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New species of *Tortanus* (Copepoda; Calanoida) from stomach contents of chum salmon juveniles collected from the Sea of Japan

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Abstract: *Tortanus* (*Eutortanus*) *komachi* n. sp. (Copepoda: Calanoida) is described from specimens found in the stomach contents of juvenile chum salmon captured off the northern Japanese coast of the Sea of Japan. The new species, known only from the type locality, is most closely related to *T.* (*E.*) *derjugini*, a species that is widely distributed from the Sea of Okhotsk to the South China Sea, with an isolated population in the Ariake Sea, southwestern Japan. The evolutionary process leading to the new species is discussed on the basis of the zoogeography of the subgenus.

Key words: *Tortanus* (*Eutortanus*) *komachi*, Copepoda, the Sea of Japan, *Oncorhynchus keta*

Introduction

The calanoid copepod genus *Tortanus* is widely distributed in coastal waters in the Indo–Pacific and the northwestern Atlantic Ocean, and currently accommodates 33 species in 5 subgenera, i.e. *Boreotortanus, Tortanus, Eutortanus, Acutanus* and *Atortus*. In the northwestern Pacific, 1 species of *Boreotortanus*, 3 species of *Tortanus*, 11 species of *Atortus* and 6 species of *Eutortanus* have been recorded (see Ohtsuka & Reid 1998; Ohtsuka et al. 2000). Recently, Ohtsuka & Reid (1998) have discussed the phylogenetic relationships, zoogeography, and speciation of each subgenus and revealed that the distributional patterns of *Eutortanus* correspond to an East Asian initial endemic element as defined by Nishimura (1980, 1981).

During ecological investigations on the feeding habits of chum salmon, *Oncorhynchus keta* (Walbaum), a new species of copepod belonging to the genus *Tortanus* (*Eutortanus*) was found in the stomach contents of juvenile salmon captured off the south coast of Akita Prefecture, the northeastern part of the Sea of Japan. The present study describes the new species, and its speciation mechanism is speculated on the basis of Ohtsuka et al. (1992) and Ohtsuka & Reid (1998).

Materials and Methods

The new species was found in the stomach contents of juvenile chum salmon, *Oncorhynchus keta*, captured in the surface layer at a station (39°18.41′N, 139°56.38′E; Depth, 20 m) off the south coast of Akita Prefecture on 28 March 1997. Juveniles of salmon were collected with surface trawls for half-beaks, *Hyporhamphus sajori* (Temminck et Schlegel). Water temperature and salinity in the surface layer at the collection site were 9.7°C and 33.20PSU, respectively.

For the present description, less damaged individuals of 19 females and 6 males were selected from 152 females and 31 males collected from the stomach contents of 44 salmon (42–56 mm in fork length). The selected specimens were examined in a 70% glycerin/distilled water solution under a compound microscope by the method of Humes & Gooding (1964). Drawings were made with the aid of a camera lucida. Terminology follows Huys & Boxshall (1991). Type specimens are deposited in the National Science Museum, Tokyo (NSMT).

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Tortanus (*Eutortanus*) *komachi* new species (Figs 1–5)

Types

Holotype: adult female, appendages dissected and mounted on glass slides, body in vial, NSMT–Cr12983. Paratypes: 2 adult males, appendages dissected and mounted on glass slides, bodies in vials, NSMT–Cr12984, NSMT–Cr12985; 18 adult females and 4 adult males, whole specimens, NSMT–Cr12986.

Body length

Adult female, range, 2.78–3.28 mm (mean±SD, 3.04±0.12 mm, n=19); adult male, range, 2.43–2.50 mm (2.46±0.03 mm, n=6).

Female

Body (Fig. 1A, B) widest at posterior end of cephalosome. Prosome 2.3 times as long as urosome. Cephalosome separate from first pedigerous somite; fourth and fifth pedigerous somites fused incompletely. Posterior ends of prosome slightly asymmetrical, produced posterolaterally into triangular process; exhibiting variability in shape (Fig. 1C–V). Urosome 3-segmented, third urosomite completely coalesced with caudal rami (Fig. 1A–D); genital compound somite almost as wide as long; genital operculum located ventromedially, semicircular with posterior middle margin concave (Fig. 1W); second urosomite with dorsodistal margin covering anterior part of third urosomite. Caudal rami asymmetrical, right slightly longer than left, posterior half of inner margin furnished with fine setules, seta I minute, seta II located medially on outer margin, seta V longest, seta VII originating from dorsal end.

Antennule (Figs 1A, 2A) reaching to anterior part of third urosomite; ancestral segments II to XIV completely or incompletely fused. Armature as follows: I, 1; II–IX, 9+2 ae; X, 1; XI, 2+ae; XII, 1; XIII, 1; XIV, 2+ae; XV, 1; XVI, 2+ae; XVII, 2+ae; XVIII, 2+ae; XIX, 2+ae; XX, 2; XXI, 2+ae; XXII, 1; XXIII, 1; XXIV, 1+1; XXV, 1+1+ae; XXVI–XXVIII, 6+ae. Antenna (Fig. 2B) with coxa and basis partly fused; coxa bearing small inner seta; basis with 2 inner setae of unequal length; basis and endopod completely fused; endopod 2-segmented, proximal segment with seta and spinular row subterminally, distal segment with 6 setae terminally and row of spinules subterminally; exopod 3-segmented, proximal segment unarmed, middle and distal segment bearing 3 and 2 setae, respectively. Mandible (Fig. 2C, D) with gnathobase with 5 cusped teeth, 2 ventralmost and dorsalmost of which monocusped while remaining 2 teeth bicusped; basis elongate with patch of minute spinules along inner margin at midlength; endopod 2-segmented, proximal segment unarmed, distal segment with 5 setae; exopod indistinctly 5-segmented. Maxillule (Fig. 2E) with basis and rami completely absent; praecoxal arthrite stout, bearing 12 spinulose setae and 1 minute setule (indicated by arrow); coxal endite with 3 stout, spinulose setae terminally. Maxilla (Fig. 2F) well developed; synocoxal endites having 1, 2, 2 and 3 setae, respectively; basal endite with 1 developed and 2 rudimentary setae. Setal formula of endopod: 1, 2, 2, 2. One seta on second endopodal segment rudimentary. Maxilliped (Fig. 2G) with setal formula of praecoxal and coxal endites: 0, 2, 2, 1. Basis unarmed; endopod unisegmented, bearing 3 inner spinulose setae and 1 outer seta.

Seta and spine formula of legs 1 to 4 (Fig. 3A–D) as follows.

	coxa	basis	exopod segment 1	exopod segment 2	exopod segment 3	endopod segment 1	endopod segment 2	endopod segment 3
Leg 1	0, 1	0, 0	0, 1;	0, 1;	II, 1, 4	0, 1;	0, 2;	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	1, 0	I, 1;	I, 1;	III, I, 5	0, 3;	1, 2, 3	

Leg 5 (Fig. 3E) 3-segmented; both coxal segments fused to form common base; basis with small seta at point three-fourths along outer margin; exopod 1-segmented, tapering distally; left exopod slightly longer than right; endopod absent.

Male

Body (Fig. 4A) more slender than that of the female. Prosome 1.7 times as long as urosome. Fourth and fifth pedigerous somites incompletely fused; posterior corner of prosome produced posteriorly into blunt process. Urosome (Fig. 4B, C) 5-segmented; genital somite with gonopore on left lateral side; second–fourth urosomites subequal in length; fifth urosomite and caudal rami fused dorsally but separate ventrally; caudal rami asymmetrical, right slightly longer than left; posterior half inner borders of caudal rami fringed with fine setules.

Right antennule (Fig. 4D, E) geniculate; ancestral segments I–VIII, XXI–XXIII, and XXIV–XXVIII completely or incompletely fused; segments XV–XIX expanded. Armature as follows: I, 1; II–V, 5+ae; VI, 2; VII, 2+ae; VIII, 1; IX, 2; X, 1; XI, 2+ae; XII, 1; XIII, 1; XIV, 2+ae; XV, 1; XVI, 2+ae; XVII, 2+ae; XVIII, 2+ae; XIX, 1+ae+process; XX, 1+ae+process; XXI–XXIII, 2+ae+2 processes; XXIV–XXVIII, 10+2ae. Segments XIX, XX, and XXI–XXIII bearing 1, 1, and 2 serrate processes along anterior margin, respectively. Antenna to maxilliped same in segmentation and setation as in female. Praecoxal arthrite of maxillule exhibiting variability in setation (indicated by arrows in Fig. 4F–I).

Legs 1–4 as in female. Leg 5 (Fig. 5A, B) right and left coxal segments fused to form common base. Right leg chelate; basis produced inwards into large triangular process (=endopod) bearing 8 ridges along outer margin,

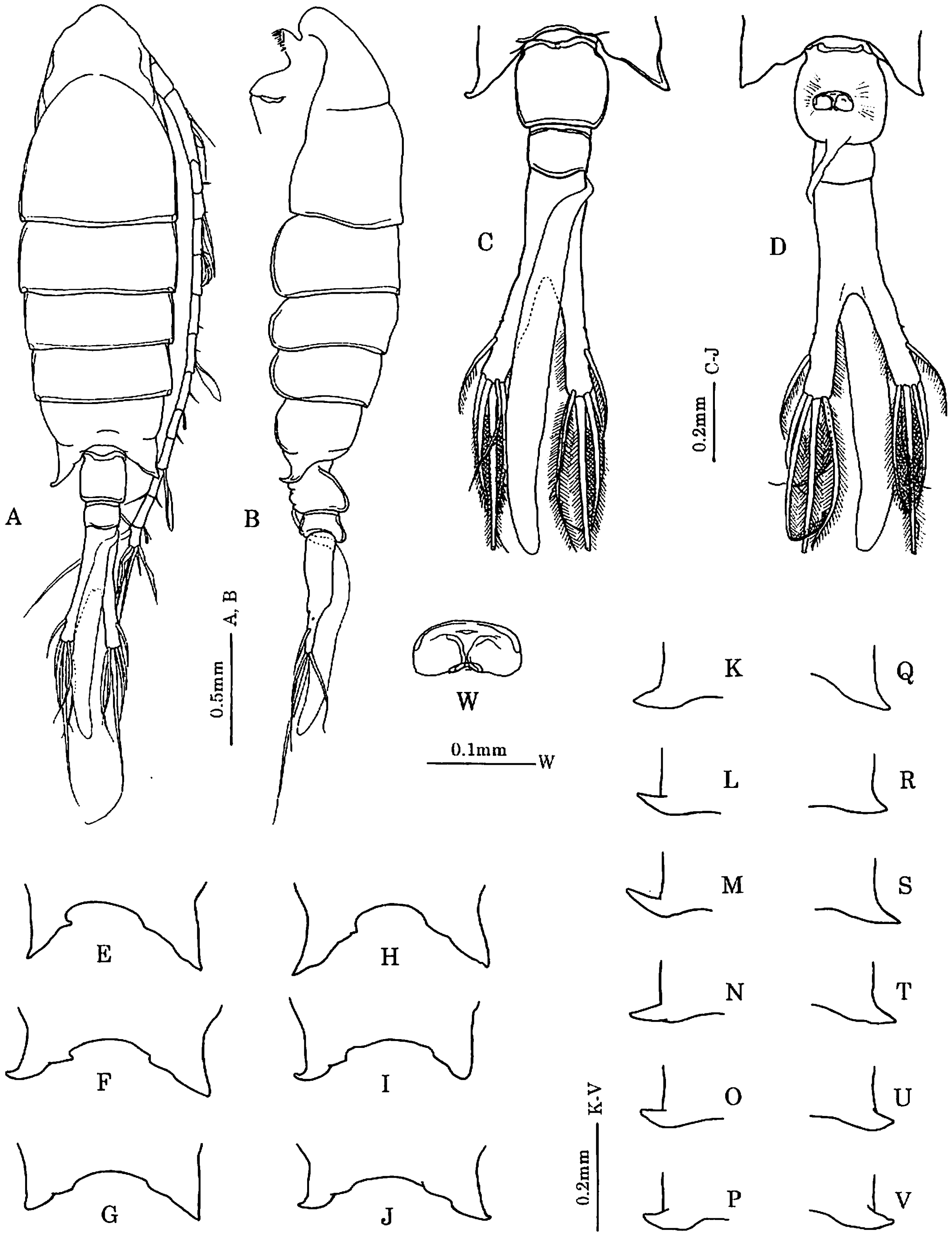

Fig. 1. *Tortanus* (*Eutortanus*) *komachi* n. sp., female. **A**. Habitus, dorsal view. **B**. Habitus, lateral view. **C**. Prosomal end and urosome, dorsal view. **D**. Prosomal end and urosome, ventral view. **E–J**. Variability of prosomal end, dorsal view. **K–P**. Variability of prosomal end, left lateral view. **Q–V**. Variability of prosomal end, right lateral view. **W**. Genital operculum.

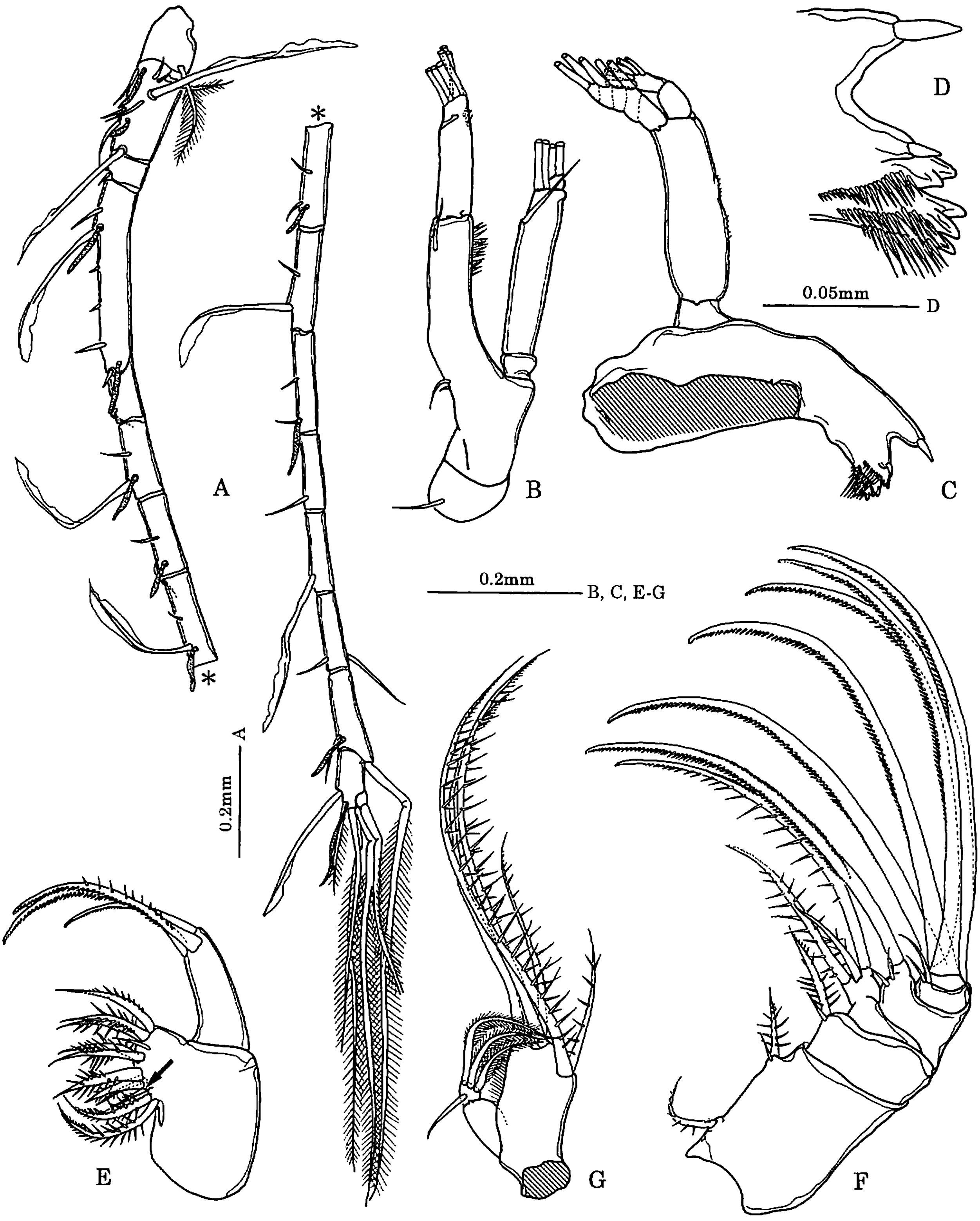

Fig. 2. *Tortanus* (*Eutortanus*) *komachi* n. sp., female. **A**. Antennule. **B**. Antenna. **C**. Mandible. **D**. Mandibular cutting edge. **E**. Maxillule, minute setule indicated by arrow. **F**. Maxilla. **G**. Maxilliped.

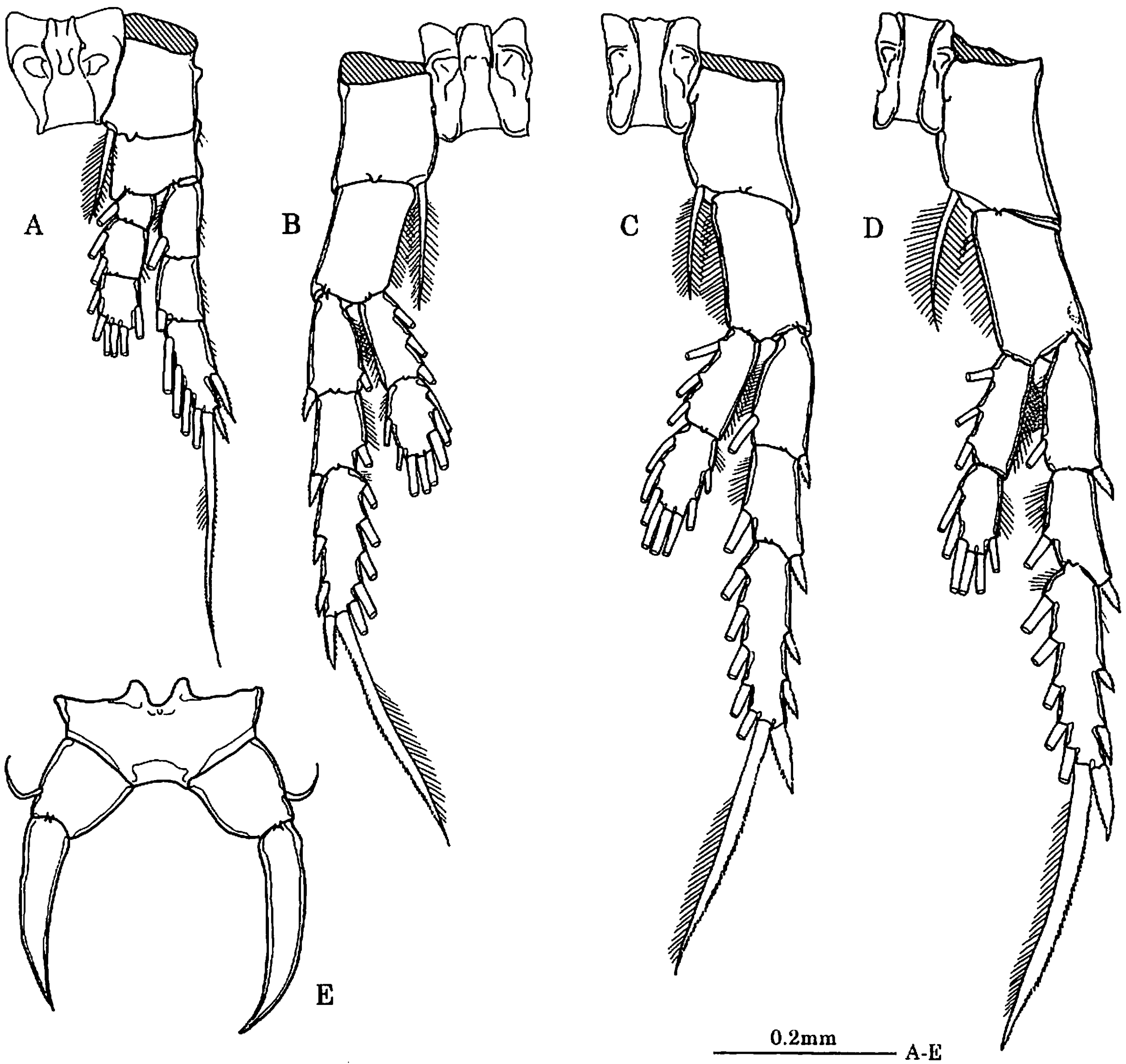

Fig. 3. *Tortanus* (*Eutortanus*) *komachi* n. sp., female. **A**. Leg 1, anterior surface. **B**. Leg 2, anterior surface. **C**. Leg 3, anterior surface. **D**. Leg 4, anterior surface. **E**. Leg 5, anterior surface.

bearing proximal notch on anterior margin, with medial and proximal seta on posterior surface; exopod smoothly curved inwards, bearing 4 short, stout spines and 2 proximal setae on posterior margin; distal two-thirds of the segment more slender than proximal. Left leg with basis bearing outer seta subterminally; exopod 2-segmented, proximal segment with short, thick spine subterminally, distal segment with tuft of fine setules and seta along proximal inner margin, and 2 medial inner and 1 terminal short spine; terminal outer portion with 17 ridges.

Comparison

The new species definitely belongs to the subgenus *Eutortanus* because of the combination of the following characters: (1) the right caudal ramus is longer than the left, (2) the maxillipedal syncoxa bears 5 setae, (3) the endopod of leg 1 is 3-segmented, (4) the second endopodal segment of leg 4 bears 6 setae, (5) the second endopodal segments of legs 2 and 3 each bears 8 setae.

The female of the new species can be readily distinguished from the 6 other members of the subgenus *Eutortanus* by the morphology of the third urosomite. The new species is distinguished from *Tortanus* (*Eutortanus*) *sheni* Hulsemann, 1988 in having a 3-segmented urosome rather than a 4-segmented urosome. The new species and *T.* (*E.*) *derjugini* Smirnov, 1935, can be separated from the remaining 4 species in having the third urosomite without any conspicuous structures on the right-side surface. The right-side surface of the urosome is armed with an acute process in *T.* (*E.*) *terminalis* Ohtsuka & Reid, 1998, a serrate margin in *T.* (*E.*) *vermiculus* Shen, 1955, a spiniform process in *T.*

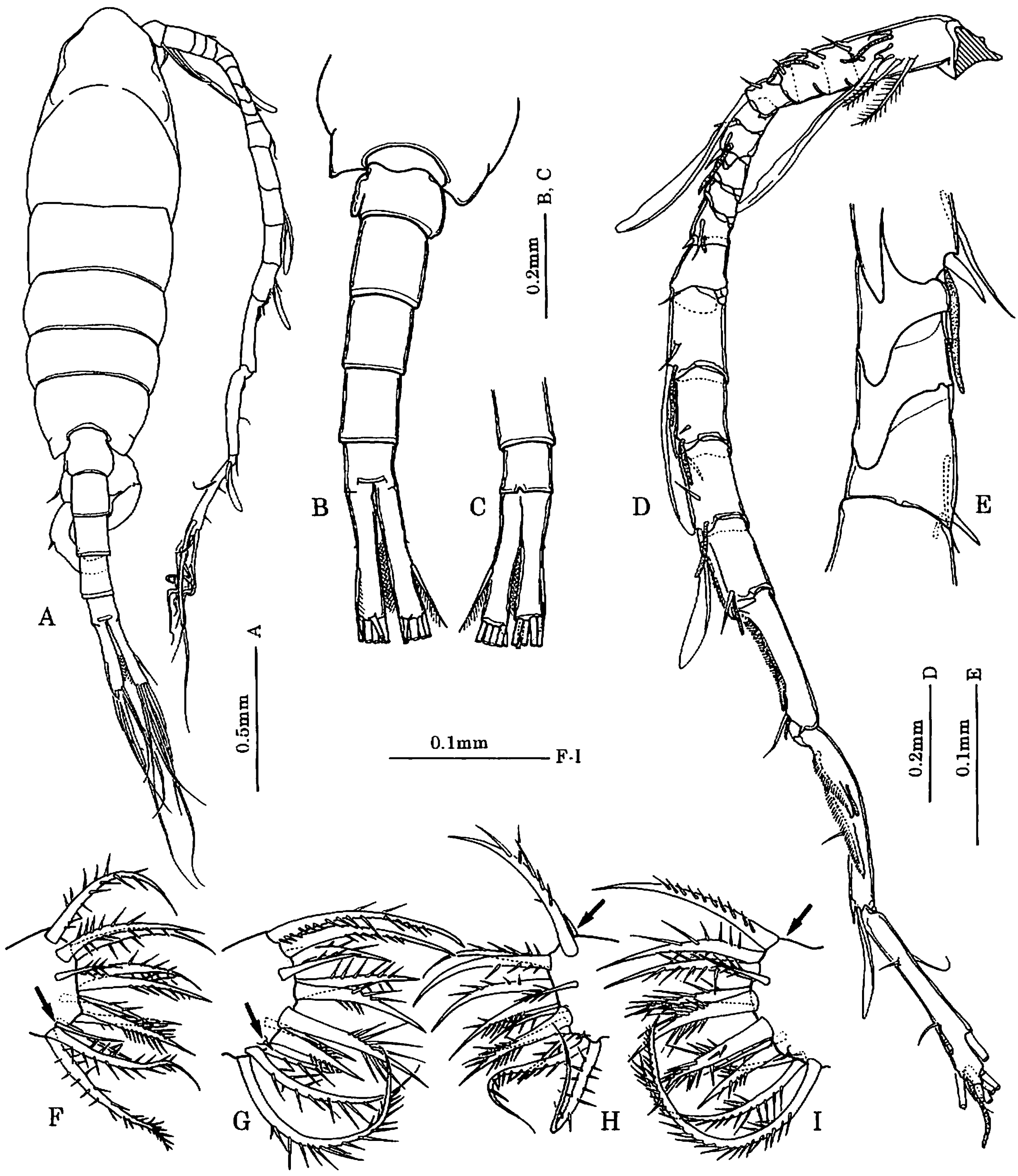

Fig. 4. *Tortanus* (*Eutortanus*) *komachi* n. sp., male. **A.** Habitus, dorsal view. **B.** Prosomal end and urosome, dorsal view. **C.** Fourth and fifth urosomites, anal somite, and caudal rami, ventral view. **D.** Right antennule, ventral view. **E.** Right antennule, segments XI–XV, dorsal view. **F–I.** Variability of maxillular praecoxal arthrite, variable portion indicated by arrows.

(*E.*) *spinicaudatus* Shen & Bai, 1956, and a developed anterolateral process in *T.* (*E.*) *dextriobatus* Chen & Zhang, 1965. The new species most closely resembles *T.* (*E.*) *derjugini* Smirnov, 1935, on the basis of the surface structure of the third urosomite in the female. However the new species can be separated from *T.* (*E.*) *derjugini* in having 2 setae on the proximal endite of the maxillary coxa rather than 1 seta as in the latter species. In addition, the third urosomite of the female is completely coalesced with the caudal ramus in the new species, whereas it is incompletely coalesced in *T.* (*E.*) *derjugini*.

The male of the new species differs from *Tortanus* (*Eutortanus*) *derjugini*, *T.* (*E.*) *dextrilobatus*, *T.* (*E.*) *sheni*, *T.* (*E.*) *spinicaudatus*, and *T.* (*E.*) *terminalis* in having a

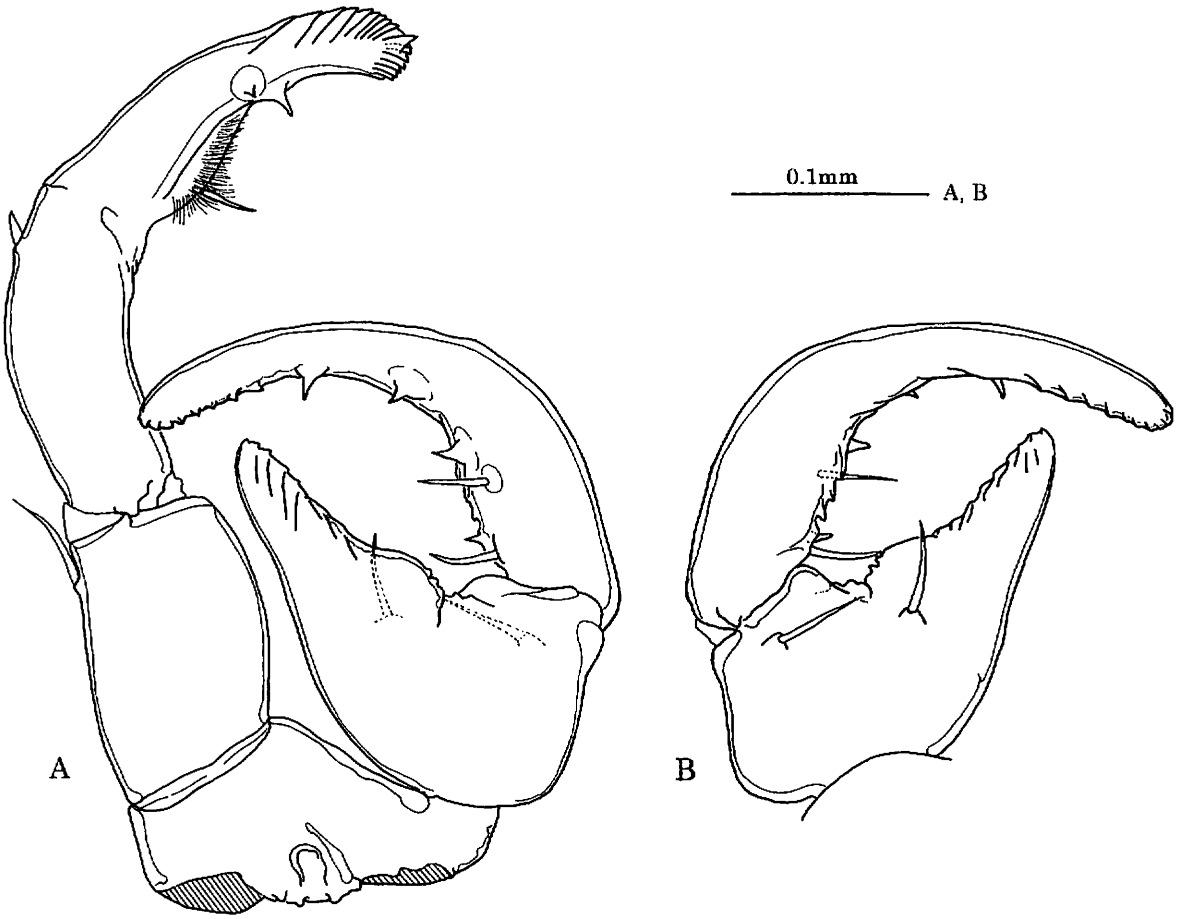

Fig. 5. *Tortanus* (*Eutortanus*) *komachi* n. sp., male. **A.** Leg 5, anterior. **B.** Right leg 5, posterior.

broader base of the inner proximal process of the right basis of leg 5 rather than a narrow base as in the latter 5 species. *T.* (*E.*) *vermiculus* and the new species have a broad base of the inner proximal process, but it differs in shape: in the new species the inner proximal process is massive and terminated with a round tip, whereas in *T.* (*E.*) *vermiculus* the tip is sharply pointed. In addition, the difference in the maxillary coxa of the female between the new species and *T.* (*E.*) *derjugini* is also found in the case of the male, and the fifth urosomite of the male incompletely coalesced with the caudal ramus in the new species, whereas in *T.* (*E.*) *derjugini* it is completely separated from the caudal ramus.

Etymology

The specific name *komachi* (meaning beautiful woman, Japanese) alludes to the women of Akita Prefecture, the type locality, which is famous for beautiful women.

Remarks

The new species was frequently found in the stomachs of juvenile chum salmon captured from the coastal waters of Akita Prefecture in Spring. In Spring of 1997, salmon juveniles that had eaten the new species were collected from an area ranging from 39°9.59′ to 39°52.41′N and from 139°53.57′ to 140°02.91′E, entirely on the southern coast of Akita Prefecture. The new species was also found in plankton samples taken simultaneously when the salmon were captured, but population densities were low (0.3–0.6 adults m^{-3}). The frequency of occurrence (number of stations where the new species was found per number of stations sampled) was 9.5% in plankton samples, whereas it was 66.7% for the stomach contents. Hence it seems that the new species has a patchy distribution and/or is selectively preyed upon by juvenile salmon (Suzuki et al. 1994).

Hitherto the known range of water temperatures and salinities at stations where the new species was found in the stomach of juvenile salmon in Spring of 1997 is 9.5–13.3°C and 32.22–33.20 PSU, respectively. *Eutortanus* was originally adapted to brackish waters (Ohtsuka et al. 1995). The new species seems to occur in relatively high-salinity waters as with *Tortanus* (*Eutortanus*) *terminalis* recorded from the Pacific coast of southern Japan (Ohtsuka & Reid 1998). However, the new species may be intolerant of the higher-salinity Tsushima Current surface water (ca. 34.5‰ in March, Nishimura 1982).

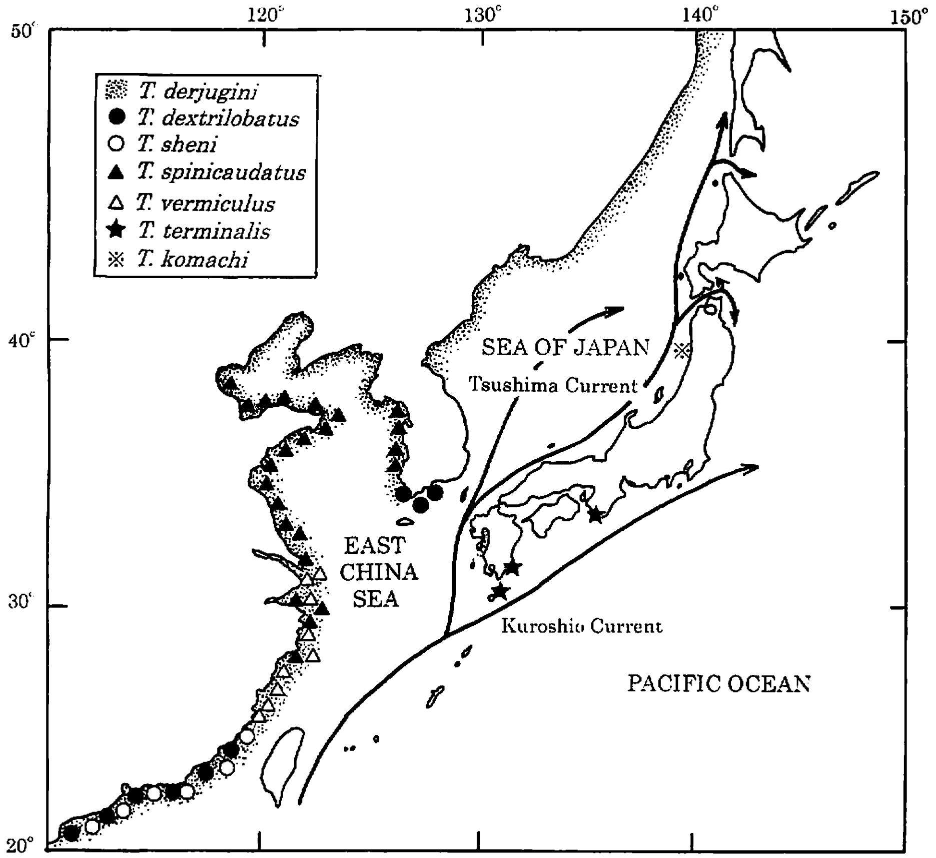

Fig. 6. Horizontal distribution of the subgenus *Tortanus* (*Eutortanus*) redrawn after Ohtsuka (1999); current system modified from Uda (1934). In *T. terminalis* and *T. komachi* symbol indicates collected site, whereas in others the distributions are schematically exhibited.

Discussion

The horizontal distributions of the six known species of the subgenus *Eutortanus* are shown in Fig. 6 with the type locality of the new species (cf. Ohtsuka 1999). The speciation of the six known species might have occurred in the ancient East China Sea gulf with low salinity water during the Middle Miocene to the Pleistocene and relatively recently members of the subgenus may have secondarily expanded their distributions in the neighboring waters of the East China Sea (see Ohtsuka et al. 1992; Ohtsuka & Reid 1998; Ohtsuka 1999). Of these species, *Tortanus* (*Eutortanus*) *derjugini* is broadly distributed in Asian continental waters from the East and South China Seas through to the Sea of Japan and the Sea of Okhotsk. It is believed to have been introduced from the ancient East China Sea gulf into the ancient Japan Sea gulf 20,000–60,000 years ago (in particular, 20,000–30,000 years ago) when cold, low-salinity continental waters from the East China Sea flowed into the Sea of Japan via the Tsushima Channel (Ohba 1983; Ohtsuka et al. 1992). The new species is known only from the type locality at present. Since the new species has never been recorded in the East and South China Seas in spite of intensive taxonomic work in these seas by Chinese scientists (e.g., Chen & Zhang 1965; Lian et al. 1994), it seems to be confined to the Sea of Japan and neighboring waters influenced by the Tsushima Current. Hirakawa (1984) reported a species of the subgenus *Eutortanus* as *T. derjugini*? from Funka Bay and the morphological characters of the species are very similar to those of the new species (Hirakawa, pers. comm.).

The new species has several advanced characters, compared with *T.* (*E.*) *derjugini*: (1) the third urosomite and caudal rami of the female are completely fused (incompletely in *T.* (*E.*) *derjugini*); (2) the right endopod of male leg 5, represented by a remarkably inward produced process, is similar in shape to that of the fifth copepodid stage of *T.* (*E.*) *derjugini* (neoteny). These morphological characters suggest that the new species might have been split off from *T.* (*E.*) *derjugini* after the species was introduced into the Sea of Japan in the late Pleistocene. The speciation of the new species is suggested to have occurred since 20,000–60,000 years ago. In the Calanoida speciation rates are estimated to fall between 10,000–1,000,000 years (Fleminger 1986). Since the subgenus *Eutortanus* is considered to be an initial endemic element (Ohtsuka et al. 1995), speciation rates of the subgeneric members seem to be relatively fast (cf. Nishimura 1980).

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