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A New Species of *Podocerus* (Crustacea: Amphipoda: Podoceridae) Associated with the Whale Shark *Rhincodon typus*

Ko Tomikawa[1,4], Makio Yanagisawa[2], Takuo Higashiji[2], Nagisa Yano[2], and Wim Vader[3]

[1] *Department of Science Education, Graduate School of Education, Hiroshima University, Higashihiroshima, Hiroshima 739-8524, Japan*
E-mail: tomikawa@hiroshima-u.ac.jp
[2] *Okinawa Churaumi Aquarium, Okinawa Churashima Foundation, 424 Ishikawa, Motobu-cho, Kunigami-gun, Okinawa 905-0206, Japan*
[3] *Tromsø Museum, Department of Zoology, University of Tromsø, 9037 Tromsø, Norway*
[4] *Corresponding author*

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A new species of podocerid amphipod, *Podocerus jinbe*, is named and described. This new species was collected from the gill rakers of the whale shark *Rhincodon typus* Smith, 1828 from off Yomitan Village, Okinawa Island, Japan. This is the first record of an amphipod associated with the whale shark. *Podocerus jinbe* sp. nov. is morphologically similar to *P. zeylanicus* (Walker, 1904), but differs from the latter by its larger body size, shorter peduncular article 1 of antenna 1, longer flagellar article 1 of antenna 1, subrectangular propodus of male gnathopod 1, anteriorly concave basis of male gnathopod 2, narrow merus of female gnathopod 2, greater number of robust setae on rami of uropods 1 and 2, and greater number of long robust setae on the telson apical lobe. Additionally, a partial DNA sequence of the mitochondrial cytochrome *c* oxidase subunit I (COI) of this species was determined for future studies.

Key Words: Podocerus jinbe, *Podocerus zeylanicus*, Japan, COI, taxonomy.

Introduction

The podocerid genus *Podocerus* Leach, 1814 is a benthic filter-feeding amphipod inhabiting temperate and tropical seas (Hughes 2012, 2013, 2016). Individuals of *Podocerus* cling to substrates with splayed pereopods and collect detritus using well-developed plumose setae on long antennae 1 and 2 (Barnard *et al.* 1988). To date, 61 *Podocerus* species have been described worldwide (Horton *et al.* 2019). In Japan, two *Podocerus* species have been recorded: *P. umigame* Yamato, 1992 from the carapace of a loggerhead sea turtle (Yamato 1992); and *P. inconspicuus* (Stebbing, 1888) from the shallow waters of southern Japan (Nagata 1965; Hirayama 1995). Since *P. umigame* is morphologically similar to *P. chelonophilus* (Chevreux and Guerne, 1888), the former has been treated as a synonym of the latter (Baldinger 2001; Kilgallen 2009; Hughes 2016).

Amphipods are associated with a wide variety of invertebrates (e.g., Vader 1983; Vader and Romppainen 1985; Bousfield 1987; Mori and Yamato 1993; Tomikawa *et al.* 2004; Vader and Tandberg 2013, 2015). However, amphipod associations with vertebrates are less common than those with invertebrates. Some groups of amphipods have been recorded from external surface of fish (Vader and Romppainen 1985; Bousfield 1987; Mori and Yamato 1993), sea turtles (Barnard 1967; Yamato 1992; Baldinger 2001), and marine cetaceans (Iwasa-Arai and Serejo 2018). The whale shark *Rhincodon typus* Smith, 1828 is the largest fish species in the world and is widely distributed over tropical oceans (Martin 2007; Rowat and Brooks 2012). Parasites belonging to various taxa have been found in and on whale sharks: Cestoda (Malhotra *et al.* 2011), Copepoda (Wilson 1944; Norman *et al.* 2000; Dippenaar 2004; Tang *et al.* 2010, 2012, 2013), Isopoda (Ota *et al.* 2012), and Trematoda (Eduardo 2010). However, there is no record of amphipods attached to a whale shark to our knowledge.

In 2017, one of the authors (MY) found numerous amphipods associated with the gill rakers of a whale shark held on the sea off the central western coast of Okinawa Island, Japan. After careful examination, they proved to be an undescribed species of the genus *Podocerus*. In this paper, we describe and illustrate this species. This study provides the first report of amphipods associated with the whale shark *Rhincodon typus*.

Materials and Methods

Sampling and morphological examination. Specimens came from a single female whale shark, captured in 2007 off Yomitan Village, Okinawa Island, Okinawa Pre-

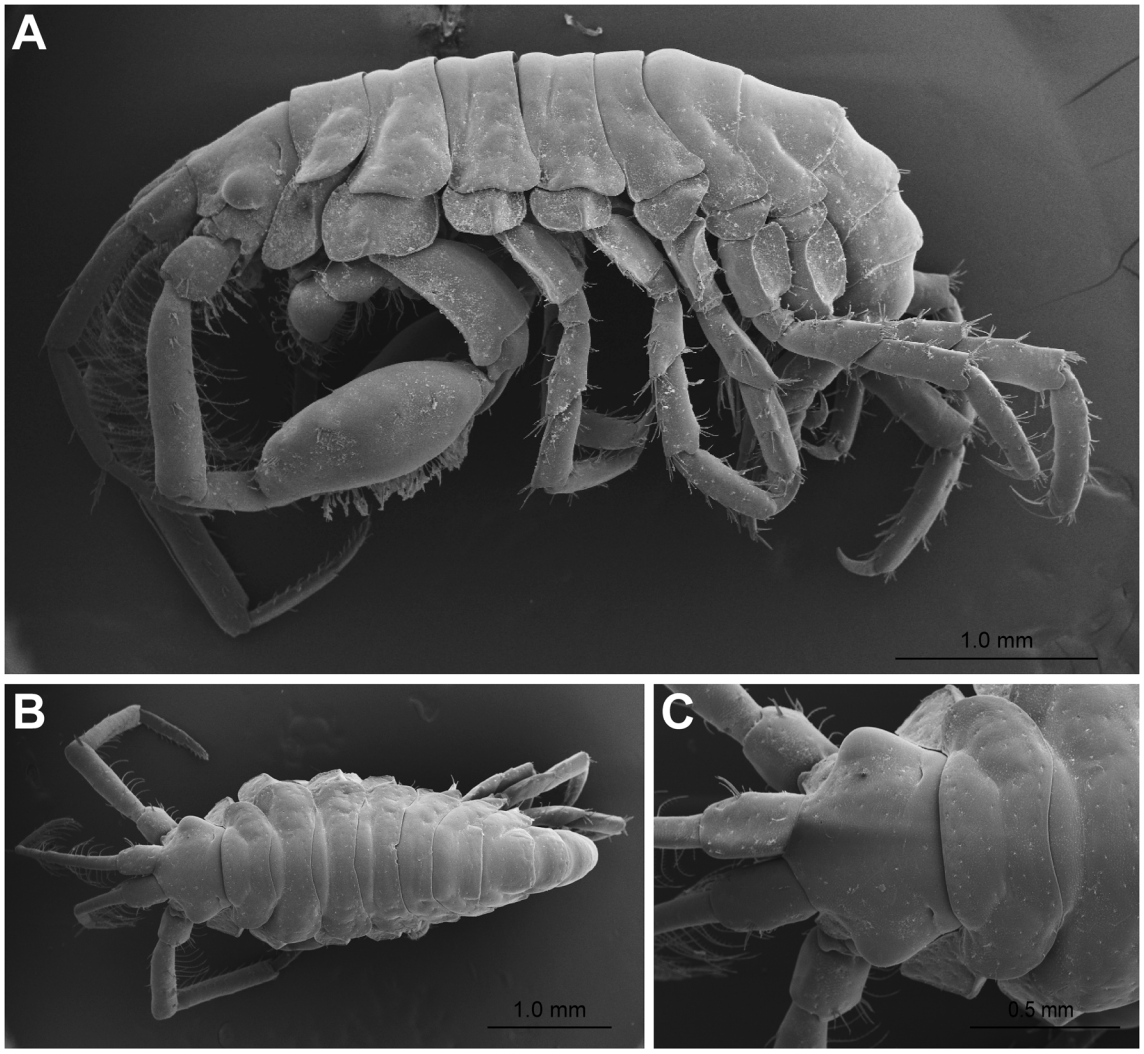

Fig. 1. *Podocerus jinbe* sp. nov., SEM photographs. A, paratype male 6.0 mm, NSMT-Cr 26050; B and C, paratype male 5.1 mm, NSMT-Cr 26049. A, habitus, lateral view; B, habitus, dorsal view; C, head, dorsal view.

fecture, Japan (26°21′51.5″N, 127°43′11.5″E). Amphipods were taken from the gill rakers of the whale shark, while it was held in an open water fish preserve, off Motobu, Okinawa Island, Okinawa Prefecture, Japan (26°40′17.8″N, 127°52′49.1″E) using a suction pump (scuba diving) by MY on 11 October 2017. Appendages of the examined specimens were dissected in 70% ethanol and mounted in gum-chloral medium on glass slides under a stereomicroscope (Olympus SZX7). The specimens were examined using a light microscope (Nikon Eclipse Ni) and illustrated with the aid of a camera lucida. The body length was measured to the nearest 0.1 mm from the tip of the rostrum to the base of the telson along the dorsal curvature. The type materials have been deposited in the Tsukuba Collection Center of the National Museum of Nature and Science, Tokyo (NSMT).

Scanning electron microscopy (SEM). Two male specimens, NSMT-Cr 26049 and NSMT-Cr 26050, were dehydrated through a graded ethanol series, and dried using hexamethyldisilazane (HMDS) (Nation 1983). They were then sputter-coated with gold and observed using SEM (JSM-6510LV).

PCR and DNA sequencing. Genomic DNA was extracted from pereopod muscle of the paratype female following the procedures in Tomikawa *et al.* (2014). The primer set of the cytochrome *c* oxidase subunit I (COI) gene [LCO1490 and HCO2198 (Folmer *et al.* 1994)] was used for PCR and cycle sequencing reactions. The PCR and sequencing methods followed Tomikawa *et al.* (2017). The DNA sequence has been deposited with the International Nucleotide Sequence Database Collaboration (INSDC) through the DNA Data Bank of Japan (DDBJ).

Family **Podoceridae** Leach, 1814
Genus ***Podocerus*** Leach, 1814
Podocerus jinbe Tomikawa, Yanagisawa, and Vader, sp. nov.
[New Japanese name: Jinbē-doronomi]
(Figs 1–5)

Material examined. Holotype: male 6.0 mm (NSMT-Cr 26048). Paratypes: male 5.1 mm (NSMT-Cr 26049), male 6.0 mm (NSMT-Cr 26050), female 3.7 mm (NSMT-Cr 26051). Further materials: 357 males and 291 females (KT private collection).

Description. *Male* (*holotype, NSMT-Cr 26048*). Body

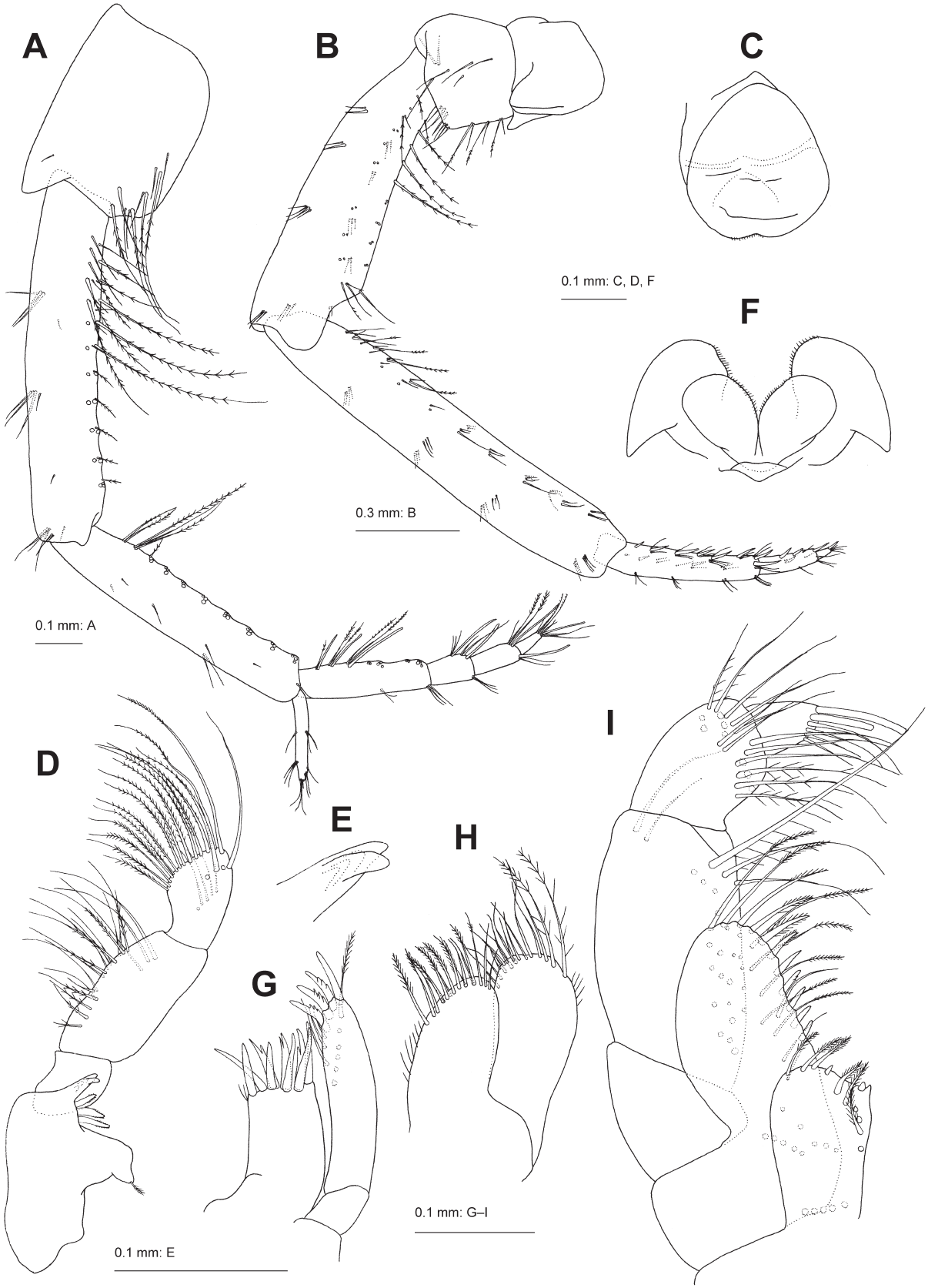

Fig. 2. *Podocerus jinbe* sp. nov., holotype male 6.0 mm, NSMT-Cr 26048. A, antenna 1 (some setae omitted), medial view; B, antenna 2 (some setae omitted), medial view; C, upper lip, posterior view; D, right mandible, lateral view (palp twisted); E, incisor of right mandible, lateral view; F, lower lip, anterior view; G, maxilla 1, anterior view; H, maxilla 2, anterior view; I, maxilliped (some setae omitted), anterior view.

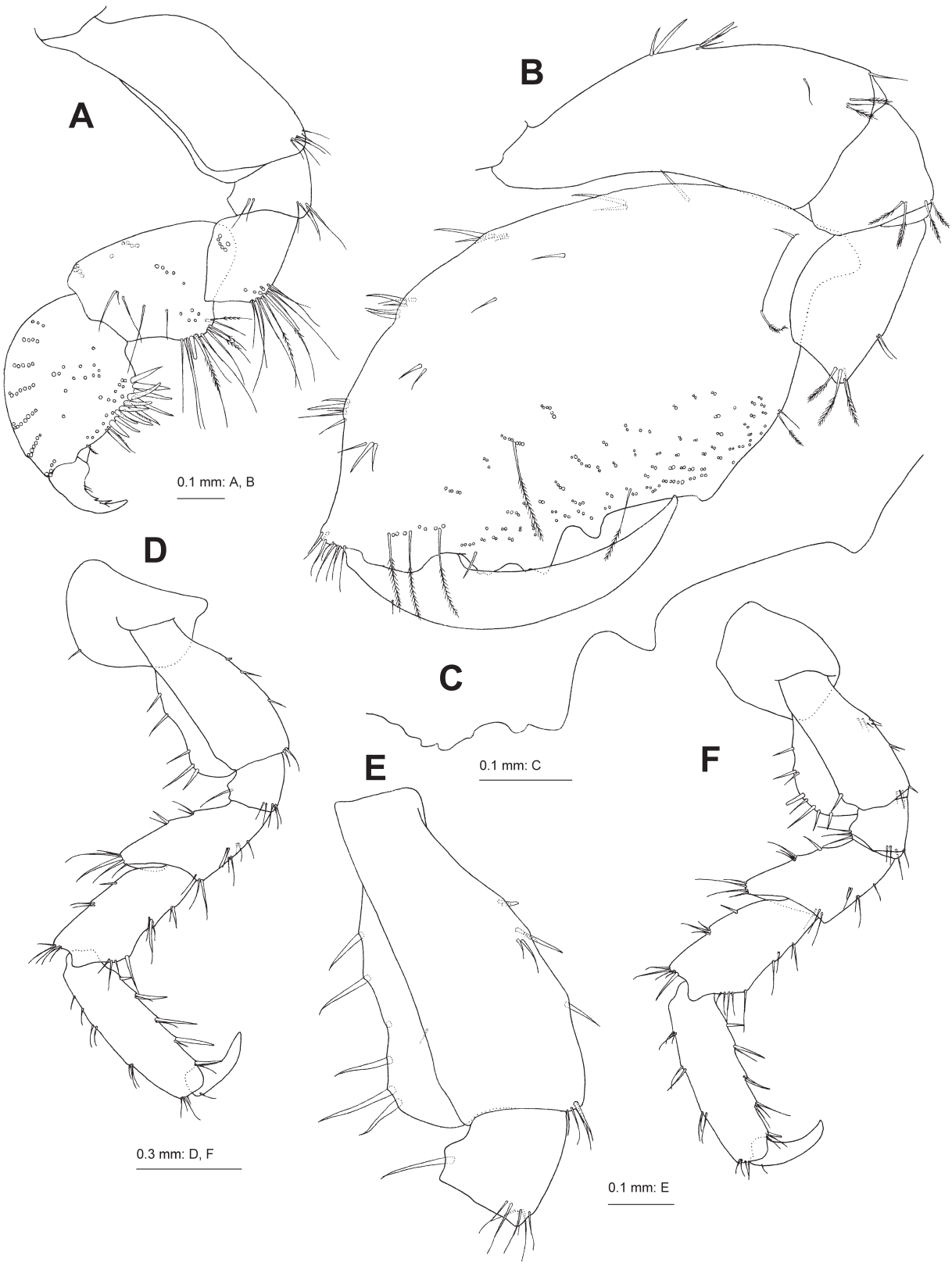

Fig. 3. *Podocerus jinbe* sp. nov., holotype male 6.0 mm, NSMT-Cr 26048. A, basis to dactylus of gnathopod 1 (some setae omitted; dactylus is strongly curved due to mounting angle), medial view; B, basis to dactylus of gnathopod 2 (some setae omitted), medial view; C, palmar margin of gnathopod 2 propodus, medial view; D, pereopod 3, medial view; E, basis and ischium of pereopod 3, medial view; F, pereopod 4.

(Fig. 1A, B; paratype males NSMT-Cr 26049–26050) weakly rugose, without dorsal carina; pereonite 7 and pleonite 1 with dorsal setae. Head (Fig. 1C; paratype male NSMT-Cr 26049) dorsally smooth; rostrum short; lateral cephalic lobe rounded.

Antenna 1 (Fig. 2A) length 0.4 times as long as body length; length ratio of peduncular articles 1–3 1.0: 1.8: 1.4; peduncular article 1 subquadrate, with long plumose setae

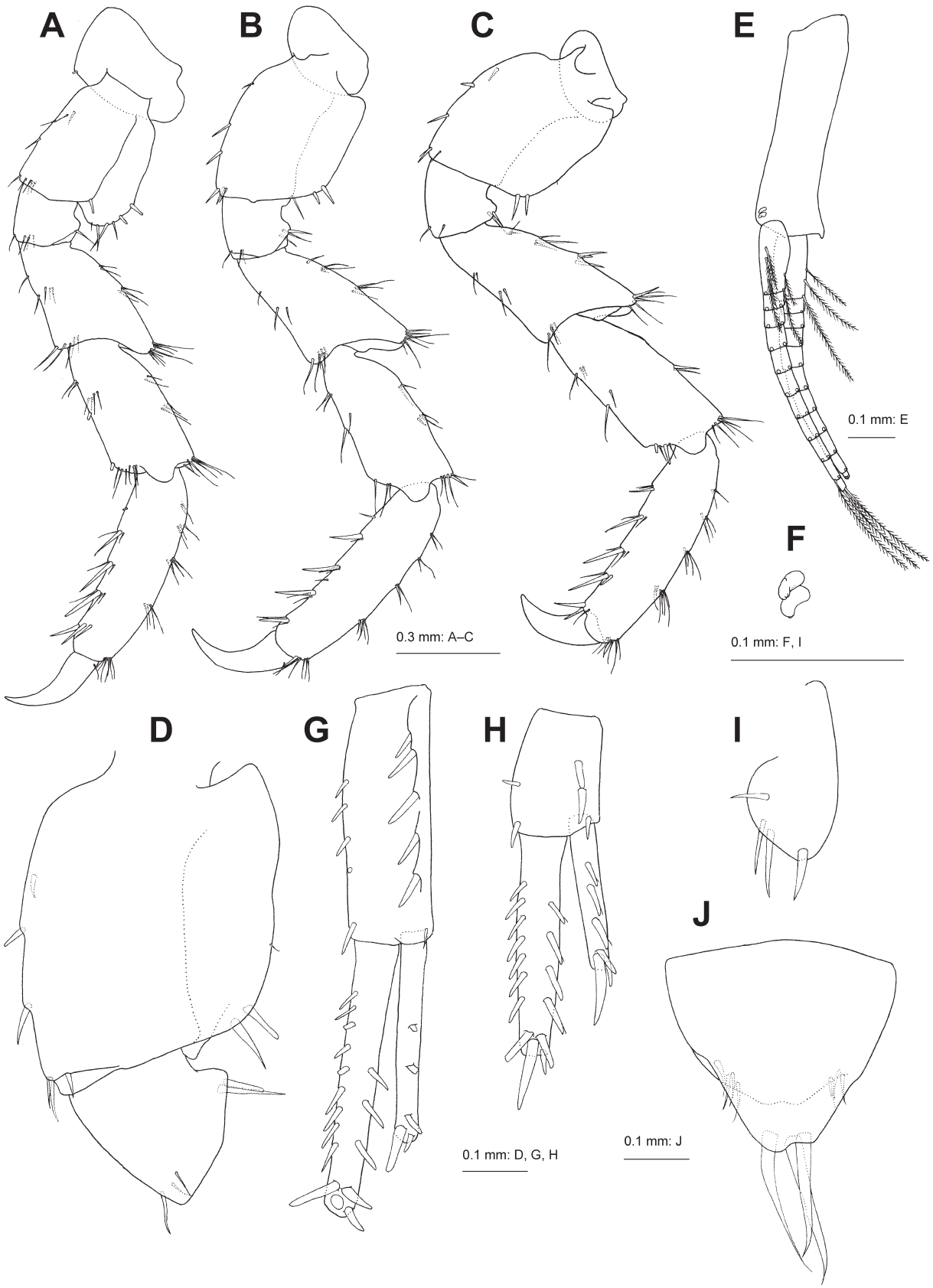

Fig. 4. *Podocerus jinbe* sp. nov., holotype male 6.0 mm, NSMT-Cr 26048. A, pereopod 5, medial view; B, pereopod 6, medial view; C, pereopod 7, medial view; D, basis and ischium of pereopod 7, medial view; E, pleopod 1, medial view; F, retinacula (coupling hooks) of peduncle of pleopod 1, medial view; G, uropod 1, dorsal view; H, uropod 2, dorsal view; I, uropod 3, dorsal view; J, telson, dorsal view.

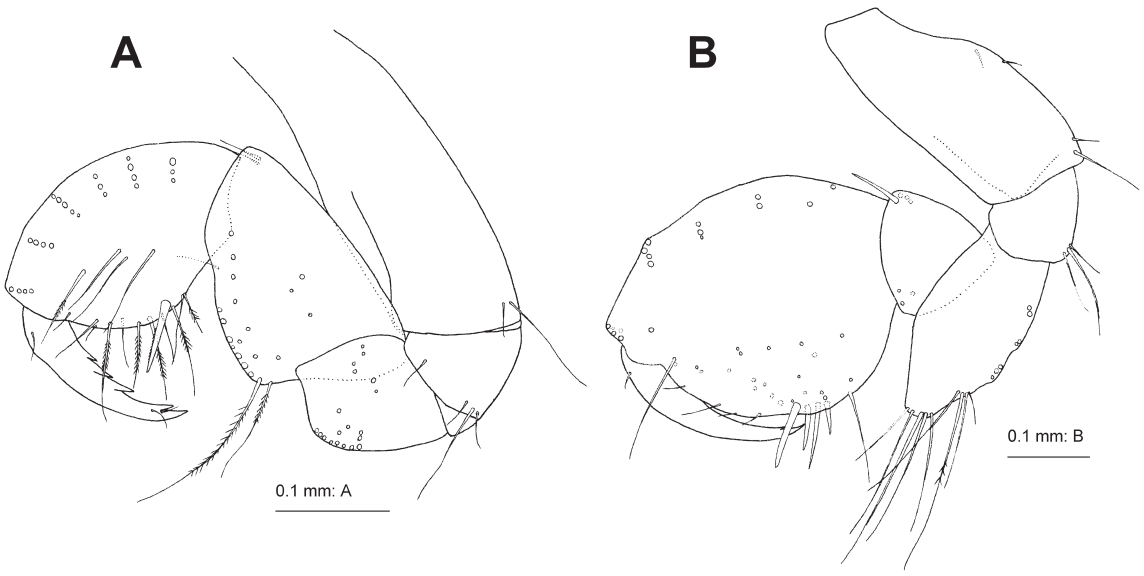

Fig. 5. *Podocerus jinbe* sp. nov., paratype female 3.7 mm, NSMT-Cr 26051. A, basis to dactylus of gnathopod 1 (some setae omitted), medial view; B, basis to dactylus of gnathopod 2 (some setae omitted), medial view.

on posterodistal corner; peduncular articles 2 and 3 with 11 and 9 clusters of long plumose setae on posterior margins, respectively; primary flagellum 4-articulate, 0.3 times as long as peduncular articles 1–3 combined, article 1 long, 3.1 times as long as article 2; accessory flagellum slender, 1-articulate, 0.3 times as long as primary flagellum. Antenna 2 (Fig. 2B) 1.5 times as long as antenna 1; peduncular article 4 with long plumose setae on posterior margin; peduncular article 5, 1.3 times as long as article 4, with short plumose and simple setae on posterior margin; flagellum 3-articulate, 0.3 times as long as peduncular articles 1–5 combined, article 1, 2.3 times as long as articles 2 and 3 combined.

Upper lip (Fig. 2C) oval, ventral margin weakly concave, with minute setae. Left and right mandibles (Fig. 2D, E) with 5-dentate incisor; molar process small, non-triturative, with a short plumose seta apically; accessory setal row with 3 setae; palp 3-articulate, length ratio of articles 1–3 1.0: 2.3: 1.5, article 1 bare, article 2 with 20 setae on ventral margin and submargin, ventral margin of article 3 lined with plumose setae, inner and outer surfaces of article 3 each with 1 cluster of setae. Lower lip (Fig. 2F) outer lobe broad, setulose; inner lobes distinct. Maxilla 1 (Fig. 2G) inner plate indistinct; outer plate rectangular with 9 serrate robust setae; palp article 2 bearing 4 robust and 9 slender setae distally. Maxilla 2 (Fig. 2H) with broad inner and outer plates; outer plate longer than inner plate, bearing long plumose setae on apical margin. Maxilliped (Fig. 2I) inner plate subrectangular, apical margin with 2 small robust setae; outer plate slightly exceeding half of palp article 2, medial margin with robust setae and long plumose setae; palp 4-articulate.

Gnathopod 1 (Figs 1A, 3A) coxa slender, subtriangular, longer than broad, anteroventral corner weakly produced, apically rounded; basis twice as long as broad, lacking anterodistal setae; carpus 1.3 times as long as broad, ventral margin weakly lobate; propodus subovate, length 1.4 times as long as wide, anterior margin with 6 clusters of slender setae, posterior margin convex with 12 robust setae and slender setae; posterior margin of dactylus 2-dentate with short setae. Gnathopod 2 (Fig. 3B, C) basis 2.3 times as long as broad, concave anteriorly, lacking anterodistal setae; posterodistal corner of merus produced with simple and plumose setae; carpus indistinct, fused with propodus, with simple and plumose setae; propodus subovate, 1.7 times as long as wide, anterior margin with 3 clusters and 1 pair of short setae and seta, medial surface with numerous plumose setae, palm straight, about 60% of length of propodus, with well-developed distal shelf, concave medially, shelf margin strongly crenulate, palm with subtriangular tooth and defining tooth, lacking robust setae near palm defining tooth; dactylus not reaching end of palm, with short seta on anteroproximal margin.

Pereopods 3 and 4 (Fig. 3D–F) basis bearing anterodistal lobe; ischium subrectangular; merus slightly shorter than carpus, produced anterodistally; propodus longer than carpus, with robust setae on posterior margin. Pereopod 5 (Fig. 4A) basis with posterodistal lobe; merus with posterodistal projection; length ratio of merus–dactylus 1.0: 1.1: 1.3: 0.6. Pereopod 6 (Fig. 4B) basis subrectangular, length 1.4 times as long as wide; posterodistal corner of merus produced; length ratio of merus–dactylus 1.0: 1.0: 1.3: 0.6. Pereopod 7 (Fig. 4C, D) basis subquadrate, length 1.3 times width; merus produced posterodistally; length ratio of merus–dactylus 1.0: 0.9: 1.1: 0.5.

Coxal gill on gnathopod 2, broad distally, gills on pereopods 3–6 slender.

Pleopods 1–3 (Fig. 4E, F) peduncle without setae, inner distal corner with paired retinacula.

Uropod 1 (Fig. 4G) biramous; peduncle 2.8 times as long as broad, medial and lateral margins with 4 and 5 robust setae, respectively, lacking ventromedial robust seta; inner ramus 1.1 times as long as peduncle, with 9 medial and 3 lateral robust setae; outer ramus 0.8 times of length of inner ramus, with 2 robust setae on lateral margin. Uropod 2 (Fig. 4H) biramous; peduncle 1.5 times as long as broad, with 1

medial and 2 lateral robust setae, ventromedial robust seta absent; inner ramus 1.7 times as long as peduncle, medial and lateral margins with 7 and 4 robust setae, respectively; outer ramus 0.8 times of length of inner ramus, bearing 3 lateral robust setae. Uropod 3 (Fig. 4I) uniramous, plate-like; with 3 apical and 1 medial robust setae.

Telson (Fig. 4J) length 0.9 times of width, dorsal lobe with 3 long robust setae apically, lower margin with short lateral setae.

***Female* (*paratype, NSMT-Cr 26051*).** Gnathopod 1 (Fig. 5A) basis slightly concave anteriorly, lacking anterodistal setae; propodus length 1.6 times as long as width, palmar margin of propodus bearing robust seta; posterior margin of dactylus 4-dentate. Gnathopod 2 (Fig. 5B) anterior margin of basis almost straight, lacking anterodistal setae; merus produced anterodistally, with plumose and simple setae; carpus free, distinct from propodus; propodus ovate, length 1.2 times width, palm convex, lacking distal shelf or teeth, with 4 robust setae near palmar corner.

Telson dorsal lobe with 4 long robust setae apically.

Etymology. The specific name is from the Japanese word for the whale shark *Rhincodon typus* '*Jinbē-zame*'; thus, it does not come from a Latin or Latinized word.

DNA Sequences. A sequence of COI (LC466202; 658 bp) was determined from the paratype female (NSMT-Cr 26051).

Distribution. Known only from Okinawa Island, Japan.

Remarks. *Podocerus jinbe* sp. nov. is morphologically similar to *P. zeylanicus* (Walker, 1904) in having the following features: body without dorsal carinae; coxa of gnathopod 1 slender and subtriangular; carpus of male gnathopod 1 weakly lobate ventrally; propodus palmar margin of male gnathopod 1 with many robust setae; carpus of male gnathopod 2 indistinct, fused with propodus; propodus palm of male gnathopod 2 with distal shelf; basis of pereopod 3 lobate anterodistally; uropods 1 and 2 without ventromedial robust seta on each peduncle; and rami of uropods 1 and 2 with marginal robust setae, but lacking comb-like rows of robust setae. *Podocerus jinbe* sp. nov. differs from *P. zeylanicus* in the following features (features of *P. zeylanicus* in parentheses): relatively large body size, up to 6.0 mm in male (small, up to 4.0 mm in male); peduncular article 1 of antenna 1 0.6 (0.8) times as long as peduncular article 2; flagellar article 1 of antenna 1 3 (2) times as long as flagellar article 2; propodus of male gnathopod 1 subrectangular (ovate); basis of male gnathopod 2 concave anteriorly (almost straight); merus of female gnathopod 2 narrow, tapering distally (broad, rounded distally); inner ramus of uropods 1 and 2 with 9 (6) and 7 (5) robust setae on its medial margins, respectively; and telson apical lobe with 3 or 4 long robust setae (1 long and 2 short robust setae). Recently, it has been revealed that many species with wide distribution areas such as *Nicippe tumida* Bruzelius, 1859 contain morphologically similar cryptic species (Matsukami *et al.* 2017). *Podocerus zeylanicus* has been recorded from various regions of the Indian Ocean and the South Pacific Ocean (Walker 1904; Chevreux 1908; Ruffo 1969; Ledoyer 1986; Hughes 2013). However, there are slight morphological variations among populations, *e.g.*, the shape of gnathopods and number of robust setae on rami of uropods (Chevreux 1908; Ledoyer 1986; Hughes 2013). Adequate specimens from various regions will be needed to evaluate whether these variations are intraspecific or not.

This is the first record of an amphipod associated with the whale shark. In this study, more than 1000 individuals of *P. zeylanicus* were collected from the whale shark. Hughes (2016) reported rapid swarming behavior of *P. chelonophilus*, on the Gold Coast, Australia with many individuals observed crawling on a floating scuba diver at 3–5 m depth. The numbers reached over 1000 within 5 minutes due to the recruitment of new individuals, a phenomenon noted to be a regular occurrence at the site (Hughes 2016). It seems that the high density of attachment of *P. jinbe* to the whale shark found in the present study resulted from similar behavior. The host whale shark was weak, had no appetite, and ultimately died 3 months later after the first recognition of the presence of *P. jinbe* (MY personal observation). We have no information about the cause of the whale shark's death. Species of *Podocerus* are filter-feeders gathering detritus in the sea with well-developed plumose setae on antennae (Barnard *et al.* 1988), and the present species also bears such characteristic antennae. Thus, it is very unlikely that the individuals of *P. jinbe* found in this study were feeding directly on the whale shark. However, it is likely that respiratory problems were caused by recruiting large numbers of amphipods to the gill. The gill rakers of a whale shark may be suitable for inhabitation by *P. jinbe* to take advantage of feeding from the strong water currents caused by the feeding and breathing of the whale shark.

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