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Dark Induced Reproductive Inhibition of *Daphnia carinata* during the 1995 Solar Eclipse

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With 3 Tables

Key words: Solar eclipse, *Daphnia carinata*, reproductive inhibition, life history parameters

Abstract

Population of *Daphnia carinata* exposed to different times on the day showed sharp inhibition of reproduction (measured different life table data) on the day of solar eclipse as compared to pre- and post-eclipse days. Sudden fall of water temperature and abrupt change to darkness as prevailed during the solar eclipse were responsible for inhibition of reproduction in *Daphnia carinata*. Cold and dark induced reproductive inhibition was also confirmed in a simulated experiment mimicing eclipse reduction in light and temperature.

1. Introduction

The total solar eclipse, a natural phenomenon caused by an interplay of light and shade, is perhaps one of the most grandest spectacles of nature. The swiftness with which the darkness descends on a perfectly clear sky may have some influence on the photobiology of aquatic animals though sharp reduction of the intensity and duration of solar radiations resulting in false night conditions as well as sharp fall of water temperature within a short period of time. Thermal budget of the sea-air interface was quite affected during the solar eclipse (IVANOV et al. 1984).

Information about the effects of solar eclipse on the biological systems are rather limited. Solar eclipse in the past was known to inhibit the growth of some groups of bacteria (JANA et al. 1981), primary productivity of phytoplankton (PATHAK & SUGUNAN 1980; JANA & DE 1981; KOHLI et al. 1983), or increase of photosynthetic activity (SHARMA & SAKSENA 1981) and chlorophyll *a* concentration in water column (VECCHIONE et al. 1986). Solar eclipse was also found responsible for chromosomal aberrations in the gonads of copepods (GOSWAMI & GOSWAMI 1982), behavioural changes of snails (MADHAVI 1983) and some air-breathing fishes (PANDEY & SHUKLA 1982), behavioural and metabolic changes of some intertidal invertebrates (PERULEKAR et al. 1987) and spawning inhibition of common carp (SHARMA 1981). Invertebrate drift pattern was altered in an Australian creek (CADWALLADER & EDEN 1977), but remained unaltered in a riverine system (SUTER & WILLIAMS 1977).

Total solar eclipse is a rare event in India as the last one of this kind was visible over the Indian mainland about 400 years ago. In India, the total solar eclipse was visible from Diamond Harbour (West Bengal, India) on October 24, 1995 at 8.49 a.m. for one minute and seventeen seconds, causing a transient change in water temperature and light regime during the period of solar eclipse. Since transient changes of temperature and light might influence the biology of invertebrates, we took this rare opportunity to examine the effect of solar eclipse on reproduction of the common zooplankton species *Daphnia carinata* on October 24, 1995 in the University of Kalyani (lat. 22°57'N; long. 88°20' E; alt. 7.8 m) which is 150 km north of Diamond Harbour, the site of the total eclipse. At Kalyani, where the investigation was carried out, the obscuration of the sun was about 98% and the eclipse lasted for two hours and forty seven minutes from 7.31 to 10.18 a.m. Experiments were also conducted during the pre- and post-eclipse days.

2. Materials and Methods

Adult individuals of *Daphnia carinata* were procured from maintenance stock and dispensed at the rate of one neonate per 30 ml culture tube containing cotton wool filtered pond water, which contained detritus and nannoplankton as source of food for *Daphnia*. The water medium in the culture tube was changed with fresh one

every twelve hours. Each adult female produced more than six neonates; these were distributed equally in six treatment groups used for different time exposures. Thus, five replicates in six groups stemmed from six females. This was done for three successive days. A single one-day old neonate was placed in a petri dish containing 30 ml of filtered pond water, on each of the three days of experiment. Five groups were exposed to natural sunlight for five different periods starting from 7.00 a.m.–16.00 p.m. every day; the other group was not exposed to natural sunlight but maintained in the laboratory. Exposure to sunlight was made in different hours prior to eclipse day (23rd October, 1995), during the eclipse day (24th October, 1995) and post eclipse day (25th October, 1995). The time of exposure to natural sunlight was: (a) 7.00–8.45 a.m., (b) 7.00–10.20 a.m., (c) 7.00–12.00 a.m., (d) 7.00 a.m.–14.00 p.m. and (e) 7.00 a.m.–16.00 p.m. After exposure to natural sunlight for specific duration, the neonate was transferred from petri dish to culture tube containing 30 ml of pond water and then reared in the laboratory for examination of reproductive performance following the method described by ALLAN (1976).

The atmospheric temperature ranged from 10–23 °C prior to and after the eclipse, whereas it was between 20° and 27 °C during the same period on pre- and post-eclipse days. Likewise, the total solar radiation and bright sunshine were reduced substantially during the eclipse period compared to remaining two days (Table 1).

Since water temperature was reduced by 4 °C during the period of solar eclipse, an experiment was performed mimicing the eclipse reduction in light and temperature within the period similar to eclipse duration. Adults of *Daphnia carinata* were procured and were reared for neonate production. One day old neonates were distributed equally in glass beakers with pond water in four different treatment groups. The conditions followed in the experiment were ambient water temperature and sunlight (ATL), ambient water temperature and diffused dark (ATD), low temperature and natural sunlight (LTL), and low temperature and diffused dark (LTD). Ice-cold water was added slowly to beakers to bring down water temperature from 23° to 19 °C (reduction by 4 °C) within about three hours either under diffused dark condition or in ambient sunlight. Five replicates from each group were dispensed at the rate of one neonate per 30 ml culture tube and then reared in the laboratory for examination of life table data following the procedure described by ALLAN (1976). Results were statistically evaluated by means of one way analysis of variance and DMR test. The level of significance was accepted at $P < 0.05$.

3. Results

The time at which first reproduction occurred in *Daphnia carinata* (5.75–7.75 days) was clearly delayed (43 to 72%) in all groups exposed to sunlight for any period on the day of eclipse when compared to either with pre- (4.5 to 4.75 days) or post- (4.0 to 5.5 days) eclipse days (ANOVA; $P < 0.05$) (Table 2). Interval between the first and second reproduction was prolonged (3.5 to 5.5 days) in the case of former when compared to pre- and post-eclipse days (1.75 to 2.75 days) (ANOVA; $P < 0.05$).

Likewise, the reproductive life span (5.5 to 6.0 days) and the total life span (12.42 to 13.5 days) of *Daphnia* were drastically reduced (22 to 58%) in all the groups exposed to sunlight during the day of solar eclipse (ANOVA; $P < 0.05$). The reproductive life span was about 64 to 74% of the total life span of *Daphnia* during the pre- and post-eclipse days, while the former comprised only 41 to 48% of the latter on the eclipse day. As result, there was drastic reduction (34 to 64%) of total offspring production (9.25 to 18.25 days per female per life span) on the day of solar eclipse compared to pre-(23 to 27.75 days per female per life span) and post-(24.75 to 32.75 days per female per life span) eclipse days (ANOVA; $P < 0.05$).

Responses of reproductive performance of *Daphnia* to different periods of exposure were more pronounced (ANOVA; $P < 0.05$) on the day of eclipse, but were not significant (ANOVA; $P > 0.05$) on other days. *Daphnia* exposed between 7.00 and 8.45 a.m. and between 7.00 and 10.20 a.m. exhibited maximum reduction of reproductive life span. The net reproductive rate, total offspring production and total life span were reduced maximally in the group exposed to sunlight between 7.00 and 12.00 a.m. Increase in length of exposure beyond the eclipse period (7.00 a.m. to 16.00 p.m.) resulted in gradual recovery of all the reproductive parameters (ANOVA; $P < 0.05$). No marked changes of reproductive parameters of *Daphnia* were evident on the pre- and post-eclipse days (ANOVA; $P > 0.05$).

Table 1. Meteorological data recorded at different hours on the day of pre-eclipse (23.10.), eclipse (24.10.) and post-eclipse (25.10.).

Time (h)	Air temperature (°C)			Water temperature (°C)			Relative humidity (%)			Bright sun shine (h)			Total solar radiant (w/h/m²)			Wind direction (degree)		
	23.10.	24.10.	25.10.	23.10.	24.10.	25.10.	23.10.	24.10.	25.10.	23.10.	24.10.	25.10.	23.10.	24.10.	25.10.	23.10.	24.10.	25.10.
7	24.42	22.46	20.66	22.85	21.20	20.95	102.4	90.70	88.40	1.0	1.0	1.0	6.45	7.48	7.02	22.85	21.2	20.95
8	26.96	24.21	22.89	24.30	24.80	23.82	90.50	88.60	79.90	1.0	0.8	1.0	17.32	15.3	17.97	24.3	24.8	23.82
9	28.06	22.75	24.87	25.05	20.10	25.80	87.10	92.00	74.10	1.0	0.6	1.0	20.3	5.41	27.51	25.05	20.1	25.8
10	29.47	24.88	26.75	27.12	24.70	26.90	79.30	89.10	67.04	1.0	0.8	1.0	35.54	26.01	35.28	27.12	24.7	26.9
12	30.30	28.87	28.62	29.40	28.65	28.45	72.90	75.40	64.57	1.0	1.0	1.0	27.6	26.93	18.53	29.4	28.65	28.45
14	30.70	29.48	29.50	29.80	28.10	28.70	68.63	65.24	57.46	1.0	1.0	1.0	30.12	31.38	30.94	29.8	28.1	28.7
16	30.68	27.42	27.25	27.90	27.20	27.70	73.70	70.60	64.42	1.0	1.0	1.0	10.36	10.4	10.5	27.9	27.2	27.7

Table 2. Life table data (mean ± s.e.) of *Daphnia carinata* at different hours on the day of pre-eclipse, eclipse and post-eclipse. Same superscripts in columns representing different hours of exposure revealed lack of significant differences (DMR test, $P > 0.05$).

Hours of exposure	First day of reproduction (A) [days]				Interval between first and second reproduction [days]				Total life span (W) [days]			
	23.10.	24.10.	25.10.	Significance	23.10.	24.10.	25.10.	Significance	23.10.	24.10.	25.10.	Significance
7–8.45 a.m.	4.75^{a} ±0.64	5.75^{a} ±0.892	4.0^{a} ±0.612	$P > 0.05$	1.75^{b} ±0.414	4.75^{a} ±0.544	2.5^{b} ±0.25	$P < 0{,}001$	18^{a} ±0.612	12.75^{b} ±0.414	17.75^{a} ±1.13	$P < 0.001$
7–10.20 a.m.	4.5^{b} ±0.559	7.25^{a} ±0.544	5.0^{b} ±0.353	$P < 0.05$	$2.75^{a,b}$ ±0.216	3.75^{a} ±0.414	1.75^{b} ±0.216	$P < 0.001$	17.5^{a} ±1.03	13.25^{b} ±0.649	18^{a} ±0.707	$P < 0.05$
7–12 noon	4.5^{b} ±0.25	7.25^{a} ±0.960	4.25^{b} ±0.414	$P < 0.05$	2.0^{b} ±0.353	3.5^{a} ±0.25	$2.5^{a,b}$ ±0.25	$P < 0.05$	17.2^{a} ±0.414	12.4^{b} ±1.22	$15.5^{a,b}$ ±1.14	$P < 0.05$
7–2.0 p.m.	4.5^{a} ±0.559	6.5^{a} ±1.14	5.5^{a} ±0.433	$P > 0.05$	2.25^{b} ±0.216	5.5^{a} ±0.25	2.0^{b} ±0.353	$P < 0.001$	17.5^{a} ±1.29	12.75^{b} ±0.649	$16^{a,b}$ ±0.935	$P < 0.05$
7–4.0 p.m.	4.5^{b} ±0.559	7.75^{a} ±0.739	5.0^{b} ±0.5	$P < 0.05$	1.75^{c} ±0.216	4.25^{a} ±0.216	2.75^{b} ±0.216	$P < 0.001$	17.5^{a} ±0.559	13.5^{b} ±0.75	16.75^{a} ±0.96	$P < 0.05$
Laboratory reared stock	6^{a} ±0.353	4.75^{a} ±0.414	5.5^{a} ±0.075	$P > 0.05$	2.25^{a} ±0.414	2.25^{a} ±0.216	3^{a} ±0.353	$P > 0.05$	17.2^{a} ±1.47	16.5^{a} ±0.55	16.75^{a} ±1.34	$P > 0.05$
Significance	$P > 0.05$	$P < 0.05$	$P > 0.05$		$P > 0.05$	$P < 0.001$	$P > 0.05$		$P > 0.05$	$P < 0.001$	$P > 0.05$	

Hours of exposure	Total number of offspring production /female/life span (S)				Reproductive peak (T) [days]				Reproductive life span [days]			
	23.10.	24.10.	25.10.	Significance	23.10.	24.10.	25.10.	Significance	23.10.	24.10.	25.10.	Significance
7–8.45 a.m.	27.75^{a} ±1.47	12.5^{a} ±2.94	29^{a} ±2.15	$P < 0.001$	13.25^{a} ±0.739	11.75^{a} ±0.216	10.5^{a} ±1.34	$P > 0.05$	13^{a} ±0.935	5.5^{b} ±1.25	13.25^{a} ±0.96	$P < 0.05$
7–10.20 a.m.	29^{a} ±1.54	16^{b} ±2.54	32.75^{a} ±1.94	$P < 0.05$	12.5^{a} ±0.55	9.75^{b} ±0.819	12.75^{a} ±0.739	$P < 0.05$	11.75^{a} ±0.544	5.5^{b} ±0.55	12.5^{a} ±1.03	$P < 0.05$
7–12 noon	24.5^{a} ±2.27	9.25^{b} ±2.76	25^{a} ±2.80	$P < 0.05$	13.25^{a} ±0.414	10.5^{a} ±1.25	13^{a} ±0.79	$P > 0.05$	11.25^{a} ±1.24	5.75^{b} ±0.96	10.75^{a} ±1.24	$P < 0.05$
7–2.0 p.m.	23^{a} ±2.15	11.25^{b} ±2.76	24.75^{a} ±1.74	$P < 0.05$	11.75^{a} ±0.739	11^{a} ±0.866	13.25^{a} ±0.414	$P > 0.05$	12.2^{a} ±0.96	5.75^{b} ±1.51	11^{a} ±1.11	$P < 0.05$
7–4.0 p.m.	28.25^{a} ±1.91	18.25^{b} ±2.35	28.25^{a} ±2.53	$P < 0.05$	12^{a} ±1.06	13^{a} ±0.935	14^{a} ±0.353	$P > 0.05$	11.25^{a} ±0.544	6^{b} ±1.90	11.5^{a} ±1.29	$P < 0.05$
Laboratory reared stock	23.25^{a} ±3.48	23.5^{a} ±1.52	23.5^{a} ±2.56	$P > 0.05$	12.25^{a} ±0.414	14.25^{a} ±0.216	14.25^{a} ±0.89	$P > 0.05$	11^{a} ±1.69	11.5^{a} ±0.25	11.25^{a} ±1.24	$P > 0.05$
Significance	$P > 0.05$	$P < 0.05$	$P > 0.05$		$P > 0.05$	$P < 0.05$	$P > 0.05$		$P > 0.05$	$P < 0.05$	$P > 0.05$	

Table 3. Responses of life table (mean ± s.e.) of *Daphnia carinata* to different simulated conditions [ambient water temperature and natural sunlight (ATL); ambient water temperature and dark (ATD); low temperature and natural sunlight (LTL) and low temperature and dark (LTD)]. Same superscripts in columns representing different conditions revealed lack of significant differences (DMR test, $P > 0.05$).

Conditions	First day of reproduction (A) [days]	Interval between first and second reproduction [days]	Total life span (W) [days]	Total number of offspring production /female/lifetime (S)	Reproductive peak (T) [days]	Reproductive life span [days]
ATL	4.2^{b} ±0.335	2.4^{a} ±0.219	22.6^{a} ±0.457	38.4^{a} ±1.73	11.2^{b} ±0.335	17^{a} ±0.401
ATD	6.6^{a} ±0.457	2.6^{a} ±0.129	$20.6^{a,b}$ ±0.457	31.6^{a} ±2.22	13.8^{a} ±0.71	15^{a} ±0.750
LTL	6.4^{a} ±0.728	3.8^{a} ± 0.659	18.8^{b} ±0.914	22.8^{b} ±3.03	14.2^{a} ±1.18	11^{b} ±1.67
LTD	7.8^{a} ±0.439	3.6^{a} ±0.457	16.6^{c} ±0.538	20.4^{b} ±1.18	15.4^{a} ±0.219	9.8^{b} ±0.335
Significance	$P < 0.001$	$P > 0.05$	$P < 0.001$	$P < 0.001$	$P < 0.05$	$P < 0.001$

The day of first reproduction in the simulated experiment, was delayed under dark as compared normal sunlight (ANOVA; $P < 0.05$). Similarly, first reproduction was also prolonged by low temperature both at light and dark conditions (ANOVA; $P < 0.05$). *Daphnia* reared under dark conditions showed considerable reduction of total life span, reproductive life span, and total offspring production per life span as compared to normal sunlight both at low and ambient water temperature; the reduction was more pronounced in the former than in latter. The reproductive peak was demonstrated almost at half of the life span, but it shifted towards the later part of life under dark or low temperature conditions (Table 3).

4. Discussion

Abrupt change to darkness and decline of water temperatur as well as their interactions as prevailed during the solar eclipse were responsible for inhibition of reproduction in *Daphnia carinata*. Such effects were confirmed from results of the simulated experiment. However, there was a gradual recovery of reproduction as the time after eclipse elapsed. It is possible that reproductive inhibition of *Daphnia carinata*, even for a short period, was caused by the cold and dark shock and their interactions which might have an effect on photosensitive cells and the circadian rhythm. It is hardly possible to explain at present the effect of solar eclipse on reproductive inhibition of zooplankton in the light of ultraviolet radiations and other astronomical data. However, it is reported that there was a reduction of UV radiations during the solar eclipse (unpubl. data). It is conclusively known that ultraviolet radiation is another environmental factor that affects inland waters (JERLOV 1950). Further research is necessary to understand the mechanism of the effect of solar eclipse on living system in the light of astronomical data.

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