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Effect of temperature on growth and fecundity of selected species of Cladocera

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Abstract

This paper highlights the biological aspects of a few sub-tropical cladocerans, *Daphnia similis, Moina macrocopa, Simocephalus vetulus* and *Ceriodaphnia cornuta* in relation to varying environmental temperatures. At all low temperatures, egg production is uniformly low in *D. similis, M. macrocopa* and *C. cornuta,* whereas higher temperatures favour increased production of eggs in *M. macrocopa, D. similis* and *C. cornuta.* In *S. vetulus,* on the other hand, environmental temperature resulted in a lowered fecund condition. Of the various species studied, the rate of egg production was the highest in *M. macrocopa* followed in decreasing order by *D. similis* and *C. cornuta.*

1. Introduction

Sushchenya[1] maintains that the efficiency of matter and energy transformation between the autotrophic and the first heterotrophic level in the aquatic food web depends largely on the productivity of zooplankton. Laboratory observations on the life cycle of selected cladocera, the dominant component in zooplankton, help in better understanding of the dynamics of zooplankton and is the mainstay of the present investigation.

Because of their high capability at all stages in their life history and nutritive importance for fry and fingerlings, four cladoceran species (*D. similis, S. vetulus, M. macrocopa* and *C. cornuta*) were intensively studied.

2. Materials and methods

Twenty newly hatched young ones of each species were segregated from the laboratory-reared stock. Each young cladocera was reared separately in a petri dish containing the culture medium comprising 40 ml of aqueous solution of 1g/l of poultry droppings. The medium was changed once every 24 h and replaced by freshly prepared filtered medium. The length increment, number of moults and number of young ones released at each instar were recorded daily. These studies were carried out at different temperatures in the laboratory simulating the prevailing field conditions.

3. Results and discussion

The neonate after release from the brood pouch of the mother passed through a varying number of pre-adult and adult instars which responded to the surrounding temperatures.

3.1 *Number of pre-adult instars*

The results of the present investigations indicate that the number of pre-adult instars at intermediate temperature regimen (18–27°C) varied between 2 and 7 species. The number of such instars was 6–7 in *D. similis,* 4 in *S. vetulus* and 2–4 in *M. macrocopa* and *C. cornuta* (Table I). Results of rearing at varying temperatures revealed an inverse relationship between temperature and the number of pre-adult instars. Thus, while a minimum number of such instars were observed at higher temperature of 30–32°C (4 in *D. similis,* 3 in *S. vetulus,* 1–2 in *M. macrocopa* and *C. cornuta*), a significant increase in the number of pre-adult instars, on the other hand, was recorded in those reared at lower temperatures. Similar results have been documented for other cladocerans that were reared at temperatures ranging from 28 to 31°C (4 pre-adult instars in *S. acutirostratus,* 5 in *D. carinata,* 2 in *M. micrura* and 2 in *C. cornuta*)[2]. That the number of pre-adult instars has an interesting relationship with changing temperature could possibly be a major contributory factor to the ubiquity in distribution of these important crustacean zooplankton elements, as has been pointed by Pennak[3] also.

3.2 *Number of adult instars*

Maximum number of adult instars in the cladocerans studied here (Tables I) occured at the intermediate (18–27°C) temperature range (15–16 in *D. similis,* 8–11 in *S. vetulus* and 12–14 in *M. macrocopa*). In *C. cornuta,* a comparatively lower number (8–11) of such instars was recorded at corresponding temperature range (Table I). However, at the lowest temperature range of 10–12°C, the number of adult instars was significantly low (7 in *D. similis* and 3 in *M. macrocopa* and *C. cornuta*). In *S. vetulus,* on the contrary, the number of such instars was interestingly quite high at low temperature rearing[10].

An intermediate number of 9 adult instars was recorded at the higher temperature ranges in both *D. similis* and *M. macrocopa,* against 13, the highest observed in *C. cornuta* and 6, the lowest recorded in *S. vetulus.* In allied species investigated at comparable temperature range of 28 to 30°C, the number of adult instars reported[2] is fairly comparable (8 in *D. carinata,* 11 in *M. micrura,* 8 in *S. vetulus* and 9 in *C. cornuta*). However, a difference has been observed in the number of adult instars of *C. cornuta,* against 9 instars reported by Navaneethakrishnan and Michael[4] from tropical conditions (13 instars were recorded in the present investigation). This difference may be attributed to differences in climatic strains investigated in the two studies.

Table 1

Life history parameters of *D. similis*, *S. vetulus*, *M. macrocopa* and *C. cornuta* at different temperature ranges

Temperature (°C)	*Months*	*Embryonic period (days)*	*No. of pre-adult instars*	*No. of adult instars*	*Av. length of primiparous instars (mm)*	*Maturity period (days)*	*Av. life span span (days)*	*Av. no. of youngs produced in whole life span*
D. similis								
10–12	Dec–Jan	4·3(0·33)	9(0·53)	7–8(1·04)	1·97(·012)	28(0·38)	59·4(0·85)	107(2·82)
18–20	Ending Aug Sept–Oct	10(0·42)	6(0·59)	16(0·59)	1·49(·136)	3·5(0·42)	67·7(0·74)	260(1·56)
25–27	April–May	3·2(0·28)	6–7(0·5)	15–16(0·5)	1·00(·01)	13(0·28)	56·4(0·82)	300(1·52)
30–32	June–July	1·3(0·33)	4(0·68)	9(0·48)	0·62(·007)	4(0·53)	14·3(0·84)	122(2·16)
S. vetulus								
10–12	Ending Nov Dec–Jan	5·6(0·42)	5(0·82)	10(0·58)	1·32(·10)	15(0·46)	69·8(0·68)	232(1·6)
18–20	Ending Aug Sept–Oct	5·6(0.33)	4(0·65)	11(0·72)	1·32(·13)	10·1(0·44)	62·8(0·92)	304(1·2)
25–27	April–May	2·62(0·34)	4(0·64)	8(0·62)	1·10(·09)	3·8(0·31)	24·8(0·63)	86(1·18)
30–32	June–July	2·06(0·46)	3(0·76)	6(0·59)	0·93(·10)	3·6(0·48)	13·9(0·44)	48(1·0)
M. macrocopa								
10–12	Dec–Jan	8·2(0·53)	5(0·5)	3–4(0·18)	0·97(0·09)	12·8(0·68)	37·3(1·1)	46(2·69)
18–20	Sept–Oct	4·4(0·72)	4(0·04)	12(0·22)	1·01(0·005)	18·3(0·72)	57·6(0·90)	300(1·62)
25–27	April–May	1·5(0·49)	2(0·1)	14(0·14)	0·83(·08)	2·5(0·59)	22·0(0·64)	225(2·01)
30–32	June–July	1(0·12)	1–2(0·49)	9(0·18)	0·91(·1)	2·0(0·69)	9·1(0·82)	111(1·82)
C. cornuta								
10–12	Dec–Jan	5·1(0·54)	4(0·14)	3(0·08)	0·49(0·46)	14·4(0·12)	29·8(0·72)	4(1·48)
18–20	Sept–Oct	3·5(0·62)	4(0·33)	8(0·62)	0·46(0·32)	8·9(0·36)	28·9(0·66)	23(2·32)
25–27	April–May	1·6(0·68)	2(0·52)	11(0·53)	0·40(0·02)	3·1(0·22)	23·2(0·54)	35(1·68)
30–32	June–July	1·1(0·71)	1–2(0·24)	13(0·52)	0·38(0·12)	2·0(0·18)	16·4(0·48)	47(1·34)

Standard deviation (±) in parentheses.

Table II

Mean pre-adult and adult instar durations of various Cladoceran species in relation to temperature variation

Instar number	*Mean instar duration (Days)*															
	Daphnia				*Simocephalus*				*Moina*				*Ceriodaphnia*			
	A	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Pre-adult																
1	3·8	2·0	1·9	0·9	2·0	1·9	1·0	1·0	2·0	2·0	1·0	0·8	3·1	1·9	1·1	2·0
2	1·0	2·0	0·9	0·8	3·0	2·9	1·0	0·8	2·0	2·2	1·0	0·9	4·2	3·0	2·0	
3	1·2	1·0	1·1	1·0	3·0	2·2	1·0	1·8	2·0	2·0			3·7	2·0		
4	2·1	1·0	2·9	0·9	4·0	3·1	0·8		2·8	2·1			3·4	2·0		
5	2·9	2·1	1·8		3·0				4·0							
6	3·9	2·0	1·3													
7	4·0															
8	4·9															
9	5·1															
10																
Adult																
1	5·9	2·1	2·9	1·0	5·3	3·8	2·8	2·0	8·0	4·5	2·0	1·0	4·5	2·0	1·2	1·1
2	5·0	3·0	2·0	1·2	5·9	6·0	2·5	1·9	8·0	4·0	2·2	1·0	5·0	6·0	1·9	0·9
3	5·0	3·8	1·9	1·1	4·8	5·1	2·0	2·0	8·5	3·9	1·0	0·9	5·9	5·0	2·0	1·2
4	5·4	3·8	4·0	0·9	5·9	5·2	3·1	2·1		4·2	2·0	1·0		3·0	2·5	0·9
5	3·1	3·8	2·8	1·9	5·1	4·9	2·9	2·3		4·0	1·9	0·9		4·0	1·8	0·8
6	2·2	6·5	1·5	1·9	5·0	5·8	2·2	2·1		4·2	1·0	0·8		3·5	2·0	2·0
7	3·9	3·9	1·9	0·9	6·0	5·0	2·5			4·9	1·0	0·9			1·5	1·9
8		3·8	3·8	0·8	5·1	5·2	3·0			4·9	1·0	0·9			1·9	0·9
9		3·1	4·0	1·0	5·7	5·8				4·9	1·0	1·0			2·0	1·0
10		3·2	3·9		6·0	5·9				4·8	1·0				1·3	0·9
11		3·0	3·1			6·0				4·5	1·9				2·0	0·8
12		4·0	2·0								1·5					1·1
13		3·4	4·1								1·5					0·9
14		3·0	3·1								1·0					
15		6·0	3·0													
16		3·0	3·5													

A: 10–12°C; B: 18–20°C; C: 25–27°C; D: 30–32°C.

Table III

Average length of various cladoceran species at different instar stages in relation to temperature variation

Instar number	*Mean length (mm)*															
	Daphnia				*Simocephalus*				*Moina*				*Ceriodaphnia*			
	A	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
1	0·59	0·61	0·58	0·57	0·53	0·56	0·53	0·51	0·48	0·48	0·49	0·48	0·28	0·30	0·26	0·24
2	0·74	0·64	0·78	0·71	0·69	0·76	0·62	0·60	0·58	0·58	0·68	0·63	0·31	0·35	0·33	0·38
3	0·92	0·74	0·91	0·88	0·90	0·97	0·84	0·81	0·62	0·66	0·83	0·91	0·34	0·40	0·40	0·43
4	1·07	1·01	1·06	1·09	1·10	1·14	0·97	0·93	0·78	0·81	1·01	1·05	0·38	0·45	0·42	0·45
5	1·18	1·16	1·25	1·28	1·23	1·32	1·10	1·04	0·87	1·01	1·08	1·11	0·49	0·46	0·45	0·47
6	1·31	1·37	1·32	1·56	1·32	1·55	1·40	1·21	0·97	1·07	1·15	1·29	0·52	0·50	0·48	0·49
7	1·56	1·49	1·40	1·72	1·59	1·70	1·49	1·43	1·14	1·14	1·23	1·32	0·54	0·54	0·50	0·50
8	1·85	1·66	1·51	1·90	1·66	1·85	1·75	1·70	1·23	1·20	1·31	1·40		0·56	0·51	0·51
9	1·97	1·98	1·57	2·01	1·84	1·94	1·99	1·83		1·27	1·38	1·44		0·58	0·51	0·52
10	2·07	2·05	1·62	2·07	1·90	2·12	2·14			1·32	1·42	1·45		0·58	0·52	0·52
11	2·31	2·16	1·68	2·12	2·10	2·20	2·27			1·36	1·51				0·53	0·53
12	2·45	2·32	1·74	2·22	2·20	2·39	2·33			1·37	1·60				0·54	0·53
13	2·49	2·33	1·75	2·23	2·39	2·41				1·42	1·63				0·54	0·53
14	2·49	2·35	1·77		2·41	2·42				1·43	1·65					
15	2·52	2·48	1·81		2·41					1·46	1·65					
16	2·62	2·52	1·89							1·50	1·67					
17		2·64	2·12													
18		2·73	2·37													
19		2·90	2·40													
20		2·92	2·49													
21		2·97	2·65													
22		2·98	2·74													
23		3·02														

A: 10–12°C; B: 18–20°C; C: 25–27°C; D: 30–32°C.

3.3 *Duration of instars*

As the juveniles grew, the duration of instars increased (Table II), a phenomenon which is not ordinarily influenced by temperature variations. Increase in instar duration with age, as presently observed, is in accord with previous records for *D. pulex, D. magna, D. longispina, S. acutirostratus* and *D. carinata* inhabiting temperate waters[5–7].

Moreover, the first primiparous instar in *D. similis, M. macrocopa* and *S. vetulus* lasted longer than their longest pre-adult instar (Table II), a finding true of *D. pulex*[5], *D. magna*[6], *D. carinata*[2] and *S. acutirostratus*[8], the cladocerans of both temperate and tropical regions. However, in *C. cornuta,* the pre-adult and primiparous instars were of equal duration. Similar results have been previously recorded in the case of *S. kingi*[2], *M. micrura*[9] and *C. cornuta*[4]. The relationships between size and number and duration of juvenile instars and generation time were discussed for 8 species of Cladocera by Bottrell[10].

3.4 *Mode of egg production*

When maintained at the intermediate temperature range of 18–20°C, *D. similis* exhibited a bimodal pattern of egg production—one at the 5th adult insar and the other at the 13th adult instar (Fig. 1) as has been reported for *S. acutirostratus* also[8]. At higher and lower temperature ranges on either side of the above regimen, only a single peak (unimodal) in egg production at 5th adult instar at all temperatures except at 10–12°C (Fig. 3) was observed in *M. macrocopa.* These observations are in line with those reported in several temperate daphnids, *viz., D. pulex*[5], *D. magna*[6] and *D. longispina*[7] where the peak in egg production has been reported to occur around the 5th adult instar, followed by a decrease in the rate of egg production. In contrast to these observations, a peculiar pattern of increasing number of eggs till the penultimate instar which has been observed in *S. vetulus* (Fig. 2) was previously recorded in *D. carinata*[4] and *D. lumholtzi.* Although *C. cornuta* did not exhibit any peak in egg production (Fig. 4) like the one reported in *S. kingi*[2], at higher temperatures (30–32°C), a bimodal pattern of egg production was, however, observed in the species.

3.5 *Egg fecundity*

The results of the present study revealed that during its average life span of 57 days, *D. similis* produced a maximum of 300 eggs at 25–27°C and a minimum of 107 eggs in about the same time at 10–12°C. At higher temperatures (30–32°C), a total of 122 eggs were produced in an average life span compressed to 14 days (Table I). A similar numerical variation in egg production under varying temperatures was seen in *M. macrocopa* (Table I) which produced around 300 eggs at 18–20°C and only 225 eggs at 25–27°C in an average life span of 22 days. Likewise, during its average life span of 63 days, *S. vetulus* produced about 304 eggs (Table II). *C. cornuta* in 16 days produced a maximum of 47 eggs at 30–32°C. Obviously, the daphnids were not

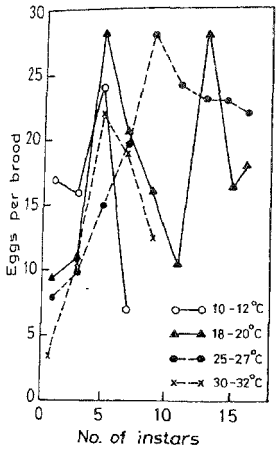

FIG 1.

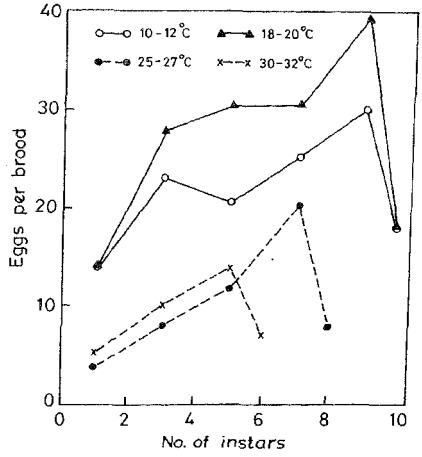

FIG 2.

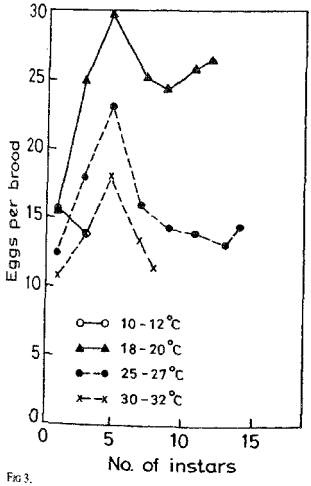

FIG 3.

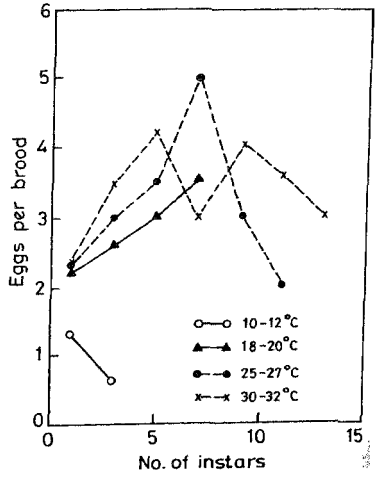

FIG 4

FIG. 1-4. Number of eggs per brood in relation to adult instar number in *D. similis* (Fig. 1), *S. vetulus* (Fig. 2), *M. macrocopa* (Fig. 3) and *C. cornuta* (Fig. 4).

as fecund at lower temperature ranges as at high and higher temperature regimen. Earlier reports on egg production of several cladocerans reveal that *D. carinata*[4] produces 142 eggs during a life span of 24 days, *D. pulex*[5] 293 eggs during an average life span extending almost twice that of *D. carinata, S. acutirostratus*[8] 248 eggs in an average life span of 44 days, *S. kingi*[2]—293 eggs in 20.5 days, *M. micrura*[11]—61 eggs in a life span extending 13 days and *C. cornuta*[12]—42 eggs in 12 days. Thus, *D. similis, M. macrocopa* and *S. vetulus* have high egg production values as compared to *D. carinata, D. pulex, S. acutirostratus* and *M. micrura* followed by *C. cornuta* in which lowest egg production is recorded.

Figures 5–8 show the cumulative frequency of egg production in various species at varying temperature regimen and the angle of slope of the regression line (*a* value) indicates the rate of egg production. The rate is uniformly low at low temperature in *M. macrocopa* (a=1·5439) and *C. cornuta* (a=1·1925) in contrast to that observed in *S. vetulus* (a=2·1532) and *D. similis* (a=1·7402) where low temperature regimens significantly favour egg production. The rate of egg production as revealed by the *a*

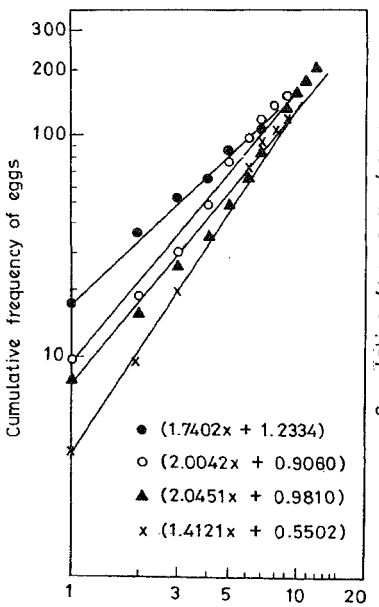

FIG 5.

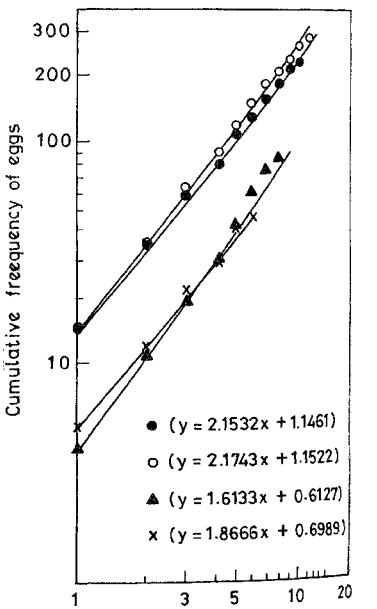

FIG 6

FIGS. 5–6. Cumulative egg production in relation to adult instar number in *D. similis* (Fig. 5) and *S. vetulus* (Fig. 6).

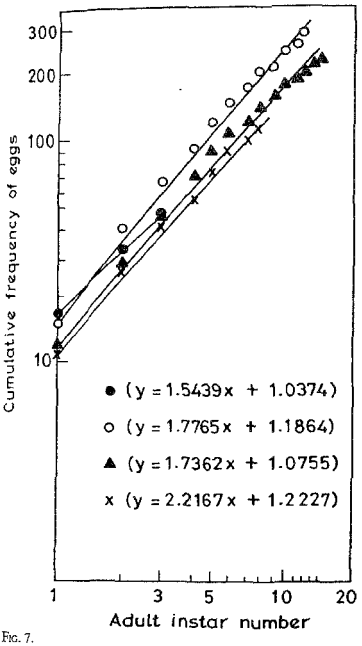

FIG. 7.

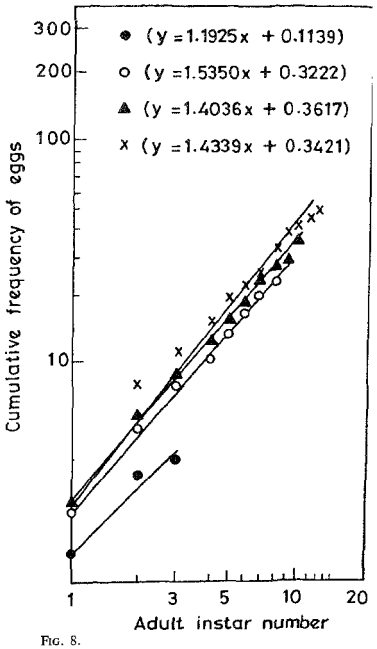

FIG. 8.

FIGS. 7–8. Cumulative egg production in relation to adult instar number in *M. macrocopa* (Fig 7) and *C. cornuta* (Fig. 8).

values bear no direct relationship to total egg production in different species. In fact, the total number of eggs produced in each species is related to their total life span.

3.6 *Effect of temperature on egg production*

The effect of temperature on egg production has been studied by several earlier workers. Berg[13] found stoppage of production of egg in *D. magna* when the temperature remained below 3–5°C for a long period, but noticed reactivation at 6–10°C. Tauson[14] studied *D. pulex* and found the temperature between 15 and 25°C to be favourable for egg production, but thre was a considerable decline above and below this range. Similar effects at higher temperatures have been reported by McArthur and Baillie[15]. Again a wide temperature range between 10 and 25°C has been reported to be optimum for egg production in *M. macrocopa* by Malhotra and Langer[16].

The present studies indicate that the number of eggs produced by *D. similis*, *M. macrocopa* and *C. cornuta* was very low at lower temperatures. At higher temperature range (30–32°C), the brood was 122, 111 and 48 in *D. similis*, *M. macrocopa* and *S. vetulus*, respectively. *C. cornuta*, exhibits variation with 47.

It may therefore be concluded that at all low temperatures the total number of eggs produced is uniformly low. High temperature favours egg production in *D. similis*, *M. macrocopa* and *C. cornuta*. However, an exceptional case is noticed in *S. vetulus*, where a rise in temperature retards egg production (Table I).

3.7 *Extent of growth during instars*

The progressive increase in the size of the individual at each instar is a measure of growth rate. Growth in cladocerans is accompanied by moulting, after which increase in size is rapid. The mean size at each instar against serial instar number for four cladocerans is presented in Table III. It indicates that the growth rate is rapid in the pre-adult phase but gradual during the reproductive phase, except in *D. similis* in which species maximum growth rate was observed between sixteenth–seventeenth and eighteenth adult instar at 25–27°C. Regarding the growth pattern the present study confirms the existing view that rapid pre-adult growth is a common feature for cladocerans irrespective of climatic differences[2,8] and greater growth in pre-adult instars compared to adult instars may be attributed to diversion of energy towards gonadal maturation in the latter. The extent of growth per instar is said to be positively correlated to the food supply[4,17]. The results on this aspect will be presented in a subsequent communication.

An analysis of growth rate revealed that in *D. similis*, maximum growth of 0·25 and 0·29 mm was recorded between Sixth–seventh and seventh–eighth instars at 10–12°C; between third–fourth and eighth–ninth instars (0·27 and 0·32 mm) at 15–20°C; between sixteenth–seventeenth and seventeenth–eighteenth instars (0·23 and 0·25 mm) at 25–27°C; between third–fourth and fifth–sixth instars (0·21, 0·19 and 0·28 mm) at 30–32°C. In *M. macrocopa*, maximum growth is between third-fourth and sixth–seventh instars (0·16 and 0·17 mm) at 10–12°C and between fourth–fifth instars (0·20 mm) at 15–20°C; between first–second and third–fourth instars (0·19, 0·15 and 0·18 mm) at 25–27°C, again between first–second and third–fourth and fifth–sixth instars (0·15, 0·28 and 0·18 mm) at 30–32°C. In *C. cornuta* and *S. vetulus* as well, growth rate was often higher during initial instars than in adult instars. These findings are in agreement with those of Murugan and Sivaramakrishnan[2,8], Navaneethakrishnan and Michael[4] and Murugan[11].

Growth in some cladocerans (*S. vetulus* and *S. cornuta*) ceased after a specific size was attained whereas in others (*D. similis* and *M. macrocopa*) it continued till the end. In all the cladoceran species, an increased growth with increase in temperature was recorded and is essentially a consequence of shortening of duration of instars. Cladocerans, when exposed to low temperature, registered a slow increase in size but usually reached a larger final size than those exposed to higher temperature.

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References

1. SUSHCHENYA, L. M. — *Marine food chains,* (J. H. Steel, ed.) Oliver and Boyd, Edinburgh, 1970, pp.127–141.
2. MURUGAN, N. AND SIVARAMAKRISHNAN, K. G. — *Hydrobiologia,* 1976, **50**, 75–80.
3. PENNAK, R. W. — In *Freshwater vertebrates of the United States,* The Ronald Press, New York, 1953, p. 769.
4. NAVANEETHAKRISHNAN, P. AND MICHAEL, R. G. — *Proc. Indian Acad. Sci.,* 1971, **73**, 117–123.
5. ANDERSON, B. G., LUMER, H. AND ZUPANIC, L. J. — *Biol. Bull.,* 1937, **73**, 433–463.
6. ANDERSON, B. G. AND JENKINS, J. C. — *Biol. Bull.,* 1942, **83**, 260–272.
7. INGLE, L., WOOD, T. R. AND BANTA, A. M. — *J. Expl Zool.,* 1937, **76**, 325–352.
8. MURUGAN, N. AND SIVARAMAKRISHNAN, K. G. — *Freshwat. Biol.,* 1973, **3**, 77–83.
9. MURUGAN, N. — *J. Inland Fish. Soc. India,* 1975, 7, 80–87.
10. BUTTRELL, H. — *Ocelogia,* 1975, **19**, 129–140.
11. MURUGAN, N. — *Freshwat. Biol.,* 1975, **5**, 245–250.
12. MICHAEL, R. G. — *J. Zool. Soc. India,* 1962, **14**, 211–218.
13. BERG, K. — *Viddenska Medd. Dansk. Naturalist Foren.,* 1931, **92**, 1–222.
14. TAUSON, A. — *Arch. Mech. Organ.,* 1930, **123**, 80–131.
15. MCARTHUR, J. W. AND BAILLIE, W. H. T. — *J. Expl Zool.,* 1929, **53**, 243–268.
16. MALHOTRA, Y. R. AND LANGER, S. — *Recent trends in limnology,* 1990, pp. 41–48.
17. HUTCHINSON, G. E. — *Introduction to lake biology and the limnoplankton,* 1967, p 1115, Wiley.