Zoeal Stages of *Alpheus brevicristatus* De Haan, 1849 (Decapoda, Caridea, Alpheidae) with a Key to the First Zoeal Larvae of Three Korean *Alpheus* Species

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Key Words:
Zoeal stage
Alpheus brevicristatus
Alpheidae

The four zoeal stages of *Alpheus brevicristatus* De Haan, 1849 are described and illustrated in detail from larvae reared in the laboratory. The larvae of *A. brevicristatus* was compared with those of the other *Alpheus* and a key to the first zoeal larvae of three Korean *Alpheus* species is provided.

Alpheus brevicristatus De Haan, 1849, one of the largest alpheid shrimps, is known to occur in Korea Strait and Yellow Sea of Korea, Japan, and Taiwan (Kim, 1977; Banner and Banner, 1984; Jeng and Chang, 1985). It inhabits shallow burrows in soft mud flats of estuary and *Zostera* belts of bay bottom (Miya, 1971) and lives in a symbiotic association with the gobies (Banner and Banner, 1982).

Very little is known about the larvae of alpheid shrimp in Korea and its adjacent waters. Yang and Kim (1996, 1999) described the third zoeal stages of both *Alpheus euphrosyne richardsoni* Yaldwyne, 1971 and *Alpheus heeia* Banner and Banner, 1975. Miyazaki (1937) reported the first zoeal stage of *A. brevicristatus* from Japanese waters but failed to provide a detailed description.

Beyond Korean waters, only two descriptions of alpheid larvae are available. Knowlton (1973) described the complete larval development of *Alpheus heterochaelis* Say, 1818 with the abbreviated life history from East America, Atlantic Ocean. Bruce (1974) described the abbreviated larval development of *Racilius compressus* Paulson, 1875 from East Africa, Indian Ocean.

The purpose of the present paper is to describe the early larval stages of *A. brevicristatus* in detail, to compare them with previously described larvae of the *Alpheus*, and to provide a key to the first zoeal larvae of three Korean *Alpheus* species.

Materials and Methods

In June 1993, ovigerous females of *Alpheus brevicristatus* were collected from sandy bottom of intertidal zone in Che-ju Island (33°29′N 126°56′E), Korea. In the laboratory, they were placed in a glass container filled with seawater with salinity of 33.3% at room temperature (20~25℃) until hatching.

When the eggs hatched, phototactic larvae were separated into 20 groups of 10 larvae per glass bowl and kept in a growth chamber at 25℃. They were fed daily with algal flagellate, *Dunaliella tertiolecta* Butcher, 1959 and diatom, *Skeletonema costatum* Cleve, 1878.

Specimen and exuviae of each developmental stage were preserved in a mixture of equal parts of seawater, 4% neutral formalin, and glycerin. Drawings were made with the help of a camera lucida. The chromatophore patterns were determined by observation of living larvae.

Results

The newly spawned eggs of *Alpheus brevicristatus* were 0.48×0.48 mm in diameter. They were spherical in later stage and measured 0.48×0.58 mm. Four zoeal stages were obtained.

First Zoea (Fig. 1)

Size. Body length 1.80-1.96 mm (mean 1.92 mm); carapace length 0.30-0.40 mm (mean 0.32 mm).

Carapace (Fig. 1A) without rostrum. Pterygostomian spines present. Eyes sessile.

Abdomen (Fig. 1A) without spines; with 6 somites, last somite fused with telson.

Telson (Fig. 1B). Triangular, with more deep posterior indentation. Posterior margin with 7+7 plumose setae. Minute setules between 4-7 setae. Uropods absent.

Antennule (Fig. 1C). Peduncle unsegmented, with long plumose inner flagellum; unsegmented outer flagellum with 3 aesthetascs, short plumose seta, and long simple seta.

Antenna (Fig. 1D). Peduncle with basal spine. Endopod less than half length of scale, with long plumose seta and small spine. Scale 5-segmented at distal end, and with 11 plumose setae plus laterodistal spine.

Maxillule (Fig. 1E). Endopod segmented, with large denticulate seta. Basal endite with 2 stout spines. Coxal endite with 3 terminal plumose and subterminal

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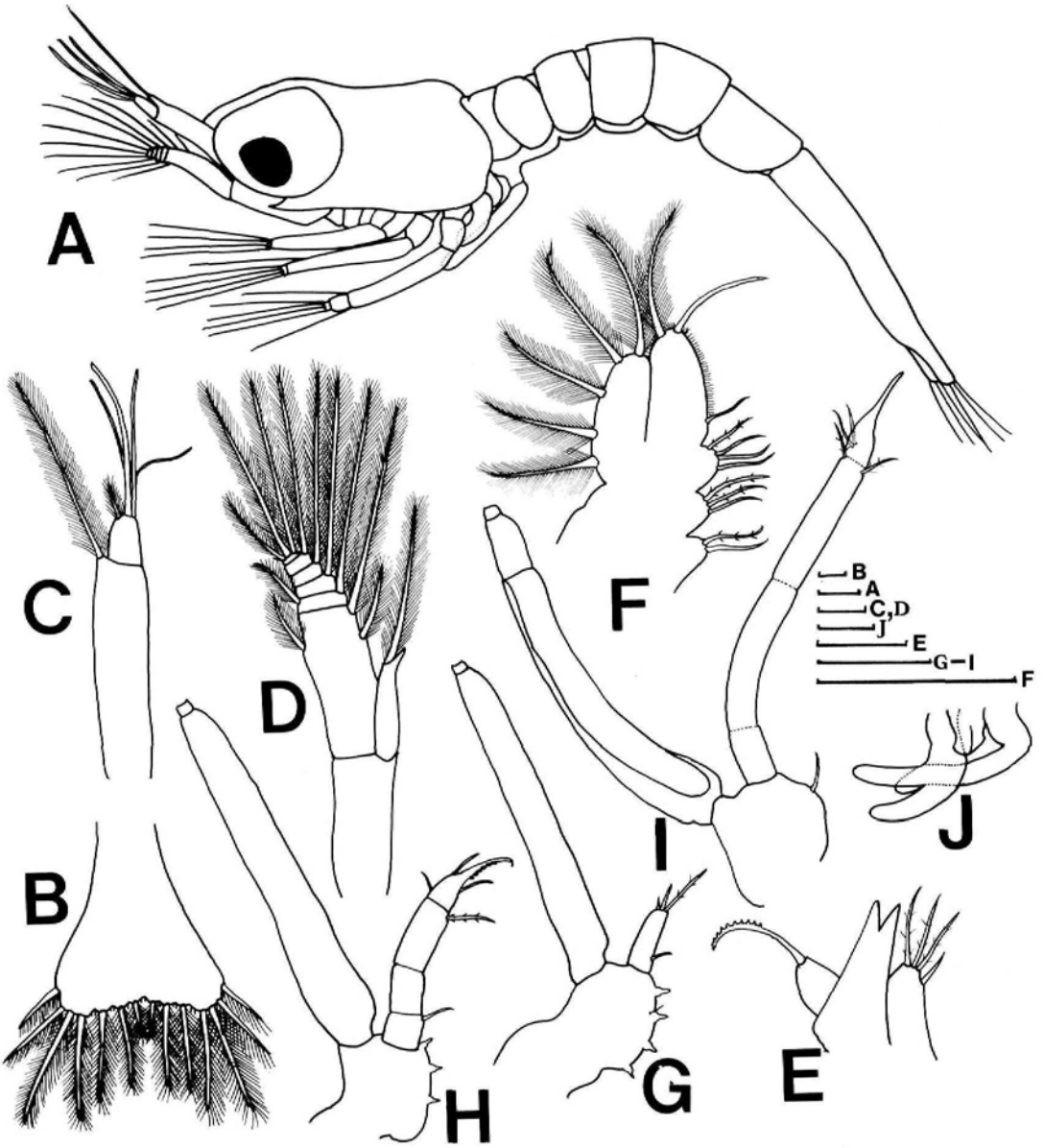

Fig. 1. First zoea of *Alpheus brevicristatus* De Haan, 1849. A, Lateral view. B, Telson. C, Antennule. D, Antenna. E, Maxillule. F, Maxilla. G, First maxilliped. H, Second maxilliped. I, Third maxilliped. J, Pereopods. Scale bars=0.1 mm.

simple setae.

Maxilla (Fig. 1F). Endopod unsegmented, with basal simple seta and 2 terminal setae and fine hairs on its margin. Proximal and distal lobes of basal endite with 3 and 4 setae, respectively. Coxal endite with plumose seta and simple seta. Scaphognathite with 5 highly plumose setae.

First maxilliped (Fig. 1G). Protopod with 4 spines and hair. Endopod segmented, with 3 terminal setae and basal simple seta. Exopod with 4 natatory plumose setae.

Second maxilliped (Fig. 1H). Protopod with 3 spines. Endopod 4-segmented, with setal formula 1, 0, 1, 3. Exopod with 5 natatory plumose setae.

Third maxilliped (Fig. 1I). Protopod with simple seta. Endopod slightly longer than exopod and incompletely 4-segmented, with setal formula 0, 0, 2, 3. Exopod with 6 natatory plumose setae.

Pereopods (Fig. 1J). First and second pereopods biramous rudiments. Fifth pereopod uniramous rudiment.

Chromatophores. Red pigments present on carapace, on junction of thorax and abdominal somites, and on abdominal somites 2-3 dorsally. Interspersion of yellow among red pigments on antennular peduncle, on anterior eyestalks and supra-region of telson. This pattern of chromatophores persisting in all zoeal stages.

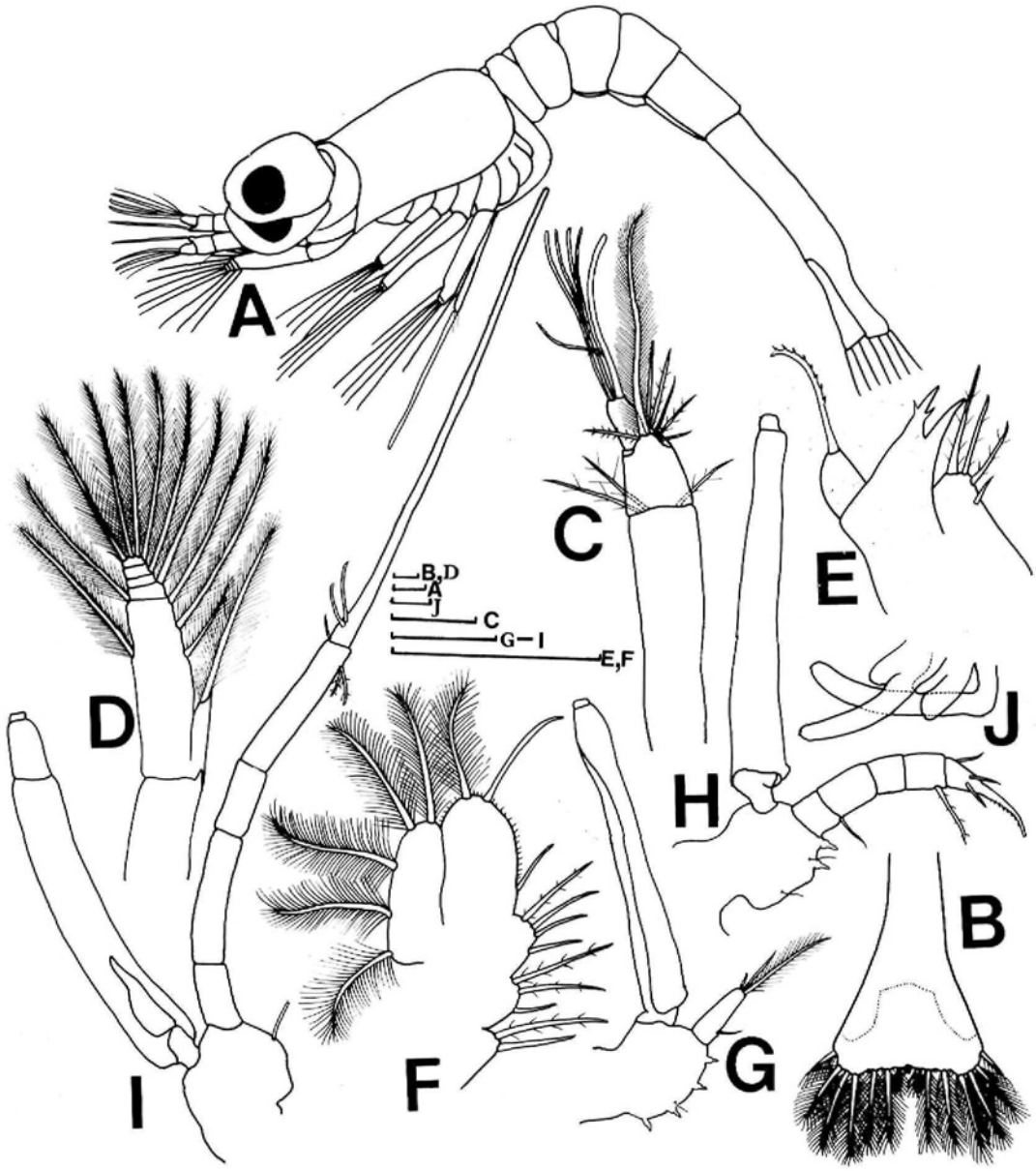

Fig. 2. Second zoea of *Alpheus brevicristatus* De Haan, 1849. A, Lateral view. B, Telson. C, Antennule. D, Antenna. E, Maxillule. F, Maxilla. G, First maxilliped. H, Second maxilliped. I, Third maxilliped. J, Pereopods. Scale bars=0.1 mm.

Second Zoea (Fig. 2)

Size. Total length 1.98-2.46 mm (mean 2.08 mm); body length 1.82-2.30 mm (mean 1.92 mm); carapace length 0.36-0.52 mm (mean 0.39 mm).

Carapace (Fig. 2A). Rostrum untoothed, longer than that in the previous stage. Supraorbital spines absent. Eyes stalked.

Abdomen (Fig. 2A) unchanged.

Telson (Fig. 2B). Posterior margin with 8+8 setae. Uropod visible within cuticle.

Antennule (Fig. 2C). Peduncle 2-segmented: proximal segment with 3 plumose setae and distal segment with 3 plumose plus 3 simple setae. Outer flagellum with 5 aesthetascs and simple seta.

Antenna (Fig. 2D) unchanged except 4-segmented scale distally.

Maxillule (Fig. 2E) unchanged.

Maxilla (Fig. 2F) unchanged.

First maxilliped (Fig. 2G) unchanged.

Second maxilliped (Fig. 2H). Protopod with 2 spines and 2 hairs. Endopod 5-segmented, with setal formula 1, 0, 0, 1, 3.

Third maxilliped (Fig. 2I). Endopod 5-segmented, with setal formula 0, 0, 0, 2, 3; dactylus long and sharply pointed.

Pereopods (Fig. 2J) more elongated than previous

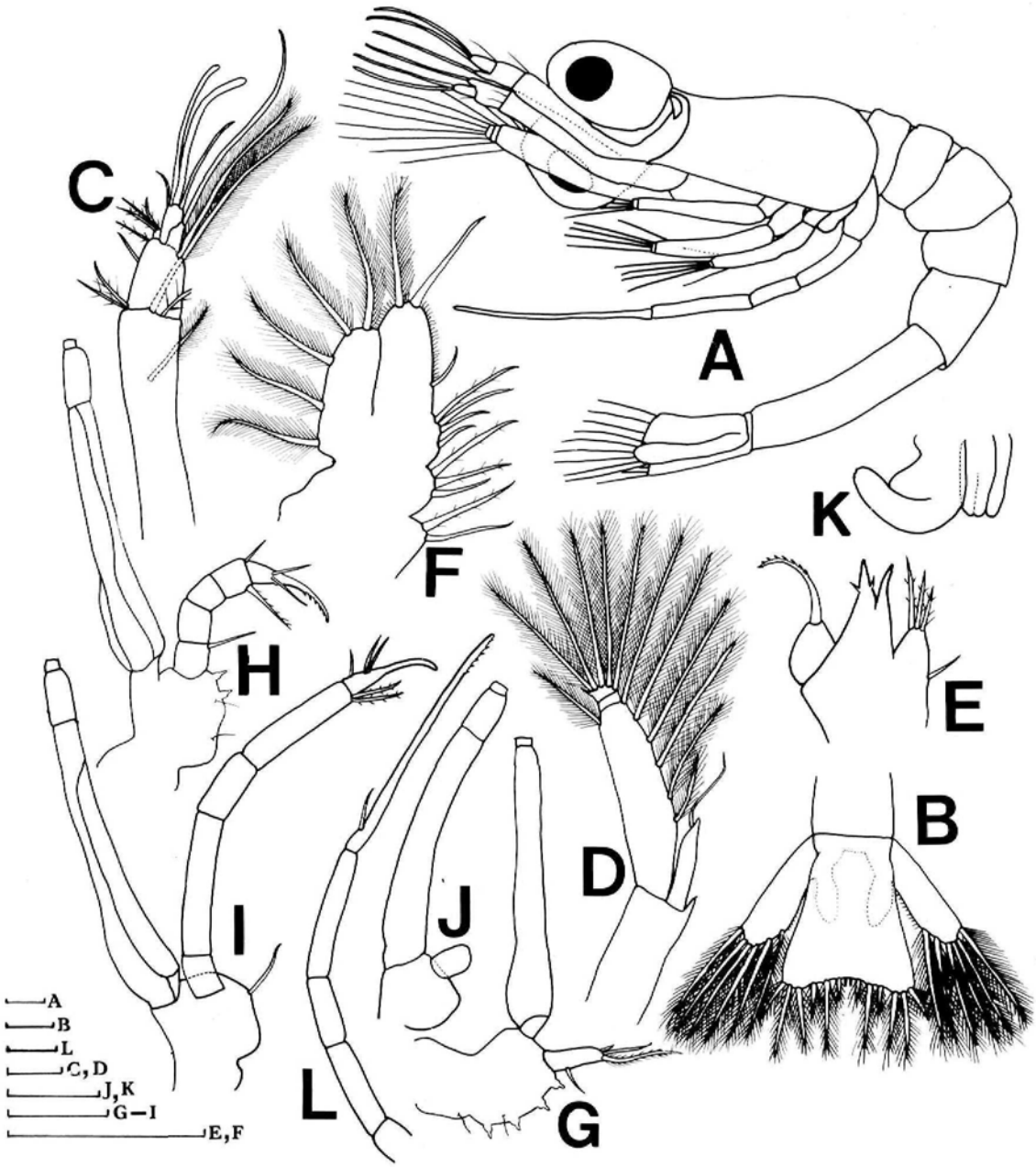

Fig. 3. Third zoea of *Alpheus brevicristatus* De Haan, 1849. A, Lateral view. B, Telson. C, Antennule. D, Antenna. E, Maxillule. F, Maxilla. G, First maxilliped. H, Second maxilliped. I, Third maxilliped. J, First pereopod. K, Second, third and fourth pereopods. L, Fifth pereopod. Scale bars=0.1 mm.

stage.

Third Zoea (Fig. 3)

Size. Total length 2.06-2.26 mm (mean 2.16 mm); body length 1.96-2.10 mm (mean 2.03 mm); carapace length 0.40-0.50 mm (mean 0.44 mm).

Carapace (Fig. 3A). Rostrum slightly elongated.

Abdomen (Fig. 3A) composed of six segments, last distinct from telson.

Telson and uropods (Fig. 3B). Telson with 7+7 plumose setae posteriorly. Uropods free: endopod rudimentary and exopod with 6 plumose setae on terminal margin.

Antennule (Fig. 3C). Peduncle 2-segmented: proximal and distal segments with 5 and 6 setae, respectively. Inner flagellum with long simple seta. Outer flagellum with 2 aesthetascs and 2 simple setae.

Antenna (Fig. 3D). Endopod with distal spine-like process and simple seta. Scale with 12 plumose setae and 2-segmented distally.

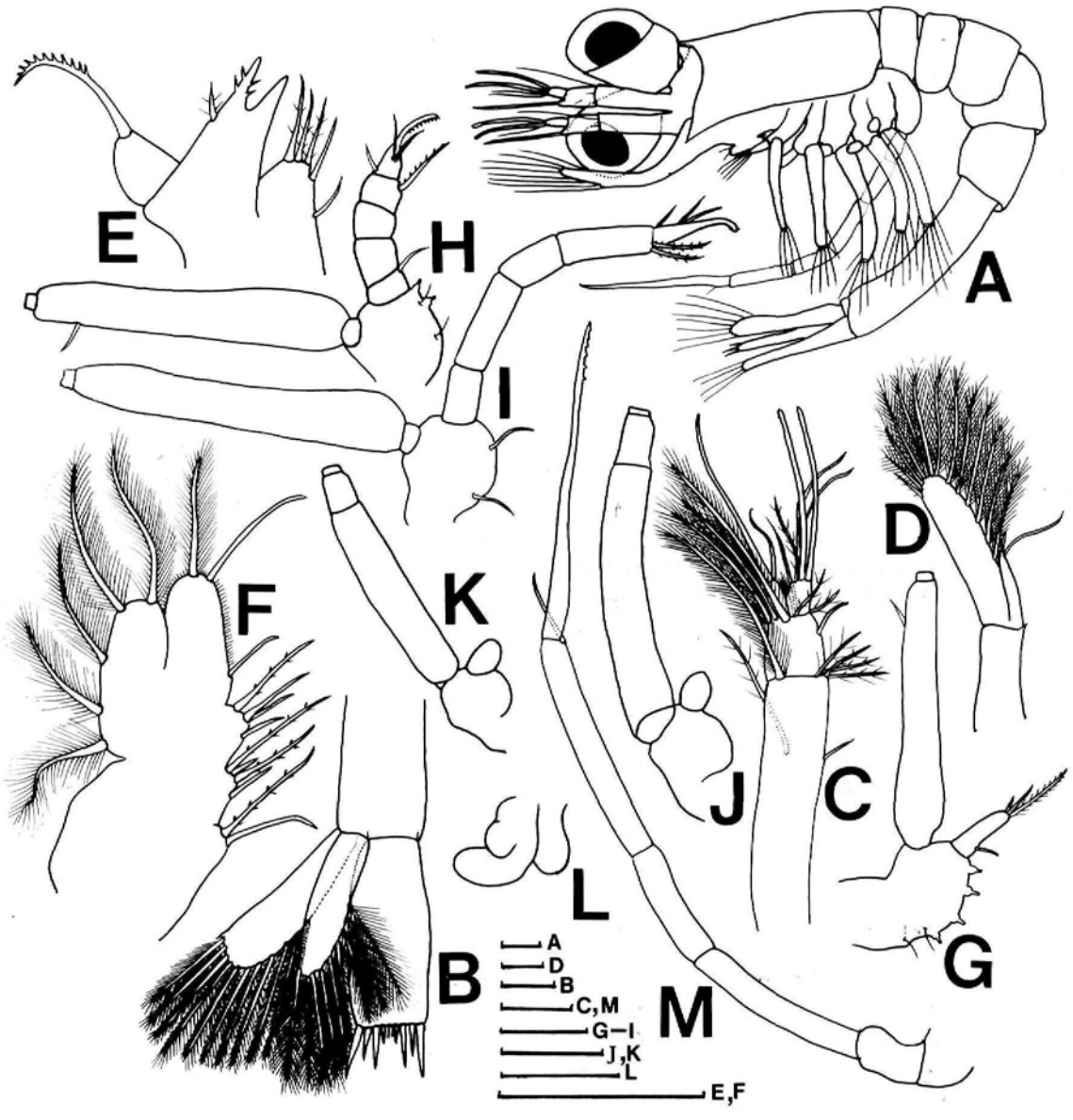

Fig. 4. Fourth zoea of *Alpheus brevicristatus* De Haan, 1849. A, Lateral view. B, Telson. C, Antennule. D, Antenna. E, Maxillule. F, Maxilla. G, First maxilliped. H, Second maxilliped. I, Third maxilliped. J, First pereopod. K, Second pereopod. L, Third and fourth pereopods. M, Fifth pereopod. Scale bars=0.1 mm.

Maxillule (Fig. 3E) unchanged.

Maxilla (Fig. 3F) unchanged.

First maxilliped (Fig. 3G). Protopod with 4 spines and 2 hairs.

Second maxilliped (Fig. 3H) unchanged.

Third maxilliped (Fig. 3I). Dactylus of endopod much shorter than previous stage.

First pereopod (Fig. 3J). Endopod rudimentary. Exopod functional, with 6 natatory plumose setae.

Third and fourth pereopds (Fig. 3K). Third pereopod now biramous rudiment and fourth pereopod uniramous rudiment.

Fifth pereopod (Fig. 3L). Endopod long and slender, extending to eyes: dactylus straight and sharply pointed, with simple seta proximally and 6 denticles distally.

Fourth Zoea (Fig. 4)

Size. Total length 2.27-2.74 mm (mean 2.51 mm); body length 2.18-2.64 mm (mean 2.41 mm); carapace length 0.51-0.56 mm (mean 0.54 mm).

Carapace (Fig. 4A) unchanged.

Abdomen (Fig. 4A) unchanged.

Telson and uropods (Fig. 4B). Telson narrow, lateral sides parallel, with 5+5 terminal spines. Uropods now consisting of endopodal and exopodal rami: endopod and exopod with 9 and 11 plumose setae plus disto-lateral spine, respectively.

Table 1. Comparison of the characteristics of the first zoeae of *Alpheus brevicristatus* as given by Miyazaki (1937) with those obtained in the present study

	Miyazaki (1937)	Present study
Antenna		
exopod	3-segmented	5-segmented
Maxillule		
coxal endite	?	4 setae
Maxilla		
endopod	2 setae	3 setae
basal endite*	?	3/4 setae
coxal endite	2-4 setae	2 setae
First maxilliped		
endopod	2 distal setae	3 distal setae
protopod	?	4 spines, 1 hair
Second maxilliped		
endopod	incompletely 3-segmented	4-segmented
protopod	?	3 spines
Third maxilliped		
endopod	?	incompletely 4-segmented
protopod	unarmed (rarely 2 spines)	1 seta
Pereopods		
biramous	pereopod 1	pereopods 1, 2
uniramous	pereopod 2	pereopod 5

*number of setae from proximal to distal lobes

Antennule (Fig. 4C). Peduncle 2-segmented: proximal and distal segments with 7 and 8 setae, respectively. Inner flagellum with 2 simple setae. Outer flagellum with 2 aesthetascs and 2 simple plus 1 plumose setae.

Antenna (Fig. 4D). Scale with 13 plumose setae and unsegmented distally.

Maxillule (Fig. 4E). Coxal endite with basal simple seta and 4 terminal setae.

Maxilla (Fig. 4F). Proximal lobe of basal endite with 2 plumose and 2 simple setae.

First maxilliped (Fig. 4G). Exopod with 4 natatory plumose setae and lateral spine.

Second maxilliped (Fig. 4H). Exopod with 5 natatory plumose setae and lateral spine.

Third maxilliped (Fig. 4I). Protopod with 2 simple setae.

First pereopod (Fig. 4J) unchanged.

Second pereopod (Fig. 4K). Endopod rudimentary. Exopod functional, with 6 natatory plumose setae.

Third and fourth pereopods (Fig. 4L) unchanged.

Fifth pereopod (Fig. 4M) unchanged.

Discussion

Miyazaki (1937) described very briefly only the first zoea *Alpheus brevicristatus* and there are significant discrepancies between the present study and that given by Miyazaki. (Table 1). The zoea described by Miyazaki has 3-segmented scale of antenna distally, 2 setae on endopod of maxilla, 2-4 setae on coxal endite of maxilla, 2 setae on endopod of first maxilliped terminally, unarmed (rarely 2 spines) protopod of third maxilliped, biramous rudiment of first pereopod, and uniramous rudiment of fifth pereopod. On the other hand, the zoea described in the present study has 5-segmented scale of antenna distally, 3 setae on endopod of maxilla, 2 setae on coxal endite of maxilla, 3 setae on endopod of first maxilliped distally, 1 seta on protopod of third maxilliped, biramous rudiments of first and second pereopods, and uniramous rudiment of fifth pereopod. These differences may result from a lack of detailed examination, rather than genetic or geographical variations.

Table 2. The first zoeal characteristics in three species of *Alpheus* from Korea and its adjacent waters

	A. brevicristatus (present study)	*A. euphrosyne richardsoni* (Yang and Kim, 1996)	*A. heeia* (Yang and Kim, 1999)
Antenna			
scale	5-segmented	4-segmented	5-segmented
Maxillule			
basal endite	2 spines	2 spines, 1 lateral seta	2 spines, 1 lateral seta
Maxilla			
basal endite*	3/4 setae	3/4 setae	2/5 setae
First maxilliped			
protopod	4 spines, 1 hair	4 spines, 2 hairs	4 spines
Second maxilliped			
endopod	4-segmented (1, 0, 1, 3)	4-segmented (1, 0, 1, 2)	4-segmented (1, 0, 1, 3)
Third maxilliped			
endopod	4-segmented (0, 0, 2, 2)	4-segmented (0, 0, 2, 3)	4-segmented (0, 0, 2, 3)
Pereopods			
biramous rudiment	pereopods 1, 2	pereopods 1, 2, 3	pereopods 1, 2
uniramous rudiment	pereopod 5	pereopods 4, 5	pereopod 5

*number of setae from proximal to distal lobes.

Table 2 shows morphological features of the first zoeae of the three species of *Alpheus* from Korean waters. The description of the first zoea of *A. brevicristatus* agrees well with those of other known species, *A. euphrosyne richardsoni* and *A. heeia* in the same genus. However, three species of *Alpheus* can be distinguished by having 5-segmented antennal scale distally, biramous rudiments of pereopods 1 and 2, uniramous rudiment of fifth pereopod and other minor mouthpart setations. The following provisional key is provided to aid in the identification of the first zoeae of three species of *Alpheus* from Korean waters.

Key to the first zoeal larvae of three Korean *Alpheus* species

1. Antennal scale 4-segmented distally; all pereopodal rudiments present ----------*A. euphrosyne richardsoni*
 - Antennal scale 5-segmented distally; pereopodal rudiments 1, 2 and 5 present----------2
2. Maxillar basal endite with 2 spines----------
 ----------*A. brevicristatus*
 - Maxillar basal endite with 2 spines and 1 lateral seta----------*A. heeia*

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[Received March 20, 1998; accepted April 15, 1998]