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# Dynamics of a population of *Ceriodaphnia cornuta* Sars (Crustacea: Cladocera) from a seasonal pond in Madurai

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**Abstract.** Investigation of the dynamics of a population of *Ceriodaphnia cornuta* indicated that the internal and external phenomena of clutch size and food supply were significant factors influencing population density and other population parameters. The relationships of clutch size with transparency and temperature were attempted. A single period of bisexual reproduction was noticed over a period of 12 months. The mean annual clutch size ranged from one to two eggs. Animals with 3 eggs were far fewer in percentage in the natural habitat. A low positive correlation of $r = 0.27$ was recorded between mean brood size and body length, indicating that small body size naturally restricts the egg laying capacity of the females. The absence of size groups III and IV in the field samples was explained. The population parameters such as finite birth rate ($B$), instantaneous birth rate ($b$), population change ($r$) and death rate ($d$) were estimated from field data for this cladoceran.

**Keywords.** *Ceriodaphnia cornuta*; population density; composition; fecundity; size distribution; birth and death rates.

## 1. Introduction

This paper is one of a series describing behavioural aspects of zooplankton population in a eutrophic pond in Madurai. The population dynamics of *Ceriodaphnia cornuta* Sars are described and related to the environmental factors wherever possible. Cladocerans, particularly *Daphnia*, are ideal microcrustaceans for studying population characteristics in natural habitat since both eggs and adults can be collected quantitatively and relatively high biological responses in terms of fecundity to changing environmental conditions in a limited duration of time. There has been a paucity of information on the ecobiological studies of *C. cornuta* from Indian peninsular waters, the exception being the contribution of Michael (1962). Hence, an attempt has been made to investigate its population density and composition, fecundity and age structure in natural habitat.

## 2. Description of the pond

The investigation was carried out in a natural shallow pond located inside the campus of Madura College, Madurai (long. 78°8′E; lat. 9°56′N). The pond has an average depth of about 2 meters in the mid region. The depth decreases gradually towards the margin. The surface area covered by water is about 600 sq. meters. The trees belonging to the genera *Pongamia*, *Azadirachta* and *Morinda* give much stability to the margin of the pond and the decomposed leaves in the form of organic matter allow enormous growth of zooplankton. The absence of rooted vegetation is noteworthy. Microflora of the class *Cyanophyceae*, *Chlorophyceae*, *Bacillariophyceae* and *Euglenophyceae* are recorded during the period of investigation. The free floating macrophytes of the family Lemnaeceae appear during certain periods. *Microcystis*, *Coelospherium*, *Clastidium*, *Nostoc*, *Capsosira* among *Cyanophyceae*; *Pandorina*, *Volvox*, *Polyedriopsis*, *Sphaerocystis*, *Ankistrodesmus*, *Eudorina*, *Scenedesmus*, *Desmids*, *Actinastrum* among *Chlorophyceae*; *Synedra*, *Cocconeis*, *Navicula*, *Tabellaria*, *Pinnularia*, *Cymbella* among *Bacillariophyceae*; *Euglena*, *Phacus* and *Trachelomonas* among *Euglenophyceae* are recorded genera of microflora.

## 3. Materials and methods

Samples were collected at weekly intervals between August 26, 1976 to July 15, 1977 from different regions of the pond. In total, 33 samples were collected covering a period of 12 months. To avoid errors caused by vertical migration of zooplankton if any, all samples were collected near mid day between 11·00 and 13·00 h. A 20 litre capacity collecting bucket was used for sampling. The samples were concentrated by filtration through a bolting silk sieve of 120 $\mu$m mesh size. The zooplankton collected on a day was mixed and the concentrates were preserved in 4% formalin. In order to evaluate cladoceran population dynamics such as densities and composition, fecundity and size distribution were recorded as followed by Murugan (1989) for *Moina micrura* population. In addition, the length (the distance from the apex of the head to the base of spine) of parthenogenetic females with eggs was measured in each sample. The data obtained from the samples were analysed for birth rate, rate of population changes and death rate following Hall (1964) and George and Edwards (1974).

Physical and chemical parameters measured each week included pH, dissolved oxygen (Winkler technique), water transparency (Secchi disc) and temperature. Maximum and minimum temperatures were recorded by a thermister at 1 m deep.

## 4. Results

Seasonal variation in maximum and minimum temperatures of water and atmosphere and water transparency are represented in figure 1. The pH fluctuation was between 7·2 and 9·5. The day time oxygen concentration fluctuated around an average of 5 ppm.

Seasonal mean density values of *C. cornuta* with allied populations of Cladocera are shown in figure 2. Figure 3 illustrates seasonal variation in the mean length of mature females and mean egg number. Figure 4 shows the relationship between the body length versus egg number. Figure 5 is a graphical representation of different size classes of *C. cornuta*. Figure 6 represents instantaneous birth rate ($b$) and rate of population change ($r$) of *C. cornuta*.

Table 1 shows seasonal variation in the percentage composition of the population of *C. cornuta*. Field observation of the highest and the lowest egg numbers and lengths of adult females of tropical and temperate Cladocera are shown in table 2. Table 3 shows the laboratory observation of the highest and the lowest egg numbers and lengths of adult females of tropical Cladocera. Table 4 shows seasonal variation in the population data for *C. cornuta*.

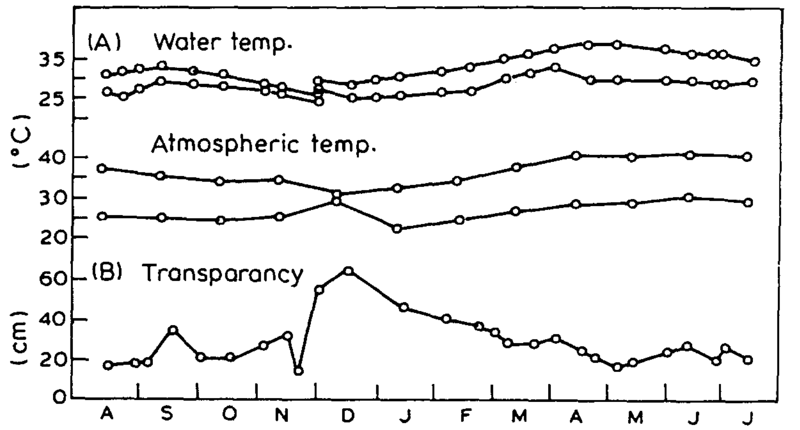


**Figure 1.** Seasonal variation in maximum and minimum temperatures of water and atmosphere and water transparency.

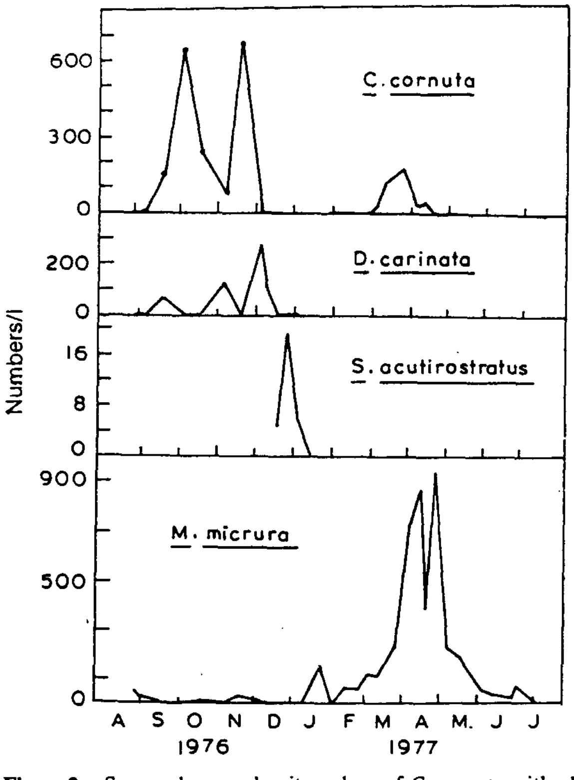


**Figure 2.** Seasonal mean density values of *C. cornuta* with allied Cladocera.

## 5. Discussion

### 5.1 *Biology*

The life span of *C. cornuta* is typical of many species of Cladocera. Under favourable environmental conditions reproduction occurs mostly by partheno-

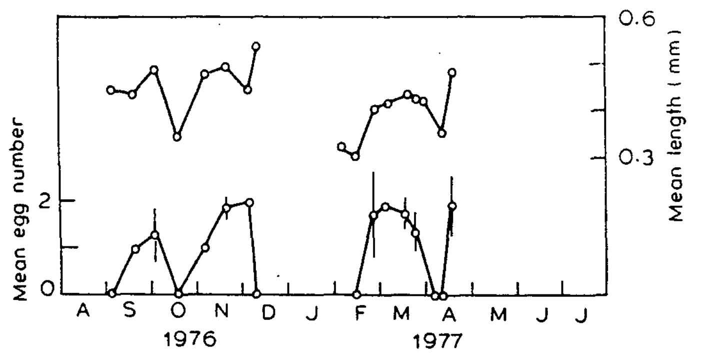


**Figure 3.** Seasonal variation in the mean length of mature females vs mean egg number.

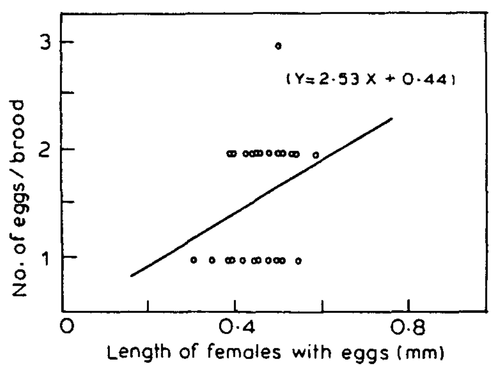


**Figure 4.** Correlation coefficient between body length and egg number.

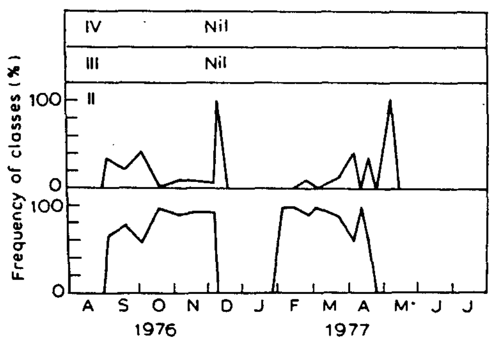


**Figure 5.** Seasonal variation of different size classes of *C. cornuta*.

genesis. Early experiments under laboratory conditions revealed that in a total life span of 21 days, this species produced 123·6 eggs in 18 clutches (Murugan 1975b). Michael (1962) observed that in a life span of 12 days, the same species released 42 eggs into the brood in 9 batches. The juveniles moult twice to reach the primiparous instar.

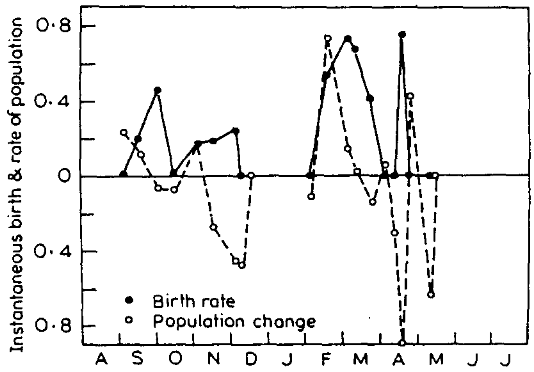


**Figure 6.** Instantaneous birth rate ($b$) and rate of population change ($r$) of *C. cornuta*.

**Table 1.** Seasonal variation in the percentage composition of the population of *C. cornuta*.

| Date | Immature females (%) | Females of mature size without eggs (%) | Females with parthenogenetic eggs (%) | Ephippial females (%) | Males (%) | No. of individuals counted |
|---|---|---|---|---|---|---|
| 1976 | | | | | | |
| 26, 29 Aug. | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 Sept. | 67 | 33 | 0 | 0 | 0 | 30 |
| 19 Sept. | 78 | 20 | 2 | 0 | 0 | 50 |
| 3 Oct. | 56 | 4 | 34 | 6 | 0 | 50 |
| 18 Oct. | 98 | 2 | 0 | 0 | 0 | 50 |
| 6 Nov. | 80 | 4 | 16 | 0 | 0 | 50 |
| 19 Nov. | 88·75 | 0 | 8·75 | 2·5 | 0 | 80 |
| 5 Dec. | 88·66 | 6·66 | 6·66 | 0 | 0 | 15 |
| 9 Dec. | 0 | 100 | 0 | 0 | 0 | 1 |
| 18, 25 Dec. | 0 | 0 | 0 | 0 | 0 | 0 |
| 1977 | | | | | | |
| 3, 12, 17, 25 Jan. | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 Feb. | 100 | 0 | 0 | 0 | 0 | 25 |
| 25 Feb. | 60 | 40 | 0 | 0 | 0 | 10 |
| 3 Mar. | 45 | 0 | 55 | 0 | 0 | 20 |
| 10 Mar. | 48 | 1·3 | 50·6 | 0 | 0 | 75 |
| 23 Mar. | 64 | 2 | 34 | 0 | 0 | 61 |
| 4 Apr. | 60 | 40 | 0 | 0 | 0 | 5 |
| 11 Apr. | 100 | 0 | 0 | 0 | 0 | 7 |
| 17 Apr. | 44 | 4 | 52 | 0 | 0 | 25 |
| 24 Apr. | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 May | 0 | 0 | 100 | 0 | 0 | 1 |
| 14 May | 0 | 0 | 0 | 0 | 0 | 0 |
| 3, 12, 29 June | 0 | 0 | 0 | 0 | 0 | 0 |
| 3, 15 July | 0 | 0 | 0 | 0 | 0 | 0 |

## 5.2 *Population density*

The population of *C. cornuta* had two adjacent peaks in density: the first at the beginning of October (625 individuals/l) and the second at the end of November

Table 2. Field observations of the highest and the lowest clutch sizes of tropical and temperate Cladocera.

| Species | Date and year | Mean maximum minimum clutch sizes | Mean length (mm) | Source |
|---|---|---|---|---|
| Tropical | | | | |
| *S. acutirostratus* | 26 Dec. 1976 | 28·9 ± 12·46 | 2·52 | Murugan (1980) |
| | 3 Jan. 1977 | 6·6 ± 2·07 | 2·01 | |
| *D. carinata* | 26 Aug. 1976 | 6·7 ± 2·25 | 2·15 | Murugan (1980) |
| | 6 Nov. 1976 | 1·0 | 1·72 | |
| *C. cornuta* | 5 Nov. 1976 | 2·0 | 0·44 | Present study |
| | 9 Sept. 1976 | 1·0 | 0·43 | |
| *M. micrura* | 12 Jan. 1977 | 4·4 ± 1·98 | 0·66 | Murugan (1989) |
| | 26 Aug. 1976 | 1·0 | 0·77 | |
| Temperate | | | | |
| *C. quadrangula* | 1960 | 2·2 | — | Smyly (1974) |
| | 1965 | 3·0 | — | |
| | 1966 | 2·7 | — | |
| | 1967 | 2·0 | — | |
| | 1968 | 2·4 | — | |
| | 1969 | 2·3 | — | |

Table 3. Laboratory observations of the highest and the lowest clutch sizes of tropical Cladocera.

| Species | Temperature (°C) | Mean maximum minimum clutch size | Mean length (mm) | Source |
|---|---|---|---|---|
| *S. acutirostratus* | 28–30 | 27·0 | 3·1 | Murugan and Sivaramakrishnan (1973) |
| | | 8·0 | 2·01 | |
| *S. kingi* | 28–30 | 20·5 | 0·79 | Murugan and Sivaramakrishnan (1976) |
| | | 4·0 | 0·92 | |
| *C. cornuta* | 28–30 | 6·0 | 0·62 | Michael (1962) |
| | | 3·0 | 0·43 | |
| *C. cornuta* | 28–30 | 9·3 | 0·70 | Murugan (1975b) |
| | | 2·4 | 0·92 | |
| *D. carinata* | 28–30 | 16–18 | 2·0–2·2 | Sumitra Vijayaraghavan (1970) |
| *M. micrura* | 28–30 | 7·7 | 0·79 | Murugan (1975a) |
| | | 3·0 | 1·00 | |

(650 individuals/l). The absence of this species from the middle of December to January seems to correlate with higher transparency, low temperature and scarcity of food. Low population amounting to about 175 individuals/l was recorded in March.

Two possible reasons for population peaks are attributed: the internal phenomenon of clutch size (figure 3) and the external phenomenon of food supply which was estimated by water transparency (figure 1B). The clutch size which is important in determining the total number of eggs in a population reached a

**Table 4.** Population data for *C. cornuta*.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Date | $N_o$ | $N_A$ | $\bar{E}$ | $1/D$ | $B$ | $b$ | $r$ | $d$ |
| Sept. 5 | 300 | 99 | 0·00 | 1 day | 0·00 | 0·00 | 0·23 | −0·23 |
| 19 | 7250 | 1595 | 1·00 | 1 day | 0·22 | 0·20 | 0·11 | 0·09 |
| Oct. 3 | 31825 | 14003 | 1·34 | 1 day | 0·58 | 0·46 | −0·06 | 0·52 |
| 18 | 12150 | 243 | 0·00 | 1 day | 0·02 | 0·02 | −0·07 | 0·09 |
| Nov. 6 | 3750 | 750 | 1·00 | 1 day | 0·20 | 0·18 | 0·17 | 0·01 |
| 19 | 33225 | 3737 | 1·90 | 1 day | 0·21 | 0·19 | −0·27 | 0·46 |
| Dec. 5 | 450 | 59 | 2·00 | 1 day | 0·26 | 0·24 | −0·45 | 0·69 |
| 9 | 75 | 75 | 0·00 | 1 day | 0·00 | 0·00 | −0·47 | 0·47 |
| 19 | 0 | 0 | 0·00 | — | 0·00 | 0·00 | 0·00 | 0·00 |
| Feb. 4 | 280 | 0 | 0·00 | 1 day | 0·00 | 0·00 | −0·11 | 0·11 |
| 24 | 30 | 12 | 1·75 | 1 day | 0·70 | 0·53 | 0·73 | −0·20 |
| Mar. 3 | 2350 | 1292 | 1·95 | 1 day | 1·07 | 0·73 | 0·14 | 0·59 |
| 10 | 6075 | 3152 | 1·84 | 1 day | 0·95 | 0·67 | 0·03 | 0·64 |
| 23 | 8475 | 3051 | 1·42 | 1 day | 0·51 | 0·41 | −0·14 | 0·55 |
| April 4 | 1500 | 600 | 0·00 | 1 day | 0·00 | 0·00 | 0·06 | −0·06 |
| 11 | 2250 | 0 | 0·00 | 1 day | 0·00 | 0·00 | −0·30 | 0·30 |
| 17 | 500 | 280 | 1·96 | 1 day | 1·09 | 0·74 | −0·89 | 1·63 |
| 24 | 0 | 0 | 0·00 | — | 0·00 | 0·00 | 0·42 | −0·42 |
| May 6 | 150 | 150 | 0·00 | 1 day | 0·00 | 0·00 | −0·63 | 0·63 |
| 14 | 0 | 0 | 0·00 | 1 day | 0·00 | 0·00 | 0·00 | 0·00 |

1. Total population size/50 litres.
2. Total adults (adults/50 litres).
3. Mean number of eggs/brood.
4. Rate of growth or development of eggs in a day which is reciprocal of duration of egg development.
5. Finite birth rate.
6. Instantaneous birth rate.
7. Observed instantaneous rate of population change.
8. Estimated instantaneous death rate.

maximum of two when the population was expanding and zero when the population was diminishing. In March inspite of its maximum clutch size the population of *C. cornuta* was not largely expanded. It may be explained by the fact that the population density of allied species of Cladocera (*M. micrura*) are high during this period.

The relationships of clutch size with water transparency and temperature were attempted to find out the influence of ecological factors on population. A comparison of figures 1B and 2 shows that the former relationship is understandable when the absence of eggs or depletion of *C. cornuta* at the time of higher transparency. Ingle *et al* (1937), Green (1956, 1966) and Hall (1964) agreed with the concept of clutch size and transparency relationship. de Bernardi (1974) and de Barnardi and Canali (1975) reported that populations of *Daphnia hyalina* show inverse relation with transparency both in Cannero and Ispra sampling stations of Lago Maggiore.

The relationship of clutch size to temperature by some authors (Tauson 1930; Green 1956; Hall 1964) was corroborated in this study. It is generally observed from figure 1A that fluctuations of maximum and minimum temperatures were between

24 and 35°C and 20 and 29°C respectively. Being a shallow body of water the temperature fluctuations are closely parallel to those of atmospheric temperatures. A comparison of figures 1A and 3 reveals the maximum clutch size at higher temperatures. It becomes obvious that temperature influences food production which in turn is responsible for larger broods. It has been reported that temperature effects on the development of population are less pronounced in deep lakes than in shallow lakes and ponds where hypolimnetic temperatures undergo considerable seasonal variations. Temperature increases with the progression of warm season are considerable and affect the entire mass, with much more pronounced and direct effect on growth rate. Therefore, temperature can affect a population in an indirect manner thus influencing the food availability which are always considerable (de Bernardi 1974).

### 5.3 *Population composition*

The percentage composition of population of *C. cornuta* was studied to determine the period of occurrence of bisexual reproduction and the extent to which females changed from parthenogenesis to producing resting eggs (Green 1966). Table 1 shows only one period of bisexual reproduction in the months of October and November. The percentage of ephippial females rose to 6 of the total population. The occurrence of ephippial females shows the instability of the population structure of *C. cornuta* in this ecosystem which is overall controlled by various causative factors such as food, temperature, crowding etc. This finding concurs with the observations of Murugan (1989) for *M. micrura* population. No males were recorded in the population of *C. cornuta*. Further, the absence of distinct sexual dimorphism in this species made the task of identifying males difficult. From this overall account it may be assumed that the low summer population of *C. cornuta* probably emerged from resting eggs in response to stimulus provided by the rise in temperature in the month of February. No females with resting eggs were found although each sample was searched carefully.

### 5.4 *Seasonal variation in egg production and body length*

The changes in the clutch size and the mean lengths of females followed the same pattern (figure 3) as in *M. micrura*. It has been reported that conditions which favour growth also favour egg production and the adult size and clutch size tend to fluctuate synchronously (Green 1966; Murugan 1989).

The mature females of this species formed a low percentage of 27·74 of the total population. The mean annual clutch size ranged from 1 to 2 eggs. The animals with clutch sizes of two eggs were found more frequently than the other and they formed 65% of the total population. Those with clutch sizes below 2 formed 33%. The animals with 3 eggs were far fewer in number than the others and amounted to about 1·78%.

The mean annual clutch size of related genus of a temperate form *C. quadrangula* (Smyly 1974) varied from 2 to 3 eggs which in this respect is more or less similar to that of *C. cornuta* (table 2). It has been reported that the most frequent occurrence of the clutch size in *C. quadrangula* was two eggs. A grand mean egg number of the similar genera (*C. pulchella*, *C. reticulata*, *C. megalops* and *C. laticaudata*) from temperate region was 3·83, 5·20, 3·85 and 2·76 respectively (Burgis 1967). Table 3 depicts the highest and the lowest clutch sizes of tropical Cladocera reared under laboratory conditions. The highest clutch was noticed in *Simocephalus acutirostratus* (Murugan and Sivaramakrishnan 1973) and the lowest in *C. cornuta* (Michael 1962). The largest individual clutch size of *C. cornuta* was 9·3 eggs (Murugan 1975b).

### 5.5 *Mean brood size vs body length*

In the natural habitat the length of the females carrying parthenogenetic eggs were varying from 0·3–0·6 mm (figure 4) in *C. cornuta.* The correlation coefficient worked out for the above relationship showed a low positive correlation of $r = 0{\cdot}27$ and the regression equation is $Y = 2{\cdot}53\,X + 0{\cdot}44$. It becomes evident that the egg number increases with the body length less rapidly since the body size of the female carrying eggs are in a narrow range. The statement that small body size naturally restricts egg laying capacity of the female concurs with the earlier observation in *M. micrura* by Murugan (1989). Several workers (Anderson *et al* 1937; Anderson and Jenkins 1942; Green 1954, 1956; Richman 1958; Burgis 1967; Buikema 1973) have observed correlation between the size of the organisms and the number of eggs produced by them. Lei and Clifford (1974) also found a significant positive correlation in the laboratory cultures of *D. schodleri.*

### 5.6 *Size distribution*

The knowledge of the distribution size of *C. cornuta* is essential for analysing the changes in the population. Different classes were recognised after studying the ontogenic development of *C. cornuta* under laboratory conditions (Murugan 1975b). The following size groups have been used.

Class I < 0·47 mm.
Class II 0·47–0·70 mm.
Class III 0·70–0·75 mm.
Class IV > 0·75 mm.

The lower limit of class II was found to correspond to the carapace length of the primiparous instar. The lower limit of the class III corresponds to the carapace length at which maximum number of eggs were noticed in the brood under laboratory observations. Changes in the frequency of each class are shown in figure 5.

First two size groups are only represented in the population as evidenced in which length of females carrying eggs ranged between 0·3 and 0·6 mm. It may be assumed that the first generation which appeared in September took about nearly 4 months to reach maturity (class II). The peaks of population coincide with maximum proportion of premature individuals rather than mature forms as in *M. micrura* (Murugan 1989). This observation concurs with the findings of George and Edwards (1974) in *D. hyalina.* The development of second cycle can also be traced by successive two-size classes. However, the other two classes (III and IV) were absent in the field throughout the period of study and were recognised only by rearing in the laboratory. A logical explanation that could be made is that the growth of this species is somehow impaired probably due to the presence of

*D. carinata* which is a more efficient filter feeder in the same niche. Parker (1958) stated with reference to fish population that number of individuals may continue to increase in the presence of limited food supply but each individual becomes stunted in size. This has indeed been true with *Daphnia.*

### 5.7 *Birth rate, rate of population change and death rate*

The observed instantaneous rates of population change ($r$) calculated from successive pairs of population density values, the instantaneous birth rates ($b$) calculated from the time of development of eggs inside the brood, are given in table 4. The estimated instantaneous death rates ($d$) which are obtained by substracting the interpolated values of $r$ from $b$ for each sample, include natural mortality.

The maximum positive $r$ value was 0·73 and the minimum value of 0·03 was recorded during the period of investigation. The mean positive $b$ value was 0·02 and the maximum value of 0·74 was recorded at the middle of April. A maximum value of 1·63 was estimated as instantaneous death rate. Recalling the density changes (figure 2) it becomes evident that the period of higher birth rates in the months of September and November correspond to the maximum density of *C. cornuta.* The birth rates are entirely realised for population increase. However in February and March large increase in birth rate did not cause an increase in population. Instead, '$r$' diminished very rapidly and death rate ($d$) also increased. This unrealistic potential population can be understood by comparing the values of $b$ and $r$ in figure 6. It is generally observed that *C. cornuta* has higher birth rate during high temperature in which respect this resembles *D. schodleri* (Wright 1965). The average values of birth rate, rate of population change and death rate for *C. cornuta* were 0·22, 0·092 and 0·34 during 1976–1977. It would be still premature to give a definite interpretation of these results which should be the main object of more detailed experimental research in this tropical peninsular India.

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## References

Anderson B G, Lumer H and Zupancic L C Jr 1937 Growth and variability in *Daphnia pulex*; *Biol. Bull.* **73** 444–463

Anderson B G and Jenkins J C 1942 A time study of events in the life span of *Daphnia magna*; *Biol. Bull.* **83** 260–272

Buikema A J 1973 Some effects of light on the growth, moulting, reproduction and survival of the Cladoceran, *Daphnia pulex*; *Hydrobiologia* **41** 391–418

Burgis J M 1967 A quantitative study of reproduction in some species of *Ceriodaphnia* (Crustacea: Cladocera); *J. Anim. Ecol.* **36** 61–75

de Bernardi R 1974 The dynamics of a population of *Daphnia hyalina* Leydig in Lago Maggiore, Northern Italy; *Mem. Ist. Ital. Idrobiol. Dott Marco de Marchi Pallanza Italy* **31** 221–243

de Barnardi R and Canali S 1975 Population dynamics of pelagic Cladocerans in Lago Maggiore; *Mem. Ist. Ital. Idorbiol. Dott Marco de Marchi Pallanza Italy* **32** 365–392

George D G and Edwards R W 1974 Population dynamics and production of *Daphnia hyalina* in a eutropic reservoir; *Freshwater Biol.* **4** 445–465

Green J 1954 Size and reproduction in *Daphnia magna* (Crustacea: Cladocera); *Proc. Zool. Soc. London* **124** 535–545

Green J 1956 Growth, size and reproduction in *Daphnia* (Crustacea: Cladocera); *Proc. Zool. Soc. London* **126** 173–204

Green J 1966 Seasonal variation in egg production by Cladocera; *J. Anim. Ecol.* **35** 77–104

Hall D J 1964 An experimental approach to the dynamics of a natural population of *Daphnia galeata* mendotae; *Ecology* **45** 94–112

Ingle L, Wood T R and Banta A M 1937 A study of the longevity, growth, reproduction and heart rate in *Daphnia longispina* as influenced by limitations in quantity of food; *J. Exp. Zool.* **76** 325–352

Lei C H and Clifford F 1974 *Field and laboratory studies of Daphnia schodleri Sars from a Winterkill lake of Alberta* (National Museums of Canada, Ottawa, Publications in Zoology No. 9)

Michael R G 1962 Seasonal events in a natural population of the Cladoceran *Ceriodaphnia cornuta* Sars and observations on its life cycle; *J. Zool. Soc. India* **14** 211–218

Murugan N 1975a Egg production, development and growth in *Moina micrura* Kurz (1874) (Cladocera: Moinidae); *Freshwater Biol.* **5** 243–250

Murugan N 1975b The biology of *Ceriodaphnia cornuta* Sars (Cladocera: Daphnidae); *J. Inland Fish. Soc. India* **7** 80–87

Murugan N 1980 *Observations on the natural history of Cladocera of a small tropical pond*, Ph.D. Thesis, Madurai Kamaraj University, Madurai

Murugan N 1989 Population dynamics of *Moina micrura* Kurz (Cladocera: Moinidae) inhabiting a eutrophic pond of Madurai (south India); *Proc. Indian Acad. Sci.* (*Anim. Sci.*) **98** 211–222

Murugan N and Sivaramakrishnan K G 1973 The biology of *Simocephalus acutirostratus* King (Cladocera: Daphnidae) Laboratory studies of life span, instar duration, egg production, growth and stages in embryonic development; *Freshwater Biol.* **3** 77–83

Murugan N and Sivaramakrishnan K G 1976 Longevity, instar duration, growth, reproduction and embryonic development in *Scapholeberis kingi* Sars (1903) (Cladocera: Daphnidae); *Hydrobiologia* **50** 75–80

Parker R A 1958 Some effects of thinning of population of fishes; *Ecology* **39** 304–317

Richman S 1958 The transformation of energy of *Daphnia pulex*; *Ecol. Monogr.* **28** 273–291

Smyly W J P 1974 Vertical distribution and abundance of *Ceriodaphnia quadrangula* (O F Muller) (Crustacea: Cladocera); *Freshwater Biol.* **4** 257–266

Sumitra Vijayaraghavan 1970 Seasonal events in a natural population of *Daphnia carinata* King; *Proc. Indian Acad. Sci.* **B71** 193–203

Tauson A 1930 Die Wirkung der ausseren Bedingungen auf die Veranderung des. Geschlechts und auf die Entwicklung von *Daphnia pulex* de Geer Roux; *Arch. Entwicklungsmech. Org.* **123** 80–131

Wright J C 1965 The population dynamics and production of *Daphnia* in Canyon Ferry Reservoir, Montana; *Limnol. Oceanogr.* **10** 583–590