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Redescriptions of two morphologically confusing sea lice *Caligus aesopus* Wilson, 1921 and *C. spinosus* Yamaguti, 1939 (Copepoda: Siphonostomatoida: Caligidae) parasitic on amberjacks (*Seriola* spp.) from Korea

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Abstract

The taxonomically confusing species of sea lice *Caligus aesopus* Wilson, 1921 and *C. spinosus* Yamaguti, 1939 are redescribed based on material taken from gills of amberjacks (*Seriola* spp.) from Korean seas. These two sea lice can be distinguished from each other by the following major differences: (1) the female abdomen of *C. aesopus* has a lateral constriction in the distal third, but that of *C. spinosus* is fusiform, without a constriction; (2) the proximal process on the first antennal segment is subcircular distally in *C. aesopus*, but tapered in *C. spinosus*; (3) the basis of leg 1 has a small tubercle in *C. aesopus*, but none in *C. spinosus*; (4) the protopod (apron) of leg 3 of *C. aesopus* has an inner patch of less than 15 large spinules, but that of *C. spinosus* has a patch of more than 25 small spinules; (5) the innermost spine on the third exopodal segment of leg 4 is distinctly longer than the nearby middle spine in *C. aesopus*, but subequal to the middle spine in *C. spinosus*; (6) the inner margin of the first maxillipedal segment of the male has four processes in *C. aesopus*, but three in *C. spinosus*; and (7) the first maxillipedal segment of the female has a tubercle on the myxal area in *C. aesopus*, but absent in *C. spinosus*.

Key words: Crustacea, copepods, taxonomy, fish parasite, caligids

Introduction

Several species of amberjack fishes (*Seriola* spp.) are currently cultured either commercially or experimentally in Korea, Australia, United States, Japan, and countries bordering the Mediterranean Sea (Sharp *et al*. 2003). Amberjacks are known to be hosts of more than ten species of caligid copepods commonly referred to as sea lice. Some of these sea lice, such as *Caligus spinosus* Yamaguti, 1939, may heavily infect farmed amberjacks and result in mortalities of the fishes (Johnson *et al*. 2004).

Wilson (1921) originally described *Caligus aesopus* as a parasite of "probably *Seriola peruana*" from the Juan Fernandez Islands in the East Pacific. This reference was unknown to many subsequent researchers due to its publication in a journal of limited distribution (Lin & Ho 2007). Another species of sea louse *C. spinosus* was inadequately described, with very limited figures, based on female specimens taken from *Seriola quinqueradiata* Temminck & Schlegel caught in Japan (Yamaguti 1939). In spite of the close similarity between *C. spinosus* and *C. aesopus*, Yamaguti (1939) did not compare his species with *C. aesopus* while he described *C. spinosus*, probably because Wilson's (1921) work was unknown to him.

Later, Shiino (1960) redescribed *C. spinosus* collected from *Seriola aureovittata* Temminck & Schelgel (= *S. lalandi* Valenciennes) and an unidentified fish from Japan. Hewitt (1963) reported *C. aesopus* from *Seriola grandis* Castelnau in New Zealand. Shiino's (1960) *C. spinosus* and Hewitt's (1963) *C. aesopus* appear to be very similar in body form sharing a characteristically truncated female genital complex and an inflated male genito-abdomen, which suggest that they are conspecific.

Fernandez & Villalba (1986) treated *C. spinosus* as a junior synonym of *C. aesopus*. Lin & Ho (2007) redescribed both sexes of *C. aesopus* in detail based on specimens from *Seriola dumerili* (Risso) caught in

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Taiwan. They also treated *C. spinosus* as a junior synonym of *C. aesopus*. In contrast to Fernandez & Villalba (1986) and Lin & Ho (2007), Hutson *et al*. (2007) recorded *C. aesopus* as a junior synonym of *C. spinosus*.

While examining sea lice parasitic on amberjacks from Korea we encountered two similar species. One of them turned out to be *C. aesopus* and the other *C. spinosus*. We found that the identity of the two species of sea lice had previously been misunderstood by copepod researchers and fishery biologists, and this taxonomic confusion will persist unless the taxonomic differences between them are elucidated. Therefore, this paper aims to solve this taxonomic problem.

Materials and methods

Fish heads obtained from the local seashore fish markets in Kangnung, Korea were transferred to the laboratory and investigated for the presence of sea lice. Additionally, fish were caught by gill net from Jeju Island. Sea lice removed from the gills of the hosts were preserved in 80% ethanol. Before microscopic observation and dissection, sea lice specimens were immersed in lactic acid for at least one hour. Dissections were done using the reversed slide method (Humes & Gooding 1964). All figures were drawn with the aid of a drawing tube. The type specimens of *C. spinosus* (SY 3836 containing 2 females and 1 male and SY 3837 containing 2 females, all mounted on slides) preserved in the Meguro Parasitological Museum, Tokyo, Japan, were examined without dissection. In the description, Roman and Arabic numerals in the armature formula represent spines and setae, respectively.

Results

Order Siphonostomatoida Burmeister, 1835

Family Caligidae Burmeister, 1835

Genus *Caligus* Müller, 1785

Caligus spinosus Yamaguti, 1939

(Figs 1–3)

Caligus spinosus Yamaguti, 1939, p. 445, pl. 14, figs. 4–8; Yamaguti & Yamasu 1960, p. 147, pl. 11, figs. 29–39; Izawa 1969, p. 127, figs. 1–20.

nec *Caligus spinosus*: Shiino 1960, p. 476, figs. 4, 5; Pillai 1963, p. 76, fig. 6.

Material examined. All specimens examined were collected from the gills of amberjacks kept in aquaria of a seashore fish market in Kangnung (37°47′44″N, 128°55′08″E) located on the coast of the Sea of Japan: 2 females collected from *Seriola quinqueradiata* Temminck & Schlegel, by I.-H. Kim, 20 May 2001; 4 females and 2 males from *S. quinqueradiata*, by I.-H. Kim, 2 July 2001; 3 females (along with 1 female of *C. aesopus*) from *Seriola lalandi* Valenciennes, by I.-H. Kim, 9 July 2001.

Description of female. Body (Fig. 1A) 3.83 mm long. Cephalothoracic shield subcircular, 1.51 × 1.65 mm; lateral zone with T-shaped ventral rib; posterior sinus deep. Fourth pedigerous somite fused with genital complex. Genital complex gradually broadened distally, slightly truncated posteriorly, 1.35 × 1.08 mm, with rounded posterolateral corners. Abdomen (Fig. 1B) 0.68 × 0.45 mm, 1-segmented, fusiform, with convex lateral margins. Caudal ramus 71 × 63 μm, slightly longer than wide, with 6 setae and 1 small dorsal setule.

Antennule (Fig. 1C) 2-segmented; proximal segment with 25 pinnate and 2 naked setae; distal segment elongated, 1.3 times longer than proximal segment, with 1 naked subterminal seta on posterior margin and 11 naked setae and 2 aesthetascs distally. Antenna (Fig. 1D) 3-segmented; first segment with small, tapering

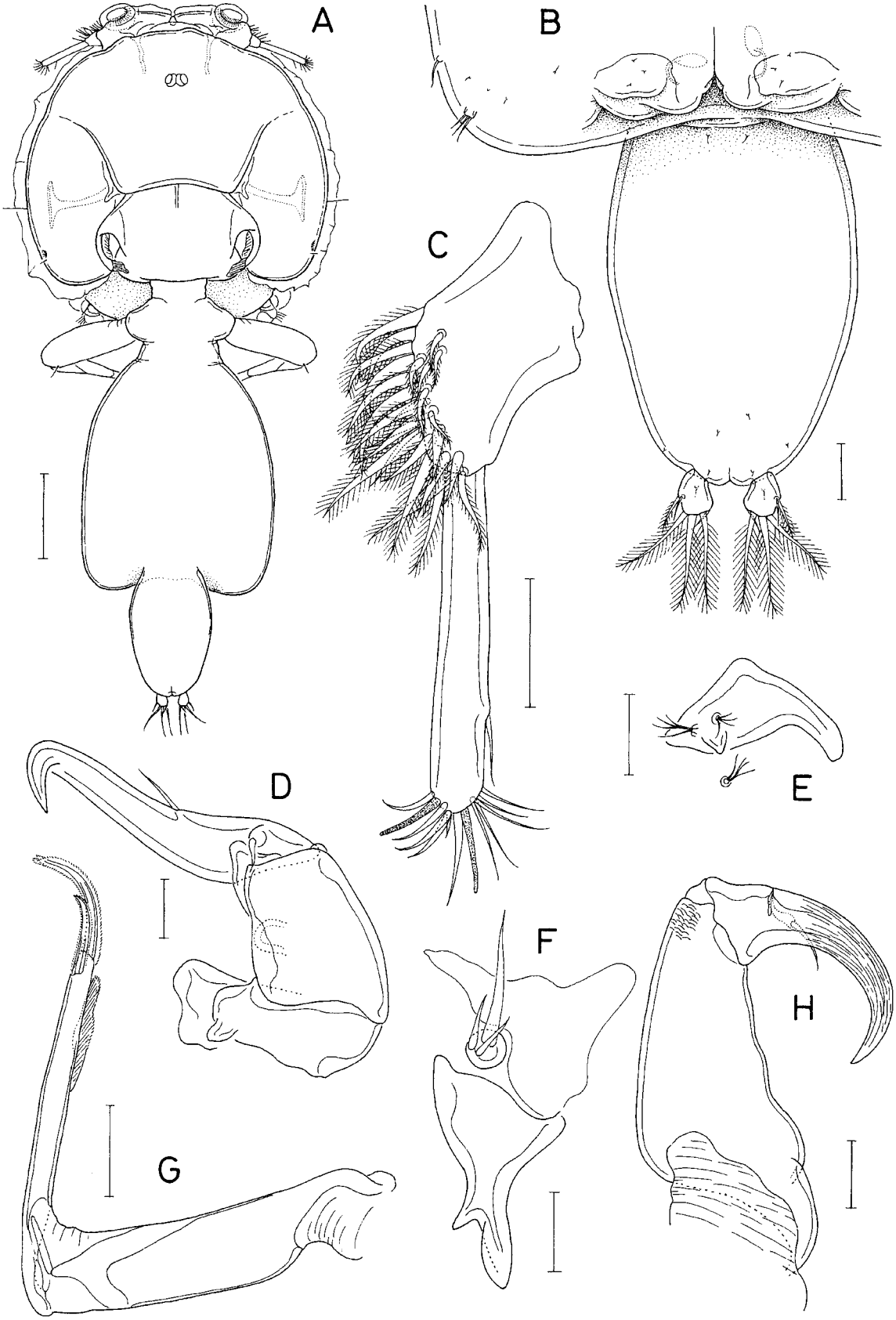

FIGURE 1. *Caligus spinosus* Yamaguti, 1939, female. A, habitus, dorsal; B, abdomen, ventral; C, antennule; D, antenna; E, postantennal process; F, maxillule; G, maxilla; H, maxilliped. Scale bars: 0.5 mm for A; 0.1 mm for B, C, G, and H; 0.05 mm for D–F.

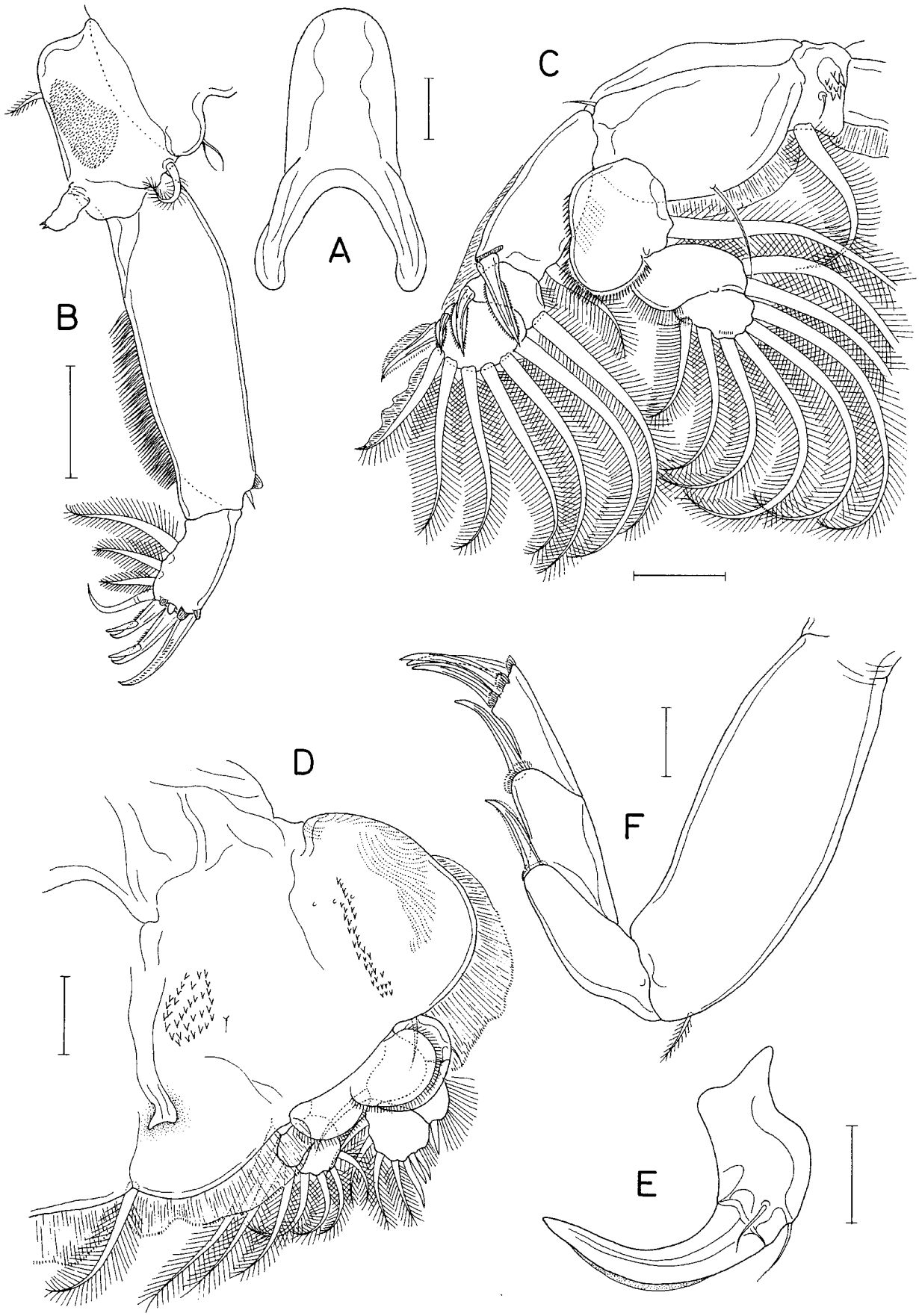

FIGURE 2. *Caligus spinosus* Yamaguti, 1939, female. A, sternal furca; B, leg 1; C, leg 2; D, leg 3; E, first exopodal segment of leg 3; F, leg 4. Scale bars: 0.05 mm for A and E; 0.1 mm for B–D, and F.

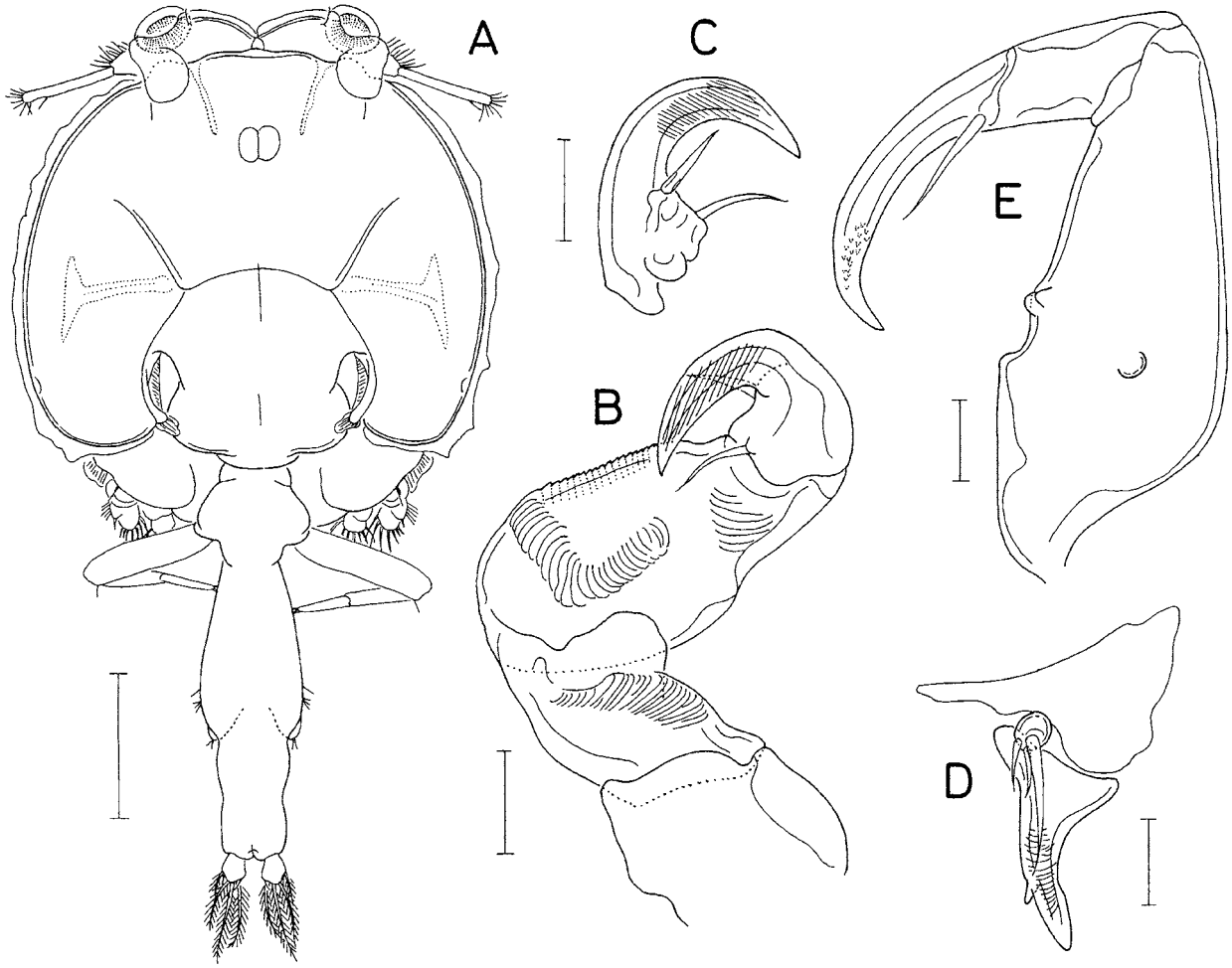

FIGURE 3. *Caligus spinosus* Yamaguti, 1939, male. A, habitus, dorsal; B, antenna; C, terminal claw of antenna; D, maxillule; E, maxilliped. Scale bars: 0.5 mm for A; 0.05 mm for B–E.

proximal process; second segment nearly quadrangular, with 1 adhesion pad; third segment forming long, distally strongly bent claw bearing 2 small setae. Postantennal process (Fig. 1E) proximally bearing 1 small posterior subsidiary process and 2 papillae each tipped with 4 setules; another papilla located posterior to postantennal process also tipped with 4 setules.

Mandible with 12 teeth distally. Maxillule (Fig. 1F) consisting of anterior papilla bearing 3 unequal setae and posterior process bearing fusiform distal tine and smaller medial tine. Maxilla (Fig. 1G) 2-segmented; proximal segment (lacertus) unarmed; slender distal segment (brachium) with large subdistal membrane (flabellum) on inner margin; calamus about 1.7 times longer than canna. Maxilliped (Fig. 1H) 3-segmented; first segment (corpus) gradually narrowed distally, with uneven inner margin; second segment (shaft) short, with 1 distal seta; third segment almost fused with second, forming strongly curved claw with longitudinal surface striations. Sternal furca (Fig. 2A) with slender, slightly incurved tines bearing blunt tips.

Armature on rami of legs 1–4 as follows:

Leg 1: exopod 1-0; III,1,3; endopod (vestigial)

Leg 2: exopod I-1; I-1; II,I,5; endopod 0-1; 0-2; 6

Leg 3: exopod I-0; I-1; III,4; endopod 0-1; 6

Leg 4: exopod I-0; I-0; III; endopod (lacking)

Leg 1 (Fig. 2B) coxa with branched outer setule; basis with pinnate outer seta, smaller pinnate inner seta, and patch of numerous minute spinules on ventral surface. Proximal exopodal segment elongate, with 1 small

outer distal naked seta and row of setules on inner margin; distal segment with digitiform process on distal margin; three distal spines each accompanied by flabelliform membrane; two inner distal spines bifurcating at about their midlength; distal seta longer than spines and naked; endopod flexible and tipped with 2 small processes. Leg 2 (Fig. 2C) coxa with large seta on inner posterior margin, 1 patch of spinules and 1 setule on ventral surface; basis with small outer seta and 1 inner setule and membrane on inner part of posterior margin; first endopodal segment expanded posterolaterally, with spinules along outer margin; outer side of basis and first exopodal segment with broad membrane (not illustrated in Fig. 2C). Leg 3 (Fig. 2D) protopod (apron) with adhesion pads and broad membrane on outer margin, longitudinal patch of spinules on mid-ventral surface, and patch of 25–34 spinules on inner ventral surface; spine on first exopodal segment (Fig. 2E) enlarged and strongly curved; distal endopodal segment partially subdivided. Leg 4 (Fig. 2F) protopod moderately expanded, with small outer distal seta; spines on first and second exopodal segments 127 and 165 μm, respectively; three spines on terminal segment 135, 156, and 146 μm from outer to inner; all spines on exopodal segments accompanied with flabelliform membranes near base. Leg 5 (Fig. 1B) represented by 1 and 3 small setae on posterolateral margin of genital complex.

Male. Body (Fig. 3A) 3.01 mm long. Cephalic shield resembles that of female. Genital complex completely fused with abdomen to form elongate genito-abdomen of 972 × 339 μm (2.87:1, excluding caudal rami). Caudal ramus 83 × 81 μm, with setules on inner margin (not figured).

Antennule armed as in female, but distal segment relatively longer than that of female. Antenna (Fig. 3B) 3-segmented as in female; first segment with 1 adhesion pad; second segment with 3 adhesion pads; third segment with 2 inner proximal setae and forming strongly curved, large claw (Fig. 3C). Postantennal process more slender than that of female.

Mandible and maxilla as in female. Maxillule (Fig. 3D) with adhesion pad on ventral surface of posterior process. Maxilliped (Fig. 3E) with 1 ventral and 3 inner small tubercles on first segment; claw with small denticles on distal part. Sternal furca with tines more slender than that of female.

Legs 1–5 as in female. Leg 6 (Fig. 3A) represented by 2 small setae on each posterolateral corner of genital complex.

Hosts and distribution. *Seriola quinqueradiata* in Japan and Korea, and *S. lalandi* in Korea.

Remarks. We examined the type specimens of *C. spinosus* loaned from the Meguro Parasitological Museum, Tokyo. Yamaguti (1939) referred to these type specimens as "one immature and four mature specimens", but we confirmed that they consist of four adult females and one adult male mounted on two slides. Although the specimens were mounted, they showed several characteristic features of *C. spinosus*: the rounded posterolateral corners of the genital double somite in the female, the absence of a lateral constriction on the abdomen, a patch of more than 20 spinules on the protopod of leg 3, and the similar sizes of the terminal spines of leg 4.

Caligus aesopus Wilson, 1921
(Figs 4–6)

Caligus aesopus Wilson, 1921, p. 72, pl. 3, fig. 8, pl. 4, figs. 11–13; Hewitt 1963, p. 71, text-figs. 4, 5; Kensley & Grindley 1973, p. 74; Fernandez & Villalba 1986, p. 40, figs. 25–49; Lin & Ho 2007, p. 42, figs. 1–3.
Caligus spinosus: Shiino 1960, p. 476, figs. 3, 4 (in part); Pillai 1963, p. 76, fig. 6.

Material examined. 1 female from the gills of *Seriola lalandi* Valenciennes kept in an aquarium of a seashore fish market in Kangnung, collected by I.-H. Kim, 4 June 2001; 1 female (along with 3 females of *Caligus spinosus*) from gills of *S. lalandi* kept in an aquarium of a seashore fish market in Kangnung, collected by I.-H. Kim, 9 July 2001; 6 females and 4 males from gills of *S. lalandi* caught with a gill net, off Gosan (33°18′35″N, 126°09′21″E) on Jeju Island, collected by M.-K. Choe, 16 August 2009.

Description of female. Body (Fig. 4A) 4.03 mm long. Cephalothoracic shield subcircular, 1.88 × 1.89 mm; lateral zone with T-shaped ventral rib; posterior sinus deep. Fourth pedigerous somite fused with genital complex. Genital complex subtriangular, truncated posteriorly, 1.25 × 1.09 mm, with slightly angular

posterolateral corners. Abdomen (Fig. 4B) 0.58 × 0.43 mm, 1-segmented, but usually divided by a constriction in the distal third of the lateral margin into a longer anterior part (maximum width 430 μm) and shorter posterior part (maximum width 275 μm). Caudal ramus (Fig. 4C) 73 × 83 μm, slightly wider than long, with 6 setae and 1 small dorsal setule.

Antennule (Fig. 4D) 2-segmented; proximal segment with 25 pinnate and 2 naked setae; distal segment elongated, 1.3 times longer than proximal segment, with 1 naked subterminal seta on posterior margin and 11 naked setae and 2 aesthetascs on distal margin. Antenna (Fig. 4E) 3-segmented; first segment with subcircular proximal process; second segment nearly quadrangular, with 1 adhesion pad; third segment forming long, distally strongly bent claw bearing 2 small setae. Postantennal process (Fig. 4F) moderately slender, proximally bearing 1 posterior subsidiary process and 2 papillae each with 5 or 6 setules; another papilla located posterior to postantennal process with 5 setules.

Mandible with 12 teeth distally. Maxillule (Fig. 4G) consisting of anterior papilla bearing 3 setae and posterior process bearing fusiform distal tine and smaller medial tine. Maxilla (Fig. 4H) 2-segmented; proximal segment (lacertus) unarmed; slender distal segment (brachium) with large subdistal membrane (flabellum) on inner margin; calamus about 1.8 times longer than canna. Maxilliped (Fig. 4I) 3-segmented; first segment (corpus) gradually narrowing distally, with small tubercle on myxal area; second segment (shaft) short, with 1 distal seta; third segment indistinctly demarcated from second, forming strongly curved claw with longitudinal surface striations. Sternal furca (Fig. 4J) with slender, incurved tines each with sclerotized ventral ridge.

Armature on rami of legs 1–4 as follows:

Leg 1: exopod 1-0; III,1,3; endopod (vestigial)

Leg 2: exopod I-1; I-1; II,I,5; endopod 0-1; 0-2; 6

Leg 3: exopod I-0; I-1; III,4; endopod 0-1; 6

Leg 4: exopod I-0; I-0; III; endopod (lacking)

Leg 1 (Fig. 5A) coxa with branched outer setule; basis with pinnate outer seta, smaller inner plumose seta, and on ventral surface small dentiform inner process and patch of numerous minute spinules. Proximal exopodal segment elongate, with 1 small outer distal seta and row of setules on inner margin; distal segment with digitiform process on distal margin; three distal spines each accompanied by flabelliform membrane; two inner distal spines bifurcating at about their midlength and distal naked seta distinctly longer than spines (Fig. 5B); endopod flexible, relatively long and tipped with 2 small processes. Leg 2 (Fig. 5C) coxa with large seta on inner posterior margin, 1 patch of spinules and 1 setule on ventral surface; basis with small outer seta, 1 inner setule, and membrane on inner part of posterior margin. First endopodal segment expanded posterolaterally, with setules on proximal part and spinules on distal part of outer margin; anterior margin of basis and outer margin of first exopodal segment with broad membrane (not illustrated in Fig. 5C). Leg 3 (Fig. 5D) protopod (apron) with adhesion pads on outer surface, broad membrane on posterior margin, longitudinal patch of spinules on mid-ventral surface, and patch of 11–14 large spinules (these spinules usually truncated) on inner ventral surface; spine on first exopodal segment (Fig. 5E) enlarged and strongly curved; distal endopodal segment partially subdivided. Leg 4 (Fig. 5F) protopod expanded, 456 × 197 μm, with small outer distal seta; spines on first and second exopodal segments 112 and 97 μm, respectively; three spines on terminal segment 97, 115, and 147 μm from outer to inner; all spines on exopodal segments accompanied with flabelliform membrane near base. Leg 5 (Fig. 4B) represented by 1 and 3 small setae on posterolateral margin of genital complex.

Male. Body (Fig. 6A) 2.34 mm long. Cephalic shield resembling that of female. Genital complex (Fig. 6B) fused with abdomen to form fusiform genito-abdomen of 761 × 433 μm (1.76:1, excluding caudal rami), leaving incomplete suture line between them, distinctly wider than fourth pedigerous somite. Caudal ramus 86 × 85 μm, with setules on inner margin.

Antennule armed as in female, but distal segment 1.6 times longer than proximal segment. Antenna (Fig. 6C) 3-segmented as in female; first segment with 1 adhesion pad; second segment with 3 adhesion pads; third segment with 2 inner proximal setae and forming strongly curved, large claw. Postantennal process (Fig. 6D) more slender than that of female.

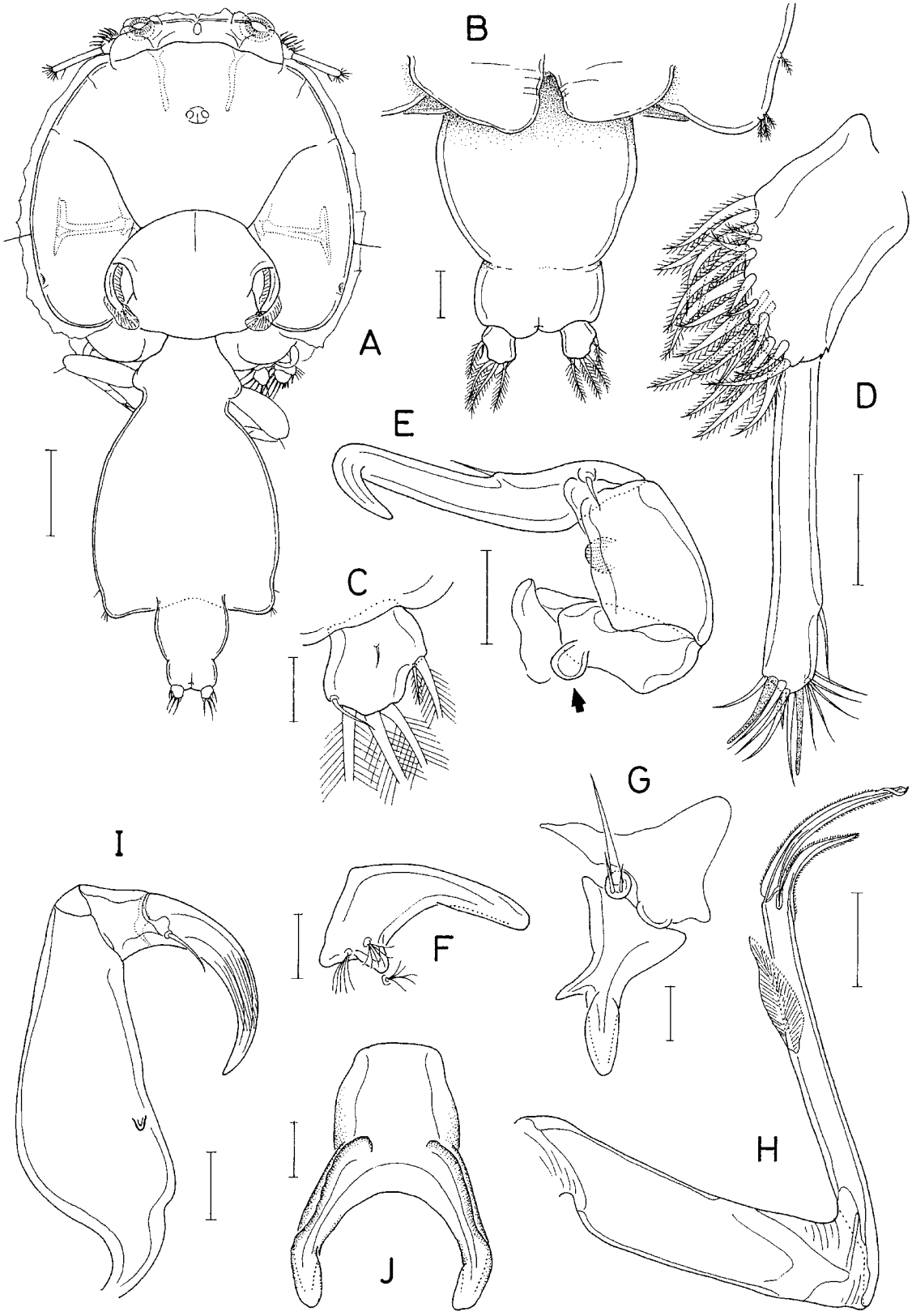

FIGURE 4. *Caligus aesopus* Wilson, 1921, female. A, habitus, dorsal; B, abdomen, ventral; C, caudal ramus, ventral; D, antennule; E, antenna; F, postantennal process; G, maxillule; H, maxilla; I, maxilliped; J, sternal furca. Scale bars: 0.5 mm for A; 0.1 mm for B, D, E, H, and I; 0.05 mm for C, F, G, and J.

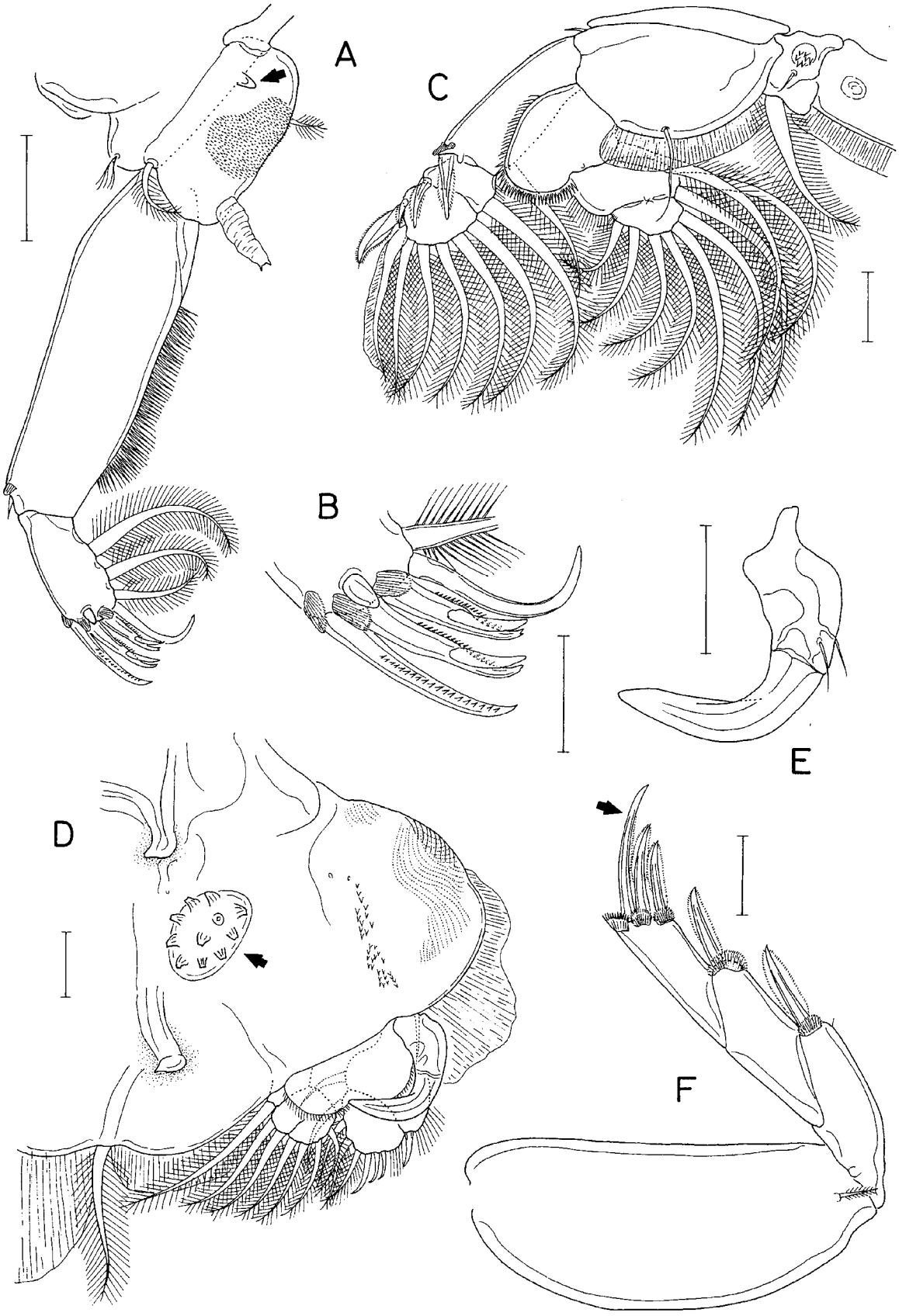

FIGURE 5. *Caligus aesopus* Wilson, 1921, female. A, leg 1; B, distal part of leg 1; C, leg 2; D, leg 3; E, first exopodal segment of leg 3; F, leg 4. Scale bars: 0.1 mm for A and C–F; 0.05 mm for B.

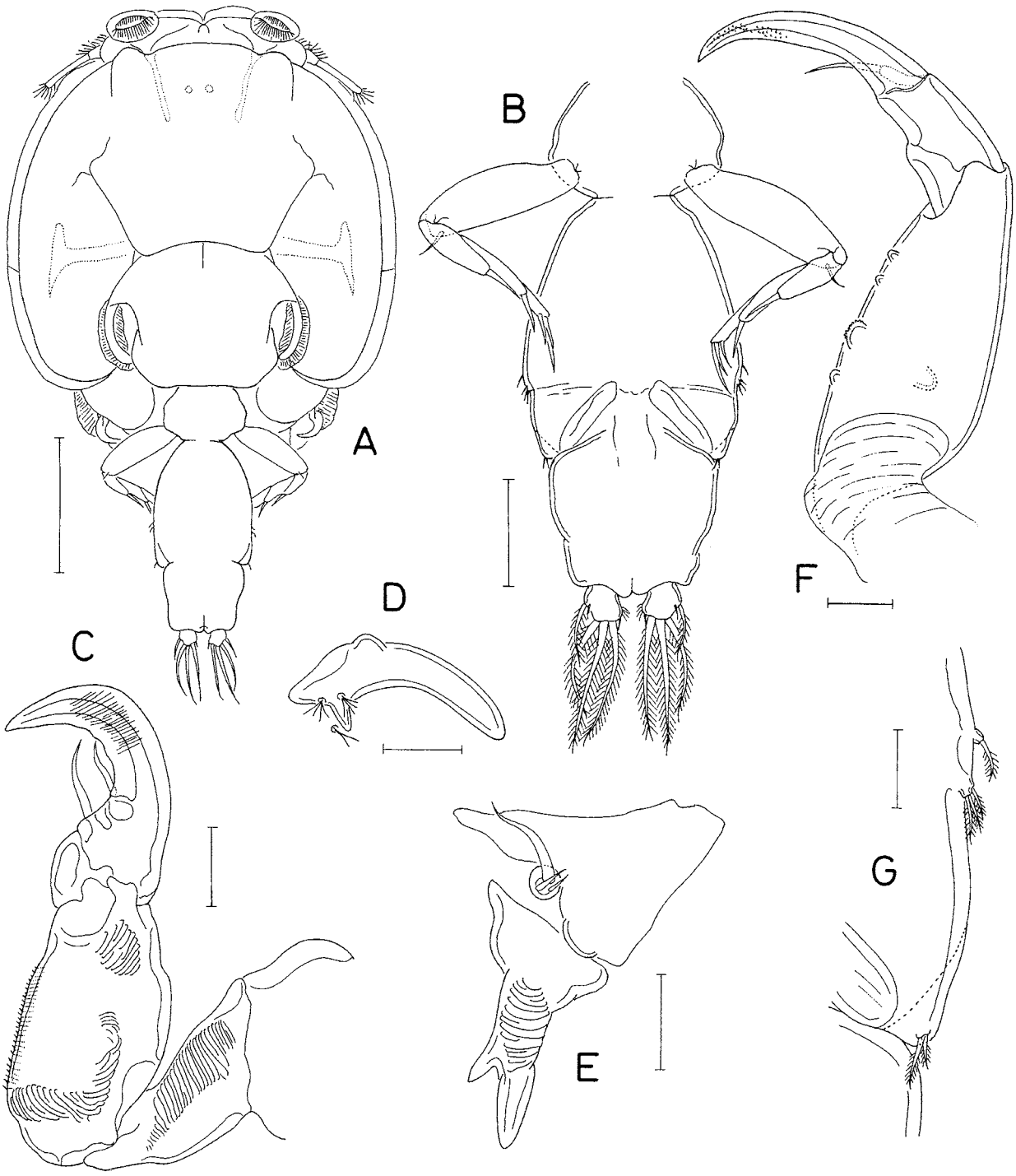

FIGURE 6. *Caligus aesopus* Wilson, 1921, male. A, habitus, dorsal; B, urosome, ventral; C, antenna; D, postantennal process; E, maxillule; F, maxilliped; G, legs 5 and 6. Scale bars: 0.5 mm for A; 0.2 mm for B; 0.05 mm for C–G.

Mandible, maxilla, and sternal furca as in female. Maxillule (Fig. 6E) with adhesion pad on ventral surface of posterior process. Maxilliped (Fig. 6F) with 1 ventral (posterior) and 4 small inner tubercles on first segment; claw with small denticles on distal part.

Legs 1–5 as in female. Leg 6 (Fig. 6G) represented by 2 small setae on each posterolateral corner of genital complex.

Hosts and distribution. "*Seriola peruana* " in Juan Fernandez, Chile; *S. grandis* in New Zealand; *S. dumerili* in Taiwan; *S. lalandi* in Japan, Korea, South Africa and Chile; and *Sphyraena obtusata* Cuvier in India.

Discussion

As shown in the above descriptions and illustrations, *Caligus aesopus* and *C. spinosus* are very similar to each other. However, they are different species and can be differentiated by the following differences: (1) the posterolateral corners of the female genital complex are slightly angular in *C. aesopus*, but rounded in *C. spinosus*; (2) the female abdomen of *C. aesopus* usually has a lateral constriction at the distal third, but that of *C. spinosus* is fusiform, without a constriction; (3) the proximal process on the first antennal segment is expanded distally (indicated by an arrow in Fig. 4E) in *C. aesopus*, but tapering in *C. spinosus*; (4) the basis of leg 1 has a small tubercle (indicated by an arrow in Fig. 5A) in *C. aesopus*, but none in *C. spinosus*; (5) the protopod (apron) of leg 3 of *C. aesopus* has a patch of less than 15 large, usually truncated, spinules (indicated by an arrow in Fig. 5D), but that of *C. spinosus* has a patch of more than 25 small spinules; (6) the innermost terminal spine (indicated by an arrow in Fig. 5F) on the third exopodal segment of leg 4 is distinctly longer than the nearby middle spine in *C. aesopus*, but subequal to the middle spine in *C. spinosus*; (7) the male genito-abdomen of *C. aesopus* is less than twice as long as wide, but that of *C. spinosus* is more than twice as long as wide; (8) the inner margin of the first maxillipedal segment of the male has four tubercles in *C. aesopus*, but three in *C. spinosus*; (9) the first maxillipedal segment of the female has a tubercles on the myxal area in *C. aesopus*, but absent in *C. spinosus*.

The original description of *C. aesopus* by Wilson (1921) contains little taxonomic informations. Yamaguti (1939) also described *C. spinosus* very briefly, based on female specimens, with illustrations of the habitus, postantennal process, maxillule, maxilla, and leg 3, of which only those of the habitus and leg 3 are taxonomically informative. These incomplete original descriptions of *C. aesopus* and *C. spinosus* lead subsequent researchers to the incorrect taxonomic recognition of these species. Later, Yamaguti & Yamasu (1960) described supplementally the male of *C. spinosus*, and their illustrated leg 4 corresponds to that of our specimens of *C. spinosus*, but differs from that of Shiino's (1960) "*C. spinosus*".

The specimens of Shiino's (1960) "*C. spinosus*" consisted of one female (Collection No. 475) from an unknown host and 12 females and one male (No. 515) from *Seriola aureovittata* (= *S. lalandi*). He stated that the female of No. 475 resembled the holotype in body size and in the configuration of the genital complex, but in the females of No. 515 from "*Seriola aureovittata*" the body was relatively larger and the genital complex ended angularly at the posterior corners. Therefore, it is certain that his female No. 475 is *C. spinosus* and those of No. 515 are *C. aesopus*. His redescription and illustrations were without doubt based on the specimens No. 515, in consideration that they conform with our specimens of *C. aesopus*. Pillai (1963) reported "*C. spinosus*" collected from the mouth cavity of *Sphyraena obtusata* Cuvier from India. But his specimens apparently belong to *C. aesopus*, as they have angular posterolateral corners of the genital complex, an incompletely two-segmented abdomen, and leg 4 in which the innermost terminal spine on the third exopodal segment is distinctly longer than the nearby spine. The sea lice examined by Izawa (1969) are indeed *C. spinosus*. His illustrations of leg 4 of the copepodid larvae and adults consistently reveal the typical feature of that species, i.e. the inner two among three distal spines on the third exopodal segment are subequal in length.

In Korean waters, *C. spinosus* is found to be a parasite of both *Seriola quinqueradiata* and *S. lalandi*, but *C. aesopus* is found only on the latter species. *Caligus aesopus* and its host *S. lalandi* show the same distribution in the Indo-Pacific from South Africa to the East Pacific. *Caligus aesopus* is known also from *Seriola grandis* in New Zealand (Hewitt 1963), *S. dumerili* in Taiwan (Lin & Ho 2007), "probably *S. peruana*" at Juan Fernandez (Wilson 1921), and *Sphyraena obtusata* in India (Pillai 1963). Therefore, its host specificity is lower than that of *C. spinosus*. In contrast to the widely distributed *C. aesopus*, *C. spinosus* is reported only from Japan and Korea. Nevertheless, it is likely that *C. spinosus* occurs in other areas, because it can parasitize the widely distributed fish host *S. lalandi*, although its occurrence on this fish is less frequent than that of *C. aesopus*.

Caligus lalandei Barnard, 1948 is another sea louse parasitc on *S. lalandi*. Unlike *C. aesopus* which is parasitic on the gills of its host, *C. lalandei* lives on the skin. *Caligus lalandei* is known from South Africa, Chile, Japan, Korea, and New Zealand (Ho *et al*. 2001). Thus this species has an almost same distributional range as that of *C. aesopus*.

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