

# A New Species of the Genus *Tegastes* (Copepoda: Harpacticoida: Tegastidae) from Hydrothermal Vents in the Okinawa Trough

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We describe a new species, *Tegastes okinawaensis*, from 583–711 meter-deep hydrothermal vents in the Okinawa Trough, Japan. This species is clearly distinguishable from its congeners by four combined characters, namely 1) the last three abdominal somites are depressed inwardly towards the body, 2) there is sexual dimorphism in the number of setae of P3 and P4, 3) the male antennule is 9-segmented, with the 7th segment formed by incomplete fusion of two segments, and 4) the caudal rami are small with a distorted quadrangular shape. Additionally, the species is easily distinguishable from its congeners by the distal endopodal segment of P4, which is armed with six setae – this character has never been reported in previous descriptions of congeners. This report is the first of a species in the genus *Tegastes* living at ocean depths of greater than 580 m in the northwestern Pacific.

**Key words:** Copepoda, Harpacticoida, Tegastidae, Okinawa, hydrothermal vents, *Tegastes okinawaensis*

## INTRODUCTION

Species in the family Tegastidae are traditionally thought to live among algal scrubs and macroalgae in the marine littoral zone, although they are often found among plankton in shallow tropical waters (Boxshall and Halsey, 2004). To date, about 60 species of Tegastidae have been described, and most species have been recorded from warm and tropical waters (Bartsch, 1999). The members of Tegastidae can be easily distinguished by their laterally compressed body shape, which is characterized by massive ventral extension of the cephalic shield and of the pleurites of the anterior urosome (Wells, 2007). With 35 species, the genus *Tegastes* Norman, 1903 is the largest genus of Tegastidae (Wells, 2007). Unfortunately, comparative studies within this genus are not possible due to incomplete species descriptions (Marcus, 1977). Furthermore, in only 15 species have both sexes been described and three *Tegastes* species were described from the male only. Recently, some tegastid harpacticoids have been characterized based descriptions of both sexes; a new genus *Smacigastes* has been described (Ivanenko and Defaye, 2004) from the deep-sea site Lucky Strike at the Mid-Atlantic Ridge, and *Tegastes nanus* has been redescribed based on specimens from Spitsbergen in the Arctic Ocean (Ferrari et al., 2007). A second species of *Smacigastes* has recently been described from the deep

sea, near tubeworm aggregations at the East Pacific Rise (Gollner et al., 2008).

During a study of hyperbenthic harpacticoid copepods living in the vicinity of hydrothermal vents in the Okinawa Trough, Japan, we found a new species of the genus *Tegastes*. The present study describes this rare tegastid from the deep sea.

## MATERIAL AND METHODS

Hyperbenthic harpacticoids were collected around vent fields in the Okinawa Trough at depths of 583–711 m using a multiple plankton sampler (DT-MPS) attached to the lower part of a deep tow system. The DT-MPS is an opening/closing sampler with four plankton nets having a mouth area of 50 cm × 20 cm and mesh size of 94 µm (Toda et al., 1995; Lee and Huys, 2000).

Copepods were dissected in lactic acid and mounted on slides using lactophenol as the mounting medium. Preparations were sealed with transparent nail varnish. All drawings were made with an Olympus BX51 differential interference contrast microscope equipped with a camera lucida. Copepods were also examined by scanning electron microscopy (SEM; Philips XL-30). Specimens were dehydrated using a graded acetone series and dried using a critical-point dryer. The dried specimens were then mount on stubs and coated with gold using an ion sputterer.

The descriptive terminology proposed by Huys et al. (1996) was adopted. Abbreviations used in the text and figures are as follows: A1, antennule; ae, aesthetasc; exp, exopod; enp, endopod; P1–P6, first to sixth thoracopod; exp(enp)-1(2,3), to denote the proximal (middle, distal) segment of a ramus. Type series are deposited at the Natural History Museum, London (NHM) and the National Institute of Biological Resources (NIBR) in Korea. Scale bars in the figures are indicated in µm.

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**RESULTS**

## Systematics

Order Harpacticoida Sars, 1903

Family Tegastidae Sars, 1904

Genus *Tegastes* Norman, 1903*Tegastes okinawaensis* sp. nov.

(Figs. 1–8)

*Type locality.* Okinawa Trough at depths of 583–711 m (28°23.397'N–28°23.027'N, 127°38.385'E–127°38.412'E).

*Material examined.* Holotype 1 ♀ (NIBRIV0000138159) dissected on eight slides. Paratypes 1 ♂ (NIBRIV0000138160) dissected on two slides, 1 ♀, 1 ♂ (NIBRIV0000138161-

162), and 2 ♀♀ (NHM 2009.104–105) in 70% alcohol. All specimens were collected from the type locality on 31 Jan 1993.

*Number of specimens.* A total of 54 tegastid specimens were collected. (*Tegastes okinawaensis* 21 ♀, 14 ♂, and 10 copepodites). Except for the new species, the other tegastids were not identified due to damage to the specimens.

*Description of the female.* Total body length 388 µm (measured from the anterior margin of the cephalic shield to the posterior margin of the caudal rami). Body laterally compressed. Whole body surface areolated, as in male (Figs. 1A, 8A). Prosome 4-segmented, consisting of cephalothorax and three somites bearing P2 to P4. Cephalothorax with

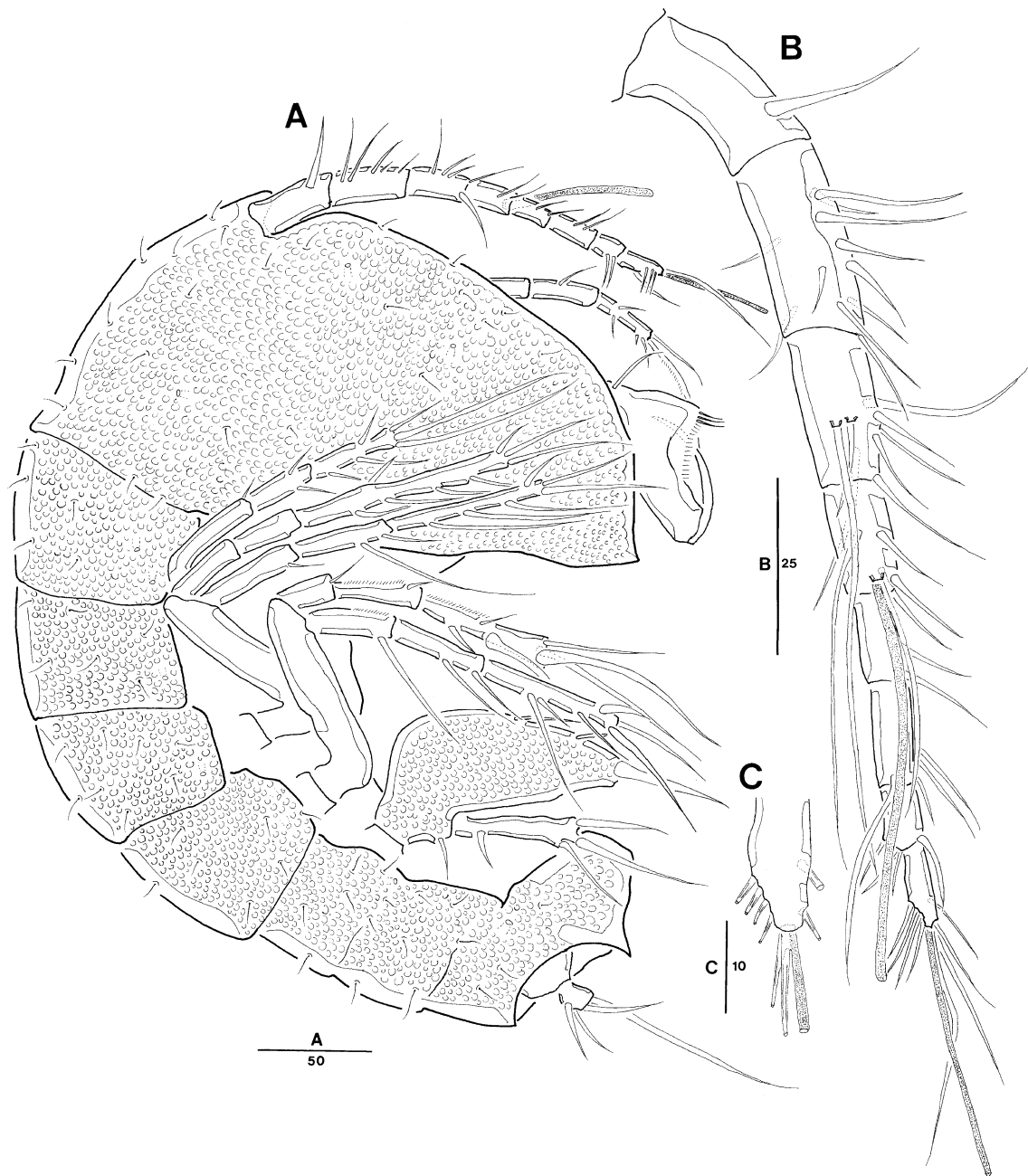
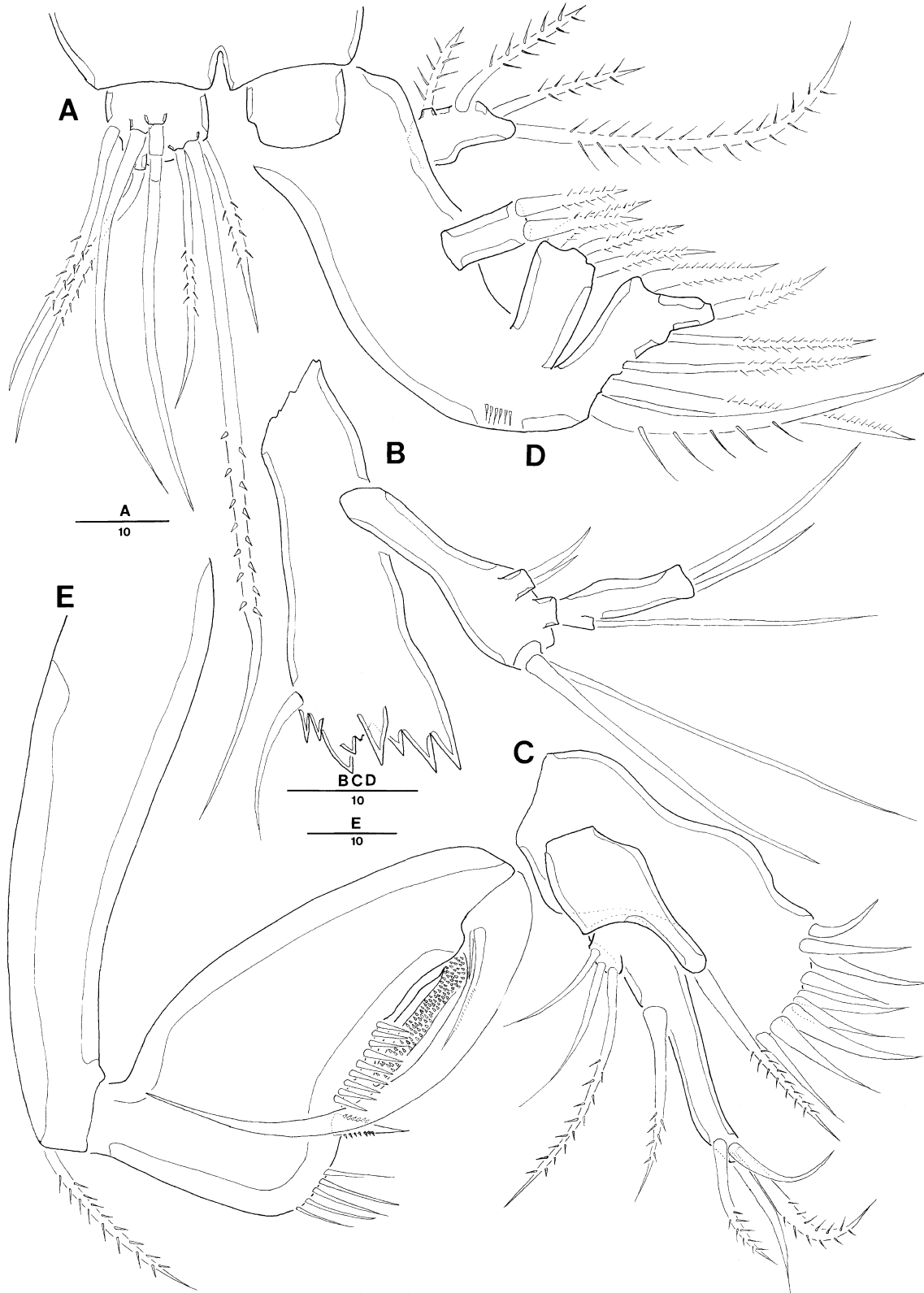


Fig. 1. *Tegastes okinawaensis* sp. nov. female. (A) habitus, lateral; (B) antennule; (C) antennular segment 8.

several sensilla and pores on dorso-lateral surface. Dorsal margin strongly curved anteriorly and posteriorly (Fig. 1A). Cephalic shield strongly extended ventrally on both sides,

with lamellae along ventral margin of cephalic shield about 3–5  $\mu\text{m}$  thick (as in the male, Fig. 8A). Urosome consisting of a P5-bearing somite, genital dou-



**Fig. 2.** *Tegastes okinawaensis* sp. nov. female. **(A)** caudal rami, dorsal; **(B)** mandible; **(C)** maxillule; **(D)** maxilla ; **(E)** maxilliped.

ble somite, and the succeeding three abdominal somites. P5-bearing somite fused to the genital double somite; no distinct separation between the other urosomites. Genital double-somite with one sharply pointed and recurved process on the ventro-lateral margin; last three abdominal

somites depressed inwardly towards the body. Genital double-somite with a genital area ventrally. Genital field (Fig. 3A) located medially and proximally. Location of copulatory pore obscure. Gonopores fused medially, forming a single genital slit covered on both sides by P6. P6 represented by

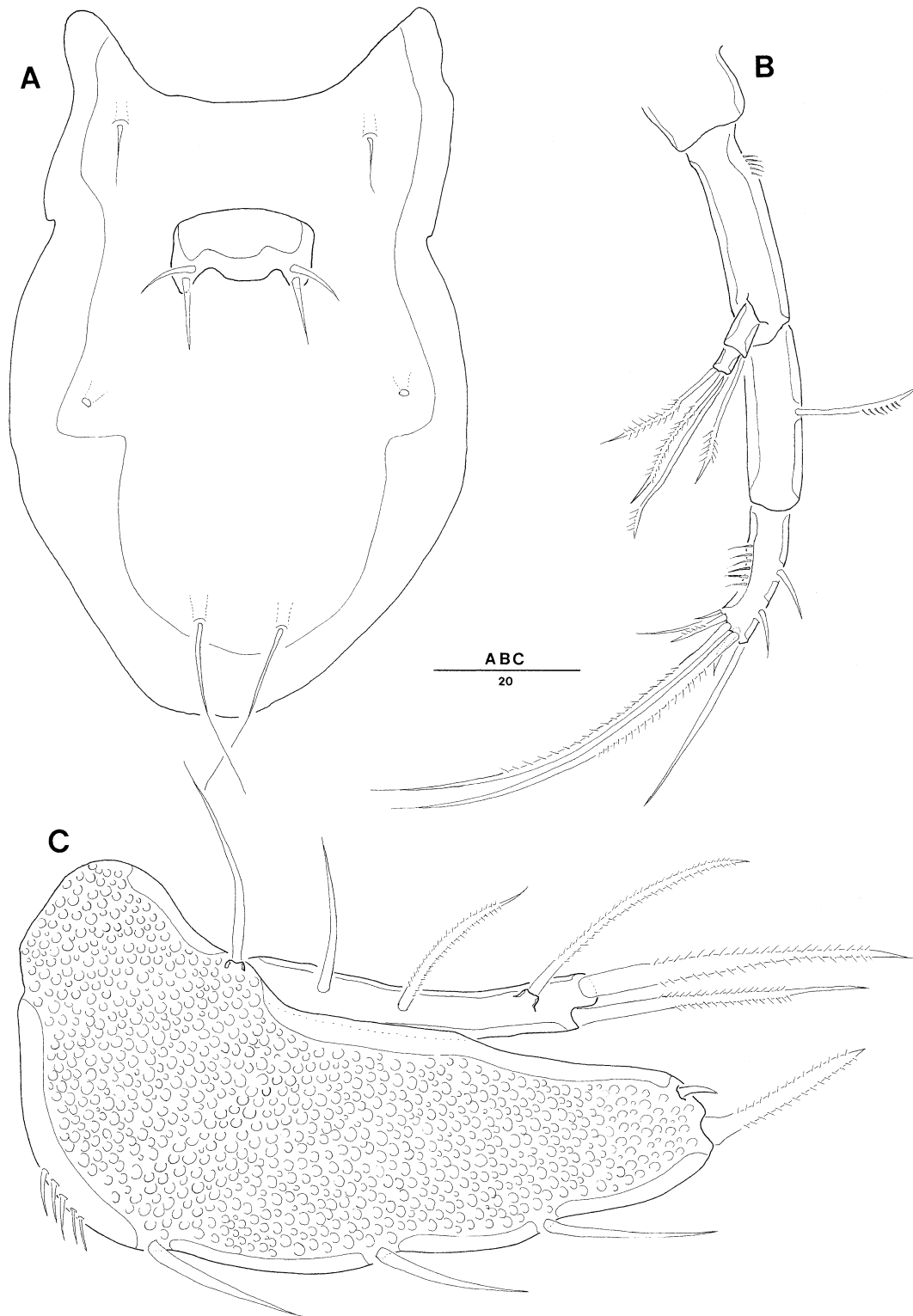


Fig. 3. *Tegastes okinawaensis* sp. nov. female. (A) genital double somite with P6, ventral; (B) antenna; (C) P5.

one plate with two setae, on the ventral side of the genital double-somite (Fig. 3A).

Caudal rami (Fig. 2A) small and about 1.2 times as wide as long, with two naked and five pinnate setae; one pinnate seta long, stout and presumably seta V; one naked seta located dorsally, tri-articulated, and presumably representing seta VII.

Antennule (Fig. 1B) 8-segmented, aesthetasc on 4<sup>th</sup> and 8<sup>th</sup> segments. Armature formula: 1-[1], 2-[11], 3-[8], 4-[4 + (1 + aesthetasc)], 5-[2], 6-[4], 7-[4], 8-[6 + acrothek]. Aesthetasc on 4th segment fused basally to one naked seta. Apical acrothek consists of a well-developed aesthetasc fused basally to two slender naked setae (Fig. 1C).

Antenna (Fig. 3B) 4-segmented, comprising coxa, basis, and two free segments. Coxa short without ornamentation. Basis with short, proximal row of spinules on the abexopodal margin. Exopod 2-segmented, with setal formula 1.021; all exopodal setae pinnate. Endopod 2-segmented; proximal segment with one pinnate abexopodal seta; distal segment with nine setae and spines (two lateral and seven apical).

Mandible (Fig. 2B). Gnathobase with one naked spine at the dorsal corner and nine major blunt overlapping teeth. Mandibular palp well-developed; basis with two naked setae; 1-segmented endopod with one lateral seta and two apical setae; exopod fused to basis and represented by two naked setae.

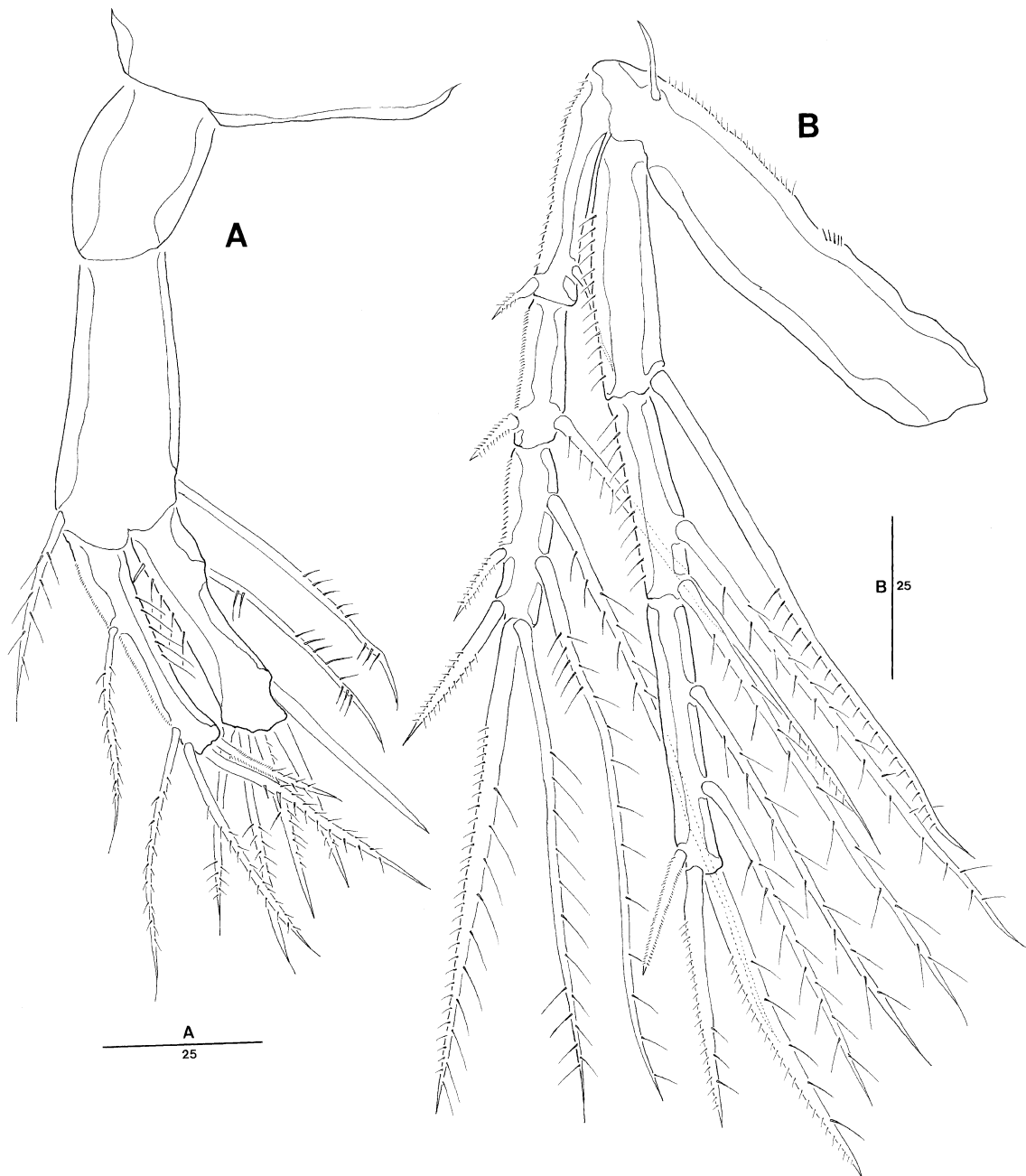


Fig. 4. *Tegastes okinawaensis* sp. nov. female. (A) P1; (B) P2.

Maxillule (Fig. 2C) well-developed. Praecoxal arthrite with nine setae and spines. Coxal endite with one stout pinnate seta. Basis elongate with two naked and two pinnate setae apically. Exopod incorporated into basis proximally; 1-segmented with one pinnate and two naked setae apically. Endopod represented by one pinnate seta at lateral margin of basis.

Maxilla (Fig. 2D). Syncoxa with three endites; Praecoxal endite with four pinnate setae, one seta elongated. Proximal coxal endite with two pinnate spines; distal coxa endite with three pinnate spines. Allobasis with three terminal pinnate setae, and three lateral pinnate lateral setae along outer margin, representing the endopod.

Maxilliped (Fig. 2E) comprising syncoxa, basis, and 1-segmented endopod. Syncoxa elongated with one pinnate seta at the inner distal corner. Basis with one pinnate stout

spine, one pad-like process ornamented with short spinules on its surface, and two rows of spinules along the palmar margin. Endopod 1-segmented, forming a strong curved spine with two small setae proximally.

Swimming legs biramous. P2–P4 with 3-segmented exopod and endopod; exopod reaching to distal margin of the respective enp-2. Each ramus ornamented with setules and spinules along the outer margins, as illustrated in Figs. 4A–B, 5A–B.

Leg 1 (Fig. 4A). Basis elongated with one outer and one inner pinnate seta. Endopod 1-segmented, wider than exopod, with one proximal, pinnate and one distal, naked inner setae, and four apical pinnate setae. Exopod 1-segmented with two apical and three outer pinnate setae.

Leg 2 (Fig. 4B). Basis with one small, naked outer seta. Each endopodal segment subequal in length; enp-1 with

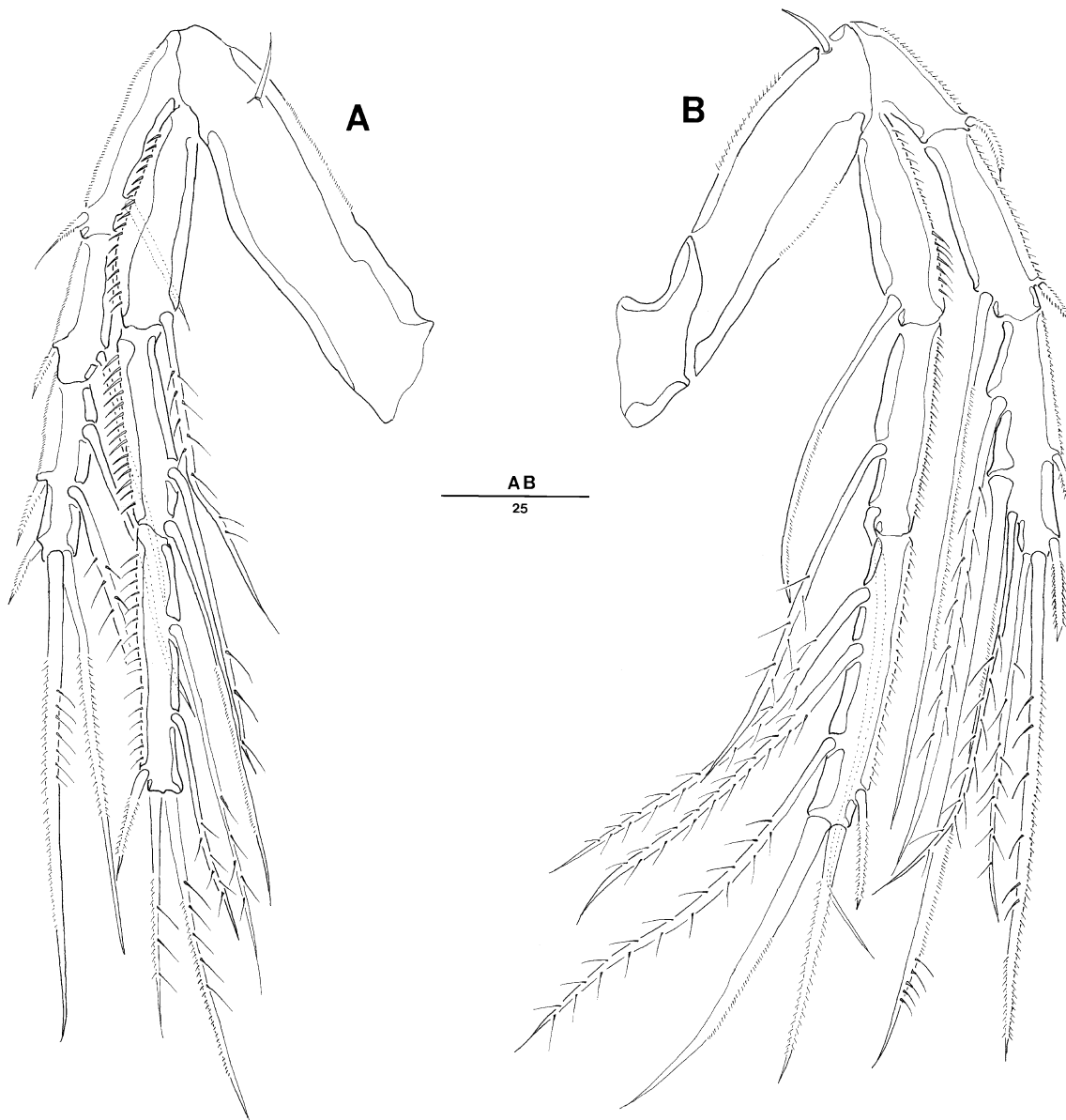
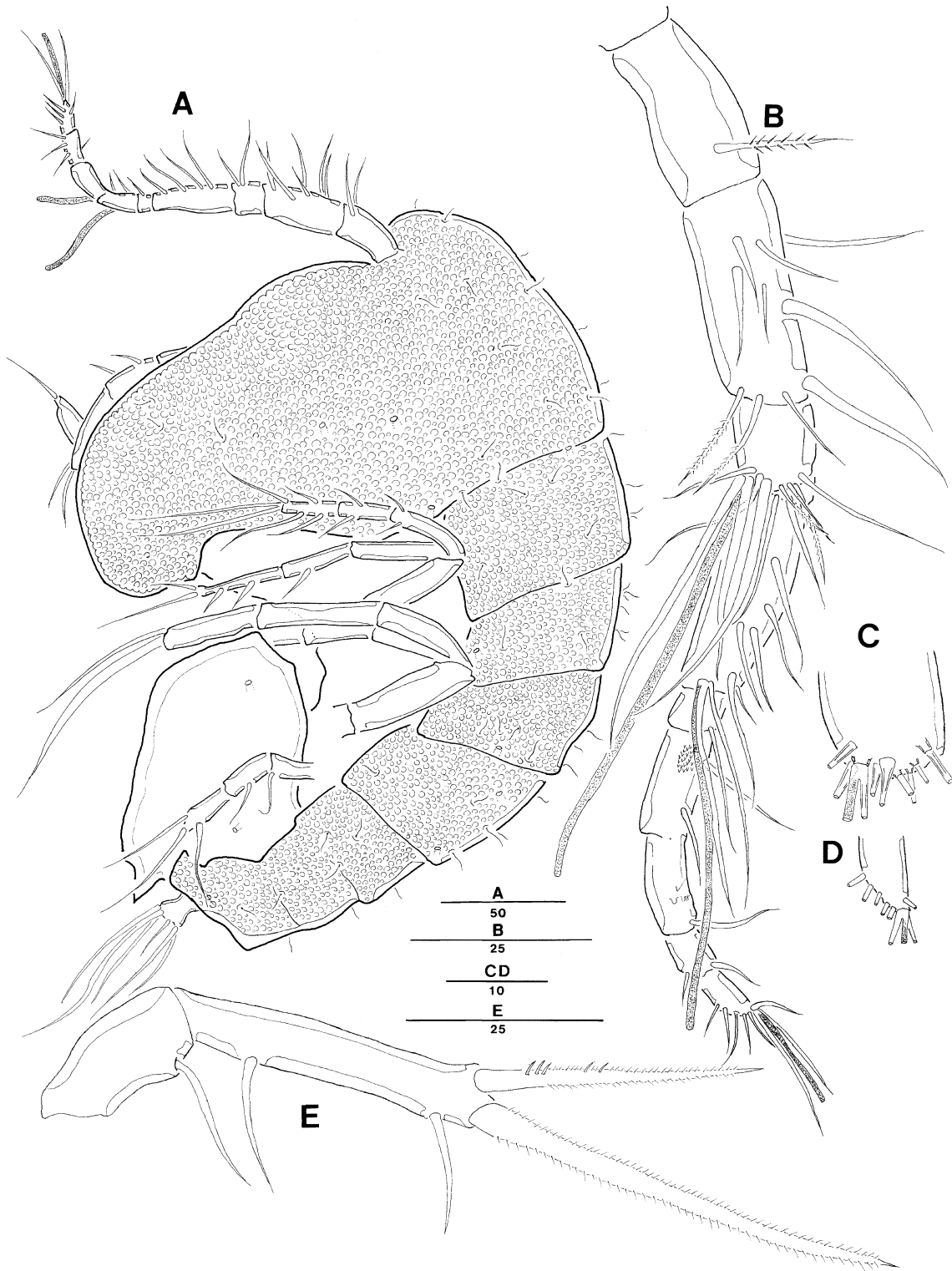


Fig. 5. *Tegastes okinawaensis* sp. nov. female. (A) P3; (B) P4.

one pinnate seta near inner distal margin; enp-2 with two inner pinnate setae; enp-3 with two inner pinnate setae, one outer and two terminal pinnate, strong spines. Each exopodal segment with row of spinules along the outer margins; exp-1 longest with one inner seta and one outer spine; exp-

2 with one inner seta and one outer spine; exp-3 with two inner and two terminal pinnate setae, and two pinnate outer spines.

Leg 3 (Fig. 5A). Basis with one small naked outer seta. Each endopodal segment with row of spinules along outer



**Fig. 6.** *Tegastes okinawaensis* sp. nov. male. (A) habitus, lateral; (B) antennule; (C) antennular segment 3; (D) antennular segment 9; E, P5.

margin; enp-1 with one inner, pinnate seta; enp-2 with two inner pinnate setae; enp-3 with two inner pinnate setae, two terminal setae and one outer spine. Exp-1 longer than exp-2 and exp-3; exp-1 with one inner seta and one outer spine; exp-2 with one inner pinnate seta and one outer spine; exp-3 with two pinnate inner setae, two terminal pinnate setae and two outer spines.

Leg 4 (Fig. 5B). Basis with one small naked outer seta, and a row of spinules on the outer margin. Each endopodal

segment has a row of spinules along the outer lateral margin; enp-1 with one inner seta; enp-2 with two inner pinnate setae; enp-3 with three inner pinnate setae, two strong terminal setae and one outer spine. All exopodal setae pinnate. Exp-1 shortest; exp-2 and exp-3 subequal in length. Exp-1 with one outer spine; exp-2 with one inner seta and one outer spine. Exp-3 with three inner and two terminal setae, and two outer spines; middle inner seta longest and thickest.

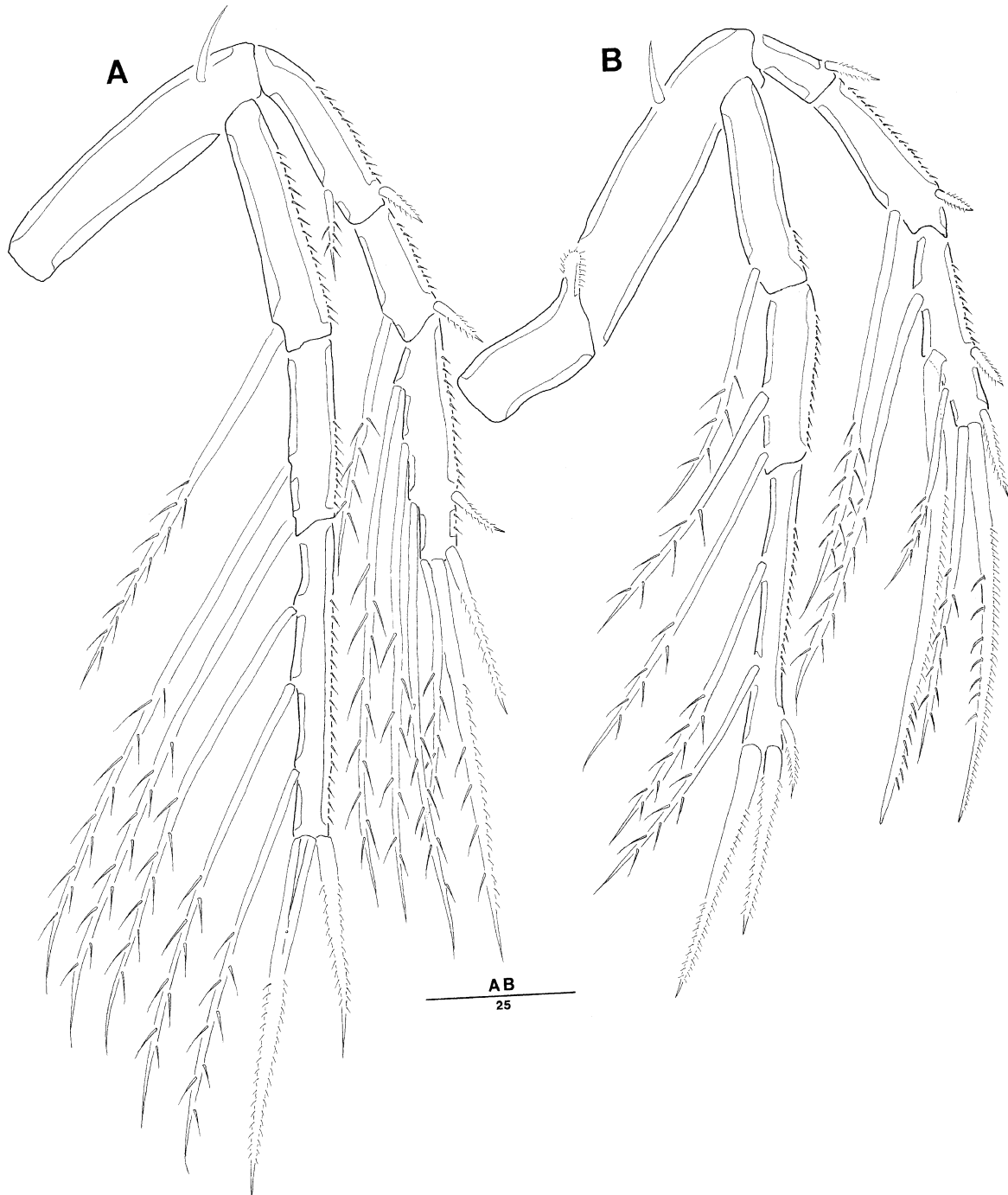


Fig. 7. *Tegastes okinawaensis* sp. nov. male. (A) P3; (B) P4.

The armature formula is as follows:

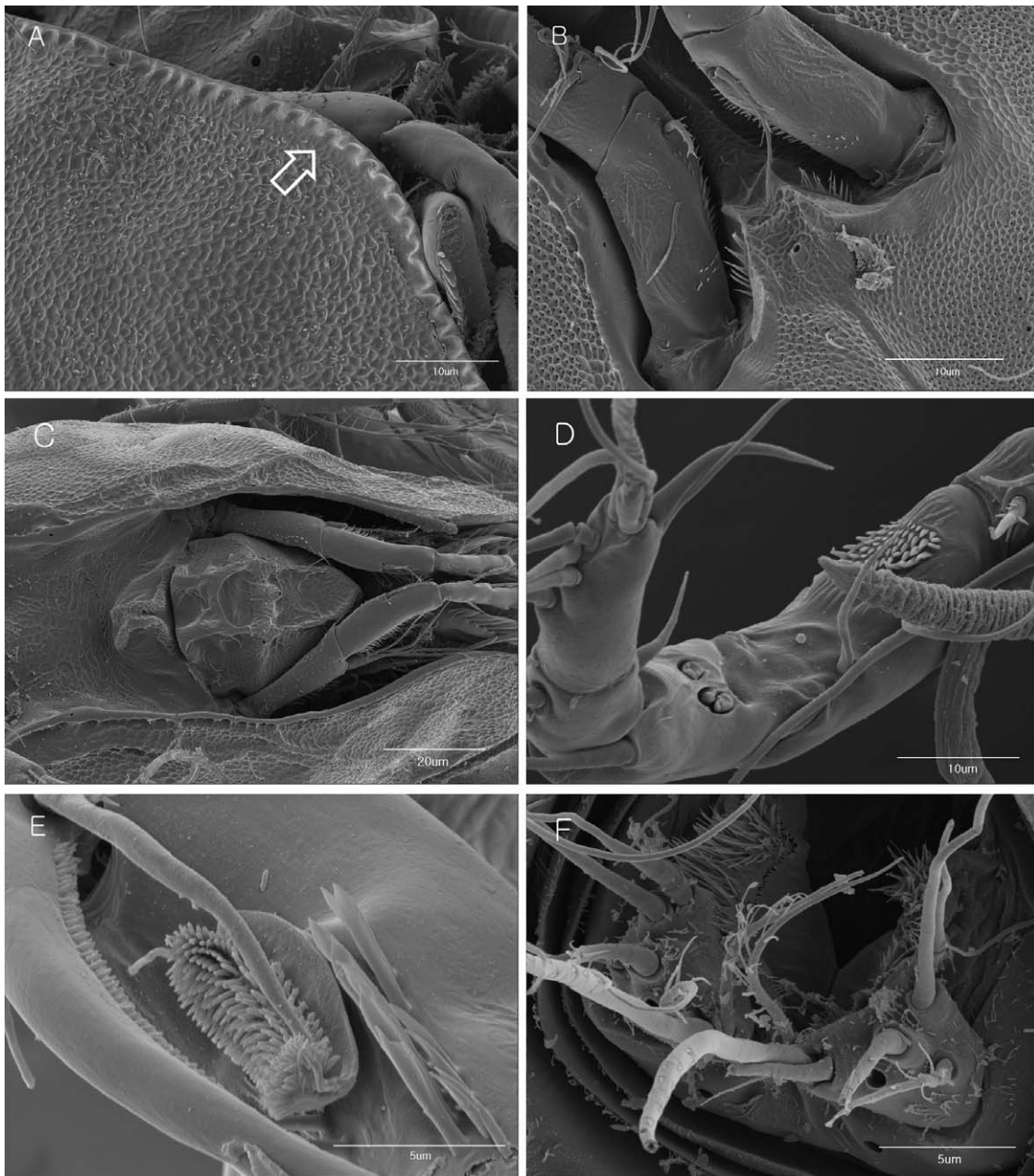
	Exopod	Endopod
P2	1.1.222	1.2.221
P3	1.1.222	1.2.221
P4	0.1.322	1.2.321

Leg 5 (Fig. 3C). Baseoendopod well-developed, with short row of spinules along the inner proximal margin, three naked inner setae, one apical, pinnate strong spine, and one small, naked outer seta; whole surface areolated. Exopod 1 segmented with three lateral and two apical strong setae.

*Description of the male.* Length 362  $\mu\text{m}$ . Similar to the female in size, shape, and somite ornamentation. Characterized by a 3–5  $\mu\text{m}$  lamellar structure along the ventral margin of the cephalosomal shield, as in the female (Figs. 6A, 8A).

Urosome (Fig. 6A) without distinct separation between each segment; genital somite and first abdominal somite fused, forming a genital double-somite as in the female; double-somite produced ventrally in one large, elongated prominence bearing distally asymmetrical genital flaps. Distal three segments depressed inwardly towards body as in the female (Figs. 6A, 8F).

Caudal rami (Fig. 8F) small, with seven setae as in the



**Fig. 8.** *Tegastes okinawaensis* sp. nov. male. SEM pictures. (A) marginal lamellae and areolated surface of the cephalic shield; (B) rostrum area, dorsal; (C) labrum and anterior view of the cephalosome; (D) distal antennular segments; (E) pad-like process on the palmar margin of the maxilliped; (F) caudal rami, posterior view.

female.

Antennule (Fig. 6B) 9-segmented and haplocer. Aesthetasc on 3<sup>rd</sup>, 5<sup>th</sup>, and 9<sup>th</sup> segments. Armature formula: 1-[1], 2-[10], 3-[8 + (1 + ae)], 4-[2], 5-[6 + (2 + ae)], 6-[1], 7-[3], 8-[2], 9-[6 + acrothek]. Seventh segment formed by two incompletely fused segments; with a modified spinulose pad and two processes (Fig. 8D). Aesthetasc on 3<sup>rd</sup> and 5<sup>th</sup> segments fused basally to one and two naked setae, respectively (Fig. 6B–C). Apical acrothek consisting of well-developed aesthetasc fused basally to two slender naked setae (Fig. 6D).

Rostrum (Fig. 8B) apically bifid, with a row of spinules on both sides, and one median pore dorsally; areolated on dorsal surface as in the cephalosome.

Labrum (Fig. 8C) well-developed; of triangular shape with one proximal, H-shaped surface ridge and two distal parallel surface ridges.

Maxilliped (Fig. 8E). Basis with modified pad-like, spinulose process on the palmar margin.

Other mouthparts including the antenna, mandible, maxillule, and maxilla similar to those in the female.

Swimming legs 1–4 similar to those in female, with the following exceptions:

Leg 3 (Fig. 7A) enp-3 with three inner pinnate and two terminal strong setae; exp-3 with three inner pinnate, two terminal strong setae, and two outer spines.

Leg 4 (Fig. 7B). Coxa with row of spinules along outer distal margin. Enp-3 with two inner pinnate and two terminal strong setae, and one outer spine. Exp-3 with three inner and two terminal pinnate setae, and two outer spines; middle inner seta shorter than that in female.

The armature formula is as follows:

	Exopod	Endopod
P2	1.1.222	1.2.221
P3	1.1.322	1.2.320
P4	0.1.322	1.2.221

Leg 5 (Fig. 6E) 2-segmented with baseoendopod and exopod; baseoendopod small and subrectangle, with one outer naked seta; exopod with two strong terminal and two lateral naked setae.

## DISCUSSION

The new species is placed in the genus *Tegastes* because of the 8-segmented female antennule, the distinct shapes of the P5 baseoendopod, and the primitive 3-segmented rami of P2–P4.

*Tegastes okinawaensis* sp. nov. shows a unique combination of characters: 1) the last three abdominal somites are depressed inwardly towards the body, 2) there are six setae on the enp-3 of P4, 3) setae numbers of P3 and P4 are sexually dimorphic, 4) the male has a 9-segmented antennule with the 7th segment formed by two incompletely fused segments, and 5) the caudal rami are small and have a distorted quadrangular shape. These unique apomorphies distinguish *T. okinawaensis* from other species in the genus *Tegastes*.

The three abdominal somites of the new species superficially resemble those of *Tegastes grandimanus* Sars, 1904 in that the posterior abdominal segments are bent inwardly

towards the body in the lateral view (Sars, 1904). However, the new species is clearly distinguishable from *T. grandimanus* by several characteristics, including the setal formula of the thoracic legs.

The most distinctive feature of the new species is that the enp-3 of P4 is armed with six setae, which has never been reported before in the genus *Tegastes*. According to Wells (2007), the distal endopodal segment of P4 in *Tegastes* has four or five setae, except for six species in which P4 has not been described. The number of setae on the distal segments of exp-3 of P3 and enp-3 of P4 (see Figs. 5A–B, 7A–B) is sexually dimorphic in *T. okinawaensis*. The male exp-3 of P3 has one more seta than the female.

Ferrari et al. (2007) also reported possible sexual dimorphisms in the seta formula, although they mentioned the possibility of polymorphism within the species. They re-described *Tegastes nanus* from Ny Ålesund, Spitsbergen, which has six setae on the distal exopodal segment of P3 in the female, and seven in the male as reported by McAlice and Coffin (1990). In addition *T. nanus* has six setae on enp-3 of P4 in the female, but five in the male. There is sexual dimorphism in the insertion site of seta in *T. nanus*, which has two inner setae and one outer spine on the enp-3 of P3 in the female, but three inner setae in the male. No other studies (Marcus, 1977; Humes 1981a, b; Humes 1984; Médioni and Soyer, 1967) have reported sexual dimorphism in the seta formula of P1–P4 in the genus *Tegastes*.

The male antennule of *T. okinawaensis* is 9-segmented with the 7th segment formed by two incompletely fused segments, which are also unique characteristics of the new species. The genus *Smacigastes* has a 10-segmented antennule, and the other Tegastidae can have up to eight segments in the antennules, in the male (Huys et al., 1996: 288; Ivanenko and Defaye, 2004).

Two small setae on the ventral side of the genital double-somite represent the P6 of the female in the new species. Although the description of P6 and genital field was very poor in the previous reports of tegastids, the genital structure is highly likely to be conserved within the family, based on the similarity of P6 between *S. micheli* and *T. nanus*.

Currently, 60 tegastid species belonging to six genera (*Tegastes* Norman, 1903; *Parategastes* Sars, 1904; *Syngastes* Monard, 1924; *Feregastes* Fiers, 1986; *Arawella* Cottarelli and Baldari, 1987; and *Smacigastes* Ivanenko and Defaye, 2004) are known from shallow waters and deep-sea (*Smacigastes*). These species are either free-living or live in association with algae, bryozoans, and cnidarians, such as hydrozoans, scyphozoans, actinarians, alcyonaceans, and scleractinians (Humes, 1981a, b; Humes, 1984; Bartsch, 1999). For example, *Tegastes knoepffleri* has been found in the bryozoans *Schizobrachiella sanguine* (Médioni and Soyer, 1967), and *Tegastes nanus* has been found in the red alga *Ceramium* sp. (Ferrari et al., 2007). Ivanenko and Defaye (2004) discovered a free-living tegastid, *Smacigastes micheli*, in the Mid-Atlantic Ridge at a depth of 1,698 m, which was the first report of Tegastidae from hydrothermal vents. A second species of *Smacigastes*, *S. barti*, has been described from hydrothermal vents on the East Pacific Rise (depth 2,500 m) by Gollner et al. (2008). These reports suggest that species in the genus *Smacigastes* inhabit hard-

substrate and nutrient-rich environments (Gollner et al., 2008).

Certain species in the genus *Tegastes* have also been reported from the deep sea. *T. coriaceus* and *T. frigidus* were reported from a depth of 385 m in the Antarctic (Brady, 1910), and *T. okinawaensis* was found at a depth of over 580 m in the northwestern Pacific. The present study expands our knowledge of the distribution of Tegastidae and is the second report of hyperbenthic harpacticoids from hydrothermal vents in the Okinawa Trough since the description of three species of aegisthids by Lee and Huys in 2000.

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