Toxic effect and accumulation of cadmium by common shrimp (*Crangon crangon, Decapoda, Natantia*)

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Common shrimp
Toxic effect
Accumulation

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Abstract

Experiments on the accumulation and elimination of cadmium in *C, crangon* were carried out in summer 1982. High mortality of the animals took place in the Cd concentrations of 50 and 100 $\mu g \cdot dm^{-3}$. In these concentrations the animals died after moulting. Cadmium content was lower in the animal bodies than in the exuvia. Level of accumulation depended on Cd concentration in water. During the elimination period (7 days), a slight decrease of Cd content in the animal body was observed after the exposure to Cd concentrations of 5 and 10 $\mu g \cdot dm^{-3}$ while in case of the 2 $\mu g \cdot dm^{-3}$ concentration, Cd content in shrimp body remained at the same level. Higher percentages of moulting animals compared to the control sample were observed in 2, 5 and 10 $\mu g \cdot dm^{-3}$ concentrations of Cd. The higher the concentration, the higher the mortality of moulting shrimps. Specimens kept in higher water salinities, and in higher cadmium concentration, accumulated lower levels of the metal than specimens in lower water salinities.

1. Introduction

Levels of cadmium in coastal and estuarine waters increased considerably in the recent years (Erlenkeuser *et al* 1974; Scholz *et al* 1978). Toxic effect of cadmium on the living organisms is rather insignificant in sea waters (Eisler 1971), whereas in fresh and brackish waters the animals are fairly susceptible to this metal (Caeley, Coleman, 1974).

Cadmium has a negative effect upon most tested marine organisms (Gardner, Yevich 1969; Eisler *et al* 1972; Jennings, Rainbow 1979; Theede *et al* 1979a, b). At the same time, it was observed that several species accumulated even high levels of cadmium without any noticeable effect. For instance, *Chidaria*, as well as adults and larvae of some *Mollusca* belong to this type of animals (Eisler *et al* 1972; Philips 1976), also as *Crustacea* (Wright 1977). Moreover, the metal is dangerous due to the possibility of dislodging and taking place of calcium (Wright 1977).

In case of marine invertebrates negative effect of cadmium was observed on the animal growth (Paffenhofer 1978; Stebbing, Hiby 1979), embryonal and larval development (Callabrese *et al* 1973; Mirkes *et al* 1978), oxygen consumption and osmoregulation (MacInnes, Thurberg 1973; Thurberg *et al* 1973). As a result ecosystem changes take place. On the other hand, cadmium accumulates in the trophic chain, this resulting in a direct danger to human beings.

Bojanowski (1981) stated after Burgmann that in the Baltic Sea the highest concentration of cadmium was found in Danish Straits (1.99 $\mu g \cdot dm^{-3}$). In other areas cadmium concentration ranged between 0.09 and 0.67 $\mu g \cdot dm^{-3}$. In the Gulf of Gdańsk average cadmium concentration in water amounts to 0.37 $\mu g \cdot dm^{-3}$, at variations within a range of 0.04–1.00 $\mu g \cdot dm^{-3}$ (Bojanowski 1981).

Crangon crangon is a common species of Baltic and North Sea coastal waters, occurring at water salinity of from 30 to $3^0/_{00}$. These waters are polluted with cadmium at a different level.

Broad spectre of cadmium concentrations was tested in this study (from 2 to 100 $\mu g \cdot dm^{-3}$). Studies were made on the effect of different cadmium concentrations upon its accumulation and elimination by *C. crangon*, frequency of moulting, and mortality of the animal. Attention was also given to the role of water salinity in cadmium accumulation rates. Knowledge on these problems is of considerable importance, as the species under study is of hight economic and ecologic value. Common shrimp is exploited by many countries for human consumption. It also constitutes a food resource for many exploited fish species.

2. Material and method

Materials for studies were collected at a station 0.5–1 m deep, with sandy bottom, located near Schilksee (FRG), Baltic Sea. The station was selected due to easy access and considerable shrimp densities *C. crangon* was caught with a river drag net, of 1 mm mesh size. Experiments were carried out in summer 1982. In the laboratory the animals were kept in sea water, at 15°C and $19^0/_{00}$ salinity. Different concentrations of cadmium ($CdCl_2$) were used. The shrimps were fed with *Mytilus edulis* every 4 days. Sea water, in which the animals were kept, was changed after each feeding. Animals of a more or less the same body size (43.2±4.8 mm) were used. Each shrimp was kept separately, in crystallizers of 6 cm diameter, filled with filtered sea water (250 ml).

Three types of experiments were carried out:

(i). 31 specimens were kept for 15 days in the Cd concentration of 50 $\mu g \cdot dm^{-3}$, and 35 specimens–for 13 days in the concentration of 100 $\mu g \cdot dm^{-3}$ ($S = 19^0/_{00}$). The control consisted of 15 specimens. Water was changed every 48 h. Numbers of moulting shrimps were recorded. Cadmium content was determined in dead animals in course of the experiment.

(ii). In order to follow the elimination of cadmium, shrimps were kept for 18 days in sea water ($S = 19^0/_{00}$) containing 2, 5 and 10 μg $Cd \cdot dm^{-3}$ and then transferred to sea water of the same salinity but with no cadmium. 26 specimens were placed in 2 $\mu g \cdot dm^{-3}$ concentration of Cd, 22–in 5 $\mu g \cdot dm^{-3}$, and 28 in 10 $\mu g \cdot dm^{-3}$. Water was changed every day during the elimination period (7 days). Control in this case consisted of 18 specimens.

(iii). 8 specimens of *C. crangon* were placed in 50 μg Cd$\cdot$dm^{-3} in Baltic Sea water of the salinity of 19$^{0}/_{00}$. Another 8 specimens (caught near Nordstrand, North Sea) were kept in the same cadmium concentration, but in salinity of 28$^{0}/_{00}$. Accumulation of cadmium in these animals was determined after 7 days.

After the accumulation or elimination period, the animals were lyophilized, dried for 24 h in 60°C and homogenized. 20 mg were taken from each sample (one shrimp = one sample) and dissolved in 200 μl of HNO_3 + HCl, 1 : 1. The acid solution was heated for 3 hours in a sand bath.

The samples were diluted with proper amount of redistilled water. 5 or 10 μl of the solution were analysed using Beckman atomic absorption spectrophotometer. The results are presented as μg Cd$\cdot$g^{-1} of dry weight, or recalculated *per* specimen.

Results

It was found that in case of 50 and 100 μg Cd$\cdot$dm^{-3} concentrations, *Crangon crangon* accumulated cadmium depending on the metal concentration in the environment, and proportionally to the exposure time. Hence, the curves are almost parallel (Fig. 1). Shrimps kept in 50 μg Cd$\cdot$l^{-1} contained on the average 0.858$\pm$0.504 μg Cd$\cdot$g^{-1} of dry weight after 3 days, while in 100 μg Cd$\cdot$dm^{-3} the accumulated level of cadmium was 3.453$\pm$0.957 μg$\cdot$g^{-1} of dry weight. In each parallel measurement, cadmium accumulation was higher in 100 than in 50 μg Cd$\cdot$dm^{-3} concentration. This proves that cadmium concentration in the environment determines metal content in the animal body. In the control samples cadmium levels amounted to 0.76$\pm$0.37 μg$\cdot$g^{-1} of dry weight. No differences were noted in cadmium accumulation by *C. crangon* males and females.

Table 1. Uptake of cadmium by *Crangon crangon* exposed to different Cd concentrations

Cd concentration [μg$\cdot$dm^{-3}]	Days	Total cadmium content within body [μg$\cdot$g^{-1}]	
		animal	exuvia
50	3	0.56	5.7
	4	1.14	2.78
	5	3.66	6.31
	3		
100	4	5.21	15.77
	5		

High mortalities of shrimps were observed in both Cd concentrations (Fig. 2). In 50 μg$\cdot$dm^{-3} 100% of specimens died after 15 days of the experiment, while in 100 μg$\cdot$dm^{-3} – after 13 days. Mortalities were similar in the initial period. In both cases L_{T10} was 3 days. On the other hand, L_{T50} was 7 days in 50 μg$\cdot$dm^{-3} concentration, and 4 days in 100 μg$\cdot$dm^{-3}. The animals moulted rarely in both cadmium concentrations but in each case the animals died after moulting.

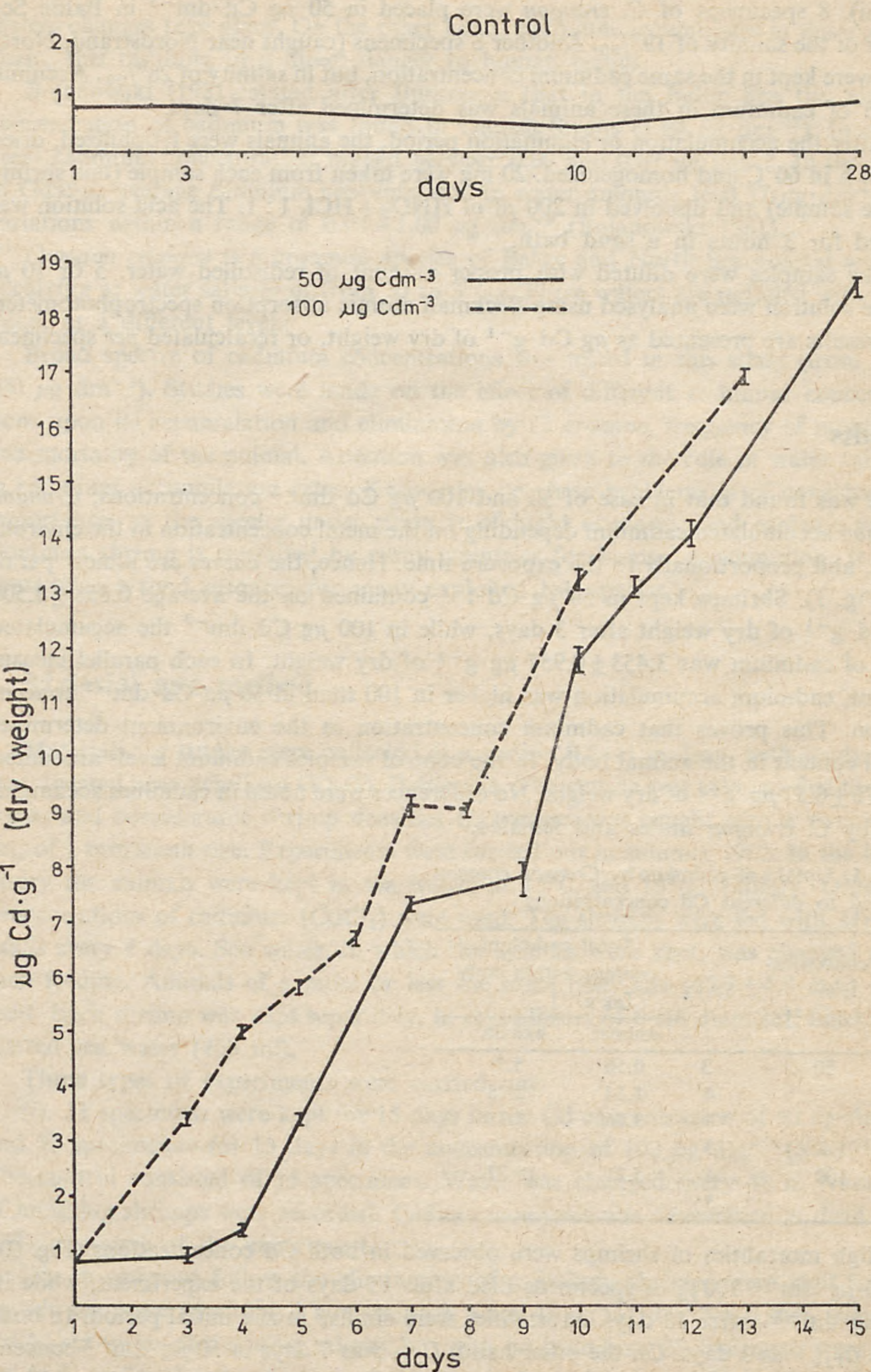

Fig. 1. Accumulation of Cd by *Crangon crangon* exposed to 50 $\mu g\ Cd \cdot dm^{-3}$ and 100 $\mu g\ Cd \cdot dm^{-3}$ in $19^0/_{00}$ salinity

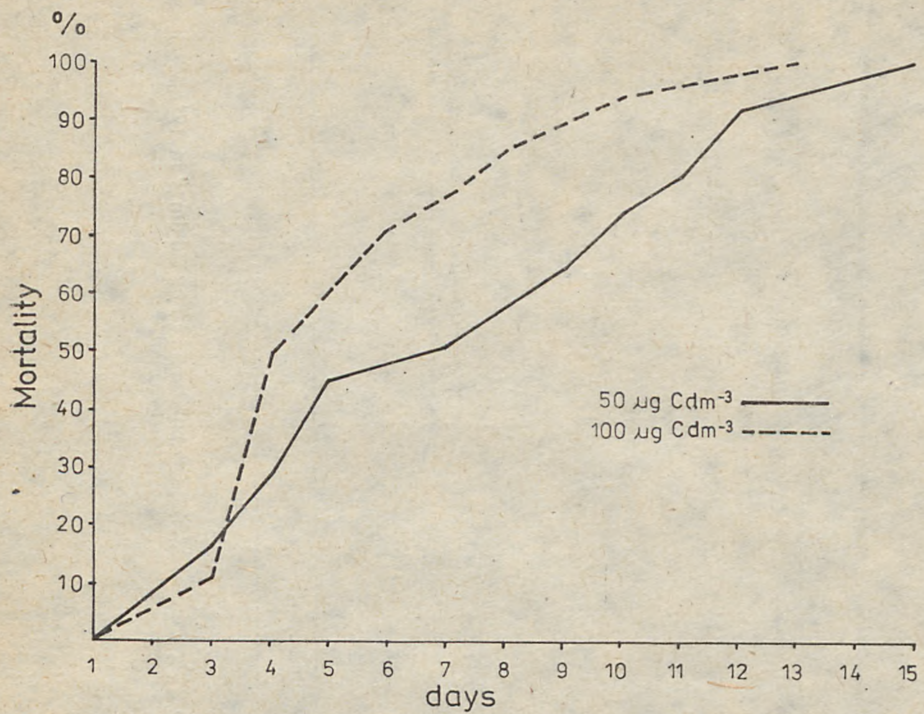

Fig. 2. Percentage mortality of *Crangon crangon*

It was found that cadmium levels were higher in the exuvia than in the animal bodies (Table 1). In the concentration of 50 $\mu g\ Cd \cdot l^{-1}$, cadmium content in shrimp body amounted to 1.14 $\mu g\ Cd \cdot g^{-1}$ of dry weight on the fourth day of the experiment, whereas the exuvia contained 2.78 $\mu g\ Cd \cdot g^{-1}$ of dry weight.

Table 2. Uptake of cadmium by females and their eggs of *Crangon crangon* exposed to 50$\mu g \cdot dm^{-3}$ Cd concentration

Days	Total cadmium content [$\mu g \cdot g^{-1}$]	
	female body	eggs
7	6.54	2.21
9	8.08	1.64
10	10.28	2.63

An opposite relationship was observed in case of females bearing eggs (Table 2). Cadmium content in the eggs was a few times lower than in the body of females from which the eggs were isolated.

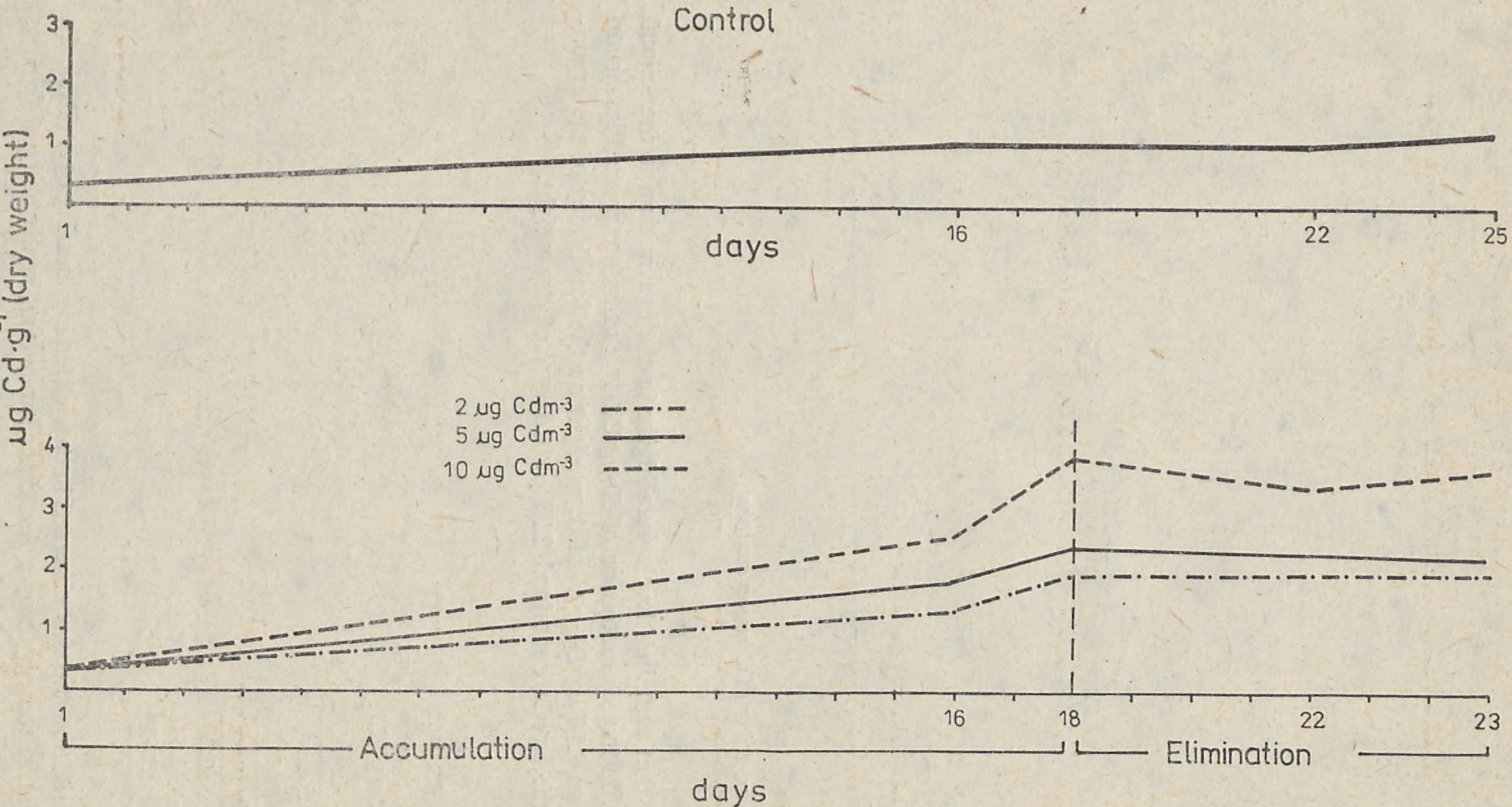

Fig. 3. Accumulation and elimination of Cd by *Crangon crangon* exposed to 2 μg $Cd \cdot dm^{-3}$, 5 μg $Cd \cdot dm^{-3}$, and 10 μg $Cd \cdot dm^{-3}$ in 19‰ salinity

Observations on cadmium accumulation by *C. crangon* kept in the concentrations of 2, 5 and 10 μg Cd·dm^{-3} confirmed that the metal uptake by shrimps depended on its concentration in the environment (Fig. 3). An increase of Cd Content in the control was caused by the presence of low levels of this metal in sea water used in the experiment.

No noticeable decrease of cadmium content in the animal bodies was observed

Table 3. Accumulation and elimination of cadmium by the whole *Crangon crangon* exposed to 2, 5, and 10 μg·dm^{-3} concentrations of Cd

Cadmium concentration [μg·dm^{-3}]	Accumulation (mean ± 50) [μg Cd·indiv^{-1}]	Elimination (mean ± 50) [μg Cd·indiv^{-1}]
2	0.230 ± 0.053	0.247 ± 0.057
5	0.319 ± 0.039	0.186 ± 0.149
10	0.519 ± 0.334	0.378 ± 0.152

Table 4. Frequency of *Crangon crangon* moulting kept in different Cd concentrations, during 18 days

Days	2 μg·dm^{-3} [a]		5 μg·dm^{-3} [b]		10 μg·dm^{-3} [c]		control [d]	
	surviving	dead	surviving	dead	surviving	dead	surviving	dead
1	–	–	–	–	–	–	–	–
2	1	–	1	–	–	1	1	–
3	1	–	–	–	–	1	–	–
4	–	–	–	–	1	–	–	–
5	–	–	–	–	1	–	1	–
6	–	–	1	–	1	–	2	–
7	–	–	1	–	1	–	–	–
8	–	–	–	–	2	–	–	–
9	1	–	–	–	–	1	–	–
10	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–
12	1	–	1	–	1	1	–	–
13	–	–	1	–	–	1	–	–
14	1	–	–	–	1	1	–	–
15	1	–	2	–	1	2	1	–
16	–	–	–	–	–	–	–	–
17	1	–	–	–	–	–	–	–
18	1	–	1	1	–	–	–	–
Together	8	0	8	1	9	8	5	0
% of moulting animals	30.0		40.9		60.7		27.7	
% of mortality	0		11		47		0	

Number of specimens placed: [a] – 26; [b] – 22; [c] – 28; [d] – 18 during the so-called elimination period (Table 3), although the water contained no cadmium, and was changed every day. In case of 2 $\mu g\ Cd \cdot dm^{-3}$ concentration, content of cadmium in the shrimps amounted to $1.901 \pm 0.132\ \mu g \cdot g^{-1}$ of dry weight

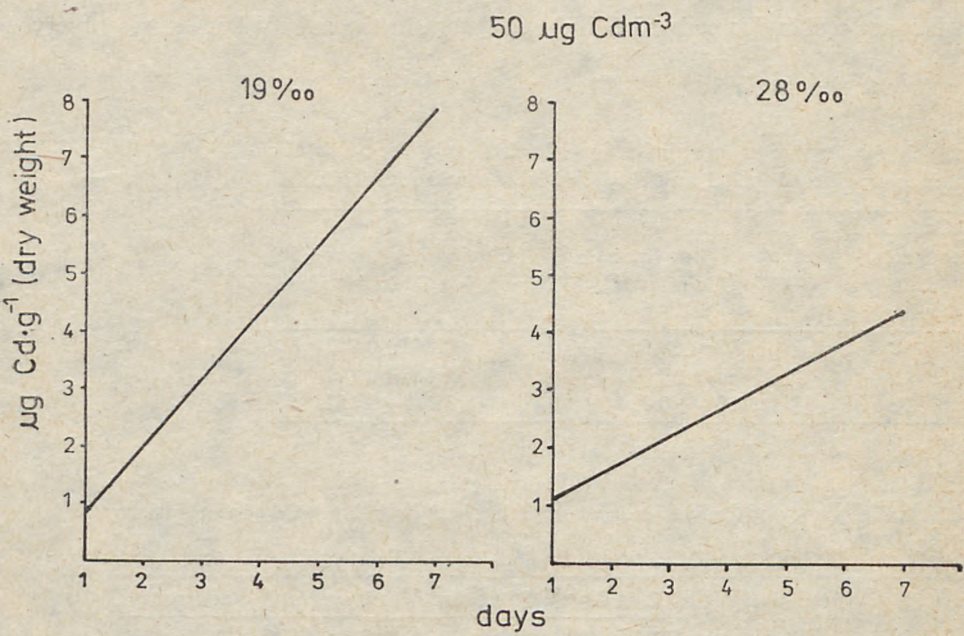

Fig. 4. Accumulation of Cd by *Crangon crangon* exposed to 50 $\mu g\ Cd \cdot dm^{-3}$ in $19^0/_{00}$ and $28^0/_{00}$ salinity

after accumulation period, and it was almost the same after the elimination period, *viz* $1.927 \pm 0.453\ \mu g \cdot g^{-1}$ of dry weight. In case of 5 $\mu g\ Cd \cdot dm^{-3}$ concentration the animals accumulated $2.397 \pm 0.831\ \mu g\ Cd \cdot g^{-1}$ of dry weight after 18 days while the metal content after the elimination period amounted to $2.203 \pm 0.662\ \mu g \cdot g^{-1}$ of dry weight of the shrimp body. In the Cd concentration of 10 $\mu g \cdot dm^{-3}$ the animals contained $3.839 \pm 0.939\ \mu g\ Cd \cdot g^{-1}$ of dry weight by the end of the accumulation period, and $3.687 \pm 0.603\ \mu g\ Cd \cdot g^{-1}$ of dry weight after the elimination period.

During the elimination period, the moulting animals contained more cadmium in their bodies (2.89 $\mu g \cdot g^{-1}$ of dry weight) than in the exuvia (0.51 $\mu g \cdot g^{-1}$ of dry weight, concentration of 5 $\mu g\ Cd \cdot l^{-1}$).

Mortality after moulting differed in cadmium concentrations of 2, 5 and 10 $\mu g \cdot dm^{-3}$ (Table 4). All moulting specimens survived the Cd concentration of 2 $\mu g \cdot dm^{-3}$, *ie* mortality of moulting animals was 0%. Similar situation was observed in the control sample. 11% of all moulting shrimps died in the Cd concentration of 5 $\mu g \cdot dm^{-3}$, and as much as 47% in the Cd concentration of 10 $\mu g \cdot dm^{-3}$.

In order to compare the effect of water salinity on the rates of cadmium uptake and accumulation, the animals were kept in 50 $\mu g\ Cd \cdot dm^{-3}$ concentration, and salinities of 19 and $20^0/_{00}$ (Fig. 4). In case of $19^0/_{00}$ salinity, cadmium accumulation by *C. crangon* was much higher, and amounted to 7.31 ± 1.08 $\mu g \cdot g^{-1}$ of dry weight, *ie* to 1.18 ± 0.04 μg $Cd \cdot indiv^{-1}$. On the other hand, in case of 28‰ salinity, *C. crangon* accumulated 4.40 ± 1.14 μg $Cd \cdot g^{-1}$ of dry weight (*ie* 0.72 ± 0.40 μg $Cd \cdot indiv^{-1}$) in the same period. By the end of the experiment, animals in the control sample contained only 1.19 ± 0.33 μg $Cd \cdot g^{-1}$ of dry weight in 19‰ salinity, and 0.85 ± 0.05 $\mu g \cdot g^{-1}$ of dry weight in 28‰. These facts point to significant effect of water salinity on cadmium uptake and accumulation by *C. crangon*. Higher water salinity resulted in decreased accumulation of this metal by the shrimp.

4. Discussion

There are two essential ways of cadmium uptake by the living organisms: directly from water or through the trophic chain – with food. In case of *C. crangon* studies were made on cadmium uptake from the surrounding environment, *viz* sea water. It was shown that levels of cadmium uptake were proportional to its concentration in water and the time of exposure. Similar direct relationship between heavy metal concentration in the environment and the animal body was observed for *Mytilus edulis* (Scholtz 1980). Moreover, the experiment revealed that high cadmium concentration in water was very toxic for *C. crangon*. Cd concentrations of 50 and 100 $\mu g \cdot dm^{-3}$ resulted in 50% mortality of the shrimp after 7 and 4 days respectively.

Studies on the negative effect of cadmium upon marine animals delt with organisms from other seas or Baltic regions, for example: *Laomedea loveni* (Theede *et al* 1979a), *Mytilus edulis* (Theede *et al* 1979b). There were no Polish papers on this problem. Dethlefsen (1977) carried out some experiments on *C. crangon* from the Labe River estuary. Most probably this is the only paper on this species. Dethlefsen (1977) carried out his experiments in water salinity of 30‰, *ie.* higher than in the present study. This was probably the reason for his observation that in 100 μg $Cd \cdot dm^{-3}$ concentration *C. crangon* accumulated 16.11 μg $Cd \cdot g^{-1}$ of dry weight during 30 days. In other words, in case of the same Cd concentration but in lower salinities, the animals accumulated similar cadmium levels in a much shorter period than the animals in higher salinities. This suggests that water salinity is most important in the uptake and accumulation of cadmium by *C. crangon*.

Møhlenberg and Jensen (1980) studied the effect of salinity on cadmium accumulation by an American oyester, *Crassostrea virginica*. These authors found that the oyester accumulated 5 times more cadmium in 10‰ salinity than in 20 and 30‰. Studies on the effect of salinity upon the polypus *Laomedea loveni* revealed the highest tolerance in low temperature and high salinity (Theede 1980).

There might be two explanations to the increased accumulation in lower salinities: Cadmium is uptaken as free Cd^{++} ion. Concentration of free cadmium ions increases at lower water salinities. This results in an increased accumulation in lower salinities, and especially in fresh waters. Secondly, salinity may indirectly affect calcium levels. At low water salinity concentration of calcium is usually low. Since the mechanism of uptake is identical for Ca^{++} and Cd^{++} ions, there is an increased possibility of saturating with cadmium of, for instance, the exeternal skeleton or other body parts in the animals which would utilize calcium in normal conditions (Mohlenberg, Jensen 1980).

During the period of the so-called elimination, metal contents in the animal organism did not decrease. The elimination period lasted only 7 days, as in case of most marine species elimination takes place in the first few days (if ever) (Benayoun *et al* 1974). Also Dethlefsen (1977) did not notice elimination of cadmium from shrimp body during 20 days. No lowering of cadmium levels was observed in *Carcina maenas*, *Patella vulgaris* and *Nucella lapillus* which were initially kept in water with 0.01 mg $Cd \cdot dm^{-3}$, and then transferred to the environment with Cd concentration of 0.0002 $mg \cdot dm^{-3}$ for 3–7 weeks. Contrarily to these examples, elimination in *Mytilus edulis* was very rapid (Theede *et al* 1979b).

Dethlefson (1977) studied cadmium content in bodies and exuvia of shrimps. He found that both contained similar levels of this metal. On the other hand, cadmium content in *C. crangon* from the Kiel Bay was much higher in the exuvia than in the animal body.

Jennings and Rainbow (1979) observed accumulation of cadmium from water by *Carcinus maens*. These authors found that the external skeleton absorbed 59–80% of total accumulation, this being a result of passive absorption by the surface. When cadmium was absorbed from food, the external skeleton contained only 22.2% of total cadmium uptake. On the other hand, the external skeleton was the first to loose cadmium when *C. meanas* was transferred to water with no cadmium. This loss constituted 78% of total amount of cadmium lost by the animals during 10 days. Relationship observed for *C. maenas* are somewhat similar to those noted for *C. crangon*, in which the exuvia contained more cadmium than the animal organism, and during the elimination period the exuvia lost more metal.

Increase in the moulting frequency of *C. crangon* was certainly due to some disturbance in the physiological functioning of the animals. Unfortunately, the shrimps were not measured so it is difficult to state whether the moulting was accompanied by body growth or whether the growth was also affected. Adult *Mytilus edulis* kept in low cadmium concentrations did not show any physiological disturbances (Theede *et al* 1979b).

It seems that the amount of cadmium uptaken by *C. crangon* was also connected with the animal size. The experiments were essentially carried out on animals of more or less the same size, so it is difficult to assess the effect of body size on cadmium accumulation. At the same time, length and weight of *C. crangon* were measured (average individual length 43.2 ± 4.8 mm, average wet weight 576 ± 224 mg), so it was possible to observe that smaller individuals accumulated more cadmium. For instance, individuals 40 mm long accumulated 12.46 μg $Cd \cdot g^{-1}$ of dry weight, while individuals 42 mm long–12.38 μg $Cd \cdot g^{-1}$, and 48 mm long–only 10.24 μg $Cd \cdot g^{-1}$ of dry weight in the same time. This phenomenon could be explained by more intensive metabolism of smaller animals (Szaniawska 1980). Certainly, this problem needs further consideration.

The observed deviation from the average weight of the animals resulted from the fact that females bearing eggs were characterized by higher weight (sometimes double) than the females of the same length but with no eggs.

As mentioned above, no differences were observed in the accumulation by females and males. The experiment was not aimed at clarifying this problem, as it is of no importance from the consumption's point of view.

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