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The Larval Development of a Fouling Organism *Balanus kondakovi* Tarasov & Zevina(Cirripedia, Thoracica)

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Nauplii and cyprid larvae were cultured in the laboratory at a temperature of 25°C of 33 parts per thousand. Larval development includes the six nauplius and a cyprid stages. Morphological characteristics such as antennules, antennae and mandibles as well as the general pattern of the thoracican Cirripedia are described and illustrated. All the nauplius larvae have trilobed labra which are typical in balanoides, with numerous slender hairs.

It is possible to compare the setation of larva of *Balanus kondakovi* with those of *B. albicostatus, B. amphitrite, B. trigonus, B. variegatus,* and *Chthamalus challengeri* by plotting of numerical setation of the antennae against the mandibles.

KEY WORDS: *Balanus kondakovi*, Cirripedia, Larval development

Balanus kondakovi Tarasov & Zevina, 1957 is a common fouling organism in the mainland coast of Asia ranging from Korea to Japan, Taiwan and Philippine (Newman and Ross, 1976; Kim, 1985). This species frequently occurs in the pilings of Laver Farm culturing *Porphyra* species along the south coast of Korea, mixed with other barnacles such as *Balanus albicostatus, B. amphitrite, B. trigonus* and *Chthamalus challengeri*.

According to the studies of plankton samples larvae of this species appeared from June to September with barnacle larvae described above. In spite of the importance of identifying free swimming larvae of barnacles for the studies of larval ecology and phylogeny, little is known on the larval development of balanomorph species in Far Eastern Asia. Therefore, description and illustration of the larval development of *B. kondakovi* would provide helpful information on the study of marine ecology of barnacle nauplii and cyprids. There are some descriptions on the nauplii of *B. kondakovi* by Karande (1979), but it is not enough to distinguish larvae of B. kondakovi from those of other species. It is desirable to describe morphological characteristics of this species in details and to compare the larvae with those of other related barnacle species.

Materials and Methods

Sessile barnacles were obtained from the pilings of Laver Farm, Kadŏkto Island, near Pusan. Upon collection, the barnacles were thoroughly rinsed with filtered sea water, and then cultured in the several aquaria sized 30 × 40 cm by 40 cm in depth. To observe the degree of maturity and hatching process of the first nauplii, egg masses were abstracted from the barnacle mantle cavity (Walley, 1965). The larvae were cultured in 6-well tissue culture plates with 10 larvae per well and some of the newly hatched larvae were preserved in 70% alcohol in order to examine several characteristics of the first nauplii. The culture was carried out in a cabinet under a photoperiod of 14h light and 10h dark and at a constant temperature of 25°C. The salinity of filtered sea water was 33 parts per thousand.

Some larvae were reared in 24-well tissue culture plates, a larva per well, in order to determine correct larval stages and to investigate variation of larvae. Larvae were transferred to filtered sea water daily and fed with the diatom *Nitzschia closterium* Smith at a density of $1.0\times10^4-2.0\times10^4$ cells per ml. Forty larvae as well as exuviae at

each stage were removed with aid of stereomicroscope and were preserved in 70% alcohol. Preserved larvae and exuviae were dissected with fine needles in a mixture of glycerine and alcohol. The basic culture method was derived from that of Bookhout and Costlow (1959) and Brown and Roughgarden (1985).

Measurements were made with an ocular micrometer. Total length was measured from the frontal side of the cephalic shield to the end of the dorsal thoracic spine. The measurement of shield width was carried out at its widest point. Shield length was measured middorsally from the frontal side of the cephalic shield to the end of the posterior shield spine.

Results

Larval development of *Balanus kondakovi* includes the six nauplius stages and a cyprid stage, showing typical pattern of development in the Balanomorph species. Nauplius larvae have a cephalic shield with a pair of frontolateral horns, a nauplius eye, frontal filaments, a trilobed labrum and three pairs of appendages. The data of size measurement of larvae are given in Table 1. In addition to the drawing of the antennules, antennae and mandibles, numerical setation (Bassindale, 1936) and alphabetical setation (Newman, 1965) are illustrated in Tables 2 and 3, respectively.

Nauplius I (Figs. 1A, 2A, 3A, 4A, 5A)

The shape of a larva at this stage is ovoid and a cephalic shield has a pair of frontolateral horns folded to the long axis of the animal. Frontal filaments are not found. A nauplius eye is present at the frontomedian region.

Nauplius II (Figs. 1B, 2B, 3B, 4B, 5B)

The cephalic shield has been extended in length and width. Abdominal process and dorsal thoracic spine have been elongated. There is a tooth on

Table 1. Dimensions of *Balanus kondakovi* Tarasov & Zevina larvae. Ten larvae were measured to give means with standard deviation at each stage.

Stage	Total length(um)	Shield Width(um)	Shield length
I	190 ± 12	120 ± 11	
II	320 ± 15	156 ± 15	
III	360 ± 18	181 ± 15	
IV	430 ± 25	212 ± 21	
V	510 ± 23	236 ± 17	325 ± 11
VI	570 ± 23	306 ± 14	360 ± 15
C	580 ± 17	247 ± 12	443 ± 12

Table 2. Numerical setation of the six nauplius stages of *Balanus kondakovi* Tarasov & Zevina.

Stage	Antennule	Antenna	Mandible
I	04211	023-03222G	013-03222G
II	04211	025-03222G	014-03232G
III	14211	025-03223G	014-03333G
IV	114211	036-04324G	014-03343G
V	11142111	038-04324G	014-04343G
VI	11142121	048-05324G	015-04443G

Table 3. Alphabetical setal formulae (Newman, 1965) of the six nauplius stages of *Balanus kondakovi* Tarasov & Zevina.

Stage	Antennule	Antenna		Mandible	
		Exopodite	Endopodite	Exopodite	Endopodite
I	4S:2S:S:S	2S:3S	3S:2S:2S:2S:G	S:3S	3S:2S:2S:2S:G
II	2SPS:SP:P:S	2P:4PS	2PS:SP:PP^{D}:SC:G	P:3PS	3S:PS:PP^{D}P:SC:G
III	S:PS2P:PS:P:S	2P:5P	3P:SP:PP^{D}:PSC:G	P:3PS	3S:SPS:PP^{D}P:2PC:G
IV	S:P:PS2P:PS:P:S	3P:5PS	3PS:SPS:PP^{D}:2PSC:G	P:4P	4S:PSP:SPP^{D}P:2PC:G
V	S:S:P:PS2P:SP:S:P:S	3P:7PS	4P:2PS:PP^{D}:3PC:G	P:4P (4PS)	4S:S2P:SPP^{D}P:2PC:G
VI	S:S:P:PS2P:PS:P:PS:S	4P:8P	5P:2PS:PP^{D}:3PC:G (P)	P:4PS (5P)	4S:3PS:SPP^{D}P:2PC:G (P)

Setal types: S = simple, P = plumose, P^{D} = plumodenticulate, C = cuspidate, G = gnathobase
Setal variation is expressed in parentheses.

the widest point of each lateral margin of cephalic shield. The frontal filaments are observed through all the subsequent stages. Labrum(Fig. 2G) is trilobed with slender hairs. There are a pair of abdominal spines on the apex of an abdominal process.

Nauplius III(Figs. 1C, 2C, 3C, 4C, 5C)

The size of nauplius larva has increased in total length and width when compared with that of nauplius II. A tooth on the widest point of cephalic shield is now disappeared. A pair of abdominal spines are present in this stage and through all the subsequent stages.

Nauplius IV(Figs. 1D, 2D, 3D, 4D, 5D)

The cephalic shield has become more rounded in shape and posterior shield spines have been added. The abdominal process bears two pairs of abdominal spines and the first pair is longer than the second.

Nauplius V(Figs. 1E, 2E, 3E, 4E, 5E)

The length of cephalic shield has increased and the dorsal thoracic spine becomes shorter when compared with that of nauplius IV. Armored shape has appeared on the apex of the abdominal process.

Nauplius VI(Figs. 1F, 2F, 3F, 4F, 5F)

A pair of compound eyes have appeared laterally to the nauplius eye. There are six pairs of thoracic spines under the thorax and the primordia of the cyprid thoracic appendages present under the exoskeleton of the thoracic spines.

Cyprid (Fig. 8)

There are six pairs of thoracic appendages and a caudal furca on the thoracic margin. Compound eyes and a median eye are present and the antennules terminate in sucker disk. The head of cyprid is packed with numerous oil cells.

Young adult (Fig. 9)

The six plates consist of a rostrum, a pair of lateral plates, a pair of carinal lata and a carina, whose pattern is typical in the genus *Balanus*. There is an orifice between scuta and terga, which is located in the top of barnacle.

Discussion

Description of barnacle larvae has been conducted over the last three decades for the identification of larvae in the free swimming stages which are essential for the studies of larval ecology and planktology (Jones and Crisp, 1954; Barnes and Barnes, 1959; Molenock and Gomez, 1972; Branscomb and Vedder, 1982; Achituv, 1986; Egan and Anderson, 1986; Dineen, 1987; Miller *et al.*, 1989). For the identification of barna-

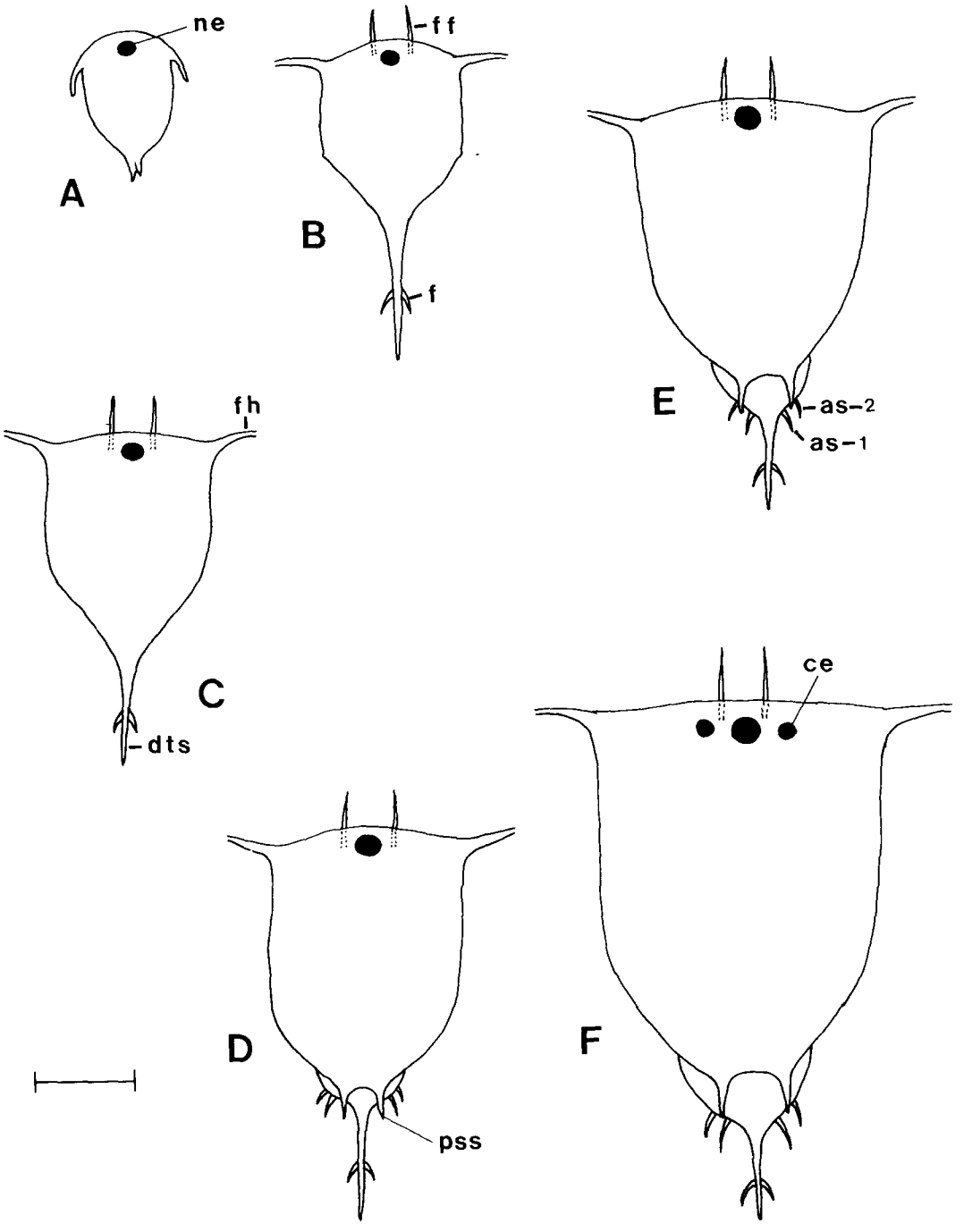

Fig. 1. Outline drawing of the six nauplius stages of *Balanus kondakovi* Tarasov & Zevina. Abbreviations: as-1, abdominal spine 1; as-2, abdominal spine 2; ce, compound eye; dts, dorsal thoracic spine; f, furca; ff, frontal filament; fh, frontolateral horn; ne, nauplius eye; pss, posterior shield spine. Nauplius stages are indicated with alphabetical numerals: A, Stage I; B, Stage II; C, Stage III; D, Stage IV; E, Stage V; F, Stage VI. Scale bar = 100 μm.

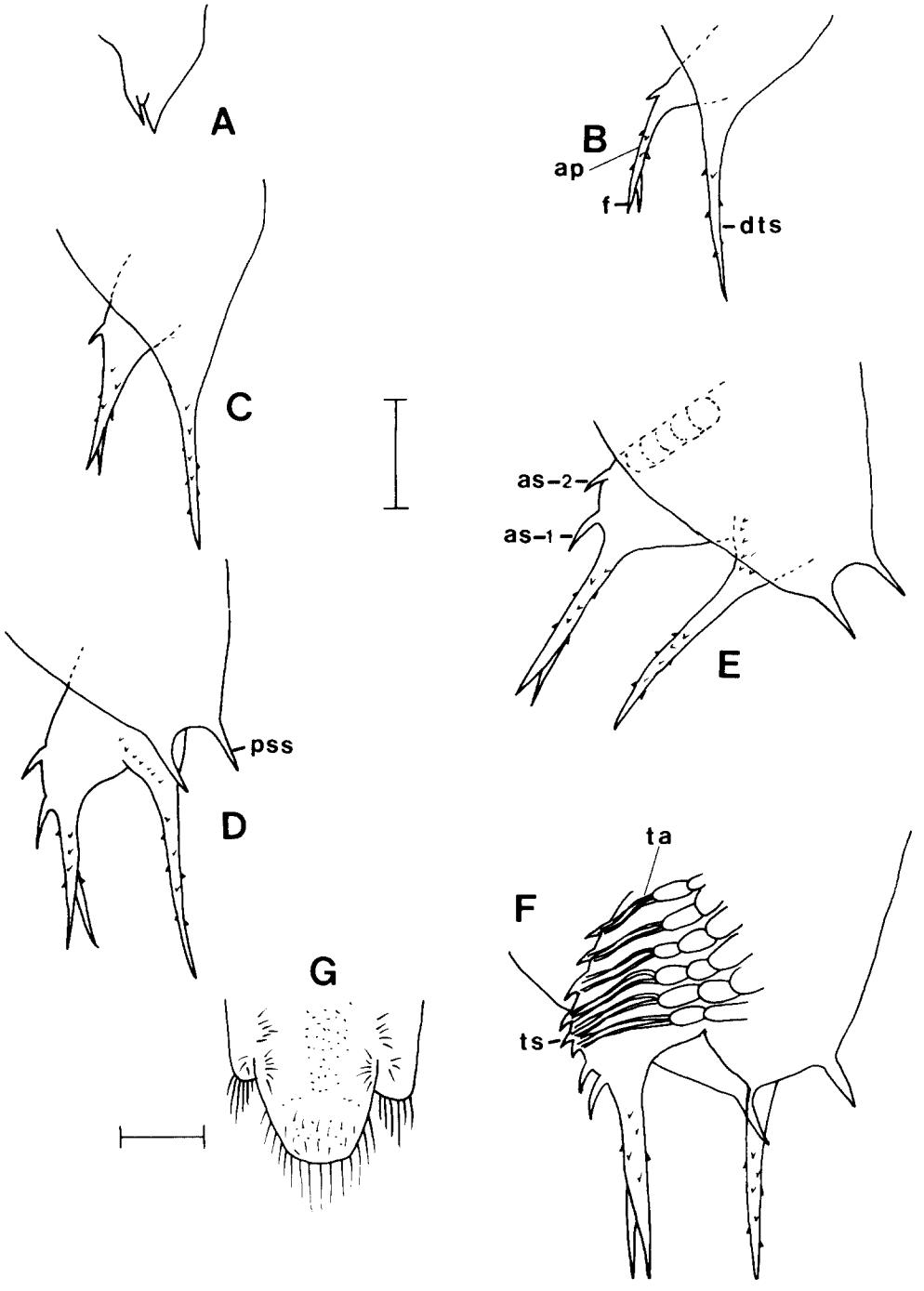

Fig. 2. Outline drawing of lateral view of the six nauplius stages and labrum of *Balanus kondakovi* Tarasov & Zevina. Abbreviations: ap, abdominal process; as-1, abdominal spine 1; as-2, abdominal spine 2; dts, dorsal thoracic spine; f, furca; pss, posterior shield spine; ta, thoracic appendage; ts, thoracic spine. Alphabetical numerals indicate nauplius stages and labrum: A, Stage I; B, Stage II; C, Stage III; D, Stage IV; E, Stage V; F. Stage VI; G, Labrum. Scale bar = 100 μm.

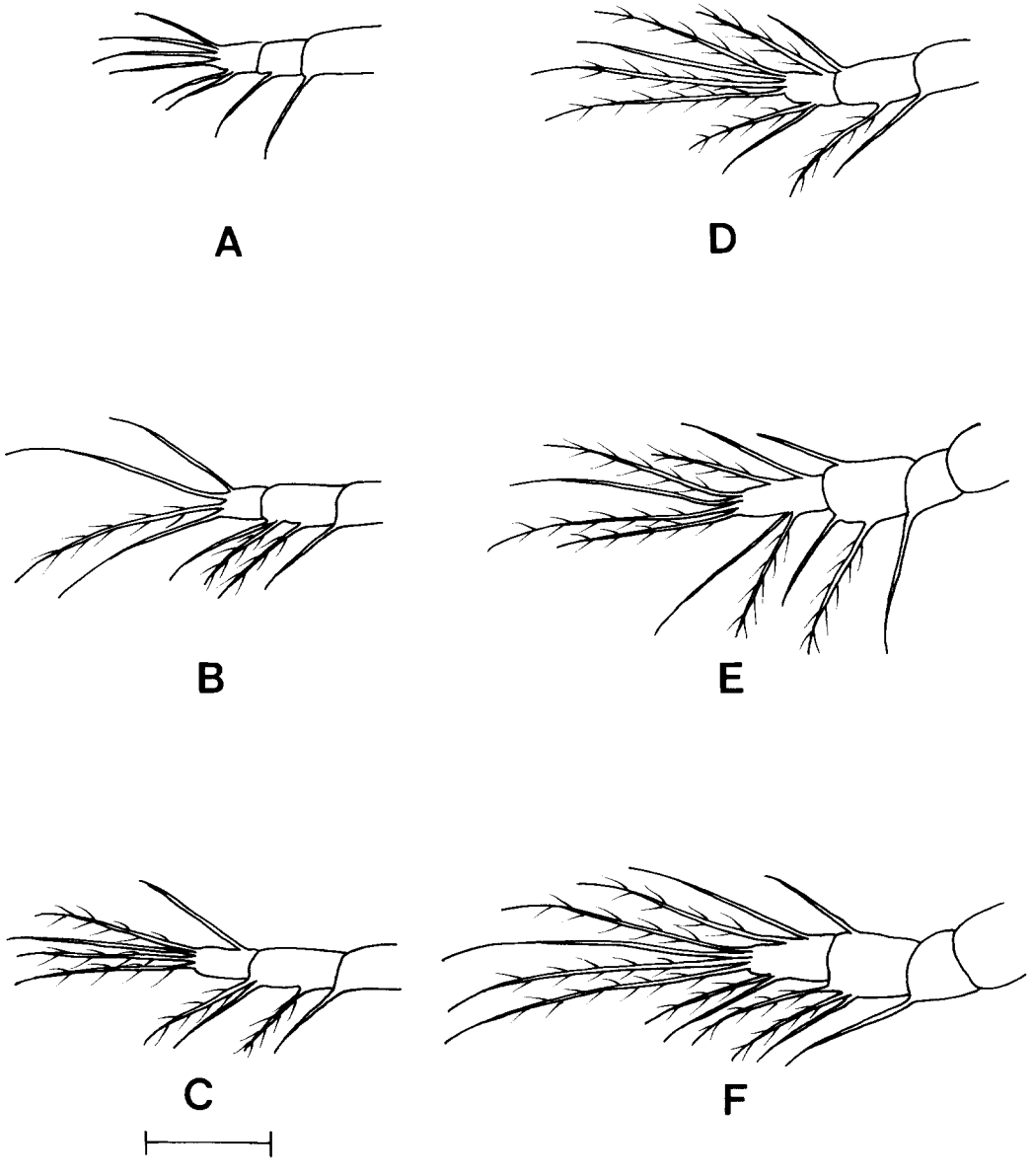

Fig. 3. Antennule of the six nauplius stages of *Balanus kondakovi* Tarasov & Zevina. Nauplius stages are indicated with alphabetical numerals: A, Stage 1; B, Stage II; C, Stage III; D, Stage IV; E, Stage V; F, Stage VI. Scale bar = 100 μm.

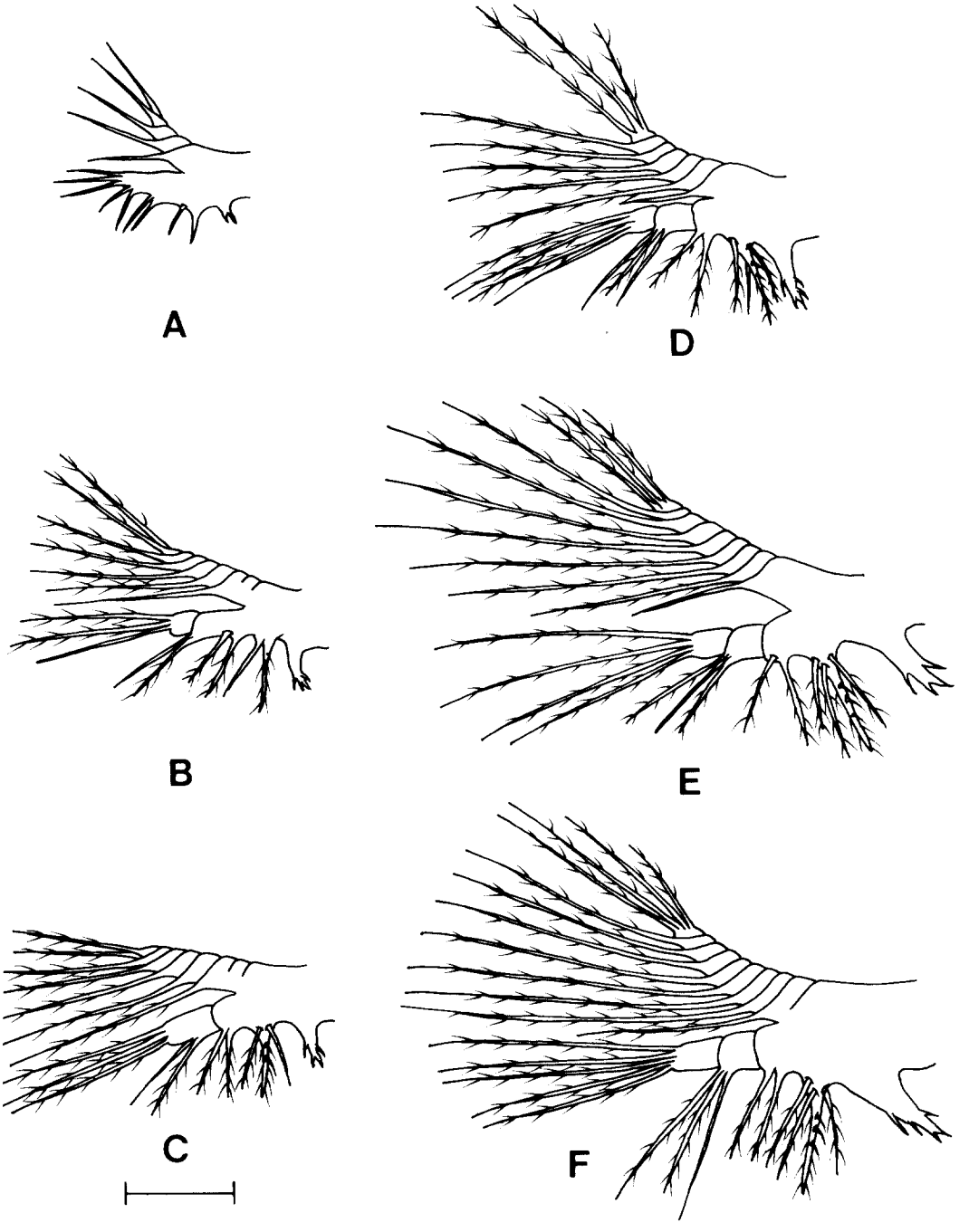

Fig. 4. Antenna of the six nauplius stages of *Balanus kondakovi* Tarasov & Zevina. Nauplius stages are indicated with alphabetical numerals: A, Stage I; B, Stage II; C, Stage III; D, Stage IV; E, Stage V; F, Stage VI. Scale bar = 100 μm.

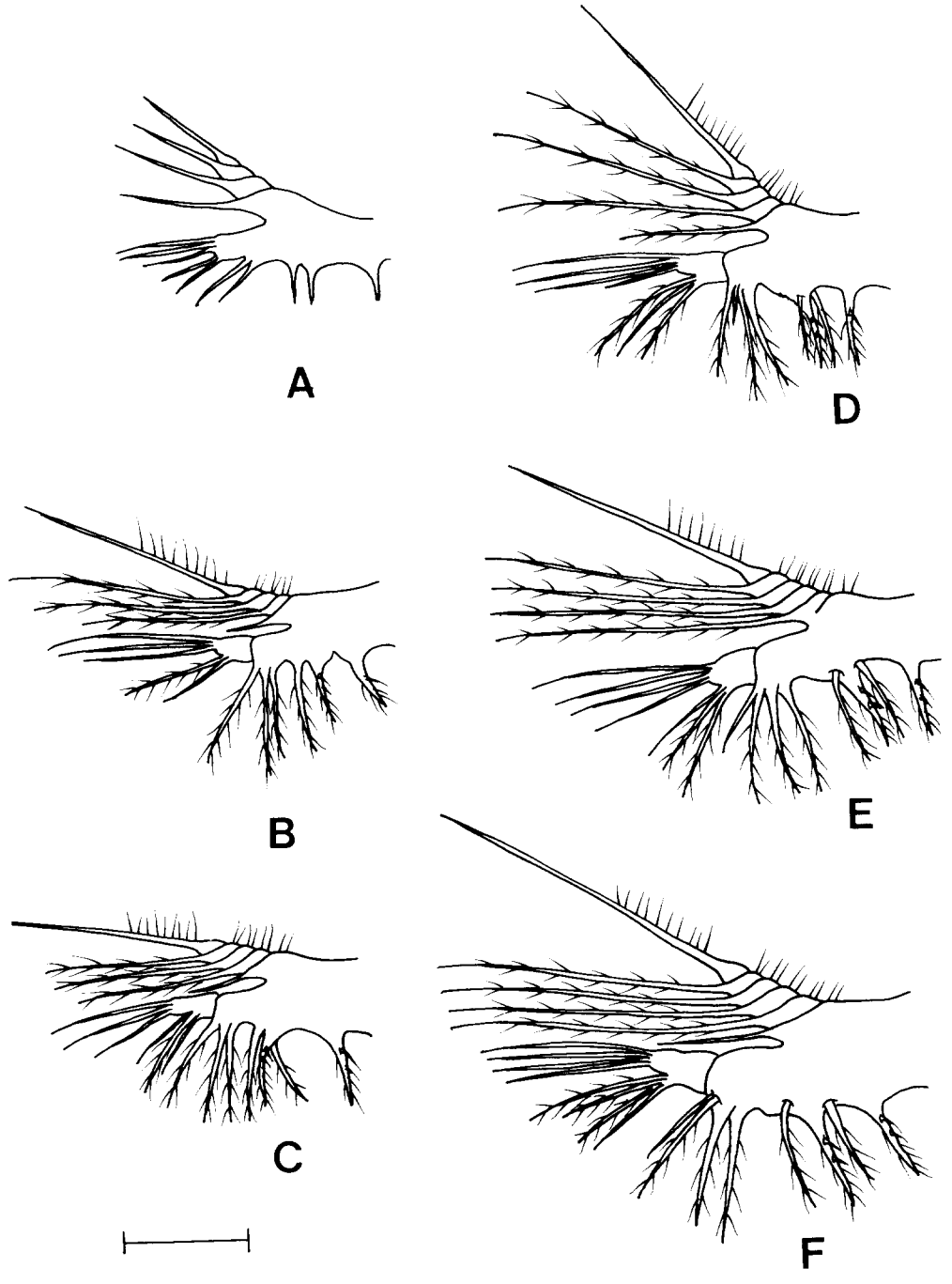

Fig. 5. Mandible of the six nauplius stages of *Balanus kondakovi* Tarasov & Zevina. Nauplius stages are indicated with alphabetical numerals: A, Stage I; B, Stage II; C, Stage III; D, Stage IV; E, Stage V; F, Stage VI. Scale bar = 100 μm.

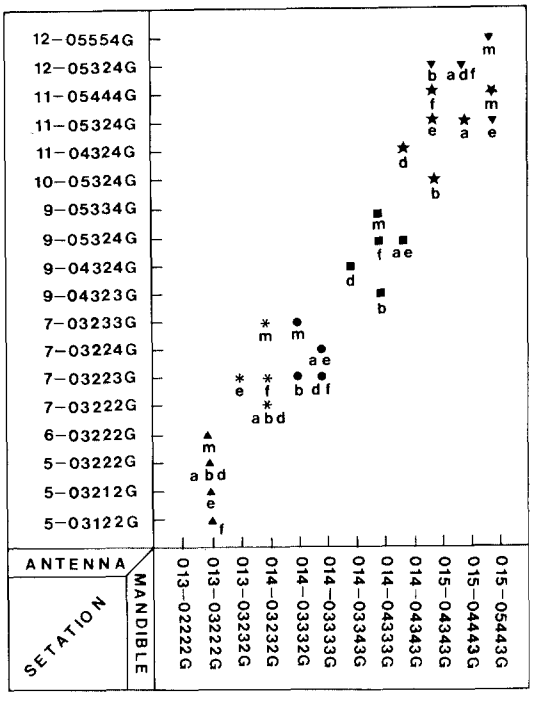

Fig. 6. Plot of numerical setation in six species, showing the progressive increase in setal complexity. Three groups according to the adult classification by Newman and Ross (1976) are as follows: (1) group of *Balanus amphitrite*; *Balanus amphitrite* (a; Egan and Anderson, 1986), *B. albicostatus* (b; Lee and Kim, in press), *B. kondakovi* (d, the present study). (2) group of *Balanus trigonus*; *B. trigonus* (e; Sandison, 1954), *B. variegatus* (f, Egan and Anderson, 1986). (3) group of genus *Chthamalus*; *C. challengeri* (m, unpublished). Symbols: ▲, Stage I; ∗, Stage II; ●, Stage III; ■, Stage IV; ★, Stage V; ▼, Stage VI.

cle larvae, Bassindale (1936) proposed a numerical setation expressing the setal number and relative location of setae on the antennules, antennae and mandibles (Table 2). We found it convenient to make plot of the numerical setation of the antennae against that of the mandibles with some modification.

Figure 6 shows the plot of the numerical setation for the six species of the genus *Balanus* and genus *Chthamalus*, illustrating the progressive increase in setal complexity. We divided six species of barnacle nauplii into groups of *Balanus amphitrite* and *Balanus trigonus* in the genus *Balanus* and group of the genus *Chthamalus*, on the basis of adult classification by Newman and Ross (1976): 1) group of *Balanus amphitrite*; *Balanus amphitrite* (a; Egan and Anderson, 1986), *B. albicostatus*(b; Lee and Kim, in press), *B. kondakovi* (d; the present study), 2) group of *Balanus trigonus*; *B. trigonus*(e; Sandison, 1954), *B. variegatus* (f; Egan and Anderson, 1986), 3) group of genus *Chthamalus*; *Chthamalus challengeri* (m; unpublished).

Examination of plankton samples in the coastal Laver Farm near Kadŏkto Island showed that the larvae of *Balanus amphitrite*, *B. albicostatus*, *B. kondakovi*, *B. trigonus* and *Chthamalus challengeri* coexisted at the same time from June to September. However, it is possible to distinguish nauplii of the genus *Balanus* with nauplii of the genus *Chthamalus* on the basis of morphological differences such as the absence of posterior shield spine, shape of cephalic shield, and the presence of hispid seta at the fourth group of antenna endopodite (Moyse, 1961; Sandison, 1967; Lang, 1979). It may also provide a diagnostic characteristic of the chthamalid nauplii to have a unilobed labrum when compared with the balanid nauplii which have a trilobed labrum (Barker, 1976). However, it is difficult to distinguish nauplii of groups of *B. amphitrite* and *B. trigonus* only by gross morphological features.

Balanus kondakovi and *B. variegatus* inhabit Southeast Asia, partially overlapping in some area. Comparison between nauplii of two species shows the same setal formulae of the antennae and mandibles at the stages III and VI. There are several similarities such as the morphological characteristics, setal types and type of foods between nauplii of *B. kondakovi* and *B. variegatus*. It is known that the antennae play a major role in collecting of food particles while the mandibles support in moving food particles toward the labrum (Gauld, 1959; Boyd, 1976; Walker *et al.*, 1987; Stone, 1989). Stone (1989) suggested that nauplii of cold waters have widely spaced setules which are well suited to harvesting diatoms typical of high latitude waters, while nauplii of warm waters have a fine meshed filter capable of filtering small flagellates predominating in warm waters. Therefore similarity of setal numbers and space between setules of barnacle appendages might reflect the

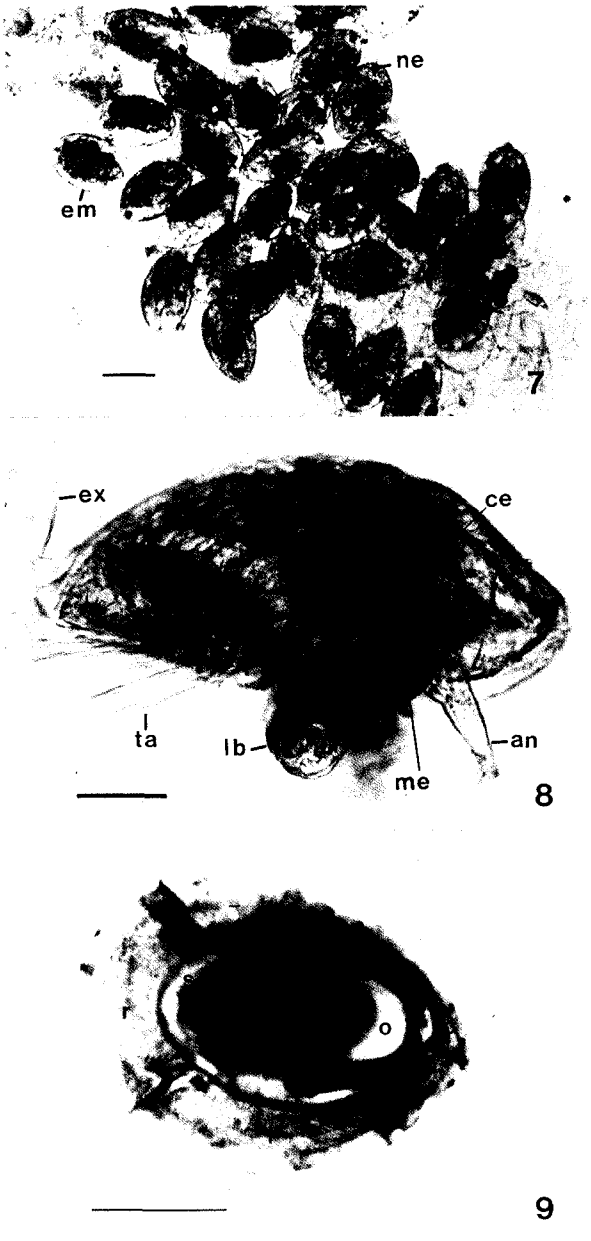

Fig. 7. Developing eggs removed from mantle cavity of adult *Balanus kondakovi* Tarasov & Zevina. Nauplius eyes are observed in the frontomedian region of cephalic shield. Abbreviations: em, egg membrane; ne, nauplius eye. Scale bar = 100 μm.

Fig. 8. *Balanus kondakovi* Tarasov & Zevina cyprid shortly after nauplius-cyprid molting. Abbreviations: an, antennule; ce, compound eye; ex, exuviae; lb, labrum; me, median eye; ta, thoracic appendages. Scale bar = 100 μm.

Fig. 9. *Young adult of Balanus kondakovi* Tarasov & Zevina five days after cyprid-adult molting showing typical pattern of genus *Balanus* in the formation of shell plates. Abbreviations: c, carina; cl, carinal latus; l, lateral; o, orifice; r, rostrum, s, scutum, t, tergum. Scale bar = 300 μm.

analogy of food particles in two species.

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세로줄 따개비(*Balanus kondakovi*)의 유생발생에 관한 연구

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세로줄 따개비의 nauplius 유생과 cyprid유생을 실험실에서 25°C의 온도와 33‰의 염분농도를 가진 해수에서 사육하였다. 본 종의 유생은 부화후 6기의 nauplius유생기를 거친후 cyprid 유생으로 변태하였다. 소촉각, 촉각 그리고 대악과 같은 부속지들의 형태학적 특징을 상세히 기술 및 도시하였는데 이는 완흉류 따개비의 유생발생 단계와 동일한 양상을 보여 주었다. 세로줄 따개비의 유생은 *Balanus* 속의 유생이 공통적으로 가지는 세부분으로 구성된 상순을 소유하는데 이들의 각 부분은 많은 세모를 가지고 있었다. 세로줄 따개비의 유생발생에 덧붙여 숫자로 표기된 자모식의 그림에 의해 본 종의 유생과 동일한 지역에 서식하는 고랑따개비, 주걱따개비, 삼각따개비 그리고 조무래기 따개비의 유생들의 동정방법을 고찰하여 보았다.