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Copepodid Stages of *Ergasilus hypomesi* Yamaguti (Copepoda, Poecilostomatoida, Ergasilidae) from a Brackish Lake in Korea

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All copepodid stages and free-swimming adults of *Ergasilus hypomesi* Yamaguti collected from plankton samples from a brackish lake in Korea are described. The antennule remains a four-segmented appendage until copepodid V. The antenna of copepodid I carries a vestigial exopod. Sexual dimorphism first appears at copepodid IV whose males bear primodial maxillipeds. Leg 5 also is sexually dimorphic from copepodid IV onwards, with its free segment bearing three setae in the female and two setae in the male. Morphological features of some appendages appearing during copepodid development are discussed. It is noticed that the early copepodids of the Ergasilidae show the characteristic setation on the biramous legs and proximal segments of the antennule.

The Ergasilidae is a family of Copepoda comprising about 160 species (Lin and Ho, 1998) with their adult female being parasitic on freshwater and marine fishes. More than 20 species of this family have been reported in the Far East. One of them, *Ergasilus hypomesi* was first recorded by Yamaguti (1936) from *Hypomesus olidus* (Brevoort) in Japan. Later, Yin (1956) reported this species from 8 other species of freshwater fishes in China. In the same country, Wang (1964) added another species of fish as a host of this copepod. Nagasawa et al. (1989) recorded 4 species of fishes as hosts of *E. hypomesi* in Japan. Therefore *Ergasilus hypomesi* is a common species in the Far East and known at present to parasitize 14 species of fishes living in freshwater and brackish water.

According to Ferrari (1988), the larvae of the ergasilid copepods had been studied by 8 different researches. However, these studies are often fragmentary (Alston et al., 1996). Since then, *Ergasilus sieboldi* Nordmann and *E. briani* Markewitsch have been thoroughly studied for their larval stages by Abdelhalim et al. (1991) and Alston et al. (1996), respectively.

In June 2000, the author had a chance to collect planktons at the Lake Songji-ho, a brackish lake located on the eastern coast of Korea. Examination of the collected plankton sample under a dissecting microscope revealed a full set of copepodid larvae and adults of 2 ergasilid species mixed with a calanoid copepod *Sinocalanus tenellus* Kikuchi and cirripedian nauplii. The copepodid larvae of one of the two ergasilid species are described in this paper.

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Materials and Methods

Specimens were collected in June, 1998, with a plankton net pulled slowly along depths of less than 50 cm in the brackish lake Songji-ho located about 100 km north of Kangnung on the eastern coast of Korea. Specimens were fixed with about 5% formalin for 1 h and then transferred to 80% alcohol. The sample included copepodids and free-living adults of 2 species of Ergasilidae, *Ergasilus wilsoni* Markewitsch and *E. hypomesi* Yamaguti. Specimens of *Ergasilus hypomesi* studied in the present paper were easily separated from *E. wilsoni* by pigmentation along the gut, because the former was pigmented with green color and the latter with blue. Identification of the species was done on the basis of morphological features of free-living adults and confirmed by examination of adult females parasitic on the host fish *Hypomesus olidus* (Brevoort) living in the same lake. Copepodids I to VI of *E. hypomesi* were separated by their size (5 size groups for copepodids I-V), body segmentation (from 6 segments in copepodid I to 10 segments in copepodid V), morphology of genital (double-) somite (for adults), and leg structure under dissecting and optical microscopes. Copepodids and adults of *E. hypomesi* sorted from the sample were 2 copepodid I, 5 copepodid II, 2 copepodid III, 1 copepodid IV female, 3 copepodid IV male, 4 copepodid V female, 3 copepodid V female, 2 free-living female adults, and 1 free-living male adult.

Before microscopical observation and dissection, the copepod material were immersed in lactic acid for at least 10 minutes. Dissection was done using the reverse slide method of Humes and Gooding (1964). Drawings were made with the aid of camera lucida. In the description, body lengths were measured from the apex of cephalothorax to the distal end of caudal rami, excluding caudal setae. The abbriviations CI to CV used in the discussion represent copepodids I to V.

Results

Copepodid I (Fig. 1)

Body (Fig. 1A) 6-segmented and 415 μm long (another specimen 401 μm long). Cephalosome 193×179 μm. Segmentation between cephalosome and first pedigerous somite not prominent. Fourth somite (=third pedigerous somite or first urosomal somite) covered ventrally by buds of leg 3 (Fig. 1B). Anal somite nearly as long as wide. Caudal ramus as long as wide, with oblique posterior margin, tubercular process on outer lateral margin, epicuticular extensions on mid-posterior part of ventral surface and outer distal corner; inner two of 6 caudal setae each inserted on attenuation of ramus, and second outer terminal seta plumous in distal half.

Rostrum not seen. Antennule (Fig. 1C) 4-segmented

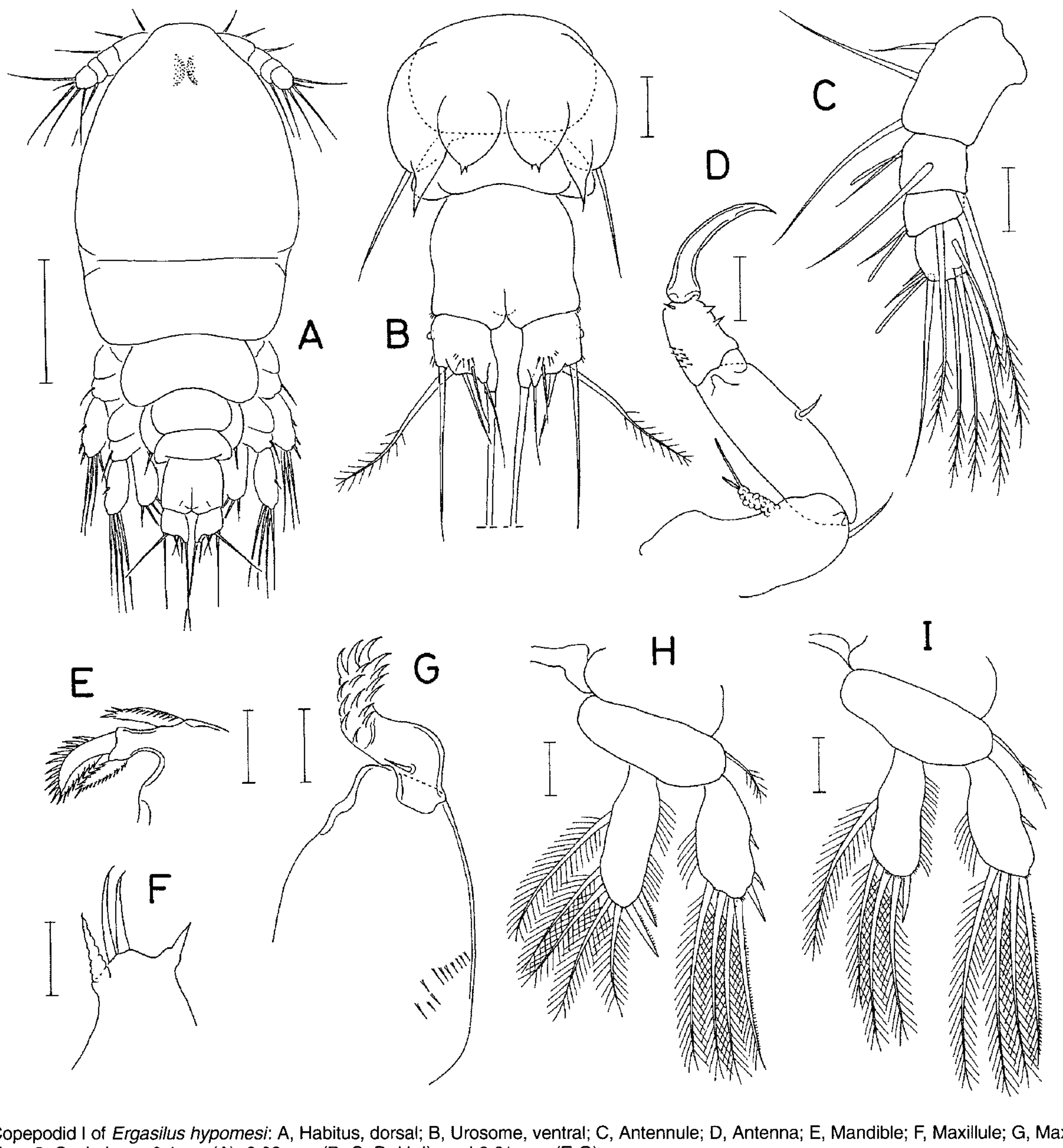

Fig. 1. Copepodid I of *Ergasilus hypomesi*: A, Habitus, dorsal; B, Urosome, ventral; C, Antennule; D, Antenna; E, Mandible; F, Maxillule; G, Maxilla; H, leg 1; I, Leg 2. Scale bars=0.1 mm(A), 0.02 mm (B, C, D, H, I), and 0.01 mm (E-G).

and 82 μm long; armature formula 3, 3+1 aesthetasc, 2+1 aesthetasc, and 7+1 aesthetasc; Antenna (Fig. 1D) 3-segmented, excluding terminal claw; first segment (coxobasis) bearing small, transparent exopod with 2 terminal setae; first endopodal segment with 1 seta near middle of medial margin; second endopodal segment slightly longer than wide, with 2 dentiform setae on medial margin and 1 small seta near outer distal corner; terminal claw distinctly longer than second endopodal segment, slender and sharply pointed at tip.

Labrum bilobed, with moderately excavated posterior margin. Mandible (Fig. 1E) with 3 foliaceous barbed setae. Maxillule (Fig. 1F) armed with 1 setiform process, 2 plain setae, and 1 fleshy seta. Maxilla (Fig. 1G) 2-segmented; basal segment with setules proximally; distal segment curved, with 1 small proximal seta and sharp teeth distally. Maxilliped absent.

Leg 1 (Fig. 1H) and leg 2 (Fig. 1I) biramous; rami 1-

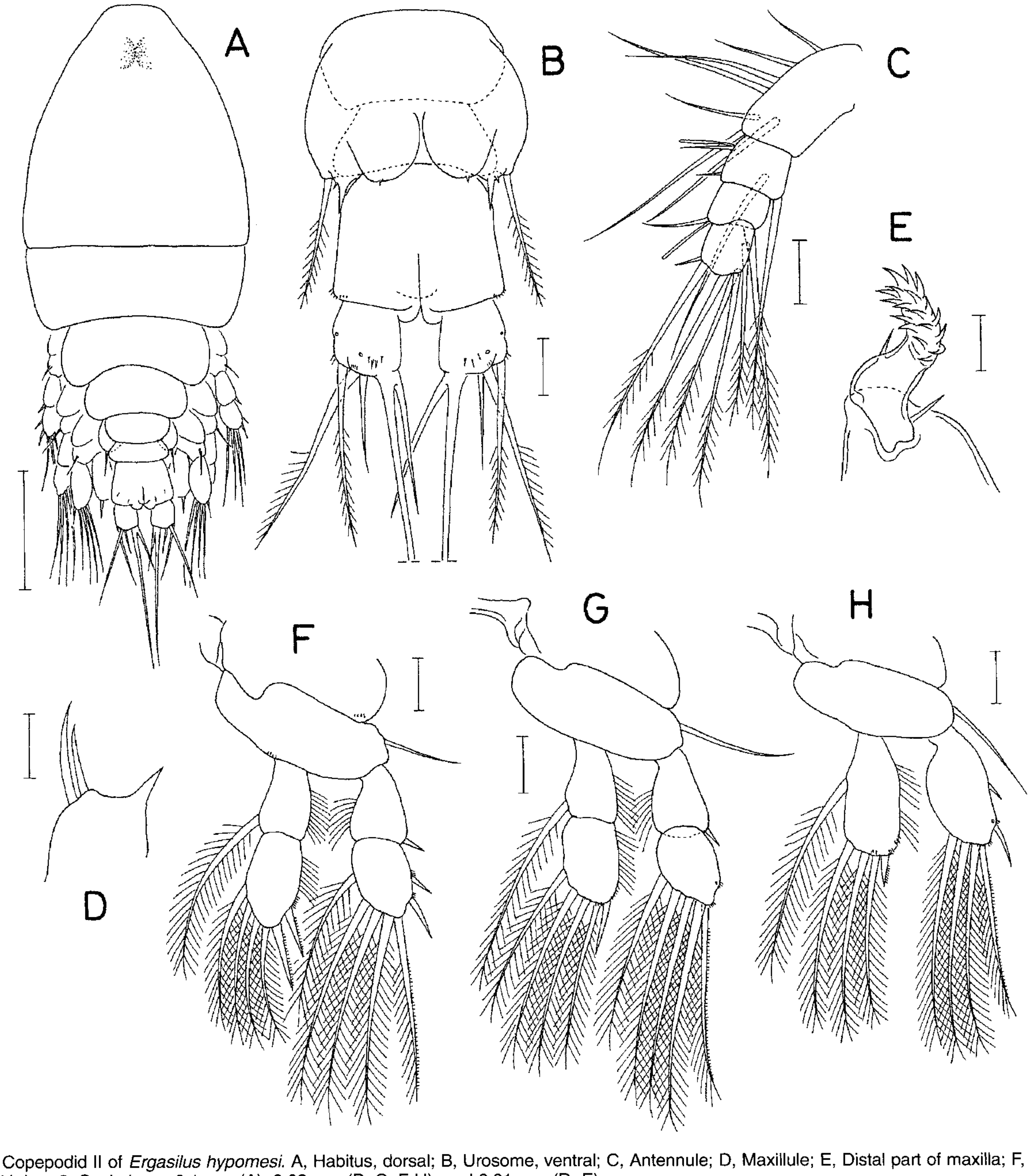

Fig. 2. Copepodid II of *Ergasilus hypomesi.* A, Habitus, dorsal; B, Urosome, ventral; C, Antennule; D, Maxillule; E, Distal part of maxilla; F, Leg 1; G, Leg 2; H, Leg 3. Scale bars=0.1 mm (A), 0.02 mm (B, C, F-H), and 0.01 mm (D, E).

segmented. Armature formula of legs 1 and 2 as follows:

	coxa	basis	exopod	endopod
Leg 1	0-0	1-0	III,4	II,5
Leg 2	0-0	1-0	I,4	I,4

Leg 3 represented by 2 lobes on ventral side of fourth somite; outer lobe (exopod) distally with 1 long seta and 1 large acute process; inner lobe (endopod) nearly circular, with 2 small pointed processes at apex.

Copepodid II (Fig. 2)

Body (Fig. 1A) 7-segmented and 467 μm (mean 467±29 μm, n=5). Cephalosome 203×184 μm. Urosome (Fig. 2B, distal 3 somites) resembling that of copepodid I. Caudal ramus with 5 setae (1 seta lost); 2 inner distal setae fused at base.

Antennule (Fig. 2C) with 7 setae on first segment and final armature state on distal 3 segments (4+1 aesthetasc, 2+1 aesthetasc, and 7+1 aesthetasc). Antenna, labrum,

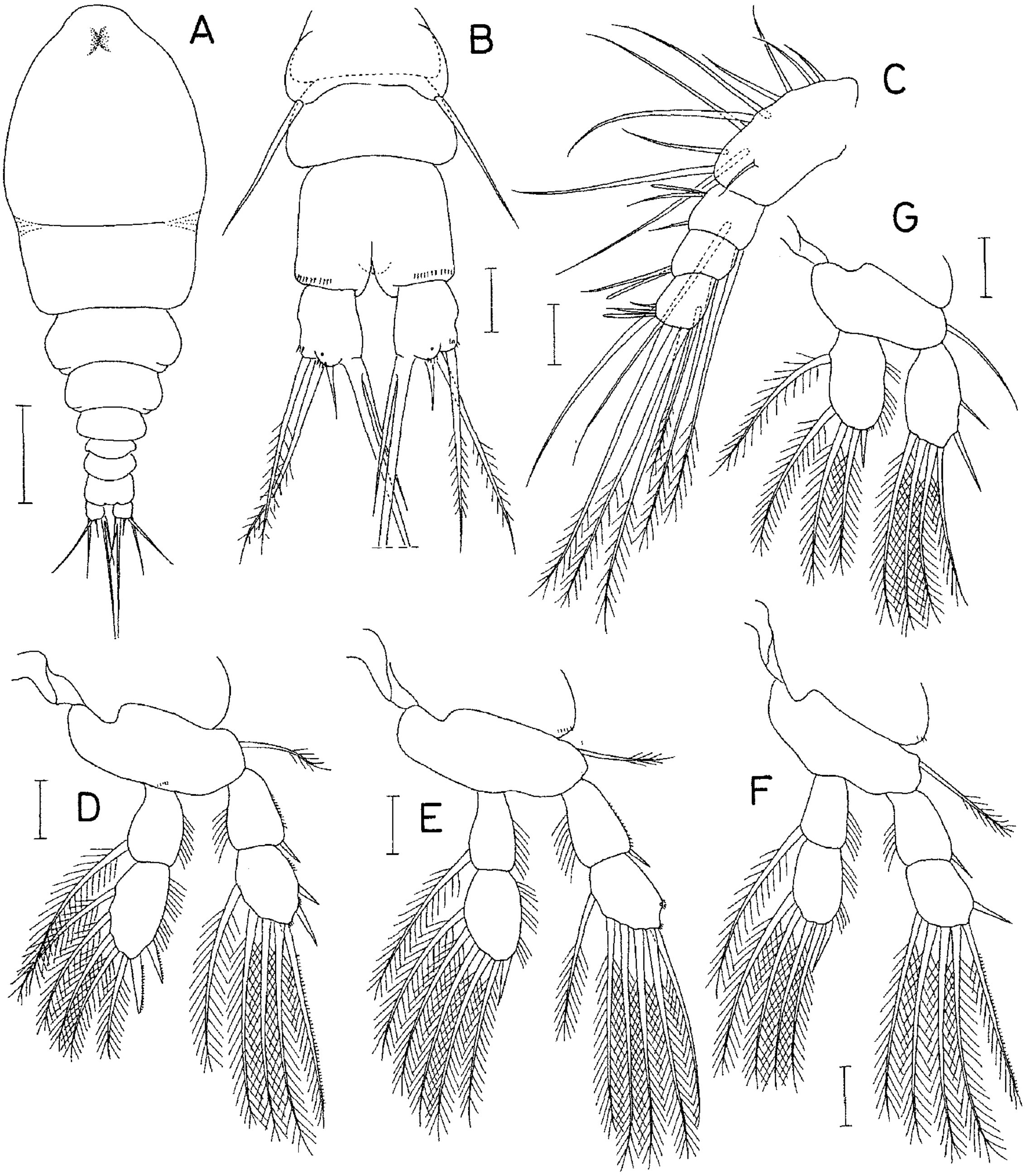

Fig. 3. Copepodid III of *Ergasilus hypomesi*. A, Habitus, dorsal; B, Urosome, ventral; C, Antennule; D, Leg 1; E, Leg 2; F, Leg 3; G, Leg 4. Scale bars= 0.1 mm (A) and 0.02 mm (B-G).

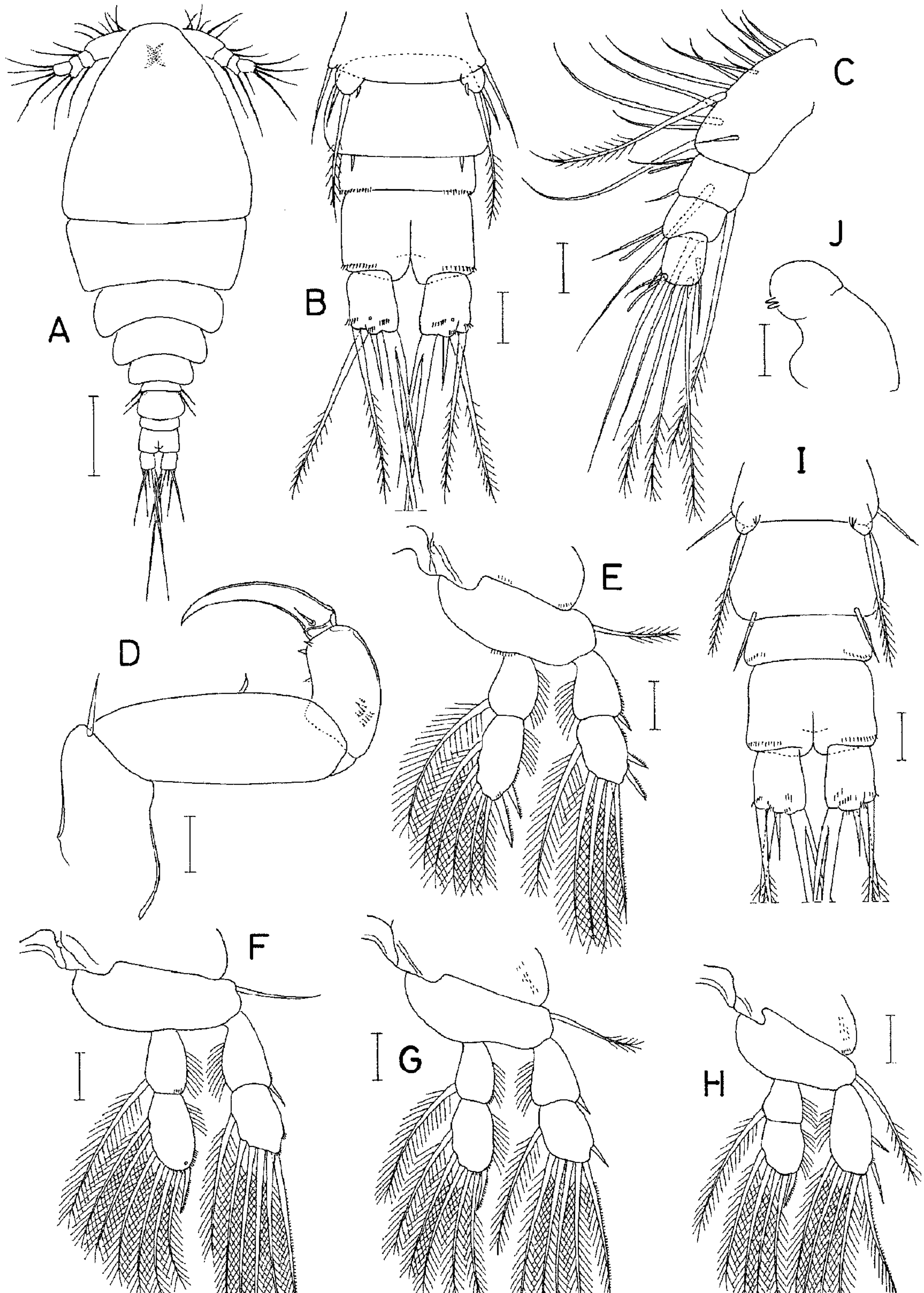

Fig. 4. Copepodid IV of *Ergasilus hypomesi*. Female: A, Habitus, dorsal; B, Urosome, ventral; C, Antennule; D, Antenna; E, Leg 1; F, Leg 2; G, Leg 3; H, Leg 4. Male: I, Urosome, ventral; J, Maxilliped. Scale bars=0.1 mm (A), 0.02 mm (B-I) and 0.01 mm (J).

mandible as in copepodid I. Maxillule (Fig. 2D) distally armed with 1 process and 2 setae (fleshy seta of CI lost). One seta added to distal segment of maxilla (Fig. 2E). Legs 1-3 biramous. Rami of legs 1 and 2 (Fig. 2F, G) 2-segmented, but those of leg 3 (Fig. 2H) 1-segmented. All these legs without inner seta on coxa. Armature formula of legs 1-3 as follows:

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

Leg 4 resembling leg 3 of copepodid I, except for following points: distal seta on outer lobe (exopod) plumose and process accompanied by 1 small spinule near base; inner lobe (endopod) tipped with 1 pointed process.

Copepodid III (Fig. 3)

Body (Fig. 3A) 8-segmented and 528 μm long (another specimen 550 μm), with faint boundary between cephalosome and first pedigerous somite. Cephalosome 230×208 μm. Urosome (Fig. 3B) curved ventrally and 3-segmented. Caudal ramus 1.2 times longer than wide, with 5 setae.

Antennule (Fig. 3C) with 11 setae on first segment. Antenna with 3 setae on inner margin of second endopodal segment (1 seta added to this margin and seta on outer distal corner lost). Mouthparts as in copepodid II.

Legs 1-4 biramous. Rami of legs 1-3 2-segmented (Fig. 3D-F). Rami of leg 4 1-segmented (Fig. 3G). Armature formula of legs 1-4 as follows:

	coxa	basis	exopod	endopod
Leg 1	0-0	1-0	I-0; II,5	0-1; II,5
Leg 2	0-0	1-0	I-0; 6	0-1; I,5
Leg 3	0-0	1-0	I-0; I,5	0-1; I,4
Leg 4	0-0	1-0	II,4	I,4

Leg 5 represented by posteroventral lobe and 1 large seta on first urosomal somite (Fig. 3B).

Copepodid IV (Fig. 4)

Female. Body (Fig. 4A) 9-segmented and 561 μm long. Cephalosome 250×235 μm. Urosome (Fig. 4B) 4-segmented, with short third urosomal somite (first abdominal somite) short. Caudal ramus as in preceding stage.

Antennule (Fig. 4C) with 15 setae on first segment. Antenna (Fig. 4D) with 1 seta added at base of terminal claw. Mouthparts as in preceding stage.

Legs 1-3 (Fig. 4E-G) with 2-segmented rami. Leg 4 (Fig. 4H) with 1-segmented exopod and 2-segmented endopod. Legs 1-4 with following armature formula:

	coxa	basis	exopod	endopod
Leg 1	0-0	1-0	I-0; II,5	0-1; II,5
Leg 2	0-0	1-0	I-0; 6	0-1; I,6
Leg 3	0-0	1-0	I-0; I,6	0-1; I,5
Leg 4	0-0	1-0	II,5	0-1; I,4

Leg 5 represented by 1 seta on posterolateral corner of first urosomal somite and lobe bearing 3 setae of very different lengths (middle one of them longest and plumose in distal half) (Fig. 4B). Leg 6 represented by 1 small seta on posteroventral margin of second urosomal somite (Fig. 4B).

Male. Body 593 μm long (mean 593±28 μm, n=3). Body form and segmentation as those of female. Maxilliped (Fig. 4J) bud-like, incompletely 2-segmented, with 2 small setae on distal segment. Other mouthparts, antennule, antenna, and legs 1-4 not different from those of female. Leg 5 represented by 1 seta on posterolateral corner and lobe bearing 1 long plumose seta and 1 small dentiforn seta. Seta on second urosomal somite representing leg 6 variable in length, shorter than half length of, or longer than, third urosomal somite (Fig. 4I).

Copepodid V (Fig. 5)

Female. Body (Fig. 5A) 10-segmented and 742 μm long (mean 715±27 μm, n=4). Cephalosome 304×296 μm. Urosome (Fig. 5B) 5-segmented but line delimiting second and third urosomal somites faint.

Antennule (Fig. 5C) with 22 setae on first segment. Antenna not changed. Mandible (Fig. 5D) as in preceding stages. Distal seta on second segment of maxilla enlarged and pinnate (Fig. 5E). Other mouthparts as for those of copepodid IV.

Legs 1-4 (Fig. 5F-I) with rami segmented as in preceding stage and following armature formula:

	coxa	basis	exopod	endopod
Leg 1	0-0	1-0	I-0; II,6	0-1; II,5
Leg 2	0-0	1-0	I-0; 7	0-1; I,6
Leg 3	0-0	1-0	I-0; I,7;	0-1; I,6
Leg 4	0-0	1-0	II,5	0-1; I,5

Leg 5 as that of copepodid IV. Leg 6 represented by 2 small setae near posterior corner of second urosomal somite (Fig. 5B).

Male. Body 614 μm long (mean 633±17 μm, n=3), shorter than that of female, but with same number of body somites. Urosome different from that of female: second urosomal somite (genital somite) longer than that of female; both third and fourth urosomal somites short.

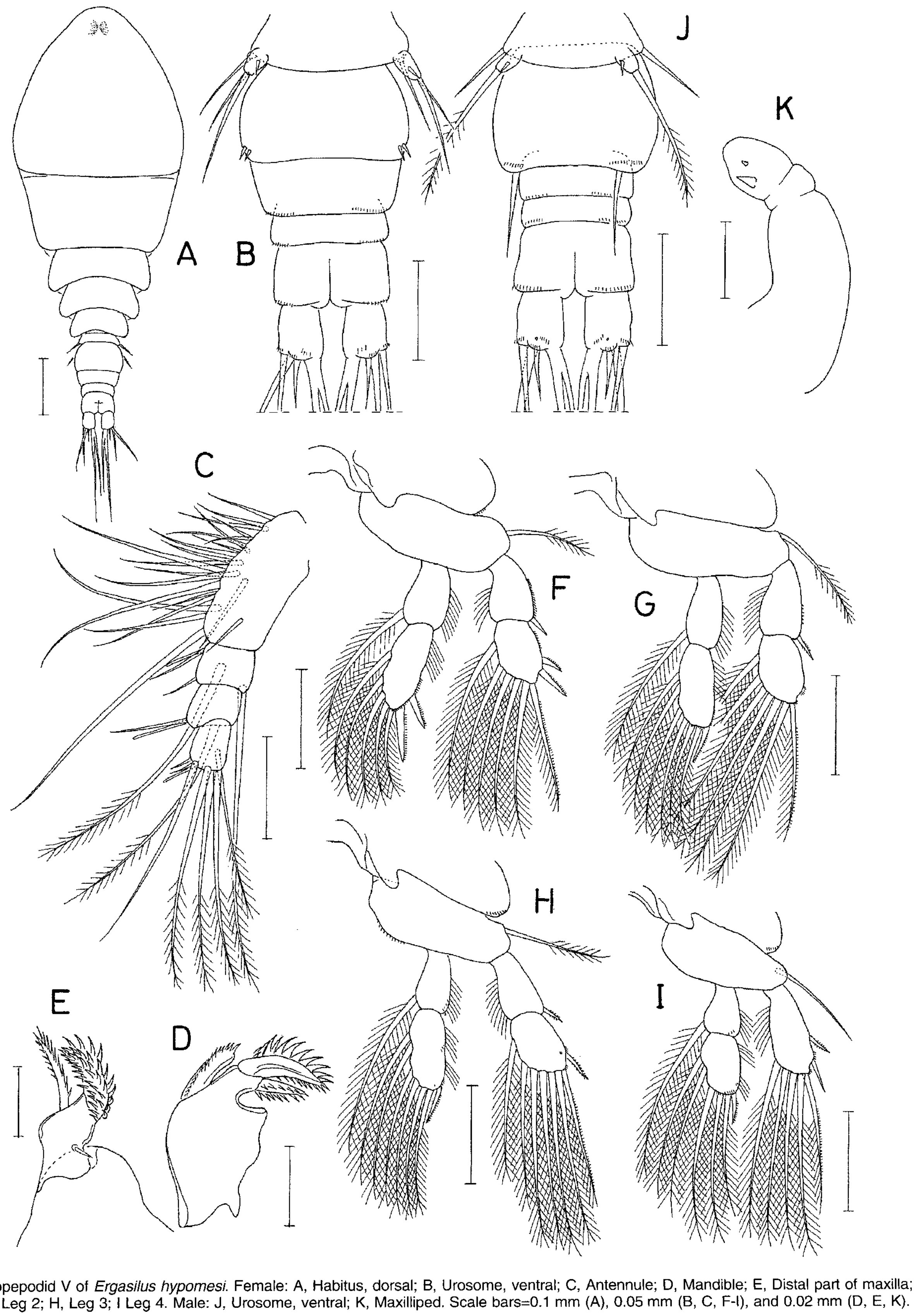

Fig. 5. Copepodid V of *Ergasilus hypomesi*. Female: A, Habitus, dorsal; B, Urosome, ventral; C, Antennule; D, Mandible; E, Distal part of maxilla; F Leg 1; G, Leg 2; H, Leg 3; I Leg 4. Male: J, Urosome, ventral; K, Maxilliped. Scale bars=0.1 mm (A), 0.05 mm (B, C, F-I), and 0.02 mm (D, E, K).

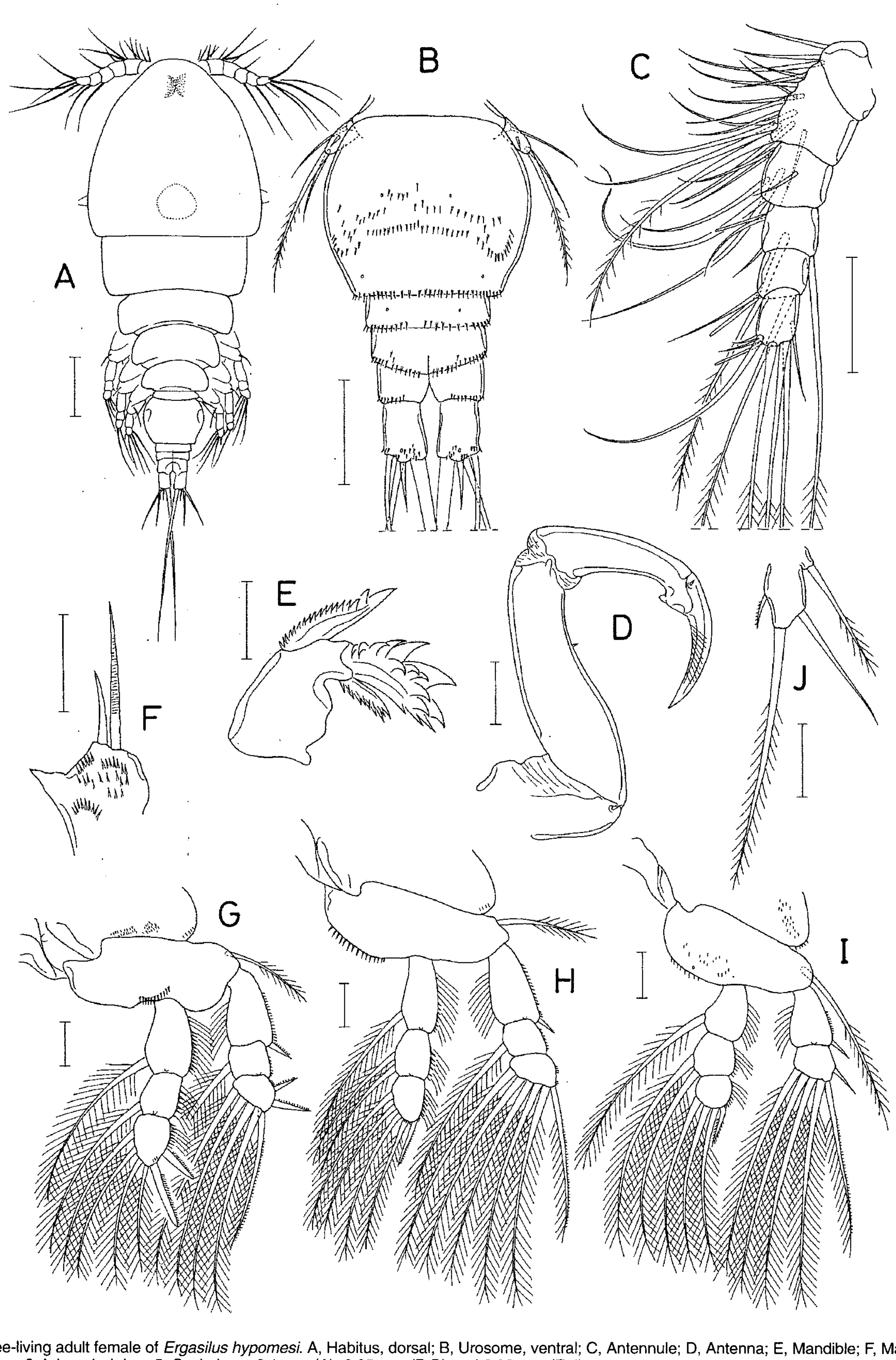

Fig. 6. Free-living adult female of *Ergasilus hypomesi*. A, Habitus, dorsal; B, Urosome, ventral; C, Antennule; D, Antenna; E, Mandible; F, Maxillule; G, leg 1; H, Leg 2; I, Leg 4; J, Leg 5. Scale bars=0.1 mm (A), 0.05 mm (B-D) and 0.02 mm (E-J).

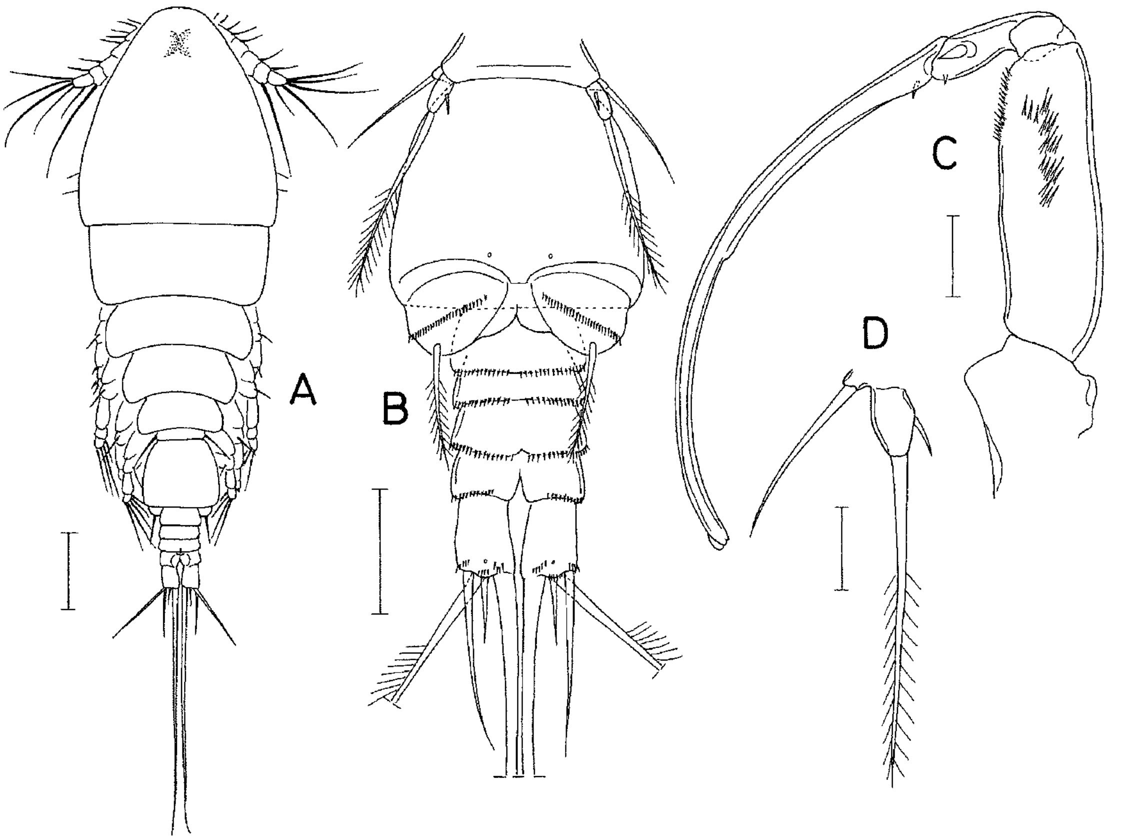

Fig. 7. Free-living adult male of *Ergasilus hypomesi*. A, Habitus, dorsal; B, Urosome, ventral; C, Maxilliped; D, Leg 5. Scale bars=0.1 mm (A), 0.05 mm (B), and 0.02 mm (C-D).

Antennule, antenna and mouthparts as for female, except for maxilliped. Maxilliped (Fig. 5K) incompletely 3-segmented; terminal segment with 2 blunt setae of different sizes.

Legs 1-4 as those of female. Leg 5 as in preceding stage. Seta representing leg 6 enlarged, extending to middle of anal somite.

Free-living adults (Figs. 6, 7)

Female. Body (Fig. 6A) cyclopiform and 738 μm long (another specimen 675 μm long). Cephalosome 304×297 μm. Genital double-somite enlarged, 86×99 μm, with spinules on ventral surface (Fig. 6B). Genital area indistinct. Genital double- and postgenital somites with spinules along posteroventral margin. Caudal ramus 30×20 μm.

Antennule (Fig. 6C) 6-segmented (2 segments added), 137 μm long, with armature formula: 3, 13, 6, 4+1 aesthetasc, 2+1 aesthetasc, and 7+1 aesthetasc. Antenna (Fig. 6D) markedly changed to a strong grasping appendage: seta on first and second segments rudimentary; setae on third segment (second endopodal segment) absent; fourth segment forming strong claw bearing 1 minute seta at base.

Middle element of mandible armed with teeth of various sizes (Fig. 6E). Maxillule (Fig. 6F) with many spinules added. Maxilla as in preceding stage. Maxilliped absent.

Legs 1-3 with 3-segmented rami. Leg 4 (Fig. 6I) with 2-segmented exopod and 3-segmented endopod. Armature formula of legs 1-4 as follows:

	coxa	basis	exopod	endopod
Leg 1	0-0	1-0	I-0; 0-1; II,5	0-1; 0-1; II,4
Leg 2	0-0	1-0	I-0; 0-1; 6	0-1; 0-2; I,4
Leg 3	0-0	1-0	I-0; 0-1; I,6	0-1; 0-2; I,4
Leg 4	0-0	1-0	I-0; I,5	0-1; 0-2; I,3

Leg 5 (Fig. 6J) represented by 1 plumose seta on posterolateral corner of first urosomal somite and free segment (18×11 μm) armed with 3 setae of different sizes (mid-terminal seta about 4 times as long as free segment, and inner lateral one about half length of free segment). Leg 6 not seen.

Male. Body (Fig. 7A) 779 μm long, narrower than that of female, and 11-segmented. Urosome (Fig. 7B) 6-

segmented. Genital somite nearly trapezoid, 93×102 μm. Caudal ramus 31×24 μm.

Antennule and antenna as in female. Maxilliped (Fig. 7C) 4-segmented, excluding terminal claw. First to third segments without armature element but second segment ornamented with spinules on lateral surface and distal part of inner margin; fourth segment distally with 1 thick, short and 1 minute setae. Terminal claw long and slender, basally with 1 minute seta. Other mouthparts as in female.

Legs 1-4 as in female. Leg 5 (Fig. 7D) armed as in male copepodid V; free segment 17×10 μm. Leg 6 represented by 1 plumose seta on genital flap (Fig. 7B).

Remarks. The adult specimens show some differences with the previous records. Both Yamaguti (1936) and Yin (1956) described the female of this species with 2 setae on the free segment of leg 5. In the specimens of the present work, one more small seta which is hardly visible in dorsal and ventral views is present on the ventral side of the segment. Yin illustrated a tiny outer spine on the third exopodal segment of leg 2. The typical shape of the antenna bearing a small tubercle at the mediodistal corner of the third segment, the absence of spine on the third exopod segment of leg 2, and the presence of a spine on the distal exopod segment of leg 4 in the examined specimens agree with the original description of Yamaguti (1936).

Discussion

It is well established that the copepodid phase of ergasilid copepods consists of 5 stages prior to the free-living adults. The examined material of *Ergasilus hypomesi* were sorted into 6 different morphs, each corresponding to CI to CV, and free-living adults. The number of setae on the caudal rami of *E. hypomesi* is 6 in CI, 5 in CII to CV, and finally 4 in adults, as in *E. briani* Markewitsch studied by Alston et al. (1996).

The change of antennular segmentation during copepodid development of *E. hypomesi* is identical to that of *E. briani*, in which the number of segments is 4 in CI to CV but abruptly becomes 6 in CV and adults. The details of antennular development are available in *E. sieboldi* Nordmann (Abdelhalim et al., 1991) and *Neoergasilus japonicus* Harada (Urawa et al., 1980), in addition to *E. hypomesi* and *E. briani*. The number of antennular segments of *E. sieboldi* is 5 in CI and CII, and 6 from CIII on, and that of *N. japonicus* is 4 in CI to CIV, 5 in CV, and 6 in adults. Therefore the segmentation of antennule in ergasilid copepodids may vary with species.

The antennule of CI of copepoda usually is 5-segmented, with known exception of 4 segments in *Ergasilus hypomesi*, *E. briani*, *Neoergaslius japonicus*, *Neanthessius renicolis* (see Izawa, 1986), *Midicola spinosus* (see Do et al., 1984), and 6 segments in *Modiolicola insignis* (see Costanzo, 1984). The setation of distal 3 segments of the ergasilid antennule is determined as early as CII, as in most copepods. In contrast, the setation of proximal segments changes throughout copepodid stages. The first segment of 4-segmented antennule of CI bears 3 setae as shown in *E. hypomesi*, *E. briani* and *N. japonicus*. On the other hand, the first and second segments of 5-segmented antennule bear 1 and 2 setae, respectively, as shown in *E. sieboldi*. Therefore, the 4-segmented antennule of the former 3 species may be interpreted to be a result of fusion of proximal 2 segments of the 5-segmented antennule. In most poecilostomatoid copepods the first segment of antennule in CI bears 2 setae or none, with exceptions that are, like the Ergasilidae, *Ostrincola koe* (see Ko, 1969) in the Myicolidae bearing 3 setae on the first segment, and *Doridicola longicauda* (see Costanzo, Calafiore and Crescenti, 1994) and *Paranthessius anemoniae* (see Costanzo, Crescenti and Calafiore, 1994) in the Rhynchomolgidae both bearing 1 on the first and 2 on the second segments. Therefore the presence of 3 setae on the first segment, or 1 and 2 setae, respectively, on the first and second segments of CI antennule in all ergasilids studied may reflect a phylogenetic importance of setation on the proximal segment(s) of the antennule.

The antenna of CI of *E. hypomesi* carries a vestigial exopod. The same structure is also reported in CI of *E. sieboldi*, *E. briani* and *N. japonicus*. The presence of an exopod in CI antenna may be thought to be a primitive trait in poecilostomatoids. However, many primitive copepods, such as *Hemicyclops ctenidis* (see Kim and Ho, 1992), *H. japonicus* (see Itoh and Nishida, 1995), *Conchyliurus quintus* (see Kim, 1994), and *Leptinogaster major* (see Humes, 1986) of the Clausidiidae, lack this structure. The phylogenetic implication of the antennary exopod in poecilostomatoid copepods seems uncertain for the time being. It is noted that at least all the fish-parasitic poecilostomatoid copepods that are known their CI have been reported to have a vestigial exopod on the antenna.

The structural change of maxillule during copepodid development is consistent in *E. hypomesi*, *E. sieboldi*, *E. briani* and *N. japonicus*. In these species the maxillule is armed with 4 elements (3 setae and 1 process) in CI, but is armed with 3 elements (2 setae and 1 process) from CII onwards. Although Gurney (1913) mentioned that the maxillule of CI of *Thersitina gasterostei* was same as in adult, this finding needs confirmation.

The stage of first appearance of male maxilliped is not uniform in the Ergasilidae. This appendage in the male *E. hypomesi* first appears in CIII as in *Thersitina gasterostei* (see Gurney, 1913). But it first appears as early as in CII in *E. briani*. in CIII in *N. japonicus*, and in CV in *E. sieboldi*. On the other hand, a female maxilliped has never been reported in the copepodids and adult of the Ergasilidae. The only other poecilostomatoid copepod known to be devoid of a female maxilliped throughout the deveolpment is *Sabellacheres illgi* (see Dudley, 1964) belonging to the family Gastrodelphyidae.

The adults of ergasilid copepods display characteristic setation on the biramous legs. In poecilostomatoid copepods, the generalized armature formula of the terminal segments of the exopod and endopod of leg 1 are III, I, 4 and I, 2, 5, respectively (Huys and Boxshall, 1991). In all ergasilid species for which the copepodid development is known, including *Sinergasilus lieni* (see Mirzoeva, 1973), the armature formulae of these segments of leg 1 are II, 5 and II, 4, respectively. This pattern of setation is determined very early in the copepodid development. In CI of most poecilostomatoid copepods the exopod of leg 1 shows armature formula IV, I, 3, with the exceptions that are IV, 4 in *Leptinogaster major* (see Humes, 1986), 8 in *Trochicola entericus* (see Bocquet et al., 1963), and V, 2 in *Colobomatus pupa* (see Izawa, 1975). In the endopod of the same leg the formula is 7 in general, with the exceptions that are I, 6 in *Conchyliurus quintus* (see Kim, 1994), *Midicola spinosus* (as *Pseudomyicola spinosus*; see Do et al., 1984), and *Acanthochondria yui* (see Izawa, 1986). On the contrary, in the Ergasilidae known for their CI, the armature formula of the exopod is III, 4 or IV, 4, and that of endopod is unexceptionally II, 5. Such patterns of setation, the reduced number of spines and the increased number of setae on the exopod and a reversed pattern in the endopod are found in other legs. For example, leg 2 exopod in CI of the Ergasilidae is armed as I, 4 (in *E. hypomesi*) or II, 4 (in *E. briani*, *E. sieboldi*, *N. japonicus* and *S. lieni*) which is compared to IV, 3 in most poecilostomatoid CI, and the endopod of the same leg is armed as I, 4 which is compared to III, 3 in most other poecilostomatoids. This uniqueness of the setation in both copepodids and adults may, therefore, reinforce the distinctiveness of the Ergasilidae.

One of characteristics of *E. hypomesi* is the absence of 1 spine on the third exopodal segment of leg 2 (armed only with 6 setae). This trait is determined very early during the copepodid development of *E. hypomesi*: this ramus in CI bears 1 spine and 4 setae (I, 4) in contrast to II, 4 in other 4 species of the Ergasilidae. Therefore, the setation of leg 2 exopod in adults may be interpreted as an important taxonomic character separating *E. hypomesi*.

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