

## Development & Predation in a Calanoid Copepod *Tortanus forcipatus* (Giesbrecht)

S. C. GOSWAMI

National Institute of Oceanography, Dona Paula 403004, Goa

Received 2 July 1977; revised received 3 November 1977

Larval stages of *T. forcipatus* (Giesbrecht) have been described in detail. Six naupliar stages and 5 copepodid stages precede the adult stage. Nauplii of this species can be easily differentiated from naupliar stages of other copepods by the presence of large and broad labrum with indented posterior margin, stout hooks on the gnathobase of the mandibles and by the arrangement of spines of the caudal armature. Copepodid stages follow the general pattern of calanoid development. Reddish-brown pigment is present at the base of their antennae in living specimens. Caudal rami are asymmetrical from the 4th copepodid stage onwards and are distinct in the adults. This asymmetry seems to be closely associated with sexual maturation. Copepodid stages are active, carnivorous and show predatory habits. Predation of adults of *T. forcipatus* on juveniles of chaetognath, *Sagitta bedoti* has been studied.

MEMBERS of the genus *Tortanus* are among the most common neritic copepods with a world wide distribution. While extensive work has been done on their systematics and geographical distribution, larval studies have not received due attention. Johnson<sup>1</sup> describes developmental stages of *T. discaudata* from Friday Harbour, Washington. No information seems to be available on the life-history of any other species of this genus. The present paper gives an account of developmental stages and predatory behaviour of *T. forcipatus*, the only species of the genus recorded from the inshore waters of Goa.

### Materials and Methods

Live as well as preserved specimens were examined for tracing different developmental stages of *T. forcipatus*. Nauplii and copepodid stages, picked up from freshly collected zooplankton samples were kept separately in finger-bowls and reared through at least one moult in the laboratory for getting the next higher stages. Details of methodology of collection and rearing of copepods were same as given earlier<sup>2-4</sup>. Nauplii were fed with mixed culture of diatoms. For the study of predatory habits of copepodid stages and adults of this species, diets comprising *Artemia* nauplii, small copepods (0.6-0.95 mm), fish eggs and larvae of the family Clupeidae and the juveniles of the chaetognath, *Sagitta bedoti* were tried. Copepodid stages and adults of *T. forcipatus* were kept separately in the culture jars containing 500-1000 ml of filtered and aerated sea water. Predation in the developmental stages was studied with the help of a hand lens and recorded hourly for 8 hr and experiments were repeated 2-3 times. All the animals given as food were well fed before the start of each experiment. Preserved specimens (8-12) of each stage were studied for calculating the average length of the larvae.

### Results

#### Developmental Stages

Only a few fertilized eggs hatched into the 1st nauplius after 24-36 hr at room temperature (25° ± 2°C) and salinity (32 to 35.5‰). No nauplii survived for more than 3 days under laboratory conditions. Nauplii of *T. forcipatus* differ from naupliar stages of other calanoid copepods mainly by their slight angular shape from 2nd naupliar stage onwards, presence of rows of minute bristles on the posterior surface of the body and by the caudal armature. The correct identity of the nauplii of this species taken from the plankton samples was established when 6 specimens of the last nauplius stage metamorphosed in the laboratory into the critical 1st copepodid stage from where it was easy to reach the adult stage.

*Naupliar stages* (Plate I, Figs. 1-6) — Stage I: Length = 0.129 mm. Body is egg-shaped (Fig. 1). Labrum is broader at the posterior surface and narrow at the anterior end. Few hair-like structures are discernible at its broader surface and remain unchanged in the subsequent stages. Antennule is long, slender and 3-segmented. Terminal segment is the longest with 3 setae, remaining 2 segments with a seta each. Coxopodite and endopodite of antenna with a masticatory hook. Exopodite is indistinctly 5-segmented, each segment with 1 seta. Endopodite of antenna is unsegmented with 2 short and 2 long setae. Exopodite of mandible is indistinctly 4-segmented, 1st 3 segments with a seta, the terminal segment with 2 setae. Endopodite is unsegmented and notched with 2 setae each above and below the notched portion. Mandible remains unchanged in the remaining stages except for addition of hooks on its basipodite. Caudal armature with 2 equal and slightly curved plumose spines.

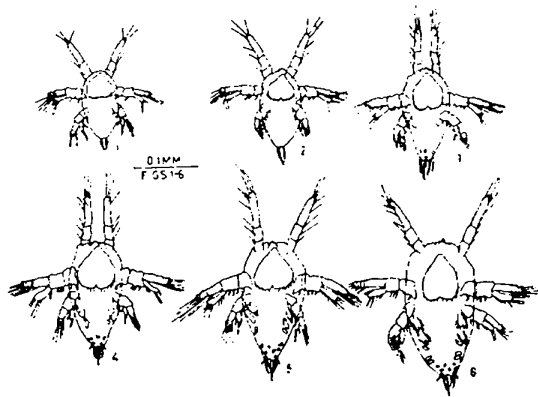


Plate I — Naupliar stages [1-6, stages 1st to VIth respectively];

Stage II: Length = 0.194 mm. Terminal and middle segments of antennule with an additional seta. Exopodite of antenna shows 6 setae, endopodite unchanged. Basipodite of both antennae and the mandibles with 1 more curved hook. Caudal armature shows 2 unequal and curved plumose spines (Fig. 2).

Stage III: Length = 0.260 mm. The changes from the previous stage are as follows:

The terminal segment of antennule with 1 additional dorsal and ventral seta (Fig. 3); exopodite of the antenna with 7 setae; 1 more hook on its basipodite; rudimentary 1st maxilla visible behind mandibles; presence of rows of minute bristles on the posterior surface of the body, caudal armature with 5 unequal spines of which 2 are plumose.

Stage IV: Length = 0.295. Endopodite of antenna shows 2 more setae on the postero-lateral surface (Fig. 4). Masticatory hooks of antennae and mandibles become stouter. Second maxilla appears as a bud-like structure behind the 1st maxilla which now shows 2 setae. Caudal armature with 6 spines of which 2 are plumose. Antennule, exopodite of antenna and rows of minute bristles remain unchanged.

Stage V: Length = 0.330 mm. The terminal segment of antennule with 1 more ventral seta. Endopodite of antenna also shows additional seta. Basipodite of mandible is now with 3 hooks. Maxillipeds are rudimentary. The rows of minute bristles are more (Fig. 5). Exopodite of antenna, 1st and 2nd maxillae and caudal armature are as in the previous stage.

Stage VI: Length = 1.350 mm. Terminal segment of antennule with 8 setae, 6 dorsal and 2 ventral. The 1st and 2nd maxillae are bilobed with 5 setae on each lobe. Rudiments of 1st and 2nd swimming legs are discernible. The other mouth parts, rows of bristles and the caudal spines remain unchanged. This stage moults into 1st copepodid stage.

The distinctive features of naupliar stages of *T. forcipatus* are compared with those of *T. discaudata* (Table 1).

*Copepodid stages* (Plate II, Figs. 7-35) — The general pattern of calanoid development is seen

TABLE 1 — COMPARISON OF CHARACTERS OF NAUPLIAR STAGES OF *T. forcipatus* WITH *T. discaudata*<sup>1</sup>

	<i>T. forcipatus</i>						<i>T. discaudata</i>					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
Length (mm)	0.129	0.194	0.26	0.295	0.33	0.35	0.12-0.14	0.185-0.205	0.230-0.26	0.3	0.32-0.34	0.36
Caudal armature	2 equal spines	2 unequal spines	5 unequal spines	6 unequal spines	6 unequal spines	6 unequal spines	2 equal spines	2 unequal spines	6 unequal spines	6 unequal spines	6 unequal spines	6 unequal spines
Setae on 3rd segment of antennule	3	4	6	6	7	8	3	4	7	9	9	9
Setae on exopodite of antenna	5	6	7	7	7	7	6	7	7	7	8	8
Setae on endopodite of antenna	4	4	4	6	7	7	3	5	5	7	7	7
Setae on exopodite of mandible	5	5	5	5	5	5	5	5	5	5	5	5
First maxilla	Absent	Absent	Bud-like	Bilobed	Bilobed with 2 setae	Bilobed with 5 setae	Absent	Absent	Bud-like	Bud-like	Bud-like	Bud-like with 3 bristles and 2 small spines
Second maxilla	do	do	Absent	Bud-like	Bud-like	Bud-like with 5 setae	do	do	do	do	do	Bud-like with 7 bristles
Maxilliped	do	do	do	Absent	Rudimentary	Rudimentary	do	do	do	Absent	Rudimentary	Rudimentary

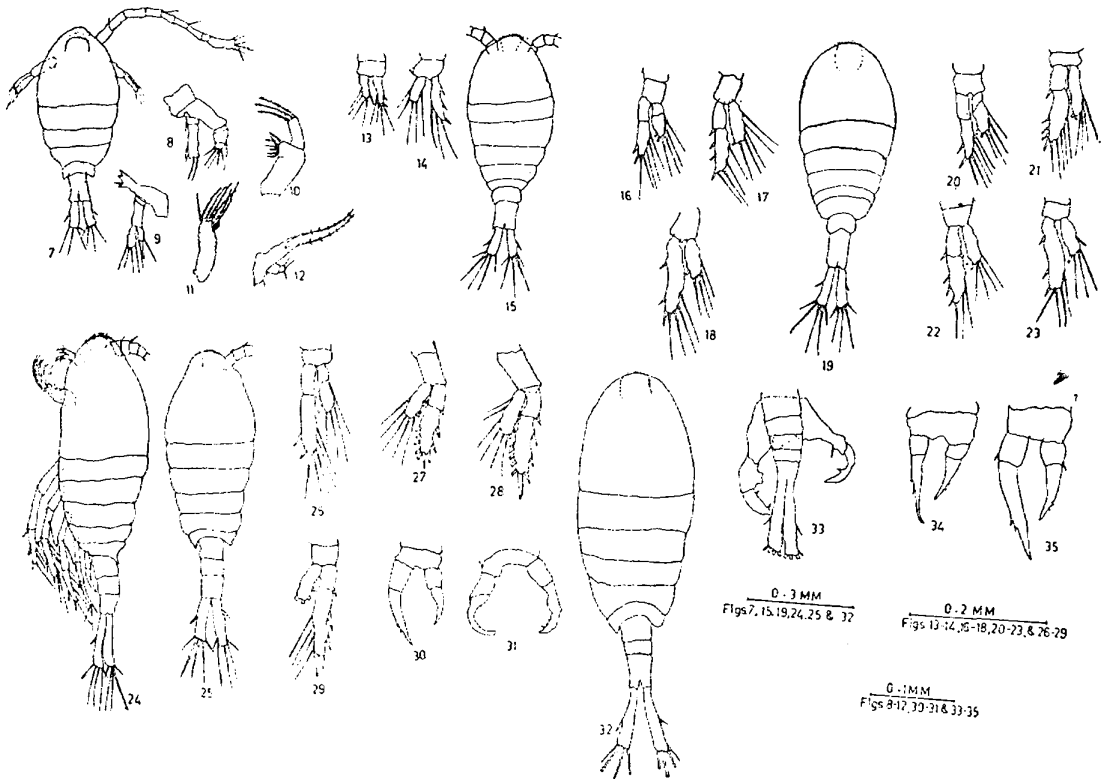


Plate II—Copepodid stages [7, stage I; 8 to 14, antenna, mandible, 1st maxilla, 2nd maxilla, maxilliped, 1st paired legs and 2nd paired legs respectively of stage I. 15, stage II; 16-18, 1st to 3rd legs respectively of stage II. 19, stage III; 20-23, 1st to 4th leg respectively of stage III. 24, stage IV (female); 25, stage IV (male); 26-29, 1st to 4th leg respectively of stage IV; 30, female 5th leg of stage IV; 31, male 5th leg of stage IV; 32, stage V (female); 33, male urosome segment and 5th leg of stage V; 34, female 5th leg of stage V; and 35, stage VI (adult) female 5th leg]

in these stages. The segmentation of body and number of spines and setae on the paired legs are their distinctive characters.

Stage I: Length = 0.537 mm. The body consists of 4 thoracic and 1 urosomal segment (Fig. 7). Caudal rami are symmetrical, each ramus with 4 setae and 1 spine. The symmetry of caudal rami is maintained up to the 3rd copepodid stage. The anterior portion of the cephalic region shows minute hairs which are visible in the subsequent stages also. Antennule is 9-segmented, generally directed upwards in live conditions. The mouth parts remain almost unchanged except for 2nd maxilla and maxillipeds which with each moult become stouter and show addition of plumose setae. The antenna is biramous, exopodite is 3-segmented with total of 6 setae (Fig. 8). The endopodite is 2-segmented having 4 setae on the distal segment, the proximal segment is notched with 1 seta. A small reddish-brown pigment spot is present at the base of the endopodite. The mandibular blade with 4 teeth, 3 large and 1 small (Fig. 9). Its palp shows small coxopodite and long basipodite, the latter bearing 2 rami with outer ramus 3 and inner 4 setae. The 1st maxilla (Fig. 10) shows a rounded lobe with 7 small bristles and a long segment armed with 3 stout plumose setae. The 2nd maxilla (Fig. 11) is

uniramous and indistinctly 6-segmented, terminal segment has 7 plumose bristles and 2 spines. Maxillipeds (Fig. 12) are biramous, outer branch shows 2 long and plumose bristles, the inner branch is 2-segmented with 3 setae. Two pairs of 1-jointed swimming legs are present, the 3rd is rudimentary. The number of setae and spines on the exopod and endopod of these legs are as shown in Figs. 13 and 14.

Stage II: Length = 0.73 mm. There are now 5 thoracic and 2 urosomal segments (Fig. 15). The number of thoracic segments remain unchanged up to adult stage. Antennule is 10-segmented. Exopods of the 2 anterior paired legs are 2-jointed and the 3rd leg is 1-jointed. Endopod of the 1st leg is 2-jointed whereas in the remaining 2 legs, it is 1-jointed. The number of setae and spines on the exopod are as shown in Figs. 16-18. Endopods of first 2 legs with a total of 6 setae whereas of the 3rd leg, with 5 setae.

Stage III: Length = 0.945 mm. The number of urosomal segments remain unchanged (Fig. 19). There are 4 pairs of legs (Figs. 20-23). The 1st and 2nd legs are similar to those of previous stage except for the number of spines and setae on the exopod of 2nd leg. Exopod of the 3rd leg is 2-jointed but endopod is 1-jointed. Exopod has a total of 4 spines

and 4 setae, endopod with 6 setae. Exopod and endopod of 4th leg are both 1-jointed, the former with 3 spines and 4 setae, the latter with only 5 setae.

Stage IV: The sexes can be differentiated at this stage, females bigger than the males ( $\text{♀} = 1.02$  mm,  $\text{♂} = 0.96$  mm). The number of body segments (5 thoracic and 3 urosomal) are the same in both the sexes (Figs. 24 and 25). Caudal rami are asymmetrical from this stage onwards, the right ramus is slightly larger than the left. Antennules are 15-segmented, they are straight in females and geniculated and bent in males. Mandibular teeth are very sharp and maxillipeds are now massive structures with 2 more plumose bristles than in the 1st copepodid stage. There are 4 pairs of legs, the 5th pair is developing in both the sexes. In the 1st leg, there is no change (Fig. 26). The 2nd and 3rd legs (Figs. 27 and 28) have their endopods with 8 setae. The exopod of the 4th leg (Fig. 29) is 2-jointed but endopod is still 1-jointed with 5 setae. Exopod shows 5 spines and 4 setae. The 5th leg is uniramous, asymmetrical in females (Fig. 30) and symmetrical in males (Fig. 31).

Stage V: The sexual differentiation is more pronounced. The urosomal segments are 3 in females and 4 in males (Figs. 32 and 33). The females are longer (1.30 mm) than the males (1.16 mm). In this stage, both the sexes assume almost all the structural characteristics of adults and the changes that follow are related to sexual maturation. Exopod and endopod of the 1st leg are both 3-jointed. Exopods of 2nd to 4th legs are 3-jointed but endopods still 2-jointed. The fifth leg in males become asymmetrical (Fig. 33) as is in the females (Fig. 34). The number of setae on the paired legs is given in Table 2.

Stage VI: This is the adult stage. The sexual dimorphism is distinct. The number of urosomal segments remain unchanged in females but there is addition of 1 urosomal segment in males than in the previous stage. Again the females are longer than the males, ( $\text{♀} = 1.96$  mm,  $\text{♂} = 1.40$  mm). The number of setae and spines on the legs in the adults are similar to the corresponding legs of the 5th copepodid stages.

*Females*—The lateral angles of the last thoracic segment are knob-like. The asymmetry of caudal rami is striking. Caudal furca is fused with the last urosomal (anal) segment. The 5th paired leg (Fig. 35) is well developed, asymmetrical and uniramous with 2 small spines at the end of each ramus.

*Males*—The lateral angles of the last thoracic segment are rounded. The 5th leg is uniramous and asymmetrical as in females but the spines on the other paired legs are stouter than those of the females.

#### Predation

While examining the preserved zooplankton samples, collected from the inshore regions of Goa, many adults of both sexes of *T. forcipatus* were observed to be holding by their prehensile organs (maxillae and maxillipeds) to the juveniles (4.4-6.2 mm) of *Sagitta bedoti* (Fig. 1). Majority of these calanoid copepods were noticed to hold on the caudal region (66%). The other area of catching in order of dominance is the region between the anterior fin and the posterior fin (32%), twisting the chaetognath at the point of the hold. Few specimens (8%) were observed to be attached in front of the anterior fin but rarely near the head of these chaetognaths. In addition to the

TABLE 2 — COMPARISON OF CHARACTERS OF COPEPODID STAGES OF *T. forcipatus* WITH *T. discandata*<sup>1</sup>

Swimming legs	<i>T. forcipatus</i>					<i>T. discandata</i>				
	I	II	III	IV	V	I	II	III	IV	V
Length (mm)	0.537	0.73	0.945	$\frac{\text{♀}}{\text{♂}} = 1.02$ $\frac{\text{♂}}{\text{♀}} = 0.96$	$\frac{\text{♀}}{\text{♂}} = 1.3$ $\frac{\text{♂}}{\text{♀}} = 1.16$	0.55	0.74	0.96	1.1	1.24-1.4
1st Total setae on exopod	4	5	5	5	6	4	5	6	6	6
1st Total setae on endopod	5	6	6	6	9	6	8	9	8	9
2nd Total setae on exopod	3	4	6	6	6	4	5	5	7	8
2nd Total setae on endopod	5	6	6	8	8	6	7	9	10	11
3rd Total setae on exopod	Rudimentary	4	4	6	6	Rudimentary	4	5	6	8
3rd Total setae on endopod		5	6	8	8		6	8	8	11
4th Total setae on exopod	Absent	Rudimentary	4	4	6	Absent	Rudimentary	4	6	8
4th Total setae on endopod			5	6	7			6	8	10
5th Total setae on endopod	do	Absent	Absent	2	2	do	Absent	Absent	3	4

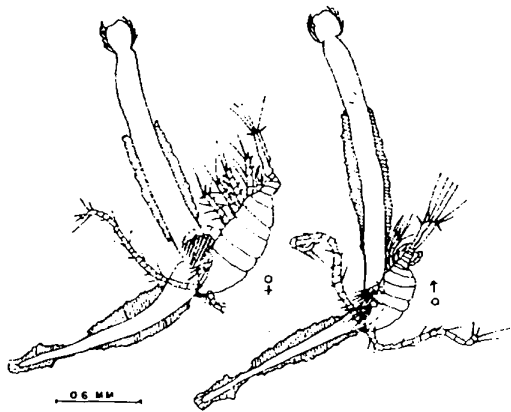


Fig. 1 — Predation of adults of both sexes of *Tortanus forcipatus* on juveniles of *Sagitta bedoti* (Chaetognatha)

chaetognaths, the adults of this copepod were seen attached to few fish larvae (16-21 mm size) of family Clupeidae.

These observations prompted further investigations on the predatory behaviour of *T. forcipatus*. A few experiments conducted in the laboratory indicate that copepodid stages and adults of the species under study never preyed on sergestids, crab zoea, polychaete larvae, barnacle larvae and juveniles of common chaetognaths other than *S. bedoti*. Study of predation and diet indicate that starvation did not influence the intensity of predation which was mostly dependent on the density of prey available. The attack on *Artemia* nauplii, copepods and fish eggs was instantaneous. Even the egg shells were eaten. The copepodid stages always avoided chaetognaths. The 1st and 2nd copepodid stages preyed only on *Artemia* nauplii and copepods, the latter being the major food item from 3rd copepodid stage onwards. The percentage of predation by the developmental stages is shown in Fig. 2A. However, the percentage is much higher for any of the 5 types of food when given separately to the developmental stages.

In spite of the fact that adults of *T. forcipatus* preyed on all the 5 types of food offered, their preference was for copepods. The pattern of predation by females and males is almost the same. The maximum and minimum number of copepods consumed is of *P. aurivilli* and *A. erythraca* respectively (Fig. 2B). In general, the ovigerous females were preyed upon more than those without eggs.

**Discussion**

*T. forcipatus* is one of the important constituents of neritic copepod population in the Goa waters. As in this species, the presence of 6 naupliar and 6 copepodid stage has also been reported in the life-history of *T. discaudata*<sup>1</sup>. Nauplii resemble those of *T. discaudata* in general shape but differ from them in length measurements, mouth parts and caudal armature. Naupliar stages of *T. discaudata* are longer and the mouth parts show more setae than those of *T. forcipatus* (Table 1).

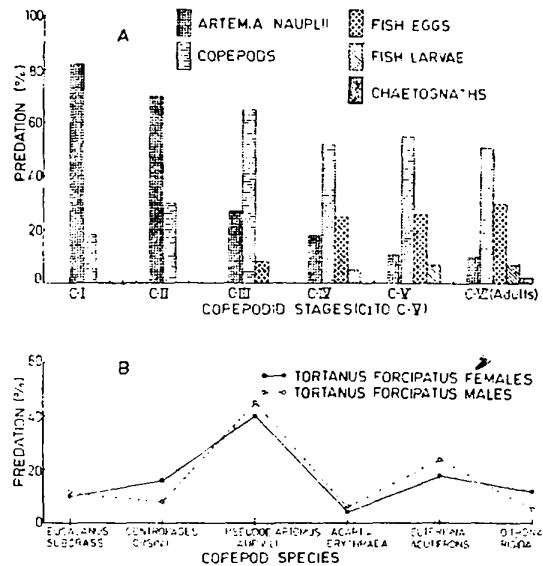


Fig. 2 — (A) Percentage of predation of copepodid stages and adults of *T. forcipatus* on 5 types of food. (B) Percentage of predation of adults of *T. forcipatus* on six common species of copepods

Mouth parts in the copepodid stages of the present species have few setae and are on the whole much simpler. Anraku and Mori<sup>5</sup> have reported that in the predatory species, the mouth parts are very simple. The 1st maxilla, 2nd maxilla and maxillipeds are modified as prehensile appendages as reported in *T. discaudata*. There are 5 thoracic and 2 urosomal segments in the 3rd copepodid stage of the present species (Plate II, Fig. 19). However, in the corresponding stage of *T. discaudata*, Johnson<sup>1</sup> has shown 6 thoracic and 2 urosomal segments. In the adult females of *T. forcipatus*, there are 5 thoracic and 3 urosomal segments as given by Mori<sup>6</sup> and Kasturirangan<sup>7</sup> in the adult females of *T. discaudata* and *T. barbatus* respectively. Johnson<sup>1</sup> has again shown 6 thoracic and 3 urosomal segments in the adult females of *T. discaudata*. The number of body segments in the adult males of *T. forcipatus* is the same as in the males of *T. discaudata*. Copepodid stages and adults of *T. forcipatus* are smaller in size than those of *T. discaudata*. Mori<sup>6</sup> has also given the length range of the adult females to be 2.2 to 2.8 mm for *T. discaudata* and 1.2 to 2 mm for *T. forcipatus*. The pattern of segmentation of the paired legs in the copepodid stages and adults of both of these species is similar but the number of setae in the former is more than the latter (Table 2).

*T. forcipatus* is a predatory species like the other members of this genus. Accounts of predation on fish eggs and larvae by the copepods have been given by earlier workers<sup>8-10</sup>. During the present studies, copepodid stages and adults of *T. forcipatus* have been observed to feed on a variety of animals including *Artemia* nauplii, copepods, juveniles of chaetognaths and fish eggs and larvae. The present

observation of predation of a calanoid copepod on the juveniles of chaetognaths is quite interesting.

**Acknowledgement**

The author is grateful to Dr S. Z. Qasim for the facilities and encouragement. Thanks are due to Dr M. J. George for useful suggestions.

**References**

1. JOHNSON, M. W., *Biol. Bull.*, **67** (1934), 182.
2. GOSWAMI, S. C., *Indian J. mar. Sci.*, **1** (1972), 128.
3. GOSWAMI, S. C., *Indian J. mar. Sci.*, **4** (1975), 60.
4. GOSWAMI, S. C., *Mahasagar, Bull. natn. Inst. Oceanogr.*, **8** (1975), 123.
5. ANRAKU, M. & MORI, M., *Limnol. Oceanogr.*, **8** (1963), 116.
6. MORI, T., *The pelagic Copepoda from the neighbouring waters of Japan* (Soyo Co. Inc., Tokyo, Japan), 1964.
7. KASTURIRANGAN, L. R., *Indian National Committee on Oceanic Research*, Publ. No. 2, 1963, 1.
8. DAVIS, C., *Ohio J. Sci.*, **59** (1959), 101.
9. LAKSHMANAN, M. A. V., *J. Bombay nat. Hist. Soc.*, **66** (1969), 391.
10. LILLELAND, K. & LASKAR, R., *Fish. Bull.*, **69** (1971), 655.