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The nauplii of *Balanus kondakovi*

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Abstract. Six naupliar stages of *Balanus kondakovi* were raised under laboratory conditions on a diet of *Dunaliella primolecta*. The nauplii of this species are generally small, with carapace, caudal spine, abdominal spine and labrum, lacking any special feature that could help in specific identification. However, these features when considered in conjunction with the limb setation help to separate these larvae from those of the others. It is one of the fast metamorphosing barnacle larvae attaining metanauplius stage in about 80 hr.

Keywords. Barnacle larvae; *Balanus kondakovi*; limb setation.

1. Introduction

Balanus kondakovi Tarasov and Zevina, 1957 an operculate barnacle, is reported from the seas of Japan, China, Sumatra, Korea, New Zealand and Australia (Henry and McLaughlin, 1975). Very recently, they identified this species in a lot sent to them by the author. *B. kondakovi* is an intertidal species and is found in abundance on timber structures and piers located in mud-flats along the east coast of India.

Henry and McLaughlin suggest that *B. kondakovi* is closely allied with *Balanus variegatus* and *Balanus reticulatus* and may provide a link between the *Pallidus* group and other groups within the *amphitrite* complex. It is believed that the fuller descriptions of the larvae of the members of the complex may provide additional information on their interrelationships.

The present work on the larvae of *B. kondakovi* is a part of the larger effort to describe the nauplii, metanauplii and cyprids of various cirripedes encountered along the Indian coasts. The literature on the subject is slowly buildnig up and some of the species studied are *Balanus amphitrite amphitrite* Darwin (Daniel 1958; Karande 1973), *Balanus variegatus* Darwin (Karande 1974a), *Balanus amaryllis euamaryllis* Broch, *Tetraclitella karandei* Ross (Karande 1974b), *Ibla cumingi* Darwin (Karande 1974c), *Chthamalus stellatus stellatus* Darwin (Daniel 1958), *Chthamalus withersi* Pilsbry and *Chthamalus malayensis* Pilsbry (Karande and Thomas 1976).

In the present paper the larvae of one unidentified *Balanus* sp. have been commented on for the reasons of comparison.

2. Materials and methods

Live specimens of *B. kondakovi* were removed from the abandoned structure along the mud-flats at Balasore, Orissa State, East India. These were maintained in small glass jars containing filtered sea water and were fed on diet of *Dunaliella primolecta* and diatoms *Pleurosigma* sp. and *Phaeodactylum* sp. The sea water was changed every day and the specimens were kept dry during night hours to minimise bacterial and protozoan growth. The embryos or the first nauplii released by these adults were reared to obtain their subsequent growth stages. A general outline of the rearing technique has been described earlier by Karande and Thomas (1971).

3. Observations

3.1. *Illustrations and data tables*

Six naupliar stages were raised and examined. The outline drawings showing the shapes and the more important processes with their spinulation are given in figure 1. Figure 2 illustrates antennal and mandibular limbs of 2nd, 4th and 6th nauplii. Figure 3 illustrates fifth setal quadrate on the endopodite of antennae of some barnacle larvae examined in this laboratory. Table 1 gives dimensions of various larval features of six nauplii. Table 2 gives alphabetical setation formulae of naupliar appendages as recommended by Newman (1965). Table 3 gives numerical formulae devised by Bassindale (1936) for the larval limbs of some *balanid, chthamalid* and *tetraclitilid* species. Table 4 presents comparative account of the setae in Indian species.

The dimensions of the naupliar features recorded in this work are averages based on the examination of at least 10 individuals of each stages. It is observed that salinity and diet considerably influence both the sizes and the setulation of the growing larvae. This was particularly noted during the studies on *I. karandei* and *I. cumingi* larvae. It is also observed that the individuals with delayed or arrested growth may give distorted picture of the setation of the limbs.

3.2. *Descriptions of the nauplii*

The pear-shaped first nauplius is 200 μ long and 135 μ wide. Its two fronto-lateral horns, still appressed to body, are 55 μ long. Like many other species frontal filaments are absent. A trilobed labrum occupies most of the anterior half of the body. The caudal and the abdominal processes though formed are not clearly demarcated from each other. The setae on naupliar limbs are without setules. This extremely fast moving larva transforms into the second nauplius within 15–20 min.

The second nauplius is 310 μ long. The frontal filaments appear at this stage and continue to grow during the subsequent growth stage. The false carapace present is without any fine spinulation at this and the subsequent growth stages. The fronto-lateral horns extend fully and are 55 μ long. These do not grow any further. A toothless, trilobed labrum 75 μ wide present bearing tufts of hair on

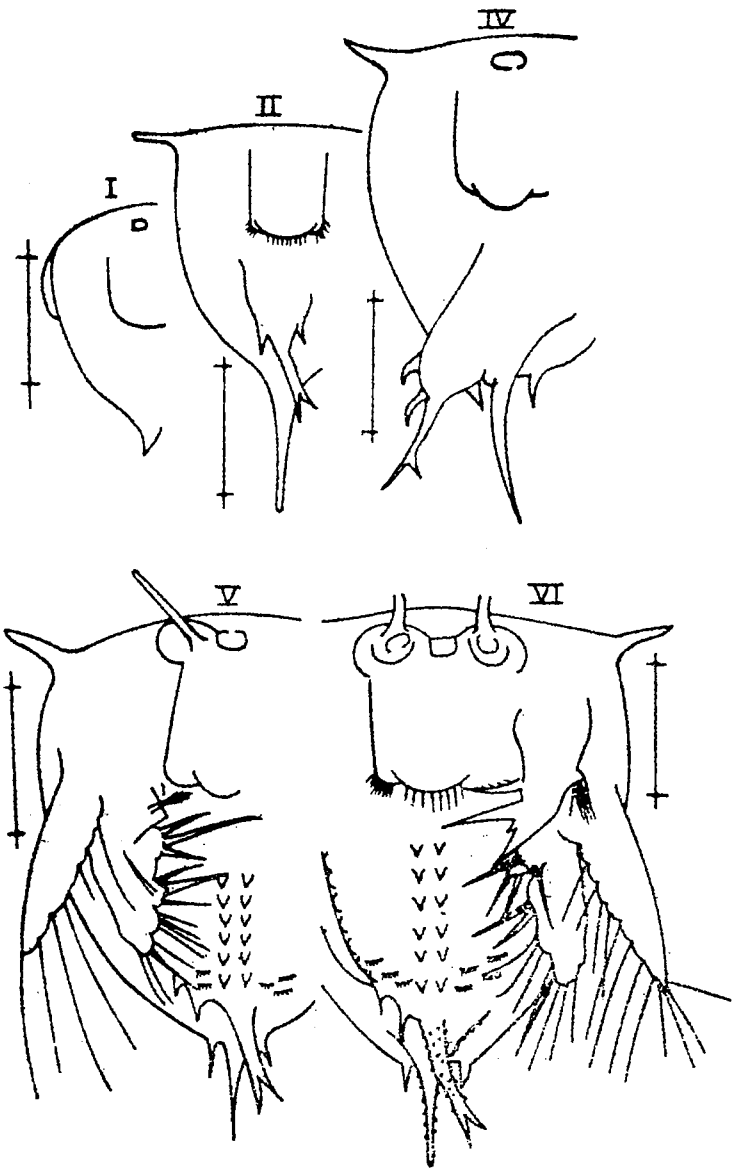

Figure 1. *Balanus kondakovi*: Outline drawings showing the more important features of I, II, IV, V and VI larvae. (All scale-bars equal 100 μ).

each of three lobes. Abdominal bulb and its process show relatively poor sculpturing. A pair of caudally directed distal abdominal spines appear. Each of these spines bears two rows of 7–8 spinules. Subequal ramii of furca measure about 30 μ. The 105 μ long caudal process is longer than abdominal process and continues to remain longer until the emergence of metanauplius larvae. It bears 8–9 spinules in two or three rows which extend upto the tip of its spine. Within a span of 12 hr the second nauplius enters into the third growth stage.

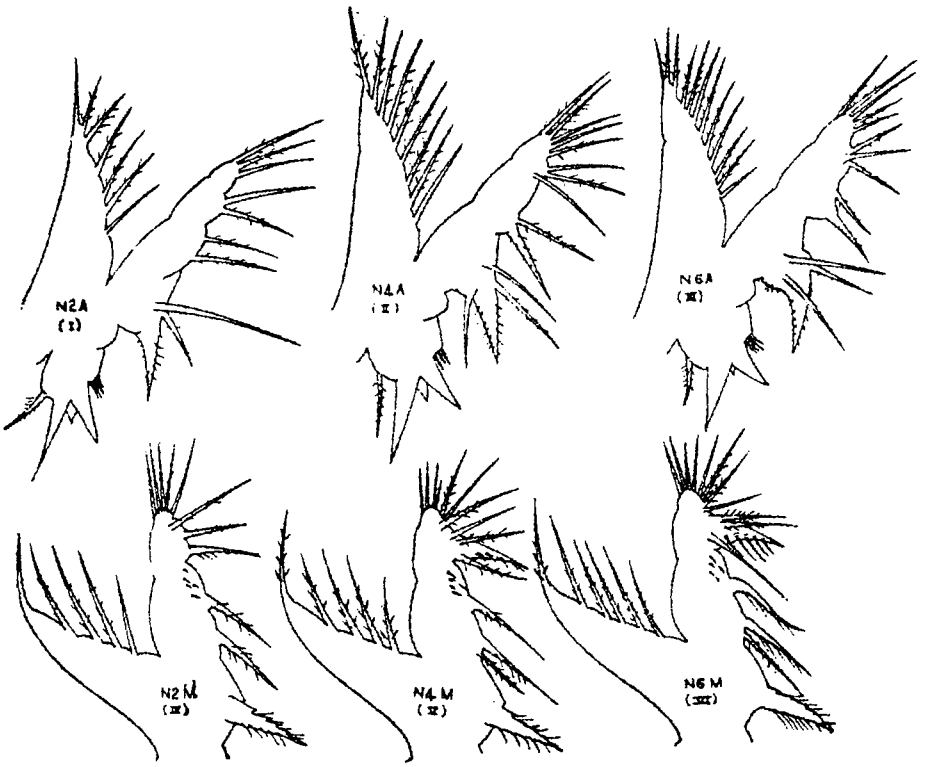

Figure 2. *Balanus kondakovi*: Antennal and mandibular limbs of second, fourth and sixth larvae. A = antenna, M = mandible (Antennal length approx. 75 μ at I nauplius and 150 μ at VI nauplius; Mandible length approx. 100 μ at I nauplius and 180 μ at VI nauplius).

The third nauplius, 310 μ long, resembles the second nauplius in general appearance. The abdominal bulb still bears only one pair of distal abdominal spines. This stage, however, can readily be identified by the preaxial seta on its antennule. From this stage onwards, distal one-third of 150 μ long caudal spine bears no spinulation. The third larva transforms into the fourth larva within 20 hr.

The fourth larva measures 350 μ and has true carapace 240 μ long and 200 μ wide. Frontal margin between two horns measures 175 μ and the posterior margin between the two carapace spines, which have now emerged, is 35 μ. Carapace is shield-shaped and this shape is generally maintained throughout the successive growth stages. Posterior carapace spines are 35 μ long. The abdomen is demarcated into segments by a series of sub-equal, inconspicuous spines. The papillae of six cirral appendages noted in many other species at this stage, however, are not yet formed. The most important change has been the emergence of paired proximal 16 μ long abdominal spines. The antennule has two preaxial setae and four postaxial setae. Antennal limb bears 23 setae as against 18 noted at the preceding stage. Within 24 hr, the fourth larva is transformed into fifth nauplius.

The fifth nauplius is a very active and healthy looking stage. The posterior carapace spines appear smaller owing to the growth of the carapace. A massive

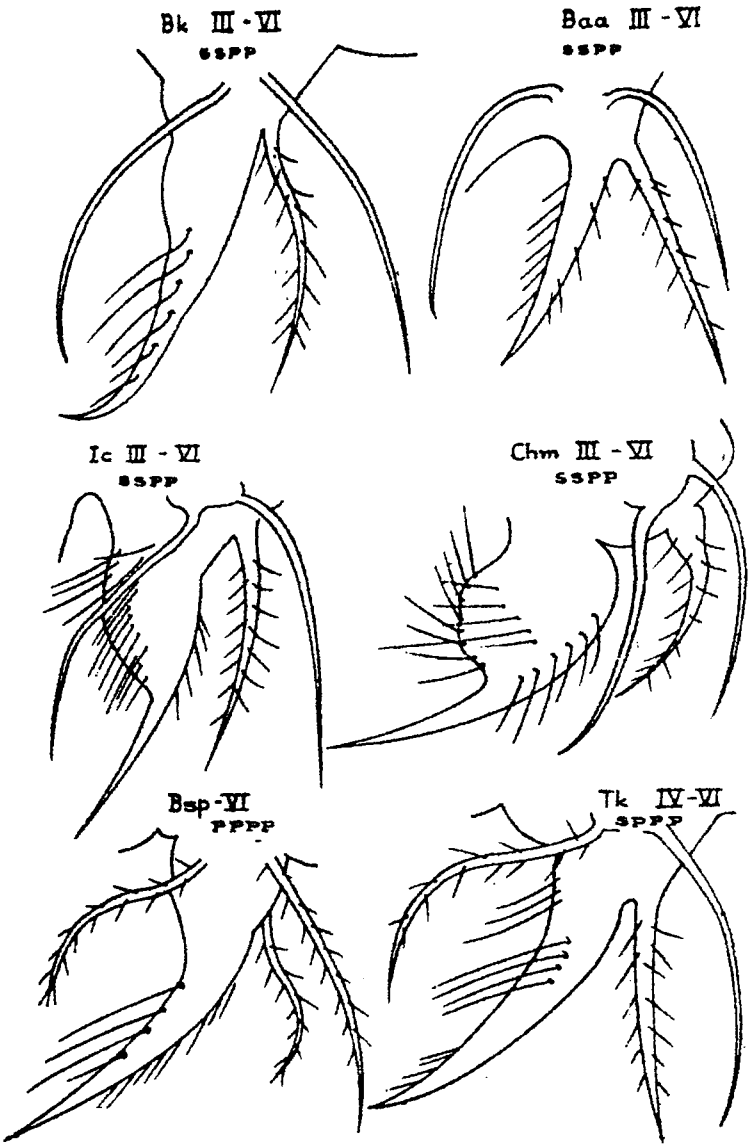

Figure 3. *Balanus kondakovi*: The 5th setal quadrate on the endopodite of antennae compared with other local species. (Semi-diagrammatic; Approx. size 65 μ) (Bk = *B. kondakovi*, Baa = *B. a. amphitrite*, Ic = *I. cumingi*, Chm = *Chthamalus malayensis*, Bsp = *Balanus* sp., Tk = *Tetraclitella karandei*).

100 μ long, 70 μ wide labrum occupies most of the space bordered by the naupliar appendages. Its median lobe now bears about ten 20 μ long spine-like processes which replace earlier hairy tufts. The frontal filaments become very conspicuous as a result of considerable increase in length. The abdomen grows bulky and unlike earlier stages shows little sculpturing. In addition to a large number of minute spinules, the distal end of the bulb shows a few multified scales. Both abdominal

Table 1. Dimensions in microns of the larval features of *Balanus kondakovi*.

Larval features	NI	NII	NIII	NIV	NV	NVI
Total length	200	310	310	350	365	425
Carapace length	..	..	..	240	290	340
Carapace width	..	..	..	200	225	275
Width between horns	..	..	..	175	225	240
Width between carapace spines	..	..	..	35	40	45
Carapace spine length	..	..	..	35	30	25
Horn length	55	55	55	55	55	55
Frontal filament	..	45	50	55	80	80
Labrum width	..	55	55	60	70	75
Labrum length	..	75	100	100	100	105
Caudal spine	..	105	150	150	150	150
Abdominal spine	..	..	95	105	105	120
Distal abdominal spine	..	30	25	25	20	20
Proximal abdominal spine	..	..	..	15	15	15

spine and caudal spine retain their spinulation and still appear strong and rigid. Six pairs of cirriform appendages, now in the form of papillae, are seen under the exoskeleton. The antennule bears all three preapical setae and five postapical setae. The additions of the setae, 25 on the antennal limb and 21 on the mandibular limb are recorded in table 3. Within a period of 24 hr the fifth larva metamorphoses into the metanauplius.

The three-eyed metanauplius is 425 μ long, having a carapace 340 μ long and 275 μ wide. For the first time the lateral margins of the carapace show slight incurving towards the midaxis of the body. The frontal margin of the carapace, however, does not participate in this bending process. The labrum is still a conspicuous organ and so are the frontal filaments. The massive abdomen occupies most of the space under the carapace. Six pairs of well organised segmental spines occur each measuring 12 μ. The abdominal cirri and a paired caudal processes are discernible under the exoskeleton. Reduced paired distal abdominal spines and proximal abdominal spines become more lateral and come closer. Abdominal and caudal spines retain their spinulation and still appear firm and strong. Antennule has 3 sub-apical and 6 post-apical setae and its subterminal segment assumes a shape and size that characterise the sixth larva. Antennal and mandibular limbs show 26 and 21 setae respectively.

3.3. *Characters of diagnostic value*

The nauplii of *B. kondakovi* are generally small. True carapace of these larvae like that of *B. a. amphitrite* is without any special feature. It lacks any sculpturing or design as is noted in *Chthamalus malayensis* and *Ibla cumingi* larvae (Karande 1974c).

The labrum, considering the overall size of the nauplius, is massive. Its median lobe extends much beyond the two lateral lobes. The hairy processes on median lobe at fifth stage are replaced by eight to nine hardy spinules. In the absence

Table 2. Setation formulae of naupliar limbs of *Balanus kondakovi*. (After Newman 1965).

Stage	A^{I}	A^{II}	M
VI	SSP PSPP SP PPS S	O SPPP PPPPPPPS	O SPPPP SPP PP SSPP*	O P PPPPP O SSSS SSPP SPPP PPP
V	SSP PSPP SP PP S	O PPPP PPPPPPS	O SPPPP SPP PP SSPP	O P PPPPS O SSSS SSPP SPPP PPP
IV	OSP PSPP SP PS O	O PPP PPPPPS	O SSPPP SSP PP SSPP	O P PPPP O SSSS SPP SPPP PPP
III	OOS PSPP SP PS O	O PP PPPPP	O PPP SP PP SSPP	O P PPPS O SSS SSP PPP PPP
II	OOO SSPS SP SS O	O SP PPPPS	O PPS SP PP SPP	O P PPPS O SSS SP PPP PP
I	OOO SSSS SS SS O	O S SSSS	O SSS SS PP SS	O S SSS O SSS SS SS PP

Unidentified *Balanus* sp. shows identical setation formulae as above except that at position (*) it has all four plumose setae.
P = plumose, S = simple.

Table 3. Setation formulae of naupliar limbs of some barnacles (After Bassindale 1936).

Species	Stage	Antenna	Mandible
Ch. malayensis (Karande and Thomas 1976)	I	0.1.4–0.3.2.2.2 (14)	0.1.3–0.3.2.2.2 (13)
	II	0.2.5–0.3.2.2.3 (17)	0.1.4–0.3.2.3.2 (15)
	III	0.2.5–0.4.2.2.4 (19)	0.1.4–0.3.3.3.3 (17)
	IV	0.2.7–0.5.3.3.4 (24)	0.1.4–0.5.3.3.3 (19)
	V	0.4.7–0.5.4.4.4 (28)	0.1.5–0.5.4.4.3 (22)
	VI	0.4.8–0.6.5.6.4 (33)	0.1.5–0.5.4.4.3 (22)
B. kondakovi and *Balanus* sp. (Present report)	I	0.1.4–0.3.2.2.2 (14)	0.1.3–0.3.2.2.2 (13)
	II	0.2.5–0.3.2.2.3 (17)	0.1.4–0.3.2.3.2 (15)
	III	0.2.5–0.3.2.2.4 (18)	0.1.4–0.3.3.3.3 (17)
	IV	0.3.6–0.5.3.2.4 (23)	0.1.4–0.4.4.4.3 (19)
	V	0.4.7–0.5.3.2.4 (25)	0.1.5–0.4.4.4.3 (21)
	VI	0.4.8–0.5.3.2.4 (26)	0.1.5–0.4.4.4.3 (21)
B. a. amphitrite (Karande 1973)	I	0.1.4–0.3.2.2.2 (14)	0.1.3–0.3.2.2.2 (13)
	II	0.2.5–0.3.2.2.3 (17)	0.1.4–0.3.2.3.2 (15)
	III	0.2.5–0.3.2.2.4 (18)	0.1.4–0.3.3.3.3 (17)
	IV	0.3.6–0.5.3.2.4 (23)	0.1.4–0.4.3.3.3 (18)
	V	0.4.7–0.5.3.2.4 (25)	0.1.5–0.5.3.3.3 (20)
	VI	0.4.8–0.5.3.2.4 (26)	0.1.5–0.5.4.4.3 (21)
T. karandei (Karande 1974b)	I	0.1.4–0.3.2.2.2 (14)	0.1.3–0.3.2.2.2 (13)
	II	0.2.5–0.3.2.2.3 (17)	0.1.4–0.3.2.3.2 (15)
	III	0.2.5–0.3.2.2.4 (18)	0.1.4–0.3.3.3.3 (17)
	IV	0.3.6–0.5.3.2.4 (23)	0.1.4–0.4.3.3.3 (18)
	V	0.4.7–0.5.3.2.4 (25)	0.1.5–0.4.4.4.3 (21)
	VI	0.4.8–0.5.3.2.4 (26)	0.1.5–0.4.4.4.3 (21)
B. balanus (Barnes and Costlow 1961)	I	0.1.4–0.3.2.2.2 (14)	0.1.3–0.3.2.2.2 (13)
	II	0.3.4–0.3.2.2.2 (16)	0.1.3–0.3.2.3.2 (14)
	III	0.3.4–0.3.2.2.2 (16)	0.1.3–0.3.2.3.3 (15)
	IV	0.4.4–0.4.3.2.2 (19)	0.1.4–0.3.3.4.3 (18)
	V	0.4.5–0.4.3.2.2 (20)	0.1.4–0.3.3.4.3 (19)
	VI	0.4.5–0.4.3.2.2 (20)	0.1.4–0.4.3.4.3 (19)

Table 4. Some setation types of the naupliar limbs of endemic cirriped species.

Species	5th setal quadrate on antennal endopodite*			4th setal quadrate on mandibular endopodite	
	SSPP	SPPP	PPPP	SPPP	PPPP
B. kondakovi	N III to VI	..	..	N IV to VI	..
B. a. amphitrite	N III to VI	..	..	N V and VI	..
I. cumingi	N III to VI	..	..	N IV and V	N VI
Ch. malayensis	N III to VI	..	..	N V and VI	..
Balanus sp.	N III to V	..	N VI	N IV to VI	..
T. karandei	..	N IV to VI	..	N IV to VI	..

* Refer to figure 3 for the details. S = simple, P = plumose.

of teeth on the labrum, these larvae resemble those of *B. a. amphitrite* and *B. variegatus* and could be easily separated from the larvae of *B. a. euamaryllis, T. karandei, I. cumingi, Ch. withersi* and *Ch. malayensis* whose labrums bear teeth or pecten of teeth during some growth stages (Karande 1974c).

The abdominal process comprised of the abdominal bulb, the stem with furcate and the abdominal spines in this species is poor in sculpturing. Like most of the other cirripedes, the distal pair of abdominal spines appears at the second nauplius and the proximal one at fourth nauplius stage. The median abdominal spine noted in *B. a. euamaryllis, B. a. amphitrite, B. variegatus* (Karande 1974), *Balanus balanus* (Barnes and Costlow 1961) and *Balanus hersperius* (Barnes and Barnes 1959) is not evident in this species. At fifth and sixth growth stages the sculpturing on the abdomen becomes more pronounced and in addition to the spinulation, a few multifid scales are also seen around the proximal pair of abdominal spines. Similar scales but having different pattern are also noted in *T. karandei* (Karande 1974c).

The pattern of setation of the antennule in this species conforms to that of the members of many other genera. The formation of the preaxial and postaxial setae follows the same sequence as noted in many other barnacles and the number of setae for each growth stage remains specific.

The number of setae on antennal limbs of each of six *B. kondakovi* nauplii is 14–17–18–23–25–26 respectively. The setulation of antennae is, therefore, poorer than that of *Ch. malayensis* or *I. cumingi*. It is, however, richer than such temperate species as *B. balanus* and *B. hesperius*. So far as mere number is considered antennal setation in *B. kondakovi* conforms to that of the three endemic species *B. a. amphitrite, Balanus* sp. and *T. karandei*. However, in all these four species, the distribution of setae, plumose or simple, and their sequence of emergence with respect to growth stages show variations. For instance the 5th group of setae close to the gnathobase (figure 3, Bk; table 4) having two simple and two plumose members is fully formed by third stage and lasts until the sixth nauplius in *B. kondakovi* and in *B. a. amphitrite*. In *B. variegatus* also, this group is fully formed by the third stage. In *Balanus* sp. this group until the fifth larva has two simple and two plumose setae but at the sixth larval stage all setae become plumose (figure 3, *B.* sp.). In *T. karandei* unlike all these species this setal group is comprised of only one simple seta and three plumose setae. Besides, all the four setae are formed by the fourth nauplius and not at the third stage as observed in other species (figure 3, Tk).

The setation of the mandibular limbs of six *B. kondakovi* larvae is without any special features. The second group of setae, that is the apical ones on the endopodite, like that in all other species are simple and the last group of three setae close to the gnathobase are always highly setulose. The fourth group of setae having one simple, two plumose and one combed member is fully formed at the fourth larval stage. Table 4 gives comparative account of these setae in some of the endemic species studied in this laboratory.

4. Discussion

The present observations on the development of *B. kondakovi* larvae and those made on other *balanid, chthamalid, tetraclitilid* and *iblid* barnacles underline the

observation of Barnes and Costlow (1961) " that while many species have one or more limbs identical, so far as known no species has identical setation on all the limbs at all the stages ". The examination of setation of eight species reveals that some amongst them may have identical numbers of setae on all six antennal limbs but none of them has setation on mandibular limbs agreeing with that of the other. The dissimilarity becomes more evident when the character of setulation, simple, plumose or combed, is considered.

It has been a common experience that when the larvae are brought up carefully and examined at appropriate time, no variations either in number or setulation amongst individuals are observed. Assuming that similar uniform growth is also achieved under natural conditions, for the larval recognition in general plankton work where identity of specific stage is in view, the examination of the total setation may prove a useful aid.

A carapace shape and sculpturing, the degree of bending of the carapace border, appearance or disappearance of posterior carapace spines or of caudal process, the presence or absence of teeth on labrum and the abdominal spinulation are some of the events, which in conjunction with the setation formulae may prove useful in devising a key for the identification of cirriped larvae even in tropical waters of India where breeding in many species is generally continuous and simultaneous.

The naupliar features including the setation may prove advantageous in attending to some of the problems in barnacle interrelationships. For instance how closely *B. kondakovi* is related to *B. variegatus* or to *B. reticulatus* and how close is *B. reticulatus* to *B. a. amphitrite* or to *B. variegatus* can be judged by the study of their larvae. The examination of the laboratory reared larvae of chthamalids, *Ch. stellatus stellatus, Ch. challengeri* and *Ch. malayensis* so identified in Indian waters by Daniel (1956), Bhatt and Bal (1960) and Karande and Palekar (1963) respectively, may for instance help to decide if these barnacles are three individual species or the synonyms.

An un-named *Balanus* sp. mentioned in the present work is found in the locales where other species like *B. kondakovi, B. variegatus, Balanus eburneous* and *B. a. amphitrite* are also present. Though unidentified as yet, its identity as the one different from all these four species and also from *Balanus amphitrite reticulatus* could be established not only from its adult features but also by comparing its larval setation with those of the others. The utility of the limb setation as a diagnostic character is thus evident.

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