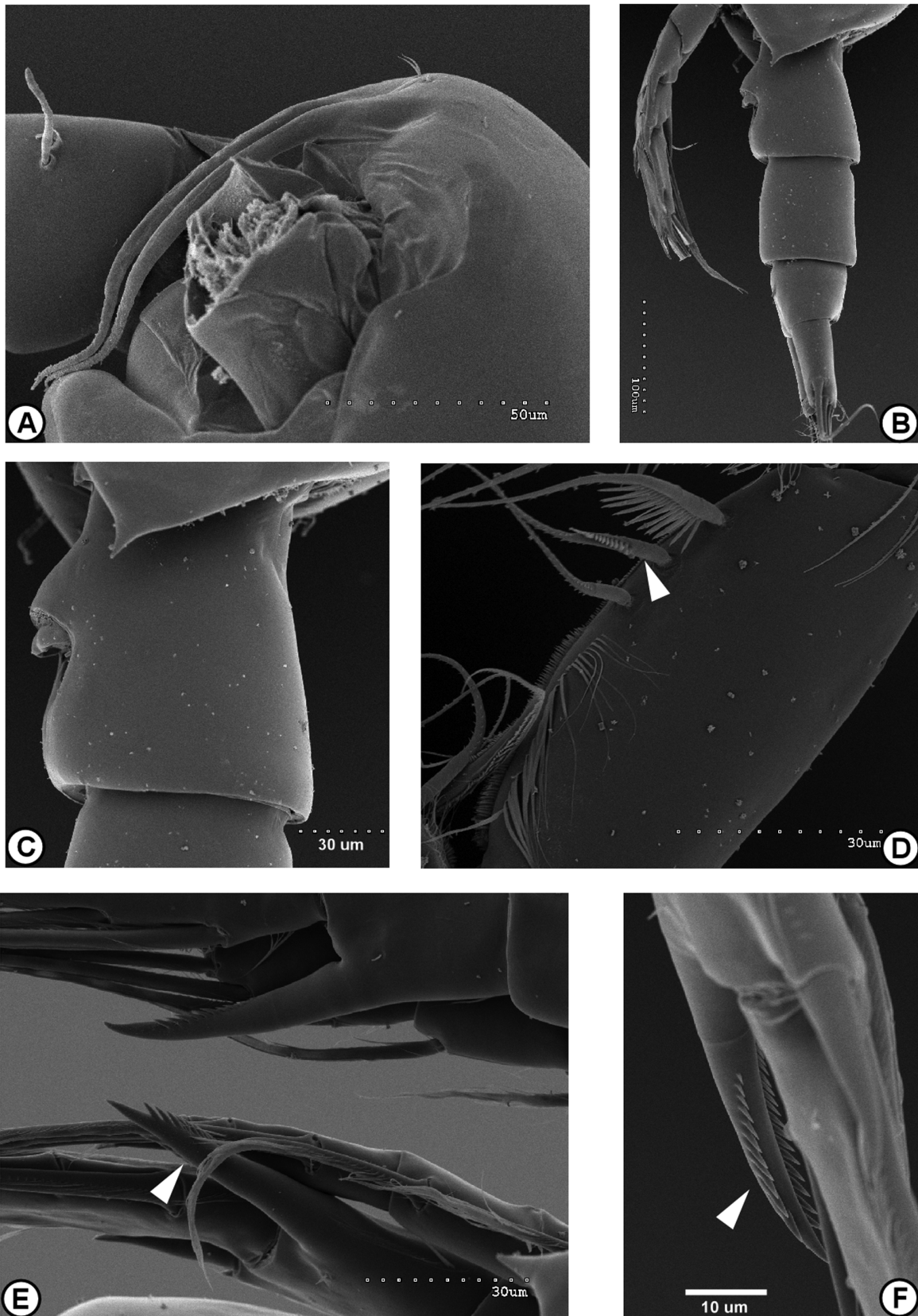
Additional paratypes. 20 adult females (body length: 1.31–1.45 mm, mean ± SD = 1.36 ± 0.06 mm) and 17 adult males (body length: 1.18–1.35 mm, mean ± SD = 1.26 ± 0.07 mm) in 70% alcohol (Registration number: NHMUK 2014.613-622 and NHMUK 2014.623-632 respectively) collected at coastal water off Obhur Creek, Jeddah, central Red Sea (21° 41.398' N, 39° 3.002' E), on 31 May 2012, 0.5 m depth.



**FIGURE 1.** Sampling sites of *Centropages mohamedi* sp. nov. and *C. orsinii* off Jeddah and entrance of Obhur Creek, central Red Sea.



**FIGURE 2.** *Centropages mohamedi* sp. nov. Female (holotype). (A) Habitus, dorsal view; (B) Habitus, lateral view; (C) Rostrum, lateral view; (D) Urosome, dorsal view; (E) Urosome, ventral view; (F) Urosome, lateral view; (G–H) Antennule. Scale bars in mm.



**FIGURE 3.** SEM micrographs of *Centropages mohamedii* sp. nov. female. (A) Rostrum, lateral view; (B) Urosome, lateral view; (C) Genital double somite, lateral view; (D) Maxillipod basis (middle seta with proximal, spirally located spinule indicated by arrow), lateral view; (E) Medial process of second exopodal segment of female leg 5 indicated by arrow; (F) Enlarged medial process of second exopodal segment of female leg 5.

**Description.** Female (holotype). Body (Fig. 2A) robust, prosome plump comprising cephalosome and five pedigerous somites; prosome about 2.3 times as long as urosome; cephalosome distinctly separated from first pediger; fourth and fifth pedigerous somites separated; fifth pedigerous somite symmetrical with posterolateral corners slightly pointed in dorsal and lateral aspects (Fig. 2A, B). Rostrum bearing long pair of frontal filaments directed postero-ventrally with broad base (Figs 2C, 3A). Urosome (Figs 2D–F, 3B) of 3 free somites; genital double somite symmetrical (Figs 3B–C); genital receptacle located half way along ventral surface covered with blunt operculum. Second urosomite symmetrical, slightly shorter than genital double somite; anal somite symmetrical and shorter than preceding free abdominal somite. Caudal rami symmetrical and approximately 2.3 times as long as wide.

Antennules (Fig. 2G, H) symmetrical, 24-segmented, extending about to middle of anal somite. Armature formula as follows: (segment 1) = 2 setae + aesthetasc (ae), (2) = 2 setae + ae, (3) = 2 + ae, VI (4) = 2 + ae, (5) = 2 + ae, (6) = 1 + ae, (7) = 2 + ae, (8) = 2 (1 spiniform) + ae, (9) = 2 + ae, (10) = 2 + ae, (11) = 1 + ae, (12) = 2 (1 spiniform) + ae, (13) = 1 + ae, (14) = 2 + ae, (15) = 2 + ae, (16) = 2 + ae, (17) = 2 + ae, (18) = 2 + ae, (19) = 2 + ae, (20) = 1 + ae, (21) = 1, (22) = 1 + 1, (23) = 1 + 1, (24) = 5+ae.

Antenna (Fig. 4A) biramous with short coxa bearing plumose seta at distomedial angle; basis with 2 subequal setae on distomedially; exopod indistinctly 7-segmented with setal formula of 1, 4, 1, 1, 1, 1, 3; endopod 2-segmented, proximal segment with 2 unequal subterminal setae; distal segment bilobed, with medial (proximal) lobe bearing 8 setae, and with lateral (distal) lobe crowned with 7 setae and transverse row of long spinules subdistally on lateral margin.

Mandibular gnathobase (Fig. 4B) with cutting edge carrying 8 teeth on coxal cutting edge and dorsal spinulose seta; ventralmost tooth largest, smooth and unicuspid, third to sixth teeth bicuspidate and third to seventh teeth ornamented with 2 rows of short spinules anterodistally at base. Palp (Fig. 4C) basis with 4 unequal setae on medial margin; exopod 5-segmented with setal formula of 1, 1, 1, 1, 2; endopod 2-segmented, proximal segment with 4 setae at distomedial corner; distal segment with 8 unequal setae and subapical random patch of spinules row of fine spinules.

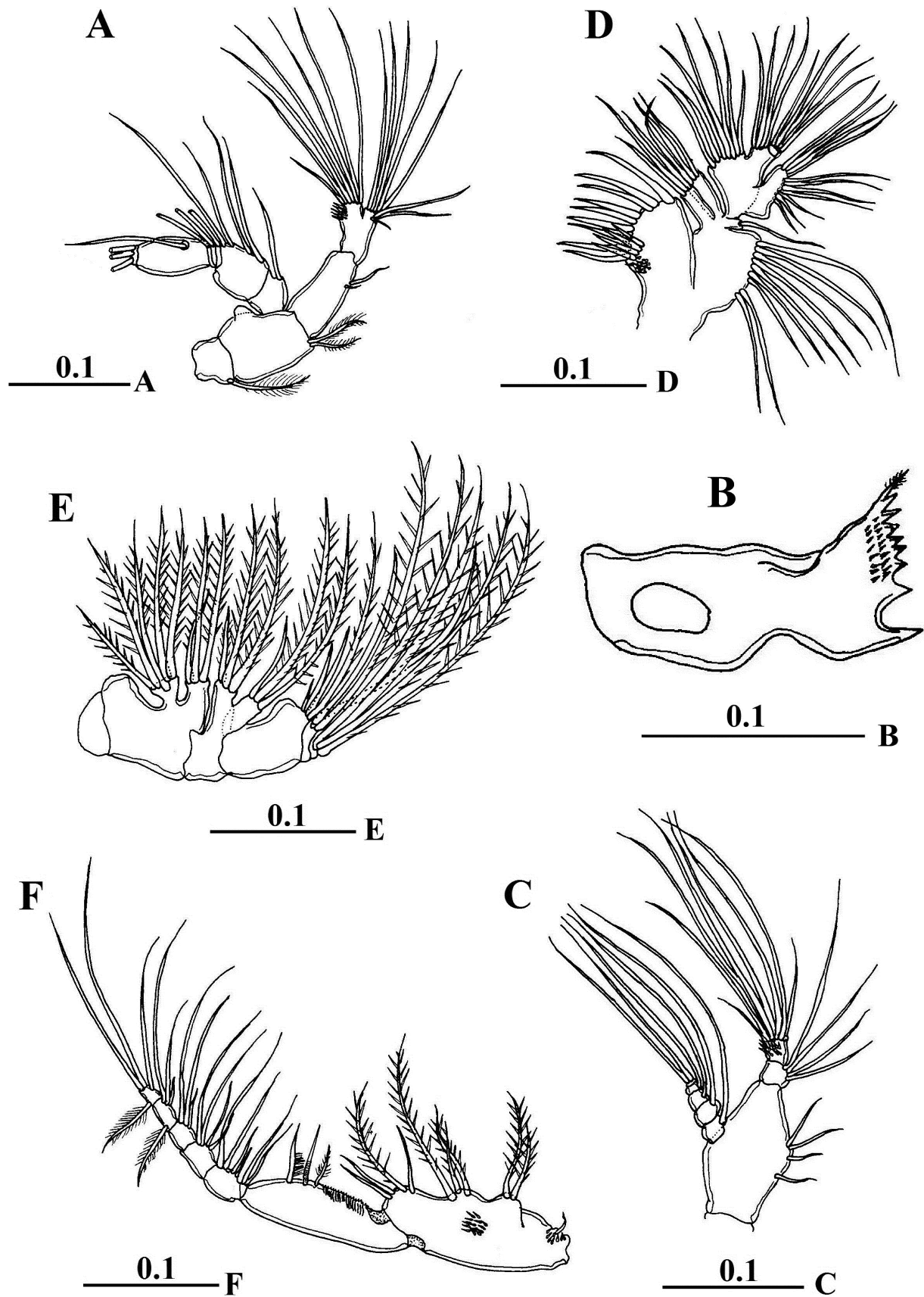
Maxillule (Fig. 4D) with praecoxal arthrite bearing 9 marginal strong spines plus four on posterior surface. Coxal epipodite with 9 setae; coxal endite with 3 spinulose setae; basal exite with 1 vestigial seta. Basis fused to exopod and endopod; proximal basal endite armed with 4 setae and on distal endite 7 setae. Exopod carrying 11 marginal setae; endopod indistinctly 2-segmented with 4 and 5 setae respectively.

Maxilla (Fig. 4E) indistinctly 7-segmented, containing partially coalesced praecoxa and coxa, basis and 2-segmented endopod. Praecoxal and coxal endites carrying 5, 3, 3 and 3 bilaterally spinulate setae respectively; basal endite with 4 setae, one longer than others; endopod 2-segmented, carrying 7 bilaterally spinulate setae.

Maxilliped (Fig. 4F) 8-segmented comprising syncoxa, basoendopod and free 6-segmented endopod (first endopodal segment almost completely incorporated into basis). Syncoxal lobes with 1, 2, 3, 4 setae on its medial margin, small patch of spinules on medial surface proximal to seta of first syncoxal lobe and other patch near the third lobe. Basis slightly shorter than syncoxa, with 3 setae (middle seta with proximal setule located in spiral pattern, Fig. 3D), row of strong spinules and long hairs along medial margin of segment proximal to basal setae; endopod with setal formula of 2, 4, 4, 3, 3 + 1, 1+2+ 1.

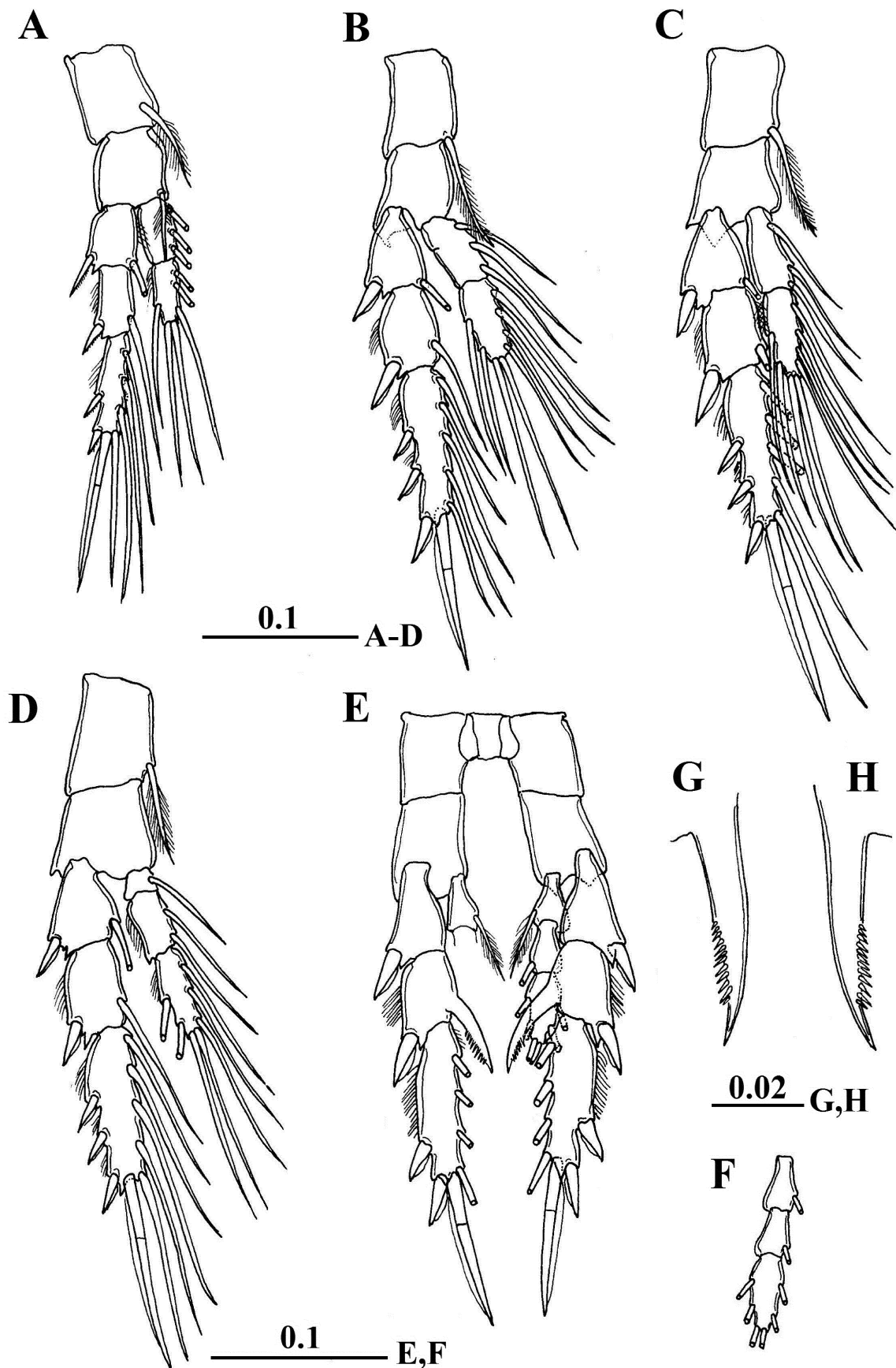
Swimming legs 1–4 (Fig. 5A–D) with 3 segmented exopod; endopod 2-segmented in legs 1–3, and 3-segmented in legs 4–5. Leg 1 with medial basal seta reaching to end of proximal endopodal segment. Leg 5 (Fig. 5E–H) symmetrical; second exopodal segment with strong medial process medially, slightly longer than segment itself with bilateral serration along distal half of lateral margin (Figs 5F–G, 3E–F). Armature of legs as follows:

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

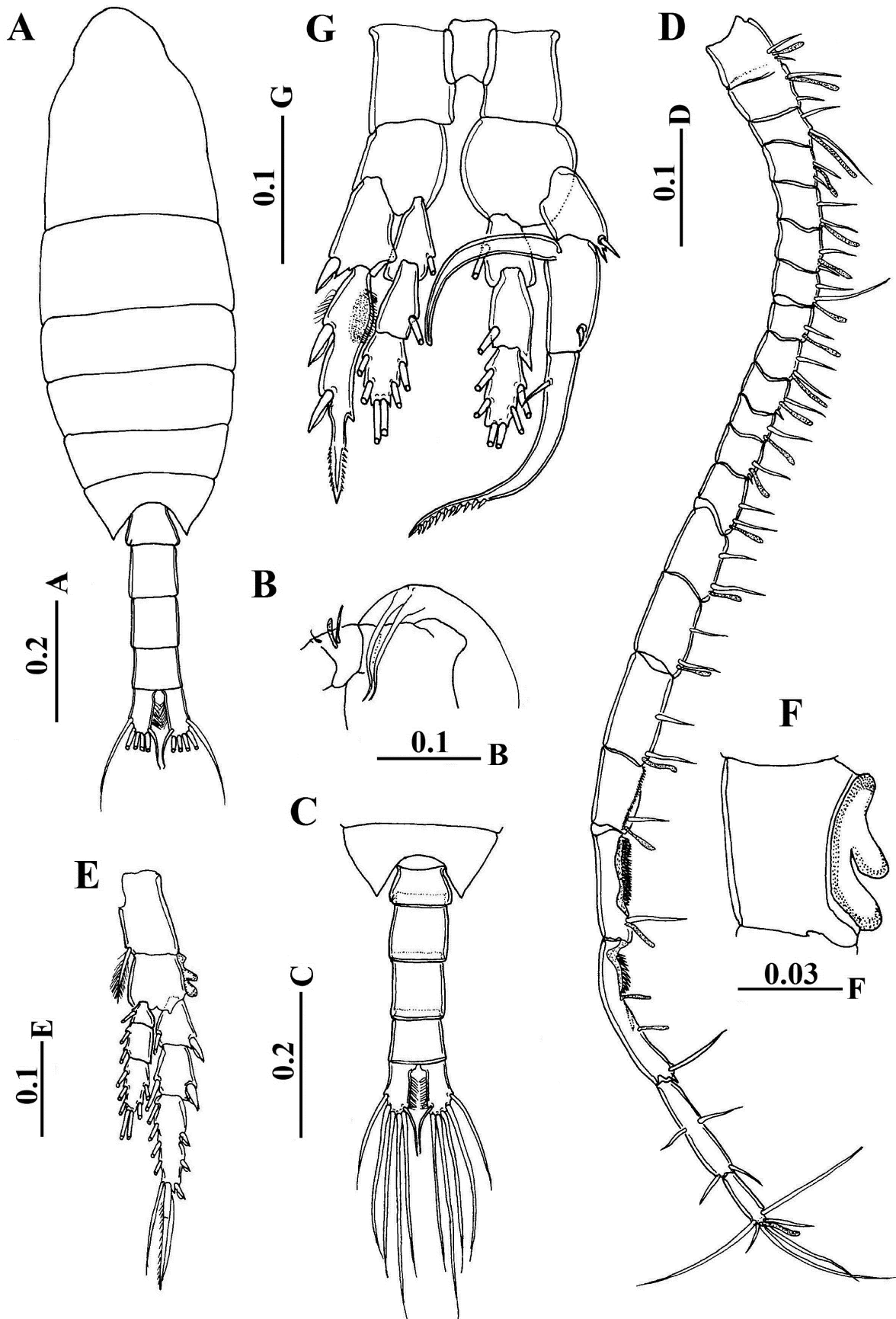


**FIGURE 4.** *Centropages mohamedi* sp. nov. Female (holotype). (A) Antenna; (B) Mandibular gnathobase; (C) Mandibular palp; (D) Maxillule; (E) Maxilla, (F) Maxilliped. Scale bars in mm.





**FIGURE 5.** *Centropages mohamedi* sp. nov. Female (holotype). (A) Leg 1; (B) Leg 2; (C) Leg 3; (D) Leg 4; (E) Leg 5; (F) Endopod of left leg 5; (G) Left medial process of second exopodal segment of female leg 5; (H) Right medial process of second exopodal segment of female leg 5. Scale bars in mm.



**FIGURE 6.** *Centropages mohamedi* sp. nov. Male (allotype). (A) Habitus, dorsal view; (B) Rostrum, ventro-lateral view; (C) Urosome, dorsal view; (D) Right antennule; (E) Right leg 4; (F) Basis of right leg 4, posterior view; (G) Leg 5, posterior view. Scale bars in mm.

Male (allotype). Body (Fig. 6A) robust, prosome plump, widest at posterior border of second pediger; prosome about 2.2 times as long as urosome comprising cephalosome and five pedigerous somites; cephalosome distinctly separated from first pediger; fifth pedigerous somite produced into slightly pointed and slightly asymmetrical corners, extending posteriorly slightly further on left side (Fig. 6A). Rostrum bearing long pair of frontal filaments sinuate at distal part and terminally directed postero-ventrally (Figs 6B, 7A). Urosome (Fig. 6C) comprising 4 free somites, symmetrical except for genital somite with single gonopore opening posterolaterally on left side ventral surface; anal somite slightly shorter than 2 preceding free somites. Caudal rami (Fig. 6C) symmetrical, about 2.3 times longer than wide.

Right antennule (Fig. 6D) 21-segmented, geniculate between segments XX and XXI (18 and 19). Ancestral segments XIX (17) and XX (18) with row of spinules produced from anterior margin respectively; segment XXI (19) with row of relatively longer spinules on proximal 1/3 terminating in long spine along segment margin. Armature as follows: (1) = 2 + ae, (2) = 2 + ae, (3) = 2 + ae, (4) = 2 + ae, (5) = 2 + ae, (6) = 2 + ae, (7) = 2 + ae, (8) = 1 + ae, (9) = 2 + ae, (10) = 2 (1 spiniform) + ae, (11) = 1 + ae, (12) = 2 (1 spiniform) + ae, (13) = 2 + ae, (14) = 2 + ae, (15) = 2 + ae, (16) = 2 + ae, (17) = 1 + ae, XX (18) = 1 + ae, (19) = 1 + process + ae, (20) = 2 + 2, (21) = 6 + ae.

Mouthpart appendages, legs 1 to 3 similar to those in female. Leg 4 asymmetrical, basis of right leg with three rounded digitiform processes spreading along lateral surface, proximal and middle ones originated from same base (proximal one smaller) (Figs 6E–F, 7B); these digitiform processes outlined with papilla-like structures (Fig. 7B).

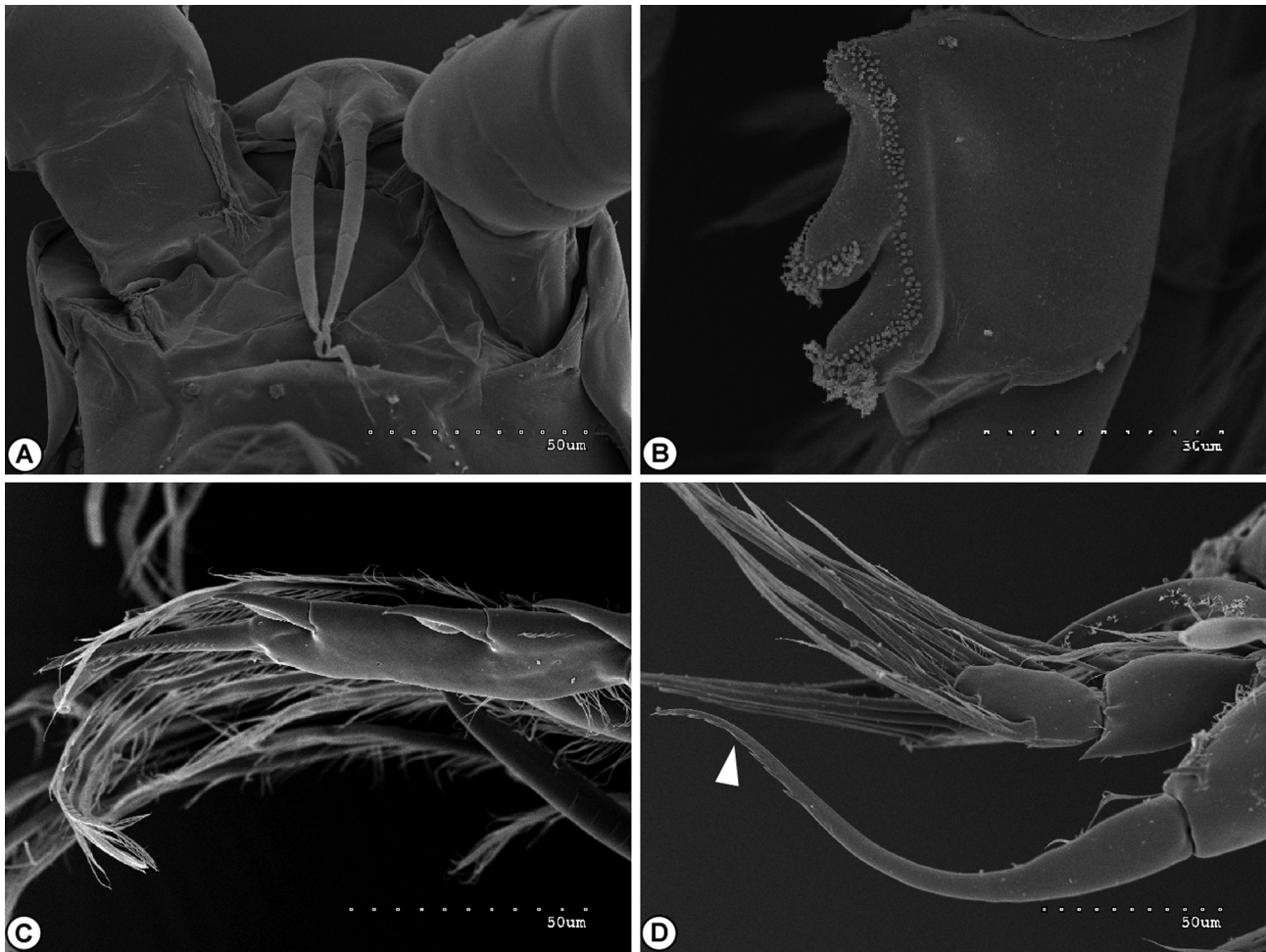
Leg 5 (Fig. 6G) strongly asymmetrical; first endopodal segment of both legs produced distolaterally into rounded process. Left leg biramous, with 2-segmented heavily sclerotised exopod and 3-segmented endopod; second exopodal segment nearly 2.3 times as long as first one, hirsute on posteromedial surface, bearing 2 lateral spines, one medial pointed process and bilaterally serrated, long distal spine fused to segment (Fig. 7C). Right leg (Fig. 6G) biramous, with broader basis than that of left leg; exopod 3-segmented; first exopodal segment short, with lateral articulated spine and adjacent pointed process distolaterally; second exopodal segment with short spine very near distolateral corner and with strongly-curved inner process originating at nearly 90 degree proximally on to medial margin; third exopodal segment long, curved inward, serrated along outer convex margin (Figs 6G, 7D), armed with slender seta on proximomedial margin and recurved distally; endopod exceeding second exopodal segment, second endopodal segment with pointed distolateral process. Setal formula of right endopod same as left endopod (0-1; 0-1; 2-2-2); right endopod slightly wider than left one.

**Molecular diversity.** A 544-bp region of the mtCOI was obtained for three individuals of *C. mohamedii* (GenBank accession Nos. KM288701-KM288703) collected from the coastal water off Obhur Creek, central Red Sea and four individuals of *C. orsinii* collected from Obhur Creek (GenBank accession Nos. KM288704-KM288707). Individuals from the same species have identical mtCOI sequences (0.000), while individuals of different species differed by 20.8 % (Table 1). The mtCOI gene tree also showed that *C. mohamedii* is clearly an undescribed species separate from *C. orsinii* (Fig. 8).

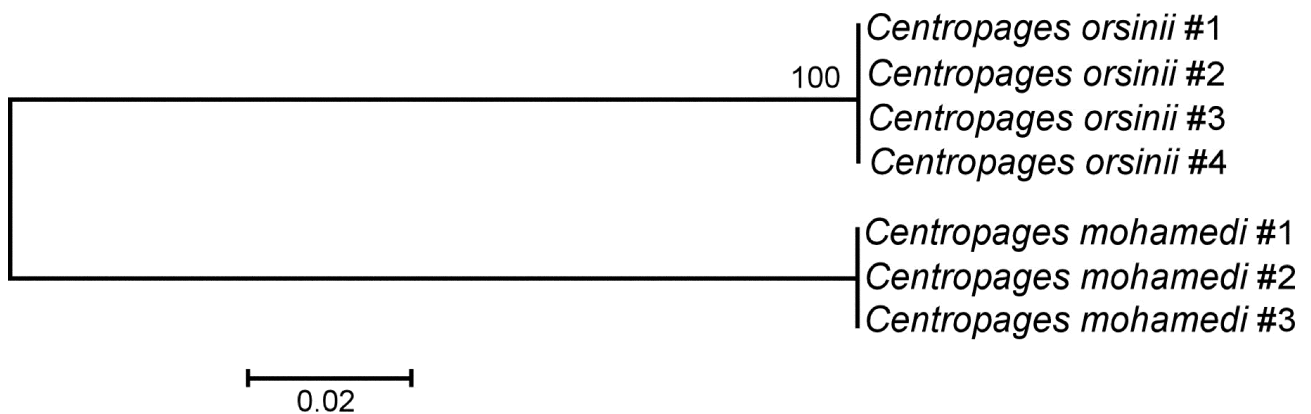
**Etymology.** The specific name *mohamedii* is dedicated to the first author's son (Mohamed) who passed away on May 2009 at 5 years old.

**TABLE 1.** Pairwise percentage differences for mtCOI sequences between individual females of *Centropages mohamedii* sp.nov. and *C. orsinii*.

	<i>Centropages mohamedii</i> #1	<i>Centropages mohamedii</i> #2	<i>Centropages mohamedii</i> #3	<i>Centropages orsinii</i> #1	<i>Centropages orsinii</i> #2	<i>Centropages orsinii</i> #3
<i>Centropages mohamedii</i> #1						
<i>Centropages mohamedii</i> #2	0.00					
<i>Centropages mohamedii</i> #3	0.00	0.00				
<i>Centropages orsinii</i> #1	20.80	20.77	20.77			
<i>Centropages orsinii</i> #2	20.77	20.77	20.77	0.00		
<i>Centropages orsinii</i> #3	20.77	20.77	20.77	0.00	0.00	
<i>Centropages orsinii</i> #4	20.77	20.77	20.77	0.00	0.00	0.00



**FIGURE 7.** SEM micrograph of *Centropages mohamedi* sp. nov. male from the Red Sea. (A) Rostrum, ventral view; (B) Basis of right leg 4, posterior view; (C) Fused exopodal segments 2 and 3 of male left leg 5; (D) Third exopodal segment of male right leg 5 (serration of distal part indicated by arrow).



**FIGURE 8.** Gene tree for mtCOI showing proportional differences between individual females of *Centropages mohamedi* sp. nov. and *C. orsinii* from neritic waters of the central Red Sea. Numbers at branch points are bootstrap values (i.e., percentage of trees with that branch point among 1000 subreplicates). The specimen numbers correspond to those in Table 1.

## Discussion

The new species (*Centropages mohamedi*) is readily distinguished from the two closely resembled species, *C. orsinii* and *C. halinus* (see also Table 2), as well as other known species, in that: (1) the posterior prosome ends of

both sexes are almost symmetrical and weakly pointed, (2) the female genital double somite is symmetrical with the seminal receptacle located posteriorly along the ventral surface and covered with a blunt operculum, (3) the symmetry of female leg 5 which has a 3-segmented exopod, of which the second exopod segment bears a strong medial process, slightly longer than the segment itself and with bilateral serration along distal part of posterior margin, (4) the basis of male right leg 4 bears 3 rounded outer border digitiform processes that are outlined with papillae-like structures, (5) the second exopodal segment of male right leg 5 bears a strong medial process curved at almost 90 degree to its segment, and (6) the third exopodal segment of male right leg 5 is curved distally with spinules along its outer margin. The bases of male leg 4 of *C. mohamedi* are asymmetrical, with the right one characterized by digitiform processes spreading along the lateral surface. Similar processes are present on the male right leg basis of *C. orsinii* collected from different regions with variability in the precise form of the processes (Boxshall & Jaume 2011). Based on our specimens of *C. orsinii* collected from Obhur Creek, central Red Sea, the processes of the right fourth legs are mostly as shown by Mulyadi (2004) from Indonesian waters.

The mtCOI has been used as an appropriate marker for species level studies in calanoid copepods because it contains sufficient diversity to address intra- and interspecific phylogenetic relationships (Bucklin & Wiebe 1998; Bucklin & Frost 2009; Eyun *et al.* 2007; Sakaguchi & Ueda 2010; Soh *et al.* 2012; Ueda & Bucklin 2006). The 20.8 % difference between *C. mohamedi* and *C. orsinii* suggests that these two species have been genetically isolated for some time.

Vervoort (1964) divided *Centropages* species into five groups (*typicus*, *furcatus*, *hamatus*, *orsinii* and *violaceus*) based on the shape of the last pedigerous somite, shape of the urosome, leg 5 morphology, and the male right antennule. Subsequently, Ohtsuka *et al.* (2003, 2005) added 2 further groups (*trispinosus* and *alcocki*), and pointed to the necessity of a revision of these species groups, since most of the species seem to be heterogeneous. The present new species falls within the *orsinii* group proposed by Vervoort (1964) that previously contained only *C. orsinii*. Here, *C. orsinii*, *C. halinus* and *C. mohamedi* are grouped as the *orsinii* group, members of which share the following features: (1) posterior corners of both sexes are weakly pointed, (2) legs 1 to 3 with 2-segmented endopods, whilst 3-segmented endopods are retained on legs 4 and 5, (3) female leg 5 possess a relatively short medial process on the second exopodal segment with bilateral serration along the distal part of the lateral margin, (4) male left leg 5 consists of 2-segmented exopod (ancestral segments 2 and 3 fused), with the second segment being fused to a relatively long bilaterally serrated distal spine, (5) male right leg 5 with second exopodal segment has short seta at the distolateral corner and relatively short medial process slightly increasing the length of the second exopodal segment, and (6) male right leg 5 with second exopodal segment curved and armed with a slender seta medially close to the basal articulation.

Of these three species, *C. mohamedi* is not only recorded from the type locality but also along the Saudi Arabian coastal waters of the Red Sea (El-Sherbiny *et al.* unpublished data), *C. orsinii* is widely distributed in the Indo-West Pacific (Greenwood 1977), and *C. halinus* is confined to the hypersaline inner region of Shark Bay, Western Australia where it is present in salinities between 39 and 44.4 (Mckinnon & Kimmerer 1988). Thus, this species group is restricted to the Indo-West Pacific region.

Asymmetry of the leg 5 is fairly common to adult male calanoids, while asymmetry of the leg 4 is very rare in copepods. It is remarkable that the male of *C. mohamedi* reveals an asymmetry in leg 4, in which the basis of the right leg carries on its posterior surface three rounded digitiform processes outlined by papillae-like structures. Asymmetry in the shape or size of the exopodal spines on male leg 4 is recorded in some other *Centropages* species. For example, in *C. sinensis*, the distal spine on the lateral margin of the third exopodal segment is enlarged, hook-like and curved outwardly on the right side (Chen & Zhang 1965); in *C. abdominalis* Sato, 1913, the length of the distolateral spine on the third exopodal segment is longer in the right leg than in the left (Mori 1964); in *C. tenuiremis* Thompson & Scott, 1903 (as *C. yamadai* Mori 1964: pl. 28, fig. 7), the lateral spine on the first and second exopodal segment is enlarged and curved on the right side (Mori 1964: pl. 28, fig. 7 as *C. yamadai* Mori, 1964); in *C. brevifurcus* Shen & Lee, 1963, the right distolateral spine on third exopodal segment is longer than left one (Ohtsuka *et al.* 2003); in *C. aegypticus* El-Sherbiny & Ueda, 2008, the lateral spines on the first and second exopodal segment of the right leg is longer than right one (El-Sherbiny & Ueda 2008a), in *C. uedai* El-Sherbiny, 2011, the lateral spine on the second exopodal segment is thicker, longer and curved in right leg (El-Sherbiny 2011), and in *C. orsinii*, the basis of the right leg carries distally three pointed processes on its posterior surface (Mulyadi 2004; Boxshall & Jaume 2011).

**TABLE 2.** Comparison of morphological features between *Centropages orsinii*, *C. halinus* and *C. mohamedi*.

	<i>Centropages orsinii</i>	<i>Centropages halinus</i>	<i>Centropages mohamedi</i> sp. nov.
Reference	Giesbrecht, 1889 Giesbrecht, 1889 and 1893	McKinnon & Kimmerer, 1988 McKinnon & Kimmerer (1988)	Present study
<b>Female</b>			
Posterior prosomal ends	Asymmetrical, right side slightly longer than left one, more pointed than other species	Symmetrical with pointed ends slightly backward directed	Symmetrical with pointed ends
Genital double somite	Asymmetrical in outline and with spiniform process ventrally ca 1.6:1	Asymmetrical with a group of spinules posterolaterally ca 1.4:1	Symmetrical without ornamentation ca 1.3:1
Proportion of length of urosomite 1: urosomite 2	Asymmetrical,	Symmetrical	Symmetrical
Medial process of second exopodal segment of leg 5	With prominent spiniform specialized seta each	Without specialized setae	Without specialized setae
<b>Male</b>			
Antennule segments XVII (15) and XVIII (16)	Slightly asymmetrical, left side longer than right one	Symmetrical	Slightly asymmetrical, left side longer than right one
Posterior prosomal ends	With 3 tapering digitiform processes on lateral and posterior surface distally	Without any processes	With 3 rounded digitiform processes spreading along lateral surface and outlined with papillae-like structure
Basis of right leg 4	With bilaterally serrated distal spine nearly 2/3 as long as the segment	With short distal spine not more than 1/3 of the segment	With bilaterally serrated distal spine nearly 2/3 as long as the segment
Distal exopodal segment of left leg 5	Not strongly curved (more than 90°)	strongly curved (nearly 90°)	strongly curved (nearly 90°) and shorter than in <i>C. orsinii</i>
Medial process of second exopodal segment of right leg 5	Swollen at base and without serration along distal part of the convex margin laterally	Swollen at base and without serration along distal part of the convex margin laterally	not swollen at base and with serration along distal part of the convex margin laterally

## Acknowledgements

This project was funded by the Deanship of Scientific Research (DSR), King Abdulaziz University (Grant no. 311-150/1433). The authors, therefore, acknowledge with thanks DSR technical and financial support. Also, we are grateful to Dr John Pearman for assistance and help with sequencing, Dr Rupert Ormond for improving the English of the text and Dr Janet Bradford-Grieve for critically reading the first draft; her suggestions and comments greatly improved this manuscript. Two anonymous referees are kindly thanked for critically reading the manuscript and providing constructive remarks.

## References

- Boxshall, G.A. & Hasley, S.H. (2004) *An Introduction to Copepod Diversity. Vol. I*. The Ray Society, London, 421 pp.
- Boxshall, G.A. & Jaume, D. (2011) *Centropages orsinii* Giesbrecht, 1889 (Copepoda, Calanoida, Centropagidae) from an anchialine cave in Vanuatu. *Zoosystema*, 34 (2), 377–387.  
<http://dx.doi.org/10.5252/z2012n2a11>
- Bradford-Grieve, J.M. (1999) The marine fauna of New Zealand: Pelagic calanoid Copepoda: Bathypontiidae, Arietellidae, Augaptilidae, Heterorhabdidae, Lucicutiidae, Metridinidae, Phyllopodidae, Centropagidae, Pseudodiaptomidae, Temoridae, Candaciidae, Pontellidae, Sulcanidae, Acartiidae, Tortanidae. *NIWA Biodiversity Memoir*, 111, 1–268.
- Bradford-Grieve, J.M., Markhaseva, E.L., Roch, C.E.F. & Abiahy, B. (1999) Copepoda. In: D. Boltovskoy (Eds.), *South Atlantic Zooplankton*. Backhuys Publishers, Leiden, pp. 869–1098.
- Brodsky, K.A. (1950) *Calanoida of the Far Eastern Seas and Polar Basin of the USSR*. Izdatel'stvo Akademii Nauk SSSR, Moskva-Leningrad, 440 pp. [English translation: Israel Program for Scientific Translations, Jerusalem, 1967]
- Bucklin, A. & Frost, B.W. (2009) Morphological and molecular phylogenetic analysis of evolutionary lineages within *Clausocalanus* (Copepoda: Calanoida). *Journal of Crustacean Biology*, 29, 111–120.  
<http://dx.doi.org/10.1651/07-2879.1>
- Bucklin, A. & Wiebe, P.H. (1998) Low mitochondrial diversity and small effective population sizes of the copepods *Calanus finmarchicus* and *Nannocalanus minor*: possible impact of climatic variation during recent glaciation. *American Genetic Association*, 89, 383–392.  
<http://dx.doi.org/10.1093/jhered/89.5.383>
- Chen, Q.-C. & Zhang, S.-Z. (1965) The planktonic copepods of the Yellow Sea and the East China Sea. I. Calanoida. *Studia Marine Sinica*, 7, 20–131. [in Chinese with English abstract]
- El-Sherbiny, M.M. (2009) First record and redescription of *Pontella princeps* Dana, 1849 (Copepoda: Pontellidae) in the Red Sea with notes on its feeding habits. *Catrina*, 4 (1), 11–20.
- El-Sherbiny, M.M. (2011) A new species of *Centropages* (Copepoda: Calanoida) from the neritic waters of Sharm El-Sheikh, the Red Sea. *Journal of the Marine Biological Association of the United Kingdom*, 91, 479–484.  
<http://dx.doi.org/10.1017/s0025315410000366>
- El-Sherbiny, M.M. & Al-Aidaros, A.M. (2013) First record and redescription of *Macandrewella cochinchinensis* Gopalakrishnan, 1973 (Copepoda, Scolecitrichidae) from the Red Sea, with notes on swarm formation. *ZooKeys*, 344, 1–15.  
<http://dx.doi.org/10.3897/zookeys.344.5519>
- El-Sherbiny, M.M. & Al-Aidaros, A.M. (2014) First report of the presence of *Acartia bispinosa* Carl, 1907 (Copepoda, Calanoida) in a semi-enclosed Bay (Sharm El-Maya), northern Red Sea with some notes on its seasonal variation in abundance and body size. *ZooKeys*, 444, 95–118.  
<http://dx.doi.org/10.3897/zookeys.444.7633>
- El-Sherbiny, M.M. & Ueda, H. (2008a) *Centropages aegypticus*, a new species of calanoid copepod from the northern Red Sea. *Journal of Marine Biological Association of United Kingdom*, 88 (1), 69–75.
- El-Sherbiny, M.M. & Ueda, H. (2008b) Redescription of the poorly known calanoid copepod *Pontella karachiensis* Fazal-Ur-Rehman, 1973 from the Red Sea with notes on its feeding habits. *Plankton and Benthos Research*, 3 (1), 10–17. | <http://dx.doi.org/10.3800/pbr.3.10>
- Eyun, S., Lee, Y., Suh, H.-L., Kim, S. & Soh, H.Y. (2007) Genetic identification and molecular phylogeny of *Pseudodiaptomus* species (Calanoida, Pseudodiaptomidae) in Korean waters. *Zoological Science*, 24, 265–271.  
<http://dx.doi.org/10.2108/zsj.24.265>
- Folmer, O., Black, M., Hoen, W., Lutz, R. & Vrijenhoek, R. (1994) DNA primers for amplification of mitochondrial cytochrome c oxidase subunit I from diverse metazoan invertebrates. *Molecular Marine Biology and Biotechnology*, 3, 294–299.
- Giesbrecht, W. (1889) Elenco dei Copepodi pelagici raccolti dal tenente di vascello Gaetano Chierchia durante il viaggio della R. Corvetta “Vettor Pisani” negli anni 1882–1885, e dal tenente di vascello Francesco Orsini nel Mar Rosso, nel 1884. *Atti della Reale Accademia dei Lincei*, 5, 811–815.
- Giesbrecht, W. (1893) Systematik und Faunistik der pelagischen Copepoden des Golfes von Neapel. *Fauna und Flora des*

*Golfes von Neapel und der angrenzenden Meeresabschnitte*, 16, 1–831, 54 pls.

<http://dx.doi.org/10.5962/bhl.title.59541>

- Greenwood, J.G. (1977) Calanoid copepods of Moreton Bay (Queensland). II. Families Calocalanidae to Centropagidae. *Proceedings of the Royal Society of Queensland*, 88, 46–67.
- Halim, Y. (1969) Plankton of the Red Sea. *Oceanography and Marine Biology. Annual Review*, 7, 231–275.
- Huys, R. & Boxshall, G.A. (1991) *Copepod evolution*. The Ray Society, London, 468 pp.
- Larkin, M.A., Blackshields, G., Brown, N.P., Chenna, R., McGettigan, P.A., McWilliam, H., Valentin, F., Wallace, I.M., Wilm, A., Lopez, R., Thompson, J.D., Gibson, T.J. & Higgins, D.G. (2007) Clustal Wand Clustal X version 2.0. *Bioinformatics*, 23, 2947–2948.
- <http://dx.doi.org/10.1093/bioinformatics/btm404>
- McKinnon, A.D. & Kimmerer, W.J. (1988) A new species of calanoid copepod from Shark Bay, Western Australia. *Record of Western Australian Museum*, 14, 171–176.
- Mori, T. (1964) *The pelagic Copepoda from the neighboring waters of Japan*. The Soyo Company Incorporation, Tokyo, 150 pp.
- Mulyadi (2004) *Calanoid copepods in Indonesian waters*. Research Center for Biology, Indonesia Institute of Science, Bogor, 195 pp. [Indonesia]
- Ohtsuka, S., El-Sherbiny, M.M. & Ueda, H. (2000) Taxonomy, functional morphology and behavioral ecology of the planktonic calanoid copepod *Tortanus* (Atortus). *Crustacean Research*, 29, 1–11.
- Ohtsuka, S., Itoh, H. & Mizushima, T. (2005) A new species of the calanoid copepod genus *Centropages* (Crustacea) collected from Shimizu Port, Middle Japan: Introduced or not?. *Plankton Biology and Ecology*, 52 (2), 92–99.
- Ohtsuka, S., McKinnon, D., Pinkaew, K., Puchakarn, S. & Chalermwat, K. (2003) New record of *Centropages brevifurcus* (Crustacea: Copepoda: Calanoida) from the Gulf of Thailand and its full redescription. *Species Diversity*, 8, 67–78.
- Razouls C., De Bovée F., Kouwenberg J. & Desreumaux, N. (2014) Diversity and geographic distribution of marine planktonic copepods. Available from: <http://copepodes.obs-banyuls.fr/en/> (accessed 25 August 2014)
- Sakaguchi, S.O. & Ueda, H. (2010) A new species of *Pseudodiaptomus* (Copepoda: Calanoida) from Japan, with notes on the closely related *P. inopinus* Burckhardt, 1913 from Kyushu Island. *Zootaxa*, 2623, 52–68.
- Soh, H.Y., Kwon, S.W., Lee, W. & Yoon, Y.H. (2012) A new *Pseudodiaptomus* (Copepoda, Calanoida) from Korea supported by molecular data. *Zootaxa*, 3368, 229–244.
- Tamura, K., Dudley, J., Nei, M. & Kumar, S. (2007) Mega 4: molecular evolutionary genetics analysis (MEGA) software version 4.0. *Molecular Biology Evolution*, 24, 1596–1599.
- <http://dx.doi.org/10.1093/molbev/msm092>
- Ueda, H. & Bucklin, A. (2006) *Acartia* (*Odontacartia*) *ohtsukai*, a new brackish-water calanoid copepod from Ariake Bay, Japan, with a redescription of the closely related *A. pacifica* from the Seto Inland Sea. *Hydrobiologia*, 560, 77–91.
- <http://dx.doi.org/10.1007/s10750-005-9513-0>
- Vervoort, W. (1964) Notes on two Pacific species of *Centropages* (Copepoda, Calanoida), *C. australiensis* Fairbridge, 1944, and *C. aucklandicus* Krämer, 1895. *Crustaceana*, 7, 293–311.
- <http://dx.doi.org/10.1163/156854064x00498>
- Weikert, H. (1987) Plankton and the pelagic environment. In: Edwards, A.J. & Head, S.M. (Eds.), *Red Sea Key Environments*. Pergamon Press, Oxford, pp. 90–111.