

***Tortanus derjugini* Smirnov (Copepoda: Calanoida)
from the Ariake Sea, western Japan, with notes
on the zoogeography of brackish-water
calanoid copepods in East Asia^{1, 2}**

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Abstract

Tortanus (Eutortanus) derjugini Smirnov is redescribed from brackish regions of the Ariake Sea, western Japan. The copepod is presumed to be an Asian continental relict because of its exclusive occurrence in Asian continental waters and the Ariake Sea in Japan. A comparison between specimens from Japanese, Korean and Chinese waters is made, and some differences were detected in the anal somite and caudal rami of females between Japanese and Korean specimens; the length/width ratio of the anal somite and the ratio of the right caudal ramus to the left one are significantly lower in the former. These differences indicate that the isolation of the Ariake Sea population from the Asian continental populations since the last transgression (ca. 6,000-10,000 years ago) has caused no great morphological variation. Zoogeography of brackish-water calanoid copepods including this species in East Asia is discussed. There are three types of distribution patterns that are supposed to be related to geological events occurring during the Cenozoic era.

Key words: *Tortanus (Eutortanus) derjugini*, Ariake Sea, East Asia, brackish-water, continental relict

The subgenus *Tortanus (Eutortanus)* consists of five species [*T. (E.) derjugini* Smirnov, 1935, *T. (E.) dextrilobatus* Chen & Zhang, 1965, *T. (E.) sheni* Hulsemann, 1988, *T. (E.) spinicaudatus* Shen & Bai, 1956; *T. (E.) vermiculus* Shen, 1955]. *T. (E.) derjugini* is most broadly distributed with a range from the Sea of Okhotsk to the South China Sea whereas the other species have hitherto been recorded only from Chinese waters (Smirnov 1929, 1935, Brodsky 1950, Chen & Zhang 1965, Ohtsuka et al. 1992). Tanaka (1965) recorded the occurrence of *T. (E.) derjugini* from the Ariake Sea, western Japan, without illustrations. Possible speciation and dispersal mecha-

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² 有明海産カラヌス目カイアシ類 *Tortanus derjugini* および東アジアにおける汽水性カイアシ類の地理分布

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nisms of *Tortanus* (*Eutortanus*) have been proposed by Ohtsuka et al. (1992). According to them, its population in the Ariake Sea has been isolated from the Asian continental populations since the last transgression (ca. 6,000–10,000 years ago) as suggested for another brackish calanoid copepod *Sinocalanus sinensis* (Poppe, 1889) (Hiromi & Ueda 1987).

The present paper redescribes *T. (E.) derjugini* from the Ariake Sea with a comparison between specimens from Japanese and Asian continental waters, and discusses the zoogeography of brackish calanoid copepods in East Asia.

Materials and Methods

Tortanus derjugini was collected from estuaries of the Ariake Sea, at the mouth of the Chikugo River on 14 March 1985 by Prof. M. Tanaka (see Hiromi & Ueda 1987, Fig. 3). Water temperature and salinity were 9.2 °C and 1.58 ‰, respectively. Nine females and 7 males were observed in the present study. Chinese and Korean specimens of the species were also examined for comparison (7 females and 3 males from Xiamen, China, March, 1981, collected by G.-S. Lian; 3 females and 1 male from Gwang Yang Bay, Korea, October 1987, collected by Dr. S.-W. Kim).

The lengths and widths of the genital double-somite and anal somite, the length of both caudal rami, and the length of both rami of leg 5 were measured in females (see Figures 1C, 4F). These measurements were restricted to specimens in which measured parts were not damaged.

The terminology used in the description of this species is based on Huys & Boxshall (1991). The segmentation of the male leg 5 is in accordance with Giesbrecht (1892).

Description

Tortanus (Eutortanus) derjugini Smirnov, 1935 (Figures 1–11)

Body length.— Ariake Sea: ♀ 2.35, 2.36 mm; ♂ 1.98, 2.09 mm; Xiamen: ♀ 2.16 mm; ♂ 2.04 mm; Gwang Yang Bay: ♀ 1.94, 2.00, 2.06 mm; ♂ 1.71 mm.

Female (Ariake Sea specimens).— Body (Figure 1A, B) widest at posterior end of cephalosome. Prosoma 2.4 times as long as urosome. Cephalosome separate from first pedigerous somite; fourth and fifth pedigerous somites fused dorsally but separate laterally (Figure 1D, E). Posterior end of last prosomal somite produced posterolaterally into wing-like expansion on both sides, slightly asymmetrical, exhibiting variability in shape (Figure 1C–S). Urosome 3-segmented with anal somite incompletely coalesced with caudal rami, suture clearly visible in some specimens (Figure 1C) but not so in other ones (Figure 7A); genital double-somite almost as wide as long (Figure 8); genital operculum concave posteromedially (Figure 1T); first abdominal somite bearing minute dorsal prominence posteriorly; anal somite

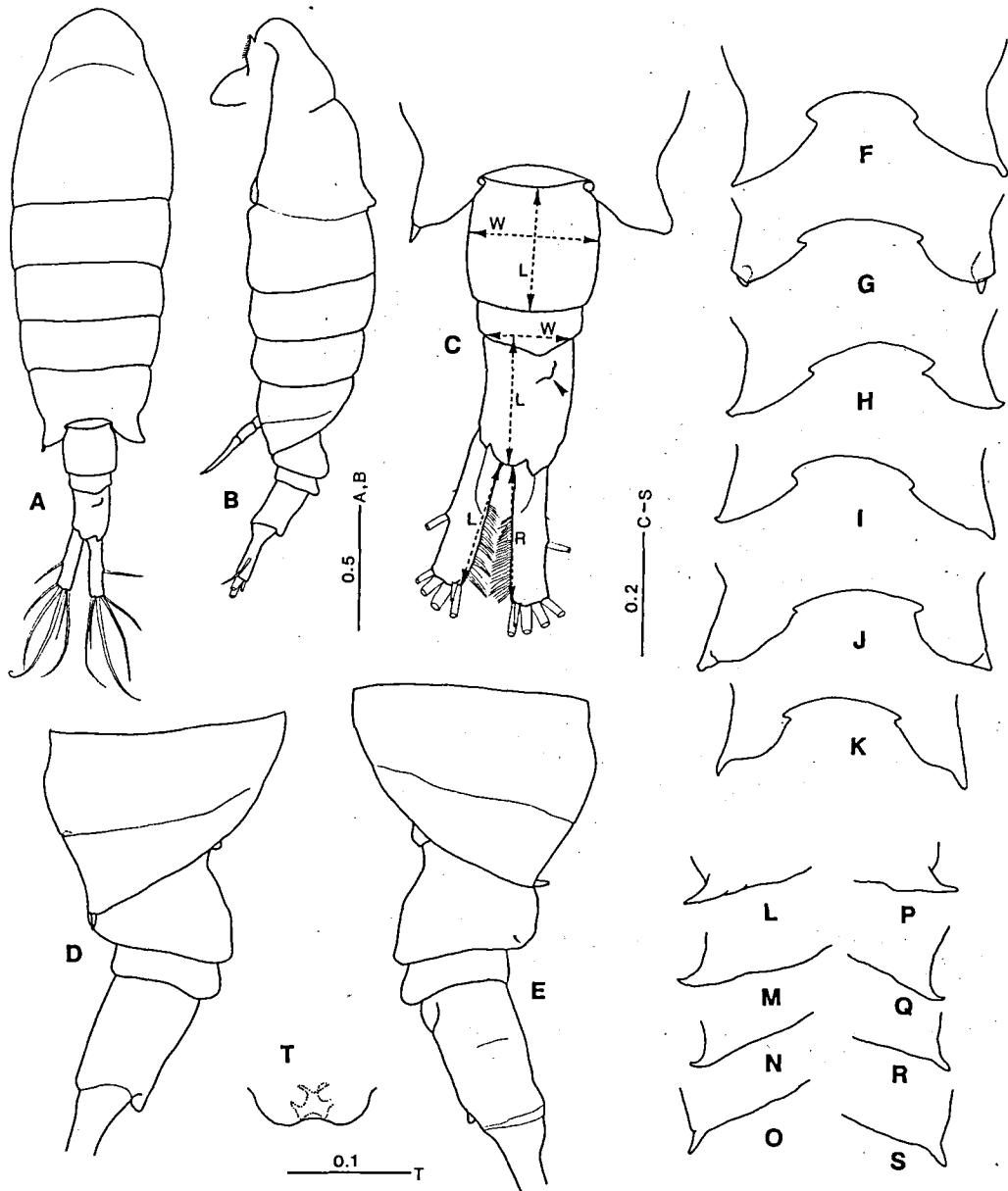


Fig. 1. *Tortanus (Eutortanus) derjugini* Smirnov, 1935, female from Ariake Sea. A: habitus, dorsal view; B: habitus, lateral view; C: prosomal end and urosome, dorsal view, minute prominence indicated by arrowhead; D: prosomal end and urosome, left lateral view; E: prosomal end and urosome, right lateral view; F-K: variability of prosomal end, dorsal view; L-O: variability of prosomal end, left lateral view; P-S: variability of prosomal end, right lateral view; T: posterior margin of genital operculum. W: width; L: length; R: length of right ramus; L: length of left ramus. Scales in mm.

longest, having low dorsal projection (Figure 1C, arrowed); caudal rami asymmetrical, right slightly longer than left, posterior half of inner margin furnished with fine

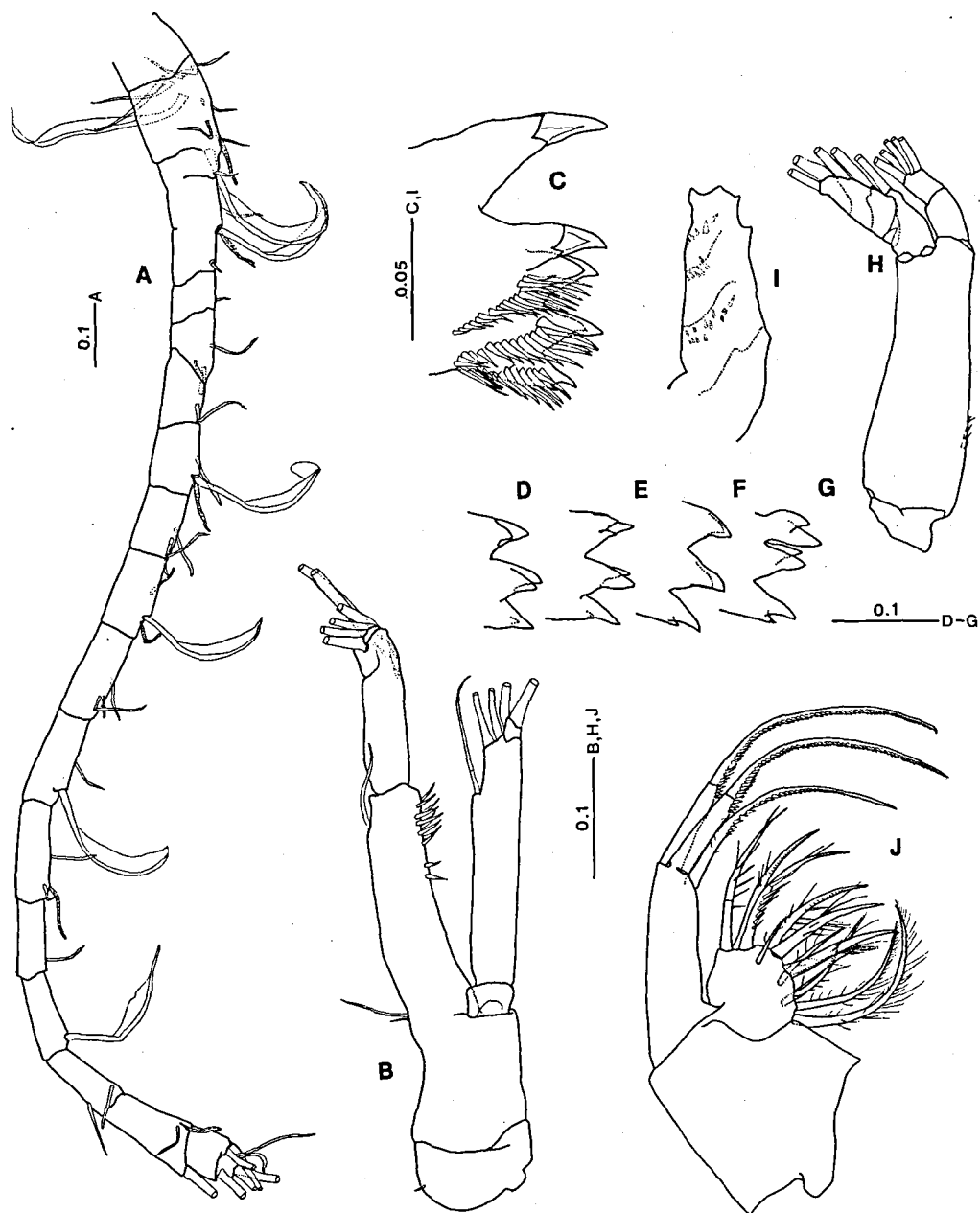


Fig. 2. *Tortanus (Eutortanus) derjugini* Smirnov, 1935, female from Ariake Sea. A: antennule; B: antenna; C: mandibular cutting edge; D-G: variability of central and dorsal teeth on mandibular cutting edge; H: mandibular palp; I: mandibular exopod, setae omitted; J: maxillule. Scales in mm.

setules, seta I minute, seta II located medially on outer margin, seta V longest, seta VII originating from dorsal end.

Antennule (Figure 2A), antenna (Figure 2B), mandible (Figure 2C-I), maxillule

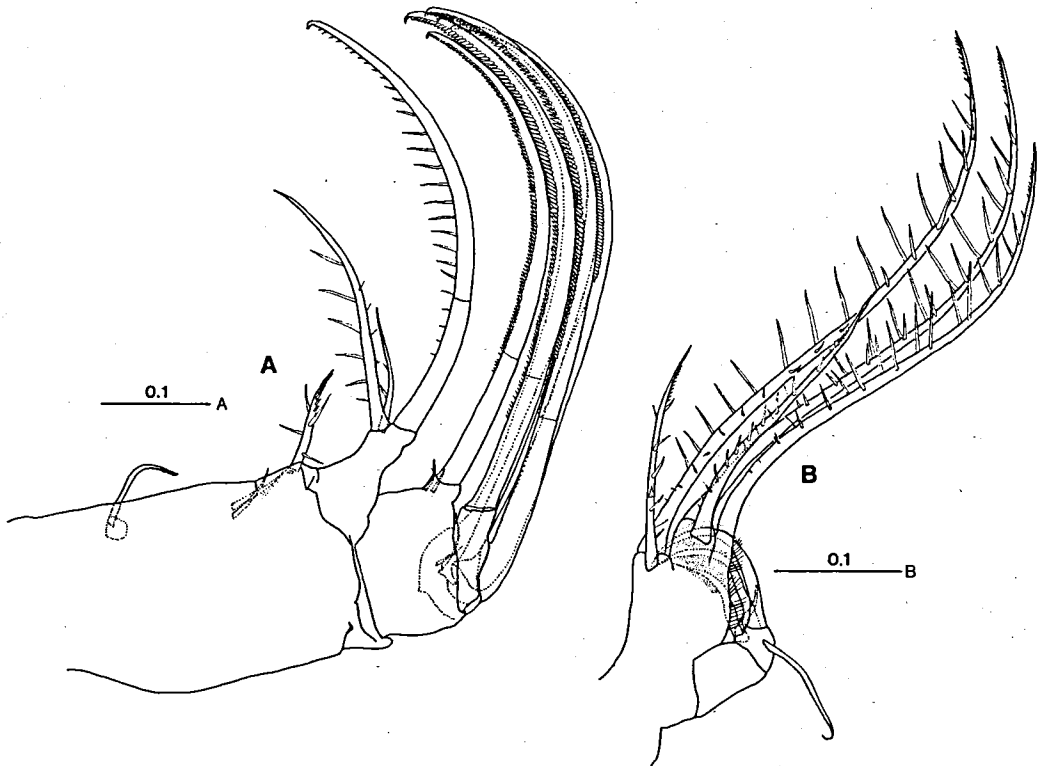


Fig. 3. *Tortanus (Eutortanus) derjugini* Smirnov, 1935, female from Ariake Sea. A: maxilla; B: maxilliped. Scales in mm.

(Figure 2J), maxilla (Figure 3A), and maxilliped (Figure 3B) having the same segmentation and setation as redescribed for *T. (E.) dextrilobatus* by Ohtsuka et al. (1992). First central tooth on mandibular cutting edge (Figure 2C–G) variable in shape, tri- or bicusped at tip, and, in one individual, expanded terminally (Figure 2G); five exopod segments of mandible almost coalesced, with three rows of minute spinules (Figure 2I).

Legs 1–4 (Figure 4A–E) with the same segmentation, setation and spinulation as in *T. (E.) dextrilobatus*, but segments of coxa, basis and both rami wider than in the latter (see Ohtsuka et al. 1992, Figs 3E, 4A–C). Endopod segments of legs 2–4 bearing fine spinules of various sizes (Figure 4C). Leg 5 also similar to that of *T. (E.) dextrilobatus* (Ohtsuka et al. 1992, Fig. 4D): coxae and intercoxal sclerite completely fused to form common base; basis with minute outer seta; endopod absent; exopod 1-segmented, left one slightly longer than right with minute setules along inner medial margin. Right exopod (Figure 4F–H) showing variability, outer proximal seta usually absent (Figure 4F,H), but very rarely present being found only in one specimen (Figure 4G); minute subterminal spinules present also rarely, in only a single specimen (Figure 4H).

Male (Ariake Sea specimens).—Body (Figure 5A) more slender than that of the

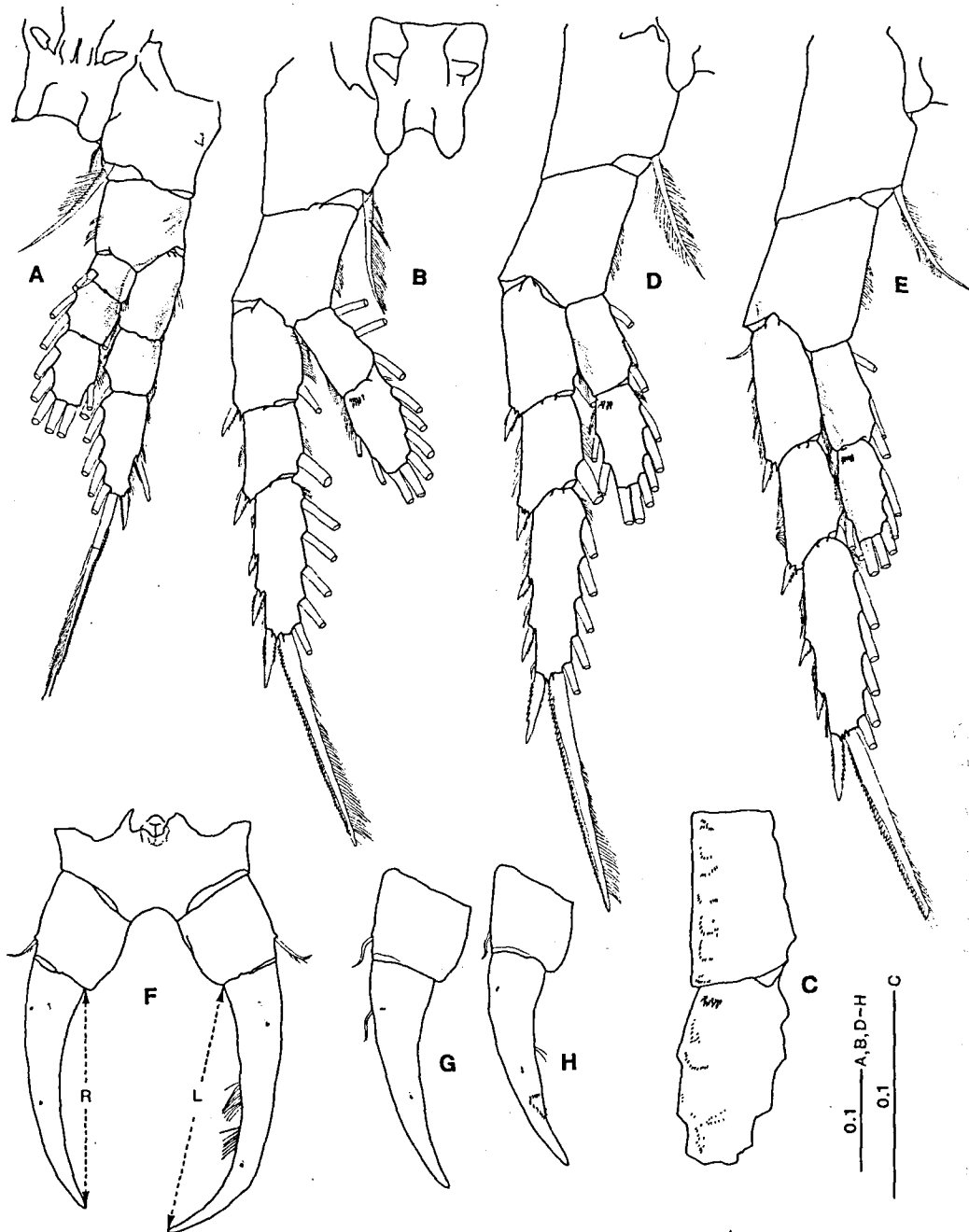


Fig. 4. *Tortanus (Eutortanus) derjugini* Smirnov, 1935, female from Ariake Sea. A: leg 1, anterior surface; B: leg 2, anterior surface; C: endopod of leg 2, setae omitted; D: leg 3, anterior surface; E: leg 4, anterior surface; F: leg 5, anterior surface; G, H: variability of right exopod of leg 5. R: length of right ramus; L: length h of left ramus. Scales in mm.

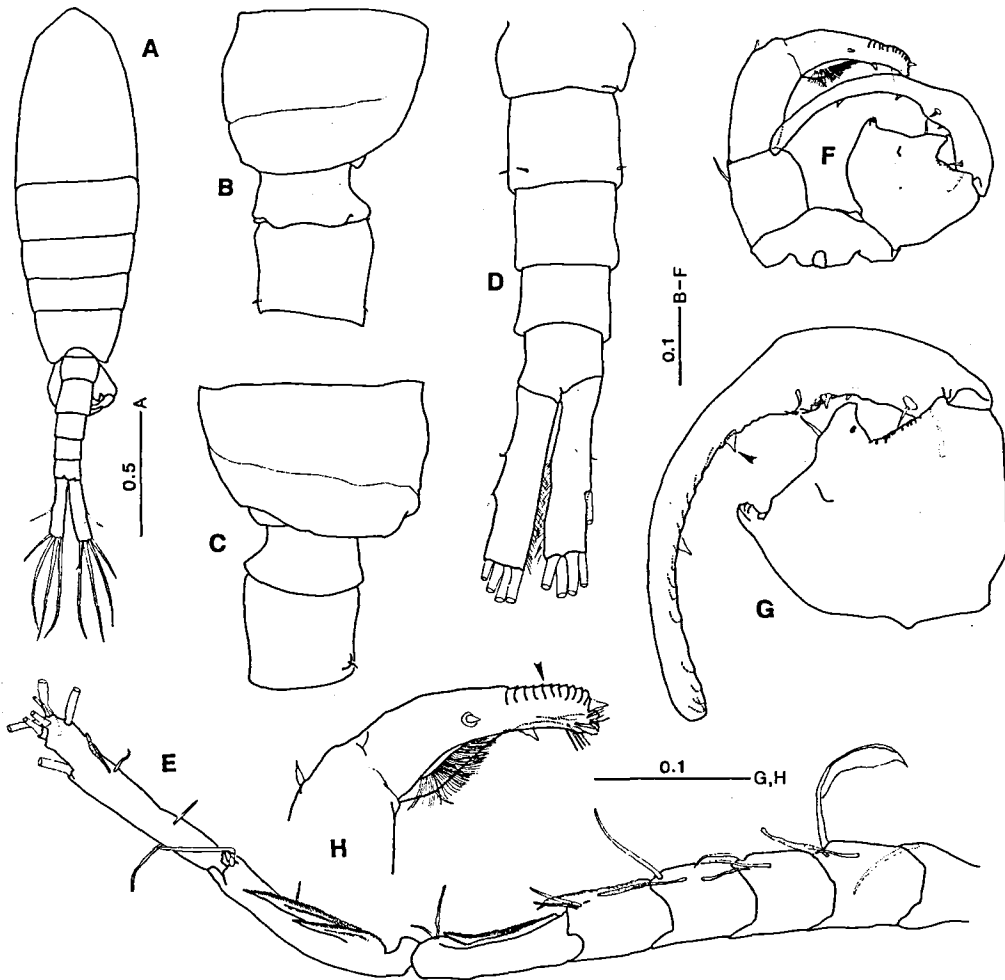


Fig. 5. *Tortanus (Eutortanus) derjugini* Smirnov, 1935, male from Ariake Sea. A: habitus, dorsal view; B: prosomal end and first and second urosomal somites, left lateral view; C: prosomal end and first and second urosomal somites, right lateral view; D: urosome, ventral view; E: right antennule; F: leg 5, anterior surface; G: exopod of right leg 5; H: terminal exopod segment of left leg 5. Scales in mm.

female. Posterolateral margins of prosomal end produced into round lobe, slightly asymmetrical (Figure 5B, C); fourth and fifth pedigerous somites fused dorsally and free laterally as in the female. Urosome (Figure 5D) distinctly 5-segmented; genital somite with gonopore on left side; first abdominal somite longest, having robust, short setules on ventrolateral sides; anal somite and caudal rami asymmetrical, right ramus longer than left.

Right antennule (Figure 5E) geniculate with the same segmentation and setation as in *T. (E.) dextrilobatus* redescribed by Ohtsuka et al. (1992). Leg 5 (Figure 5F) similar to that of *T. (E.) dextrilobatus* (see Ohtsuka et al. 1992, Fig. 5B), but the proximal segment of the right exopod wider than in the latter. The setation and

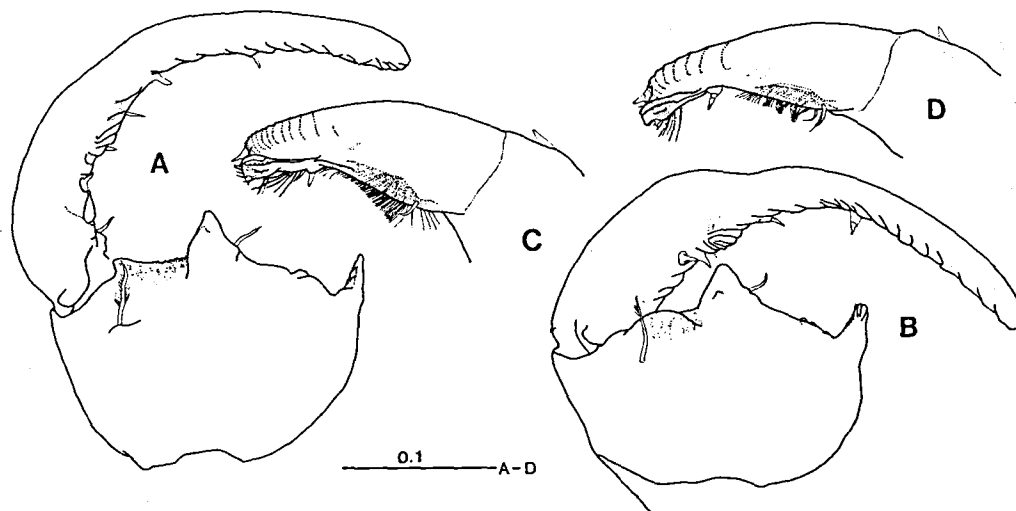


Fig. 6. *Tortanus (Eutortanus) derjugini* Smirnov, 1935, male from Ariake Sea. A, B: right exopod of leg 5; C, D: terminal exopod segment of left leg 5. Scales in mm.

spinulation are the same as in *T. (E.) dextrilobatus* (Ohtsuka et al. 1992). The number of outer terminal ridges on the second exopod segment of the left 5th leg ranging from 7 to 12 (Figure 5H, arrowed); that of ridges along the posterior half of the inner margin of the second exopod segment of the right 5th leg (posterior part beyond the fifth element indicated by arrowhead in Figure 5G) ranging from 13 to 16.

Variability.- Variability was found in the thoracic ends (Figure 1F-S), the urosome (Figures 1C, 7A, 8-10) and leg 5 (Figure 4F-H) in females, and leg 5 in males (Figures 5G, 6) from the Ariake Sea.

Comparison.-The genital double-somites, anal somites, caudal rami and legs 5 of females were compared between specimens from Japanese, Korean and Chinese waters (Figures 7-11). The length/width ratio of the anal somite (Figure 9) and the ratio of the right caudal ramus length to the left (Figure 10) were significantly lower in the Ariake Sea than in Korea (t -test, $P < 0.05$), indicative of geographic variation between specimens in these two localities. However, the differences in these ratios were not significant between the Ariake Sea-Chinese specimens or between the Chinese-Korean specimens. The other ratios examined, namely the length/width ratio of the genital double-somite (Figure 8) and the right/left length ratio of the exopod of leg 5, showed no significant differences amongst these three localities.

Brodsky (1950) reported regional differences in body length in this species: in the Okhotsk Sea ♀ 2.03-2.26 mm, ♂ 1.81-1.97 mm; in the Japan Sea ♀ 1.71-1.93 mm, ♂ 1.40-1.65 mm. In addition, a spinular row along the posterior margin of the female genital double-somite is present in the former and absent in the latter (Smirnov

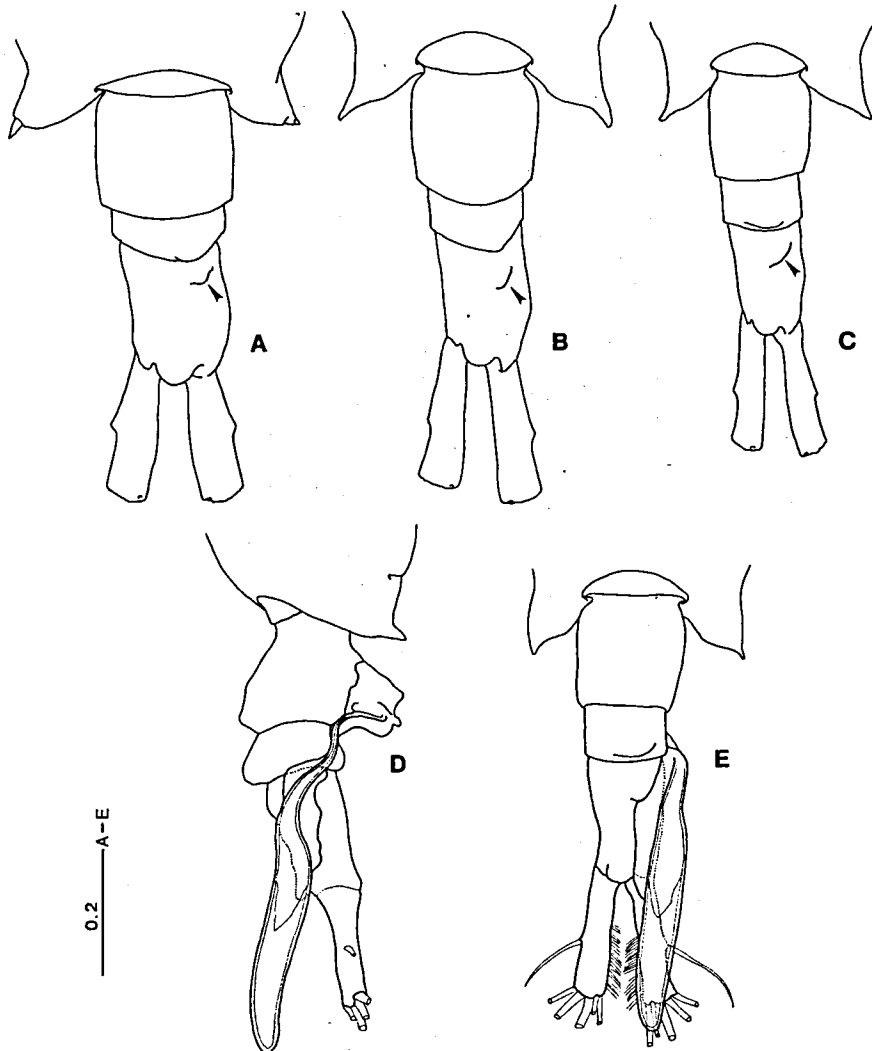


Fig. 7. *Tortanus (Eutortanus) derjugini* Smirnov, 1935, female from Ariake Sea (A), Xiamen (B) and Gwang Yang Bay (C-E). A-C: urosome, dorsal view, low prominence on anal somite arrowed; D: urosome with spermatophore on genital double-somite, lateral view; E: same as D, dorsal view. Scales in mm.

1935, Brodsky 1950). The present specimens from the Ariake Sea are also larger than the latter, but lack a spinular row on the female genital double-somite. Chen & Zhang (1965) mentioned that body length is 2.00–2.30 mm in females and 1.80–2.00 mm in males from the East China Sea. Therefore Japan Sea specimens are rather smaller than those from other regions.

Discussion

The subgenus *Tortanus (Eutortanus)* may have originated from the ancient East China Sea, a huge gulf of low salinity which existed during the Middle Pliocene to

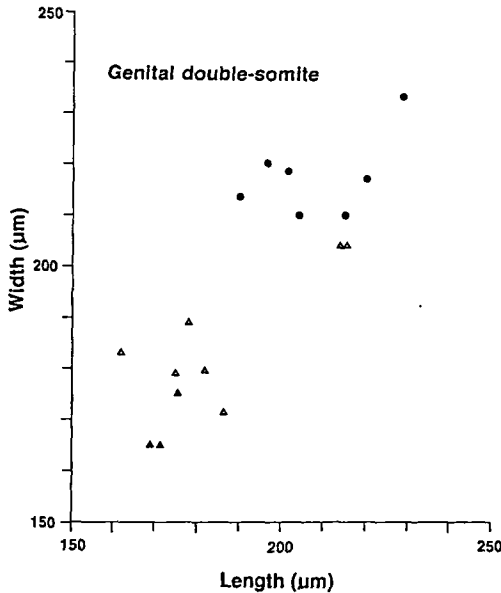


Fig. 8. Length and width of genital double-somite of females of *Tortanus* (*Eutortanus*) *derjugini* Smirnov, 1935. Solid circle: Ariake Sea, Japan; open triangle: Xiamen, China; solid triangle: Gwang Yang Bay, Korea.

Pleistocene, and is referred to as a typical East Asian "initial endemic" element based on its restricted distribution in the brackish waters of East Asia (Nishimura 1980, 1981). "Initial endemic" is in contrast with "relict endemic", and an initial endemic element refers to a group of organisms which originally appeared in a restricted area and has not yet expanded its distribution. According to Nishimura (1980), an initial endemic element is characterized by both high speciation in a restricted region and high variability in a species. The subgenus accommodates five species in a limited region of East Asia (Ohtsuka et al. 1992), and some morphological variabilities of *T. (E.) derjugini* detected in the present and previous studies may exhibit intraspecific variation characteristic of an initial endemic element.

Brackish-water calanoid copepods in East Asia are provisionally categorized into three types based on the geographic range of their distributions (Table 1). In this paper brackish-water copepods are defined as those which are most abundantly distributed in brackish waters with a decrease in number towards both fresh-water and the open sea. Contrary to the high diversity of families of marine calanoid copepods, these brackish-water copepods are composed of only five families and seven genera, all of which are assigned to the superfamily Centropagoidea excepting the Paracalanidae (superfamily Megacalanoidea). Type I belongs to an East Asian endemic element that could have originated on the coasts of the ancient East China Sea or the Japan Sea (Nishimura 1980, 1981), and contains ca. 80 % of the above-listed copepods. There are four subtypes in this type depending on whether the species is restricted to continental waters or not. *Acartia tsuensis* Ito, 1956 and *Pseudodiaptomus ishigakiensis* Nishida, 1985 (Type Ia) have hitherto been recorded solely in Japan (Shen & Mizuno 1984, Nishida 1985, Walter 1986, Oka et al. 1991a). *Acartiella sinensis* Shen & Lee, 1963, *Sinocalanus laevidactylus* Shen & Tai, 1964, *S. solstitialis* Brehm, 1923, *Pseudodiaptomus bulbosus* Shen & Tai, 1964, *P. forbesi*

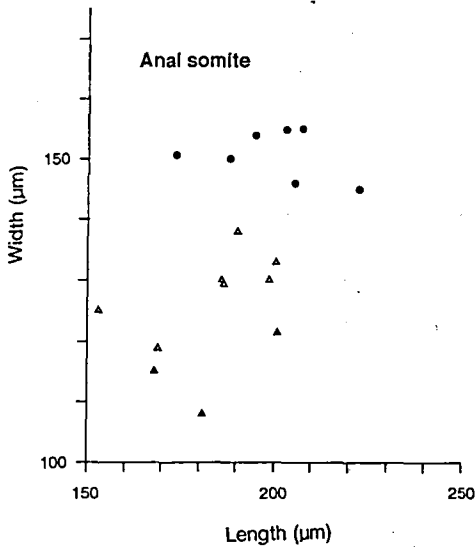


Fig. 9. Length and width of anal somite of females of *Tortanus* (*Eutortanus*) *derjugini* Smirnov, 1935. Solid circle: Ariake Sea, Japan; open triangle: Xiamen, China; solid triangle: Gwang Yang Bay, Korea.

Burckhardt, 1913, *P. infatus* Shen & Tai, 1964, *P. poplesia* Shen, 1955, *P. spatulatus* Shen & Tai, 1964, *Tortanus dextrilobatus*, *T. sheni*, *T. spinicaudatus* and *T. vermiculus* (Type Ib) are restricted to the continental coasts.

Types Ic and Id are distributed in both continental and island waters. The geographic ranges of Type Ic species differ somewhat for each species. *Acartia sinjiensis* Mori, 1940 is apparently a warm-water species and is distributed in the tropical waters of Singapore and Java as well as in the temperate and subtropical waters of Japan (Ueda unpublished). On the other hand, *Eurytemora pacifica* Sato, 1913 prefers cold waters and its northernmost distribution reaches Alaska (Heron 1964). In Japan Type Id, which is composed of *S. sinensis* Poppe, 1889 and *T.*

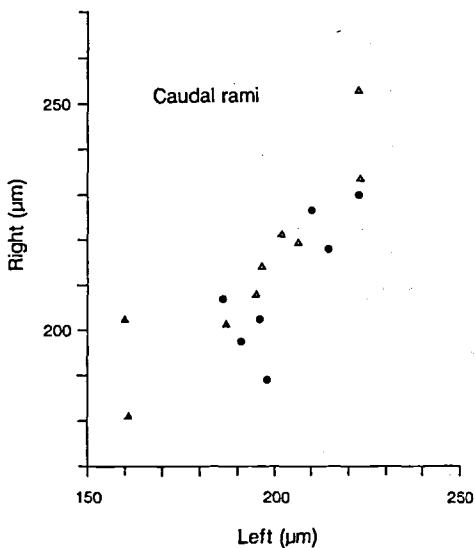


Fig. 10. Length of left and right caudal rami of females of *Tortanus* (*Eutortanus*) *derjugini* Smirnov, 1935. Solid circle: Ariake Sea, Japan; open triangle: Xiamen, China; solid triangle: Gwang Yang Bay, Korea.

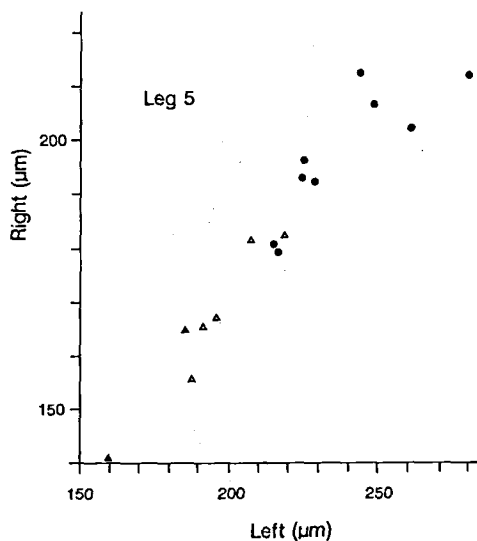


Fig. 11. Length of left and right rami of female leg 5 of *Tortanus* (*Eutortanus*) *derjugini* Smirnov, 1935. Solid circle: Ariake Sea, Japan; open triangle: Xiamen, China; solid triangle: Gwang Yang Bay, Korea.

derjugini, occurs exclusively in the Ariake Sea, whereas Type Ic is found in a broad range of brackish waters in Japan. The Ariake Sea is famous for the presence of a wide variety of Asian continental relicts of vertebrates and invertebrates (cf. Sugano 1981, Hiromi & Ueda 1987). A possible zoogeographic explanation for the present distribution of the isolated populations of these two copepods in the Ariake Sea from the main continental populations has been proposed by Hiromi & Ueda (1987) and Ohtsuka et al. (1992): the populations in the Ariake Sea may have been isolated from the continental ones by the last transgression (ca. 6,000–10,000 years ago). On the continental coast, *T. derjugini* has a distribution along the eastern Asian continental margin from the Sea of Okhotsk to the South China Sea (Ohtsuka et al. 1992), whereas *S. sinensis* has not been recorded from these regions yet, and is reported to be confined to the Yellow Sea and the East China Sea (Hiromi & Ueda 1987). It is not certain whether the species is absent from northeastern Asian continental waters or whether sampling efforts have been insufficient.

Type II consists of *Acartia hudsonica* Pinhey, 1926, *Eurytemora affinis* (Pope, 1880) and *E. herdmani* (Thompson & Scott, 1897). These species are recognized as belonging to an Arctic-temperate cold-water element, which is distributed in both the North Pacific and the North Atlantic (Ekman 1953, Nishimura 1980, 1981). According to Nishimura (1980, 1981), this element may have originated from the North Pacific, and then dispersed exclusively from the northern Pacific to the northern Atlantic during the Miocene-Pleistocene. *Tortanus discaudatus* (Thompson & Scott, 1897), which is suggested to constitute an independent subgenus in the genus *Tortanus* (Ohtsuka 1992, Ohtsuka & Reid in preparation), also belongs to this element although this species occurs in waters of higher salinity than *Eurytemora* species and is not regarded as a brackish-water copepod.

Acartia southwelli Sewell, 1914, *Bestiolina similis* (Sewell, 1914) and *Pseudodiaptomus marinus* Sato, 1913 constitute Type III, and belong to the Indo-West Pa-

Table 1. Distribution patterns of brackish calanoid copepods in East Asia.

Type of distribution	Literature
Family	
Species	
I. East Asian initial endemic element	
Ia. Endemic to Japanese waters	
Acartiidae	
<i>Acartia tsuensis</i>	Ito (1956); Shen & Mizuno (1984)
Pseudodiaptomidae	
<i>Pseudodiaptomus ishigakiensis</i>	Nishida (1985); Oka et al. (1991a)
Ib. Endemic to continental waters	
Acartiidae	
<i>Acartiella sinensis</i>	Shen & Lee (1963,1966); Chen & Zhang (1965); Shen & Mizuno (1984); Lian & Lin (1994); Ueda (unpublished)
Centropagidae	
<i>Sinocalanus laevidactylus</i>	Shen & Tai (1964); Chen & Zhang (1965); Shen & Mizuno (1984); Lian & Lin (1994)
<i>S. solstitialis</i>	Shen & Lee (1963); Shen & Mizuno (1984); Lian & Lin (1994);
Paracalanidae	
<i>Bestiolina amoyensis</i>	Li & Huang (1984); Lian & Lin (1994)
Pseudodiaptomidae	
<i>Pseudodiaptomus bulbosus</i>	Shen & Tai (1964); Walter (1986)
<i>P. forbesi</i>	Burckhardt (1913); Shen & Lee (1963, 1966); Shen & Mizuno (1984); Lian & Lin (1994)
<i>P. incisus</i>	Shen & Lee (1963); Lian & Lin (1994)
<i>P. infatus</i>	Shen & Tai (1964); Walter (1986)
<i>P. penicillus</i>	Li & Huang (1984); Lian & Lin (1994)
<i>P. poplesia</i>	Shen (1955); Shen & Mizuno (1984), Lian & Lin (1994)
<i>P. spatulatus</i>	Shen & Tai (1964); Walter (1986)
Tortanidae	
<i>Tortanus dextrilobatus</i>	Chen & Zhang (1965); Ohtsuka et al. (1992); Lian & Lin (1994)
<i>T. sheni</i>	Shen & Lee (1963); Lian & Lin (1994)
<i>T. spinicaudatus</i>	Shen & Bai (1956); Chen & Zhang (1965), Kim (1985); Lian & Lin (1994)
<i>T. vermiculus</i>	Shen (1955); Chen & Zhang (1965), Lian & Lin (1994)
Ic. On continental coasts and broadly in Japanese waters	
Acartiidae	
<i>Acartia sinjiensis</i>	Ueda & Hiromi (1987); Ueda (unpublished)
Centropagidae	
<i>Sinocalanus tenellus</i>	Kikuchi (1928); Smirnov (1929), Brodsky (1950); Chen & Zhang (1965); Kikuchi et al. (1978); Shen & Mizuno (1984); Kim (1985); Lian & Lin (1994)
Pseudodiaptomidae	
<i>Pseudodiaptomus inopinus</i>	Burckhardt (1913); Smirnov (1929); Shen & Lee (1963); Chen & Zhang (1965); Kikuchi et al. (1978); Shen & Mizuno (1984); Walter (1986); Lian & Lin (1994)
Temoridae	
<i>Eurytemora pacifica</i>	Sato (1913); Mori (1937); Brodsky (1950); Heron (1964); Chen & Zhang (1965); Kim (1985); Lian & Lin (1994)
Id. On continental coasts and exclusively in the Ariake Sea	
Centropagidae	
<i>Sinocalanus sinensis</i>	Shen (1955); Chen & Zhang (1965); Shen & Mizuno (1984); Hiromi & Ueda (1987); Lian & Lin (1994)
Tortanidae	
<i>Tortanus derjugini</i>	Smirnov (1935); Brodsky (1950); Chen & Zhang (1965); Ohtsuka et al. (1992); Lian & Lin (1994)
II. Arctic-temperate cold-water element	
Acartiidae	
<i>Acartia hudsonica</i>	Bradford (1976); Ueda (1986)
Temoridae	
<i>Eurytemora affinis</i>	Wilson (1932); Shen & Mizuno (1963)
<i>E. herdmanni</i>	Wilson (1932); Brodsky (1950); Shen & Mizuno (1984)
III. Indo-West Pacific warm-water element	
Acartiidae	
<i>Acartia southwelli</i>	Shen et al. (1979); Shen & Mizuno (1984)
Paracalanidae	
<i>Bestiolina similis</i>	Shen & Lee (1966); Nishida (1985); Oka et al. (1991b)
Pseudodiaptomidae	
<i>Pseudodiaptomus marinus</i>	Sato (1913); Brodsky (1950); Chen & Zhang (1965); Kim (1985); Walter (1986); Fleminger & Kramer (1988); Lian & Lin (1994)

cific warm-water element which is thought to have been derived directly from the Tethys fauna (Nishimura 1981). The first has not been recorded in Japanese waters yet. These copepods seem to prefer relatively high salinities. The occurrence of *B. similis* is in waters ranging from 7.9 to 32.9 ‰ in salinity (reported as *B. sinicus*, Oka et al. 1991b). The occurrence of *P. marinus* has been reported from brackish waters other than the Indo-West Pacific, i.e., from Hawaii (Jones 1966), Mauritius (Grindley & Grice 1969) and California (Fleminger & Kramer 1988), but these disjunct populations seem to have been recently formed by introduction through human activity (reviewed by Cordell et al. 1992).

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