Bull. Environ. Contam. Toxicol. (1990) 44:135–141

Bulletin of Environmental Contamination and Toxicology

Life Table Evaluation of the Effects of Cadmium Exposure on the Freshwater Cladoceran, *Moina macrocopa*

C. K. Wong and P. K. Wong

Department of Biology, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong

Cadmium has long been recognized as a highly toxic and dangerous environmental pollutant. Like most heavy metals, the concentration of cadmium in unpolluted fresh waters is generally less than 1 µg/L (Babich and Stotzky 1978). The main sources of cadmium in the aquatic environment are industrial wastes and mine drainage. As a result of industrial activities such as electroplating and battery manufacture, there has been an alarming increase in the concentration of cadmium in the Hong Kong waters during recent decades (Chan et al. 1974). Of many organisms in freshwater environments, crustacean zooplankton appears to be the most sensitive to cadmium. Anderson (1950) reported 64-h acute cadmium toxicity to Daphnia magna at concentrations < 1.6 µg/L. Reproduction of Daphnia is generally reduced by cadmium at concentrations less than 1 µg/L (Bertram and Hart 1979; Biesinger and Christensen 1972; Marshall 1978). In spite of the importance of zooplankton in freshwater communities and the sensitivity of zooplankters to cadmium toxicity, little information on the effects of cadmium on zooplankton species other than Daphnia is available.

The freshwater cladoceran Moina macrocopa Straus is widely distributed (Edmondson 1959). In Hong Kong it is common in small ponds and rice paddies and is mass cultured by local fish farmers as a fish food. Its small size and high reproductive rate in the laboratory make it an ideal test organism for aquatic toxicologists. The purpose of this paper is to use the life table method to study the effect of cadmium on the survival and reproductive capacity of this commercially important zooplankter.

MATERIALS AND METHODS

Moina macrocopa were from laboratory cultures raised from a single parthenogenetic female. Bioassays were carried out with a

Send reprint request to C.K.Wong at above address

cohort of newborn (± 24 h) neonates obtained by isolating egg-bearing females from stock cultures. Stock and experimental animals were maintained in uncontaminated water (pH 6.5) from Kowloon Reservoir, Hong Kong. Twenty or 30 neonates, 10 in each 150 mL beaker containing 100 mL of filtered (0.125 mm mesh) reservoir water at 28 ± 2°C, were used for each test condition. Cadmium concentrations used were 0 (control), 0.001, 0.005, 0.01, 0.1, 1, 5, and 10 mg/L. Test solutions were prepared by adding aliquots of $CdCl_2$ from a stock solution to each beaker and were changed every 24 h. During each change, the number of surviving animals was counted and newborn young were discarded. Chlorella sp. in log growth phase was added to the beakers to feed the animals after each change. Algal concentrations were not determined, but equal volumes of algal suspension were added to all beakers. Surplus algal cells were always observed still in suspension when the test solution was changed. To minimize uptake of cadmium by Chlorella (Carney et al. 1986), the beakers were only weakly illuminated during the day time by light coming in through a window. By means of atomic absorption spectrophotometry it was determined that the loss of cadmium from test media of 1 and 5 mg/L was 0% after 24 h and 6% after 48 h. The entire cohort of animals was observed through its life-span.

Life table parameters for each population were calculated according to Ricklefs (1973). l_x, the survivorship at age x, was measured as the proportion or percentage of individuals in the population that survived to age x. The fecundity at age x (m_x) represented the number of births per female of age x, during the time interval x to x + 1. The net reproductive rate, symbolized by R_0, was the total expected number of births by a female during her lifetime. It was calculated from the equation :

$$R_0 = \sum l_x m_x$$

The intrinsic rate of population increase, r, was calculated by solving the equation :

$$\sum l_x m_x e^{-rx} = 1$$

The mean generation time, T, was the duration required for a population to increase by the factor R_0. It was derived from the equation :

$$T = \frac{\ln R_0}{r}$$

RESULTS AND DISCUSSION

Survivorship of Moina macrocopa in cadmium solutions was presented in Figure 1. Survivorship among treatments were compared using the Wilcoxon paired-sample test, with day of death

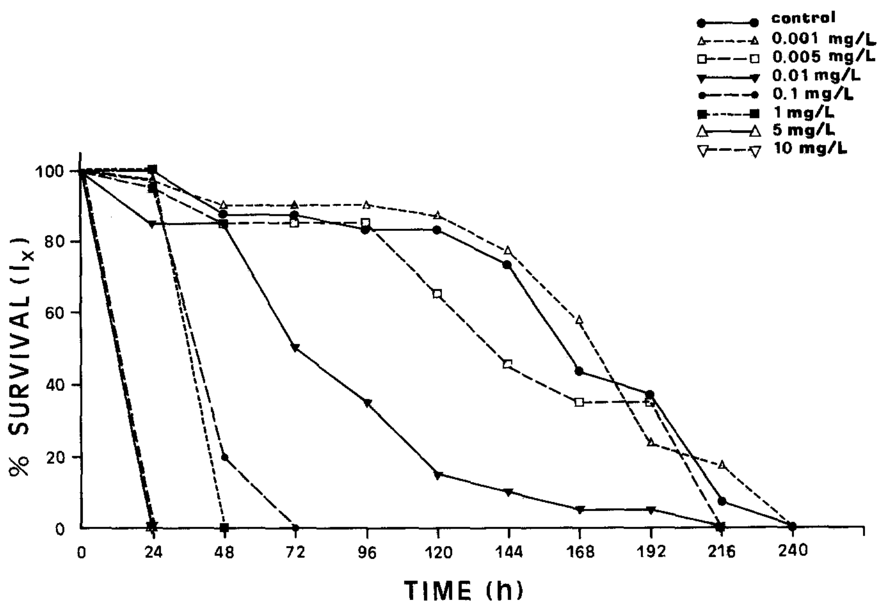

Figure 1. Survivorship curves for M. macrocopa in control and seven concentrations of cadmium.

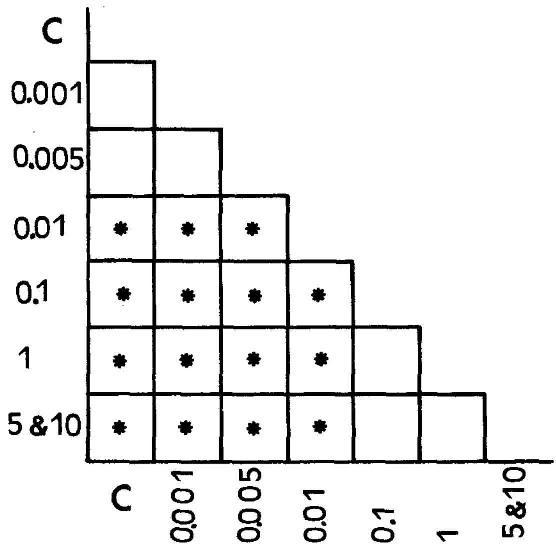

Figure 2. Comparison of survivorship curves for M. macrocopa. C represents control. Concentrations are given in mg/L. Asterisks indicate a significant difference between treatments (P < 0.05).

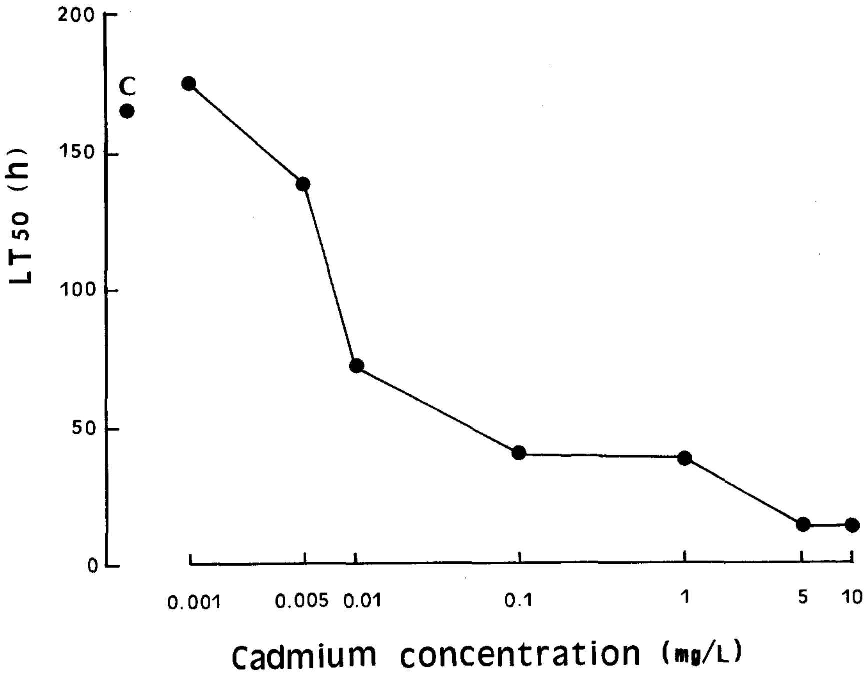

Figure 3. LT_{50} values for M. macrocopa plotted against cadmium concentrations. C denotes value for control.

as the ranked observation (Fig. 2). Survivorship at 0.001 and 0.005 mg/L was not significantly different from survivorship of control. Survivorship at 0.01 mg/L and all higher concentrations was significantly different from survivorship at 0.005 mg/L and all lower concentrations. There was a rapid decrease in LT_{50} at 0.01 mg/L and higher concentrations (Fig. 3). LT_{50} at 0.01 mg/L was less than 50% that of control. At 5 and 10 mg/L, the LT_{50} was less than 24 h.

Animals in control did not reproduce earlier than animals exposed to cadmium (Fig. 4). First reproduction for animals in cadmium solution of 0.01 mg/L and lower concentrations occurred between 72 and 96 h. Animals at 0.1 mg/L and higher concentrations did not survive to the onset of reproduction. Wilcoxon paired-sample tests ranking the number of young per female per day were used to test for significant differences in fecundity among treatments (Fig. 5). Fecundity at 0.001 mg/L was not significantly different from control. Fecundity at 0.005 and 0.01 mg/L was significantly different from control and 0.001 mg/L. Three separate peaks were observed in the fecundity curves for control, 0.001, and 0.005 mg/L. Fecundity curve at 0.01 mg/L, on the other hand, showed only one peak. This suggested that while animals exposed to 0.005 mg/L and lower cadmium concentrations developed three broods, those at 0.01 mg/L managed only one.

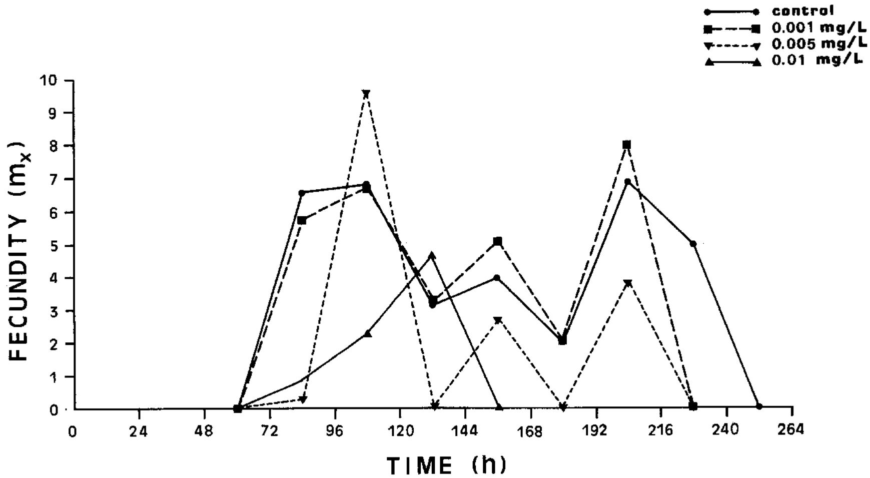

Figure 4. Fecundity curves for M. macrocopa in control and three concentrations of cadmium.

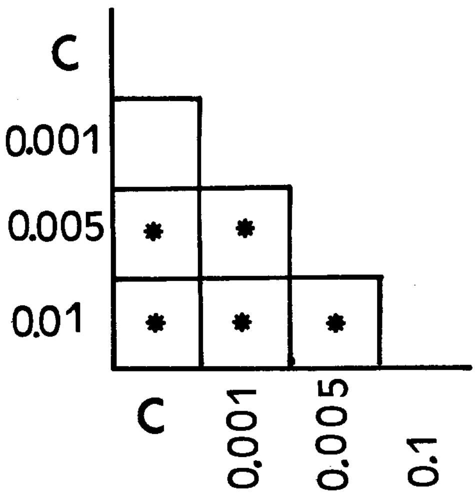

Figure 5. Comparison of fecundity curves for M. macrocopa. C represents control. Concentrations are given in mg/L. Asterisks indicate a significant difference between treatments ($P < 0.05$).

The net reproductive rate, R_o, defines the total number of eggs that a female may be expected to lay during her entire lifetime. Cadmium concentration at 0.001 mg/L had no obvious effect on the net reproductive rate (Table 1). But the reproductive capability of the animals was markedly reduced as cadmium concentration

Table 1. Life table information for M. macrocopa at various cadmium concentrations.

Cadmium concentration (mg/L)	R_o	r	T (days)
0	16.39	0.57	4.89
0.001	18.34	0.57	5.07
0.005	7.28	0.38	5.20
0.01	1.13	0.02	5.16
0.1	0	-	-
1	0	-	-
5	0	-	-
10	0	-	-

reached 0.005 mg/L or higher. The net reproductive rate at 0.005 mg/L was 44 % that of control. The net reproductive rate was just around 1 at 0.01 mg/L, indicating that reproduction has been reduced to the replacement level.

The intrinsic rate of population increase, r, measures the growth performance of populations under different concentrations of cadmium (Table 1). It showed little change at cadmium concentration of 0.001 mg/L. At 0.005 mg/L and higher concentrations, the intrinsic rate of population increase dropped drastically. At 0.1 mg/L the r value was zero because all the females died before reproducing. The generation time, T, also increased with increasing concentration of cadmium.

The results of this study show that athough the survivorship of M. macrocopa was not affected by cadmium at 0.005 mg/L or lower concentrations, fecundity and net replacement rate were clearly reduced as a result of exposure to cadmium concentrations at or in excess 0.005 mg/L. Thus the r value at 0.005 mg/L was only 71% that in uncontaminated water. This is very close to the results of Marshall (1978) that the population carrying capacity of Daphnia galeata mendotae was reduced by 50% at cadmium concentration of 0.0077 mg/L and the results of Bertram and Hart (1979) that the r value of Daphnia pulex was reduced by about 50% at cadmium concentration of 0.005 mg/L. The value of the intrinsic rate of population increase indicates that exposure to cadmium at concentrations of 0.001 mg/L or lower would probably not have a deleterious effect on the population dynamics of M. macrocopa. Factors that have not been considered in this study include the ability of cadmium-stressed animals to avoid predation and respond to other physical and chemical variables in the environment. It is clear that freshwater cladocerans are very sensitive to cadmium pollution. Because of their role as the most important grazers of the phytoplankton in ponds, lakes, and reservoirs, cladocerans may be crucial in determining the overall impact of cadmium pollution on the food web of these ecosystems.

REFERENCES

Anderson BG (1950) The apparent thresholds of toxicity to Daphnia magna for chlorides of various metals when added to Lake Erie water. Trans Am Fish Soc 78:96-113

Babich H, Stotzky G (1978) Effects of cadmium on the biota: influence of environmental factors. Adv Appl Microbiol 23:55-117

Bertram PE, Hart BA (1979) Longevity and reproduction of Daphnia pulex (de Geer) exposed to cadmium-contaminated food or water. Environ Pollut 19:295-306

Biesinger KE, Christensen GM (1972) Effects of various metals on survival, growth, reproduction, and metabolism of Daphnia magna. J Fish Res Bd Can 29:1691-1700

Buikema Jr AJ, Benfield EF (1979) Use of macroinvertebrate life history information in toxicity tests. J Fish Res Bd Can 36:321-328

Chan JP, Cheung MT, Li FP (1974) Trace metals in Hong Kong waters. Mar Pollut Bull 5:171-174

Carney GC, Shore P, Chandra H (1986) The uptake of cadmium from a dietary and soluble source by the crustacean Daphnia magna. Environ Res 39:290-298

Edmondson WT (1959) Freshwater biology. John Wiley and Sons Incorporation, New York

Marshall JS (1978) Population dynamics of Daphnia galeata mendotae as modified by chronic cadmium stress. J Fish Res Bd Can 35:461-469

Ricklefs RE (1973) Ecology. Chiron Press, Newton, Massachusetts

Received June 18, 1988; accepted February 2, 1989.