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The First Zoeal Stages of *Parapanope euagora* and *Halimede fragifer* (Decapoda: Pilumnoidea: Galenidae) Hatched in the Laboratory

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ABSTRACT

The first zoeas of *Parapanope euagora* and *Halimede fragifer* hatched in the laboratory from two ovigerous galenid crabs of Pilumnoidea were collected from Jindo Island, Jeolanam-do, southern Korea. Their morphologies are described in *P. euagora* for the first time in the world and re-described in *H. fragifer* with the color images of live zoeas. In this study, they show a general morphology of Pilumnoidea by having a long antennal exopod, an endopod of the maxillule with 1, 2+4 setae, an endopod of the maxilla with 3+5 setae, and a fork of the telson with two lateral armatures. However, the first zoea of *P. euagora* differs from other known zoeas of pilumnoid species including *H. fragifer* by having a long antennal exopod with a medial seta and spine, not two spines, and a fork of telson with two lateral setae, not a seta and spine. Such characteristics of the antennal exopod and the fork of telson are reported for the first time in the pilumnoid zoeas. A comparison between the first zoeal stage of *H. fragifer* in this study and that of Terada shows minute differences in the characteristics of the antennule and the fork of telson.

Keywords: Galenidae, first zoea, *Parapanope euagora*, *Halimede fragifer*, Korea

INTRODUCTION

The crabs of the Pilumnoidea are recognized by the following characteristics of all male abdominal somites freely articulating, a long and slender gonopod 1, a very short and sigmoidal gonopod 2, and a penis which protrudes from the condyle of the fifth ambulatory coxa (Ng et al., 2008). At present, over 390 species of three families (Galenidae, Pilumnidae, and Tanaochelidae) have been recorded in the world. Over 380 species of the Pilumnidae exist in the world, and 15 species are known from Korean waters (Table 1). In the Galenidae, 12 species are reported in the world (Ng et al., 2008). Among them, only two species, *Parapanope euagora* De Man 1895 and *Halimede fragifer* (De Haan 1835) are recorded from Korean waters (Table 1).

In the Pilumnoidea, larval descriptions of Pilumnidae are known for nine species belonging to six genera from Korea and adjacent waters (Table 1). The larval description of Galenidae is only available for the first and second zoeal stages of *H. fragifer* described by Terada (1985), however, his description is not adequate for the modern larval description suggested by Clark et al. (1998). The larval stage of *P. euagora* is unknown until now. Therefore, the aims of this study are to describe and illustrate the first zoeal stages of *P. euagora* and *H. fragifer* in detail and compare their morphologies with the previously described zoeas of the Pilumnoidea.

MATERIALS AND METHODS

Ovigerous crabs were collected in the intertidal region in Jindo-gun, Jeolanam-do, southern Korea on 26 Jul 2012 for *Parapanope euagora* and 26 Jul 2013 for *Halimede fragifer*. The first zoeas hatched in the laboratory on 28 Jul 2012 for *P. euagora* and 30 Jul 2013 for *H. fragifer*, respectively. The first zoeas were preserved in 95% ethyl alcohol for examination. A high mortality followed, and no larvae reached the second zoeal stage. The digital photos of the living zoeas were taken using a Leica EZ40 microscope (Leica, Wetzlar, Germany) and then processed in photoshop. The zoeal specimens were dissected using a Leitz zoom stereomicroscope,

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Table 1. List of species of the superfamily Pilumnoidea from Korean waters and its known larval stages

Family	Species	Reference	Larval stages	Sources
Galenidae Alcock, 1898	*Halimede fragifer* (De Haan 1835)	Kim and Kim (1997)	Z1-2	Terada (1985)
	Parapanope euagora De Man 1895	Kim and Kim (1997)		
Pilumnidae Samouelle, 1819	*Echinoecus pentagonus* (A. Milne-Edwards 1879)	Kim and Kim (1997)	Z1-3, Mega	Van Dover et al. (1986)
	Echinoecus nipponicus Miyake 1939	Lee et al. (2011)		
	Harrovia elegans De Man 1887	Kim and Kim (1997)		
	Harrovia japonica Balss 1921	Lee and Ko (2009a)	Z1-4	Lee and Ko (2009b)
	Actumnus elegans De Man 1888	Kim and Kim (1997)		
	Actumnus marissinicus Takeda and Kim 1977	Kim and Kim (1997)		
	Benthopanope indica (De Man 1887)	Kim and Kim (1997)	Z1-4, Mega	Ko (1995)
	Heteropilumnus ciliatus (Stimpson 1858)	Kim and Kim (1997)	Z1-3	Ko and Yang (2003)
	Neoactumnus convexus Sakai 1965	Lee et al. (2008)		
	Pilumnopeus granulatus Balss 1933	Ko and Takeda (2000)	Z1-4, Mega	Ko (1997)
	Pilumnopeus makianus (Rathbun 1931)	Kim and Kim (1997)	Z1-4	Lee (1993)
	Pilumnus longicornis Hilgendorf 1878	Kim and Kim (1997)	Z1	Clark and Paula (2003)
	Pilumnus minutus De Haan 1835	Kim and Kim (1997)	Z1-4, Mega	Ko (1994a, 1997)
	Pilumnus trispinosus (Sakai 1965)	Kim and Kim (1997)	Z1-4, Mega	Ko (1994b)
	Zehntneriana amakusae (Takeda and Miyake 1969)	Lee et al. (2011)		

Z, zoeal stage; Mega, megalopal stage.

and appendages were examined under a Leitz Laborlux S microscope. The appendages were mounted in ethylene glycol and drawings were prepared with the camera lucida. The setal counts on the appendages and the lengths of measurement were based on the mean of 10 specimens of zoeas. The sequence of the zoeal description is based on the malacostracan somite plan and described from the anterior to posterior. The setal armature on appendages is described from the proximal to distal segments and in order of endopod to exopod. The long plumose natatory setae of the first and second maxillipeds were drawn truncated. The chromatophoric patterns were observed with living zoeas. A micrometer was used for the zoeal measurements: carapace length (CL) from the base of the rostral spine to the most posterior carapace margin and rostral and dorsal spine length (RDL) from the tip of the rostral carapace spine to the tip of the dorsal carapace spine. The specimens were examined and the spent females were deposited in Silla University, Korea.

RESULTS

Order Pilumnoidea Samouelle, 1819
Family Galenidae Alcock, 1898
Genus *Parapanope* De Man, 1895

***Parapanope euagora* De Man, 1895 (Fig. 1A)**

First zoea (Figs. 1B, 2)

Size: CL 0.36±0.05 mm; RDL 0.77±0.05 mm.

Chromatophores (Fig. 1B): black chromatophores which occurring behind eyes and on abdominal somites 1–4 ventrally.

Carapace (Figs. 1B, 2A, A′): dorsal spine with few minute tubercles, less than CL, slightly longer than rostral spine; rostral spine slightly longer than antennal protopod; lateral spines present, half length of rostral spine; 1 pair of posterodorsal setae present; each ventral margin with spinules; eyes sessile.

Antennule (Fig. 2B): uniramous; endopod absent; exopod with 2 long, stout aesthetascs, 1 shorter, thinner aesthetasc, 3 unequal simple setae, all terminal.

Antenna (Fig. 2C): biramous; endopod bud absent; protopod with 2 rows of spinules on distal half; exopod spinulate on distal half, with 2 equal setae medially, tip reaching tip of protopod.

Mandibles (Fig. 2D): asymmetrical; right molar with 4 teeth, left molar with 3 teeth, confluent with incisor process; palp absent.

Maxillule (Fig. 2E): coxal endite with 7 setae; basial endite with 5 setae and 2 teeth; endopod 2-segmented, proximal

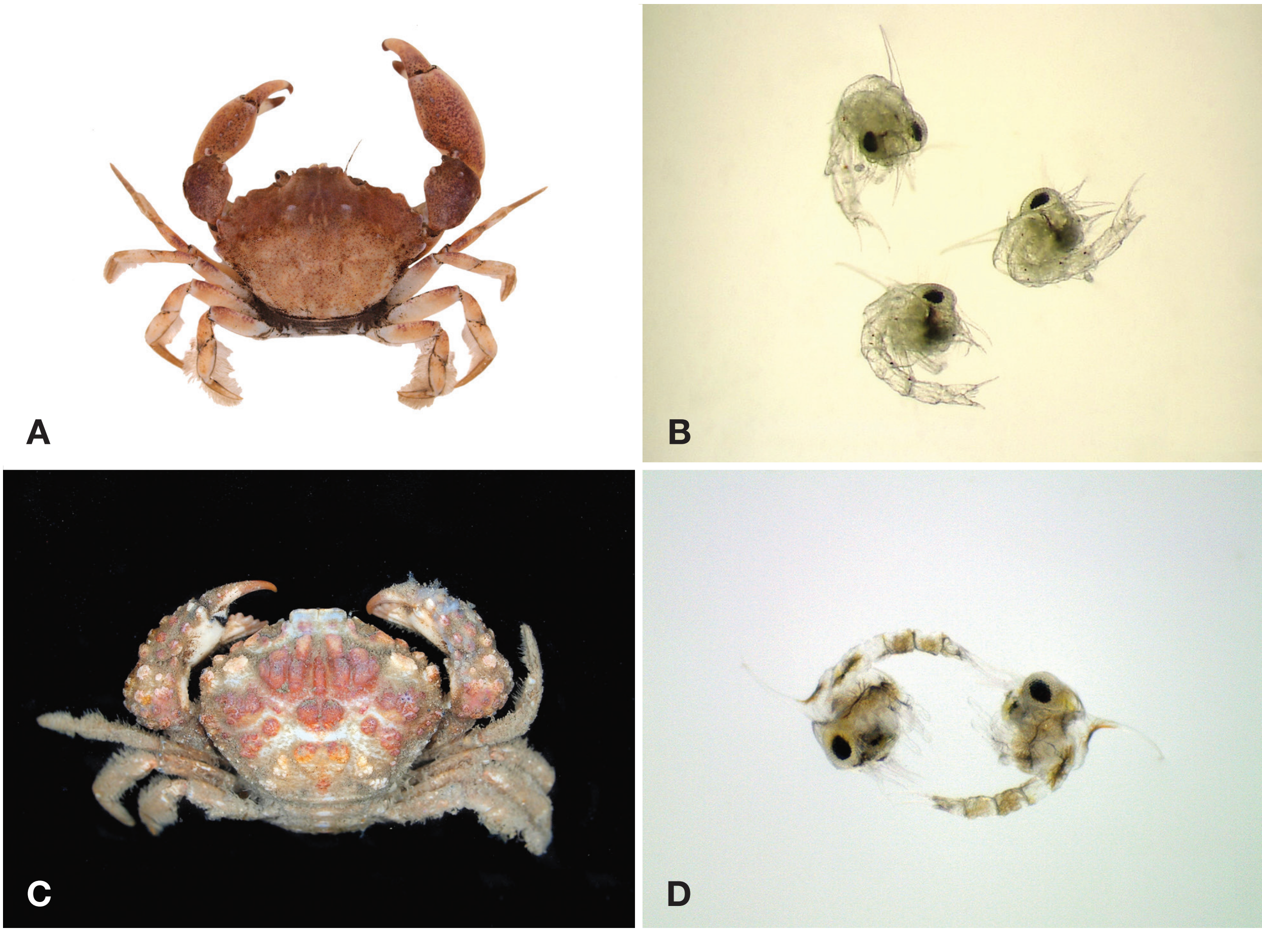

Fig. 1. Color photos of crab and the first zoeas of *Parapanope euagora* and *Halimede fragifer*. A, Crab of *P. euagora*; B, First zoeas of *P. euagora*; C, Crab of *H. fragifer*; D, First zoeas of *H. fragifer*.

segment with 1 seta, distal segment with 6 (2 subterminal, 4 terminal) setae; exopod seta and epipod absent.

Maxilla (Fig. 2F): coxal endite bilobed, with 6+4 setae; basial endite bilobed, with 5+4 setae, 1 tooth; endopod bilobed, with 3+5 setae; exopod (scaphognathite) margin with 4 plumose setae, 1 distal process.

First maxilliped (Fig. 2G): coxa without seta; basis with 10 setae, arranged 2+2+3+3; endopod 5-segmented, with 3, 2, 1, 2, 5 (1 subterminal, 4 terminal) setae; exopod 2-segmented, distal segment with 4 long terminal plumose natatory setae.

Second maxilliped (Fig. 2H): coxa without seta; basis with 4 setae, arranged 1+1+1+1; endopod 3-segmented, with 1, 1, 6 (2 subterminal, 4 terminal) setae; exopod 2-segmented, distal segment with 4 long terminal plumose natatory setae.

Abdomen (Fig. 2I): five somites; somite 2 with 1 pair of lateral processes directed anteriorly; somite 3 with 1 pair of lateral processes directed posteriorly; somites 2–5 each with 1 pair of posterodorsal setae; pleopod absent.

Telson (Fig. 2I, I′): each fork extremely long, spinulated laterally, with 2 lateral setae, 1 dorsomedial spine; posterior margin with 3 pairs of setae.

Genus *Halimede* De Haan, 1833

Halimede fragifer **(De Haan 1835) (Fig. 1C)**

First zoea (Figs. 1D, 3)

Size: CL 0.42±0.03 mm; RDL 0.92±0.02 mm.

Chromatophores (Fig. 1D): yellowish brown chromatophores which occurring behind eyes, on basis of dorsal spine posteriorly, on basis of each maxilliped, on abdominal somites 1, 2 medially, margins of abdominal somites 4, 5 posteriorly, telson ventrally.

Carapace (Figs. 1D, 3A, A′): dorsal spine with few minute tubercles, slightly less than CL, twice longer than rostral spine; rostral spine slightly shorter than antennal protopod;

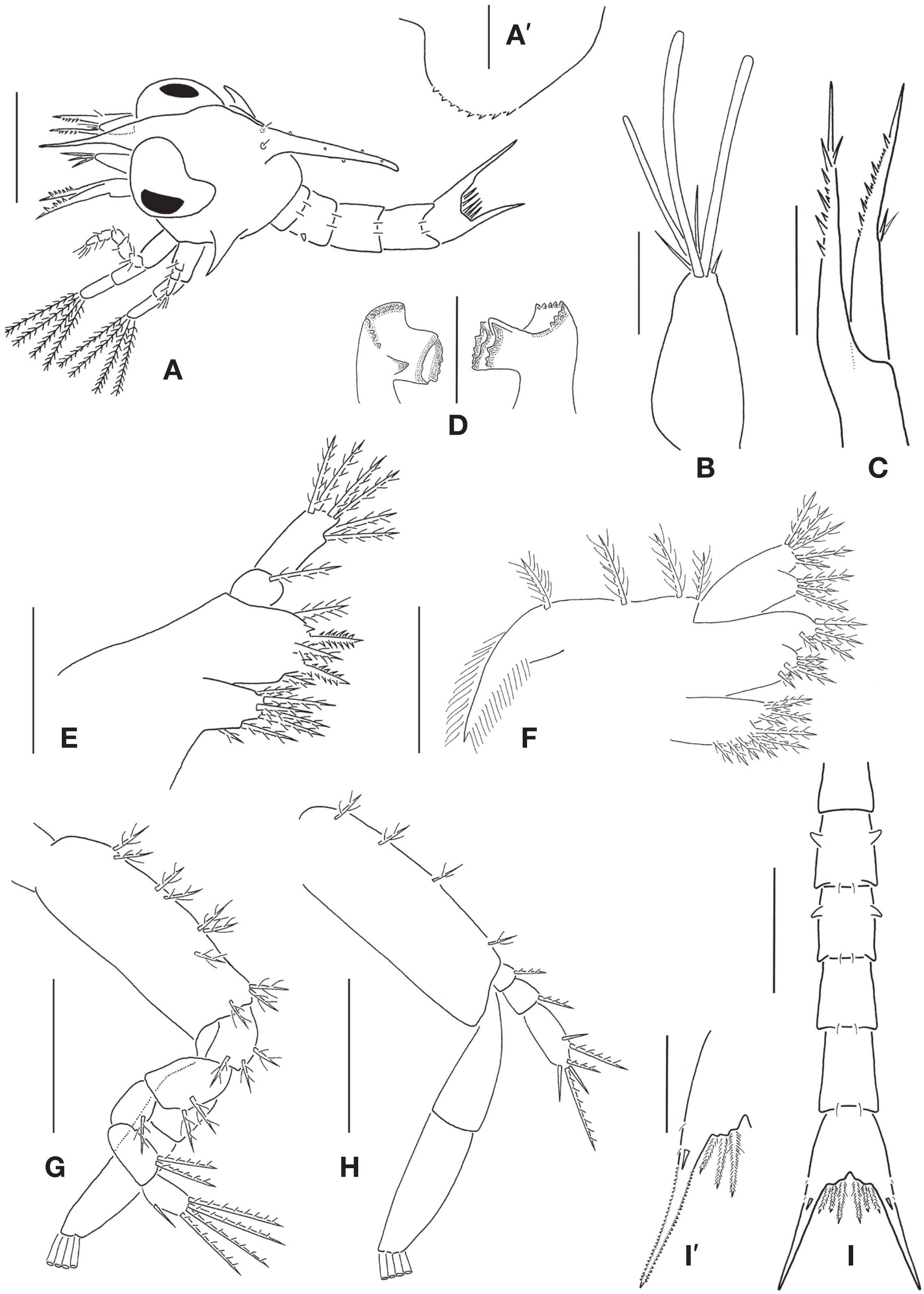

Fig. 2. *Parapanope euagora*, first zoeal stage. A, Lateral view; A′, Lateral expansion of carapace; B, Antennule; C, Antenna; D, Mandibles; E, Maxillule; F, Maxilla; G, First maxilliped; H, Second maxilliped; I, Dorsal view of abdomen and telson; I′, Fork of telson. Scale bars: A=0.3 mm, I=0.2 mm, A′, B–H, I′=0.1 mm.

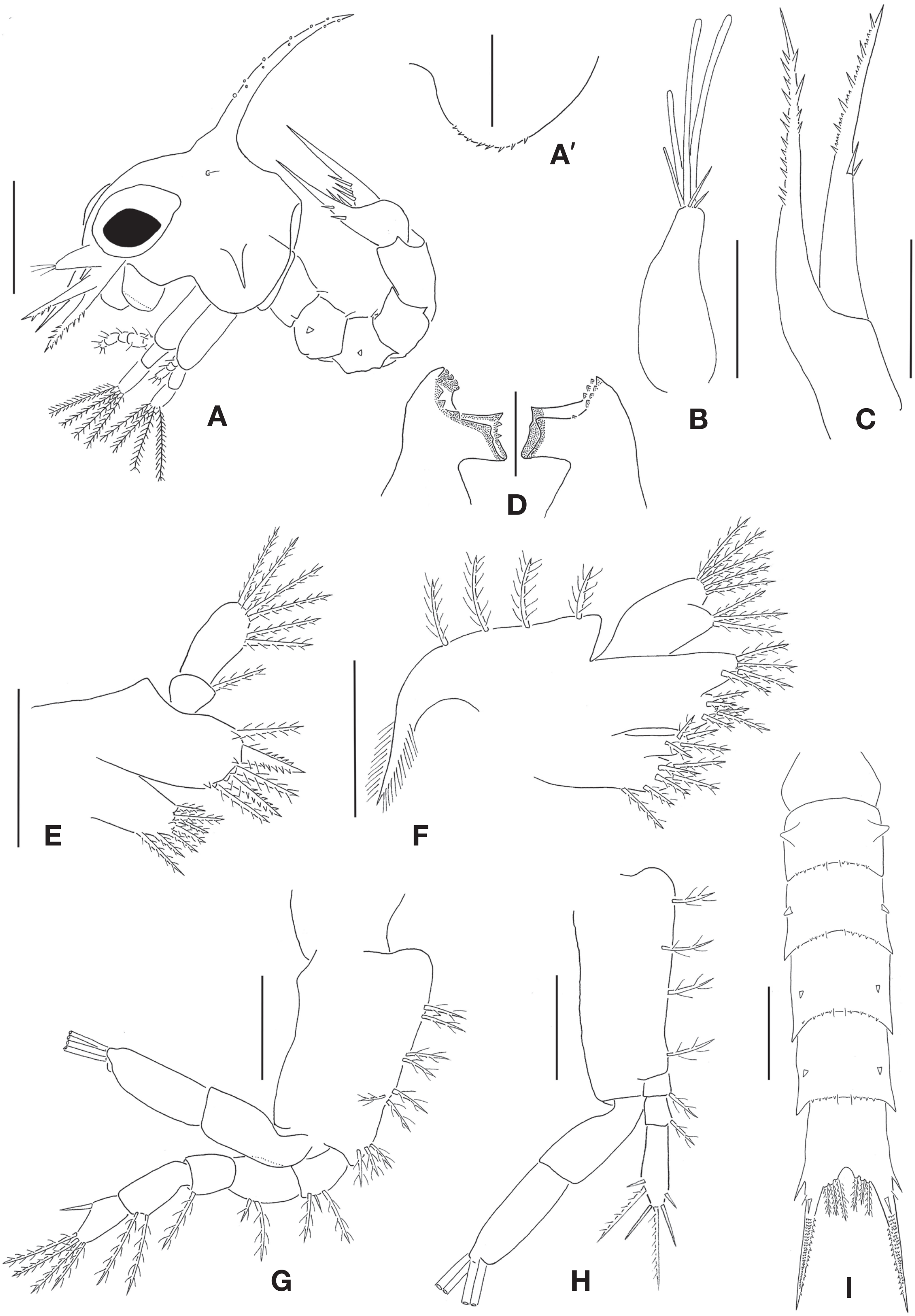

Fig. 3. *Halimede fragifer*, first zoeal stage. A, Lateral view; A′, Lateral expansion of carapace; B, Antennule; C, Antenna; D, Mandibles; E, Maxillule; F, Maxilla; G, First maxilliped; H, Second maxilliped; I, Dorsal view of abdomen and telson. Scale bars: A=0.3 mm, I=0.2 mm, A′, B–H=0.1 mm.

Table 2. Comparison of the first zoeal characteristics between *Halimede fragifer* and *Parapanope euagora* of the family Galenidae

	Halimede fragifer		*Parapanope euagora*
	Terada (1985)	Present study	Present study
Size			
CL/RDL	0.35 mm/0.76 mm	0.42 mm/0.92 mm	0.36 mm/0.77 mm
Carapace			
Dorsal, rostral, lateral spines	Long, long, short	Long, long, short	Long, long, short
Antennule	2 aesthetascs, 2 setae	4 aesthetascs, 2 setae	3 aesthetascs, 3 setae
Antenna			
Protopod	Spinulate	Spinulate	Spinulate
Exopod	Longer than protopod spinulate 2 unequal medial spines	As long as protopod spinulate 2 unequal medial spines	As long as protopod spinulate 1 equal medial seta, spine
Maxillule			
Coxal endite	7 setae	7 setae	7 setae
Basial endite	5 setae	5 setae	5 setae
Endopod	1, 2+4 setae	1, 2+4 setae	1, 2+4 setae
Maxilla			
Coxal endite	6+4 setae	6+4 setae	6+4 setae
Basial endite	5+4 setae	5+4 setae	5+4 setae
Endopod	3+5 setae	3+5 setae	3+5 setae
1st maxilliped			
Basis	2, 2, 3, 3 setae	2, 2, 3, 3 setae	2, 2, 3, 3 setae
Endopod	3, 2, 1, 2, 5 setae	3, 2, 1, 2, 5 setae	3, 2, 1, 2, 5 setae
2nd maxilliped			
Basis	1, 1, 1, 1 setae	1, 1, 1, 1 setae	1, 1, 1, 1 setae
Endopod	1, 1, 6 setae	1, 1, 6 setae	1, 1, 6 setae
Abdomen			
Lateral processes	Somites 2–5	Somites 2–5	Somites 2, 3
Posterodorsal setae	Somites 2–5	Somites 2–5	Somites 2–5
Telson	1 lateral spine, 1 lateral seta, 1 dorsomedial spine	1 lateral spine, 1 lateral seta, 1 dorsomedial spine	2 lateral setae, 1 dorsomedial spine
Fork	Not spinulate	Spinulate	Spinulate

lateral spines present, half length of rostral spine; 1 pair of posterodorsal setae present; each ventral margin with spinules; eyes sessile.

Antennule (Fig. 3B): uniramous; endopod absent; exopod with 2 long, stout aesthetascs, 2 shorter, thinner aesthetascs, 2 unequal simple setae, all terminal.

Antenna (Fig. 3C): biramous; endopod bud absent; protopod with 2 rows of spinules on distal half; exopod spinulate on distal half, with 2 unequal spines medially, tip reaching tip of protopod.

Mandibles (Fig. 3D): asymmetrical; right molar with 3 teeth, left molar with 4 teeth, confluent with incisor process; palp absent.

Maxillule (Fig. 3E): coxal endite with 7 setae; basial endite with 5 setae and 3 teeth; endopod 2-segmented, proximal segment with 1 seta, distal segment with 6 (2 subterminal, 4 terminal) setae; exopod seta and epipod absent.

Maxilla (Fig. 3F): coxal endite bilobed, with 6+4 setae; basial endite bilobed, with 5+4 setae, 1 tooth; endopod bilobed, with 3+5 setae; exopod (scaphognathite) margin with 4 plumose setae, 1 distal process.

First maxilliped (Fig. 3G): coxa without seta; basis with 10 setae, arranged 2+2+3+3; endopod 5-segmented, with 3, 2, 1, 2, 5 (1 subterminal, 4 terminal) setae; exopod 2-segmented, distal segment with 4 long terminal plumose natatory setae.

Second maxilliped (Fig. 3H): coxa without seta; basis with 4 setae, arranged 1+1+1+1; endopod 3-segmented, with 1, 1, 6 (3 subterminal, 3 terminal) setae; exopod 2-segmented, distal segment with 4 long terminal plumose natatory setae.

Abdomen (Fig. 3I): five somites; somite 2 with 1 pair of lateral processes directed laterally; somites 3–5 each with 1 pair of lateral processes directed posteriorly; somites 2–5 each with 1 pair of posterodorsal setae and 8 denticles on posterior margin; pleopod absent.

Telson (Fig. 3I): each fork long, covered with spinules, with 1 stout lateral spine, 1 minute lateral seta and 1 stout dorsomedial spine; posterior margin with 3 pairs of setae.

Table 3. Comparison of the first zoeal characteristics for the Pilumnoidea from Korean waters

Species	Carapace spine			Antennal exopod	Lateral processes of abdominal somites	Lateral armature of fork of telson	References
	Dorsal	Rostral	Lateral				
Galenidae							
Halimede fragifer	Long	Long	Short	Spinulate, 2 unequal medial spines	2–5	1 seta, 1 spines	Present study
Parapanope euagora	Long	Long	Short	Spinulate, 1 medial seta and spine	2, 3	2 setae	Present study
Pilumnidae							
Echinoecus pentagonus	Long	Short	Short	Spinulate, 2 unequal medial spines	2, 3	1 seta, 1 spines	Van Dover et al. (1986)
Harrovia japonica	Long	Short	Short	Spinulate, 2 unequal medial spines	2, 3	1 seta, 1 spines	Lee and Ko (2009b)
Benthopanope indica	Long	Short	Absent	Spinulate, 2 unequal medial spines	2	1 seta, 1 spines	Ko (1995)
Heteropilumnus ciliatus	Long	Long	Short	Spinulate, 2 unequal medial spines	2, 3	1 seta, 1 spines	Ko and Yang (2003)
Pilumnopeus granulatus	Long	Short	Short	Spinulate, 2 unequal medial spines	2, 3	1 seta, 1 spines	Ko (1997)
Pilumnopeus makianus	Long	Long	Short	Spinulate, 2 unequal medial spines	2, 3	1 seta, 1 spines	Lee (1993)
Pilumnus longicornis	Long	Long	Short	Spinulate, 2 unequal medial spines	2, 3	2 spines	Clark and Paula (2003)
Pilumnus minutus	Long	Short	Short	Spinulate, 2 unequal medial spines	2–5	1 seta, 1 spines	Ko (1994a)
Pilumnus trispinosus	Long	Short	Absent	Spinulate, 2 unequal medial spines	2–5	1 seta, 1 spines	Ko (1994b)

DISCUSSION

The first zoeal stage of *Parapanope euagora* is described for the first time, and the first zoeal stage of *Halimede fragifer* is redescribed in this study.

Terada (1985) described the first and second zoeal stages of *H. fragifer*. Hence, the first zoeal characteristics of this study are compared to his description. As a result, minute differences in zoeal size, numbers of antennular aesthetascs, and the spinulate fork of telson (Table 2) were observed. Such differences may be due to preservation techniques of zoeas and overlooking the antennule and fork of telson.

The first zoeal stage of *P. euagora* is reported for the first time in this study; therefore, the zoeal description of Galenidae is now available for two species, *P. euagora* and *H. fragifer*. It is similar to that of *H. fragifer*, however, can be distinguished by the following characteristics: The antennule with three aesthetacs and three setae, and the antennal exopod with one seta and one spine medially, the second and third abdominal somites with lateral processes, and the fork of telson with two lateral seate (Table 2).

Ko and Lee (2012) summarized the morphological characteristics of the first zoeas of Pilumnoidea as follows: long antennal exopod and protopod wih subequal length, and the antennal exopod with two medial spines; the endopods of the maxillule and maxilla each have 1, 2+4 setae, and 3+5 setae, respectively; and the fork of telson has one seta and one spine laterally. The first zoeal stage of *H. fragifer* agrees well with the known zoeas of Pilumnoidea, but that of *P. euagora* differs from them by having the antennal exopod with one seta and one spine medially and the fork of telson with two setae laterally (Table 3). Such types of the antennal exopod and the fork of telson are reported for the first time in the Pilumnoidea, therefore, a re-evaluation of the taxonomic status of *P. euagora* should be needed.

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