# STUDIES ON THE CLADOCERANS OF THE SOUTH-WEST COAST OF INDIA

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BY

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This is to certify that this thesis is an authentic record of the work carried out by the candidate under my supervision and guidance in the Department of Aquatic Biology and Fisheries, University of Kerala and that no part thereof has been presented for any other degree, diploma or associateship.


1/2/95

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## DECLARATION

*I hereby declare that this thesis is a bona fide record of research work done by me under the guidance of Dr. C.M. Aravindan, Professor, Department of Aquatic Biology and Fisheries, Trivandrum, and that no part thereof has been presented earlier for any degree, diploma or similar title of any other University.*

Rani Mary Jacob

**Rani Mary Jacob**

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CONTENTS

# PREFACE

The Cladocera, commonly termed as the "Water Fleas", due to the hops and leaps taken by them, belong to subclass Branchiopoda, a group of lower crustaceans, which is well represented in freshwater plankton, but only a few species of them are found in brackish waters and fewer still in the sea.

Our knowledge of this group from Indian waters is rather scanty, despite the fact that during certain seasons they make up a predominant portion of the zooplankton, and in such cases they play an important role in the food cycle of the aquatic ecosystem. Further, the high reproductive potential through parthenogenesis is a remarkable biological and ecological feature by which the cladocerans are distinguished from all other planktonic crustaceans. The significance of these organisms as food for both the fry and adult fish was first indicated by Frobes (1883) (as quoted by Pennak, 1953) and since then the importance of their study has often been emphasised and this group has become an attractive subject of intensive research by Fishery Biologists.

A considerable body of information has accumulated chiefly with the systematics and the distribution of this group from the different parts of India and recently a monograph on the cladoceran from this country was published by Michael and Sharma (1988) under Fauna of India Series. However, except for a preliminary account by Raghunathan (1988)

comprising of ten species from northern Kerala there is practically no detailed account on the cladoceran fauna of Kerala in southern India. Hence the need for such a study was felt and the present study on the planktonic cladocerans of the southern Kerala was initiated in February 1992.

While reviewing the systematics of cladocerans along the southern Kerala coast, it was noticed that the moinids which are important live food for prawns and fishes were very common in the estuarine and freshwaters of Kerala. Further, a perusal of literature revealed that the population structure and reproductive biology of *Moina micrura* had not been adequately studied in Kerala. Another moinid, *Moinodaphnia macleayi* which is also an ideal live food for many aquarium fishes is also available and there is practically no account on the biology of this species and hence it was thought worth-while attempting a study on its development and also on some aspects of its biology.

In spite of notable studies on the distribution and abundance of marine cladocerans, detailed information on the reproduction of marine cladocerans in Indian waters is still lacking and hence it was felt that more studies on the population characteristics and reproductive biology of two common marine species namely *Evadne tergestina* and *Penilia avirostris* will further enhance our knowledge on Indian Cladocera.

In view of this, a study on the taxonomy, ecology and biology of the cladocerans of the south-west coast of India was taken up and the results of the investigations are embodied in the present thesis entitled "Studies on the cladocereans of the South-west coast of India".

The thesis is presented in six chapters.

Chapter I deals with taxonomy of planktonic cladocerans of southern Kerala and is mostly a redescriptive work. It includes a brief description of 19 species along with illustrations on their salient features to give visual impact for the written text. A list of Cladocera recorded from Kerala is also furnished.

Chapter II comprises the hydrography and population characteristics of planktonic cladocerans from two biological realms--a)Marine and b) Backwater. The influence of physico-chemical parameters on the population density and distribution has also been investigated.

Chapters III & IV furnish accounts on the reproductive biology of two species each in marine and backwater biotopes. Herein are included egg production, development and the growth pattern. The effect of physico-chemical parameters on the brood size and brood composition has also been elucidated.

Chapter V is set exclusively to explain the results of diurnal behaviour of the cladocerans in the above two biotopes.

Chapter VI reveals the nature of incidence of cladoceran fauna in the southern Kerala region. Nineteen species have been identified of which four are new records to Kerala State. The species association and a tabulated statement is presented showing the nature of distribution of cladoceran in various localities.

Necessary diagrams to illustrate the biotopes as well as the morphological, developmental and growth factors accompany the descriptions.

# CHAPTER I

## SYSTEMATIC ACCOUNT OF CLADOCERANS OF SOUTHERN KERALA

# INTRODUCTION

The term Cladocera was coined by Latreille (1829) and it is derived from the Greek words Klados (= branch) and Keras (= horn), after the two branched second antennae, which are the chief organs of locomotion in these animals.

An exhaustive review of literature concerning the 'Water Fleas' (cladocerans) has recently been provided by Sharma (1991). It would be redundant to go over the ground once again. Nevertheless, a brief survey of the history of work on the systematics of Cladocera seems warranted in this thesis and is provided below.

In the twelfth edition of the "Systema Naturae" Linne (1767) grouped all Branchiopoda known to him under one genus, *Monoculus* (= with one eye). But the outline of our present systematical arrangement was given by Muller (1785), who was the first to subdivide Linne's *Monoculus* into several genera: *Daphnia, Lynceus* and *Polyphemus*. Latreille (1817) used Muller's system and called the Branchiopoda (= Entomostraca Muller) the fifth order of the Crustacea. In 1829 he distinguished the Branchiopoda (= gill feet) as the first order within the Entomostraca; the latter was, in this new edition, the second main division of the Crustacea (the first one is the Malacostraca). He used here, for the first time, the name Cladocera for one of the groups of his Branchiopoda--Lophyropa. To this group belong his "*Polyphemus*", with only one known genus at that time: *Polyphemus* (Muller, 1785).

Milne-Edwards (1840) was the first who divided the Branchiopoda into two independent orders, the Phyllopoda and the Cladocera. This scheme was followed for a long time, with only minor changes (Wagler, 1927). The unnaturalness of this scheme was apparent to Calman (1909) and he suggested that the subclass Branchiopoda be divided into the four orders namely Anostraca, Notostraca, Conchostraca and Cladocera.

The order Cladocera was originally classified into two broad divisions called Calyptomera and Gymnomera based on the relative size of the carapace covering the body (Sars, 1865). Litynski (1916) pointed out that the subdivision of the Cladocera into Calyptomera and Gymnomera should be considered tentative. Further, classification of these divisions, based on gross morphology, led to the establishment of four tribes namely Ctenopoda, Anomopoda, Onychopoda and Haplopoda, the first included under the Calyptomera, the other three under Gymnomera. Subsequently Eriksson (1934) while pointing out the distinctiveness of the genus *Leptodora* (Family : Leptodoridae) in having a naupliar stage, considered it more an aberrant cladoceran. Thus, while retaining this genus within the Haplopoda, Eriksson grouped all the other tribes as Eucladocera including the Ctenopoda, Anomopoda and Onychopoda. Later on Brooks (1959), in accordance with the taxonomic rules of formulating family group names, preferred to elevate Sars' tribes to super-families, thus replacing Ctenopoda by Sidoidea, Anomopoda by Chydoridae and Onychopoda by Polyphemoidea. According to this classification the order Cladocera had two suborders i.e., Haplopoda

with a single family Leptodoridae Sars and Eucladocera having the above super-families. These super-families, in turn, included seven families : Sidoidea with the families Sididae and Holopedidae; Chydoroidea with Daphniidae, Bosminidae, Macrothricidae and Chydoridae, and Polyphemoidea with the family Polyphemidae. While presenting a critical world review of the genera *Moina* and *Moinodaphnia* Goulden (1968) erected a new family Moinidae. These two genera had earlier belonged to the family Daphniidae. In a very recent monographic treatment of the world Chydoridae, Smirnov (1971) enumerated a total of eleven cladoceran families namely Sididae, Daphniidae, Moinidae, Bosminidae, Macrothricidae, Chydoridae, Polyphemidae, Leptodoridae, Podonidae, Holopedidae and Cercopagidae.

Thus the taxonomy of cladocerans has been a subject of sporadically critical study since the early nineteenth century, but has been taken up seriously by taxonomists only during the past few decades. In this context, the works of Baird (1850), Lilljeborg (1900), Keilhack (1909), Birge (1918), Henry (1922), Wagler (1937), Bening (1941), Dolgopolskaja (1958), Herbst (1962), Sramek *et al.* (1962), Manuilova (1964), Scourfield and Harding (1966), Flossner (1972), Della Croce (1974), Dumont and Velde (1977), Fernando (1974, 1978), Rajapaksa and Fernando (1982) and Idris (1983) require special mention since they have been of fundamental importance in formulating the modern classification of the Order Cladocera.

Studies on Indian cladocerans date back to the second half of the nineteenth century. It was perhaps Baird (1860) who reported for the first time cladocerans from India. Then Gurney (1906, 1907) reported several Indian cladocerans. Daday (1908) reported about Cladocera of Tibet, while Arora (1931) made exhaustive studies on the Entomostraca of Lahore, Punjab. Brehm (1936) studied the cladocerans of Yale-north India expedition and daphnids recorded by Yale-north India expedition were separately highlighted by Brehm and Waltereck (1939). Subsequently Brehm (1950, 1953, 1963) reported a few more cladocerans from India including a new species of *Moina*. Biswas (1964, 1965, 1971, 1980) published a series of papers on cladocerans of Rajasthan, Assam and adjacent hill states of northeastern India. He described one new species each of the genus *Latona* and *Chydorus* respectively from Rajasthan. Petkovski (1966) examined Ganapati's collections from Ajma reservoir and Nimeta Water Works, Baroda city and documented eleven species including the description of *Indialona ganapati*. This was followed by the contribution to the cladoceran fauna of Kashmir by Das and Akhtar (1970). Nayar (1971) reported more cladocerans from Rajasthan, Michael (1973) from Madurai region, Patil (1976) from Shillong area, Nasar (1977) from Bihar and Sharma (1978) from Calcutta and nearby areas. Michael and Hann (1979) and Sharma and Tiwari (1981) carried out further studies on head pores of some species of Chydoridae. Durgaprashad (1980) made systematic studies on Branchiopoda of Guntur and nearby areas of Andhra Pradesh. Cladocera of Dharwad

region in Karnataka State were studied in detail by Patil and Gouder (1982). Studies on planktonic cladocerans of Tamil Nadu were made by Raghunathan (1983, 1984, 1985a,b). Latitudinal distribution studies of Indian Cladocera were made by Fernando and Kanduru (1984). A review on taxonomic studies and biogeography was provided by Sharma and Michael (1987).

With reference to estuaries and coastal waters, *Penilia avirostris* Dana and *Evadne tergestina* Claus were for the first time reported from Indian waters by Brehm (1953). Studies on Cladocera of east coast were made by Prasad (1954) from Gulf of Mannar and by Muthu (1956) from Madras coast. Likewise Rajagopal (1962) recorded *Evadne tergestina* and *P. avirostris* from Madras coast. From Porto-Novo waters, Sundarraj and Krishnamurthy (1975) noticed both *Penilia* sp. and *Evadne* sp. Kaliyamurthy (1975) observed *Penilia and Evadne* from Pulicat Lake. From West coast, Mukundan (1967), Krishnamurthy (1967), Madhupratap (1981), Rani Mary Jacob *et al.* (1986) recorded both these species. Also Della Croce and Venugopal (1972) reported occurrence of *E. tergestina* and *P. avirostris* from coastal waters of Arabian Sea. From Cochin backwaters George (1958), Pillai and Pillai (1975) recorded both *E. tergestina* and *P. avirostris.* Balakrishnan Nair *et al.* (1984, 1985) observed the marine species in Kadinamkulam and Ashtamudi backwaters. Naomi *et al.*(1989, 1994) studied the occurrence of *E. tergestina* and *P. avirostris* in the eastern Arabian Sea.

It is seen that cladoceran fauna of Kerala has received very little attention as against that from other parts of India, where continual efforts are being made to study them. Recently a monograph on the cladoceran taxa known from India was published by Michael and Sharma (1988) and also a preliminary report on freshwater cladocerans by Raghunathan (1988), but these works have contributed very little to the cladoceran fauna of South Kerala region. Hence it was felt desirable to attempt a taxonomic study on the species occurring in different hydrographic conditions as part of the present study. Further salient features of each species together with illustrations were also necessary anticipating that it would be of some help to future workers.

## MATERIAL AND METHODS

During 1992-1993 samples were collected from marine habitats, namely Vizhinjam and Kovalam, the brackishwaters of Neendakara, Ashtamudi Lake, Veli Lake, Kadinamkulam Lake, the freshwaters of Pamba, Achencovil and Periyar rivers and also from temple ponds and tanks in and around Trivandrum district. The localities of sample collection are shown in Fig. I.

Cladoceran samples were collected using plankton nets of 12.5 and 50 cm mouth diameter. Two mesh sizes (0.4 mm and 0.135 mm) were used. Samples were immediately fixed and preserved in 4% formaldehyde.

The sorting and identification of cladocerans were done with a stereo-dissecting microscope. The specimens were mounted on micro-slide (without cover slip) and a few drops of glycerine were added to hold the specimen. For detailed study of the particular parts of the animal, the specimens were dissected by a fine dissecting needle. All the illustrations given are camera lucida drawings made with the aid of a compound microscope.

For detailed observation of the head shield the technique adopted was that of Megard (1965). The specimens were placed on the watch glass and a few drops of concentrated HCl were added. This was heated until acid fumes were formed. The specimens were then transferred to mounting medium where the head shield was separated using dissecting needle. Since the head pores were structurally the same as was recorded by Michael and Sharma (1988) these illustrations are avoided here.

The key used in separating the different families is that of Smirnov (1971). For genera and species no single key can be cited as quite effective but the works of Brooks (1957, 1959), Frey (1959, 1962), Goulden (1968), Smirnov (1974, 1976), Idris (1983), Michael and Sharma (1988) and Battish (1992) served well in delineating them properly.

Of the eleven extant families of the order Cladocera, only seven are represented in the present collection; they are: Sididae, Daphniidae, Moinidae, Bosminidae, Macrothricidae, Chydoridae and Podonidae. Since systematics was not the only aspect of the present

study, it must be confessed that more attention could not be paid to it, resulting in the recording of only 19 species. Further the aim of the present study has been to give as detailed and accurate descriptions and illustrations as possible, even though almost all these species have been reported earlier from India.

No attempt is made here to give a complete synonymy for any species, instead only some important works pertaining to each species are mentioned. In any such work wherein an exhaustive synonymy and/or illustrations are provided, such works are referred to and are indicated by 'literature and synonymy' in parenthesis.

The general distribution of each species is given under two heads--in India and elsewhere, the latter refers to the presently known distribution of each species on a global basis.

Though most of the species are amply illustrated by the earlier workers, the specimens dealt with in this thesis are deposited in the reference collection of the Department of Aquatic Biology and Fisheries of the University of Kerala at Trivandrum.

# RESULTS

## LIST OF SPECIES

Class : CRUSTACEA Pennant, 1777*
Subclass : BRANCHIOPODA Latreille, 1817
Order : CLADOCERA Latreille, 1829

Family : SIDIDAE Baird, 1850
1. *Penilia avirostris* Dana, 1849
2. *Diaphanosoma sarsi* Richard, 1894
3. *Latonopsis australis* Sars, 1888

Family : DAPHNIIDAE Straus, 1820
4. *Ceriodaphnia cornuta* Sars, 1885
5. *Scapholeberis kingi* Sars, 1903

Family : MOINIDAE Goulden, 1968
6. *Moina micrura* Kurz, 1874
7. *Moinodaphnia macleayi* (King, 1853)

Family : BOSMINIDAE Sars, 1865
8. *Bosminopsis deitersi* Richard, 1895

Family : MACROTHRICIDAE Norman & Brady, 1867
9. *Macrothrix laticornis* (Jurine, 1820)

Family : CHYDORIDAE Stebbing, 1902

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* As given by Abele G. Lawrence 1982

Subfamily : CHYDORINAE Stebbing, 1902

10. *Chydorus sphaericus* (O.F. Muller, 1776)
11. *Chydorus faviformis* Birge, 1893
12. *Chydorus barroisi* Richard, 1894
13. *Dunhevedia crassa crassa* King, 1853
14. *Dadaya macrops* (Daday, 1898)

Subfamily : ALONINAE Frey, 1967

15. *Alona davidi punctata* (Daday, 1898)
16. *Biapertura karua* (King, 1853)
17. *Oxyurella singalensis* (Daday, 1898)
18. *Indialona globulosa* (Daday, 1898)

Family : PODONIDAE Mordukhai-Boltovskoi, 1968

19. *Evadne tergestina* Claus, 1877

## CLASSIFICATION AND DESCRIPTION OF SPECIES

ORDER - CLADOCERA Latreille, 1829

Head distinct with large median eye, some species with an ocellus; head bears antennules and antennae; antennule, in most cases with olfactory setae laterally or terminally; antennae attached close to the posterior margin of the head, large and biramous (except Holopedidae); body compact, with faint segmentation and completely enclosed by carapace (except in Polyphemidae and Leptodoridae); four to six pairs of thoracic appendages; in males first pair of legs modified and bear hooks; post-abdomen small and usually bent under the thorax and terminates in pair of claws and 2 long abdominal claws; reproduction mainly parthenogenetic.

### KEY TO FAMILIES OF CLADOCERA

1.a - Body and legs covered with valves .....2

b - Body and legs not covered with valves.....7

2.a - Six pairs of legs of similar structure ...SIDIDAE Baird, 1850

b - Five or six pairs of legs of different structure.....3

3.a - Dorsal ramus of antennae 4 segmented, ventral ramus three segmented.....4

b - Dorsal and ventral rami 3 segmented .....6

4.a - Antennules short and immobile .....DAPHNIIDAE Straus, 1820

b - Antennules long and mobile.....5

5.a - Antennules situated on antero-ventral side of the head .....MACROTHRICIDAE Norman & Brady, 1867

b - Antennules located on the ventral margin of the head but not at anterior end .....MOINIDAE Goulden, 1968

6.a - Antennules fused with the rostrum, forming a snout like structure .....BOSMINIDAE Sars, 1865

b - Antennules or base of antennules covered by head shield or rostrum .....CHYDORIDAE Stebbing, 1902

7.a - Head short .....8

b - Head oblong .....LEPTODORIDAE Lilljeborg, 1861

8.a - Caudal appendages well developed, slightly shorter than body ..... POLYPHEMIDAE Baird, 1845

b - Caudal appendages very short .....
.....PODONIDAE Mordukhai Boltovskoi, 1968

## Family I. SIDIDAE Baird, 1850

Head large, cervical sinus present; antennule large, movable, with olfactory setae (except in *Penilia* where antennules of females small and truncated). Antennae biramous and the ventral ramus of antennae with terminal setae only. Eyes large, ocellus small or absent. Six pairs of identical flattened legs.

## Genus 1. *Penilia* Dana, 1849

Body and legs covered by bivalve carapace; antennules of females small and truncated, sensory setae terminal.

Type: *Penilia avirostris* Dana, 1849

### 1. *Penilia avirostris* Dana, 1849
(Fig. 1, a-e)

*Penilia avirostris* Dana, 1849, p. 47.

*P. avirostris* Dolgopolskaja, 1958, p. 38; figs. 7-12 (literature and synonymy)

Material : Several specimens (parthenogenetic females) collected off Vizhinjam, Kovalam, Neendakara and Veli Lake. A single male and sexual female could be obtained from Vizhinjam.

Description : Head with prominent rostral points in females, roundish in males. Antennules small and truncated in female while it is as long as the carapace in adult males. Six pairs of legs, most posterior reduced; strong hook at the distal end of the first leg in males. Copulatory organs longer than post-abdomen in adults. All the free carapace edged with spines; a large spine at the infero-posterior angle of carapace.

Size : Female - 800-1100 µm

Male - 890 µm

Distribution in India : Along the Indian coasts it is quite common in the inshore waters and also in estuaries and backwaters.

Elsewhere : This is widely distributed in the coastal waters of tropical oceans and in warm temperate regions, but rarely in open waters.

## Genus 2. *Diaphanosoma* Fischer, 1850

Head large and without rostrum, fornix and ocellus. Head and body distinctly divided; eye large. Antennules short and truncated. Ventral margin of the valves with or without duplicature, postero-ventral margin usually with a series of marginal denticles. Post-abdomen without anal spines; claws with 3 long basal spines.

Type: *Sida brachyura* (Liévin, 1848).

### 2. *Diaphanosoma sarsi* Richard, 1894
(Fig. 2, a-e)

*Diaphanosoma sarsi* Richard, 1894, p. 365; pl. 15, figs. 1-8.

*D. sarsi* Michael & Sharma, 1988, p. 44; fig. 9, a-d (literature and synonymy)

Material : Several specimens collected from Ashtamudi, Kadinamkulam and Veli lakes. All of them were parthenogenetic females.

Description : Female with characters of the genus; antennules small with truncated olfactory setae and a slender flagellum. Ventral

margin convex, duplicature forming wide angle (more than $90^{o}$) with the margin anteriorly; postero-ventral corner broadly rounded and armed with a series of small denticles (12-22) followed by a series of fine setules and ending with 2 long distinct spinules (Fig. 2e). Post-abdomen narrow and with curved and sharply pointed claw with three basal spines decreasing in size proximally. Anal denticles absent; lateral surface with groups of slightly longer spinules.

Size : 560-650 $\mu$m

Distribution in India : Madurai, Bihar, Rajasthan and West Bengal

Elsewhere : Pantropical

## Genus 3. *Latonopsis* Sars, 1888

Head large and without a distinct rostrum. Dorsal ramus of antennae 2-segmented and ventral ramus 3-segmented. Antennule long and segmented. Posterior margin of valves with long setae. Shell gland distinct.

Type : *Latonopsis australis* Sars, 1888.

### 3. *Latonopsis australis* Sars, 1888
(Fig. 3, a-f)

*Latonopsis australis* Sars, 1888, p. 6; pl. 1, figs. 1-6.

*L. australis* Michael & Sharma, 1988, p. 41; fig. 8, a-e (literature and synonymy).

Material : Several specimens collected from Veli Lake, Periyar River and a tank in Trivandrum. No males in the material examined.

Description : Body oblong. Head large, indistinctly separated from the body (Fig. 3a ) Rostrum absent. Eye situated in the antero-dorsal end of head. Ocellus minute and located near the base of labrum. Antennules long and segmented, first segment broad and short with groups of short setae, flagellum has more than 10 joints and finely setose; Antennae short and broad with half the length of the body. Ventral margin of valves with numerous long setae, three or four setae at the postero-ventral corner longer. Post-abdomen rather short and without anal denticles, lateral surface with 9 or 10 pointed denticles. Proximal end of the post-abdomen bears two long abdominal setae.

Size : 710 $\mu$m

Distribution in India : Madurai, Maharashtra, Rajasthan. Recorded herein for the first time from Kerala.

Elsewhere : Australia, Oriental Regions.

## Family II DAPHNIIDAE Straus, 1820

Antennules small and immobile. Antennae long, setae 0-0-1-3/1-1-3. Five pairs of legs, the first two pairs prehensile, the fifth with large curved setae. Post-abdomen distinctly demarcated from body, more

or less compressed, always with anal spines; claws denticulate or pectinate; never with basal spine. Eyes large, ocellus small or absent.

## Genus 4. *Ceriodaphnia* Dana, 1853

Body size small (less than 1 mm); head with or without horn-like process. Cervical depression present; postero-dorsal corner of valve with two short, pointed spines.

Type : *Ceriodaphnia quadrangula* (O.F. Muller, 1776)

### 4. *Ceriodaphnia cornuta* Sars, 1885
(Fig. 4, a-d)

*Ceriodaphnia cornuta* Sars, 1855, p. 26; pl. 5, figs. 1-3.

*C. cornuta* Michael & Sharma, 1988, p. 51; fig. 12, a-b (literature and synonymy).

Material: Several parthenogenetic females collected from Ashtamudi Lake and Periyar River. No males collected.

Description : Body rounded or oval. Head produced in front of antennules as pointed rostrum. Head also with horn-like process on anterior margin in some specimens, separated from body by a cervical depression. Eyes large, ocellus small. Antennules short, broad with sensory setae on apex. Antennae with characteristic setae of daphnids, 0-0-1-3/1-1-3. Valves with hexagonal reticulations and postero-dorsal corner with two pointed

processes. Post-abdomen broad with five anal spines. Claw long, stout almost as long as dorsal-distal margin and finely setulate.

Size : 480 μm.

Distribution in India : Known from West Bengal, Bihar, Kerala, Rajasthan, Tamil Nadu, Maharashtra and Meghalaya.

Elsewhere : Cosmotropical

## Genus 5. *Scapholeberis* Schoedler, 1858

Posterior margin of valves almost straight vertically, ventral margin straight horizontally with spine on postero-ventral corner. Anal groove of post-abdomen evenly rounded with 4 or 5 denticles; body oval or almost quadrate, not compressed; rostrum, fornix well developed.

Type : *Daphnia mucronata* O.F. Muller, 1785

### 5. *Scapholeberis kingi* Sars, 1903
(Fig. 5, a-e)

*Scapholeberis kingi* Sars, 1903, p. 8; pl. 1. fig. 2, a-e.

*S. kingi* Michael & Sharma, 1988, p. 73; fig. 20, a-c (literature and synonymy)

Material : Few parthenogenetic females from Veli Lake and also from a pool in Neyyatinkara, Trivandrum.

Description : Body more or less quadrate, slightly compressed laterally. Head relatively small and slightly depressed, rostrum rounded. Eyes large, ocellus small. Antennules short and attached to posterior margin of rostrum, with a long sensory setae and a group of six sensory setae on the apex. Antennae with setae 0-0-1-3/1-1-3. Fornix well developed; valves almost rectangular, postero-ventral corner of each valve produced with a short spine pointing backwards; ventral margin of valves with fine setae; post-abdomen well defined with 4-5 anal spines. Claw long, slightly curved with spinules along concave surface, abdominal process developed.

Size : 710 µm

Distribution in India : Recorded from West Bengal, Tamil Nadu, Kashmir and Nilgiri Hills, Meghalaya, Assam and Kerala (northern).

Elsewhere : Africa, Australia, North America, Sri Lanka, Germany, China, Thailand and Indonesia.

## Family III MOINIDAE Goulden, 1968

### Genus 6. *Moina* Baird, 1850

Head large, rounded, sometimes with depression above eye; body thick and heavy; valves somewhat rhomboid, not wholly covering the body, ocellus absent; antennules covered by short spines and long fine

setules laterally. Post-abdomen with bident tooth and 3-16 feathered teeth.

6. *Moina micrura* Kurz, 1874
(Fig. 6, a-h)

*Monoculus rectirostris* Jurine, 1820, p. 134; pl. 13, figs. 3-4
*Moina micrura* Kurz, 1874, p. 13, pl. 1; fig. 1
*M. micrura* Michael & Sharma , 1988, p. 86; fig. 26 a-f (literature and synonymy)

Material : Parthenogenetic females (both ovigerous and non-ovigerous) were collected from Veli Lake. Also from Ashtamudi Lake and a tank in the Department of Aquatic Biology and Fisheries, Trivandrum. Males and resting eggs were collected from the tank.

Description : Body elliptical, head large with a distinct cervical depression. Eyes large, ocellus absent. Antennules long and movable covered by several rows of short spinules and long fine setules, with a group of sensory setae on the apex (Fig. 6d). Antennal setae reach the posterior margin of valves. Valves thin, slightly reticulated, dorsal margin rounded, ventral margin with a series of spines, followed by spinules distally; posterior corner rounded with hook like denticles. Abdomen short and with distal conical part. Post-abdomen with bident and 7-9 feathered lateral setae, decreasing in size proximally. Claw long, curved slightly, convex surface serrated on proximal third, concave surface pectinate at the base and with fine setae distally.

Antennules of male very long and stout modified into clasping organ, denticulate with small recurved hooks at apex and also with basal setae. First leg with hook.

Size : Female 500-1100 µm
Male 690 µm

Distribution in India : Tamil Nadu, Kerala, West Bengal, Nilgiri Hills and Rajasthan.

Elsewhere : Africa, Syria, USSR, France, Philippines.

## Genus 7. *Moinodaphnia* Herrick, 1887

*Moinodaphnia* is closely related to genus *Moina* Baird. It was erected by Herrick in 1887 because of its difference from *Moina* in the shape of the head and carapace which completely covers the body and in the presence of an ocellus. Antennules long with one long lateral setae.

Type : *Moinodaphnia macleayi* (King, 1853).

### 7. *Moinodaphnia macleayi* (King, 1853)
(Fig. 7, a-f)

*Moina macleayii* King 1853, p. 251; pl. 5.
*Moinodaphnia macleayii* Sars 1901, p. 16; pl. 3, figs. 1-10.
*M. macleayi* Michael & Sharma 1988, p. 94; fig. 28, a-e (literature and synonymy).

Material : Several parthenogenetic females (ovigerous and non-ovigerous) from Veli Lake and a few females from Kadinamkulam Lake.

Description : Body compressed and crested dorsally with elliptical valves completely covering the body except head. Head small and trigonal in shape. Eyes large; very slight supraocular depression. Ocellus characteristic of the genus located much closer to the base of antennules than to the eye. Antennules long and slender with a long lateral seta and a cluster of sensory setae on the apex (Fig. 7c). Distal segment of the four segmented exopod of antenna with four setae. Ventral margin of valve rounded with marginal spines. Abdomen has well developed abdominal process. Post-abdomen with tapering distal end, feathered spines and a bident spine; claws without pecten but with fine setae.

Size : 600-880 µm

Distribution in India : South India and West Bengal.

Elsewhere : Widely distributed in tropics.

## Family IV BOSMINIDAE Sars, 1865

Body short and rounded or oval. Ocellus absent; six pairs of legs; no abdominal process and hepatic caecae. Antennules immobile and large.

## Genus 8. *Bosminopsis* Richard, 1895

Antennules united at base and diverging at apex; with several sensory setae on ventral side.

Type : *Bosminopsis deitersi* Richard 1895.

### 8. *Bosminopsis deitersi* Richard, 1895
(Fig. 8, a-d)

*Bosminopsis deitersi* Richard, 1895, p. 96; figs. 1-4.

*B. deitersi* Michael & Sharma, 1988, p. 99; fig. 30, a-e.(literature and synonymy)

Material : Several parthenogenetic females (ovigerous and non-ovigerous) from Pamba River, Achencovil River, Ashtamudi Lake and Periyar River.

Description : Body oval or round, maximum height at posterior part of body. Head large with long rostrum. Antennules long, united with each other at base and diverging at apex, with 6-8 sensory setae on ventral side. Antennae with both rami, 3 segmented. Eyes large. Postero-ventral corner with sharply pointed marginal spine. Post-abdomen broad and tapering; with about seven short spinules on post-anal edge followed by a row of setae proximally. Claw large with one large basal spine.

Size : 270 µm.

Distribution in India : Kerala, Yamuna river, Delhi.

Elsewhere : Asia, Africa, North and South America.

## Family V MACROTHRICIDAE Norman & Brady, 1867

Head well defined, antennules long and movable, usually inserted at anterior end of the ventral surface of head. Five or six pairs of legs present; first two for grasping and sixth, if present, rudimentary. Abdominal process absent (except for *Ilyocryptus)*; post-abdomen large, often bilobed; anus terminal or lateral. Labrum with keel or projection. Valves often crested, fornices well marked.

### Genus 9. *Macrothrix* Baird, 1843

Body slightly compressed, head about $1/4^{th}$ of the body size with dorsal crest. Eyes prominent, ocellus small. Labral plate straight or concave with protuberance sometimes; antennules large with spines on surface, located at the tip of rostrum. Antennal setae 0-0-1-3/1-1-3. Post-abdomen small, often bilobed. Intestine simple without caecae.

Type : *Macrothrix laticornis* (Jurine, 1820).

9. *Macrothrix laticornis* (Jurine, 1820)
(Fig. 9, a-f)

*Monoculus laticornis* Jurine, 1820, p. 151.

*Macrothrix laticornis* Lillijeborg, 1853, p. 50; Tab. 3, figs. 8-9.

*M. laticornis* Michael & Sharma, 1988, p. 106; fig. 33, a-f (literature and synonymy).

Material : Several parthenogenetic females from Veli Lake, temple tanks and ponds in and around Trivandrum and Achencovil River.

Description : Carapace oval with small projection at the posterior end. Valves reticulated; serrations on dorsal edge seen only in postero-dorsal region. Head arched, eyes large and ocellus small. Antennules broader at the apex with rows of setules; olfactory setae (4-5) unequal. Antennal setae 0-0-1-3/1-1-3. Post-abdomen broad, not bilobed with numerous spines; the latter spines terminal. Claw small and curved; ventral setae arranged in groups of three.

Size : 390 µm.

Distribution in India : Recorded from Tamil Nadu, Kerala, Ladakh and Nilgiri Hills.

Elsewhere : Holarctic, Neotropical and Oriental.

## Family VI. CHYDORIDAE Stebbing, 1902

Body oval, globular or rounded; completely enclosed by a carapace and head shield. Head shield with head pores usually. Head not demarcated from the body, ocellus prominent, even bigger than eye in some cases; fornices extend to meet the rostrum, forming a beak which protects the antennules, antennae small, rami three jointed, labrum with a keel; post-abdomen compressed, no true abdominal process. Intestine convoluted. This family is divided into four subfamilies of which three, namely: Eurycercinae, Chydorinae and Aloninae are represented in India. In the present study the latter two families are recorded.

### Subfamily 1. CHYDORINAE Stebbing, 1902

Body height greater than length. Two major pores separated, on midline of head shield. Two minor pores seen between major pores. Anus in proximal part of post-abdomen; claws of females with two basal spines in most species. No hepatic caecae.

#### Genus 10. *Chydorus* Leach, 1816

Body spherical to ovate in shape, postero-ventral corner without denticles (except in *Chydorus barroisi*), dorsal and ventral margin of post-abdomen parallel or almost parallel. Claw with two basal spines almost equal in size.

Type : *Chydorus sphaericus* (O.F. Muller, 1776).

10. *Chydorus sphaericus* (O.F. Muller, 1776)
(Fig. 10, a-e)

*Lynceus sphaericus* O.F. Muller, 1776, p. 119.

*Chydorus sphaericus* Lilljeborg, 1900, p. 561; pl. 77, figs. 8-25.

*C. sphaericus* Michael & Sharma, 1988, p. 139; fig. 44, a-h. (literature and synonymy)

Material : Few specimens from Veli Lake and Achencovil River.

Description : Body almost circular in outline, length slightly more than height. Valves with faint reticulations. Rostrum pointed. Ocellus near the eye. Posterior margin of head shield rounded. Head pores typical of this subfamily; antennal setae 0-0-3/0-1-3, antennule with sensory setae. Labral plate with blunt apex. Post-abdomen short with 7-10 anal spines. Claw with two almost equal basal spines and setae on concave margins.

Size : 300 µm.

Distribution in India : West Bengal, Bihar, Kashmir, Ladakh and Nilgiri Hills.

Elsewhere : Cosmopolitan.

11. *Chydorus faviformis* Birge, 1893
(Fig. 11, a-e)

*Chydorus faviformis* Birge, 1893, p. 307; pl. 13, figs. 7-8.

*C. faviformis* Michael & Sharma, 1988, p. 144; fig. 46, a-g. (literature and synonymy)

Material : One specimen from Pamba River.

Description : Body rounded in outline. Shell of the head and the body is curved with deep polygonal cells, as an outfolding of the outer layer of valves. Rostrum pointed and head shield too with polygonal cells. Head pores typical of genus, minor pores closer to anterior than posterior one. Ocellus smaller than eye. Antennules not reaching the apex of rostrum. Labrum convex and bluntly pointed at apex. Post-abdomen wide, anal spines 9-10; lateral surface armed with 8-9 groups of fine setae. Claw setulated on the concave surface and with two basal spines, one of which is thin and smaller.

Size : 300 µm.

Distribution in India : Kashmir, Shillong. It is here recorded for the first time from Kerala.

Elsewhere : Northeast of North America, Sri Lanka, China, Malaysia and Australia.

12. *Chydorus barroisi* Richard, 1894
(Fig. 12, a-c)

*Pleuroxus barroisi* Richard, 1894, p. 375; figs. 9-12.

*Chydorus barroisi* Sars, 1895, p. 25; pl. 4, figs. 9-13.

*C. barroisi* Michael & Sharma, p. 149; fig. 49, a-d (literature and synonymy)

Material : Several specimens from Ashtamudi Lake, Anchencovil River and Periyar River.

Description : Body highly arched with maximum height in the middle. Dorsal and ventral margins almost convex, posterior margin straight and postero-ventral corner with denticle. Head shield short and broad; head pore absent. Antennules short, conical and not reaching apex of rostrum. Rostrum short and slightly pointed. Plate of labrum serrated with 4-5 teeth on anterior margin (Fig. 12b) and with nipple-like structure on the apex. Ocellus smaller than eye. Post-abdomen short with 9 unequal anal spines. Claw slightly curved, setulated along the concave surface and with 2 basal spines.

Size : 260 $\mu$m

Distribution in India : Gujarat, West Bengal, Kerala and Tamil Nadu.

Elsewhere : Cosmotropical.

## Genus 11. *Dunhevedia* King, 1853

Eye rather small, ocellus smaller than the eye, rostrum slightly long and antennules not reaching the apex of rostrum. Head shield with 2 main pores and 2 lateral pores.

Type : *Dunhevedia crassa* King, 1853.

### 13. *Dunhevedia crassa crassa* King, 1853
(Fig. 13, a-e)

*Dunhevedia crassa* King, 1853, p. 261, pl. 7f

*D. crassa crassa* Smirnov, 1971, p. 320; figs. 358-360.

*D. crassa crassa* Michael & Sharma, 1988, p. 157; fig. 52, a-e (literature & synonymy)

Material : Few specimens from Veli Lake and Kadinamkulam Lake.

Description : Form oval, curved dorsally, maximum height slightly before the middle; postero-ventral corner of valve with long denticle, ventral margin of valve with feathered setae, longest in the middle. Antennule thick, tapering distally, ending before rostrum. Antennal setae 0-0-3/0-1-3. Plate of labrum without spines, with pointed apex. Ocellus very small nearer to eye than to apex. Head pores typical of the genus. Post-abdomen oval with 15-18 anal spines and numerous groups of scattered spinules on lateral surface and with one basal spine about $1/4^{th}$ the length of claw.

Size : 360 µm.

Distribution in India : West Bengal, Baroda, Rajasthan, Tamil Nadu and Kerala.

Elsewhere : Holarctic, Ethiopian, Indo-Malayan and Australian regions. Also southern part of European USSR.

## Genus 12. *Dadaya* Sars, 1901

Eyes rather large, ocellus elongated and about the same size as the eye; rostrum short but antennules project far beyond the apex of rostrum; head shield with only one head pore situated far from the posterior margin.

Type : *Dadaya macrops* (Daday, 1898).

### 14. *Dadaya macrops* (Daday, 1898) (Fig. 14, a-d)

*Alona macrops* Daday, 1898, p. 38; fig. 17.

*Dadaya macrops* Sars, 1901, p. 73; pl. 11, fig. 5, a-b.

*D. macrops* Michael & Sharma, 1988, p. 162; fig. 54, a-f (literature and synonymy).

Material : Only two specimens from Pamba River.

Description : Form oval, valves with distinct lines and polygonal patterns; ventral margin with series of setae. Postero-ventral corner rounded with distinct denticle followed by fine setules

along posterior margin. Head pore single and closer to centre. Antennules projecting beyond rostrum. Labrum with long beak-like process. Ocellus and eye unusually large. Post-abdomen with irregularly sized anal spines; claw curved with slightly long basal spine and setules on concave surface of claw.

Size : 360 µm.

Distribution in India : Kerala and Tamil Nadu.

Elsewhere : Ethiopian, Indo-Malayan, Australian and Neotropical regions.

## Subfamily 2. ALONINAE Frey, 1967

With two or three main head pores, situated in median line of head shield and with two minor pores situated lateral to the major pores. Claws usually with single basal spine or sometimes without it. Anus in proximal part of post-abdomen.

### Genus 13. *Alona* Baird, 1843
(emend Smirnov, 1971)

Body subquadrate in outline, compressed; valves rectangular. Anterior margin of head-shield not broadly rounded; not projecting in

lateral view. Three main head pores. Rostrum short and blunt. Post-abdomen with post-anal spines and lateral setae.

Type : *Alona quadrangularis* (O.F. Muller, 1776)

15. *Alona davidi punctata* (Daday, 1898)
(Fig. 15, a-f)

*Alona punctata* Daday, 1898, p. 39; fig. 18, a-e.
*Alona davidi punctata* Smirnov, 1971, p. 370; fig. 432.
*A. davidi punctata* Michael & Sharma, 1988, p. 177; fig. 61, a-c (literature and synonymy).

Material : Few specimens from Veli Lake.

Description : Body evenly curved dorsally, maximum height in the middle. Rostrum blunt. Post-abdomen with 10-12 groups of anal spines and groups of fine setae on the lateral side. Claw with setae on concave margin and a basal spine. Ocellus small nearer to rostrum. Antennules small with a tuft of sensory setae. Labral plate with almost pointed apex. Faint striations seen on the postero-ventral margin of the left valve.

Size : 530 $\mu$m.

Distribution in India : Tamil Nadu, Andhra Pradesh and West Bengal. It is here recorded for the first time from Kerala.

Elsewhere : Ethiopean, Australian regions and Argentina.

## Genus 14. *Biapertura* Smirnov, 1971

Body oval in outline; head shield with rounded anterior margin. Two main head pores connected by narrow channel. Labral plate large. Post-abdomen with anal spine dorsally; groups of setules on lateral surface. Claw with single small basal spine.

Type: *Biapertura affinis* (Leydig, 1860).

### 16. *Biapertura karua* (King, 1853)
(Fig. 16, a-e)

*Alona karua* King, 1853, p. 260; pl. 8.

*Biapertura karua* Smirnov, 1971, p. 479; figs. 600-604.

*B. karua* Michael & Sharma, 1988, p. 207, fig. 72, a-f (literature and synonymy).

Material : Few specimens from Veli Lake and Kadinamkulam Lake.

Description : Oval in form; head shield rounded posteriorly produced into pointed rostrum antero-ventrally; two main head pores connected; keel of labrum rounded; eyes moderate size, ocellus small. Eye, ocellus and rostrum equidistant; antennule small with six to seven sensory setae. Antennae with typical setae. Valves striated with occasional polygons. Postero-ventral corner of valves with 3-5 denticles; ventral margin with spinules. Post-abdomen broadly rounded with eight or nine anal spines. Lateral setae in groups and first seta of some of the distal

groups projecting beyond the margin of post-abdomen. Claw with very small basal spine, about $1/10^{th}$ the length of claw.

Size : 350 µm.

Distribution in India : Tamil Nadu, Andhra Pradesh, West Bengal and Meghalaya. It is here recorded for the first time from Kerala.

Elsewhere : Cosmopolitan.

### Genus 15. *Oxyurella* Dybowski & Grochowski, 1894

Body oval in form. Postero-ventral corner of valves rounded without denticles. Rostrum blunt. Two separated main head pores with 2 small and 2 lateral pores. Post-abdomen slender with anal spines. Claw with one or more basal spines situated some distance from base.

*Type* : *Oxyurella tenuicaudis* (Sars, 1862)

### 17. *Oxyurella singalensis* (Daday, 1898)
(Fig. 17, a-d)

*Alonopsis singalensis* Daday, 1898, p. 43; fig. 25, a-b.
*Oxyurella singalensis* Fryer, 1957, p.232.
*O. singalensis* Michael & Sharma, 1988, p. 212; fig. 74, a-f (literature and synonymy)

Material : Two specimens from Veli Lake

Description : Subovate, valves with dots and lines parallel to ventral margin. Antennules not reaching apex of rostrum. Main head pores two, small pores four; two between the main pores, the other two laterally about half way between main pores. Labral plate with blunt apex. Post-abdomen slightly narrow distally; anal denticles 11-13 with decreasing in size proximally. Claw large with one basal spine some distance from base and three short accessory spines at base proximal to the basal spines.

Size : 610 µm

Distribution in India : West Bengal, Kerala.

Elsewhere : Ethiopian and Indo-Malayan regions, also known from North east China.

## Genus 16. *Indialona* Petkovski, 1966

Body oval and rounded; single main head pore; rostrum short and blunt. Post-abdomen tapering with a claw rather long and with a short basal spine.

*Type* : *Indialona globulosa* (Daday, 1898)

18. *Indialona globulosa* (Daday, 1898)
(Fig. 18, a-c)

*Alona globulosa* Daday, 1898, p.37, fig. 16.

*Indialona globulosa* Fernando, 1974, figs. 116-118, 171j.

*I. globulosa* Michael and Sharma, 1988, p. 225; fig. 78, c-f (literature and synonymy)

Material : Few female specimens from Veli Lake.

Description : Body highly arched dorsally, maximum height before middle (Fig. 18a). Postero dorsal corner rounded and without denticles. Valves with distinct lines. Rostrum blunt. Ocellus smaller than eye. A single head pore. Antennules not reaching apex of rostrum. Labral plate bluntly denticulate. Post-abdomen long and broad. Anal margin concave with very small anal spines. About 11-13 lateral groups of setae, the distal most spinules being the longest and stoutest in each group; claw rather long setulated on concave surface and with a short basal spine.

Size : 450 µm.

Distribution in India : Kerala, Tamil Nadu and West Bengal.

Elsewhere : Indo-Malayan, Neotropical and Nearctic regions.

## Family VII. PODONIDAE Mordukhai-Boltovskoi, 1968

Abdomen short; antennule rudimentary; sessile eye and brood chamber large; without ocellus.

### Genus 17. *Evadne* Loven, 1836

Without cervical notch; brood chamber conical in form.

Type : *Evadne nordmanni* Loven, 1836.

#### 19. *Evadne tergestina* Claus, 1877
(Fig. 19, a)

*Evadne tergestina* Claus, 1877; tabl. 5, figs. 15-16.

*E. tergestina* Dolgopolskaja, 1958, p. 56; figs. 23-26 (literature and synonymy)

Material : Only parthenogenetic females from Vizhinjam, Kovalam, Neendakara and Veli Lake.

Description : Body oval in shape, dorsally rounded without spine. Brood pouch from hemispherical to semioval. Carapace with rows of pigment cells; two muscle bands in 'V' form. Exopodites of legs I-IV respectively with 2,3,3 and 1 setae.

Size : 700-900 μm.

Distribution in India : Indian seas mostly in coastal waters and open sea.

Elsewhere : All warm and temperate waters of ocean between Lat. $45^{O}$N and $35^{O}$S.

# DISCUSSION

The cladoceran taxonomy was stated (Frey, 1967) to be expanding explosively beyond the horizons perceived a few years ago and hence over 400 species of freshwater cladocerans were known to be described from different parts of the world. One hundred and nine species of cladocerans are so far known from Indian waters (Sharma, 1991). During the present investigation, nineteen species of cladocerans belonging to seventeen genera have been recorded from southern Kerala. Ten species have been documented by Raghunathan (1988) from Wynad, Kozhikode and Trichur districts (northern Kerala). Earlier Brehm (1953) and Michael and Hann (1979) have reported a few species from Kerala including marine forms. However, the total number of species recorded from Kerala is less when compared to the total number of species recorded from other parts of India.

Out of the nineteen presently recorded cladocerans three species belong to Sididae, two species each to Daphniidae and Moinidae, one species each to Bosminidae, Macrothricidae and Podonidae, and nine species to Chydoridae. This study shows that species belonging to family Chydoridae were dominant and this is in accordance with the findings of Sharma (1991) wherein he has stated that Chydoridae represented a significant fraction (i.e. most important) not only in India but also in the inland waters of other South Asian countries. It is also significant to note that the following cladocerans are recorded

for the first time from Kerala region: *Latonopsis australis, Chydorus faviformis, Alona davidi punctata* and *Biapertura karua.*

In this study only the planktonic forms have been considered. An investigation into the deeper water (benthic forms) may prove more productive faunistically.

# CHAPTER II

## DISTRIBUTION AND ABUNDANCE OF CLADOCERANS IN RELATION TO HYDROGRAPHY FROM TWO SELECTED BIOTOPES

# INTRODUCTION

In view of the significance of cladocerans in the aquatic ecosystem, an understanding of their pattern of distribution, intensities and seasonal fluctuations is of utmost importance. Further, they are noted for their appearance quite abruptly in the plankton, when the environmental conditions are favourable. Since these factors exert a noticeable influence on this group, it is essential to have an understanding of these basic characteristics before going into the details of other biological aspects.

Observations on the distribution and abundance of Cladocera were made over almost a century. Dologopolskaja (1958), Bainbridge (1958), Wickstead (1963), Della Croce (1964), Thiriot (1970) and Gieskes (1971) have reviewed the earlier investigations on marine and estuarine cladocerans. Most recent studies include those of Kim (1985), Onbe (1985), Fonda-Umani (1986), Della Croce and Angelino (1987) and Cai and Bingji (1990).

Along the Indian shores, Rajagopal (1962) worked on the cladocerans of the Madras waters and Della Croce and Venugopal (1972) studied the cladocerans of Indian ocean. Pillai and Pillai (1973) worked on the ecology of cladocerans of the Cochin backwaters. Madhupratap (1981) reviewed the available information on this group from the coastal and estuarine waters of the south-west coast of India.

Specific studies have been recently carried out by Raghunathan (1983) in Ennore estuary, Naomi *et al.* (1989, 1994) on the distribution of Cladocera in the eastern Arabian Sea and the Bay of Bengal and Goswami and Devassy (1991) in Mandovi-Zuari estuaries of Goa.

Several papers dealing with the primary and secondary production rates in relation to hydrography of Vizhinjam inshore waters are available in literature (Mathew and Nair, 1980; Dharmaraj *et al.*, 1980; Divakaran *et al.*, 1980 and Rani Mary Jacob *et al.*, 1986, 1987). Likewise works of Mathew and Nair (1981) and Arunachalam *et al.* (1982) on the phyto and zooplankton of Veli Lake, a backwater habitat, are noteworthy. From these studies it was clear that the cladocerans are important members of the plankton fauna in these areas and the ecology of this group is still poorly known in many respects despite their significance to the aquatic ecosystem. Hence the present study is aimed at understanding the species composition of cladocerans in the two contrasting stations, the Vizhinjam inshore waters and the Veli backwater on the Trivandrum coast, their seasonal distribution and succession in relation to hydrographic features and comparison of their quantitative distribution in the estuarine and neritic waters along the west coast of India.

## DESCRIPTION OF THE STUDY AREAS

The State of Kerala which occupies an area of 38,828 sq. km is one of the most picturesque and fertile areas in the southern-most tip of India. Vizhinjam (Fig. II) selected for the present investigation is situated on the west coast of Kerala about 12.8 km south of Trivandrum at $8^{O}22'$N Lat. and $76^{O}55'$E Long. It represents a typical marine biotope and there is no freshwater influence except during the monsoon rains. The inshore waters is free from any kind of pollutants. This station supports a rich pelagic fishery and is, besides an important aquaculture centre. The study site was selected directly opposite the Vizhinjam light house, facing the Arabian Sea.

An outstanding feature of the Kerala coast is the presence of large number of perennial/temporary estuaries popularly known as the backwaters ('Kayal' in Malayalam) and one such backwater, the Veli Lake is the second station chosen for the present study. This lake is one of the smallest of the lakes in the southern part of the State situated 5 km north-west of Trivandrum city (Fig. III). The lake is almost 1 km long and 0.3 km broad and progressively widens from the bar mouth to the eastern part. It is connected to Kadinamkulam Lake in the north, Akulam Lake in the east and Chackai canal in the south. The site chosen for the present study is close to the sea and is about 150 m away from the sand-bar. Thus the first station is part of the Arabian sea while the second one is adjacent to the same being separated from it by a

narrow strip of sandy beach which breaks open for a few days during the monsoon seasons, thus getting temporary access to the sea. Therefore the important factors that affect these two sites are the tides, waves, wind and currents. The tide is semi-diurnal; waves are influenced by the south-west and north-east monsoon cycles. The south western part of peninsular India receives full benefit of the south-west monsoon in the form of heavy rainfall during June to September as well as some precipitation from the north-east monsoon during October to January. The consequent changes in the hydrographic conditions may considerably influence the nature, incidence and biology of the fauna and flora of these habitats.

## MATERIAL AND METHODS

In this study, plankton and water samples were collected from two different areas along the Trivandrum coast of south-west India. Samples from Vizhinjam waters were taken with a net of 50 cm mouth diameter and made up of nylobolt (400 $\mu$m, mesh size) in surface hauls from February 1992 to January 1993 at fortnightly intervals. At Veli Lake hauls were made with a net of 12.5 cm mouth diameter and made of fine bolting silk (135 $\mu$m mesh size) in horizontal surface tows during the same period as mentioned above but at monthly intervals. In both these stations the samples were collected between 05.00 and 06.00 hrs by 10 minutes surface hauls and the net was towed by a country craft. The plankton samples were preserved in 4% formaldehyde. Displacement volumes of the

samples were estimated using a burette and calibrated 50 ml perspex filtering cylinder. Depending on the volume, each sample from a net tow was split to 1/4 or 1/8 subsample with the Folsom splitter and all the cladocerans in one such subsample were examined and counted in order to determine the numerical abundance of the cladocerans. The values for the whole were computed for 100 $m^3$ of water.

Hydrographic data were recorded by analysis of surface water samples following standard methods. Surface temperature at the time of collection was measured using an ordinary centigrade thermometer. The hydrogen-ion concentration (pH) of the water was estimated with the help of an 'Elico' pH meter.

For the estimation of dissolved oxygen, water samples were collected in BOD bottles, taking care not to trap any air bubbles. The samples were fixed on the spot using manganous sulphate and alkaline potassium iodide and analysed in the laboratory by the modified Winkler method (Martin, 1968).

For the estimation of salinity, samples were collected in polythene bottles and estimated titrimetrically by the Mohr-Knudsen method (Martin, 1968).

For the estimation of nutrients water samples were collected in polythene bottles, filtered, preserved with chloroform and stored in the refrigerator till the time of analysis which was always within 24 hours from the time of collection. Inorganic phosphate, nitrite, and silicate were estimated following the method given by Strickland and

provide typical examples involving counts of events, where the upper limit to the count is infinite. In behavioural studies counts of incidents in a time interval of specified length are often recorded. Under ideal conditions, the Poisson model may be appropriate for the number of events observed. In behavioural studies involving primates and other animals incidents usually occur in spurts or clusters. The net effect is that the number of recorded events is more variable than the simple Poisson model would suggest. Hence a variance stabilising transformation is suggested by considering the square root of observed counts while fitting the Poisson count data model. The model is fitted with the help of a computer using appropriate software (LIMDEP).

To facilitate interpretation, the data obtained were analysed seasonwise as follows: February to May (pre-monsoon), June to September (Monsoon), October to January (post-monsoon) based on the rainfall data from the Meteorological Department, Trivandrum.

# RESULTS

Data on hydrography, cladoceran abundance and distribution in Vizhinjam inshore waters and Veli Lake revealed the following relationship between the parameters investigated.

## VIZHINJAM INSHORE WATER--A TYPICAL MARINE HABITAT

### Environmental conditions

For the sake of convenience the results of the two collections made during each month were combined and the average of each month was taken. Table 1 shows the monthly and seasonal variations of the physico-chemical factors, the meteorological data such as the rainfall and the tide height.

The surface temperature fluctuated from a minimum of 24.5$^{o}$C to a maximum of 30.5$^{o}$C with a difference of 6$^{o}$C between the maximum and minimum temperatures. The temperature values decreased after the onset of monsoon and this dip was almost persistent till the end of the monsoon period (September). Except for slight dip in July and September, surface salinity was well above 34 ppt in most of the months of the period of study. Dissolved oxygen values varied from a minimum of 3.27 ml/l in August to a maximum of 5.75 ml/l in September. The variation in pH was very narrow and it amounted to 0.3 units between the highest value (8.15) and lowest value (7.85). Maximum phosphate content (4.13 µg at./l) was recorded in July and the lowest (0.21 µg at./l) value during March 1992. Nitrite content fluctuated from 0.02 to

0.82 µg at./l. An increase in nitrate content during the pre-monsoon months and a steady decrease during the post-monsoon months was very obvious. Silicate content fluctuated from 3.07 µg at./l to 30.68 µg at./l. However, in contrast to nitrate, a definite lowering of silicate was evident during the pre-monsoon months. A sharp increase in the chlorophyll *a* content (10.30 $mg/m^3$) was noticed in November (post-monsoon) and in all other months the values showed very narrow fluctuations. During the collection period the highest tide occurred in November (0.97 m) and the lowest in May (0.03 m) at the Vizhinjam coast.

Cladocerans

Table 2 shows the variations of the cladoceran species. *Evadne tergestina* and *Penilia avirostris* were the two marine species recorded in Vizhinjam waters and these species were present only during certain months of the year.

*Evadne tergestina*

This species was present in the samples almost during all seasons but was dominant in the months of May, September and November. During this period more than half of the parthenogenetic population was observed to carry the brood pouch with early stages of development.

In the year 1992, this species first appeared in February but only in low numbers during the second fortnight. In March they were totally absent, whereas in April they reappeared and there was a rapid

building up of the population reaching a maximum of 2813 individuals per 100 $m^3$ in May. Subsequently fairly good percentage of individuals were observed during July and August although in June they were altogether absent. In September this species reappeared in association with a bloom of *Thalassiosira subtilis* forming a major peak in their abundance (4766 individuals/100 $m^3$). After a gap in October with just a few individuals they reappeared to form another peak in November in association with *P. avirostris* and 'green' *Noctiluca miliaris*. Comparatively less percentage of individuals were recorded in the collections made in December and once again they were not observed in January.

*Penilia avirostris*

This species, a representative of family Sididae was found to occur only during April, August and November, the highest number being recorded in November in association with *E. tergestina* and 'green' *N. miliaris*. In all these populations juveniles and parthenogenetic adults with all the stages of development were observed. Further in this collection a single male and a sexual female with resting eggs were also recorded.

As regards statistical analysis, the Poisson count data model fitted with the help of a computer showed that in the case of *P. avirostris* based on Table 5, four variables turned out to be important as seen from the significant T-values for coefficients ($P < 0.05$) for

surface water temperature, dissolved oxygen, rainfall and chlorophyll *a*. While the work was done, it was observed that the other variables were not significantly related. Further, this regression worked out in a meaningful manner only when these four variables were used. It may be seen that the model gave a good fit by the chi-square value (Table 5). Also, the usefulness of the model could be assessed from Table 6 providing probabilities for observed value equalling the predicted value. It may be seen that in 16 out of 24 cases, P (predicted = observed) turned out to be greater than 0.05.

Similarly in *E. tergestina* (Table 7) it was observed that 9 variables such as surface water temperature, salinity, dissolved oxygen, nutrients, rainfall and chlorophyll *a* were found to be important as seen from the significant T-values for coefficients ($P < 0.05$). It may be seen from Table 8 that in most of the cases P (predicted = observed) were found to be either greater or almost equal to 0.05.

## VELI LAKE--A BACKWATER HABITAT

### Environmental conditions

Surface temperature showed a bimodal distribution during the period of study (Table 3). Temperature values decreased after the onset of the monsoon and maximum temperature values were recorded during the pre-monsoon period. The range in temperature values was $26^{o}C$-$32^{o}C$ (December-January and April respectively). Surface salinity showed

maximum variation and fluctuated between 0.75 ppt (September) and 5.5 ppt (May) (Table 3). The commencement of the decreasing trend coincided with the onset of the monsoon and during the post-monsoon period a gradual increase in salinity values was noticed. By the pre-monsoon months, maximum values were recorded. An increase in oxygen values was noticed during the post-monsoon months and a sharp dip in oxygen values was noticed in May and September (Table 3). The hydrogen-ion concentration of the water during most of the months remained on the alkaline side (Table 3) and it varied between 6.84 in October and 7.77 in January. The surface water of Veli Lake was observed to be very rich in phosphate, values of which fluctuated between 0.56 and 20.10 µg at./l. Higher values were recorded in February and October (Table 3). Low levels of silicate was recorded during the pre-monsoon season. The cumulative effect of south-west and north-east monsoons was probably reflected in August and November when the silicate attained its peak of 122.73 µg at./l and 130.40 µg at./l respectively (Table 3). Likewise chlorophyll *a* also attained its peak in August and November-December corresponding to the increase in silicate content. Rainfall was one of the major hydrographical parameters which showed distinct seasonal variations (Tables 1 & 3). The heaviest shower of the south-west monsoon season was observed in June (581.10 mm) followed by the next peak in October (358.40 mm) of north-east monsoon season. January to March was a completely dry period with no measurable quantity of

rainfall. Regarding tide height, the highest tide occurred in February and the lowest in May.

Cladocerans

The cladoceran component in Veli Lake was represented by six families of limnetic and marine species, of which the families Sididae, Moinidae and Macrothricidae were represented by 3,2 and 1 species respectively. Family Chydoridae was represented by six species whereas family Podonidae had only one species. The only dominant species in this lake was the limnetic moinid *Moina micrura*. The other species of this group were recorded only during the post-monsoon period (Table 4). Marine species *E. tergestina* and *P. avirostris* were found only in October and November months; this migration of marine organisms, was due to heavy rainfall which caused the removal of the sand-bar and the formation of temporary opening between the sea and the lake and thus the entire lake was under the overriding influence of the sea during this period.

*Moina micrura* (Table 4)

This species of family Moinidae was observed in the samples during almost all seasons but was dominant during the monsoon period. They were common in the plankton collected during February 1992. After a gap of three months they reappeared and attained the peak occurrence in June. During this period nearly 80% of the parthenogenetic females

were observed to carry brood pouches with advanced stages of development. After July 1992 their numbers dwindled in the collections until during September, November and January when they were completely absent.

*Moinodaphnia macleayi*

This species, another representative of the family Moinidae, was found to occur only in January 1993 but in fairly large percentage in association with a mixed phytoplankton bloom (Table 4). However, this population comprised only of parthenogenetic females with all the stages of development.

*Scapholeberis kingi*

This species of family Daphniidae is the sole representative which appeared in very small numbers only in January.

*Macrothrix laticornis*

This is the only species representing the family Macrothricidae in Veli Lake and was found in almost all the months of the post-monsoon period except December. They occurred at their maximum in October and thereafter gradually diminished.

Species of Family Chydoridae

The family Chydoridae was represented by six species of which *Dunhevedia crassa crassa* and *Indialona globulosa* were predominant only during October 1991. *Chydorus sphaericus* was present in October and January. *Biapertura karua, Oxyurella singalensis* and *Alona davidi punctata* made their appearance only in January when they were found to occur in lesser numbers.

*Penilia avirostris*

This species of family Sididae was recorded only in October in association with *E. tergestina* and other plankters. Further all the females were parthenogenetic forms with different stages of development.

*Evadne tergestina*

This species belonging to family Podonidae was observed only in October and November when the sand-bar was temporarily open and all the individuals recorded were parthenogenetic, with most of them being in early and advanced stages of development.

Considering the relationship between *Moina micrura* (the dominant species at Veli Lake) and the hydrographic factors it was found out by Poisson regression model that variables such as surface water temperature, dissolved oxygen, nutrients, hydrogen-ion concentration and chlorophyll *a* were significantly related as seen from the significant T-values for coefficients ($P < 0.05$) (Table 9). Further, it

was also observed from Table 10 that the probabilities for observed value equalled predicted values in almost all the observations and hence P (predicted = observed) turned out to be greater than 0.05 in all cases.

TABLE 1

Station I: Monthly average of selected physico-chemical parameters of water, rainfall, chlorophyll a tide height and the occurrence of blooms and swarms at Vizhinjam inshore station

| Selected parameters | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. |
| Surface water temperature (°C) | 28.75 | 29.00 | 30.25 | 30.53 | 26.00 | 26.00 | 24.50 | 25.75 | 27.00 | 28.75 | 27.00 | 26.50 |
| Salinity (°/₀₀) | 34.63 | 35.50 | 35.25 | 35.25 | 35.00 | 33.75 | 34.25 | 33.88 | 35.00 | 34.00 | 34.50 | 35.25 |
| Dissolved oxygen (ml/l) | 4.57 | 4.40 | 4.06 | 4.44 | 4.52 | 4.40 | 3.27 | 5.75 | 4.80 | 4.63 | 5.19 | 5.42 |
| pH | 7.95 | 7.85 | 8.09 | 8.13 | 8.10 | 8.05 | 8.15 | 7.90 | 7.89 | 7.89 | 8.09 | 8.13 |
| Phosphate (µg at./l) | 0.36 | 0.21 | 1.33 | 1.59 | 1.84 | 4.13 | 1.31 | 0.79 | 1.50 | 0.37 | 3.01 | 0.94 |
| Nitrite (µg at./l) | 0.18 | 0.02 | 0.02 | 0.46 | 0.28 | 0.28 | 0.29 | 0.82 | 0.07 | 0.10 | 0.15 | 0.10 |
| Nitrate (µg at./l) | 2.23 | 0.05 | 1.11 | 2.07 | 1.20 | 0.07 | 1.73 | 0.40 | 0.07 | 0.09 | 0.04 | 0.04 |
| Silicate (µg at./l) | 4.22 | 8.06 | 3.07 | 8.44 | 16.92 | 15.84 | 11.31 | 9.70 | 30.68 | 4.25 | 11.36 | 5.07 |
| Rainfall (mm) | Trace | 0.00 | 31.80 | 188.70 | 581.10 | 237.50 | 102.40 | 115.40 | 358.40 | 316.40 | 26.20 | Trace |
| Chlorophyll a (mg/m³) | 2.40 | 5.00 | 2.18 | 2.23 | 4.13 | 2.85 | 1.17 | 4.36 | 2.04 | 10.30 | 5.19 | 5.63 |
| Tide height (m) | 0.43 | 0.24 | 0.10 | 0.03 | 0.45 | 0.10 | 0.56 | 0.56 | 0.65 | 0.97 | 0.77 | 0.85 |
| Blooms/Swarms | - | - | - | - | - | - | Fragilaria oceanica and Coscinodiscus sp | Thalassiosira subtilis | - | Noctiluca miliaris green type | Salpa democratica | Nil |

TABLE 2

Fortnightly (I & II) and monthly average (in parenthesis) of marine cladocerans (i.e. as No/100 $m^3$) including five categories at Vizhinjam inshore station

| Species | Pre-monsoon | | | | | | | | Monsoon | | | | | | | | Post-monsoon | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb. | | Mar. | | Apr. | | May | | Jun. | | Jul. | | Aug. | | Sep. | | Oct. | | Nov. | | Dec. | | Jan. | |
| | I | II | I | II | I | II | I | II | I | II | I | II | I | II | I | II | I | II | I | II | I | II | I | II |
| Evadne tergestina | | | | | | | | | | | | | | | | | | | | | | | | |
| Parthenogenetic category IA | - | - | - | - | 11 | 31 | - | 1936 | - | - | 57 | - | - | - | - | 770 | - | - | 408 | - | - | 45 | - | - |
| IB | - | 56 | - | - | 6 | 71 | - | 826 | - | - | 57 | - | 45 | - | - | 272 | 91 | - | 815 | - | - | 45 | - | - |
| II | - | 125 | - | - | 23 | 331 | 79 | 2739 | - | - | 113 | - | 227 | - | - | 8481 | - | - | 3124 | - | 23 | 91 | - | - |
| III | - | - | - | - | - | - | - | 45 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| IV | - | - | - | - | - | - | - | - | - | - | 11 | - | - | - | - | 9 | - | - | 91 | - | - | - | - | - |
| Total | - | 181 | - | - | 40 | 433 | 79 | 5547 | - | - | 238 | - | 272 | - | - | 9532 | 91 | - | 4529 | - | 23 | 181 | - | - |
| | (91) | | (-) | | (237) | | (2813) | | (-) | | (119) | | (138) | | (4766) | | (46) | | (2265) | | (204) | | | |
| Penilia avirostris | | | | | | | | | | | | | | | | | | | | | | | | |
| Parthenogenetic category IA | - | - | - | - | 26 | - | - | - | - | - | - | - | 57 | - | - | - | - | - | 272 | - | - | - | - | - |
| IB | - | - | - | - | 59 | - | - | - | - | - | - | - | 57 | - | - | - | - | - | 634 | - | - | - | | |
| II | - | - | - | - | 20 | - | - | - | - | - | - | - | 623 | - | - | - | - | - | 317 | - | - | - | - | - |
| III | - | - | - | - | 6 | - | - | - | - | - | - | - | 28 | - | - | - | - | - | 2173 | - | - | - | - | - |
| IV | - | - | - | - | 71 | - | - | - | - | - | - | - | 197 | - | - | - | - | - | 255 | - | - | - | - | - |
| Gamogenetic Male | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 3 | - | - | - | - | - |
| Female | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 3 | - | - | - | - | - |
| Total | - | - | - | - | 184 | - | - | - | - | - | - | - | 962 | - | - | - | - | - | 3657 | - | - | - | - | - |
| | (-) | | (-) | | (92) | | (-) | | (-) | | (-) | | (481) | | (-) | | (-) | | (1829) | | (-) | | (-) | |
| Grand total of cladocerans | - | 181 | - | - | 224 | 433 | 79 | 5547 | - | - | 238 | - | 1234 | - | - | 9532 | 91 | - | 8186 | - | 23 | 181 | - | - |

TABLE 3

Station II - Veli Lake: Monthly variation of selected physico-chemical parameters of water, rainfall, chlorophyll a tide height and the occurrence of bloom at Veli backwater station

| Hydrographic paramaters | Pre- monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. |
| Surfac water temperature (°C) | 27.50 | 29.00 | 32.00 | 31.00 | 30.00 | 27.00 | 29.50 | 29.50 | 28.50 | 28.70 | 26.00 | 26.00 |
| Salinity (°/₀₀) | 4.00 | 3.50 | 3.75 | 5.50 | 4.00 | 1.75 | 3.00 | 0.75 | 2.50 | 3.50 | 4.00 | 2.88 |
| Dissolved oxygen (ml/l) | 5.40 | 5.41 | 3.61 | 2.48 | 4.51 | 4.96 | 4.96 | 3.10 | 4.50 | 4.96 | 5.87 | 6.43 |
| pH | 7.40 | 7.60 | 7.60 | 7.49 | 7.00 | 6.90 | 6.90 | 7.10 | 6.84 | 7.02 | 7.02 | 7.77 |
| Phosphate (ug at./l) | 20.10 | 3.36 | 5.42 | 10.85 | 8.32 | 0.56 | 1.57 | 1.09 | 7.48 | 0.67 | 3.37 | 0.56 |
| Nitrite (ug at./l) | 1.00 | 0.73 | 1.46 | 0.91 | 0.46 | 0.38 | 0.00 | 0.59 | 0.567 | 0.64 | 0.11 | 0.70 |
| Nitrate (ug at./l) | 7.20 | 0.83 | 4.14 | 10.12 | 0.92 | 2.30 | 2.95 | 0.67 | 0.649 | 0.51 | 0.02 | 0.19 |
| Silicate (ug at./l) | 6.14 | 17.64 | 14.57 | 7.67 | 12.12 | 45.26 | 122.73 | 11.12 | 19.18 | 130.40 | 51.39 | 19.37 |
| Rainfall (mm) | Trace | 0.00 | 31.80 | 188.70 | 581.10 | 237.50 | 102.40 | 115.40 | 358.40 | 316.40 | 26.20 | Trace |
| Chlorophyll a ($mg/m^3$) | 3.28 | 6.26 | 2.84 | 6.17 | 5.73 | 2.45 | 17.67 | 2.98 | 8.63 | 13.65 | 21.54 | 3.58 |
| Tide height (m) | 1.03 | 0.90 | 0.80 | 0.11 | 0.44 | 0.78 | 0.75 | 0.74 | 0.71 | 0.73 | 0.90 | 0.75 |
| Blooms | Microcystis colonies | - | Microcystis colonies (minor) | <——> | Microcystis colonies | - | - | - | - | - | - | Volvox sp. and filamentous algae (mixed bloom |

TABLE 4

Monthly variation (No./100 $m^3$) of cladoceran fauna at Veli Station with special emphasis to *Moina micrura*

| | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. |
| *Diaphanosoma sarsi* | – | – | – | – | – | – | – | – | – | – | – | 9 |
| *Latonopsis australis* | – | – | – | – | – | – | – | – | 56 | – | – | – |
| *Moina micrura* | 849 | 6 | – | – | 6998 | 543 | 74 | – | 272 | – | 45 | – |
| *Moinodaphnia macleayi* | – | – | – | – | – | – | – | – | – | – | – | 490 |
| *Scapholeberis kingi* | – | – | – | – | – | – | – | – | – | – | – | 9 |
| *Macrothrix laticornis* | – | – | – | – | – | – | – | – | 79 | 11 | – | 9 |
| *Chydorus sphaericus* | – | – | – | – | – | – | – | – | 17 | – | – | 75 |
| *Dunhevedia crassa crassa* | – | – | – | – | – | – | – | – | 101 | 11 | 6 | 6 |
| *Alona davidi punctata* | – | – | – | – | – | – | – | – | – | – | – | 6 |
| *Indialona globulosa* | – | – | – | – | – | – | – | – | 74 | – | – | – |
| *Biapertura karua* | – | – | – | – | – | – | – | – | – | – | – | 3 |
| *Oxyurella singalensis* | – | – | – | – | – | – | – | – | – | – | – | 3 |
| *Evadne tergestina* | – | – | – | – | – | – | – | – | 4075 | 11 | – | – |
| *Penilia avirostris* | – | – | – | – | – | – | – | – | 181 | – | – | – |
| *Moina micrura* category IA (parthenogenetic) | 68 | – | – | – | 2264 | – | – | – | – | – | – | – |
| ,, IB | 226 | – | – | – | – | – | – | – | – | – | – | – |
| ,, II | 256 | 6 | – | – | 2536 | 317 | 74 | – | 272 | – | 45 | – |
| ,, III | 209 | – | – | – | 1811 | 226 | – | – | – | – | – | – |
| ,, IV | – | – | – | – | 1177 | – | – | – | – | – | – | – |
| Total of *Moina micrura* | 849 | 6 | – | – | 6998 | 543 | 74 | – | 272 | – | – | – |

TABLE 5

Estimates of coefficient and related statistics from the Poission regression for *Penilia avirostris*

Maximum likelihood estimates
Log - likelihood = -110.55
Chi - squared = 372.38
G - squared = 211.56

| Variable | Coefficient | Std. Error | T - ratio | Prob:t:≥x | Mean of x | Std.D of x |
|---|---|---|---|---|---|---|
| Surface water temperature | 0.409154 | 0.037576 | 10.889 | 0.00000 | 27.50000 | 2.06945 |
| Dissolved oxygen | -2.87078 | 0.293687 | -9.775 | 0.00000 | 4.62083 | 0.68524 |
| Rainfall | 0.002468 | 0.0017789 | 2.290 | 0.02203 | 163.15833 | 177.98417 |
| Chlorophyll *a* | 0.350493 | 0.036680 | 9.555 | 0.00000 | 3.95833 | 2.41245 |

TABLE 6

Observed frequencies with square root transformation and expected frequencies for Penilia avirostris

| Observation | Observed Y | Predicted Y | Residual | X (i) β | Pr (y*=y) |
|---|---|---|---|---|---|
| 1. | 0.00000 | 0.659380 | -0.6594 | -0.4164 | 0.5172 |
| 2. | 0.00000 | 0.607170 | -0.6072 | -0.4989 | 0.5449 |
| 3. | 0.00000 | 3.573600 | -3.5736 | 1.2736 | 0.0281 |
| 4. | 0.00000 | 2.012600 | -2.0126 | 0.6994 | 0.1336 |
| 5. | 13.56500 | 1.228400 | 12.3363 | 0.2057 | 0.0000 |
| 6. | 1.73210 | 19.965000 | -18.2324 | 2.9940 | 0.0000 |
| 7. | 0.00000 | 3.629800 | -3.6298 | 1.2892 | 0.0265 |
| 8. | 0.00000 | 1.809300 | -1.8093 | 0.5929 | 0.1638 |
| 9. | 0.00000 | 1.530800 | -1.5308 | 0.4258 | 0.2164 |
| 10. | 0.00000 | 2.129300 | -2.1293 | 0.7558 | 0.1189 |
| 11. | 0.00000 | 0.528180 | -0.5282 | -0.6383 | 0.5897 |
| 12. | 0.00000 | 0.866490 | -0.8665 | -0.1433 | 0.4204 |
| 13. | 31.01600 | 3.693300 | 27.3228 | 1.3065 | -41.3177 |
| 14. | 0.00000 | 3.131500 | -3.1315 | 1.1415 | 0.0437 |
| 15. | 0.00000 | 0.021162 | -0.0212 | -3.8555 | 0.9791 |
| 16. | 0.00000 | 0.011878 | -0.0119 | -4.4330 | 0.9882 |
| 17. | 0.00000 | 0.113810 | -0.1138 | -2.1732 | 0.8924 |
| 18. | 0.00000 | 0.886240 | -0.8862 | -0.1208 | 0.4122 |
| 19. | 60.42400 | 50.005000 | 10.4184 | 3.9121 | 0.0185 |
| 20. | 0.00000 | 5.463000 | -5.4630 | 1.6980 | 0.0042 |
| 21. | 0.00000 | 0.364090 | -0.3641 | -1.0104 | 0.6948 |
| 22. | 0.00000 | 0.050946 | -0.0509 | -2.9770 | 0.9503 |
| 23. | 0.00000 | 0.046586 | -0.0460 | -3.0665 | 0.9503 |
| 24. | 0.00000 | 0.097559 | -0.0976 | -2.3273 | 0.9070 |

Poisson regression

TABLE 7

Estimates of coefficients and related statistics from the Poisson regression for *Evadne tergestina*

Maximum likelihood estimates
Log - likelihood = 256.77
Chi - squared = 2135.7
G - squared = 456.60

| Variable | Coefficient | Std. Error | T - ratio | Prob:t:≥x | Mean of x | Std.D of x |
|---|---|---|---|---|---|---|
| Surface water temperature | 0.357873 | 0.064543 | 5.920 | 0.00000 | 27.50000 | 2.0694 |
| Salinity | 0.277956 | 0.101090 | 2.790 | 0.00597 | 34.6916 | 0.9016 |
| Dissolved oxygen | 1.47048 | 0.184561 | 7.967 | 0.00000 | 4.6208 | 0.6852 |
| Phosphate | 0.158214 | 0.0522382 | 3.029 | 0.00246 | 1.45417 | 1.4479 |
| Nitrite | 0.779287 | 0.229613 | 3.394 | 0.00069 | 0.23333 | 0.3171 |
| Nitrate | 0.451893 | 0.0811331 | 5.570 | 0.00000 | 0.77083 | 1.0872 |
| Silicate | -0.079658 | 0.0204843 | -3.889 | 0.00010 | 10.73750 | 8.6812 |
| Rainfall | 0.002192 | 0.00064331 | 3.409 | 0.00065 | 163.15833 | 177.9847 |
| Chlorophyll *a* | 0.144619 | 0.0476257 | 3.037 | 0.00239 | 3.95833 | 2.4124 |

TABLE 8

Observed frequencies with square root transformations and expected frequencies for the cladoceran E. tergestina

| Observation | Observed Y | Predicted Y | Residual | X (i) β | Pr (y*=y) |
|---|---|---|---|---|---|
| 1. | 13.45400 | 24.26200 | -10.8088 | 3.1889 | 0.0061 |
| 2. | 0.00000 | 5.92800 | -5.9280 | 1.7797 | 0.0027 |
| 3. | 0.00000 | 5.93220 | -5.9322 | 1.7804 | 0.0027 |
| 4. | 0.00000 | 2.57090 | -2.5709 | 0.9442 | 0.0765 |
| 5. | 6.32460 | 16.86000 | -10.5352 | 2.8249 | 0.0021 |
| 6. | 20.80900 | 4.50400 | 16.3047 | 1.5050 | 0.0000 |
| 7. | 8.88820 | 23.43100 | -14.5428 | 3.1541 | 0.0004 |
| 8. | 74.47800 | 63.54730 | 10.9317 | 4.1518 | 0.0190 |
| 9. | 0.00000 | 18.40500 | -18.4055 | 2.9126 | 0.0000 |
| 10. | 0.00000 | 3.13180 | -3.1218 | 1.1416 | 0.4360 |
| 11. | 15.46000 | 13.27100 | 2.1890 | 2.5856 | 0.0850 |
| 12. | 0.00000 | 0.22185 | -0.2218 | -1.5058 | 0.8010 |
| 13. | 16.49200 | 0.14419 | 16.3482 | -1.9366 | -64.1435 |
| 14. | 0.00000 | 0.58344 | -0.5834 | -0.5388 | 0.5580 |
| 15. | 0.00000 | 6.93310 | -6.9331 | 1.9363 | 0.0010 |
| 16. | 97.63200 | 42.40300 | 55.2289 | 3.7472 | 0.0000 |
| 17. | 9.53940 | 5.78800 | 3.7514 | 1.7558 | 0.4640 |
| 18. | 0.00000 | 0.18163 | -0.1816 | -1.7058 | 0.8339 |
| 19. | 67.29800 | 37.75600 | 29.5420 | 3.6311 | 0.0000 |
| 20. | 0.00000 | 16.51740 | -16.5100 | 2.8044 | 0.0000 |
| 21. | 4.97580 | 11.10600 | -6.3098 | 2.4075 | 0.0183 |
| 22. | 13.45400 | 8.74410 | 4.7095 | 2.1684 | 0.0364 |
| 23. | 0.00000 | 27.08200 | -27.0825 | 3.2989 | 0.0000 |
| 24. | 0.00000 | 9.32040 | -9.3204 | 2.2322 | 0.0001 |

Poisson regression

TABLE 9

Estimate of coefficients and related statistics from the Poisson regression for the cladoceran Moina micrura

| Variable | Coefficient | Standard error | T-ratio | Pro:t:≥x | Mean of x | Std.D.of x |
|---|---|---|---|---|---|---|
| Surface water temperature | 1.999560 | 0.27633400 | 7.236 | 0.00 | 28.72500 | 1.86310 |
| Dissolved oxygen | 7.353740 | 1.38276000 | 5.318 | 0.00 | 4.67833 | 1.14931 |
| pH | -12.486700 | 2.03370000 | -6.140 | 0.00 | 7.22000 | 0.32872 |
| Nitrate | 0.268943 | 0.05013200 | 5.365 | 0.00 | 2.54167 | 3.17045 |
| Silicate | -0.0357236 | 0.00537065 | -6.652 | 0.00 | 38.13250 | 43.63148 |
| Chlorophyll a | 0.188895 | 0.03969500 | -4.759 | 0.00 | 7.89833 | 6.36045 |

TABLE 10

Observed frequencies with square root transformation and expected frequencies

| Observation | Observed | Predicted | Residual | x(i)c | Pr(y*= y) |
|---|---|---|---|---|---|
| 1 | 29.140 | 29.78500000 | -0.6449 | 3.3940 | 0.0732 |
| 2 | 2.450 | 3.60610000 | -1.1561 | 1.2826 | 0.1999 |
| 3 | 0.000 | 0.01344000 | -0.0134 | -4.3095 | 0.9866 |
| 4 | 0.000 | 0.00000400 | 0.000 | -12.3872 | 1.0000 |
| 5 | 83.650 | 88.00100000 | -4.3514 | 4.4774 | 0.0391 |
| 6 | 23.300 | 17.17400000 | 6.1264 | 2.8434 | 0.0308 |
| 7 | 8.600 | 10.74600000 | -2.1465 | 2.3746 | 0.1070 |
| 8 | 0.000 | 0.00047514 | -0.0005 | -7.6519 | 0.9995 |
| 9 | 16.490 | 12.55000000 | 3.9399 | 2.5297 | 0.0557 |
| 10 | 0.000 | 0.40888000 | -0.4089 | -0.8943 | 0.6644 |
| 11 | 6.710 | 4.94870000 | 1.7613 | 1.5991 | 0.1148 |
| 12 | 0.000 | 2.54560000 | -2.5456 | 0.9344 | 0.0784 |

# DISCUSSION

Out of the four species of cladocerans recorded from the Indian Ocean, viz. *E. tergestina, E. spinifera, Podon polyphemoides* and *P. avirostris, E. tergestina* is widely distributed in both coastal and oceanic waters and the other species are restricted to the coastal waters (Della Croce and Venugopal, 1972). Nair *et al.* (1973) reported that the peak abundance of cladocerans was noted off Cochin, Goa, Gulf of Cambay and the Karachi coast. Naomi *et al.* (1989, 1994) studied the abundance of Cladocera of the shelf and oceanic area of Arabian Sea and the Bay of Bengal and found that cladocerans abounded in the Wadge Bank area off Cape Comerin and the coastal waters of Vizhinjam, Karwar and off Tuticorin, Coromondel coast and Paradip. It may be seen that most of these areas are noted for their high biological productivity and rich pelagic fishery resources. In Vizhinjam inshore waters Rani Mary Jacob *et al.* (1986) have recorded swarms of *E. tergestina* and *P. avirostris* during the period June-October. However, the present study did not exhibit any distinct swarm but they occur in more or less numbers in all the seasons with peaks in May, July, September and November (monsoon and early post-monsoon months) which is in concurrence with the observations of Menon *et al.* (1972) in Cochin waters and Naomi (1986) in Karwar.

The association of cladocerans with phytoplankton blooms especially of diatoms is fairly well known (Wickstead, 1963). On many

occasions *E. tergestina* and *P. avirostris* were associated with blooms of setoid diatoms (Selvakumar, 1970), *Trichodesmium* sp. (Sakthivel and Haridas, 1974), *Fragilaria oceanica* (Naomi and Mathew, M.S.) or with *Noctiluca miliaris* as reported by Rani Mary Jacob (1986) in Vizhinjam. In the present study at Vizhinjam these marine species were associated with blooms of phytoplankters such as *Fragilaria oceanica* in August, *Thalassiosira subtilis* in September and *Noctiluca miliaris* (green type) in November.

It is suggested by Wickstead (1963) that these diatoms which occur as blooms maintain the $O_2$ and $CO_2$ concentrations at acceptable levels for the *P. avirostris* as the former supplies $O_2$ for the latter. Further, when these diatoms disappear quite rapidly, the lowering of the $O_2$ concentration in the water will have its effect on *P. avirostris* and may cause parthenogenetic females to produce resting eggs and males. Hence $O_2$ acts as one of the limiting factors in the population explosion of *P. avirostris.*

The same author also stated that each population of *P. avirostris*, in its particular area, will have a temperature threshold related to local conditions. From this idea of a temperature threshold it would follow that *P. avirostris* will have a single population in areas with a 'regular annual temperature cycle' (Zanzibar) and two populations in areas with a 'temperature cycle with two peaks' (Singapore). It is interesting to note that in Vizhinjam inshore waters too the two major peaks in the temperature cycle can be considered

typical of areas influenced by monsoon change over period. The suggested relationship between *P. avirostris* and the increase in phytoplankton causing blooms can explain the relationship found by Goswami and Devassy (1991) between marine cladocerans (*P. avirostris* and *E. tergestina*) and chlorophyll *a*. Thus the studies by these earlier workers suggest a close relationship between *P. avirostris*, surface temperature, dissolved oxygen and chlorophyll *a*. The influence of the above cited factors on the abundance of *P. avirostris* has also been established in the present investigation by the Poisson regression method (Table 5).

As regards *E. tergestina* in addition to these factors, nutrients also play a significant role in its distribution and abundance. It is very clear from Tables 1 & 2 that the relatively poor occurrence of *E. tergestina* during January-March could be due to depleted nutrient concentrations and meagre rainfall. This is in agreement with the studies made by Goswami and Devassy (1991) wherein they also observed that cladocerans were less in numbers during the pre-monsoon months due to lower concentration of nutrients. Further, as opined by Rodriguez and Vives (1984) the seasonal occurrence of this group and the sequence of the dominant species appears to be directly influenced by temperature and associated factors.

The studies in Veli Lake (backwater) indicate that the limnetic cladocerans were more common than the marine species. The observations made by Villate and Orive (1981) and Yves Rincé *et al.* (1989) are also

in accordance with this, specifically the conclusion that freshwaters species were dominant in Plencia and Loire estuaries respectively. However, in some permanent estuaries such as Neendakara, Ashtamudi, Ennore and Hooghly the marine forms such as *E. tergestina* and *P. avirostris* were dominant (Balakrishnan Nair *et al.*, 1985; Raghunathan, 1983; Sarkar and Choudhury, 1987). Further, a detailed study of the cladocerans of the Veli Lake was worked out for the first time although Arunachalam *et al.* (1982) have made a preliminary study on the zooplankton of this lake.

Bandyopadhyay and Datta (1987) studied the influence of some environment parameters on *M. micrura* in a freshwater pond in Calcutta. Since this species occurred throughout the year multiple regression analysis was worked out and it was observed that nitrate, dissolved oxygen, phosphate and primary productivity exhibit considerable influence on their abundance. This finding is partly substantiated in the present study (Table 9).

Another interesting aspect is that marine species *E. tergestina* and *P. avirostris* were recorded in Veli backwater only in October and November when the bar mouth was open temporarily. The salinity was a mere 3 ppt during this period thereby showing that these species have a wide range of salinity tolerance. Earlier records on the occurrence of marine cladocerans in relation to salinity also showed that they are available in a wide range of salinities (George, 1958; 2-11 ppt;

Rajagopal, 1962; 23.11 to 34.45 ppt; Menon *et al.*, 1972; 0.6 to 32.8 ppt). However, from the results of Poisson regression analysis (Table 7) it is seen that salinity influence the abundance of *E. tergestina* at Vizhinjam to a certain extent. Further, Fonda-Umani (1986) has also reviewed the distribution of *E. tergestina* and found this stenohaline.

A noteworthy feature of cladocerans was that the species diversity of this group was seen only during the post-monsoon period in Veli backwater. Nair and Tranter (1972) recorded cladocerans from the mouth of the estuary and stated that they were conspicuous by their absence towards the head of the estuary during the pre-monsoon period. This is in accordance with the observations of Fernando (1980) and Raghunathan (1983) who mentioned that the lesser species diversity is a unique feature of this group.

The results of these investigations have therefore considerably enhanced our knowledge of the interaction between the dominant species of cladocerans with the physico-chemical characteristics of the environments.

# CHAPTER III

## REPRODUCTIVE BIOLOGY – OBSERVATIONS ON THE MARINE SPECIES

# INTRODUCTION

Reproduction in cladocerans is parthenogenetic during the greater part of the year in most habitats, and only female young are produced, this capacity endows them with a high rate of reproductive ability and enables them to form swarms outnumbering all other plankters of the zooplankton community. At times during the population peaks when depression factors appear some of these parthenogenetic females produce males or gamogenetic females, whilst the other parthenogenetic females and their broods still reproducing parthenogenetically produce fewer and fewer parthenogenetic individuals. Though the marine cladocerans, belonging to the genera *Evadne, Podon and Penilia* have received wide attention (Bainbridge, 1958; Della Croce, 1964, 1966; Onbe, 1968, 1978a,b; 1983 Gieskes, 1970; Kim and Onbe, 1989; Yoo and Kim, 1990) there is dearth of information on the marine species in Indian waters, especially regarding their reproductive biology.

On reviewing the work done on the biological aspects of marine cladocerans in India, the following few works only touch upon this aspect. Della Croce and Venugopal (1973) have merely reviewed the population cycle and the influence of environmental factors on the reproductive potential of *P. avirostris* Dana in the Indian Ocean. The only paper on the occurrence and fertility of *P. avirostris* is that of Vijayalakshmi and Venugopal (1972) in Porto Novo waters. In this account the occurrence of three types of individuals, viz.

parthenogenetic females, sexual females and males, is reported with a note on their fecundity. However, our knowledge of the biology and life cycle of *E. tergestina* from Indian waters is limited. Very recently Naomi *et al.* (1994) have mentioned the size range and fecundity of this species in a study made on the distribution and abundance of the marine cladocerans of the Eastern Arabian Sea. Thus even though a few papers are available on this subject our present knowledge of the reproductive biology of marine cladocerans from the south-west coast of India is inadequate. This was one of the reasons that prompted the present investigation and the present study includes the results of detailed comparative observations on the reproductive biology of two marine species namely *Evadne tergestina* CLAUS and *Penilia avirostris* DANA along the south Kerala coast of India.

## MATERIAL AND METHODS

The method of plankton collection and analysis of the samples have been described already (Chapter II). In order to study the size distribution and patterns of growth, at least 50 undamaged parthenogenetic females (less if 50 could not be obtained) were sorted out and the individual specimens were measured under a microscope using an ocular micrometer for both standard length (SL) and gross length (GL) defined by Onbe (1983), i.e., for *E. tergestina* SL: the distance between the shallow notch at the cervical part and the tip of the caudal furca; GL : the maximum distance from the tip of the head to the

dorsoposterior edge of the brood pouch. In the case of *P.avirostris*, SL is the distance between the crown of the head to the base of the caudal setae and GL is the same as mentioned above but instead of the brood pouch it is upto the posterior tip of the carapace (Fig. IV).

Measured specimens were carefully dissected and the number of egg/embryos per batch was counted. Gross length of each egg/embryo was measured with an ocular micrometer. The developmental stages of the brood also was traced and the drawings of egg and embryo were made with the aid of 'Meopta' binocular compound microscope. The mean embryo length was calculated for each female and compared with both the body lengths. Similarly the embryo number was correlated with size of the parent and the embryo length.

Since it was difficult to rear the animals in the laboratory for the whole duration that the animal takes to complete the life cycle, the growth pattern in the field population alone was studied based on the fortnightly size structure of the total population. For this size frequency studies the individuals are classified into discrete groups for convenience. Further, the use of developmental stages of embryo in determining the stages of instar was realized by Green (1956). Thus in this study the parthenogenetic females were grouped into the following four categories based on the reproductive state of the animal (Mordukhai-Boltovskoi and Rivier, 1971; Onbe 1977) (Plate I, 1-11).

I The new born females or neonates (Plate I. 1,6) and newly moulted females, after release of young (Plate I. 2,7).

II The females with early, developing embryos in the brood pouch (Plate I. 3,8).

III The females with advanced embryos in which appendages are formed and the eye is completed (Plate I. 4,9,10).

IV The females just before release of young and the young have already passed out of the brood pouch into the interior of the shell of the mother animal (Plate I. 5,11).

In the present study the first category was further grouped into two as IA - new born neonates and IB - newly moulted female after release of young (Plate I. 1,2,6,7).

## RESULTS

### A. *EVADNE TERGESTINA* CLAUS :

The year-round studies made in Vizhinjam showed that in this species breeding was most intense in April to May, July to September and November to December and thus the sequence of generations was inferred to a certain extent from the available data (Fig. 24). Further, in all the collections made, only parthenogenetic females were observed with different stages of development.

Stages in embryonic development

The distinctive stages in the embryonic development of *E. tergestina* are as follows: (Fig. 20, a-i).

Stage 1 : At the time of emergence the eggs are spherical measuring from 30 to 45 µm in length. Usually 6-10 eggs are deposited at one time. In this stage most of them are blastulae with a central cavity (Fig. 20, a)

Stage 2 : The embryo had elongated antero-posteriorly and a distinct head was not yet formed. The size of this stage ranged from 60 to 70 µm (Fig. 20, b)

Stage 3 : The embryo had developed a distinct head lobe with a pair of rudimentary antennae as well as the rudiments of the first pair of thoracic appendage. The size of this stage ranged from 90 to 100 µm (Fig. 20, c).

Stage 4 : In this the antennae were elongated and the appearance of another rudimentary pair of thoracic segments and appendages was evident. The size ranged from 110 to 120 µm (Fig. 20, d).

Stage 5 : This stage showed a distinct head lobe demarcated from the posterior part. Rudiments of two more pairs of thoracic segments and appendages appeared. The optic and cerebral ganglia were formed and

they gave the appearance of a cross on the middle of the head region. The appearance of alimentary canal and ovary was observed. The size ranged from 130 to 170 $\mu$m (Fig. 20, e).

Stage 6 : In this stage, the head of the embryos become inclined and occupies a ventral position and therefore the embryos were found to be in a lateral position. The oocytes had become mature and measured about 15 $\mu$m. The size of the embryos was found to range from 180 to 200 $\mu$m (Fig. 20, f,g)

Stage 7 : This is the last stage before emergence with the biramous antennae, well developed eye and thoracic appendages. At this stage the embryos (the miniature adults) have already passed out of the brood pouch into the inside of the shell of the mother animals, in whose brood pouch blastulae of the next brood were already formed. Their measurements ranged from 200 to 250 $\mu$m (Fig. 20, h,i).

Liberation of brood

When the development was complete, the gravid females released the brood in a single batch and then rapidly swam away leaving the new born 'neonates' to fend for themselves. At times they remained clustered together beneath the adults for the first couple of hours even though they were actually miniature adults since they already have mature eggs (the first clutch of eggs). The eggs in the miniature

adults once again undergo development to release the next brood and this process is continued to form many such broods and hence they are iteroparous. In general for most cladocerans every time a brood is released there is an ecdysis or moulting and an increase in the length of the adult animal is observed and all these broods form a generation.

### Number of eggs or embryos

In Vizhinjam fecundity (i.e., number of eggs or embryo per gravid female) was relatively high whenever the species appeared in fairly good numbers with almost all the categories, the only exception was that of 26.9.'92 (Table 11; Fig. 27). However, on this day samples were collected at 3 hourly intervals from 05.00 hrs to 17.00 hrs and it was discovered that in all these samples the fecundity was almost constant (Table 25). On the contrary in Veli Lake the fecundity was not constant when diurnal studies were carried out on 24.10.'92 (Table 26).

### Number of eggs or embryos and size of the parent

Egg production when correlated with the size of the maternal body (Table 12) showed that there was no significant correlation between the two factors. This shows that fertility is not related to parental size but evidently due to additional intrinsic or extrinsic factors.

### Number of eggs or embryos and size of the embryo

Egg production when correlated with the size of the egg or embryo showed significant negative correlation ($r = -0.4935$, $P < 0.01$, $n = 480$) thereby showing that clutch size decreases with increase in size of egg or embryo (Table 13).

### Embryo length and size of the parent

Positive correlation was seen between the embryo length and SL ($r = 0.39133$, $P < 0.01$, $n = 480$) as well as GL ($r = 0.5328$, $P < 0.01$, $n = 480$). This result suggested that the development of the embryo depends on the increase of GL by the expansion of the brood pouch (Table 13).

### Growth in the field

During the embryonic life spent in the maternal brood pouch, the egg in the animal grew gradually from 21 to 50 μm to a fully developed, ready to emerge embryo of about 230–270 μm in most of the months of collection (Fig. 26). Nearly all the stages of development (egg to releasing of embryo) were distinct in the populations of 30.5.'92, 15.7.'92, 26.9.'92 and 2.11.'92. All embryonic stages and the process of birth, have been described in previous sections.

In spite of an overlapping of generations in the life cycle of *E. tergestina*, a pattern of uniform growth could be traced from the histograms (Fig. 24). In Vizhinjam a year-round reproductive activity was seen with one population in pre-monsoon, two each in monsoon and

post-monsoon seasons. The length frequency histograms were found to show many peaks which can be discriminated as modes. However, when sequential samples are examined, the passage of peaks of abundance can to a certain extend indicate growth and the marked modes in the figure, no doubt correspond with the moulting classes.

In April, two peaks representing the size classes 301-350 µm and 401-450 µm were clear during the first fortnight (Fig. 24). These individuals falling in size class 301-350 µm had attained 351-400 µm in the second fortnight of April and those of 401-450 µm reached 451-500 µm and so on. A new population made its appearance in May (30.5.'92) thereby shifting the mode to the left and as in the previous case each size class of May could be traced to the next size class of 15.7.'92. Similarly another population could be traced in August to September. Further, in November a distinct population with all the size classes and stages were observed and the recruitment of young ones caused a shifting of the modes once again to the left as in May and September (Fig. 24). This was followed by another population in December. However, during certain months viz. January, March and June it was totally absent, while in some months, the death or grazing of older animals combined with comparatively low recruitment into the population caused only animals of a particular size to come into existence.

Thus, from this interpretation of the life cycle of *E. tergestina*, it is clear that at least 5-6 populations appeared in Vizhinjam waters and the rate of growth of individuals in the field for

a population was within the range 250-650 µm (SL) and 300-980 µm (GL) but the size frequency groupings were different between seasons. Small parthenogenetic females were observed in May and thus the population started from 250 µm which was the minimum size recorded in this locality.

It is also clear from the length frequency histograms that each population was found to last 20-30 days although there was overlap of generations in certain months. Further, in each population even though various size classes represent the moult classes, their exact number cannot be assessed in this species as moulting is independent of incubation which will be explained in the following section. However, the diurnal studies made in Vizhinjam and Veli waters showed that brooding time lasts for nearly one or two days as the new born neonates with blastulae which appeared in the collections made at dawn became eyed stages by dusk (Chapter V).

Population structure

Monthly variations in the percentage composition of the population are depicted in Figure 25. The categorisation of the population into four main categories is already furnished in the foregoing section (Material and methods). The percentage occurrence of this species in different categories of development in various size groups (Table 14) showed that the predominant component of the

population was females of Category II especially those in the 451-500 µm size class followed by 551-600 µm size class. Further, except for the collection on 30.5.'92 this category was observed only from a particular size class onwards. The highest percentage of category IA was seen in the size class 251-300 µm and 301-350 µm; whereas that of category IB was observed in size classes 501-550 µm and 551-600 µm. A very small proportion of category III was recorded in 351-400 µm and 401-450 µm size classes; likewise category IV was represented only in size classes 451-500 µm and 501-550 µm size classes. Hence it is clear that moulting is independent of incubation and that could be the reason why categories II, III and IV were observed only from a particular size onwards (Table 14; Fig. 25).

B. *PENILIA AVIROSTRIS* DANA

In Vizhinjam waters, breeding was observed in all the three seasons of the year (i.e., one in April, a second in August and a third in November). However, in Veli Lake this species was observed only in October. In all these collections, only parthenogenetic females were recorded with almost all the stages of development. However, a single male and a gamogenetic female were observed for the first time in Vizhinjam in the collections of 2.11.'92 (Fig. 1b and Plate II. 17,18). Further, *P. avirostris* was always found to coexist with *E. tergestina* suggesting that these two species inhabit the same ecological niche.

Stages in embryonic development

In *P. avirostris*, the developmental processes can be divided into 12 stages based principally on the formation of appendages. These distinctive stages (Fig. 21, a-l) are as follows.

Stage 1 : The eggs are oval and much longer than broad, measuring from 70 or 80 μm in length. Usually 8-10 eggs are deposited at a time. Generally the same number were found on either side, but exceptions to this were found. The eggs had segmented, showing the beginning of gastrulation.

Stage 2 : The embryo differentiated into the anterior and posterior part, as anterior end flattened itself very slightly dorso-ventrally and become broader than the posterior.

Stage 3 : One of the first changes noticed in the outward shape of the embryo was a widening of the anterior region and the appearance of two rounded prominences. During this stage the appearance of these two prominences projecting posteriorly on either side of the anterior end which will form the second antennae begin as an angle on either side of the rounded anterior end of the embryo.

Stage 4 : The mandibles were formed during this stage and they appeared as paired outgrowth just posterior to the second antennae which by then was well defined as two processes projecting posteriorly.

Stage 5 : A maxillary region was differentiated posterior to the mandible. The two projections of the second antennae grew backwards rapidly. The rudiments of the first pair of thoracic appendages appeared. The angle (first antennae) on either side of the anterior end increased in prominence and formed rounded lumps projecting anteriorly.

Stage 6 : The second pair of thoracic appendages made their appearance. The projections of the second antennae showed bifurcation.

Stage 7-9 : In each of these stages an addition of rudiments of thoracic appendages were seen in concurrence with a slight increase in the length of the embryo.

Stage 10 : The rudiments of the sixth pair of thoracic appendages appeared. In the maxillary region, the first and second maxillae were seen. The bifurcation of the second antennae was pronounced.

Stage 11 : Differentiation of the thoracic appendages into endopodites and exopodites was distinct. The second antennae have reached nearly

half the size of the embryo. Their bifurcation had deepened and the two lobes were clear.

Stage 12 : In this stage the gradual completion of the carapace with morphologically differentiated embryo and the antennae reaching almost the tip of the body were observed. The alimentary canal was well developed and at this stage the embryo was ready for emergence.

Liberation of the brood

As in *E. tergestina* the gravid females of *P. avirostris* released the brood and then rapidly swam away leaving the neonates to fend for themselves. However, this species was ovoviviparous as the young ones at the time of emergence had only developing oocytes in their ovaries and not paedogenetic as in *E. tergestina*.

The newly hatched young or juveniles with only developing oocyte ranged from 420 µm to 677 µm in GL. The appearance of first batch of eggs was seen in different size classes in the three populations observed in Vizhinjam (Table 16).

Number of eggs or embryos

In Vizhinjam, fecundity was relatively high (Table 15; Fig. 29B) whenever the species appeared in good numbers and also when the temperature was high or maximum (Tables 1 & 2). However, on 19.10.'92, the samples collected at three hour intervals from 05.00 hrs to 17.30

hrs showed that in all of them fecundity ranged from 5 to 6 eggs or embryos/female with highest mean of 4.66. In Veli Lake fecundity was higher and ranged from 6 to 8 eggs/female (mean 6.38)

**Number of eggs or embryos and size of the parent**

Egg production, when correlated with the size of the maternal body showed significant positive correlation between the two factors ($r = 0.3761$, $P < 0.01$, $n = 253$). This shows that fertility is related to parental size (Table 13; Fig. 30).

**Number of eggs or embryos and size of the embryos**

Egg production when correlated with the size of the egg or embryo showed significant negative correlation ($r = -0.3184$, $P < 0.01$, $n = 253$) indicating that clutch size decreases with increase in the size of the egg or embryo (Table 13).

**Embryo length and size of the parent**

Positive correlation can be seen between embryo length and gross length (GL) only ($r = 0.1699$, $P < 0.01$, $n = 253$). This result suggests that the development of the embryo is dependent on the increase of GL by the expansion of the brood pouch (Table 13).

Growth:

Considering embryonic growth, the egg in the ovigerous animal grew gradually from 70 to 80 μm to a fully developed embryo of about 370 μm in size. Almost all the stages of development were observed in all the populations recorded in Vizhinjam (Fig. 29A).

The length frequency histogram had a peculiar form in this case and hence as in *E. tergestina, P. avirostris* too had several peaks and these individual modes correspond to broods or instars. Thus *P. avirostris* too is iteroparous producing more than one brood per female. Each clutch gave rise to a brood of young and all the broods produced by a female belonged to the same generation. So in Vizhinjam waters three distinct populations were recognised (Fig. 28).

A perusal of Figure 28A shows that the growth curve of *P. avirostris* had a stepwise form (i.e. from 400 to 1100 μm). The appearance of first batch of eggs varied in the three populations (Fig. 30); in the first population it was seen in the size class 701-800 μm (747 μm); in the second it was in the size class 601-700 μm (700 μm) and in the third it was seen in 801-900 μm (817 μm) thereby showing that the growth rate and life span varied between populations of the various seasons. From Figure 30 it is clear that in each population there were at least 9-12 broods but varying in different seasons. The brooding time must be just a few days but from the available data the life span of this species cannot be found out unless one took daily samples for a particular period. An interesting aspect noticed in this

study was that the growth increment from one mode to the next mode (i.e., 1 moult to the next) was almost equal (Fig. 30).

**Population characteristics**

The variations in the percentage composition of the population are depicted in Figure 28B and Table 17.

On the basis of embryonic development the animals were ascribed into four main categories as mentioned in the case of *E. tergestina. However, in P. avirostris* only category I was different from that of *E. tergestina.* Here, in category I, newborn neonates or juveniles and the multiparous female with only developing oocytes are included. The appearance of first clutch of eggs started only from category II. Further, in the present study the newly moulted multiparous females of category I were dealt with as a separate category, IB. Thus based on 12 developmental stages, in each of the three ovigerous categories (i.e., categories II-IV) four developmental stages were included for the sake of convenience.

The percentage frequency of this species in different categories of development in various size groups (Table 17) showed that predominant component of the population was females of categories IB and IV especially those in the size class 801-900 µm followed by the size class 901-1000 µm. The highest percentage of category IA was seen in the size class 601-700 µm. In this species the individuals of category IA (non-ovigerous) were recorded only in the first three size

classes ranging from 401 to 700 µm; whereas the individuals of categories II, III and IV (ovigerous females) were recorded in all the size classes from 701 to 1100 µm (Table 17) although a few numbers are represented in the size class 601-700 µm. This clearly showed that this species had distinct juvenile and adult instars and further moulting was dependent on incubation.

TABLE 11

Fecundity as number of eggs or embryos borne by parthenogenetic females of E. tergestina taken at Vizhinjam station in different months

| Date | No. of specemens | Minimum | Maximum | Fecundity mean | Standard deviation |
|---|---|---|---|---|---|
| 20-2-'92 | 15 | 1 | 6 | 3.13 | ± 1.15 |
| 6-4-'92 | 14 | 3 | 6 | 4.29 | ± 1.48 |
| 20-4-'92 | 73 | 2 | 8 | 5.08 | ± 2.07 |
| 6-5-'92 | 10 | 3 | 4 | 3.10 | ± 0.03 |
| 30-5-'92 | 154 | 1 | 6 | 5.14 | ± 1.05 |
| 15-7-'92 | 42 | 3 | 10 | 6.12 | ± 1.49 |
| 6-8-'92 | 19 | 3 | 6 | 3.26 | ± 0.71 |
| 26-9-'92 | 41 | 2 | 8 | 3.68 | ± 1.25 |
| 8-10-'92 | 10 | 4 | 6 | 5.60 | ± 0.66 |
| 2-11-'92 | 64 | 3 | 8 | 5.53 | ± 1.74 |
| 4-12-'92 | 8 | 3 | 4 | 4.00 | ± 0.50 |
| 27-12-'92 | 30 | 3 | 6 | 5.13 | ± 0.81 |

TABLE 12

Mean number of eggs or embryos at given size of parent of Evadne tergestina at Vizhinjam Station for the period February '92 to January '93

(Figure in parenthesis indicates number of specimens examined)

| Length (µm) Size - class | 20-2-'92 | 6-4-'92 | 20-4-'92 | 6-5-'92 | 30-5-'92 | 15-7-'92 | 6-8-'92 | 26-9-'92 | 8-10-'92 | 2-11-'92 | 4-12-'92 | 27-12-'92 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 201 - 250 | - | - | - | - | 4.83 (6) | - | - | - | - | - | - | - | 4.83 (6) |
| 251 - 300 | - | - | - | - | 5.17 (30) | 6.00 (2) | - | 3.00 (1) | - | - | - | - | 5.15 (33) |
| 301 - 350 | - | 6.00 (4) | 6.00 (2) | - | 5.08 (34) | - | - | 4.00 (4) | - | 6.00 (2) | - | - | 5.15 (46) |
| 351 - 400 | - | - | 7.00 (6) | - | 5.00 (48) | 5.29 (7) | - | 3.88 (9) | - | 5.60 (5) | - | 5.00 (2) | 5.08 (77) |
| 401 - 450 | 5.20 (5) | 3.43 (7) | 4.66 (12) | 3.00 (4) | 5.46 (32) | 5.80 (32) | 3.10 (18) | 3.11 (9) | - | 6.00 (7) | - | 5.14 (7) | 4.61 (111) |
| 451 - 500 | 2.10 (10) | 4.00 (3) | 3.75 (24) | 3.00 (5) | 5.33 (3) | 6.36 (19) | 6.00 (1) | 3.33 (12) | 6.00 (4) | 5.33 (15) | 3.85 (7) | 4.28 (7) | 4.15 (110) |
| 501 - 550 | - | - | 5.36 (19) | 4.00 (1) | 6.00 (1) | 10.00 (2) | - | 4.00 (5) | 5.33 (6) | 4.81 (27) | 5.00 (1) | 5.67 (10) | 5.22 (72) |
| 551 - 600 | - | - | 5.40 (10) | - | - | 8.00 (2) | - | 4.00 (1) | - | 7.00 (6) | - | 5.50 (4) | 5.52 (25) |
| 601 - 650 | - | - | - | - | - | - | - | - | - | 7.00 (2) | - | - | 7.00 (2) |

TABLE 13

Regression equation

| Marine species | Between variables | Regression equation | Correlation coefficient |
|---|---|---|---|
| 1. Evadne tergestina | Y - Egg/Embryo length<br>X - Gross length | Y = -71.7020 + 0.2355 x | 0.5328** |
| | Y - Egg/Embryo number<br>X - Embryo length | Y = 6.0160 -0.0141 x | -0.4935** |
| 2. Penilia avirostris | Y - Egg/Embryo length<br>X - Gross length | Y = 43.1404 + 0.1212 x | 0.1699** |
| | Y - Egg/Embryo number<br>X - Embryo length | Y = 5.4260 -0.0059 x | -0.3184** |
| | Y - Egg/Embryo number<br>X - Gross length | Y = 0.2104 + 0.005 x | 0.3761** |
| | Y - Egg/Embryo number<br>X - Standard length | Y = 2.2802 + 0.0031 x | 0.2312** |

** Significant (P < 0.01)

TABLE 14

Percentage occurrence of the different categories (based on the stage of development) of parthenogenetic females of Evadne tergestina in various size groups at Vizhinjam Station for the period February '92-January '93

| Size class (µm) | Total No. of individuals | Category IA (%) | Category IB (%) | Category II (%) | Category III (%) | Category IV (%) |
|---|---|---|---|---|---|---|
| 201 - 250 | 6 | 83.33 | - | 16.67 | - | - |
| 251 - 300 | 33 | 84.85 | 6.06 | 9.09 | - | - |
| 301 - 350 | 46 | 60.87 | 4.35 | 34.78 | - | - |
| 351 - 400 | 78 | 38.46 | 29.49 | 26.92 | 3.85 | - |
| 401 - 450 | 111 | 15.32 | 38.74 | 45.05 | 0.90 | - |
| 451 - 500 | 109 | 3.67 | 31.19 | 61.47 | - | 4.59 |
| 501 - 550 | 72 | - | 50.00 | 47.22 | - | 2.78 |
| 551 - 600 | 23 | - | 47.83 | 52.17 | - | - |
| 601 - 650 | 2 | - | - | 100.00 | - | - |
| Total Number | 480 | | | | | |

TABLE 15

Fecundity as number of eggs or embryos borne by parthenogenetic females of P. avirostris from Vizhinjam Station in different months

| Date | No. of specemens | Minimum | Maximum | Fecundity mean | Standard deviation |
|---|---|---|---|---|---|
| 6-4-'92 | 34 | 1 | 6 | 4.12 | ± 1.12 |
| 6-8-'92 | 49 | 3 | 5 | 3.88 | ± 0.56 |
| 2-11-'92 | 67 | 2 | 8 | 5.37 | ± 1.39 |

TABLE 16

Mean number of eggs or embryos at given size of parent of Penilia avirostris at Vizhinjam Station for the period February '92 to January '93

(Figure in parenthesis indicates number of specimens examined)

| Length (µm) Size - class | 6-4-1992 | 6-8-1992 | 2-11-1992 |
|---|---|---|---|
| 601-700 | - | 4.00 (2) | - |
| 701-800 | 3.00 (3) | 3.89 (19) | - |
| 801-900 | 3.85 (14) | 3.86 (28) | 5.20 (15) |
| 901-1000 | 4.47 (17) | - | 5.25 (32) |
| 1001-1100 | - | - | 5.8 (20) |

TABLE 17

Percentage occurrence of the different categories of parthenogenetic Penilia avirostris in various size groups at Vizhinjam Station for the period February '92-January '93

| Size class (µm) | Total No. of individuals | Category IA (%) | Category IB (%) | Category II (%) | Category III (%) | Category IV (%) |
|---|---|---|---|---|---|---|
| 401 - 500 | 6 | 100 | - | - | - | - |
| 501 - 600 | 18 | 100 | - | - | - | - |
| 601 - 700 | 32 | 71.88 | 21.88 | 6.25 | - | - |
| 701 - 800 | 45 | - | 51.11 | 28.89 | 11.11 | 8.89 |
| 801 - 900 | 80 | - | 28.75 | 17.50 | 10.00 | 43.75 |
| 901 - 1000 | 64 | - | 23.44 | 28.13 | 15.63 | 32.81 |
| 1001 - 1100 | 23 | - | 13.04 | 34.78 | 13.04 | 39.13 |
| Total number | 268 | | | | | |

# DISCUSSION

The year-round study made in Vizhinjam waters has shown that *E. tergestina* was particularly abundant in April to May, July to September and November to December representing all the three seasons of the year. In all these collections wherein they form peaks nearly all the categories of the population were represented showing that intense breeding periods are discernible during this part of the year. Likewise *P. avirostris* also was observed in all the three seasons (April, August and November) in Vizhinjam. However, in Veli Lake these marine species were noticed only in October. Further, in all these collections these species owe their high reproductive potential to parthenogenesis. However, a single male and a gamogenetic female of *P. avirostris* were observed for the first time in Vizhinjam in the collections of November although Della Croce and Venugopal (1972); Vijayalakshmi and Venugopal (1972) and Naomi *et al.* (1994) have recorded them in their collections from Indian waters. This shows that the parthenogenetic mode of reproduction in these cladocerans in Vizhinjam is certainly indicative of optimal environmental conditions and food supply such as temperature, dissolved oxygen, chlorophyll content and so on. Thus it is believed by the present author that several stages in the life cycle of these animals are such a clear expression of conditions in the milieu and this finding is in tune with the observations made by Gieskes (1970). Furthermore, the experimental work of Banta (1939) has

demonstrated conclusively that the mode of reproduction is influenced by environmental factors. So also Wiborg (1955) have found out that under favourable circumstances, large populations, consisting almost entirely of females may be established both in neritic and in oceanic waters.

In *P. avirostris*, the developmental processes may be divided into 12 stages based principally on the formation of appendages, whereas in *E. tergestina*, seven stages were recorded from egg to embryo before emergence. This is in tune with the observations made by Della Croce and Bettanin (1965) and Onbe (1978a). The only difference between these two species is that the embryo of *E. tergestina* before emergence is a miniature adult which bears its own egg in the embryonic brood space whereas in *P. avirostris* it has only developing oocytes at birth and hence is a juvenile after liberation of brood. This paedogenetic reproduction in *Evadne* was also observed by Bainbridge (1958); Gieskes (1970) and Onbe (1978a). Also, ovoviviparity in *P. avirostris* was recorded by several authors (Della Croce and Bettanin, 1965; Della Croce, 1966; Vijayalakshmi and Venugopal, 1972 and Onbe, 1978a).

The size range and fecundity were different between seasons in both the species. This has been observed by Della Croce (1966) and Onbe (1978a). However, the standard length and gross length of *E. tergestina* was smaller than those observed by Naomi *et al.* (1994) whereas in *P. avirostris* they were bigger than those reported by the same author.

Considering the effect of physico-chemical parameters on the size of the broods (Tables 1 & 2) in *P. avirostris* it is evident that the number of embryos attained its maximum in April and November when temperature was high. Vijayalakshmi and Venugopal (1972) have also observed that the size of the broods produced by parthenogenetic females of *P. avirostris* is controlled by temperature and associated factors. Although Poggensee and Lenz (1981) have reported negative correlation between temperature, body size and number of embryos per female in *Podon leuckarti* and *Evadne nordmanni*, in the present study no such relationships were noticed in *E. tergestina*. Hence in this species the decrease or increase of the brood size may be the consequence of overcrowding, reduction in food supply or simply a rhythm inherent in the population and these possibilities are subjects for further research.

Cheng (1947), Green (1954, 1956), Bainbridge (1958) observed a clear-cut correlation between egg number and size of the parent in many marine and freshwater cladocerans. Onbe (1978a) showed a positive correlation between the number of eggs or embryo per batch and the body length of parthenogenetic females in *E. nordmanni*. However, in the present investigation no such significant correlation was recorded in *E. tergestina* and this is borne out in the studies made by Onbe (1978a, 1983) on *Podon polyphemoides* and *P. schmackeri*. In the case of *P. avirostris* significant positive correlation was recorded between egg

number and size of the parent both in the present study and also in the earlier studies by Onbe (1978a) and Vijayalakshmi and Venugopal (1972).

A significant relationship between body length and embryo length was observed in both *E. tergestina and P. avirostris* and this was more pronounced in GL x EL relationship as given by Kim and Onbe (1989) in *P. schmackeri.*

A significant negative correlation between the size of embryo or egg and the number of the same in these two species showed that a decrease in clutch size was seen as embryo length increased and this is characteristic of some crustaceans like prawn and crab.

Regarding growth pattern, the length frequency graphs showed several modes; in both species the modes represented the broods or instars in the life cycle to a certain extent. In *P. avirostris* deposition of first clutch of eggs was seen at a particular size class which varied according to season (Table 16; Fig. 30) whereas in *E. tergestina* this deposition of eggs was in the embryo when it is in the brood pouch. Although Pavlova (1959) and Onbe (1978a) have recorded 8 instars (2 juvenile and 6 adult instars) in *P. avirostris*, in Vizhinjam waters about 9 to 12 size classes were seen (Fig. 30). Further since distinct juvenile size classes (category IA) and ovigerous females (categories II, III and IV) were recorded in all the adult size classes it is clear that in this species moulting was dependent on incubation. Another interesting aspect noted in this study was that the increase in length from one mode to the next mode (i.e., 1 moult to the next) was

always found to be the same (Fig. 30). This observation was in tune with the studies made by Brooks (1886) on the stomatopod *Lysiosquilla minuta* wherein he found out that the mean lengths of erichthus larvae of this species are related to each other like the successive terms of a geometric progression with a ratio of 1.25; in other words the increase rate from 1 moult to the next is always 1.25. Further investigation of several species of crustaceans showed that this rate may vary widely in a single species, even at the same stage according to living conditions (Teissier, 1936). In addition, the growth rate for one individual may be independent of each other in two consecutive moults (Teissier, 1937).

From the size frequency histograms of *E. tergestina* of Vizhinjam (Table 14; Fig. 25) it is clear that individuals of category IA with mature eggs are observed only in the first two size classes and thus have their own first moult without releasing young and become category II which after further development become categories III and IV and then release their own first brood of young when 2 days or 3 days old with the second or third moult respectively and that could be the reason why categories II, III and IV were observed only from a particular size onwards (Table 14). Hence it is evident that moulting in *E. tergestina* is independent of incubation as observed by Gieskes (1970) in *E. nordmanni*. Rammner (1931) claimed that only with a third moult were young released for the first time. Further, Bryan (1979) is also of the opinion that *E. tergestina* has its own first moult the

following morning without releasing young and then releases the first brood of young when two days old with its second moult. Thus unless the animal is reared in the laboratory the total number of moults and total life span cannot be determined from the field data. Moreover since moulting is independent of incubation the size or length at which the first release of neonates takes place is also difficult to ascertain.

This study has thus revealed that in *P. avirostris* distinct periods such as egg, juvenile and adult are recognized in their life cycle. Further, there are distinct juvenile and adult instars and at the close of each adult instar four events follow one after another in rapid succession. These are : the release of young from the brood chamber to the outside, moulting, increase in size and release of a new clutch of eggs to the brood chamber. However in *E. tergestina* there are no juveniles in their life cycle since parthenogenesis is accompanied by neoteny (i.e., the embryos mature before birth) and hence when liberated are miniature adults. So juvenile instars are absent in this species and contrary to *P. avirostris* one or more adult instars take place before the first release of 'neonates' or newborn and an interesting conclusion from the present investigation is that moulting seems to occur independently of egg incubation.

# CHAPTER IV

## OBSERVATIONS ON THE REPRODUCTIVE BIOLOGY OF CLADOCERANS FROM A BACKWATER

# INTRODUCTION

A notable number of publications have dealt with different biological aspects of freshwater and brackishwater cladocerans. These observations were initiated in India by Michael (1962) but all other contributions resulted during the last two decades (1971-1990). A majority of these studies included observations on various parameters of life history i.e., longevity, growth, fecundity and embryonic development. These aspects have so far been examined in ten species of the family Daphniidae, two species each of the families Sididae and Moinidae and one species of the family Chydoridae (Michael, 1962; Navaneethakrishnan and Michael, 1971; Murugan and Sivaramakrishnan, 1973, 1976; Murugan and Venkataraman, 1977; Murugan and Job, 1982; Sharma *et al.*, 1984; Jana and Pal, 1984). Thus far only a few publications have referred to the biology of *Moina micrura* from Indian waters (Murugan, 1975, 1989a; Jana and Pal, 1985). Another species of the family Moinidae, *Moinodaphnia macleayi* King was first reported by Brehm (1953) in Indian waters but is very rare except for some specimens from a tank in Trivandrum and from a ditch and pond in Punjab. Further, this species is least known for its biology and ecology among the important cladocerans in India (Michael and Sharma, 1988).

Very recently the Department of Biotechnology, under the auspices of the Scientific Advisory committee, has constituted 13 'Task Forces'

of which 'Aquaculture and Biotechnology' is considered to be the most important one. In this context 'selective enrichment of biota' (*Spirulina, Brachionus, Moina*) is given the highest priority since their role as 'live food' has been emphasised by innumerable aquatic biologists. Hence although the various biological aspects of *Moina micrura* Kruz have been covered, still it is worthwhile to discuss the observations made on this species from a backwater biotope (The Veli Lake) with special emphasis to statistical correlation. In addition the morphology and reproduction of *M. macleayi* using specimens sorted out from a collection in Veli Lake is also dealt with as its development and growth are described and illustrated for the first time.

## MATERIAL AND METHODS

As given in Chapter III measurements of SL, GL, EL and number of eggs or embryos were noted using a binocular microscope and ocular micrometer. Statistical analyses were also carried out as mentioned in the previous chapter, between parent size and number and size of eggs or embryos. Further, these moinids are also classified into four main categories as in *Penilia avirostris* (Plate II, 19-23).

# RESULTS

## A. *MOINA MICRURA* Kurz

The year-round studies made in Veli Lake showed that in this species breeding was most intense during February and June (Fig. 31). Further, in all the collections made, only parthenogenetic females were observed with different stages of development.

### Stage in embryonic development

As the stages in embryogenesis are as mentioned in the studies made by Murugan (1975), descriptions on the same are not repeated. However, the stages are illustrated in Figure 22, a-d, in order to compare them with those of *M. macleayi*.

### Liberation of the brood

As in *P. avirostris* the gravid females released the brood leaving the 'neonates' or newborn to look after themselves. Hence this species was ovoviviparous as the young ones at the time of emergence had only developing oocytes in their ovaries.

These newly hatched young or juveniles with only developing oocytes ranged from 373 to 583 $\mu$m in GL. The appearance of the first batch of eggs was seen in different size classes in the populations from the Veli Lake (Tables 20 & 21).

Number of eggs or embryos

In Veli Lake fecundity was relatively the lowest when the species appeared at the beginning of February (Table 18; Fig. 34). Then it showed a sharp increase in June (i.e., the highest value) and further decreased steadily until the end of August, increased again in early October and then decreased to a lower value in December.

Number of eggs or embryos and size of the parent

Egg production when correlated with size of the maternal body showed significant negative correlation between the two factors (Tables 19 & 20A; Fig. 35). This shows that there was a decrease in fertility with the increase in size; GL ($r = -0.6890$, $P < 0.01$, $n = 216$) as well as in SL ($r = -0.7043$, $P < 0.01$, $n = 216$).

Number of eggs or embryos and size of the embryos

Egg number when correlated with size of egg or embryo showed no significant relationship ($r = -0.0651$, $n = 216$).

Embryo length and size of the parent

Positive correlation was recorded between EL and SL ($r = 0.2306$, $P < 0.01$, $n = 216$) as well as GL ($r = 0.2221$). Hence in the species development of eggs/embryos is dependent on SL more than GL (Table 19).

Growth in the field

As regards embryonic growth, the egg (91-120 µm) in the maternal brood pouch attained a maximum size of 220-370 µm at the time of emergence (Fig. 33).

As in *P. avirostris*, in this species also several peaks occur and each one corresponds to the broods. Hence this species too is iteroparous producing more than one brood per female (Fig. 31). Further, a perusal of the length frequency histograms showed that except for June the size range of the adult was almost the same in all the collections with this species. Thus the rate of growth of individuals in the field for a population was within the range 350 to 817 µm (SL) and 373 to 887 µm (GL) but the size frequency groupings was different between seasons. Small parthenogenetic females were observed in June and thus the population started from 350 µm which was the minimum size recorded in this lake (Fig. 32).

Similarly the appearance of the first batch of eggs was seen in the size class 701-800 µm (723/747 µm) in all the samples. However, in June this was observed in the size class 501-600 µm (513 um). From Fig. 35 it is clear that in each population there are at least 4 to 6 broods but the size groupings were varying in different seasons. Further, as in *P. avirostris* an almost equal growth increment was observed between successive adult moults (Table 20B ; Fig. 35).

Population characteristics

On the basis of embryonic development the animals are ascribed to the previously mentioned four main categories as in *P. avirostris*. Fig. 32 shows that the predominant component of the population is ovigerous females (i.e. categories, II, III and IV); nonovigerous females were recorded only in February and June. Further, it is observed that individuals of category IA were recorded only in the size class 501-600 µm in February and 301-500 µm in June whereas all the ovigerous categories were recorded in almost all the size classes from the appearance of first batch of eggs in each population (Table 21; Fig. 32).

B. *MOINODAPHNIA MACLEAYI* King

It will be seen from Table 3 that this species was present only in January '93 at Veli Lake and all the individuals examined were parthenogenetic. The gross length frequency distribution is shown in Fig. 36. The SL of parthenogenetic females ranged from 440-800 µm and GL from 490-880 µm.

Distinctive stages in the embryonic development of *Moinodaphnia macleayi* (Fig. 23, a-d)

Stage 1 : The newly deposited egg was more or less spherical with a granulated translucent central zone and an outer egg membrane. The size of egg ranged from 90 to 100 µm (Fig. 39).

Stage 2 : The embryo was elongated anteroposteriorly. A distinct head was not yet formed. At this stage, rudiments of antennae were seen and the egg membrane was cast off leaving the naupliar membrane as the boundary.

Stage 3 : Rudiments of the head lobe was noted. At this stage the stumpy antennary rudiments of stage 2 had developed further in the antero-lateral sides. The appearance of four rudimentary thoracic appendages was observed.

Stage 4 : This is the last stage before emergence. It was characterised by a distinct head lobe and a prominent eye in the cephalic region. The segmented antennae lengthened and became biramous with setae. The caudal furca also appeared.

Liberation of the brood

When the development is complete, the gravid female releases the brood in a single batch and hence it has ovoviviparous parthenogenesis. The newly hatched young or neonates with only developing oocytes ranged from 490 to 670 µm (GL).

Number of eggs and embryos and size of the parent

The mature females of this species formed 57.65% of the total population (Table 22). The clutch size ranged from 8 to 10 eggs per clutch. In the present study when these parthenogenetic females were

examined no significant correlation between the size of the parent and number of eggs was observed. Likewise no correlation was evident between egg number and embryo length.

### Embryo length and size of the parent

Positive correlation was recorded between EL and SL ($r = 0.8149$, $P < 0.01$, $n = 29$) as well as GL ($r = 0.5955$). Hence in this species development of egg/embryo is dependent on SL more than GL (Table 19).

### Growth in the field

It is clear from the Table 22 that the smallest neonate (category IA) recorded in the collection had a gross length of 490 μm; the maximum length attained was 880 μm. Further in this sample the length at which mature egg first appeared was 710 μm. Similarly the eggs (90–100 μm) attained a maximum size of 210–270 μm at the time of emergence. Thus from the length frequency histograms (Table 22; Fig. 38) it is found that the various size classes represent the nine adult broods or moult classes.

### Population characteristics

As given in Chapter III the parthenogenetic females are grouped into four main categories. Table 22 shows that although all the size groups are well represented, the predominant component of the population comprises of ovigerous females (57.66%) followed by

juveniles (38.5%) and multiparous females after release of young (3.84%). Among the ovigerous females, the animals of length 790-820 μm are found to form the prominent length group as evidenced by their maximum percentage. The appearance of mature eggs were recorded from size group 710 μm onwards. Further, the predominant size class of juveniles was 611-640 μm.

TABLE 18

Fecundity as number of eggs or embryos borne by parthenogenetic individuals of Moina micrura taken during different months for the period February '92 to January '92 at Veli Station

| Date | No. of specemens | Minimum | Maximum | Fecundity mean | Standard deviation |
|---|---|---|---|---|---|
| 7-2-'92 | 40 | 1 | 2 | 1.65 | ± 0.56 |
| 5-6-'92 | 66 | 3 | 7 | 4.29 | ± 1.50 |
| 9-7-'92 | 40 | 2 | 4 | 2.93 | ± 0.99 |
| 7-8-'92 | 11 | 2 | 4 | 2.36 | ± 0.77 |
| 18-10-'92 | 24 | 3 | 4 | 3.63 | ± 0.63 |
| 5-12-'92 | 20 | 1 | 3 | 2.30 | ± 0.56 |

TABLE 19

Regression equation

| Backwater species | Between variables | Regression equation | Correlation coefficient |
|---|---|---|---|
| 1. Moina micrura | Y - Egg/Embryo length<br>X - Gross length | Y = 67.7972 + 0.1045 x | 0.2221** |
| | Y - Egg/Embryo length<br>X - Standard length | Y = 67.5182 + 0.1151 x | 0.2306** |
| | Y - Egg/Embryo number<br>X - Gross length | Y = 11.0361 - 0.0103 x | -0.6890** |
| | Y - Egg/Embryo number<br>X - Standard length | Y = 10.9482 - 0.0112 x | -0.7043** |
| 2. Moinodaphnia macleayi | Y - Egg/Embryo length<br>X - Gross length | Y = -616.82 + 0.9736 x | 0.5955** |
| | Y - Egg/Embryo length<br>X - Standard length | Y = -519.469 + 1.0271 x | 0.8149** |

** Significant ($P < 0.01$)

TABLE 20

A. Mean number of eggs or embryos at given size class of parents of M. micrura at Veli Lake
(Figure in parenthesis indicates the number of specimens examined)

| Size class Interval (µm) | 7-2-'92 | 5-6-'92 | 9-7-'92 | 7-8'92 | 18-10-'92 | 5-12-'92 | Mean |
|---|---|---|---|---|---|---|---|
| 301-400 | - | - | - | - | - | - | - |
| 401-500 | - | - | - | - | - | - | - |
| 501-600 | - | 5.33 (59) | - | - | - | - | 5.33 (59) |
| 601-700 | - | 5.14 (7) | - | - | - | - | 5.14 (7) |
| 701-800 | 1.48 (21) | - | 2.70 (17) | 2.36 (11) | 3.50 (6) | 2.36 (11) | 2.27 (66) |
| 801-900 | 1.84 (19) | - | 3.22 (22) | - | 3.66 (18) | 2.44 (9) | 2.84 (68) |
| 901-1000 | - | - | 4.00 (1) | - | - | - | 4.00 (1) |
| B. Mean number of eggs or embryos and size of parent of M. mucrura at Veli Lake | | | | | | | |
| 513 | - | 4.25 (4) | - | - | - | - | |
| 537 | - | 4.84 (19) | - | - | - | - | |
| 560 | - | 5.35 (26) | - | - | - | - | |
| 607 | - | 6.60 (10) | - | - | - | - | |
| 723 | - | - | - | 2.00 (3) | - | - | |
| 747 | 2.00 (1) | - | - | 2.00 (1) | 3.00 (3) | 2.50 (4) | |
| 770 | 1.00 (1) | - | 2.00 (2) | - | 4.00 (1) | 2.50 (6) | |
| 793 | 1.47 (19) | - | 2.80 (15) | 2.57 (7) | 4.00 (2) | 1.00 (1) | |
| 817 | 1.77 (13) | - | 3.23 (13) | - | 3.88 (19) | 2.44 (9) | |
| 840 | 2.00 (1) | - | 3.17 (6) | - | 3.75 (4) | - | |
| 863 | - | - | 3.33 (9) | - | 3.20 (5) | - | |
| 887 | 2.00 (10) | - | - | - | - | - | |
| 933 | - | - | 4.00 (1) | - | - | - | |

TABLE 21

Percentage occurrence of the different categories of parthenogenetic females of M. micrura at Veli Station for the period February '92-January '93

| Size class (µm) | Category IA (%) | Category IB (%) | Category II (%) | Category III (%) | Category IV (%) | Total No. of individual |
|---|---|---|---|---|---|---|
| 301 - 400 | 100.00 | - | - | - | - | 11 |
| 401 - 500 | 100.00 | - | - | - | - | 11 |
| 501 - 600 | 25.00 | 1.25 | 31.25 | 26.25 | 16.25 | 80 |
| 601 - 700 | - | 12.50 | - | - | 87.50 | 8 |
| 701 - 800 | - | 21.42 | 63.10 | 15.48 | - | 84 |
| 801 - 900 | - | 1.45 | 40.58 | 52.17 | 5.80 | 69 |
| 901 - 1000 | - | - | - | 100.00 | - | 1 |
| Total | | | | | | 264 |

TABLE 22

Percentage occurrence of the different categories of parthenogenetic females of Moinodaphnia macleayi in various size groups at Veli Station during January '93

| Size class (µm) | Category IA (%) | Category IB (%) | Category II (%) | Category III (%) | Category IV (%) | Total No. of individuals |
|---|---|---|---|---|---|---|
| 491-520 | 9.62 | - | - | - | - | 5 |
| 521-550 | 3.84 | - | - | - | - | 2 |
| 551-580 | 1.92 | - | - | - | - | 1 |
| 581-610 | 1.92 | - | - | - | - | 1 |
| 611-640 | 11.53 | - | - | - | - | 6 |
| 641-670 | 9.62 | - | - | - | - | 5 |
| 701-730 | - | - | - | 3.84 | - | 2 |
| 731-760 | - | - | - | - | - | - |
| 761-790 | - | - | 3.84 | 3.84 | - | 8 |
| 791-820 | - | - | 15.38 | 9.62 | 11.53 | 15 |
| 821-850 | - | - | - | 1.92 | - | 1 |
| 851-880 | - | 3.84 | - | - | 7.69 | 6 |
| Total | 38.5 | 3.84 | 19.22 | 19.22 | 19.22 | 52 |

# DISCUSSION

The year-round study made in Veli Lake has shown that *M. micrura* was predominant in the zooplankton samples in February and June. However, *M. macleayi* was observed only in January in association with other species of cladocerans and a mixed phytoplankton bloom. In all these collections wherein they form peaks nearly all the categories of the population were represented, thereby showing that intense breeding periods of these species are discernible during this part of the year. Further the dominance of parthenogenetic juveniles and gravid females show that the environmental conditions are favourable for growth and reproduction of these species. Since these species were in association with a mixed phytoplankton bloom whenever it occurred in fairly good percentage, the availability of food has also played an important role in the development of these species in a backwater lake (Table 3). This is in tune with the observations made by Banta (1939), Wiborg (1955), Green (1956) and Murugan (1989a)

In both these moinids the embryonic stages may be divided into 4 or 5 stages based principally on the formation of head lobe and appendages. This observation is in agreement with the studies made by Murakami (1961) and Duangswasdi (1981) on *M. macropa* and also by Murugan (1975) on *M. micrura*. However, in all these investigations the liberated 'neonates' or newborn young are juveniles with only

developing oocytes and hence reproduction is by ovoviviparous parthenogenesis.

In comparison to *M. micrura* of the same area, *M. macleayi* had high fecundity (8-10 eggs/gravid female) (Fig. 38). However, in *M. micrura* the highest fecundity was recorded in June (Table 18) although this showed wide fluctuations between seasons. Such size variation may be due to the influence of a variety of factors which may be either intrinsic or extrinsic (Green, 1956; Kerfoot, 1974; Murugan, 1989a).

Another interesting finding is that in June (Figs. 31, 33) the size of the animal was smaller but the number of eggs or embryos was found to be more than in the other months but with smaller size. It may be that with more food being available, there is a tendency for the animal to form smaller eggs (Hutchinson, 1951; Lack, 1954). Thus when food is scarce bigger eggs are formed to store more food which the embryo can utilize at a later stage when food becomes scarce in the environment.

In *M. macleayi*, egg production when correlated with size of the maternal body showed no significant correlation. Murugan (1989) recorded very low correlation ($r = 0.13$) between the length and number of eggs per brood in *M. micrura*. However, in the present collection significantly negative correlation was observed between these two factors in *M. micrura* showing that there is a decrease in fertility with increase in parent size. Further, in both these moinids significant positive correlation was seen between size of the embryo

and size of the parent. It was also seen that the development of embryo is dependent on standard length more than gross length which is contrary to the observations in marine cladoceran where this relationship was more pronounced in GL x EL relationship. However, no significant correlation was observed between egg number and size of the embryo in both these moinids whereas in the marine species significant correlation was observed which showed a decrease in clutch size as EL increased. It is rather difficult to give reasons for these variations. However, these may be influenced by environmental conditions and physiological state of the mother, and the latter's genetic constitution (Slobodkin, 1954; Green, 1956; Hutchinson, 1967).

Considering growth patterns in moinids, the length frequency graphs showed several modes corresponding to the broods or instars in the life cycle to a certain extent. This is in accordance with the studies made by Murugan (1975, 1989a), Jana and Pal (1985, 1989), Hudec (1988) and Wang *et al.* (1991) in *M. micrura*. From the specimens obtained from Veli Lake it was gathered that mature eggs were observed from the size range 710–730 µm onwards in the case of *M. macleayi* and 723–747 µm onwards in *M. micrura* in all the collections except for the sample in June (Table 20) According to Murugan (1975) the first clutch of eggs appeared in size 602 µm. Although Murugan (1975) recorded 11 adult instars in his laboratory observations made on *M. micrura* in the present study about six and nine size classes representing adult instars were observed (Table 20B; Figs. 35, 38) in *M. micrura* and *M.*

*macleayi* respectively. Further, since distinct juvenile size classes (category IA) and adult size classes (categories II, III and IV) were recorded it is evident that moulting was dependent on incubation.

In this study a striking feature contrary to the observations made by Murugan (1975) in *M. micrura* was noticed. That is the growth increment between successive adult moults was almost equal (Table 20B). However, in *M. macleayi* this was seen only in 1 or 2 successive moults. This finding clearly indicates that the growth rate observed in the laboratory under controlled conditions are quite different from what is observed in the field. However, as already mentioned in the foregoing chapter, in many species of crustaceans this rate may vary even in the same species depending on living conditions (Brooks, 1886).

While summing up, the present investigations on these tropical cladocerans have shown that most of the sequential events in the life cycle are similar to those from other regions, the number and size of the young are results of the interaction of the environment and various intrinsic factors such as the age, size and genetic characteristics of the mother.

# CHAPTER V

## DIURNAL VARIATION OF THE CLADOCERANS AND THEIR ENVIRONMENT

# INTRODUCTION

A fuller understanding of planktonic systems in nature cannot be ensued without a review of their diurnal changes as it is essential to design strategies of sampling and to estimate the inter-relations and productivity of zooplankton populations. Our knowledge about the diurnal variations of the zooplankton and hydrographical aspects from the west coast of India is mainly due to the studies of Pillai and Pillai (1973), Madhupratap and Rao (1979), Goswami *et al.* (1979), Mathew *et al.* (1977), Gajbhiye *et al.* (1984) and Madhupratap *et al.* (1991). However, a diurnal study exclusively on cladocerans with special emphasis on their reproductive cycle has not been carried out so far in the Indian waters, although Bosch and Taylor (1973), Onbe (1974, 1978), Bryan (1979) and Mullin and Onbe (1992) have made some preliminary diel studies on the cladoceran of U.S.A., Japan and Gulf of Mexico. In view of this, a comparative investigation of diurnal periodicity on parthenogenetic reproduction of two species of cladocerans, *Evadne tergestina* Claus and *Penilia avirostris* Dana was taken up in two coastal locations--the Vizhinjam inshore station and the Veli Lake (a tropical backwater habitat), both in Trivandrum. In addition, the hydrographic parameters influencing the reproductive cycle of these species are also presented and it is for the first time that such a study has been carried out in this region. The description of the study areas are already presented in Chapter II.

## MATERIAL AND METHODS

For studying the diurnal variation in hydrographic parameters and cladoceran fauna with special emphasis on reproductive cycle from the two chosen stations, water and plankton samples were taken at 3 hourly intervals for a 12 hour period at Vizhinjam and 24 hour period at Veli Lake. The study at Vizhinjam Station was carried out during the month of September and October whereas at Veli Lake it was conducted on 24.10.'92 for a 24 hrs period from 06.00 hrs.

Hydrographic parameters such as temperature, hydrogen-ion concentration (pH), salinity, dissolved oxygen and nutrients were determined using standard methods (Chapter II). Plankton samples were also collected from the surface using the same net as mentioned in Chapter I. The samples obtained were taken in separate labelled bottles and preserved in formalin and taken to the laboratory for analysis. The cladocerans were sorted out and counted in order to determine their numerical abundance. Further, based on the reproductive state of the animal the population composition of the dominant species was grouped into four main categories as already furnished in Chapter III. The variations in the height of the tide during the 12 hrs cycle at Vizhinjam and 24 hrs cycle at Veli coast were noted down from the Indian Tide Tables for the year 1992.

# RESULTS

## Environmental conditions of the two environments

The 3 hourly variation in hydrographic parameters at Vizhinjam and Veli Lake are presented in Table 23.

In Vizhinjam, on 26.9.'92 the surface temperature varied from 27.5°C to 29°C and was maximum at 11.00 and 14.00 hrs and minimum at 05.00 hrs. Likewise on 19.10.'92 the maximum was recorded at 14.30 hrs. On both the days of collection the maximum salinity was recorded during 11.00 to 14.00 hrs. Dissolved oxygen and pH values were more or less steady throughout the period of observations. On 26.9.'92 phosphate values fluctuated from 0.04 to 0.71 µg at./l and silicate 3.53 to 9.97 µg at./l. Nitrite and nitrate values were quite high on 19.10.'92 when compared to the values observed on 26.9.'92.

In Veli Lake (Table 24), the surface water temperature varied widely between 29°C and 33°C and was maximum at 15.00 hrs of 24.10.'92 and minimum at 06.00 hrs. Salinity values ranged from 3 ppt to 5.75 ppt. High dissolved oxygen values were recorded from 12.00 hrs to 24.00 hrs. There was a gradual increase in pH values. Phosphate values were very low throughout the period of observation; nitrite values were high during 06.00–12.00 hrs and nitrate values were more or less constant. Silicate values were very high in all the collections with a maximum during 06.00–12.00 hrs.

Although values for chlorophyll *a* were recorded only twice (05. 00 /06.00 hrs and 17.00/18.00 hrs) on all the three days of observation (i.e., both at Vizhinjam and Veli stations) there was an increase in value at dusk.

**Diurnal distribution of cladoceran population**

*Evadne tergestina*

On 26.9.'92, only *E. tergestina* was recorded along with other important zooplankters such as copepods, chaetognaths, appendicularians and a phytoplankton bloom comprising *Thalassiosira subtilis*. In Vizhinjam only parthenogenetic females of *E. tergestina* were recorded (Table 23) which contained embryos with pigmented eyes (i.e., category IV) only in the collection at 05.00 hrs and the relative abundance of small animals (neonates) was significantly greater from 06.00 to 11.00 hrs than at other times. Animals with early stages of development (category II) were observed in all the collections in fairly good numbers and were dominant too. Advanced stages of categories II and III occurred only during 14.00-17.00 hrs. The number of embryos per gravid female ranged from 2 to 8 with a mean of 3.68 at 05.00 hrs (Table 25).

In Veli Lake (Table 24) no eyed embryos (category IV) of *E. tergestina* were observed in any of the collections made from 24.10.'92 to 25.10.'92. However, in collections made during 06.00 and 18.00 hrs, advanced stages of categories II were recorded. Individuals of categories II were particularly abundant at 06.00 hrs of 24.10.'92.

Similarly neonates were more common during 06.00–09.00 hrs. Multiparous females after release of neonates (category IB) were recorded only during 06.00 hrs. The number of embryos per gravid female (Table 26) ranged from 2 to 8 with a mean of 4.20 (maximum at 06.00 hrs).

*Penilia avirostris*

From the Table 23 showing the diurnal distribution of *P. avirostris* in Vizhinjam on 19.10.'92 it is evident that only parthenogenetic females were recorded; they were totally absent or occurred in very few members from 05.30 to 11.30 hrs but all the categories were recorded during 14.00–17.00 hrs. However, in Veli Lake in a diurnal study made on 24.10.'92 this species representing all categories was observed only at 06.00 hrs. In Vizhinjam waters the number of embryos per gravid female ranged from 2 to 6 with a mean of 4.00 at 11.30 hrs and 4.66 at 14.30 hrs (Table 27). However, in Veli Lake fecundity was higher and the number ranged from 3 to 8 with a mean of 6.38.

TABLE 23

Station I - Vizhinjam - 3 - Hourly variation in the physico-chemical parameters, tide height, chlorophyll a and marine cladocerans (No./100 m³) at Vizhinjam inshore station in September and October

September (26.9.1992)

| Parameters | Time (in hours) | | | | |
|---|---|---|---|---|---|
| | 05.00 | 08.00 | 11.00 | 14.00 | 17.00 |
| Surface water temperature (°C) | 27.50 | 28.50 | 29.00 | 29.00 | 28.00 |
| Salinity (°/••) | 35.00 | 35.00 | 36.00 | 36.00 | 35.00 |
| Dissolved oxygen (ml/l) | 6.09 | 5.41 | 5.87 | 5.75 | 6.09 |
| pH | 7.91 | 7.91 | 7.90 | 7.92 | 7.92 |
| Phosphate (µg at./l) | 0.37 | 0.71 | 0.34 | 0.04 | 0.37 |
| Nitrite (µg at./l) | 0.13 | 0.22 | 0.00 | 0.02 | 0.17 |
| Nitrate (µg at./l) | 0.14 | 0.09 | 0.01 | 0.02 | 0.05 |
| Silicate (µg at./l) | 3.53 | 9.28 | 9.97 | 7.67 | 3.84 |
| Chlorophyll a (mg/m³) | 4.36 | —— No Data —— | | | 5.23 |
| Tide height (m) | 0.32 | | 0.82 | | 0.35 |
| Evadne tergestina (Parthenogenetic females) | | | | | |
| Category I A | 770 | 150 | 496 | 24 | 200 |
| I B | 272 | 134 | 48 | 24 | 42 |
| II | 6490 | 282 | 8285 | 1000 | 2740 |
| III | - | - | - | 16 | 92 |
| IV | 2000 | - | - | - | - |
| Total | 9532 | 566 | 8829 | 1064 | 3074 |

October (19.10.1992)

| Parameters | Time (in hours) | | | | |
|---|---|---|---|---|---|
| | 05.30 | 08.30 | 11.30 | 14.30 | 17.30 |
| Surface water temperature (°C) | 26.00 | 26.50 | 27.90 | 28.50 | 27.50 |
| Salinity (°/••) | 35.00 | 35.50 | 36.00 | 36.50 | 36.00 |
| Dissolved oxygen (ml/l) | 4.29 | 4.51 | 4.29 | 4.29 | 4.29 |
| pH | 7.86 | 7.83 | 7.86 | 7.91 | 7.90 |
| Phosphate (µg at./l) | 1.12 | 0.75 | 2.06 | 2.25 | 1.12 |
| Nitrite (µg at./l) | 0.09 | 0.04 | 0.46 | 0.73 | 0.55 |
| Nitrate (µg at./l) | 0.01 | 0.18 | 0.32 | 0.37 | 0.37 |
| Silicate (µg at./l) | 38.35 | 38.35 | 31.45 | 23.01 | 29.15 |
| Chlorophyll a (mg/m³) | 2.04 | — No Data — | | | 2.92 |
| Tide height (m) | 0.83 | | 0.60 | | 0.72 |
| Evadne tergestina (Parthenogenetic) category II only | - | 23 | 11 | - | - |
| Penilia avirostris (Parthenogenetic females) | | | | | |
| Category I A | - | - | - | 6 | 119 |
| I B | - | - | - | 64 | 91 |
| II | - | - | - | 192 | 158 |
| III | - | 45 | 12 | 64 | 11 |
| IV | - | - | - | 170 | 57 |
| Total | - | 45 | 12 | 496 | 436 |

TABLE 24

Station - II : Veli lake - 3 - Hourly variation in the physico-chemical parameters, tide height, chlorophyll a and the cladoceran fauna (No./100 m³) at Veli Lake (24.10.1992 to 25.10.1992)

| Parameters | Time (in hours) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 06.00 | 09.00 | 12.00 | 15.00 | 18.00 | 21.00 | 24.00 | 03.00 | 06.00 |
| Surface water temperature (°C) | 29.00 | 30.00 | 32.00 | 33.00 | 32.00 | 30.00 | 32.00 | | 29.00 |
| Salinity (°/••) | 3.00 | 3.00 | 3.00 | 4.00 | 5.50 | 5.75 | 5.50 | | 3.50 |
| Dissolved oxygen (ml/l) | 4.51 | 4.51 | 6.09 | 6.09 | 6.54 | 6.32 | 6.54 | | 4.74 |
| pH | 7.02 | 7.37 | 7.50 | 7.87 | 8.28 | 7.72 | 8.06 | | 7.10 |
| Phosphate (µg at./l) | 0.08 | 0.04 | 0.04 | 0.04 | 0.04 | 0.08 | 0.08 | | 0.04 |
| Nitrite (µg at./l) | 1.63 | 1.15 | 1.21 | 0.46 | 0.31 | 0.18 | 0.31 | | 0.37 |
| Nitrate (µg at./l) | 0.45 | 0.74 | 0.56 | 0.23 | 0.23 | 0.51 | 0.31 | | 0.37 |
| Silicate (µg at./l) | 115.06 | 122.73 | 122.73 | 107.39 | 107.39 | 103.55 | 107.39 | | 107.39 |
| Chlorophyll a (mg/m³) | 8.63 | —— No data —— | | | 15.18 | —— No data —— | | | |
| Tide height (m) | 0.54 | 0.86 | - | 0.22 | - | - | 0.96 | | 0.55 |
| Evadne tergestina | | | | | | | | | |
| Category I A | 521 | 114 | 11 | 50 | 30 | - | - | | - |
| I B | 1450 | - | - | - | - | - | - | | - |
| II | 6182 | 377 | 119 | 80 | 104 | 68 | 175 | | 57 |
| III | - | - | - | - | - | - | - | | - |
| IV | - | - | - | - | - | - | - | | - |
| Total | 8153 | 491 | 130 | 130 | 134 | 68 | 175 | | 57 |
| Penilia avirostris | | | | | | | | | |
| Category I A | 45 | - | - | - | - | - | - | | - |
| I B | 45 | - | - | - | - | - | - | | - |
| II | 45 | - | - | - | - | - | - | | - |
| III | 23 | - | - | - | - | - | - | | - |
| IV | 227 | 6 | - | 11 | 6 | - | - | | - |
| Total | 385 | 6 | | 11 | 6 | - | - | | - |
| Macrothrix laticornis | - | 17 | - | - | - | - | - | | - |
| Latonopsis australis | - | 6 | - | - | - | - | - | | - |
| Moina micrura | - | 6 | - | - | - | - | - | | 11 |
| Grand total of cladocerans | 8538 | 526 | 130 | 141 | 140 | 68 | 175 | | 68 |

TABLE 25

Fecundity as number of eggs or embryos taken at Vizhinjam during a diurnal study of Evadne tergestina

| Time (hours) | No. of specemens | Minimum | Maximum | Fecundity mean | Standard deviation |
|---|---|---|---|---|---|
| 05.00 | 41 | 2 | 8 | 3.68 | ± 1.26 |
| 08.00 | 27 | 1 | 6 | 3.44 | ± 1.55 |
| 11.00 | 21 | 1 | 6 | 3.33 | ± 1.39 |
| 14.00 | 41 | 1 | 6 | 3.39 | ± 1.48 |
| 17.00 | 44 | 1 | 8 | 3.50 | ± 1.71 |

TABLE 26

Fecundity as number of eggs or embryos taken at Veli Lake during a diurnal study of Evadne tergestina

| Time (hours) | No. of specemens | Minimum | Maximum | Fecundity mean | Standard deviation |
|---|---|---|---|---|---|
| 06.00 | 46 | 2 | 6 | 4.20 | ± 1.95 |
| 09.00 | 42 | 2 | 6 | 2.83 | ± 1.43 |
| 12.00 | 25 | 2 | 8 | 2.84 | ± 1.73 |
| 15.00 | 37 | 2 | 6 | 2.68 | ± 1.02 |
| 18.00 | 40 | 1 | 8 | 3.63 | ± 1.92 |
| 21.00 | 10 | 2 | 4 | 2.80 | ± 0.60 |
| 24.00 | 28 | 1 | 4 | 2.93 | ± 0.84 |
| 06.00 | 5 | 3 | 4 | 3.40 | ± 0.49 |

TABLE 27

Fecundity as number of eggs or embryos taken at Vizhinjam during a diurnal study of Penilia avirostris

| Time (hours) | No. of specemens | Minimum | Maximum | Fecundity mean | Standard deviation |
|---|---|---|---|---|---|
| 05.30 | - | - | - | - | - |
| 08.30 | 10 | 3 | 5 | 4.54 | ± 0.67 |
| 11.30 | 4 | 3 | 5 | 4.00 | ± 0.70 |
| 14.30 | 41 | 3 | 6 | 4.66 | ± 0.87 |
| 17.30 | 32 | 2 | 6 | 4.50 | ± 0.93 |

# DISCUSSION

It is evident from the present investigation that the hour at which the maximum density of *E. tergestina* reached at the water surface was more during the early hours of the day in all the days of observation (September and October) at Vizhinjam and Veli Lake (Tables 23 & 24). This is in conformity with the studies made on the cladocerans of the seas around India by Naomi *et al.* (1989) wherein it is mentioned that except in March, April, August and November the day samples contained more cladocerans. Likewise *P. avirostris* was also dominant during the day time although at Veli Lake it was observed only during 06.00 hrs and at Vizhinjam station it was observed only from 11.00–17.00 hrs. However, Goswami *et al.* (1979) observed more members of *Penilia* in the night samples while *E. tergestina* occurred more in the day samples.

The diurnal variation in 2 species of cladocerans, *E. tergestina and P. avirostris*, is an aspect which has not been worked out in any detail especially with special reference to reproduction. Bosch and Taylor (1973) has worked on the diurnal vertical migration of an estuarine cladoceran *Podon polyphemoides* in the Chesapeake Bay, U.S.A. Onbe (1977), Bryan (1979) and Mullin and Onbe (1992) have studied the diurnal reproductive cycle of *E. tergestina* and *P. avirostris* and found that parthenogenetic female *Evadne* contained embryos with pigmented eyes only at night and apparently released neonates near dawn

or in the morning. This release of the young of *E. tergestina* just before dawn was probably developed as a defense mechanism, since *Evadne* bearing well developed young have several well developed eyespots and it would be to its advantage to be in this condition during the hours of darkness. This finding is in agreement with the observation made in the present study although only a study of 12 hour duration was made at Vizhinjam Station in addition to a 24 hour study at Veli Lake (Tables 23 & 24). At Vizhinjam station females of category IV (with eyed embryos) were observed in the 05.00 hrs collection (Table 23) indicating that liberation of the young from the mother animal occurred in the darkness between midnight and dawn. Further, this fact must be the reason why at Veli Lake, category IV was not observed since the first collection was at 06.00 hrs although females of advanced stages (category II) were observed then. With the onset of the release of the young females of category IA (i.e., the newborn or neonates), they begin to increase rapidly until they constituted the major portion of the population during 06.00–11.00 hrs. Thereafter, embryonic development seemed to proceed very fast; females of category IA began to decrease and those of category II increased abruptly to comprise nearly 80–100% of the population before sunset. Further, some of the females of category II had become advanced category II and category III during 17.00–18.00 hrs at both Vizhinjam and at Veli stations. However, at Veli Lake, from 21.00–06.00 hrs only females of category II were recorded and that too in few numbers and hence the exact time of

release of neonates could not be observed. This rhythmicity in the development of parthenogenetic embryos within the adult is surprising in both Vizhinjam and Veli Lake. However, since the collections were carried out in the September-October period, when according to Naomi *et al.* (1989) the night collection recorded very low numbers of cladocerans, this may be one reason why females of categories III and IV were not observed in the present collections at Veli Lake. Further according to Mullin and Onbe (1992) the individuals of categories III and IV were observed at levels below 10 m which may be another reason for their absence in night collections.

Regarding *P. avirostris*, females may contain mature embryos at any time, but were most likely to do so at night (Mullin and Onbe, 1992). This is partly substantiated in the collections made on 19.10.'92 at Vizhinjam station. But at Veli Lake it was observed in fairly good numbers only during 06.00 hrs and was sparsely recorded during other times.

A better picture of the reproductive cycle of cladocerans cannot be ensued without a review of the diurnal changes of different physico-chemical parameters taking place within it as according to Morris and Taylor (1983), the complex and predictable diurnal changes in physical conditions within rock pools are the result of interactions between physico-chemical and biological processes.

It is seen from the present investigation that the water temperature in all the three days of observation at both Vizhinjam

inshore waters and Veli Lake measured least during early morning hours i.e., between 05.00 and 06.00 hrs. It gradually increased from 08.00 to 15.00 hrs after which there was again a decline in temperature. This is in agreement with the findings of Satyanarayana Rao and Chalapati Rao (1962); and Shynamma and Balakrishnan (1973). Maya (1990) also got the same results and the amplitude in temperature variation was found to be $5^{O}C$ in her study at Kovalam coast. However, in the present study it was $1.5^{O}C$ at Vizhinjam station and $4^{O}C$ at Veli Lake. So also Mathew *et al.* (1977) recorded the maximum at 15.00 hrs and minimum at 06.00 hrs and the amplitude in temperature variation was $2.2^{O}C$.

Salinity recorded the maximum values at 14.00 hrs in both the days of observation at Vizhinjam station and this is in tune with the observations of Mathew *et al.* (1977) who found the same peak in salinity values during 12.00–14.00 hrs. However, at Veli Lake the maximum salinity values were recorded between 21.00 and 24.00 hrs.

In both Veli and Vizhinjam stations dissolved oxygen values did not show any direct relationship with tide. This is in agreement with Ealey and Chittleborough (1958) as they too observed very little variation in oxygen values with the tide. Likewise Rangarajan (1958) did not find any correlation between oxygen content and tide in Vellar estuary.

Phosphate, neither follows any definite pattern nor shows any correlation with time and tide in the diurnal observations made at Veli Lake and Vizhinjam station. This is in consonance with the findings of

Shynamma and Balakrishnan (1973) at Cochin backwaters. Except for silicate, the concentrations of other nutrients were not so constant but varied irregularly depending on sampling time. Regarding chlorophyll *a*, Krishnamurthy and Purushothaman (1971) recorded peak values of pigments in the late evening (19.05 hrs) and this in tune with the present observation wherein chlorophyll *a* showed an increase at dusk (17.00–18.00 hrs) in all the 3 days of observation at both Vizhinjam station and Veli Lake.

In conclusion, broods of *E. tergestina* in both environments tended to mature at dusk and night and the release of broods was probably maximal just before dawn. Further, the reproductive rhythmicity in this species was the same in the two environments. However, broods of *P. avirostris* tended to mature at any time of the day and a definite rhythmicity was not observed as in *E. tergestina* as all the stages of development were recorded at most of the observations of the day. It was also recorded that the surface waters of Vizhinjam and Veli stations were well oxygenated as the dissolved oxygen values were well above 4 ml/l in all the observations made during these diurnal studies. Although salinity and temperature values showed fluctuations, rainfall data obtained from 'India Meteorological Department' recorded the maximum rainfall in October and moderate rainfall in September. So also chlorophyll *a* content in these areas was rather high when compared to observations in other parts of the year.

Thus it is quite clear that these special ecological conditions prevailing in this period of observation have certainly been conducive to the breeding of these two species of cladocerans.

# CHAPTER VI

## PLANKTONIC CLADOCERAN RESOURCES WITH SPECIAL REFERENCE TO SPECIES ASSOCIATION

# INTRODUCTION

A prerequisite for the success of aquaculture is the availability of a suitable feed at a reasonable cost. In the traditional aquaculture in India, the prawns are grown on naturally available food and no supplementary food is provided. However, in intensive culture, supplementary feed in the form of pelleted feeds or live food are essential for the growth of larval forms in hatcheries. Many organisms ranging from bacteria to brine shrimps qualify as potential food sources. Cladocerans also form a promising live food item for larvae and adults of fishes and prawns (Murugan and Moorthy, 1990).

Cladocerans of the genera *Daphina, Moina, Bosmina, Ceriodaphnia* and *Chydorus* have been used as live food in the culture of fish fry (Alikunhi *et al.*, 1955; 1980; Ivleva, 1973; Masters, 1975; Huisman, 1976; Marciak and Bogdan, 1979; Styczynska *et al.*, 1979; Billard, 1980; Gillet, 1980; Murugan, 1983a,b, 1989b) and of *Macrobrachium* larvae (Alikunhi *et al.*, 1980). Although these organisms are freshwater organisms, in frozen condition they have been used successfully to feed marine organisms also (Norman *et al.*, 1979). Large scale culture of *Moina* sp. was carried out (Muthu, 1982, 1983; Thirunavakarasu and Palanichamy, 1983; Shirgur and Indulkar, 1987) to use it as live feed for prawn larvae. Further, effects of *Moina micrura* as a replacement of *Artemia* spp. in the production of *Macrobrachium rosenbergi* post larvae were carried out and significantly higher production rate was obtained

in larvae fed with 50 : 50 mixture of *Artemia* and *Moina* cultures on poultry manure (Alam *et al.* 1993).

Shim Kim Fah (1988) has pointed out that the nutritional value of *Moina* sp., an important live food for tropical aquarium fishes, is very high. It contains about 93.5 per cent of moisture and about 6.5 per cent dry matter. On a dry weight basis, *Moina* contains 70 per cent crude protein, 16.4 per cent crude fat, 9.9 per cent ash and about 3.7 per cent nitrogen free extract. Furthermore, the high calcium content of *Moina* sp. makes it an important diet for the brooder fishes. Considering the importance of free amino acids on fish nutrition, Dabrowski and Rusiecki (1983) have identified seventeen free amino acids in *Daphnia pulex* and *Ceriodaphnia cornuta.* They observed that sufficient free amino acids which can be easily absorbed by the gut of the fish larvae are essential for the survival and growth of fish larvae since in the early stages of some species of fish, the gastrointestinal tract and proteolytic enzyme system are not fully developed. With this in view the present author made some preliminary studies on the survival and growth of the early larvae of gold fish (i.e., immediately after yolk absorption) by feeding them *ad libitum* and also with restricted rations of juveniles of *M. micrura* and found them as a suitable live food item. However, the experiment could not be repeated due to shortage of the early fish larvae. Very recently the Department of Biotechnology has considered the intensive culture of *Moina* spp. under a separate head "Selective enrichment of biota".

India has a 5689 km coast line supporting a rich cladoceran fauna. A review of Indian cladocerans has already been given in Chapter I. Considering the importance of cladocerans as promising live food in aquaculture a survey of the various species of this group was initiated in February 1992 from some selected centres of Kerala coast (South-west coast of India) as this area remains virtually unexplored with regard to the distribution of cladocerans both in time and space. Though a preliminary report on the incidence of cladocerans from the Northern Kerala has been published recently (Raghunathan, 1988), our knowledge on the distribution, ecology and availability of the more common and cultivable species of cladocerans is lacking from Kerala. Hence the present work was undertaken with a view to exploring and utilising the cladoceran resources of the south-west coast of India. The present chapter, hence, embodies a detailed survey of the cladoceran fauna along the south-west coast of India more specifically the southern Kerala, and also the various hydrographical parameters which would be helpful in introducing their mass culture for aquaculture purposes. Further, the species co-occurrence in this group was also worked out in detail as they were recorded from various habitats such as freshwater, estuarine and marine (*vide infra*).

# MATERIAL AND METHODS

Apart from the two main study centres along the south-west coast of India eight other centres were chosen and a detailed survey of the fauna was undertaken during the year 1992-1993. Of these, in five stations namely Vizhinjam, Kovalam, Veli, Neendakara and Ashtamudi, samples were collected regularly for a period of 13 months. In all the other centres samples were collected only occasionally. Collection, preservation and identification of specimens are given in Chapter I & II.

## STATIONS INVESTIGATED (Fig. I)

1. Vizhinjam : A detailed description is already furnished in Chapter II.
2. Kovalam ($8^{O}23'39"$ N Lat. and $76^{O}57'E$): This is a precipitous rocky shore facing the full impact of the sea, enriched with algal flora and fauna associated with them.
3. Veli Lake : Detailed description is given in the Chapter II
4. Kadinamkulam Lake ($8^{O}35'N$ Lat. and $76^{O}45'E$ Long.): This is a brackishwater lake of southern Kerala which opens into the sea at Perumathura by a temporary bar mouth. The backwater is connected to the Anchuthengu backwater on the north and Veli Lake on the south.
5. Neendakara ($8^{O}56'N$ Lat. and $76^{O}83'E$ Long.) : This is one of the biggest fish landing centres of the west coast of India, located at

the mouth of the Ashtamudi estuary and has a permanent connection with the sea.

6. **Ashtamudi** ($8^{O}53'$N Lat. and $76^{O}31'$E Long.): This represents the heart of the estuarine system and is a major fishing zone. It is the second largest estuary in Kerala covering an area of 32 $Km^2$ and branches off into eight creeks known by different names. The collection site is located directly opposite the Perumon bridge.
7. **Pamba River** ($9^{O}20'$N Lat. and $76^{O}38'$E Long.): This river is the third longest River in Kerala. It is formed by the confluence of the Rivers like Pamba Aar, the Kakki Aar, the Arudai Aar, the Kakkad Aar and the Kall Aar. The collection site is near the banks of the Pamba at Mannar ("Aar", in vernacular mean river).
8. Anchencovil River ($9^{O}17'$N Lat. and $76^{O}25'$E Long): Several small streams originating from the Pasukida Meth and Reshi Malai join together to form this river. At Pallipad (collection site) the river splits up into several smaller branches and the main branch flows in a northwesterly direction to join the Pamba River at Veeyapuram.
9. Periyar River ($10^{O}6'$N Lat. and $76^{O}20'$E Long.): This is the longest of all the rivers in Kerala and also the largest in potential and is formed by several streams having their origin in the Sivagiri group of hills. It traverses through rocks, sandy beds and gorges in many taluks of various districts. The collection site is near the banks of the Periyar where the annual Sivarathri festival at Alwaye is held.

10. Pool and Temple Tank in Trivandrum District ($8^{O}17'$N and $8^{O}47'$N Lat. and $76^{O}41'$E-$77^{O}16'$E Long) : Trivandrum is the southernmost District and the city Trivandrum is the capital of Kerala State. The pool selected for investigation is in Neyyantinkara which is the southernmost Taluk of the District and the temple tank is at Uloor and the small tank is at the Aquarium Campus of the University of Kerala.

## RESULTS

During the present investigation, 19 species of cladocerans were collected from different stations (Table 28) along the southern Kerala.The occurrence of these species in the different types of habitats in relation to hydrographic parameters are given in Table 29.

It is evident from the Table 28 that only two species namely *Evadne tergestina* and *Penilia avirostris* are marine although they were found in the estuarine waters along with other limnetic forms. Excluding these two species, another 15 species were observed both in the backwater and freshwater habitats. The remaining two species, *Chydorus faviformis* and *Dadaya macrops* were observed only in freshwater conditions.

SPECIES CO-OCCURRENCE

**a. Percentage of co-occurrence:** Among the 19 species of cladocerans collected during the present investigation, the number of samples in which these cladocerans were recorded are given below.

*Evadne tergestina* - 22 samples; *Penilia avirostris* - 12 samples; *Moina micrura* - 11 samples; *Diaphanosoma sarsi* - 9 samples; *Macrothrix laticornis* - 6 samples; *Biapertura karua* - 6 samples; *Bosminopsis deitersi* - 5 samples; *Chydorus barroisi* - 5 samples; *Dunhevedia crassa crassa* - 5 samples; *Ceriodaphnia cornuta* - 4 samples; *Chydorus sphaericus* - 4 samples; *Latonopsis australis* - 3 samples; *Moinodaphania macleayi* - 2 samples; *Scapholeberis kingi* - 2 samples; *Alona davidi punctata* - 2 samples; *Chydorus faviformis* - 1 sample; *Dadaya macrops* - 1 sample; *Indialona globulosa* - 1 sample and *Oxyurella singalensis* - 1 sample.

The percentage of co-occurrence calculated by the method adopted by Green (1971) is as follows:

$$\text{PC - Percentage of co-occurrence} = \frac{C}{a+b-c} \times 100$$

C - Number of samples containing both species (A + B)

a - number of samples containing species A

b - number of samples containing species B

Since there are only two species in the marine environment the percentage of co-occurrence is calculated based on the species recorded in estuaries and freshwater habitats. In that case *E. tergestina* are

recorded only in 10 samples, *P. avirostris* in 8 samples and the other species are represented as given above.

The first dominant species is *M. micrura* followed by *E. tergestina, D. sarsi* and *P. avirostris.* The species association of these dominant species is presented in Table 30.

The percentage of co-occurrence values indicate that *P.avirostris* and *E. tergestina* have maximum value of 80%. Next to it are *Diaphanosoma sarsi* and *Biapertura karua* with 50%. *D. sarsi* along with *Ceriodaphnia cornuta* occupies the next position with 30% followed by *D. sarsi* and *Moinodaphnia macleayi* with 22.22%.

TABLE 28

Occurrence of various species in different type of habitat

| Types of habitat | Neyya-tinkara pool | Tank in Aquarium | Temple tank in Ulloor | Achen-kovil river | Periyar river | Pamba river | Kadinam-kulam lake | Veli lake | Ashta-mudi lake | Neenda-kara estuary | Vizhinjam open sea | Kovalam open sea |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MARINE SPECIES | | | | | | | | | | | | |
| 1. Evadne tergestina | - | - | - | - | - | - | - | - | - | - | + | + |
| 2. Penilia avirostis | - | - | - | - | - | - | - | - | - | - | + | + |
| BACKWATER AND ESTUARINE | | | | | | | | | | | | |
| 1. Evadne tergestina | - | - | - | - | - | - | - | + | + | + | - | - |
| 2. Penilia avirostris | - | - | - | - | - | - | - | + | + | + | - | - |
| 3. Diaphanosoma sarsi | - | - | - | - | - | - | + | + | + | + | - | - |
| 4. Latonopsis australis | - | + | - | - | + | - | - | + | - | - | - | - |
| 5. Ceriodaphnia cornuta | - | - | - | - | + | - | - | - | + | + | - | - |
| 6. Scapholeberis kingi | + | - | - | - | - | - | - | + | - | - | - | - |
| 7. Moina micrura | - | + | - | - | - | - | - | + | + | + | - | - |
| 8. Moinodaphnia macleayi | - | - | - | - | - | - | + | + | + | - | - | - |
| 9. Bosminopsis deitersi | - | - | - | + | + | + | - | - | + | - | - | - |
| 10. Macrothrix laticornis | - | - | + | + | - | - | - | + | - | - | - | - |
| 11. Chydorus sphaericus | - | - | - | + | + | - | - | + | + | - | - | - |
| 12. C. barroisi | - | - | - | + | + | - | - | - | + | - | - | - |
| 13. Alona davidi punctata | - | - | - | - | - | - | - | + | + | - | - | - |
| 14. Biapertura karua | - | - | - | - | + | - | + | + | - | - | - | - |
| 15. Dunhevedia crassa crassa | - | - | - | - | - | - | + | + | - | - | - | - |
| 16. Oxyurella singalensis | - | - | - | - | - | - | - | + | - | - | - | - |
| 17. Indialona globulosa | - | - | - | - | - | - | - | + | - | - | - | - |
| FRESHWATER ONLY | | | | | | | | | | | | |
| 1. Chydorus faviformis | - | - | - | - | - | + | - | - | - | - | - | - |
| 2. Dadaya macrops | - | - | - | - | - | + | - | - | - | - | - | - |
| Total number of species occuring in different habitats | 1 | 2 | 1 | 4 | 6 | 3 | 4 | 14 | 10 | 5 | 2 | 2 |

+ = Present

- = Absent

TABLE 29

The physico-chemical parameters of water and cladocerans of the various habitats
(Marine, Estuarine and Freshwater)

| Habitat/Species | Salinity (‰) | Water temberature (°C) | Dissolved Oxygen (ml/l) | pH | Phosphate (µg at./l) | Nitrite (µg at./l) | Nitrate (µg at./l) | Silicate (µg at./l) | Date | Sampling period |
|---|---|---|---|---|---|---|---|---|---|---|
| FRESHWATER | | | | | | | | | | |
| I. Pamba River (Mannar) | 0.10 | 31.50 | 4.50 | 7.49 | 0.01 | 0.002 | 0.019 | 0.78 | 21-2-'93 | Once |
| 1. Bosminopsis deitersi | | | | | | | | | | |
| 2. Chydorus laviformis | | | | | | | | | | |
| 3. Dadaya macrops | | | | | | | | | | |
| II. Periyar River (Alluva) | 0.50 | 30.00 | No data | 7.25 | 0.001 | 0.008 | Nil | 0.69 | 23-5-'93 | Once |
| 1. Latonopsis australis | | | | | | | | | | |
| 2. Bosminopsis deitersi | | | | | | | | | | |
| 3. Ceriodaphnia cornuta | | | | | | | | | | |
| 4. Chydorus barroisi | | | | | | | | | | |
| 5. C. sphaericus | | | | | | | | | | |
| 6. Biapertura karua | | | | | | | | | | |
| III. Achencovil River (in Pallipad) | 0.50 | 31.00 | 4.00 | 7.38 | Nil | 0.002 | 0.042 | 1.10 | 20-2-'93 | Once |
| 1. Bosminopsis deitersi | | | | | | | | | | |
| 2. Chydorus sphaericus | | | | | | | | | | |
| 3. C. barroisi | | | | | | | | | | |
| 4. Macrothrix laticornis | | | | | | | | | | |
| TRIVANDRUM DISTRICT | | | | | | | | | | |
| IV.A. Pool in Neyyatinkara | ——— No Data ——— | | | | | | | | 4-8-'93 | Once |
| 1. Scapholeberis kingi | | | | | | | | | | |
| B. Tank (Aquarium) | Nil | 26.00 | 4.60 | 7.80 | 1.70 | 0.02 | 0.06 | 0.61 | 27-7-'92 | one month |
| 1. Moina micrura | | | | | | | | | | |
| 2. Latonopsis australis | | | | | | | | | | |
| C. Temple Tank (in Ulloor) | ——— No Data ——— | | | | | | | | | |
| 1. Macrothrix laticornis | | | | | | | | | | |

Contd.....2

Table 29 Cont.....

The physico-chemical parameters of water and cladocerans of the various habitats
(Marine, Estuarine and Freshwater)

| Habitat/Species | Salinity ('/••) | Water temberature (°C) | Dissolved Oxygen (ml/l) | pH | Phosphate (µg at./l) | Nitrite (µg at./l) | Nitrate (µg at./l) | Silicate (µg at./l) | Date | Sampling period |
|---|---|---|---|---|---|---|---|---|---|---|
| BACKWATER/ESTUARY | | | | | | | | | | One year ('92-'93) monthly collection |
| V. Veli Lake | | | | | | Refer table 3 & 4 | | | | |
| VI. Kadinamkulam Lake | 2.00 | 27.05 | 8.7 | 6.92 | 5.20 | 0.29 | 2.89 | 38.53 | 12-10-'92 | Once |
| 1. Diaphanosoma sarsi | | | | | | | | | | |
| 2. Biapertura karua | | | | | | | | | | |
| 3. Moinodaphnia macleayi | | | | | | | | | | |
| 4. Dunhevedia crassa crassa | | | | | | | | | | |
| VII. Ashtamudi Lake | | | | | | | | | | One year ('92-'93) monthly collection |
| AUGUST | 3.00 | 27.00 | 4.74 | 7.50 | 0.37 | 0.018 | 0.138 | 84.37 | 3-8-'92 | |
| 1. Bosminopsis deitersi | | | | | | | | | | |
| 2. Chydorus barroisi | | | | | | | | | | |
| SEPTEMBER | 5.50 | 31.00 | 5.64 | 7.74 | nIL | 0.22 | 0.24 | 61.36 | 21-9-'92 | |
| 1. Penilia avirostris | | | | | | | | | | |
| 2. Evadne tergestina | | | | | | | | | | |
| 3. Moina micrura | | | | | | | | | | |
| 4. Alona davidi punctata | | | | | | | | | | |
| OCTOBER | 2.50 | 28.0 | 5.19 | 6.68 | 1.87 | 0.13 | 0.60 | 268.46 | 15-10-'92 | |
| 1. Ceriodaphnia cornuta | | | | | | | | | | |
| 2. Diaphanosoma sarsi | | | | | | | | | | |
| 3. Moina micrura | | | | | | | | | | |
| 4. Bosminopsis deitersi | | | | | | | | | | |
| 5. Chydorus barroisi | | | | | | | | | | |
| NOVEMBER | 9.00 | 28.00 | 3.38 | 7.45 | 0.37 | 0.09 | 0.13 | 72.10 | 4-11-'92 | |
| 1. Evadne tergestina | | | | | | | | | | |
| 2. Penilia avirostris | | | | | | | | | | |
| 3. Chydorus barroisi | | | | | | | | | | |

Contd.....3

Table 29 Cont.....

The physico-chemical parameters of water and cladocerans of the various habitats
(Marine, Estuarine and Freshwater)

| Habitat/Species | Salinity (‰) | Water temberature (°C) | Dissolved Oxygen (ml/l) | pH | Phosphate (ug at./l) | Nitrite (ug at./l) | Nitrate (ug at./l) | Silicate (ug at./l) | Date | Sampling period |
|---|---|---|---|---|---|---|---|---|---|---|
| DECEMBER | 21.00 | 28.50 | 6.32 | 7.80 | 0.49 | 0.04 | 0.03 | 21.55 | 14-12-'92 | |
| 1. Evadne tergestina<br>2. Penilia avirostris<br>3. Diaphanosoma sarsi | | | | | | | | | | |
| VIII. Neendakara | | | | | | | | | | |
| SEPTEMBER | 34.50 | 28.00 | 4.51 | 7.50 | Nil | 0.18 | 0.14 | 6.83 | 21-9-'92 | One year ('92-'93) monthly Collection |
| 1. Penilia avirostris<br>2. Evadne tergestina | | | | | | | | | | |
| OCTOBER | 4.00 | 30.00 | 5.19 | 7.70 | 0.14 | 0.35 | 0.16 | 184.08 | 15-10-'92 | |
| 1. Penilia avirostris<br>2. Evadne tergestina<br>3. Diaphanosoma sarsi<br>4. Ceriodaphnia cornuta | | | | | | | | | | |
| NOVEMBER | 36.00 | 26.00 | 4.96 | 8.00 | 1.87 | 0.02 | 0.09 | 10.13 | 4-11-'92 | |
| 1. Evadne tergestina<br>2. Penilia avirostris | | | | | | | | | | |
| DECEMBER | 32.00 | 28.00 | 5.64 | 8.15 | 0.56 | 0.02 | 0.05 | 3.84 | 14-12-'92 | |
| 1. Evadne tergestina<br>2. Penilia avirostris | | | | | | | | | | |
| MARINE | | | | | | | | | | |
| IX. Vizhinjam Inshore waters | | | | Refer table 1 & 2 | | | | | | One year ('92-'93) fortnightly collection |

Contd.....4

Table 29 Cont.....

The physico-chemical parameters of water and cladocerans of the various habitats (Marine, Estuarine and Freshwater)

| Habitat/Species | Salinity ('/••) | Water temberature ('C) | Dissolved Oxygen (ml/l) | pH | Phosphate (µg at./l) | Nitrite (µg at./l) | Nitrate (µg at./l) | Silicate (µg at./l) | Date | Sampling period |
|---|---|---|---|---|---|---|---|---|---|---|
| X. Kovalam waters | | | | | | | | | | |
| APRIL | 34.00 | 30.00 | 4.74 | 8.09 | 0.71 | 0.04 | Nil | 1.61 | 6-4-'92 | One year ('92-'93) monthly collection |
| 1. Penilia avirostris<br>2. Evadne tergestina | | | | | | | | | | |
| MAY | 36.00 | 30.20 | 6.09 | 8.09 | 0.37 | 0.09 | 2.30 | 10.74 | 6-5-'92 | |
| 1. Evadne tergestina | | | | | | | | | | |
| JULY | 34.50 | 27.00 | 4.96 | 7.50 | 5.61 | 0.37 | 0.09 | 5.40 | 15-7-'92 | |
| 1. Evadne tergestina | | | | | | | | | | |
| AUGUST | 33.00 | 28.50 | 3.61 | 8.11 | 1.87 | 0.18 | 2.72 | 13.19 | 6-8-'92 | |
| 1. Penilia avirostris<br>2. Evadne tergestina | | | | | | | | | | |
| OCTOBER | 35.00 | 27.00 | 5.75 | 7.94 | 1.31 | 0.18 | 0.004 | 23.78 | 8-10-'92 | |
| 1. Evadne tergestina | | | | | | | | | | |
| NOVEMBER | 36.00 | 27.50 | 4.74 | 8.11 | 0.34 | 0.04 | 0.10 | 0.69 | 2-11-'92 | |
| 1. Penilia avirostris<br>2. Evadne tergestina | | | | | | | | | | |

TABLE 30

Species co-occurrence of dominant species with other species

| | |
|---|---|
| I. Moina micrura | |
| 1. Moina micrura with Dunhevedia crassa crassa | 14.29% |
| 2. M. micrura with Penilia avirostris | 11.76% |
| 3. M. micrura with Evadne tergestina | 10.53% |
| 4. M. micrura with Alona davidi punctata | 10.00% |
| 5. M. micrura with Indialona globulosa | 9.09% |
| 6. M. micrura with Latonopsis australis | 7.69% |
| 7. M. micrura with Chydorus sphaericus | 7.14% |
| 8. M. micrura with Bosminopsis deitersi | 6.67% |
| 9. M. micrura with Chydorus barroisi | 6.67% |
| 10. M. micrura with Macrothrix laticornis | 6.25% |
| II. Evadne tergestina | |
| 1. Evadne tergestina with Penilia avirostris | 80.00% |
| 2. E. tergestina with Ceriodaphnia cornuta | 16.16% |
| 3. E. tergestina with Dunhevedia crassa crassa | 15.38% |
| 4. E. tergestina with Diaphanosoma sarsi | 11.76% |
| 5. E. tergestina with Indialona globulosa | 10.00% |
| 6. E. tergestina with Alona davidi punctata | 9.09% |
| 7. E. tergestina with Chydorus sphaericus | 7.69% |
| 8. E. tergestina with C. barroisi | 7.14% |
| 9. E. tergestina with Latonopsis australis | 8.33% |

contd.....2

Table 30.....contd

Species co-occurrence of dominant species with other species

| | |
|---|---|
| III. *Diaphanosoma sarsi* | |
| 1. *Diaphanosoma sarsi* with *Biapertura karua* | 50.00% |
| 2. *D. sarsi* with *Ceriodaphnia cornuta* | 30.00% |
| 3. *D. sarsi* with *Moinodaphnia macleayi* | 22.22% |
| 4. *D. sarsi* with *Dunhevedia crassa crassa* | 16.66% |
| 5. *D. sarsi* with *Penilia avirostris* | 13.33% |
| 6. *D. sarsi* with *Evadne tergestina* | 11.76% |
| 7. *D. sarsi* with *Oxyurella singalensis* | 11.11% |
| 8. *D. sarsi* with *Scapholeberis kingi* | 10.00% |
| 9. *D. sarsi* with *Alona davidi punctata* | 10.00% |
| 10. *D. sarsi* with *Chydorus sphaericus* | 8.33% |
| 11. *D. sarsi* with *C. barroisi* | 7.69% |
| 12. *D. sarsi* with *Macrothrix laticornis* | 7.14% |
| 13. *D. sarsi* with *Moina micrura* | 5.26% |
| IV. *Penilia avirostris* | |
| 1. *Penilia avirostris* with *Evadne tergestina* | 80.00% |
| 2. *P. avirostris* with *Ceriodaphnia cornuta* | 20.00% |
| 3. *P. avirostris* with *Chydorus barroisi* | 18.18% |
| 4. *P. avirostris* with *Diaphanosoma sarsi* | 13.33% |
| 5. *P. avirostris* with *Indialona globulosa* | 12.50% |
| 6. *P. avirostris* with *Moina micrura* | 11.76% |
| 7. *P. avirostris* with *Alona davidi punctata* | 11.09% |
| 8. *P. avirostris* with *Latonopsis australis* | 10.00% |
| 9. *P. avirostris* with *Chydorus sphaericus* | 8.33% |
| 10. *P. avirostris* with *Dunhevedia crassa crassa* | 8.33% |
| 11. *P. avirostris* with *Macrothrix laticornis* | 7.69% |

# DISCUSSION

The results indicate that two species of cladocerans are exclusively marine although they are observed in estuarine habitats. In the five stations where survey was carried out during the three seasons viz. the pre-monsoon (February-May), Monsoon (June-September) and post-monsoon (October-January) it could be seen that *Evadne tergestina* was the dominant species in all the marine and truly estuarine stations and limnetic species were common in the other estuaries and freshwaters. The occurrence and abundance of marine cladocerans in several estuaries along the south-west coast of India has been reviewed by Madhupratap (1981). Similarly George (1958), Menon *et al.* (1972), Pillai and Pillai (1975), Raghunathan and Srinivasan (1983) and Goswami and Devassy (1991) have studied the seasonal fluctuations of *P. avirostris* and *E. tergestina* in the estuarine waters of Cochin, Ennore and Goa respectively. In their studies it was observed that *E. tergestina* was dominant although both the species were characterised by seasonality in distribution. Further the period of their abundance, in all these centres, was during the post-monsoon months. Moreover it was seen that they attain maximum occurrence and abundance both in the sea and in the backwater at more or less the same time (Table 29). It is also apparent that there is a south to north movement of cladocerans along the west coast of India which is evident from the reports of

their distribution and abundances (Pillai and Pillai, 1975) during different months of the year from various centres.

Although *P. avirostris* and *E. tergestina* are observed in salinities ranging from 3.0 ppt to 36.0 ppt, pH was always well above 7.5 and oxygen was also well above 4 ml/l (except for one observation in Ashtamudi on 4.11.'92) (Table 29). However, nutrient values were showing wide fluctuations. *Chydorus faviformis* and *Dadaya macrops* were found only in Pamba river which is a purely freshwater river and pH almost 7.5. Except for *Diaphanosoma sarsi* and *Chydorus barroisi* which were recorded in Ashtamudi estuary when salinities of 21 ppt and 9 ppt were registered respectively, all other cladocerans were found in both freshwater and backwater habitats not exceeding a salinity of 5.5 ppt. Further, in these backwaters or estuaries when there was a reduction in salinity, freshwater species of cladocerans were found to dominate than at other times.

A study of the data collected during the present survey shows that certain species frequently occur together and these species groups characterize particular habitats and it suggests that the groups are composed of species that have similar reactions to properties of the environment. This is substantiated by the studies of Fager and McGowan (1963) on the co-occurrences of species in North Pacific. Raghunathan (1983) too has worked on the co-occurrence of cladoceran species and has arrived at the same conclusion.

A unique feature of this group is the lesser species diversity in tropics in comparison with temperate waters (Fernando, 1980). This situation is in contradiction with the accepted norms on the distribution of the species in most of the groups of animals since there are more species in the tropics than in temperate region. This peculiar aspect is in consonance with the present findings as in most of the study sites there were not more than 5 species at any given time.

The present survey, in general has revealed that Kerala coast has the topography and physico-chemistry conducive to a reasonably rich cladoceran fauna (Plate II, 12-16). Of late ASEAN countries have become world's greatest producers and exporters of tropical aquarium fishes. A major difficulty faced by this expanding industry is the supply of live food, specifically *Moina* sp. However, the results of the study on species co-occurrence and the relevant hydrographic parameters would certainly pave way to mass cultivation of cladocerans (Table 29) and thus provide a steady supply of these live food for the successful breeding and larval management of many aquarium fishes.

# SUMMARY

## SUMMARY


1. The history of the systematics of the Order Cladocera is traced through the literature from Linne (1767) to the present day. A comprehensive account of Indian cladocerans is also provided.
2. Full redescription is furnished of nineteen species of cladocerans found along the southern coast of Kerala. Illustrations of the different characters of taxonomic value, are also presented.
3. The following species are recorded for the first time from Kerala: *Latonopsis australis, Chydorus faviformis, Biapertura karua* and *Alona davidi punctata.*
4. Cladoceran fauna, hydrographical and meteorological data pertaining to the Vizhinjam inshore station, a marine habitat and also Veli Lake, a backwater system were studied during a period of one year extending from February 1992 to January 1993. As regards statistical analysis the Poisson model was adopted to assess the influence of the environmental parameters on the distribution and abundance of cladocerans.
5. The marine cladocerans *Evadne tergestina* and *Penilia avirostris* make up a significant part of the zooplankton in Vizhinjam waters. The year-round study made in this station has shown that *E. tergestina* was recorded in most of the months (i.e., except for

January, March and June) whereas *P. avirostris* was observed only during three months (i.e., April, August and November).

6. It was seen by Poisson modelling that dissolved oxygen, surface water temperature, rainfall and chlorophyll *a* turned out to be significantly important in the case of *P. avirostris*. However, in *E. tergestina* except for pH all the other environmental parameters which were recorded in the present study were found to be significantly related.

7. The cladoceran component in Veli Lake was represented by six families of limnetic and marine species, of which families Sididae, Moinidae and Macrothricidae were represented by three, two and one species respectively. Family Chydoridae was represented by 6 species whereas family Podonidae had only one species. The only dominant species in this lake was the limnetic moinid *Moina micrura*. The other species of this group were noticed only during the post-monsoon period. Marine species *E. tergestina* and *P. avirostris* were recorded only in October and November months.

8. In Veli Lake the impact of different environment parameters on the dominant species *M. micrura* has been described in the light of the Poisson regression analysis and the results showed that the probabilities for observed values equalled predicted values in almost all the observations. Further, it was seen that the model showed a good fit by the chi-square value.

9. In Vizhinjam these marine species were associated with phytoplankton blooms such as *Fragilaria oceanica* in August, *Thalassiosira subtilis* in September and *Noctiluca miliaris* (green type) in November. Likewise in Veli Lake *Moina micrura* and *Moinodaphnia macleayi* were associated with a mixed phytoplankton bloom in January-February period and in June.

10. The marine species *E. tergestina* and *P. avirostris* occurring in Vizhinjam waters owe their high reproductive potential to parthenogenesis. Except for a single male and gamogenetic female which appeared on 2.11.'92, all the females so far recorded in Vizhinjam were only parthenogenetic.

11. All embryological stages of *P. avirostris* and *E. tergestina* are described in detail. In *P. avirostris* the developmental processes are divided into 12 stages based principally on the formation of appendages. As regards *E. tergestina* there are only seven distinctive embryonic stages. However, this species has functional ovaries at a very early embryonic stage.

12. The embryo of *E. tergestina* before emergence is a miniature adult which bears its own eggs in the embryonic brood space whereas in *P. avirostris* it has only developing oocytes at birth and hence is a juvenile after liberation of brood. Thus, *E. tergestina* is paedogenetic and *P. avirostris* is ovoviviparous.

13. In the case of *E. tergestina* the length frequency graphs showed several modes and from the modes it was clear that each size class

of one collection could be traced to the next size class of the succeeding collection and so on. Thus in Vizhinjam five to six populations were observed. As regards *P. avirostris* only three distinct populations were noticed. In both these species the size range and fecundity were different between seasons.

14. The population composition of these cladocerans was grouped into four main categories (i.e., category I - neonates and newly moulted females; category II - female with early developing embryos; category III - females with advanced stage of embryos; category IV - females just before release of embryos) based on the reproductive state of the animal.

15. As regards *E. tergestina*, more than half of the population was observed to carry embryos with early stages of development (Category II) whereas in *P. avirostris*, categories II-IV were dominant.

16. Both the marine species were iteroparous as the modes observed represented the broods in the life cycle to a certain extent. The only difference is that in *E. tergestina* there are no juvenile instars and moulting is independent of incubation since females of categories II and III are seen only from a particular size class onwards. However, in *P. avirostris* moulting is dependent on incubation and there are distinct juvenile and adult instars in its life cycle.

17. In *E. tergestina* no significant correlation was found between egg number and size of the parent. However, in *P. avirostris* fertility was size dependent.

18. In both these marine species a significant relationship was observed between body length and embryo length and this was more pronounced in gross length (GL) x embryo length (EL) relationship.

19. A clear cut decrease in clutch size was noticed in both the marine species as a significant negative correlation between size of the embryo and number of the same was discerned.

20. *Moina micrura* and *Moinodaphnia macleayi*, members of the family Moinidae which primarily inhabit freshwater ponds and lakes, are recorded for the first time in a brackishwater lake of Kerala (The Veli Lake).

21. Both these moinids have the same embryonic stages as *Moina macrops*. Further the present investigation has revealed that most of sequential events in its life cycle are familiar to those generally observed in Cladocera from other regions.

22. It is seen that *M. macleayi* had high fecundity (8-10 eggs/gravid female) when compared to *M. micrura* of the same area.

23. As regards statistical correlation studies it is seen that in *M. macleayi* fertility was not size dependent. However, *M. micrura* showed a decrease in fertility with increase in parental size.

24. In both these moinids significant positive correlation was seen between size of embryo and size of the parent; however, contrary

to the observations in marine species, the development of embryo is dependent on standard length more than the gross length of adult.

25. As in *P. avirostris* reproduction in moinids is by ovoviviparous parthenogenesis. The length frequency histograms had many peaks corresponding to the broods and thus are iteroparous. The growth of the adult varies in different months in the case of *M. micrura*. So also the appearance of the first batch of eggs and the number of broods varied in the populations recorded in this study.

26. The diurnal periodicity on parthenogenetic reproduction of *E. tergestina* and *P. avirostris* in the two above mentioned coastal locations were studied during September-October months. In addition the hydrographical parameters influencing the reproductive cycle of this species were also presented and it is for the first time that such a study has been carried out from this region.

27. Broods of *E. tergestina* in both the environments tended to mature at dusk and night and the release of broods was probably maximal just before dawn. With the onset of the release of the young females (the newborn or neonates) at dawn, they begin to increase rapidly until they constituted the major portion of the population during 0600-1100 hrs. Thereafter, embryonic development seemed to proceed fast; neonates began to decrease and those of categories II and III increased abruptly to comprise nearly 80-100% of

population before sunset. This rhythmicity was the same in these two different stations.

28. Broods of *P. avirostris* tended to mature at any time of the day and a definite rhythmicity was not observed as in *E. tergestina* as all the stages were present at most of the observations of the day.

29. The environmental conditions which prevailed during the period of observation (i.e., diurnal studies) were found to be conducive to the breeding of these two species of cladocerans in both the stations.

30. The present survey on the incidence of cladocerans has revealed that southern Kerala region has the topography and physico-chemistry conducive to a reasonably rich cladoceran fauna. Out of the 19 species recorded, two species *E. tergestina* and *P. avirostris* are truly marine although they were observed in estuaries and backwaters with other limnetic species. Excluding these two species, another 15 species were observed in both backwater and freshwater habitats. The remaining two species *Chydorus faviformis* and *Dadaya macrops* were registered only in freshwater conditions.

31. The marine species were found to attain maximum abundance both in the sea and the backwaters at more or less the same period.

32. A unique feature of this group is lesser species diversity; in most of the study sites there are not more than five species at a time.

33. The results of the study on species co-occurrence and the relevant hydrographic parameters would certainly help in the selection of tolerant and suitable species as live food for many cultivable species of fish and prawns and thus this group has become a manipulating tool in the hands of aquaculturists to increase fish production.

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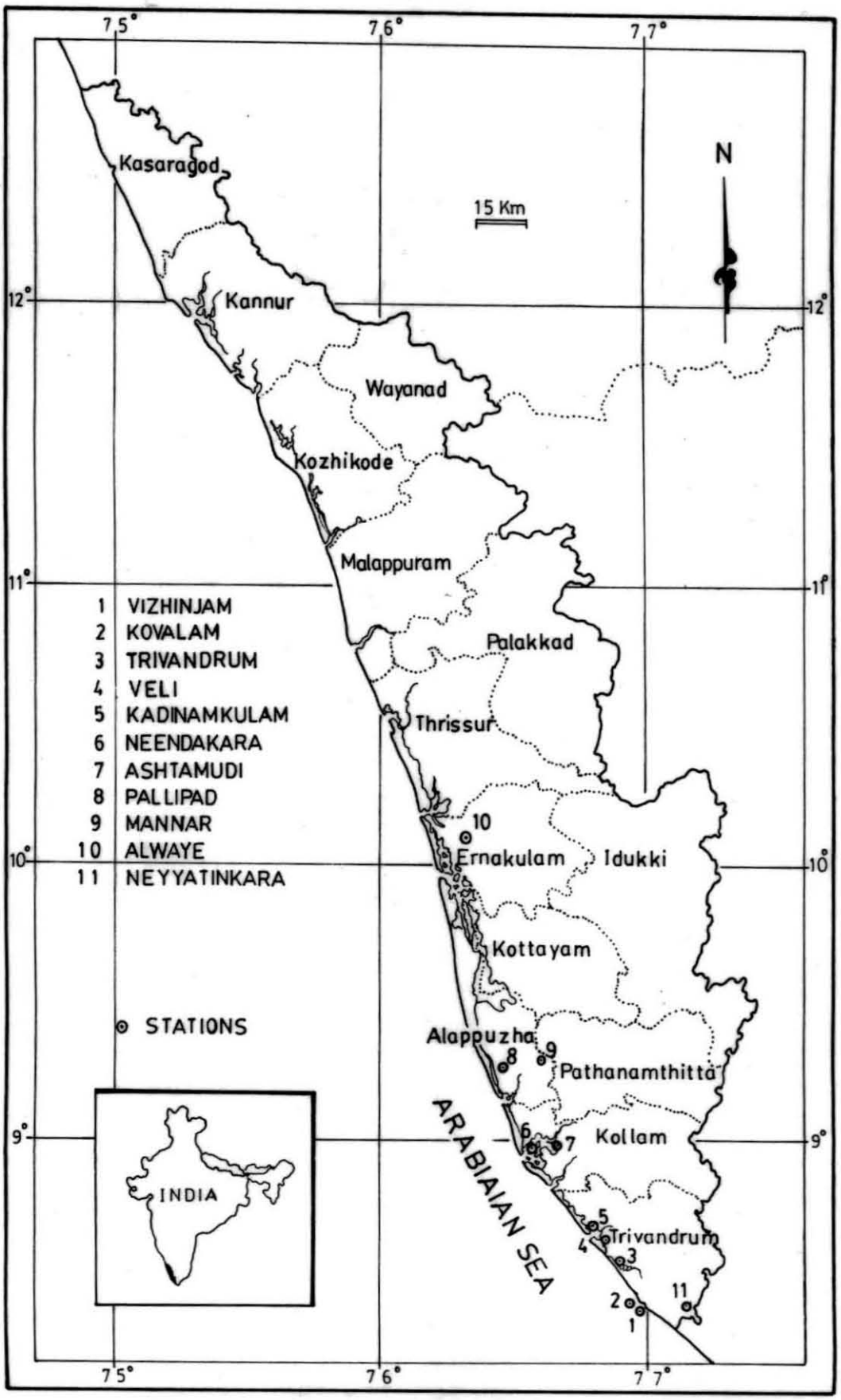
**FIG. I. MAP OF STATIONS INVESTIGATED FOR CLADOCERAN RESOURCES IN SOUTHERN KERALA**



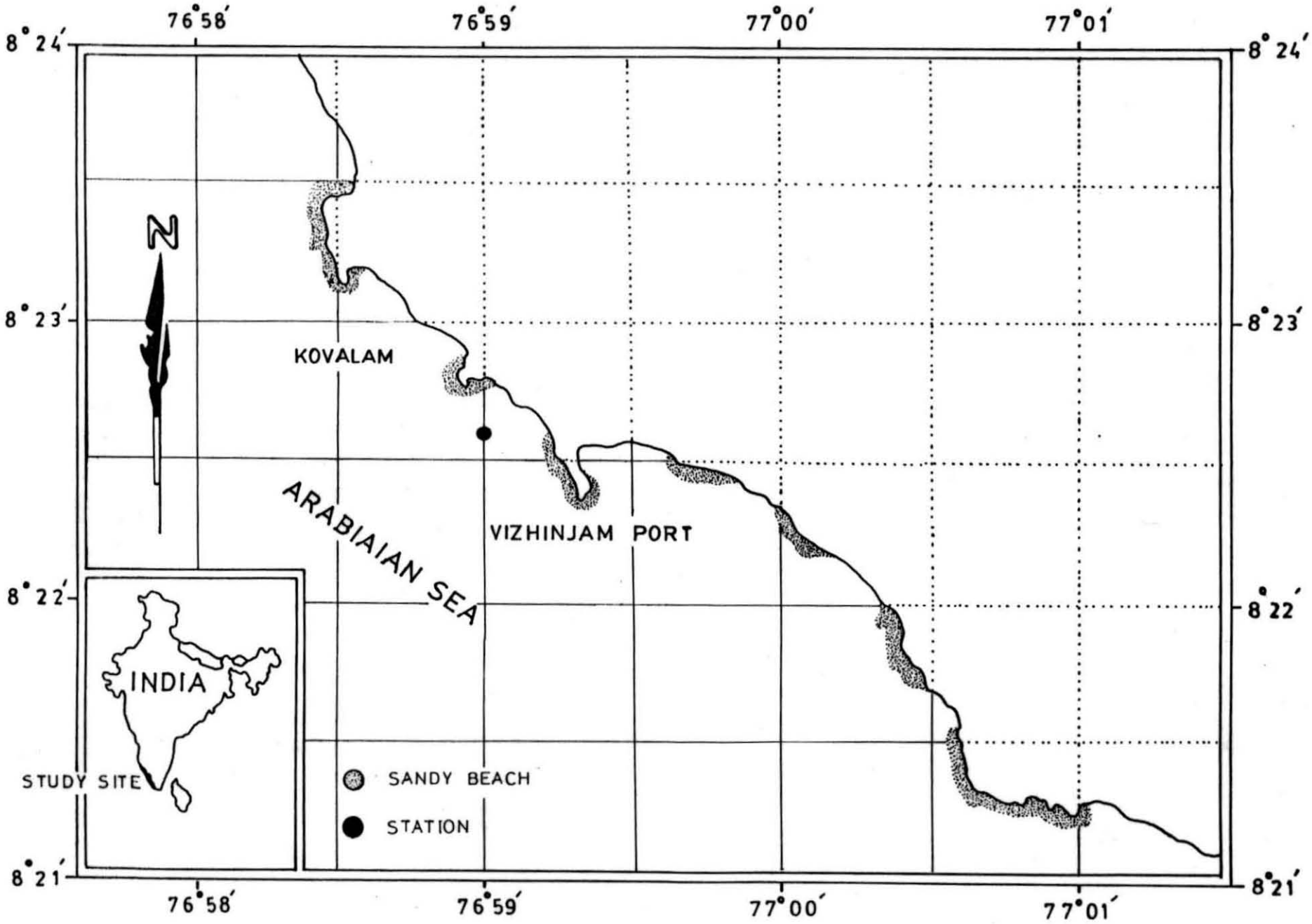



**Fig. II. Map of Vizhinjam showing the station of field study.**

**Fig. III. Map of the Veli lake showing the station of field study.**

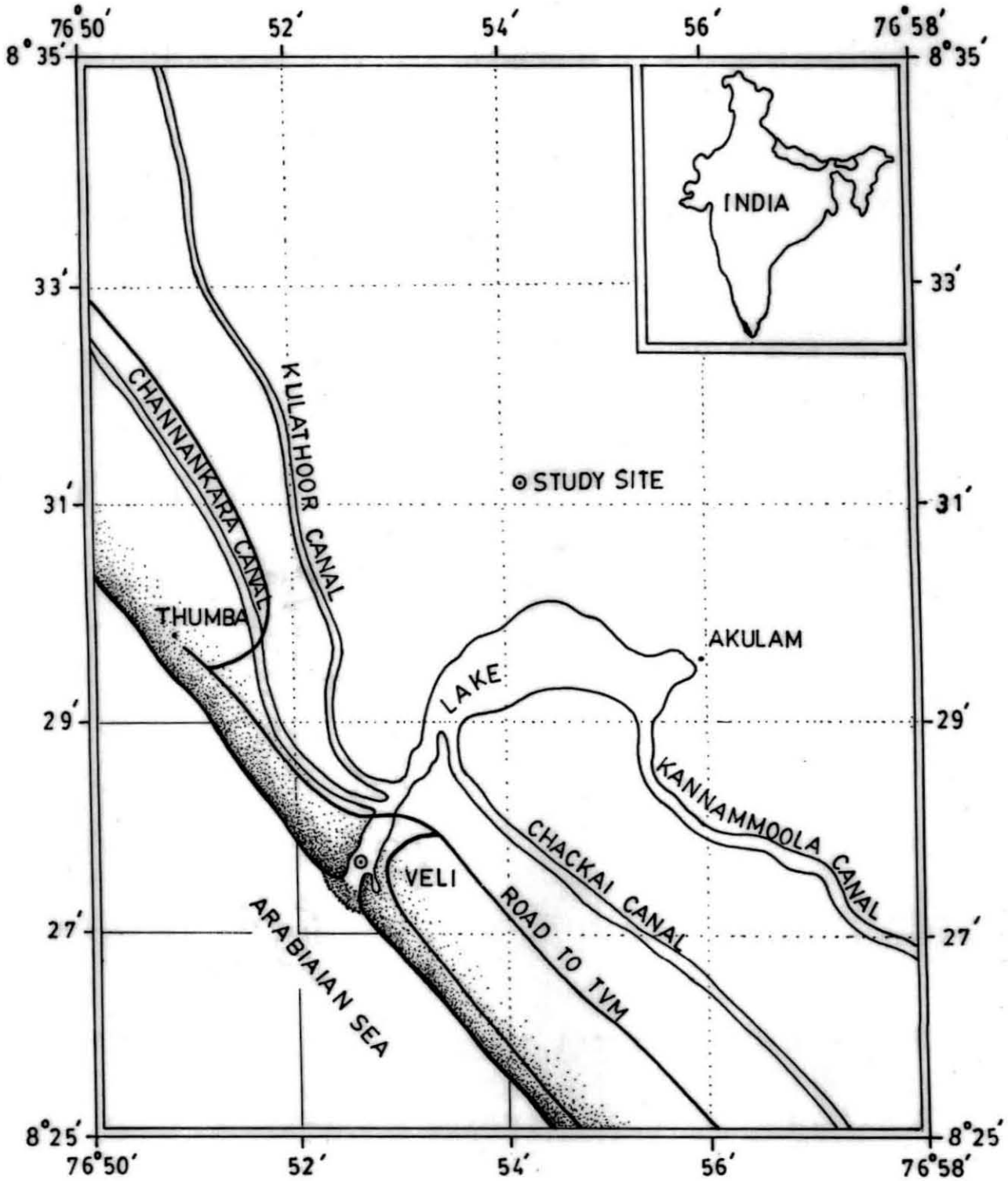
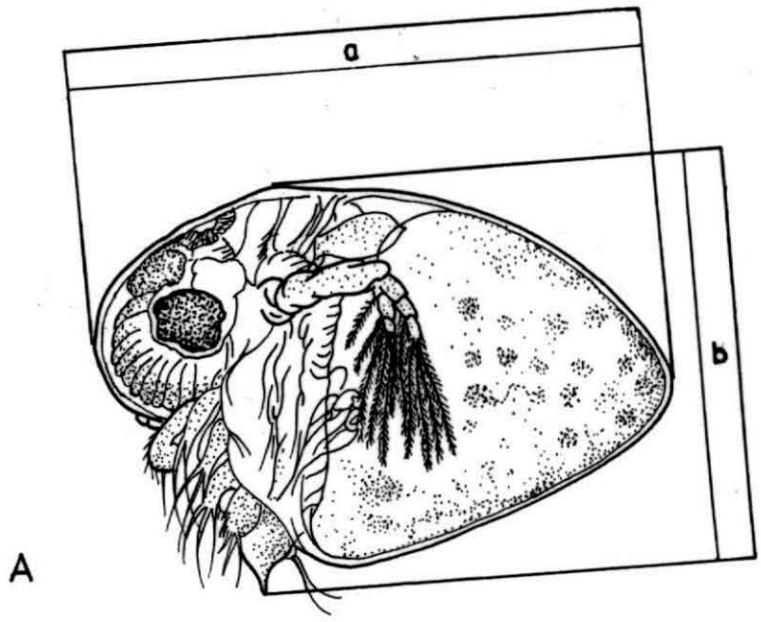
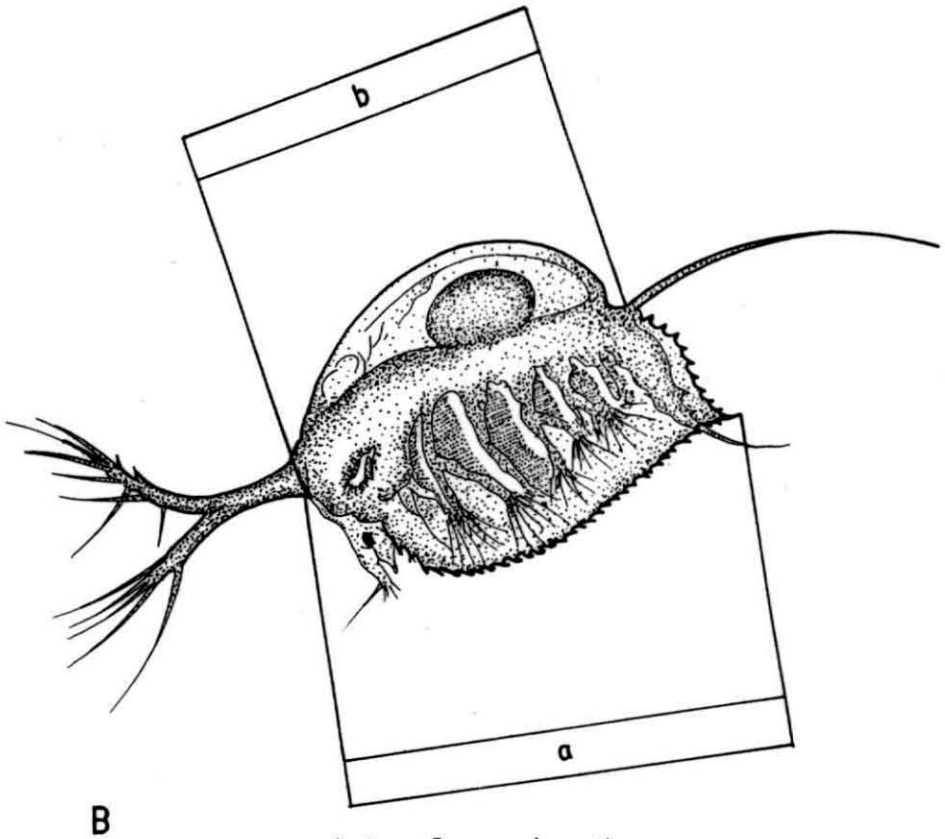


**Fig. IV. Method of measurement of *Evadne tergestina* (A) and *Penilia avirostris* (B)**




A




B

(a) , Gross length

(b) , Standard length.

Fig. 1 *Penilia avirostris* Dana

a. Female b. Male c. Antenna d. Post-abdomen
e. Postero-dorsal region

Fig. 2 *Diaphanosoma sarsi* Richard

a. Female b. Antenna c. Antennule d. Post-abdomen
e. Postero-ventral region

*Figs. 1 - 2*

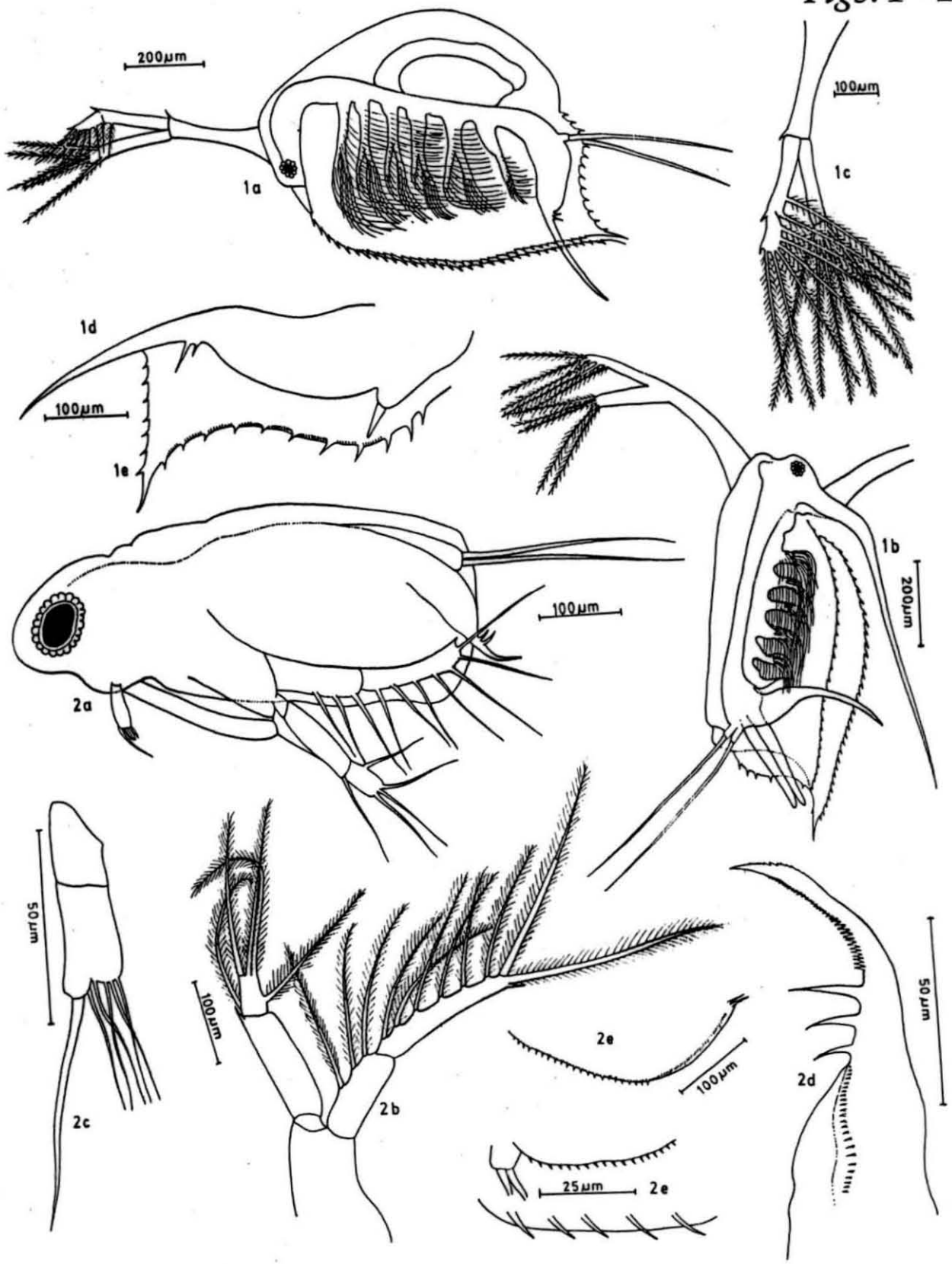

200µm
1a
100µm
1c
1d
100µm
1e
1b
200µm
100µm
2a
50µm
2c
100µm
2b
2e
100µm
2d
50µm
25µm
2e

Fig. 3 *Latonopsis australis* Sars

a. Female b. Antenna c. Antennule d. Post-abdomen
e. Posterior region f. Postero-ventral region

Fig. 4 *Ceriodaphnia cornuta* Sars

a. Female b. Antenna c. Antennule d. Post-abdomen

Fig. 5 *Scapholeberis kingi* Sars

a. Female b. Antenna c. Antennule d. Post-abdomen
e. Ventral region

*Figs. 3 - 5*

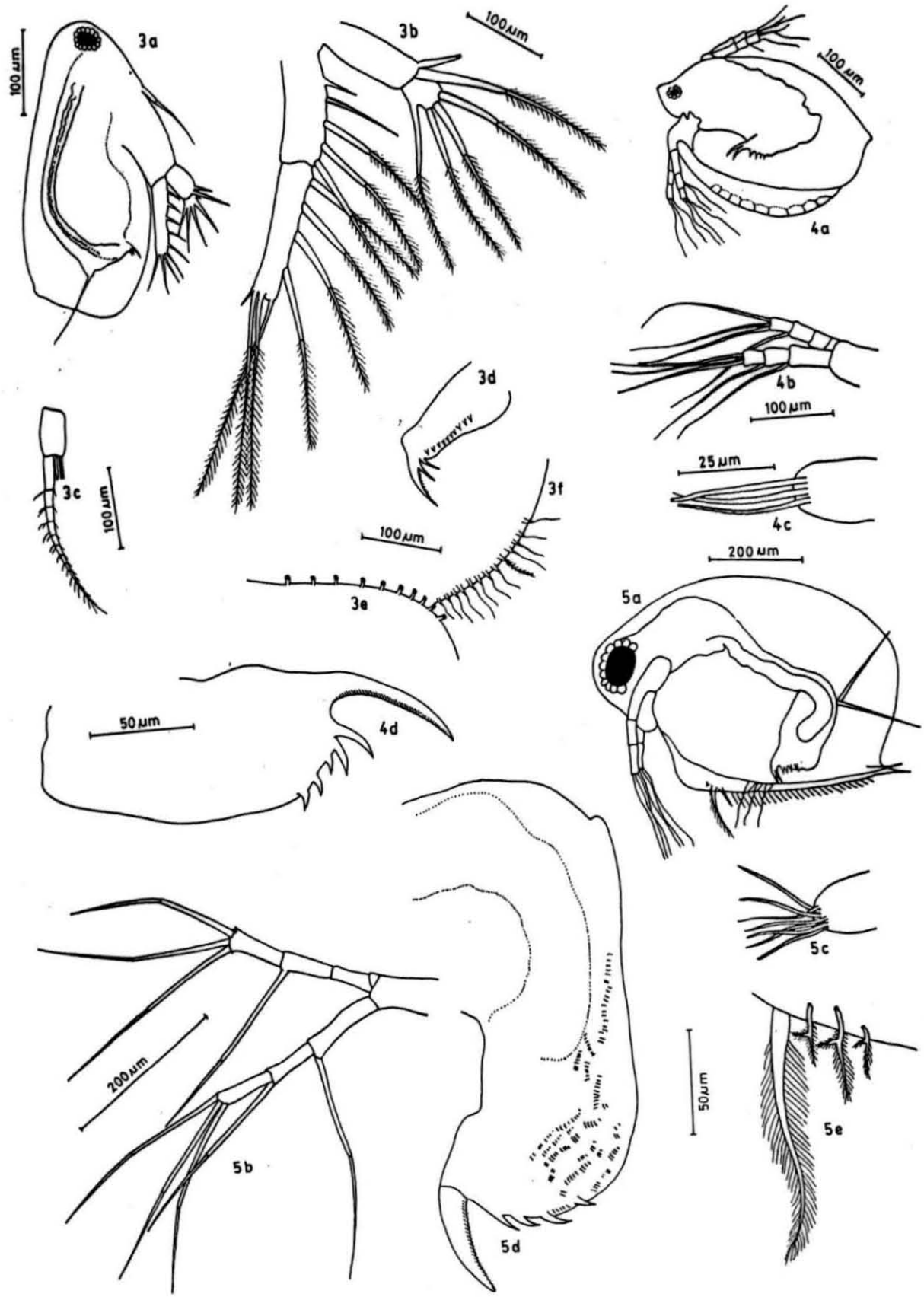
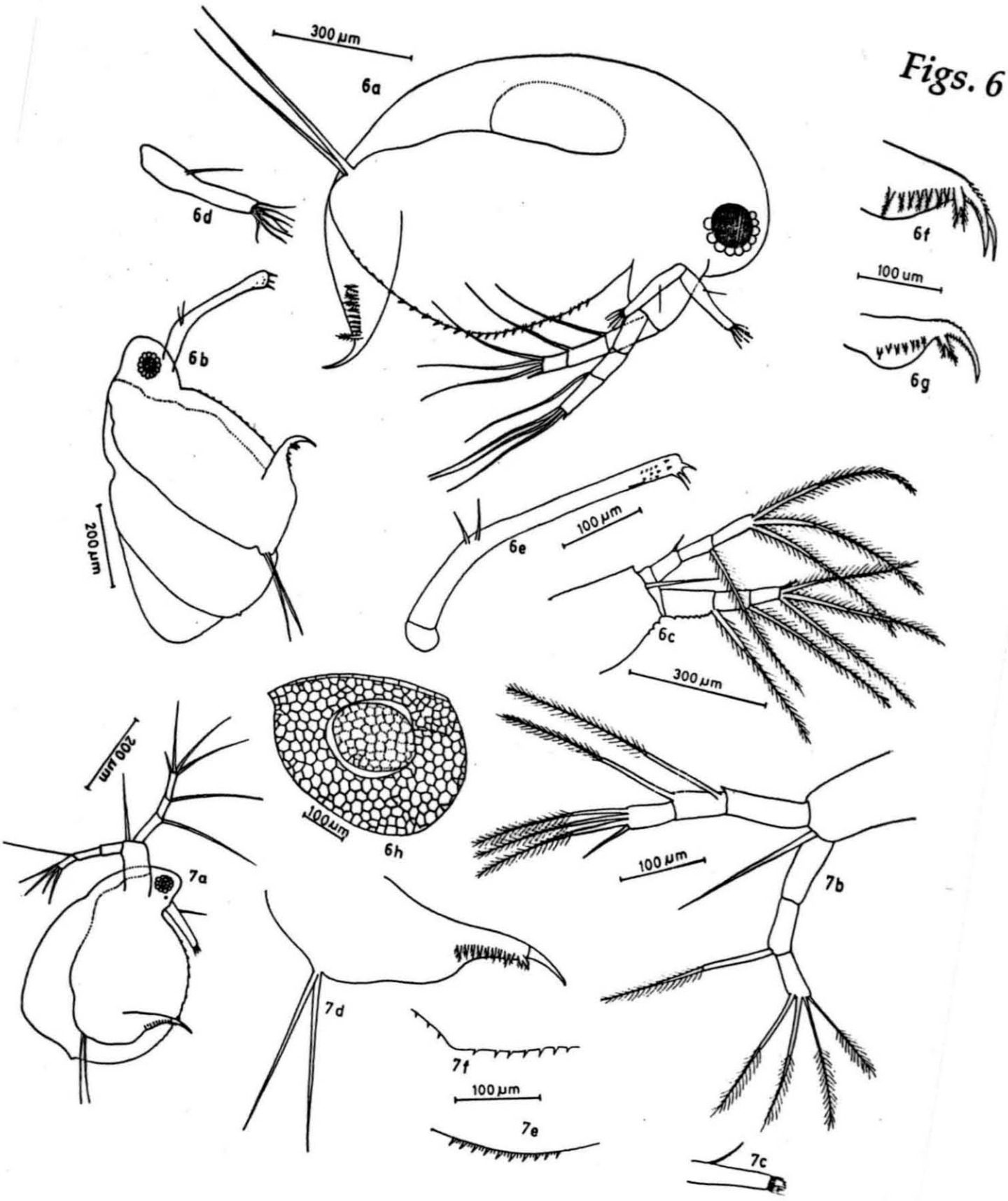

3a
100 µm
3b
100µm
4a
100 µm
4b
100 µm
3d
3c
100 µm
25 µm
4c
3f
100 µm
3e
200 µm
5a
50 µm
4d
5c
200 µm
5b
5d
50µm
5e

Fig. 6 *Moina micrura* Kurz

a. Female b. Male c. Female antenna d. Female antennule e. Male antennule f. Female post-abdomen g. Male post-abdomen h. Resting egg

Fig. 7 *Moinodaphnia macleayi* (King)

a. Female b. Antenna c. Antennule d. Post-abdomen e. Ventral margin of valve f. Posterior corner of valve


Figs. 6
300 µm
6a
6d
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200 µm
6f
100 um
6g
6e
100 µm
6c
300 µm
200 µm
6h
100 µm
7a
100 µm
7b
7d
7f
100 µm
7e
7c

Fig. 8 *Bosminopsis deitersi* Richard

a. Female b. Antenna c. Antennule d. Post-abdomen

Fig. 9 *Macrothrix laticornis* (Jurine)

a. Female b. Antenna c–d. Antennules e. Post-abdomen
f. Posterior margin of valve

# *Figs. 8 - 9*

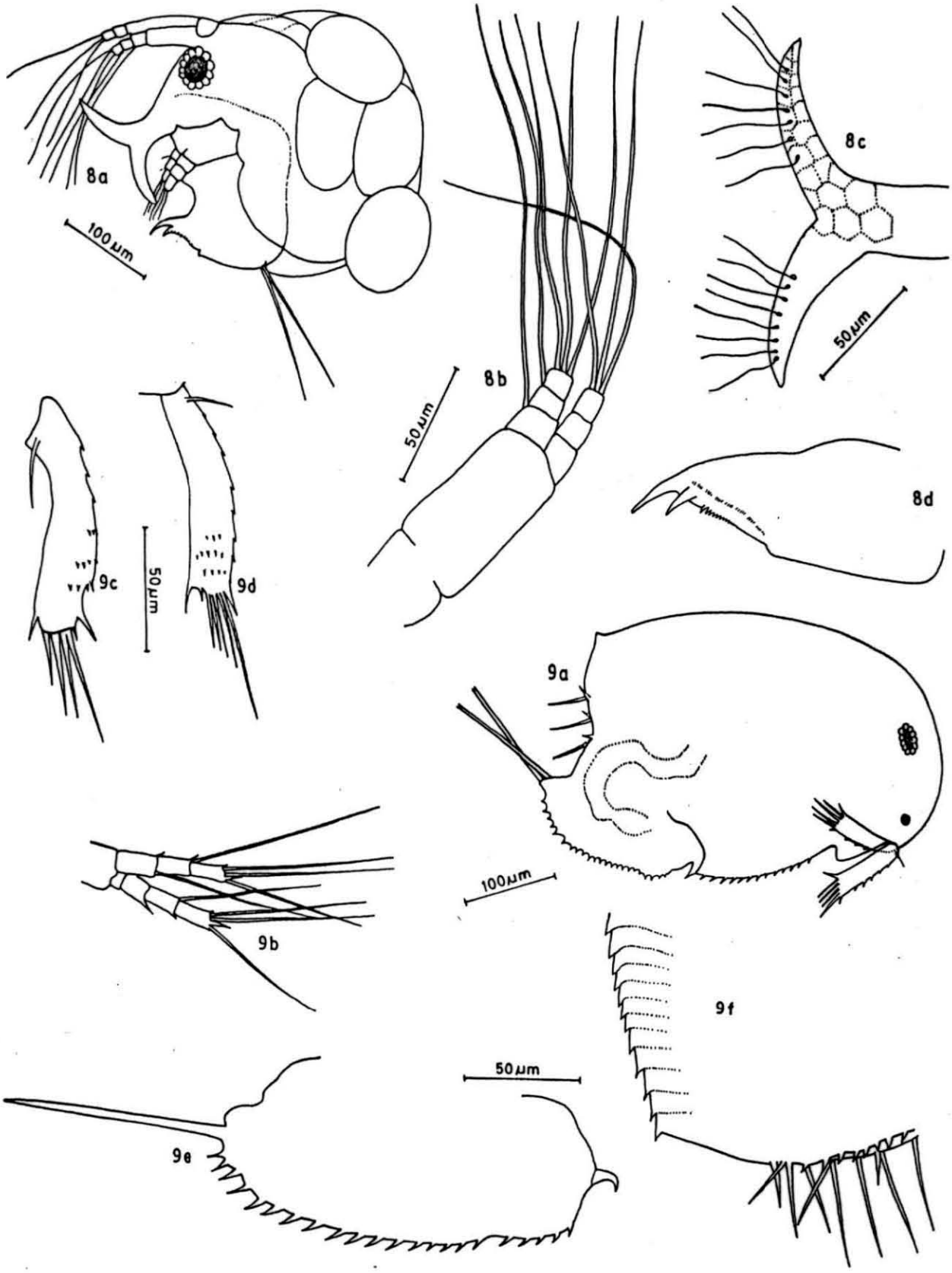


Fig. 10 *Chydorus sphaericus* (O.F. Muller)

a. Female b. Antennule c. Post-abdomen d. Ventral margin of valves (enlarged) e. Outer ramus of endite of leg 1.

Fig. 11 *Chydorus faviformis* Birge

a. Female b. Antennule c. Labral plate
d. Post-abdomen e. Right valve (enlarged)

Fig. 12 *Chydorus barroisi* Richard

a. Female b. Plate of labrum c. Post-abdomen

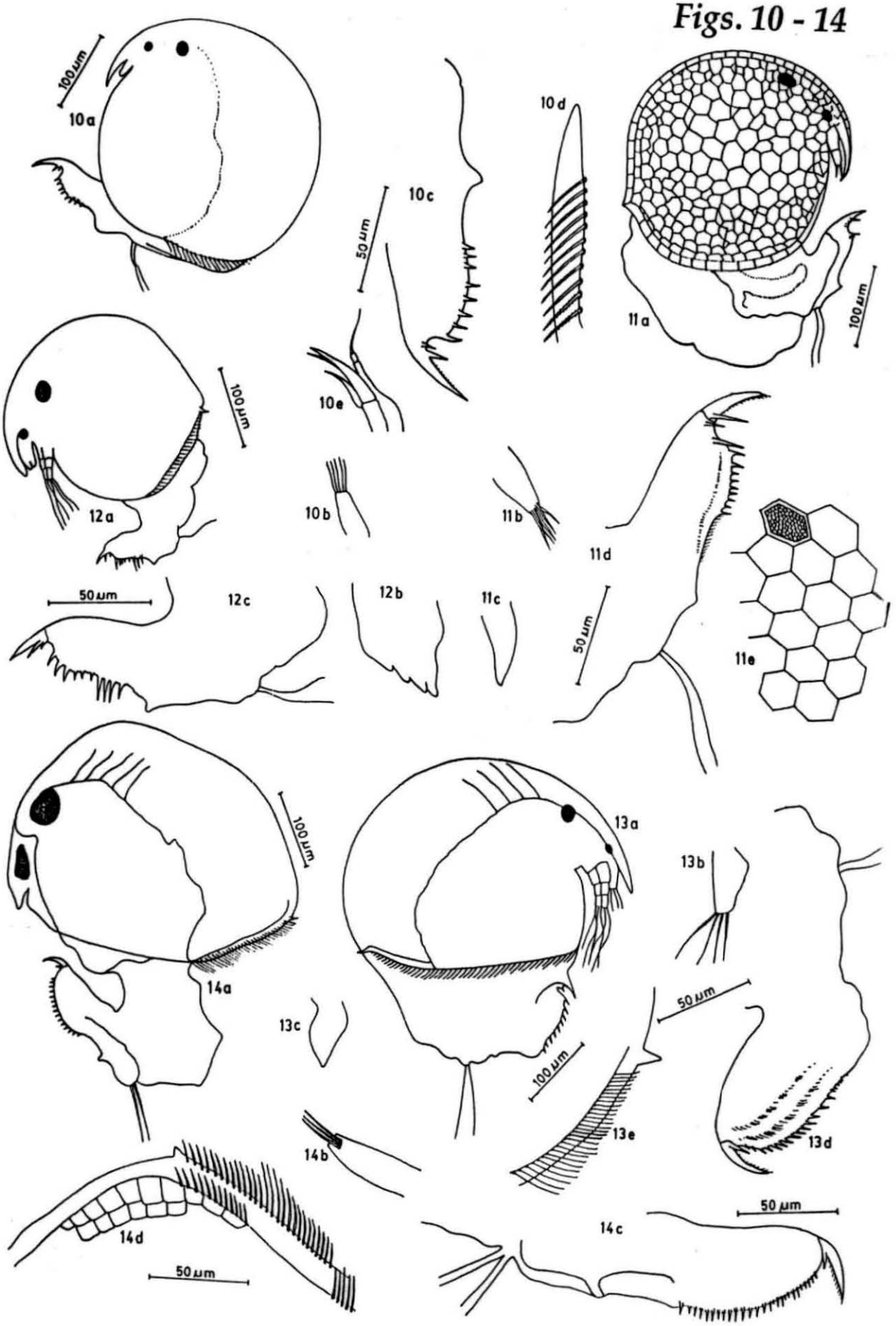
Fig. 13 *Dunhevedia crassa crassa* King

a. Female b. Antennule c. Plate of labrum
d. Post-abdomen e. Ventral margin of valves (enlarged).

Fig. 14 *Dadaya macrops* Daday

a. Female b. Antennule c. Post-abdomen d. Postero-ventral part of ventral margin of left valve (enlarged)

*Figs. 10 - 14*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100 µm
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13b
14a
13c
50 µm
100 µm
13e
13d
14b
50 µm
14c
14d
50 µm

Fig. 15 *Alona davidi punctata* (Daday)

a. Female b. Antennule c. Plate of labrum
d. Post-abdomen e. Postero-ventral region of left valve (enlarged)

Fig. 16 *Biapertura karua* (King)

a. Female b. Antennule c. Plate of labrum
d. Postabdomen e. Postero-ventral valve (enlarged)

Fig. 17 *Oxyurella singalensis* (Daday)

a. Female b. Antennule c. Labrum d. Post-abdomen, tip enlarged

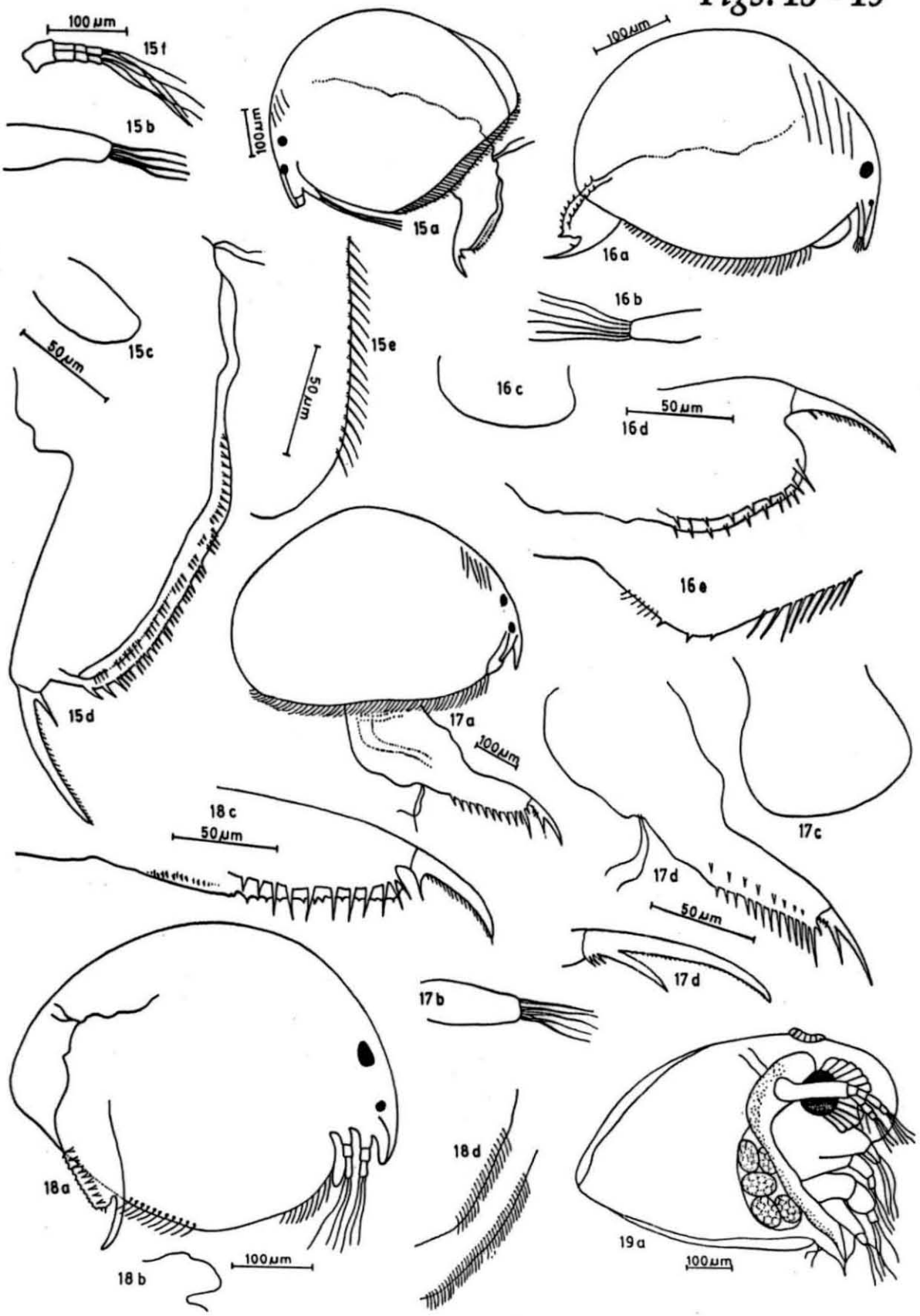
Fig. 18 *Indialona globulosa* (Daday)

a. Female b. Labral plate c. Post-abdomen
d. Postero-ventral margin of valve

Fig. 19 *Evadne tergestina* Claus

a. Female

# *Figs. 15 - 19*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15 c
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15 e
16 c
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17 a
100µm
17 c
18 c
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17 d
50 µm
17 d
17 b
18 a
18 d
19 a
100µm
18 b
100µm

Fig. 20 *Evadne tergestina*

a. Spherical eggs, b. Elongated headless embryo c. Embryo with distinct head lobe and first pair of thoracic appendage d. Embryo with 2 pairs of thoracic appendage e. Embryo with distinct optic and cerebral ganglia appearing as cross on the middle of head f-g. Embryo with inclined head and in lateral position h-i. Embryo with biramous antennae with blastulae of next brood and hence miniature adult

Fig. 21 *Penilia avirostris*

a. Segmented egg
b. Embryo differentiated into anterior and posterior part
c. Appearance of two prominences (second antennae) distinct
d. Appearance of mandible clear
e. Maxillary region differentiated and appearance of 1st pair of thoracic appendage
f-i. In each stage addition of rudiments of thoracic appendage and bificurcation of antennae
j. Rudiments of 1st and 2nd maxillae seen, bifurcation of antennae pronounced
k. Differentiation of thoracic appendage in endo and exopodites
l. Completion of carapace and antennae reaching tip of body, embryo ready for emergence

Fig. 22 *Moina micrura*

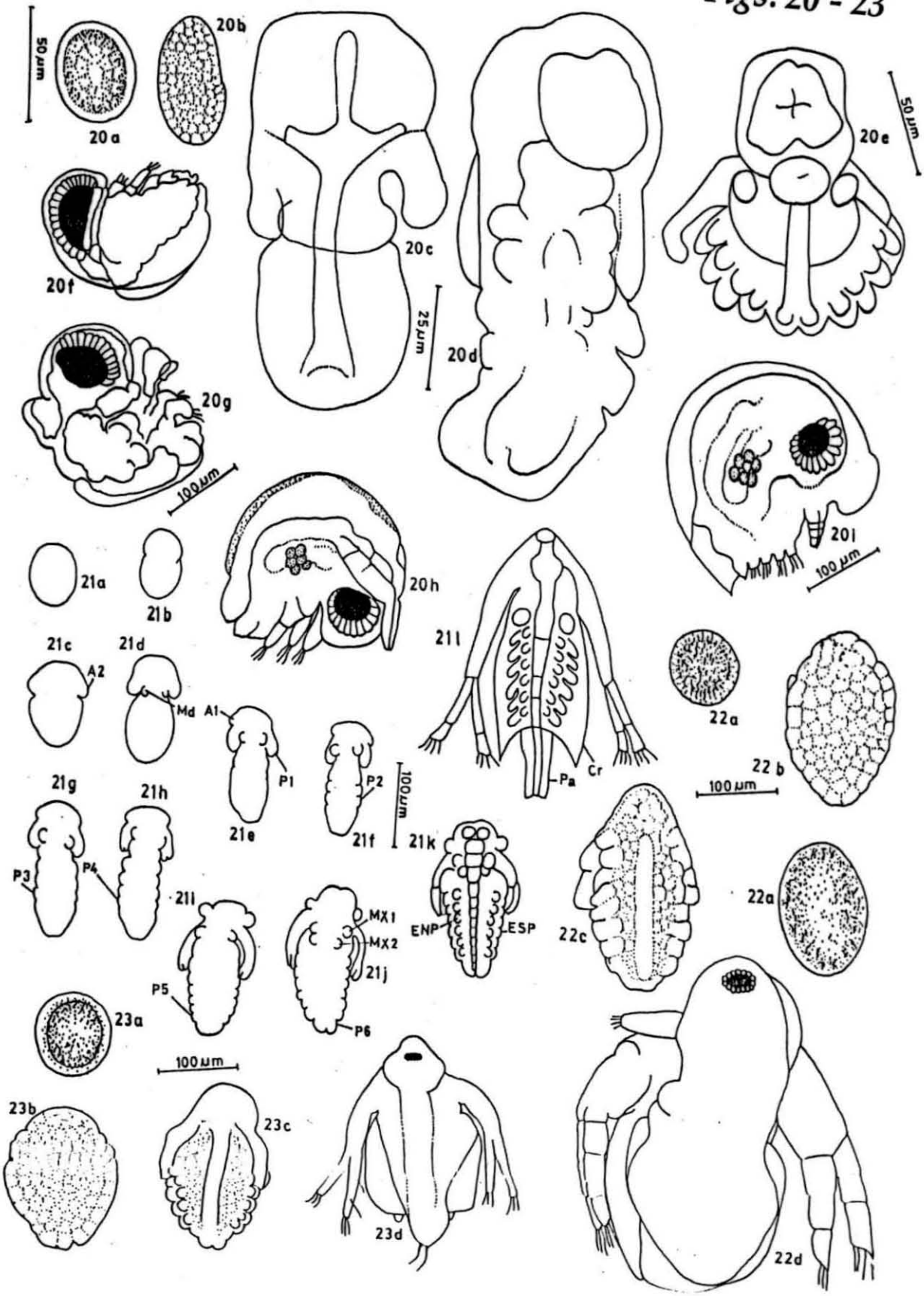
a. Spherical and granulated eggs (early)
a. Elongated embryo (late)
b. Elongated, headless embryo
c. Embryo with distinct head and rudiments of appendage
d. Embryo with elongated antennae and antennules

Fig. 23 *Moinodaphina macleayi*

a. Spherical egg
b. Elongated embryo
c. Embryo with distinct head and rudiments of appendage
d. Embryo with elongated antennae and carapace complete

| | | | |
|---|---|---|---|
| $A_1$ | - Antenna (first) | $A_2$ | - Antenna (second) |
| Cr | - Carapace | Enp | - Endopodite |
| Esp | - Exopodite | $Mx_1$ | - Maxilla (first) |
| $Mx_2$ | - Maxilla (second) | $P_1$-$P_6$ | - Thoracic appendages |

*Figs. 20 - 23*


50 µm
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20h
20i
100 µm
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21b
21c
A2
21d
Md
A1
P1
21e
P2
21f
100 µm
21g
P3
P4
21h
21i
P5
MX1
MX2
21j
P6
21k
ENP
ESP
21l
Pa
Cr
22a
22b
100 µm
22c
22a
23a
100 µm
23b
23c
23d
22d

**Fig. 24 :** **Percentage Size frequency of parthenogenetic individuals of *Evadne tergestina* at Vizhinjam station for the period of February '92 to January '93. Lengths in micra.**

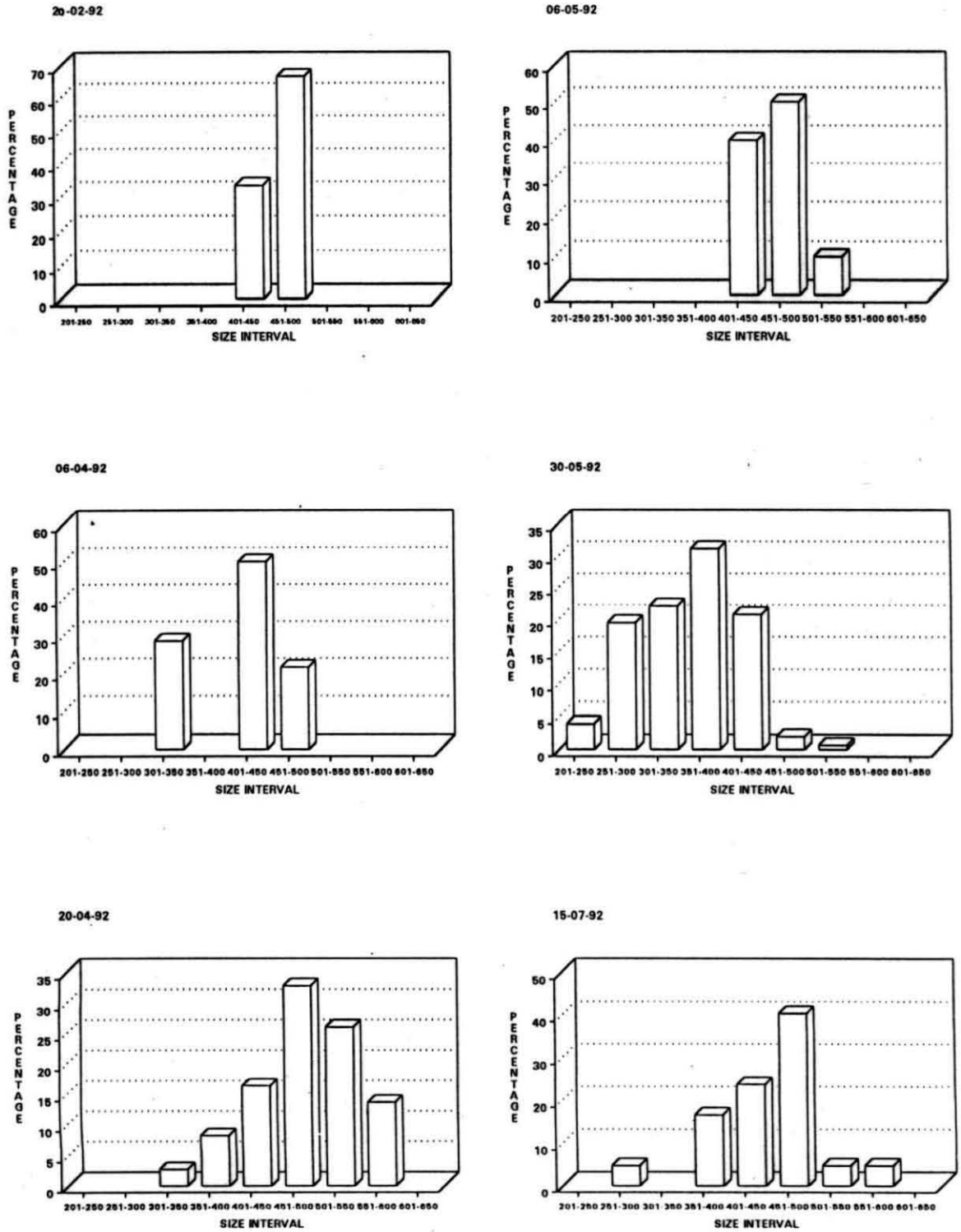


**Fig. 24 :** **(Contd..)**

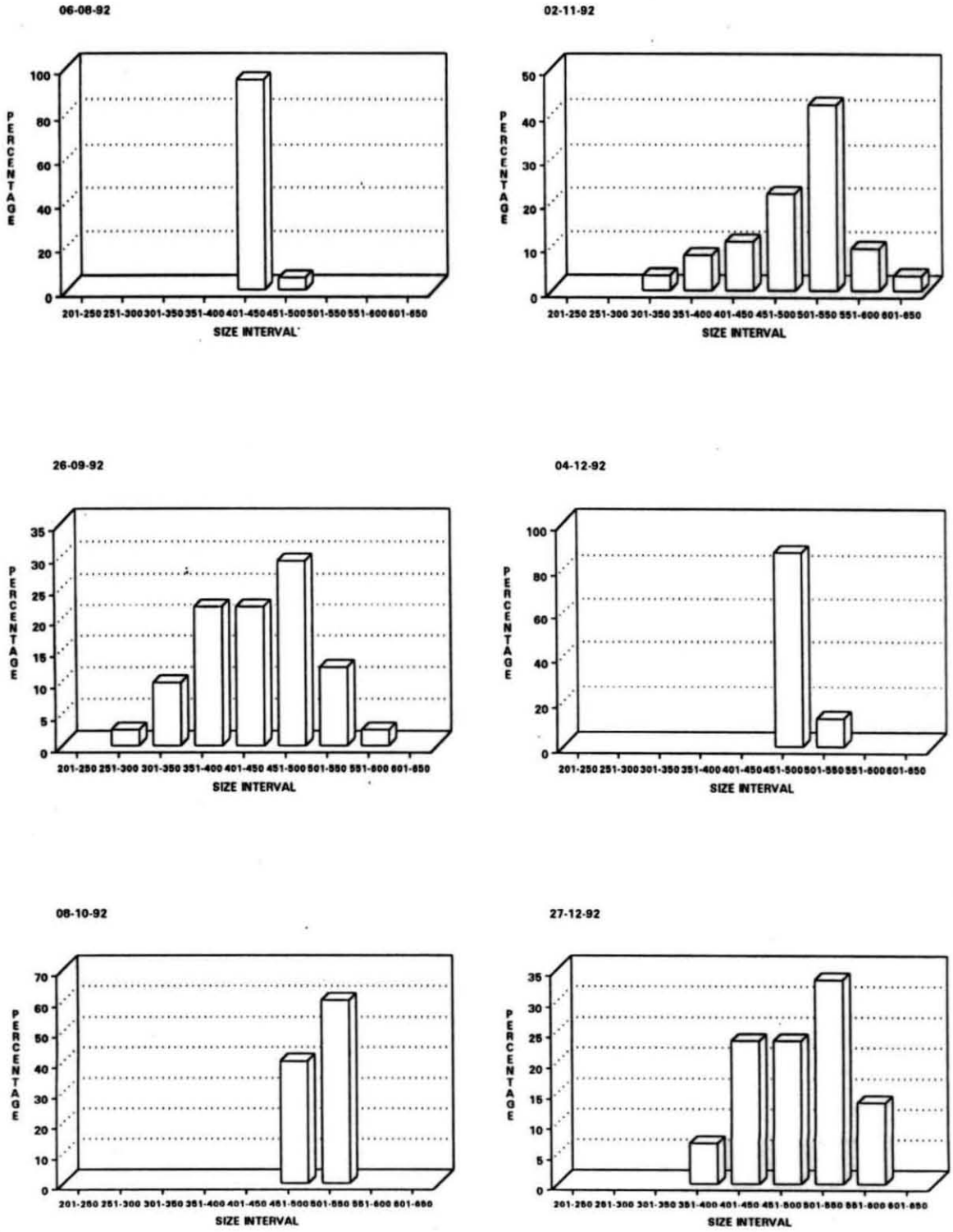

06-08-92
02-11-92
26-09-92
04-12-92
08-10-92
27-12-92
PERCENTAGE
SIZE INTERVAL
201-250 251-300 301-350 351-400 401-450 451-500 501-550 551-600 601-650

**Fig. 25 :** **Percentage size frequency of the various categories of *E. tergestina* at Vizhinjam station for the period of February '92 to January '93. Lengths in micra**

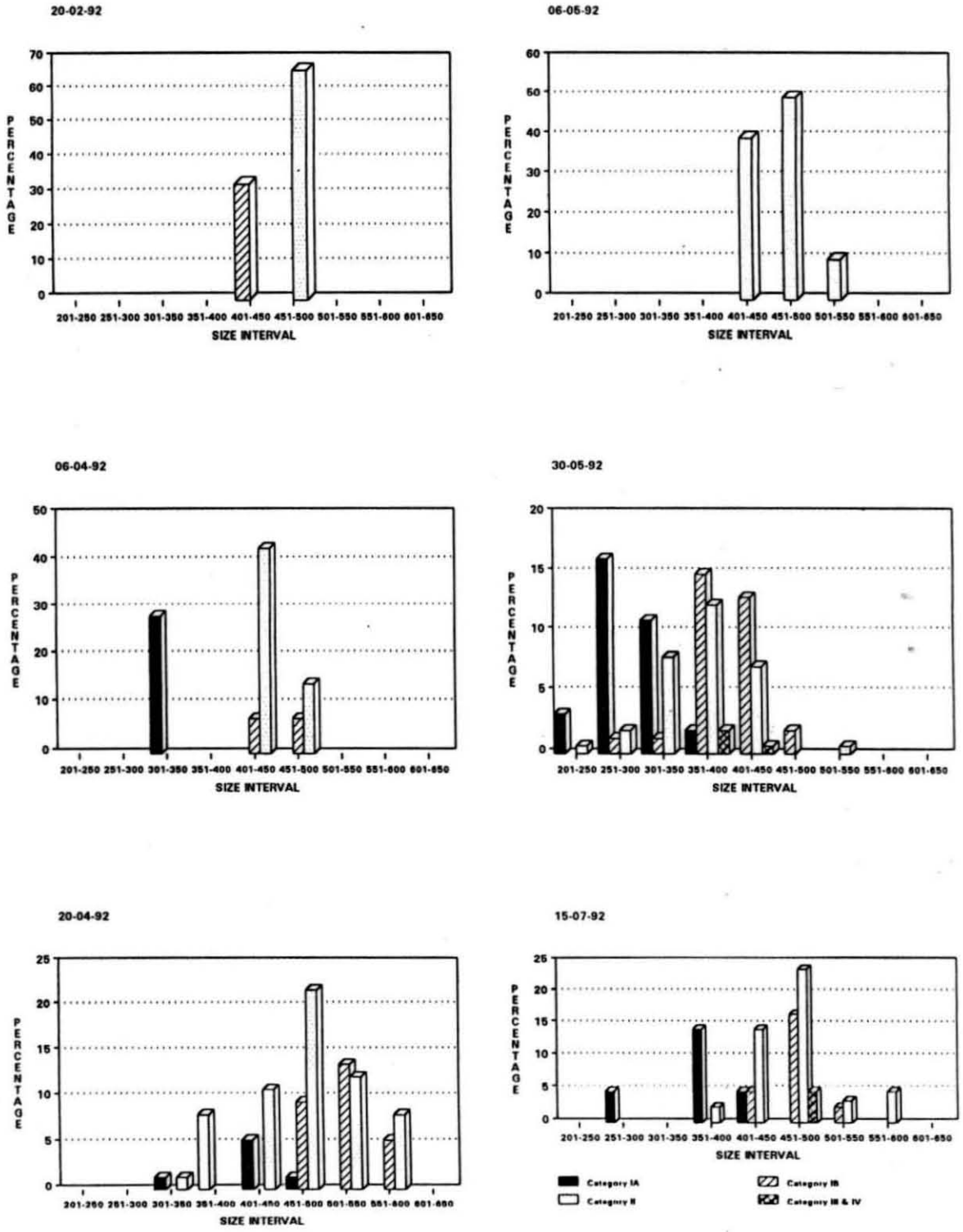
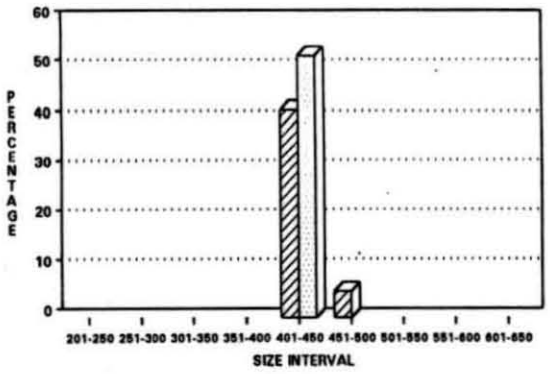
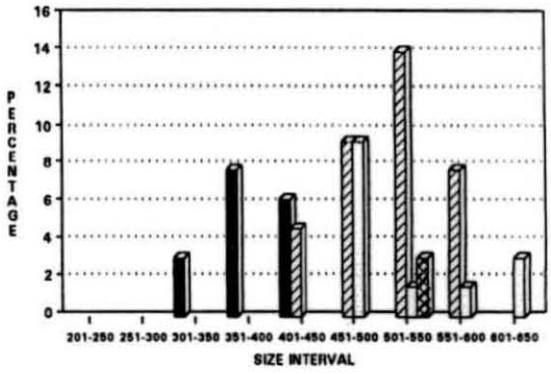


**Fig. 25 :** **(Contd..)**

06-06-92




02-11-92

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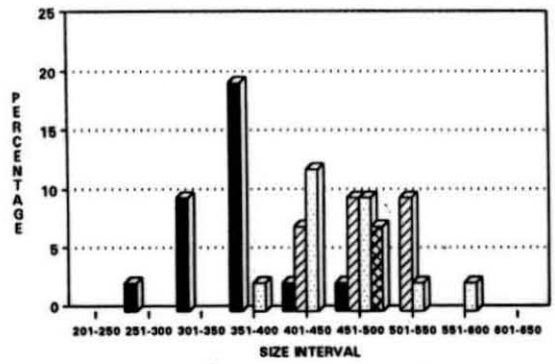


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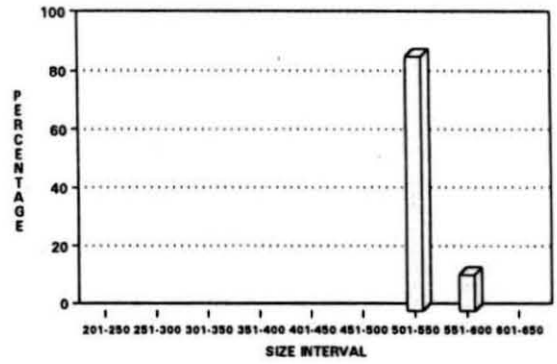


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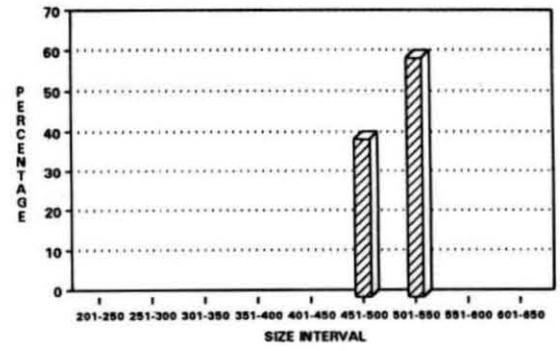



27-12-92

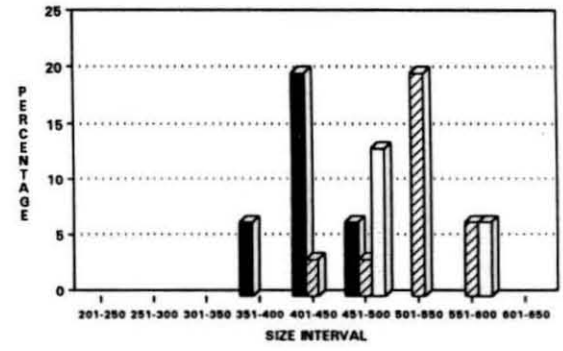


**Fig. 26 :** **Percentage size frequency of the eggs or embryos of *E. tergestina* at Vizhinjam station for the period of February '92 to January '93. Lengths in micra.**

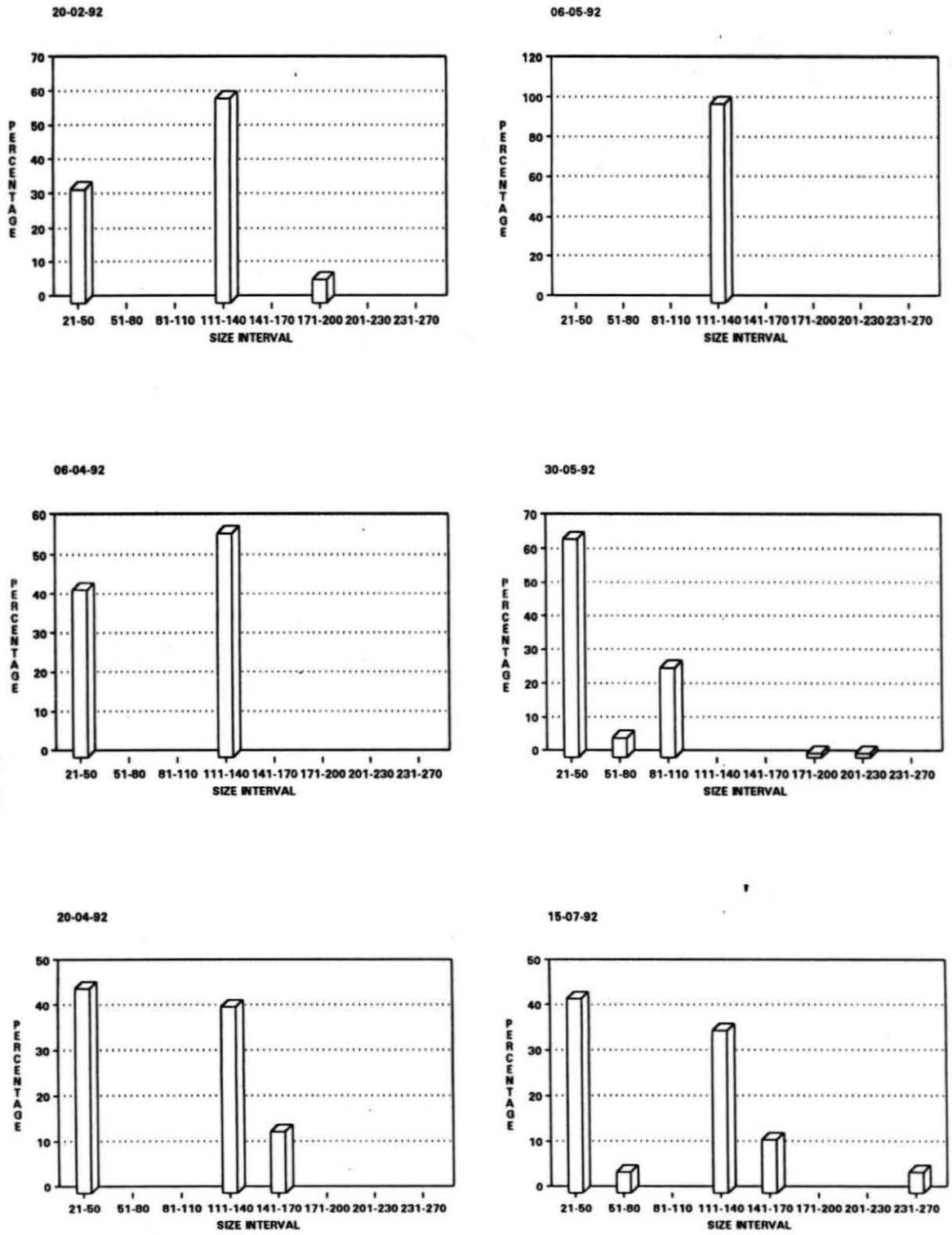


**Fig. 26 :** **(Contd..)**

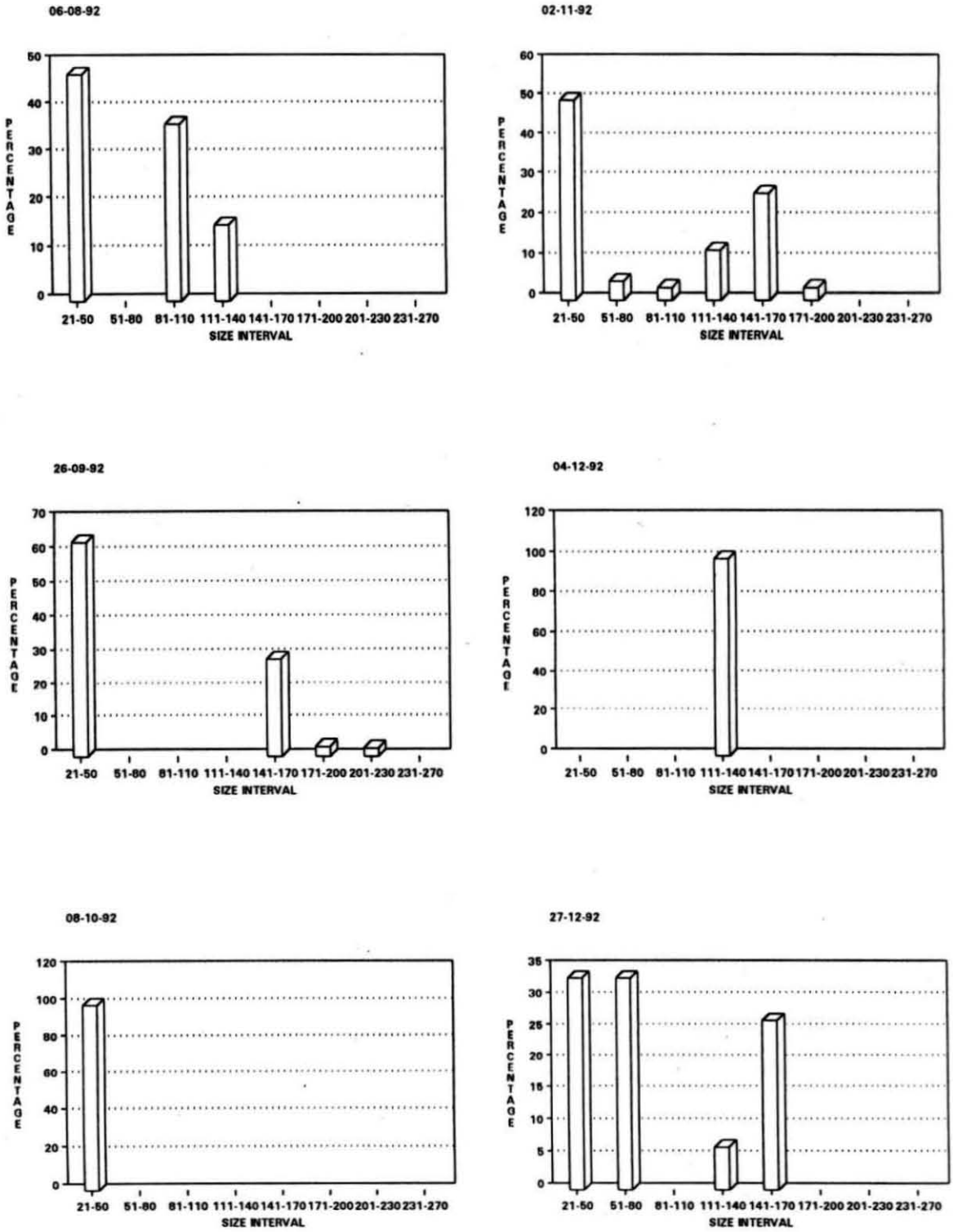

06-08-92
02-11-92
26-09-92
04-12-92
08-10-92
27-12-92
PERCENTAGE
SIZE INTERVAL
21-50
51-80
81-110
111-140
141-170
171-200
201-230
231-270

**Fig.27 :** **Percentage frequency distribution of the number of eggs or embryos in *E.tergestina* at Vizhinjam station for the period of February '92 to January '93.** Lengths in micra.

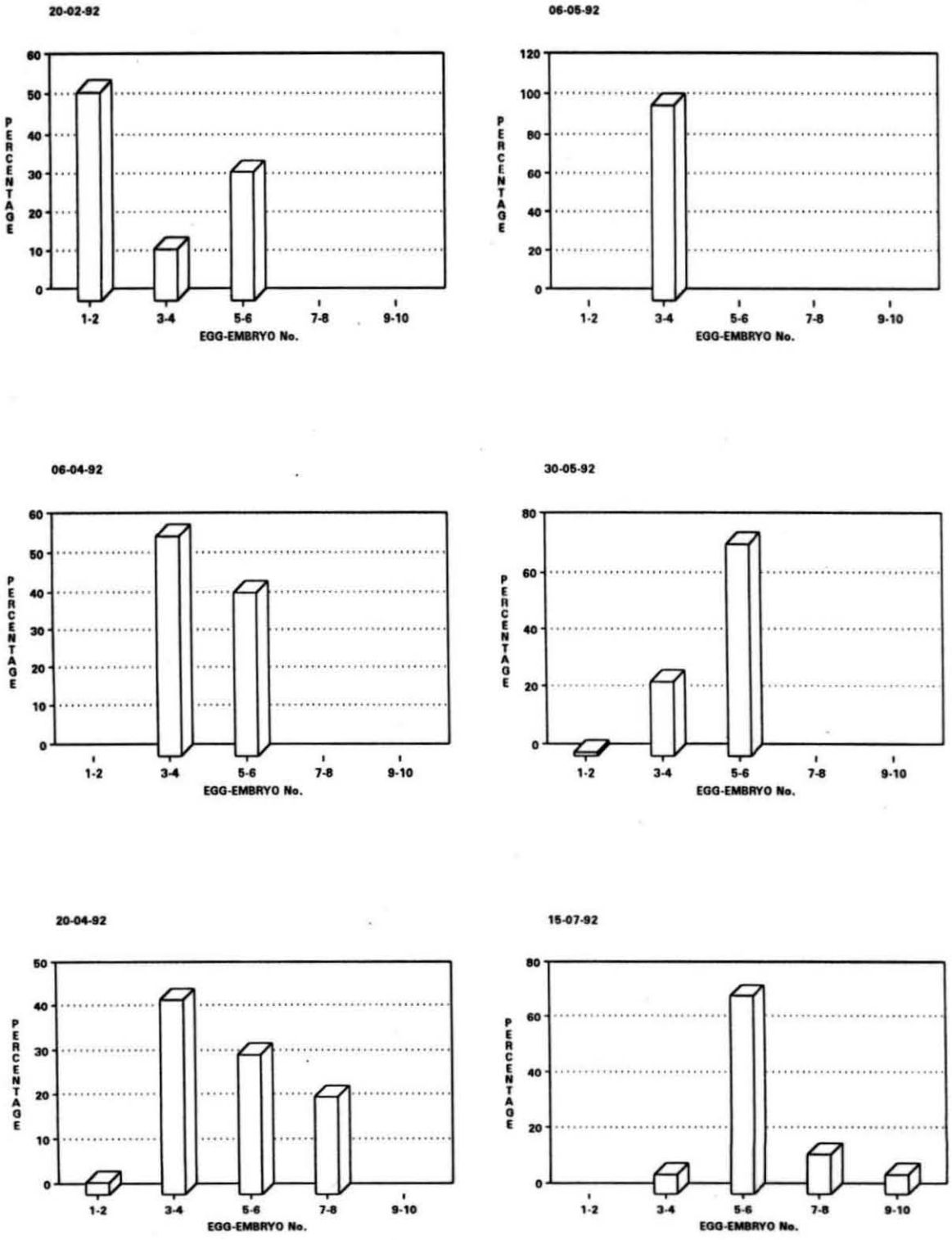


**Fig. 27 :** (Contd..)

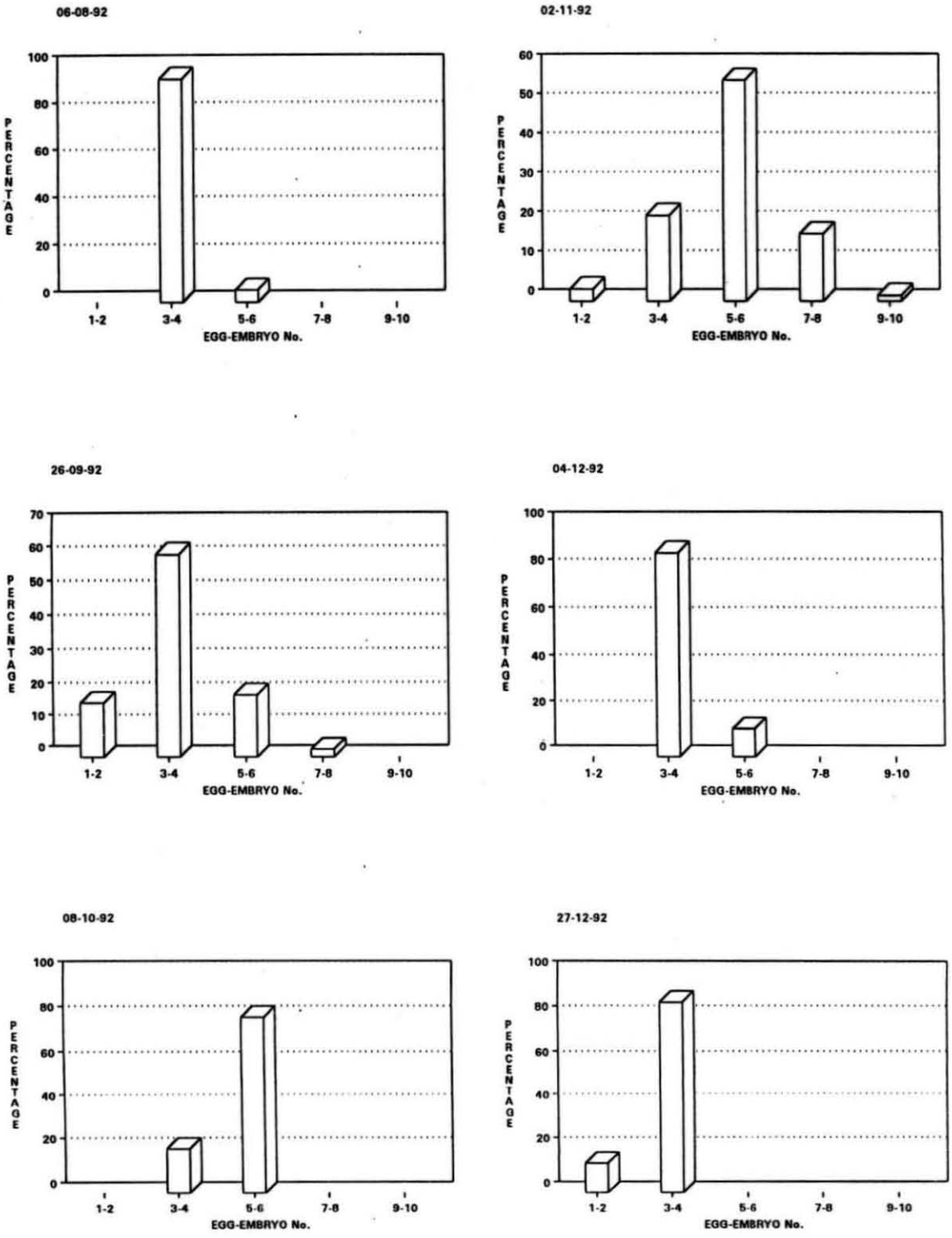

06-08-92
PERCENTAGE
100
80
60
40
20
0
1-2
3-4
5-6
7-8
9-10
EGG-EMBRYO No.
02-11-92
PERCENTAGE
60
50
40
30
20
10
0
1-2
3-4
5-6
7-8
9-10
EGG-EMBRYO No.
26-09-92
PERCENTAGE
70
60
50
40
30
20
10
0
1-2
3-4
5-6
7-8
9-10
EGG-EMBRYO No.
04-12-92
PERCENTAGE
100
80
60
40
20
0
1-2
3-4
5-6
7-8
9-10
EGG-EMBRYO No.
08-10-92
PERCENTAGE
100
80
60
40
20
0
1-2
3-4
5-6
7-8
9-10
EGG-EMBRYO No.
27-12-92
PERCENTAGE
100
80
60
40
20
0
1-2
3-4
5-6
7-8
9-10
EGG-EMBRYO No.

**Fig. 28 :** **Percentage size frequency of parthenogenetic individuals of *Penilia avirostris* (A) and their categories (B) at Vizhinjam station for the period Frequency '92 to January '93.** Lengths in micra

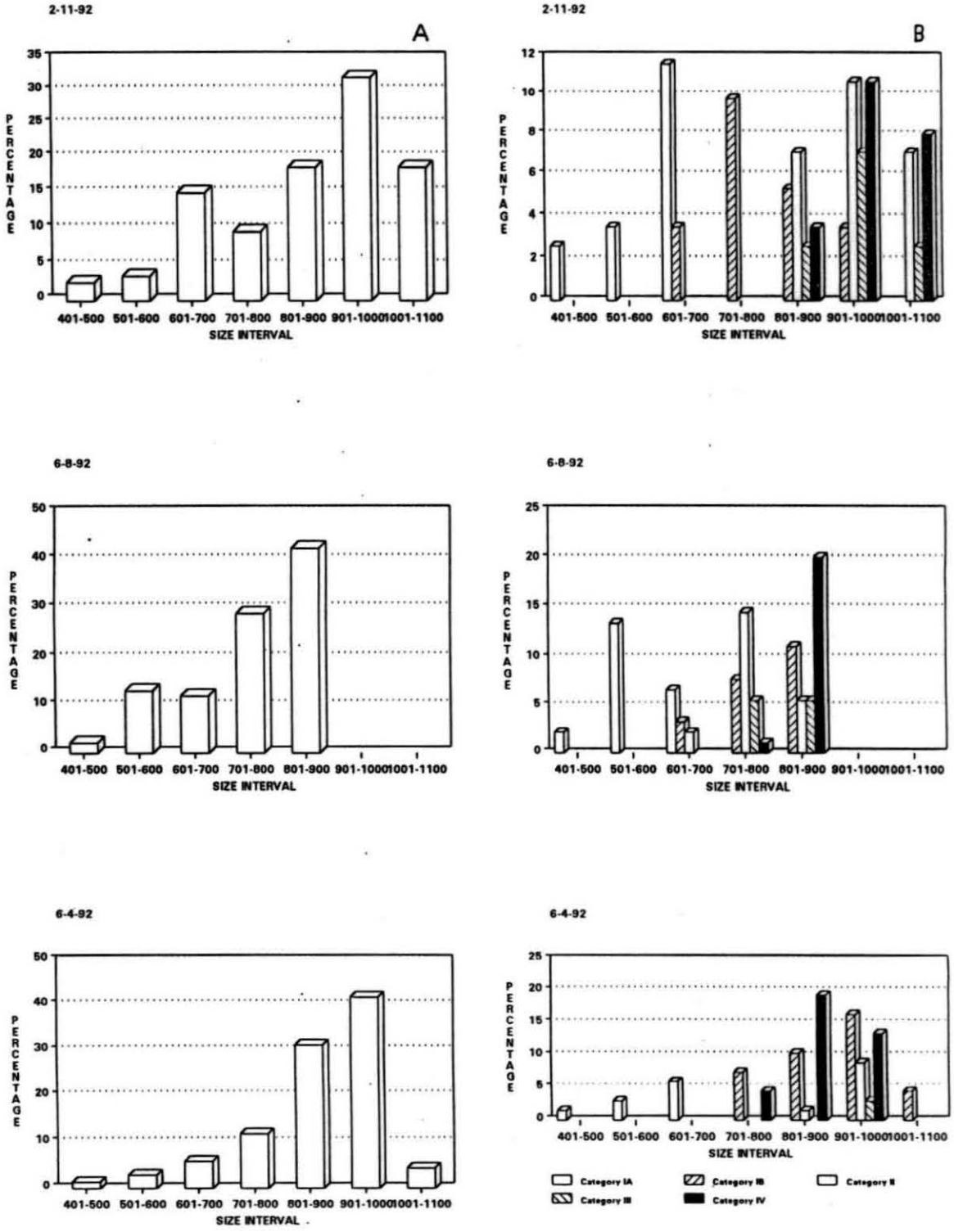


**Fig.29 :** **Percentage size frequency of egg or embryos (A) and precentage of number of eggs or embryos (B) of *P.avirostris* at Vizhinjam station for the period of February '92 to January '93** Lengths in micra.

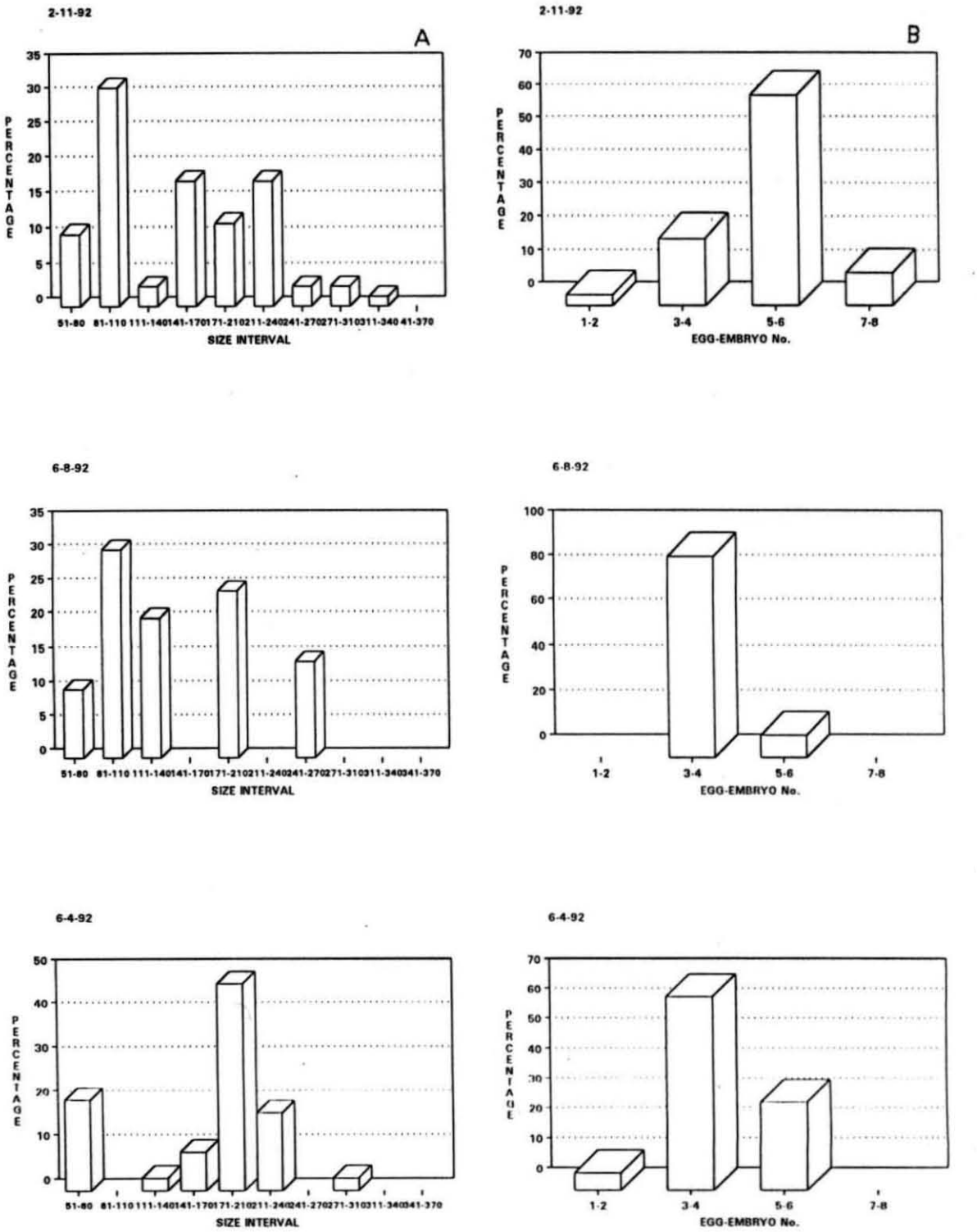


**Fig. 30 :** **Mean number of eggs or embryos and size of parent of *P. avirostris* at Vizhinjam station for the period of February '92 to January '93.** Lengths in micra

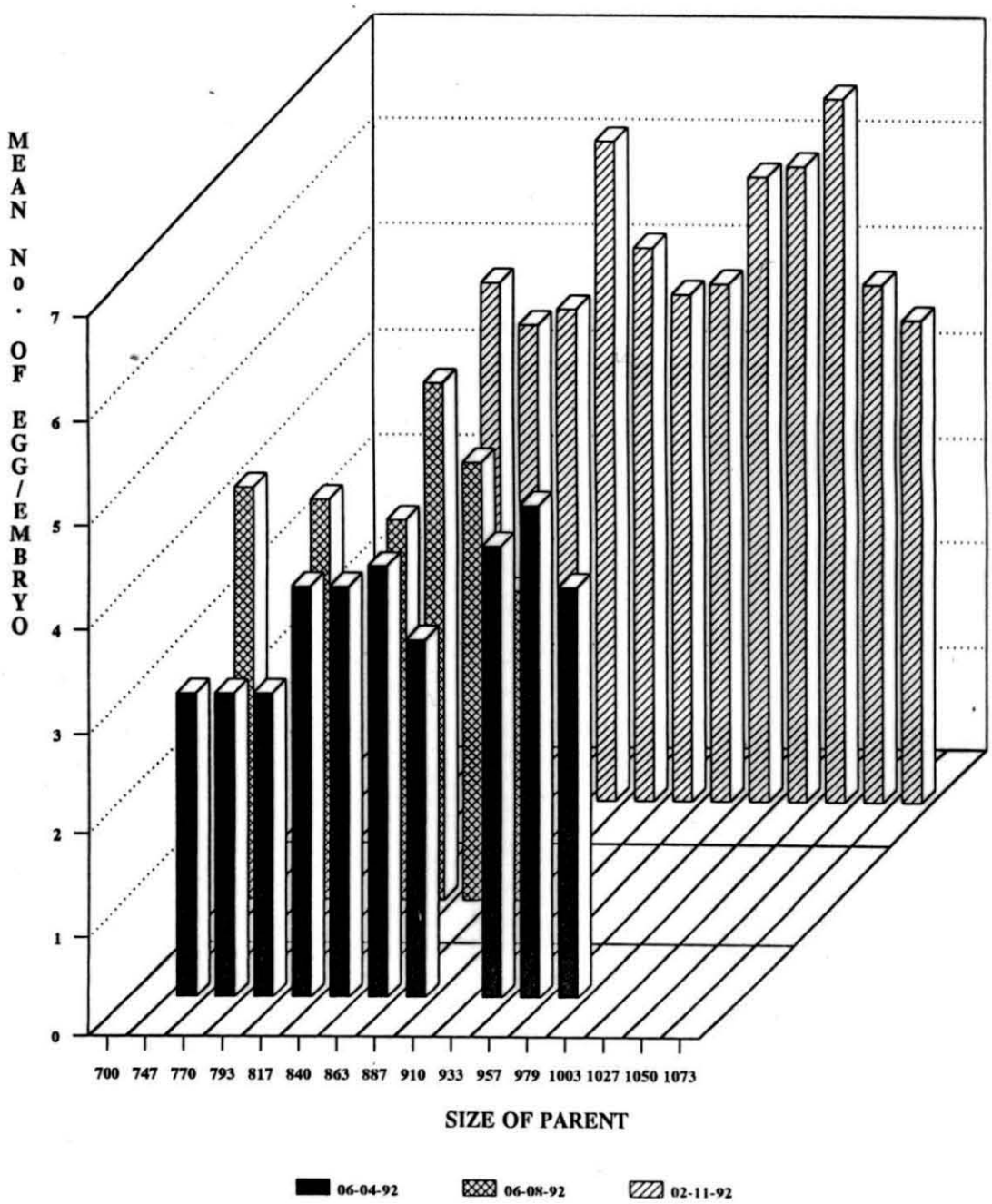


**Fig. 31 :** **Percentage size frequency of parthenogenetic individuals of *Moina micrura* at Veli station for the period of February '92 to January '93.** Lengths in micra

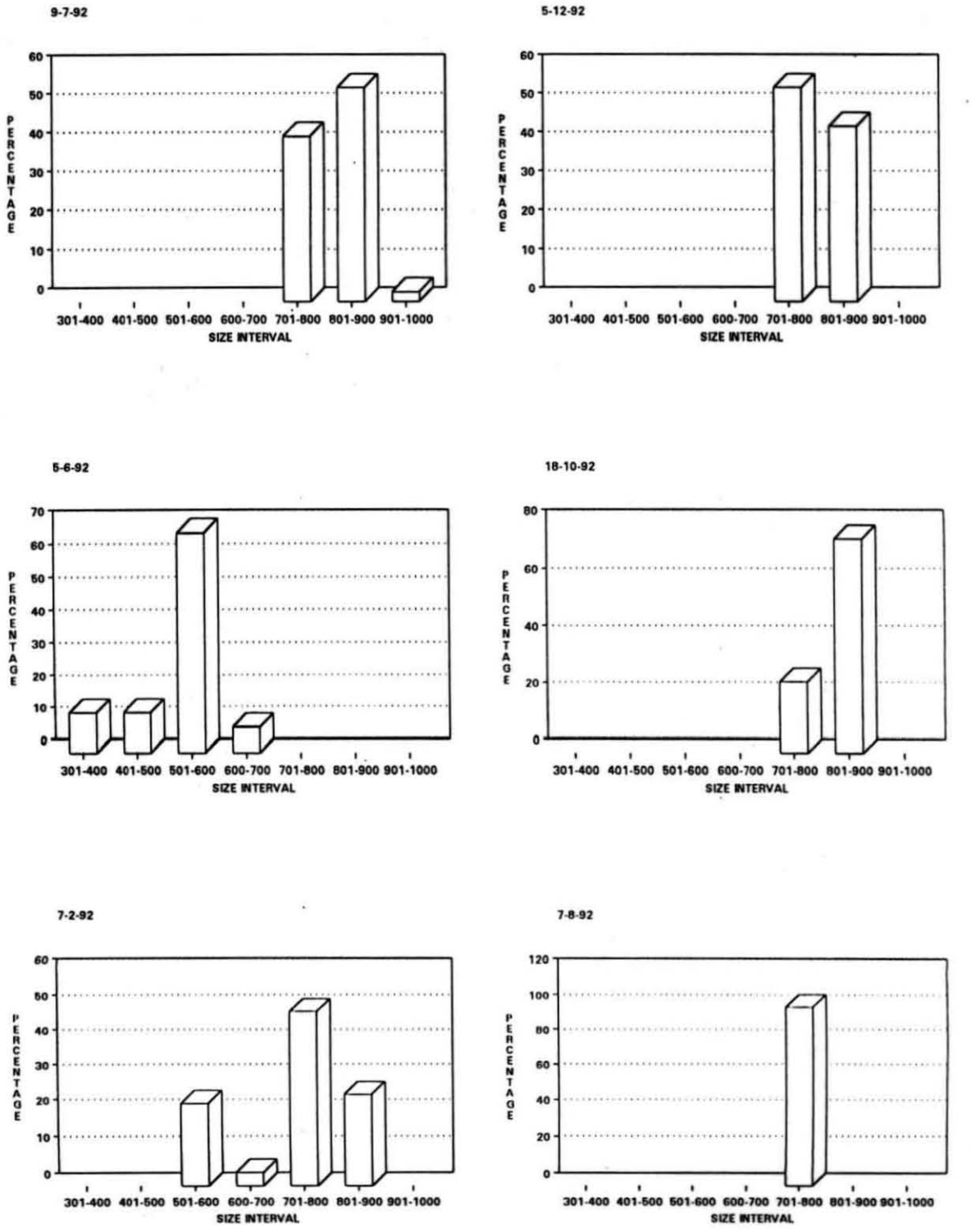


**Fig. 32 :** **Percentage size-frequency of the various categories of *M.micrura* at Veli station for the period of Februaru '92 to January '93 Lengths in micra**

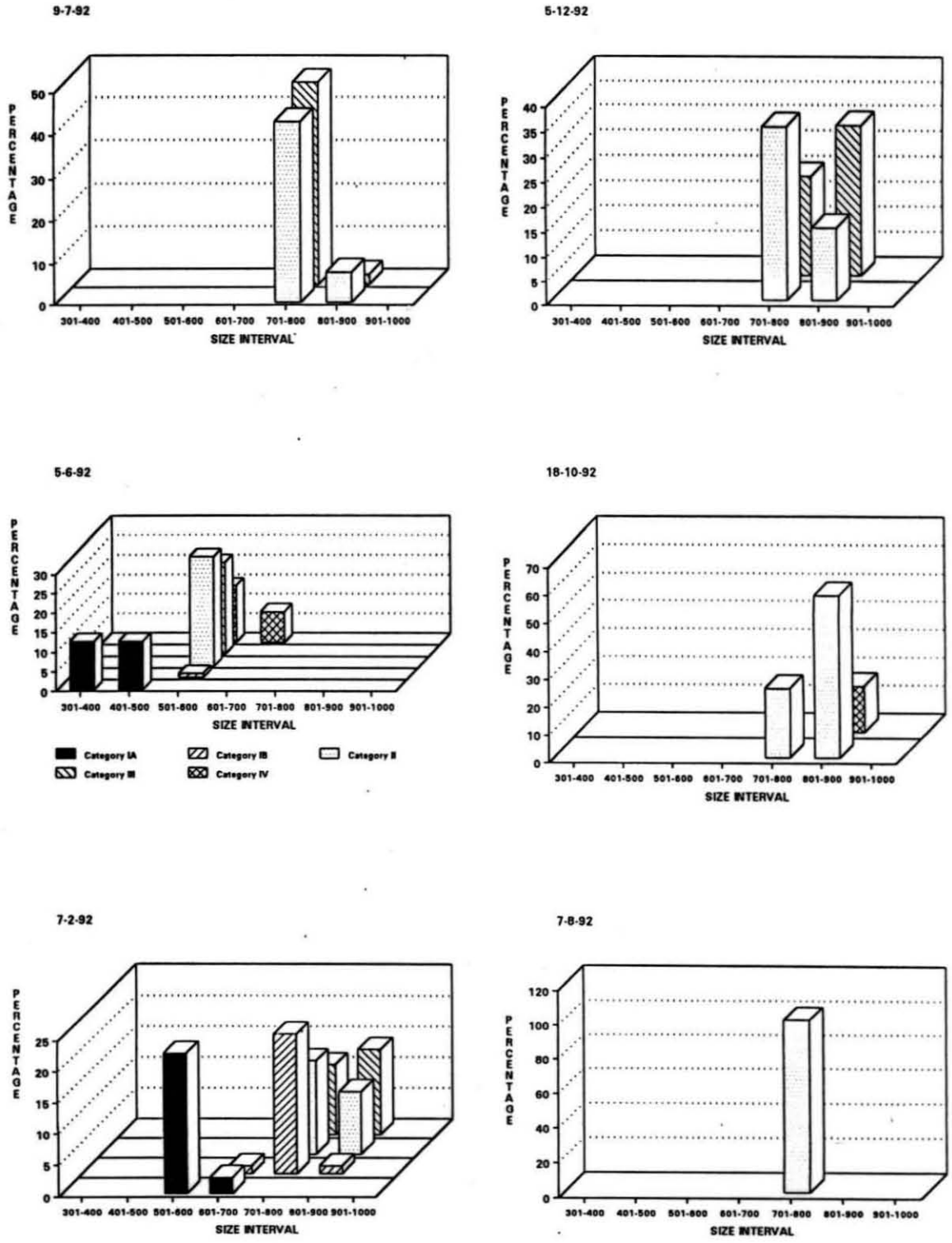


**Fig.33 :** **percentage size frequency of the egg or embryos of the parthenogenetic females of *M.micrura* at Veli station during the period of February '92 to January '93.**
Lengths in micra.

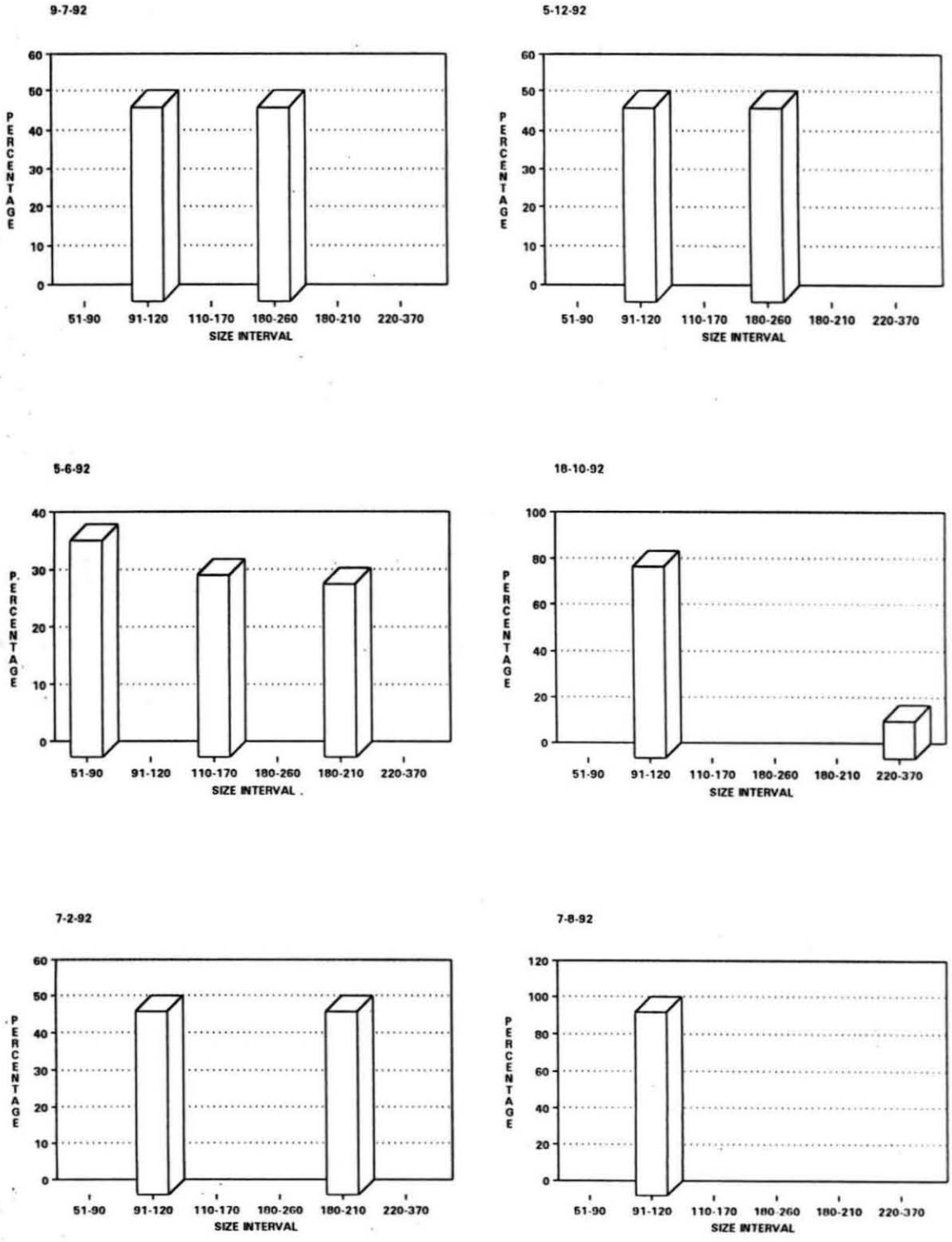


**Fig.34 :** **Percentage frequency distribution of the number of egg or embryos in *M.micrura* at Veli station** Lengths in micra.

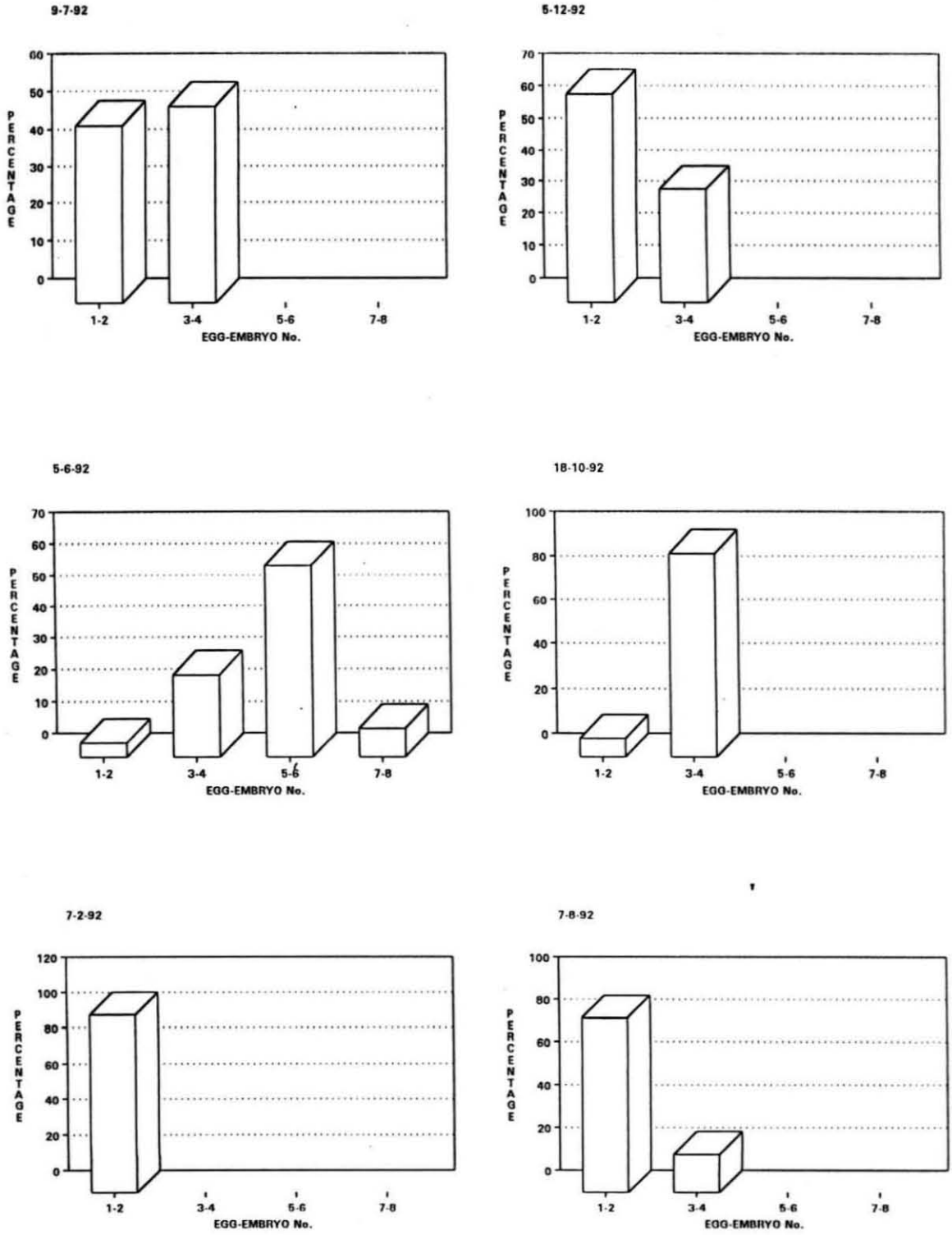


**Fig. 35 :** **Mean number of eggs or embryos and size of parent of *M. micrura* at Veli station.**
Lengths in micra

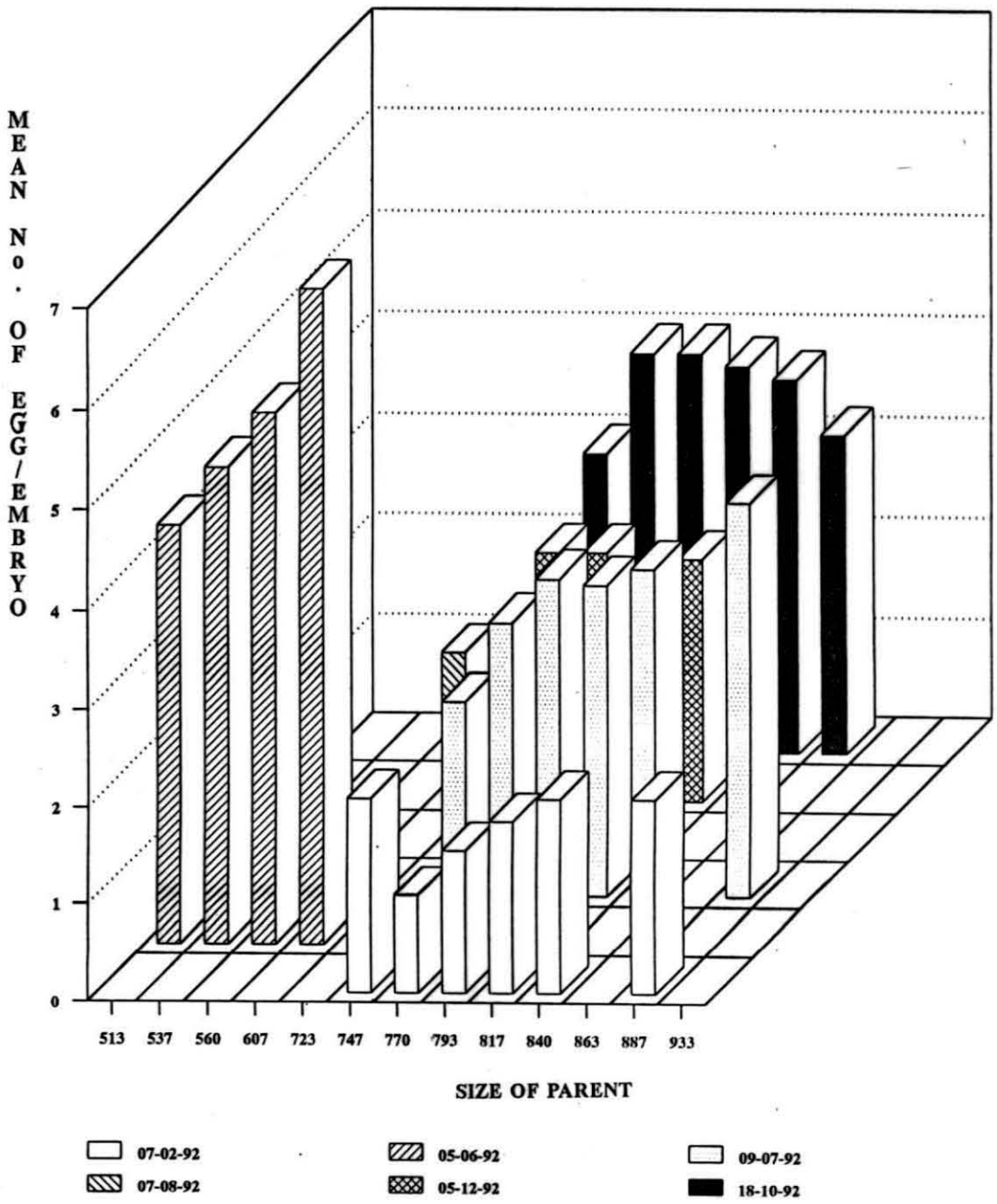
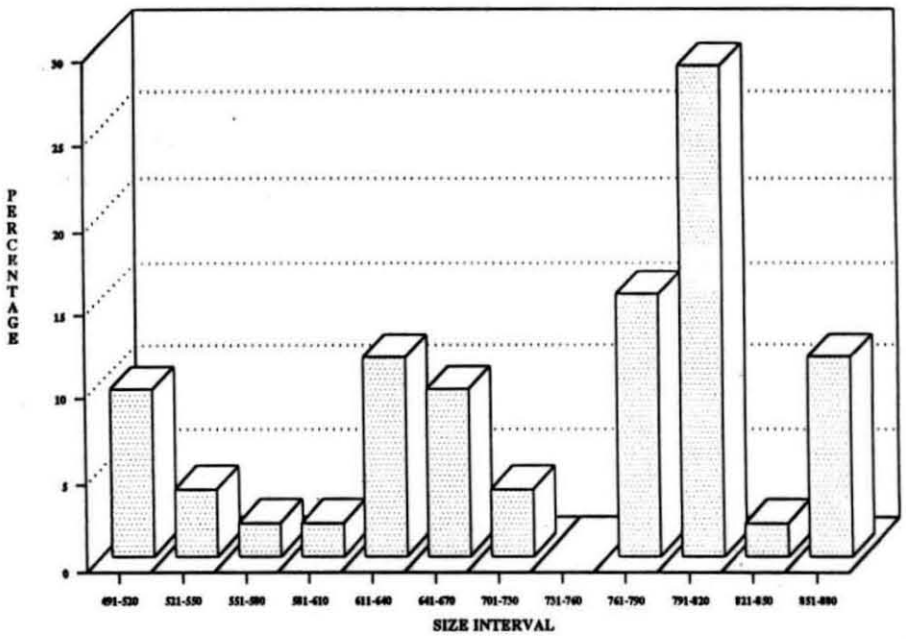


**Fig. 36 :** **Percentage size-frequency of parthenogenetic individuals of *Moinodaphnia macleayi* at Veli station collected during January '93.** Length in micra



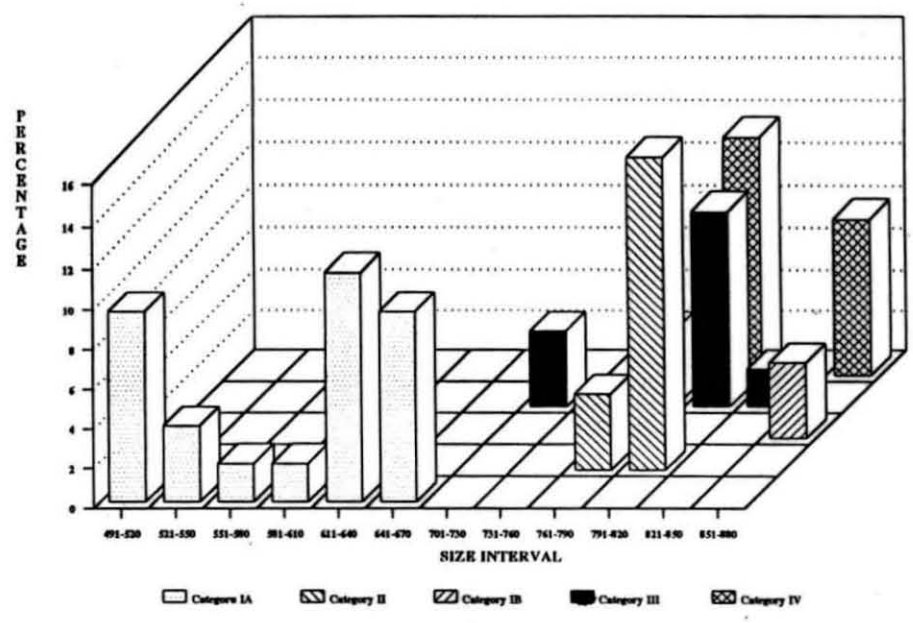
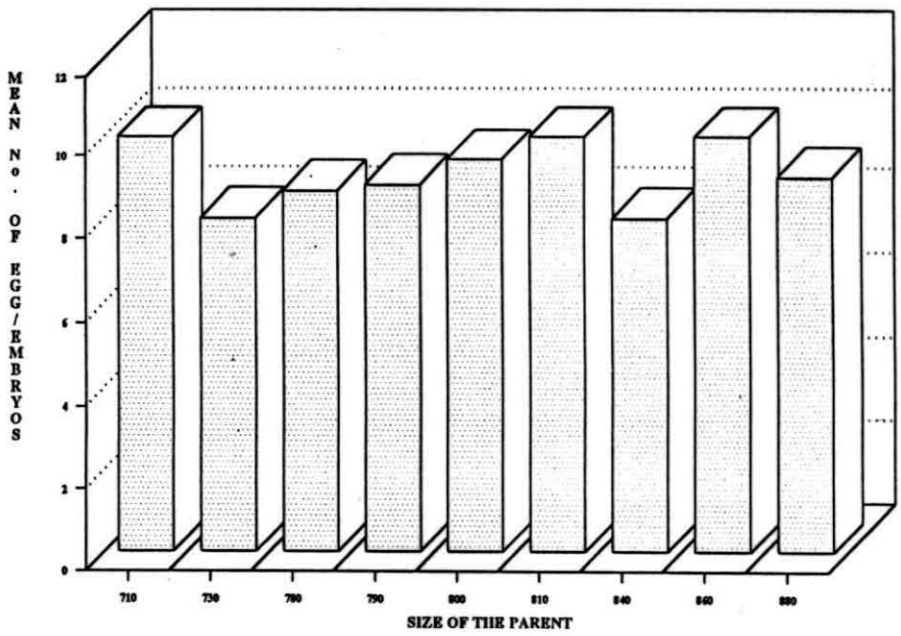




**Fig. 37 :** **Percentage size frequency of the various categories of M.macleayi at Veli station collected during January '93**

**Fig. 38 :** **Mean number of eggs or embryos and size of parent of *M. macleayi* at Veli station collected during January '93** Lengths in micra



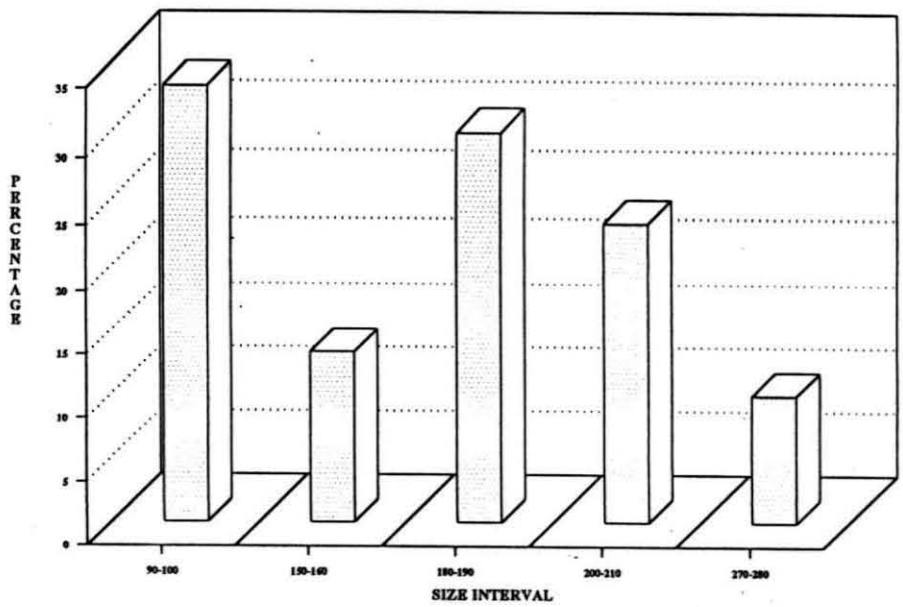
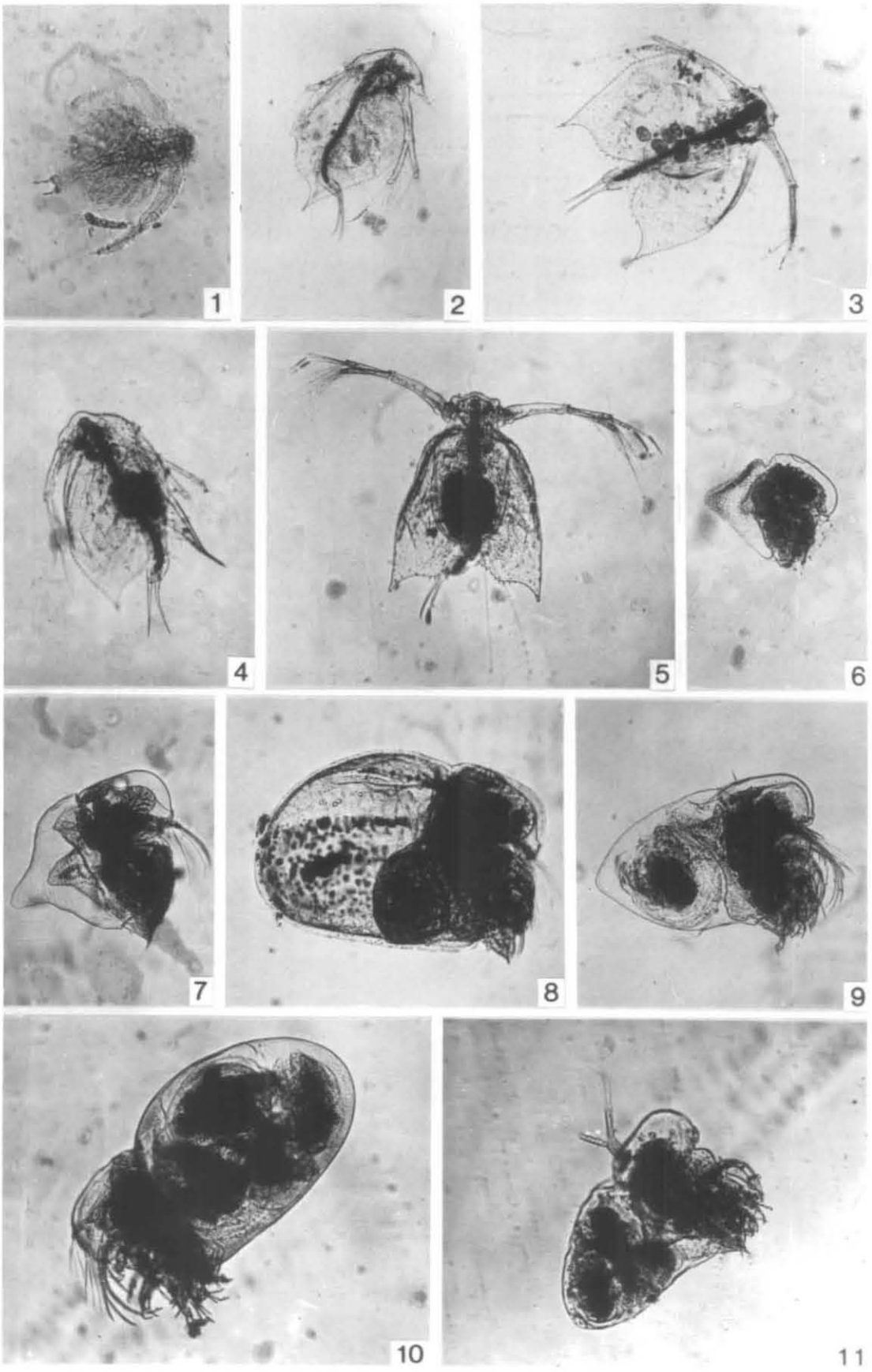




**Fig. 39 :** **Percentage size-frequency of the eggs or embryos of parthenogenetic female of *M. macleayi* at Veli station during January '93.**

## PLATE I

| | | |
|---|---|---|
| Fig. 1 | *Penilia avirostris* | Category IA |
| Fig. 2 | *P. avirostris* | Category IB |
| Fig. 3 | *P. avirostris* | Category II |
| Fig. 4 | *P. avirostirs* | Category III |
| Fig. 5 | *P. avirostris* | Category IV |
| Fig. 6 | *Evadne tergestina* | Category IA |
| Fig. 7 | *E. tergestina* | Category IB |
| Fig. 8 | *E. tergestina* | Category II |
| Fig. 9 & 10 | *E. tergestina* | Category III |
| Fig. 11 | *E. tergestina* | Category IV |

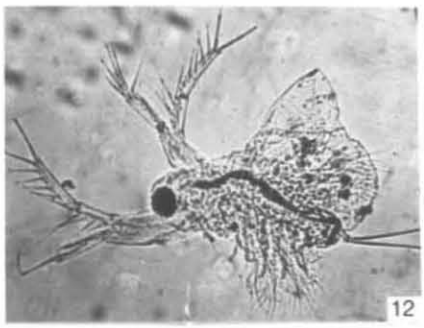
# PLATE I



## PLATE II

| | | |
|---|---|---|
| Fig. 12 | *Diaphanosoma sarsi* | Culturable species |
| Fig. 13 | *Moina micrura* | |
| Fig. 14 | *Ceriodaphnia cornuta* | |
| Fig. 15 | *Scapholeberis kingi* | |
| Fig. 16 | *Bosminopsis deitersi* | |
| Fig. 17 | *Penilia avirostris* (Male) | |
| Fig. 18 | *P. avirostris* (Gamogenetic female) | |
| Fig. 19 | *Moinodaphnia macleayi* | Category IB |
| Fig. 20 | *M. macleayi* | Category II |
| Fig. 21 | *M. macleayi* | Category IA |
| Fig. 22 | *M. macleayi* | Category III |
| Fig. 23 | *M. macleayi* | Category IV |

# PLATE II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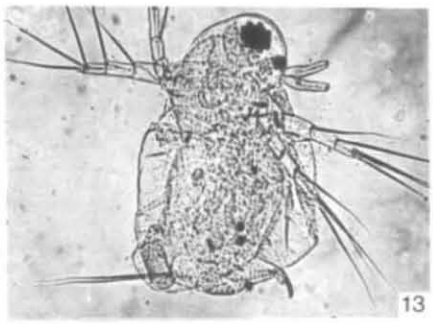
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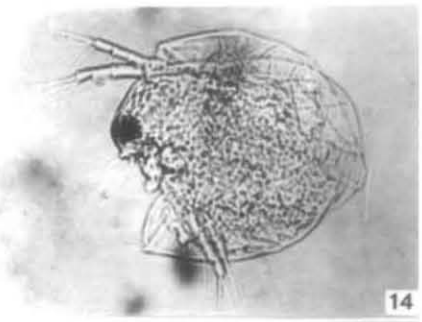
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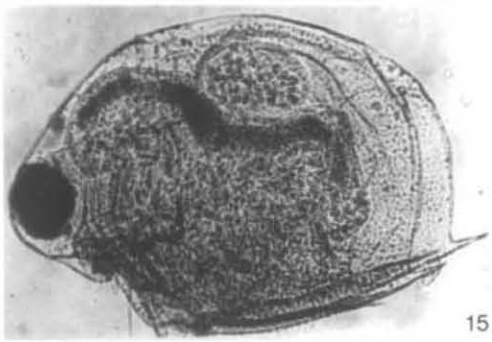
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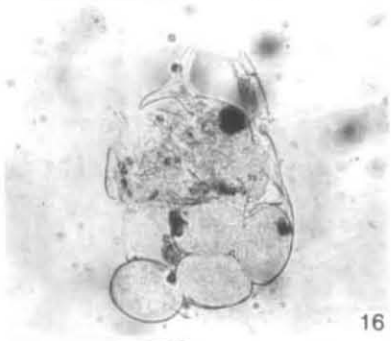
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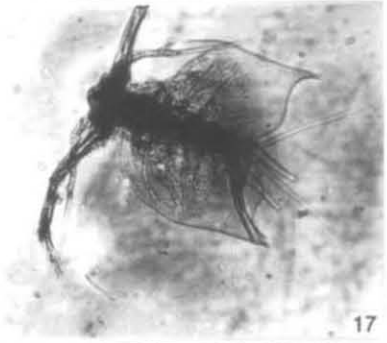
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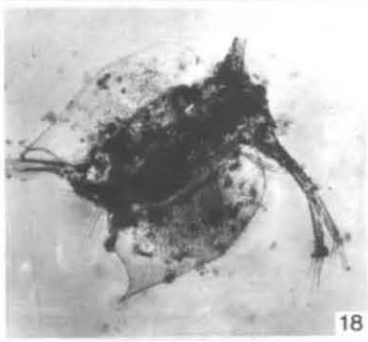
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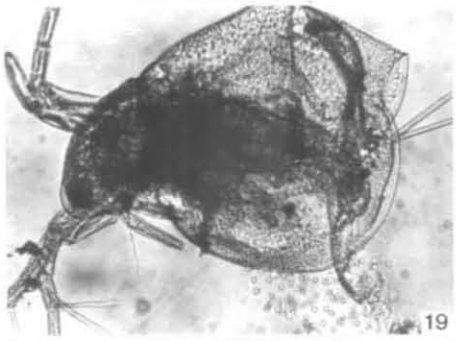
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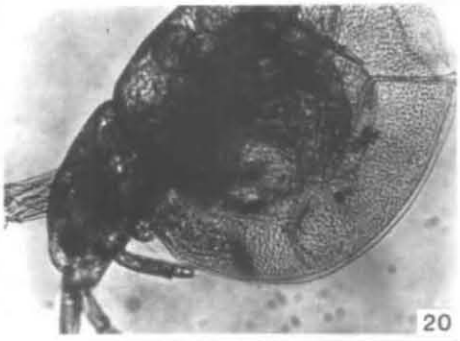
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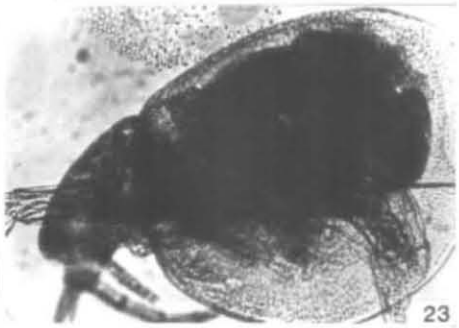
21


22


23