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Heavy metal concentrations and size effects in the mesopelagic decapod crustacean *Systellaspis debilis*

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ABSTRACT: Specimens of the oceanic decapod crustacean *Systellaspis debilis* from the NE Atlantic were analysed for whole body concentrations of Cu, Zn, Fe, Mn and Cd. Concentrations of Zn, Fe, Mn and Cd decreased with increasing dry weight; Cu concentrations increased. Theoretical metabolic requirements for Zn, Mn and Fe in a decapod crustacean were estimated and are closely matched by the concentrations measured in *S. debilis*. The low copper concentrations may be explained by a low body content of haemocyanin.

INTRODUCTION

Trace metals are generally more concentrated in marine organisms than in the surrounding seawater and concentration factors may reach many thousand fold. Marine organisms are obligate accumulators of metabolically essential metals like copper, zinc and iron but also accumulate non-essential metals such as cadmium and lead, possibly via transport pathways common to essential metals. The potential of marine organisms, especially invertebrates, to concentrate trace metals has prompted their use as monitors of metal concentrations in estuarine and coastal environments (Phillips 1976a, b, 1977, 1980, Bryan & Hummerstone 1978, Bryan et al. 1980), and a large volume of data has been accumulated (e.g. Eisler 1981).

Oceanic waters away from anthropogenic influence may be expected to have 'background' concentrations of trace metals and indeed measurements have shown concentrations to be considerably (more than 10 times) lower than in coastal waters (Bruland 1983, Jones & Jeffries 1983). Metal concentrations in oceanic invertebrates might therefore be expected to be considerably lower than those in coastal species. There are however relatively few data on trace metal concentrations in oceanic invertebrates which can be used to make such comparisons. Leatherland et al. (1973) reported concentrations of several metals in a number of pelagic organisms from the NE Atlantic. Of particular note in their study were the high concentrations of cadmium (3 to 13 µg Cd g^{-1} dry wt) in 3 species of decapod crustaceans. These cadmium concentrations are comparable to those found in decapod crustaceans from cadmium-polluted coastal environments, such as the Bristol Channel, Britain (Peden et al. 1973, Hardisty et al. 1974). More recently Ridout et al. (1985) reported concentrations of Mn, Fe, Cu, Zn and Cd in the mesopelagic decapod *Systellaspis debilis* from several sites in the E Atlantic, supporting data presented by Leatherland et al. (1973).

The effect of individual animal size on metal concentrations has been widely recognised, particularly in monitoring studies using indicator species (e.g. Boyden 1977, Phillips 1977, Bryan et al. 1980). While knowledge of size-metal concentration relationships is clearly important for such studies, they may have a wider significance by being indicative of the biology and physiology with regard to metals of the organisms studied.

In order to minimize the effect of any size-metal concentration relationships, Ridout et al. (1985) presented data for *Systellaspis debilis* of only a limited size range. The present study extends this work by examining the effect of size on the concentrations of Cu, Zn, Fe, Mn and Cd in *S. debilis*. The measured metal concentrations are also examined in terms of estimated metabolic requirements.

MATERIALS AND METHODS

Sampling. *Systellaspis debilis* (Milne Edwards) were collected on 9 Jun 1984 (0530 to 0730 h) at 35° 48′ N,

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18° 51′ W, in a rectangular mid-water trawl (4.5 mm mesh) with a closing cod-end at a sampling depth of 590 to 700 m during RRS *Discovery* Cruise No. 148. Specimens were sexed prior to being transferred to individual polythene bags and deep frozen (−20 °C) for shipment to the U.K.

Sample preparation and analysis. After thawing, specimens were rinsed in double-distilled water to remove particulate matter, then dried in acid-washed test-tubes at 60 °C to constant weight. Dried samples were digested using concentrated nitric acid (Aristar grade, BDH Ltd; ~3 ml g^{-1} dry material) at 100 °C. Digested samples were made up to volume with double-distilled water and analysed for copper (Cu), zinc (Zn), iron (Fe), manganese (Mn) and cadmium (Cd) using a Varian AA375 atomic absorption spectrophotometer with flame atomization and deuterium arc background correction. All body metal concentrations are quoted in µg g^{-1} dry weight.

Data were fitted to linear regression equations using analysis of variance according to Sokal & Rohlf (1969).

RESULTS

Fig. 1 to 5 show linear plots of concentration against dry weight for the 5 metals studied. As there were no apparent differences in metal concentration-size relations between juveniles, males and females, the regression equations are based on all individuals. Tables 1 & 2 summarize the statistical data.

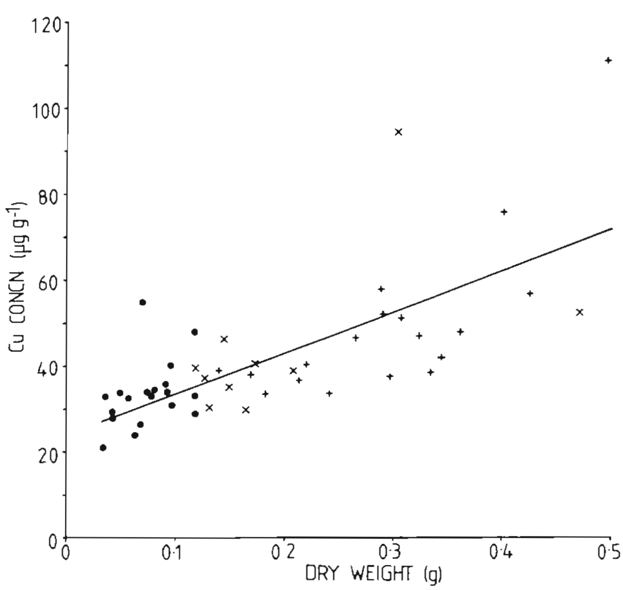

Fig. 1. *Systellaspis debilis*. Relation between copper concentration (Y) and individual dry weight (X). Fitted curve is Y = 95.47 X + 24.27 See Table 2 for regression statistics. (●) Juveniles; (×) males; (+) females

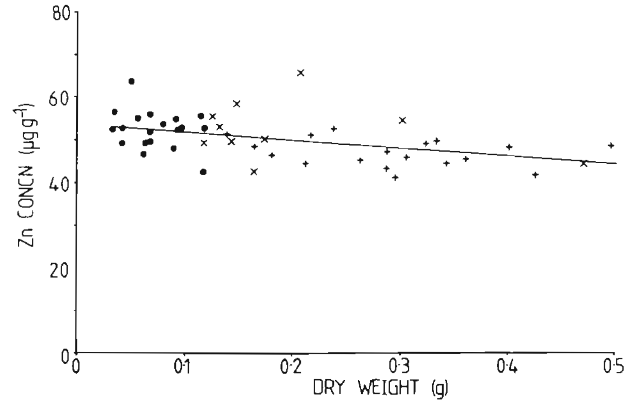

Fig. 2. *Systellaspis debilis*. Relation between zinc concentration (Y) and individual dry weight (X). Fitted curve is Y = 53.63 − 19.22 X. Other details as for Fig. 1

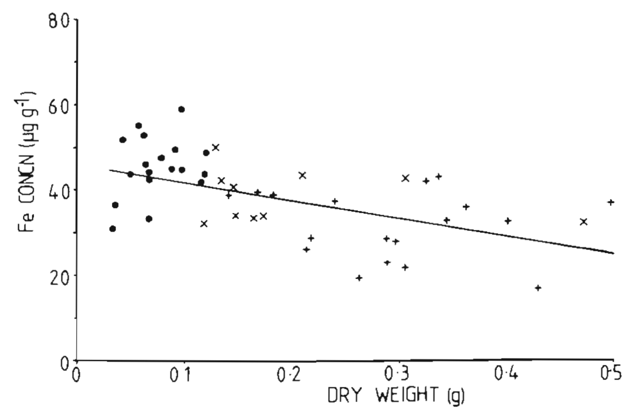

Fig. 3. *Systellaspis debilis*. Relation between iron concentration (Y) and individual dry weight (X). Fitted curve is Y = 46.07 − 41.14 X. Other details as for Fig. 1

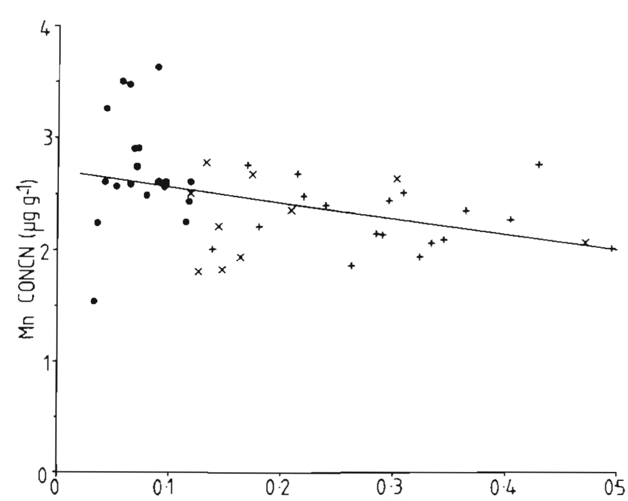

Fig. 4. *Systellaspis debilis*. Relation between manganese concentration (Y) and individual dry weight (X). Fitted curve is Y = 2.71 − 1.347 X. Other details as for Fig. 1

Table 1. *Systellaspis debilis*. Dry weight (g) and metal concentration (µg g^{-1}) in decapods collected in a single mid-water trawl in the NE Atlantic Ocean

		Metal concentration				
	Dry weight	Cu	Zn	Mn	Fe	Cd
Mean	0.1850	41.9	50.1	2.46	38.1	12.8
SD	0.1256	16.8	5.2	0.45	9.4	2.9
Range	0.0355–0.4972	20.9–112	40.8–65.4	1.53–3.66	16.4–58.5	5.7–17.8
n	47	47	47	47	46	47

Table 2. *Systellaspis debilis*. Regression data for linear relations $C = a + bW$, where C is metal concentration (µg g^{-1}), W dry weight (g) and a (the intercept) and b (the regression coefficient) are constants. Fs: F statistic; p: probability that $b = 0$; r^2: square of the correlation coefficient

Metal	a	b	Fs	p	r^2
Cu	24.268	95.472	46.64	<0.001	0.509
Zn	53.627	−19.218	12.41	<0.001	0.216
Fe	46.073	−42.452	20.88	<0.001	0.322
Mn	2.714	− 1.347	7.45	<0.01	0.142
Cd	14.794	−10.742	12.67	<0.001	0.220

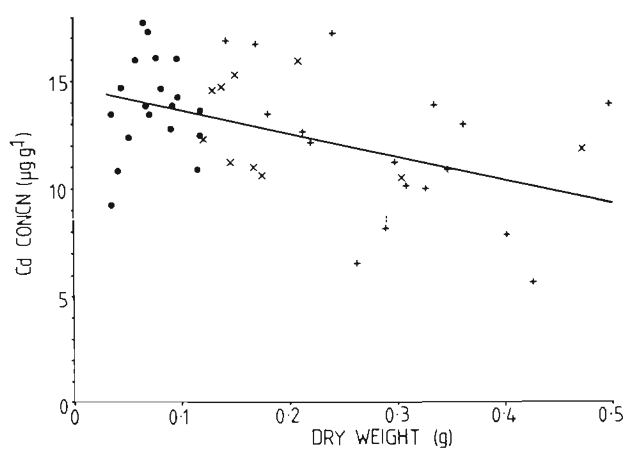

Fig. 5. *Systellaspis debilis*. Relation between cadmium concentration (Y) and individual dry weight (X). Fitted curve is $Y = 14.79 - 10.74\,X$. Other details as for Fig. 1

For all the metals analysed, the concentration varied significantly ($p < 0.05$) with the dry weight of the shrimps, decreasing for Zn, Fe, Mn and Cd, increasing for Cu.

White & Rainbow (1985) have examined the metabolic requirements of crustaceans for zinc and copper by estimating the amounts required for enzymatic and non-enzymatic uses. The calculations were largely based on the proportion of enzymes known to be associated with copper or zinc and on the concentration, and metal content, of the respiratory pigment haemocyanin typically found in coastal decapod crustaceans (White & Rainbow 1985). Such calculations can be extended to estimate the metabolic requirements of manganese and iron in crustaceans (Table 3). There is no known metabolic requirement for cadmium. Table 4 compares estimated metal requirements with measured concentrations in *Systellaspis debilis*.

DISCUSSION

The concentration of copper in *Systellaspis debilis* increased with increasing size from 20.9 to 112 µg Cu g^{-1}. The concentration in the smallest individuals is therefore of the order of the estimated enzymatic requirement alone. This suggested that small *S. debilis* might have little or no haemocyanin. Preliminary measurements on whole specimens have shown that small *S. debilis* (ca 0.1 g) have less than half the haemo-

Table 3. Estimates of enzymatic, haemocyanin and total requirements (µg g^{-1}) for Cu, Zn, Fe and Mn in crustaceans (after White & Rainbow 1985)

	Cn	Zn	Fe	Mn
No. of metal-associated enzymes[a]	30	80	70	12
Percentage of total enzyme no. (2137)[b]	1.40	3.74	3.28	0.56
Average no. of metal atoms per molecule of metal-associated enzyme	2.95	1.41	1.5	1.25
Estimated enzymatic requirement	26.3	34.5	27.4	3.9
Haemocyanin metal requirement[c]	57.4	36.3	–	–
Total metabolic requirement	83.7	70.8	27.4	3.9

[a] Bowen (1979); [b] Dixon & Webb (1979); [c] White & Rainbow (1985)

Table 4. *Systellaspis debilis*. Comparison of estimated metabolic metal requirements with measured concentrations (μg g^{-1})

	Cu	Zn	Fe	Mn
Estimated enzymatic requirement	26.3	34.5	27.4	3.9
Estimated haemocyanin requirement	57.4	36.3	0	0
Total requirement	83.7	70.8	27.4	3.9
Measured metal concentration (range)	20.9–111.6	40.8–65.4	16.4–58.5	1.5–3.7

cyanin (per unit weight) of that in the coastal decapod species *Palaemon elegans* (unpubl. obs.), which typically has a copper concentration of 110 μg Cu g^{-1} (White & Rainbow 1982). In larger *S. debilis* however the haemocyanin concentration approaches that in *P. elegans* and it is probable that this explains the corresponding increase in copper concentration. Juvenile *S. debilis* undergo a less distinct daily vertical migration than adults (Roe 1984, pers. comm.). This may be related to the low haemocyanin content of young decapods and might indicate that low bioavailability of copper in the mesopelagic environment is a limiting factor to the activity of these animals, at least until sufficient copper has been accumulated to allow increased haemocyanin levels.

The concentration of zinc in *Systellaspis debilis* decreased slightly with increasing size ranging from 65.4 to 40.8 μg Zn g^{-1}, in good agreement with the figure of 50 μg Zn g^{-1} reported by Leatherland et al. (1973). The estimated total metabolic requirement for zinc is slightly above the measured concentrations in *S. debilis* but this may be explained by the relatively low haemocyanin concentrations, the zinc possibly being involved in stabilisation of the quaternary structure of the haemocyanin molecule (Martin et al. 1977, see White & Rainbow 1985). By comparison coastal natantian decapod species have body zinc concentrations that are regulated at 80 to 100 μg Zn g^{-1} over a wide range of external zinc concentrations (White & Rainbow 1982, Devineau & Amiard-Triquet 1985).

The concentration of iron in *Systellaspis debilis* decreased with increasing size though most samples were close to the estimated metabolic requirement of 27 μg Fe g^{-1}. The iron concentrations in *S. debilis* are lower than the few reported measurements on crustaceans (see Eisler 1981) although White (1982) found concentrations of 15 to 55 μg Fe g^{-1} in *Palaemon elegans*.

The concentrations of manganese in *Systellaspis debilis* again decreased with increasing size but the concentrations were very low and indeed were slightly lower than the calculated metabolic requirement for the metal, 3.9 μg Mn g^{-1}. There are few reported concentrations of manganese in decapod crustaceans; Bryan & Ward (1965) reported 128 μg g^{-1} in *Homarus vulgaris* though most (98 %) of the manganese was associated with the heavily calcified exoskeleton. Concentrations in less calcified forms are lower; Knauer (1970) reported 6.1 μg Mn g^{-1} in *Penaeus* spp. and White (1982) found 7.9 μg g^{-1} in *Palaemon elegans*. While these concentrations are somewhat higher than found in *S. debilis*, concentrations in euphausids, 2.2 to 4.5 μg Mn g^{-1} (Martin & Knauer 1973, Fowler 1977), are in good agreement and closely match the estimated metabolic requirements.

As discussed by Ridout et al. (1985) the cadmium concentrations for *Systellaspis debilis* agree well with the figure of 13 μg g^{-1} reported by Leatherland et al. (1973) but are considerably higher than concentrations typical of coastal decapods, 1 to 2 μg g^{-1} (White & Rainbow 1982). Given the low concentrations of cadmium in oceanic waters it is likely that the diet is the major source of cadmium (Ridout et al. 1985).

The concentrations of all 5 metals showed significant, though often small, variations with individual dry weight but approximate to the estimated metabolic requirements. With the exception of copper it is possible that the decrease in concentration with increasing dry weight is a surface area effect relating to a proportion of the total metal content associated with the external surface of the decapods and therefore not under metabolic influence. While such an effect would tend to give a curvilinear relation the variability in these data may mask such trends. A variety of curvilinear models fitted to these data showed little if any improvement over the linear model and have therefore not been considered here.

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