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Levels of Trace Metals and Effect of Body Size on Metal Content and Concentration in *Arctica islandica* L. (Mollusca: Bivalvia) from Kiel Bay, Western Baltic

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The levels of four trace metals (Cd, Cu, Pb, and Zn) in the whole soft body and in different organs of the ocean quahog *Arctica islandica* were evaluated from four stations in Kiel Bay, Western Baltic. The relationships between the contents and concentrations of these metals and body size (weight and length) were also investigated. Double logarithmic plots of metal contents and concentrations against dry body weight and shell length, respectively, show straight-line relationships. The results indicate that smaller individuals have higher concentrations of Cu and Zn, two essential metals, while larger individuals have higher concentrations of Cd and Pb, two non-essential metals. The calculated regression slopes of metal content against dry-body weight revealed that Cd and Cu appear to be affected by maturation since two different slopes are observed for both metals before and after maturation. This was not obvious for Pb and Zn. Pooled slopes of metal content against dry-body weight for all animal sizes indicated that Cu and Zn have a one common slope of (0.82) and Cd and Pb another common one of (1.51). Plots of metal concentrations against shell length indicated also that Cu and Zn have one common slope of (−0.54) and Cd and Pb another one of (1.56). Moreover, it was possible to calculate one final slope of (1.53) for Cd and Pb from both content/weight and concentration/length plots. This indicates that *A. islandica* may have one metabolic strategy for the essential metals and another for the non-essential metals.

The ocean quahog *Arctica* (*Cyprina*) *islandica* (Linnè) is a large bivalve mollusc that is widely distributed through the boreal Atlantic and adjacent areas, the German North Sea and the western Baltic (Jagnow & Gosselk, 1987). Recently, interest has focused on *A. islandica* for reasons related to human nutrition. In Kiel Bay, *A. islandica* is the most important species of the benthic community with regard to biomass as well as production (Brey *et al.*, 1990), and constitutes an important part of the diet of the commercially important fish cod (*Gadus morhua*) (Arntz, 1973, 1977, 1980; Arntz & Weber, 1970; Brey *et al.*, 1990). In North America, *A. islandica* is becoming commercially important for human consumption as a replacement for the dwindling stocks of the surf clam, *Spisula solidissima* (Thompson *et al.*, 1980b; Murawski *et al.*, 1982; Steimle *et al.*, 1986).

Arctica islandica is one of the slowest growing and longest lived of the continental shelf pelecypods (Murawski *et al.*, 1982; Forster, 1981). The largest clam of this species ever recorded from the Baltic measured 74 mm with an estimated age of nearly 23 years (Brey *et al.*, 1990), while individuals of the Atlantic may reach an age of >100 years and a length of >100 mm (Thompson *et al.*, 1980a; Murawski *et al.*, 1982). *Arctica islandica* is sedentary (Theede *et al.*, 1969; Thompson *et al.*, 1980a), resistant to oxygen deficiency and hydrogen sulphide (Theede *et al.*, 1969; Dries & Theede, 1974) and inhabits the silty sands that frequently contain higher levels of contaminants than coarser sands. Consequently, *A. islandica* may be particularly susceptible to contamination and may act as a good offshore biological indicator (Steimle *et al.*, 1986).

Although some studies on contaminant body burdens of *A. islandica* have been reported (Wenzloff *et al.*, 1979; Steimle *et al.*, 1986), most of these studies have been confined to the northwest Atlantic. In the Baltic there have been no studies of trace metals in *A. islandica*. Here we document concentrations of four trace metals, Cd, Cu, Pb, and Zn in the whole soft body and in different organs of *A. islandica* from the Baltic as well as considering the influence of dry-body weight and shell length on tissue metal content and concentration, respectively.

Materials and Methods

Sampling protocol and analytical procedure

Arctica islandica were caught by dredging from four stations in Kiel Bay (Fig. 1) between July 1992 and January 1993 and frozen for later analysis. In the laboratory all bivalves were measured, removed from their shells and the mantle cavity washed briefly with distilled water. All animals were analysed individually for metals in whole soft tissues except for those analysed for metals in organs. Here organs from 3–4 animals (56–58 mm shell length) were pooled together. Soft tissues were freeze-dried for 1 week, weighed and ground to powder. Subsamples of nearly 20 mg were weighted and digested in quartz vessels with TEFLON covers to allow acid reflux to take place. The digestion mixture used was composed of 1:1, v:v, nitric:perchloric super pure acids (Fischer, 1983). The volume of the mixture used was always 10 times the sample mass. Digestion took place in a sand bath where the temperature was increased gradually up to 200°C over the first 5 h. Subsequently, digestion was allowed to continue for a further 10 h. Finally, samples were dried via evaporation on a hot plate at nearly 100°C and the volumes were brought to 1 ml using 1 N HCl. Subsequent dilutions using 0.2% HNO_3 were performed and the concentrations of Cd, Cu, Pb, and Zn measured using a flameless atomic absorption spectrophotometer type Perkin–Elmer 3030 with automatic sampler and Zeeman background corrector. *Mytilus edulis* tissue, CRM 278, provided by the Commission of the European Communities, Community Bureau of References, was used as reference material and all the accepted recoveries of the four metals were above 90%.

Treatment of the data

All calculations refer to dry weight of soft tissues. One way analysis of variance (ANOVA) was applied to investigate the differences in metal concentrations between stations. Where significant differences were observed, the Tukey test (honestly significant difference test) was used to determine which means were significantly different from others.

Treatment of the data concerning the relationship between metal content and concentration and body size follows the outlines given by Boyden (1974, 1977). He suggested that plotting metal content or concentration against body size on double logarithmic scales generally produces a straight-line relationship that can be easily defined by an equation according to:

$$\text{Log(metal)} = \log(a) + b\log(\text{body size}),$$

where (a) is the intercept and (b) is the slope. Comparisons of slopes are based on the 95% confidence intervals. Differences are considered real when the confidence intervals do not overlap.

Results and Discussion

No significant differences in metal concentrations were observed between clams from the four stations except for Zn (F_3, $35 = 3.03$, $P = 0.05$). Clams from Süderfahrt and Millionenviertel contained significantly higher Zn concentrations than those from Dorschmulde and Vejsnäs Channel (Tukey test, $P < 0.05$) (Table 1). This difference may be because clams from Süderfahrt and Millionenviertel were sampled in July, when all mature *A. islandica* are in a reproductive state (Jaeckel, 1952; von Oertzen, 1972). It is known that reproduction is accompanied by variations in the physio-

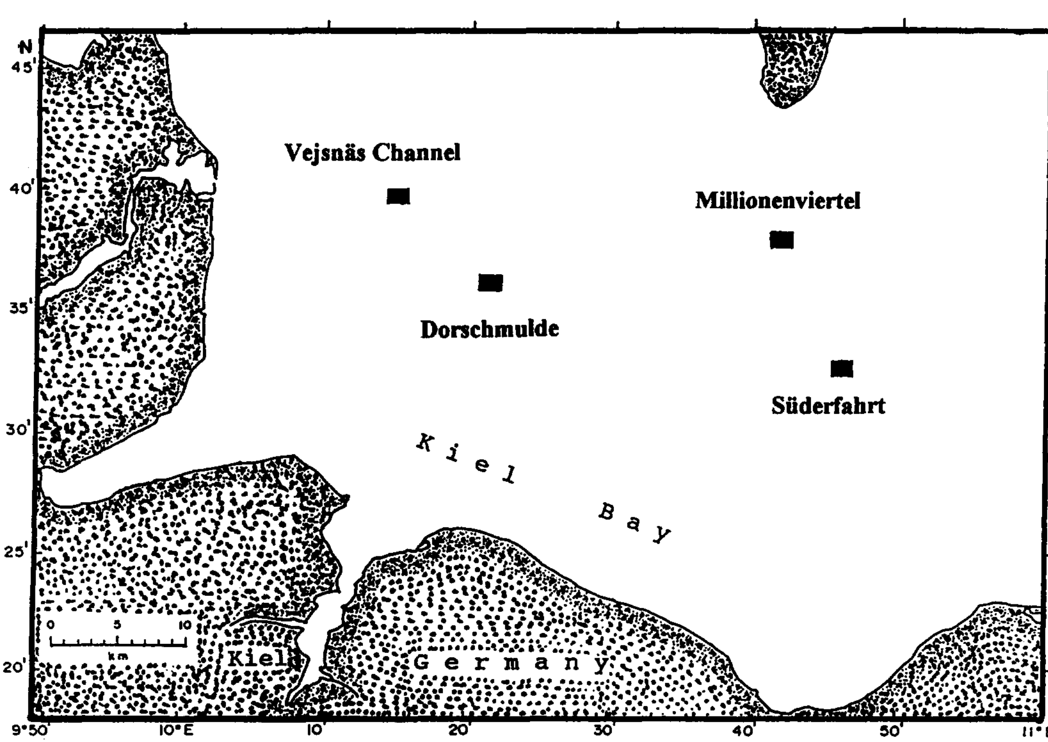

Fig. 1 Kiel Bay showing the location of the stations.

TABLE 1

Comparison of mean trace metals concentrations (μg g^{-1} dry wt) in the whole body of *Arctica islandica* from the Baltic and the northwest Atlantic.

Area and reference	Cd	Cu	Pb	Zn
Georges Bank-Nantucket				
Sick (1978)	1.10	3.50	0.35	252
Payne *et al.* (1982)	4.50	5.40	3.50	150
Steimle *et al.* (1986)	1.40	10.3	4.10	62
Block Island Sound				
Steimle *et al.* (1986)	1.90	10.0	10.2	102
New York Bight				
Steimle *et al.* (1986)	1.30	11.3	5.70	95
Chesapeake Bight				
Steimle *et al.* (1986)	2.20	5.40	4.70	71
Present study*				
Süderfahrt, July 1992	0.76	14.9	0.84	226
	(0.25)	(3.27)	(0.19)	(45.6)
Millionenviertel, July 1992	0.50	15.3	1.55	188
	(0.07)	(4.80)	(0.26)	(26.9)
Dorschmulde, Sept. 1992	0.91	13.3	1.08	144
	(0.25)	(1.20)	(0.33)	(32.9)
Vejsnäs Channel, Sept. 1992	0.75	13.8	1.25	113
	(0.19)	(1.98)	(0.46)	(14.3)

*Average ± SD (in brackets) of 10 individuals of medium size (40–60 mm shell length).

logical conditions of molluscs and in the affinity of metals for biochemical substances (Oesterberg, 1974). Cd and Pb concentrations from the Baltic seemed to be less than those reported from the northwest Atlantic (Table 1), Cu and Zn concentrations were, however, comparable. It is worthy to note that the possible difference in size of the animals analysed from both areas may account for the difference in their Cd and Pb concentrations since the two metals were found to increase with size (Figs 2, 3) and animals from the northwest Atlantic grow more than those from the western Baltic. Animals analysed from the northwest Atlantic were reported to be of 'medium size' which may, in fact, mean that they were bigger than our medium-sized animals. Zn and Cu are two essential metals that can be regulated by animals, thus it is logical to compare their concentrations in both areas.

Different organs show different capacities for accumulating metals (Table 2). Highest metal concentration occurred in the gills, followed by the kidney, digestive gland, mantle, foot, anterior adductor muscle and finally posterior adductor muscle. Metal concentrations seem to be associated with organ function. The gills are responsible for the water flow and are exposed to a large water mass and thus are expected to have high metal concentrations. The kidney, digestive gland and the mantle, which are responsible for filtration, digestion and secretion of the shell material, respectively, also contain elevated metal concentrations. The foot muscle contains relatively higher metal concentrations than the anterior and posterior adductor muscles perhaps owing to its contact with the sediment. Both adductor muscles appear to have similar Cu and Zn concentrations although the anterior tends to

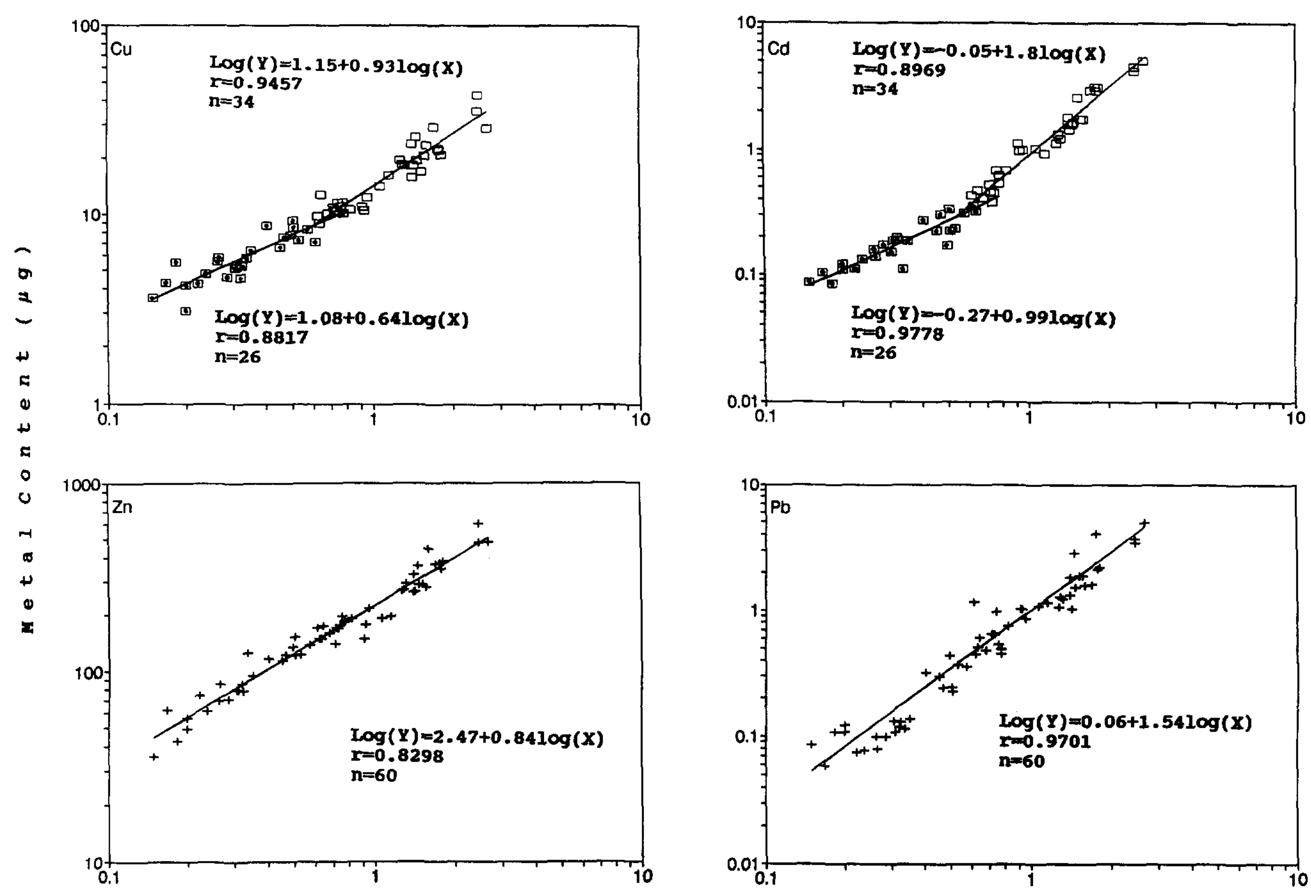

Fig. 2 The relationship between four trace metal contents and dry weight of *A. islandica* from Süderfahrt in Kiel Bay in July 1992. ⊡: animals of shell length 30.1–45 mm, □: animals of shell length 45.2–73.7 mm and +: animals of shell length 30.1–73.7 mm.

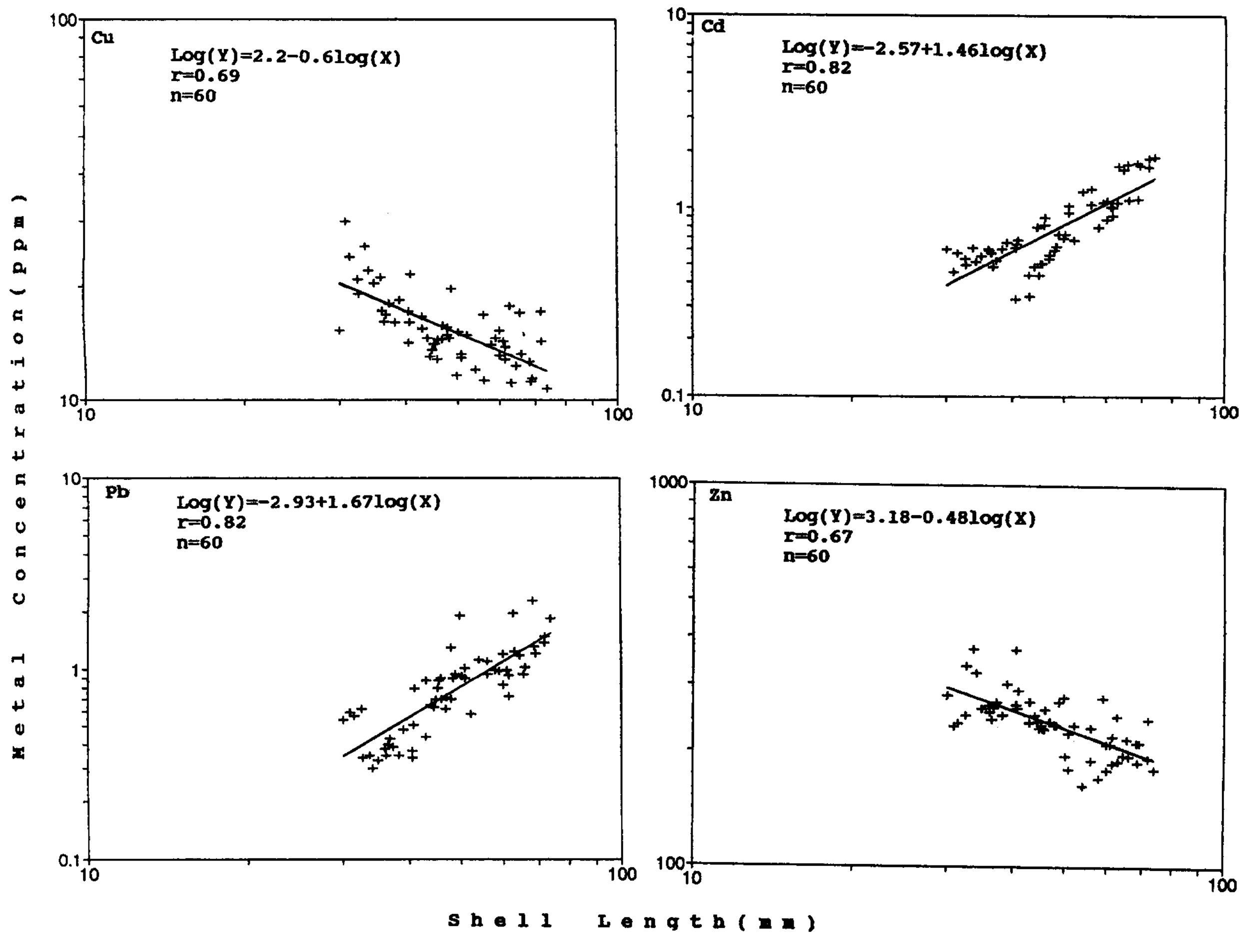

Fig. 3 The relationship between four trace metal concentrations and shell length of *A. islandica* from Süderfahrt in Kiel Bay in July 1992. +: animals of shell length 30.1–73.7 mm.

TABLE 2

Mean metal concentrations (μg g^{-1} dry wt) ± SD and rank in metal richness (in brackets) of the organs of *Arctica islandica* from Dorschmulde in Kiel Bay in January 1993.

	Cd	Pb	Cu	Zn	Total rank score
Posterior adductor muscle	0.12 ± 0.02 (1)	0.49 ± 0.41 (1)	2.27 ± 0.16 (2)	55.4 ± 7.2 (2)	6
Anterior adductor muscle	0.76 ± 0.17 (5)	1.17 ± 0.41 (5)	1.75 ± 0.36 (1)	49.5 ± 9.3 (1)	12
Foot	0.78 ± 0.09 (6)	0.60 ± 0.16 (2)	3.12 ± 0.24 (3)	83.3 ± 4.6 (3)	14
Mantle	0.67 ± 0.12 (4)	0.65 ± 0.14 (3)	5.00 ± 0.8 (4)	141 ± 13.6 (5)	16
Digestive gland	0.32 ± 0.05 (3)	0.9 ± 0.09 (4)	13.45 ± 0.9 (6)	139 ± 19.0 (4)	17
Kidney	0.20 ± 0.05 (2)	2.27 ± 0.27 (7)	40.1 ± 1.5 (7)	146 ± 5.60 (6)	22
Gills	1.35 ± 0.38 (7)	2.14 ± 0.50 (6)	6.66 ± 0.68 (5)	240 ± 20.8 (7)	25

Means are obtained from four pooled samples with 3–4 clams (56–58 mm shell length) in each.

accumulate more Cd than Pb than the posterior. Concentrations of metals in organs of *A. islandica* from the northwest Atlantic are only available from the foot muscle (Wenzloff *et al.*, 1979). Concentrations are reported on a wet weight basis, but when converted to dry weight, by multiplying by eight (Steimle *et al.*, 1986), indicate that animals from the Baltic have relatively lower concentrations.

The content/weight results indicate that, represented on a linear scale, the relationship between metal content and dry weight is curved with larger individuals containing less Cu and Zn and more Cd and Pb than would be expected if metal content were directly related to weight. Metal content is related to dry weight by the following equation:

$$\text{Metal } (\mu g) = a(\text{weight})^b,$$
$$b < 1 \text{ for Cu and Zn}, \quad b > 1 \text{ for Cd and Pb},$$

where (a) is the intercept and (b) is the slope.

As described by Boyden (1977), logarithmic trans-

TABLE 3
Information relating element content to body weight and element concentration to shell length of *Arctica islandica* from Süderfahrt in Kiel Bay, July 1992.

Metal and (*n*)	Shell length (mm)	Body weight (g dry wt)	Real intercept (a) value	Regression coefficient (b)	Correlation coefficient (r)*	± 95% confidence limit of (b)
Weight/content analysis						
Cd						
(26)	30.1–45.0	0.15–0.53	0.54	0.99	0.9778	0.21
(34)	45.2–73.7	0.63–2.89	0.89	1.80	0.8969	0.13
Common						
(60)	30.1–73.7	0.15–2.89	0.93	1.48	0.9761	0.09
Cu						
(26)	30.1–45.0	0.15–0.53	12.02	0.64	0.8817	0.15
(34)	45.2–73.7	0.63–2.89	14.10	0.93	0.9457	0.11
Common						
(60)	30.1–73.7	0.15–2.89	14.10	0.80	0.9694	0.05
Pb						
(60)	30.1–73.7	0.15–2.89	1.15	1.54	0.9701	0.10
Zn						
(60)	30.1–73.7	0.15–2.89	295.1	0.84	0.8298	0.05
Length/concentration analysis						
Cu						
(60)	30.1–73.7	0.15–2.89	158.5	−0.60	0.69	0.17
Cd						
(60)	30.1–73.7	0.15–2.89	0.0027	1.46	0.82	0.27
Pb						
(60)	30.1–73.7	0.15–2.89	0.0012	1.67	0.82	0.31
Zn						
(60)	30.1–73.7	0.15–2.89	1513.6	−0.48	0.67	0.14

*All values are significant at $P \leqslant 0.001$.

formations of this equation yield straight-line relationships (Fig. 2). Williamson (1980) suggests that the variations in metal content between smaller and larger mussels may be due to the difference in their metabolic activity which may affect the metabolism of metals. However, the contents of Cu and Zn reach a plateau in the larger size group which may indicate that these two essential metals are associated with growth, which also reaches such a plateau in older individuals (Lobel & Wright, 1982). Cd and Pb, on the other hand, did not show this pattern and thus seem to be associated directly with age rather than growth. The reduction of growth in old mussels has been reported to be related to sexual maturity (Bayne *et al.*, 1976) and thus it could be due to energy direction toward gamete production at the expense of the energy available for growth (Cossa *et al.*, 1979). The growth plateau seems to affect the slopes of Cd and Cu in regression of x vs y because the slope of Cd changes from (0.99) to (1.8) before and after reaching this plateau and that of Cu changes from (0.64) to (0.93) (Fig. 2). The first slopes (0.99 and 0.64) are obtained from mussels with a shell length <45 mm and an estimated age of <10 years. Thompson *et al.* (1980b) reported that the average age of maturity in *A. islandica* is 9.4 years. Thus, sexual maturation could account for this change in the slopes. Similar results for Cd in *M. edulis* have been reported by Cossa *et al.* (1979). The authors suggested that the change in the slopes may be due to biochemical changes occurring upon reaching adulthood. Fischer (1983) also noticed this change in the slope of Cd content in *Astarte borealis*. It is, however, interesting to note that no significant difference was observed between the slopes of Cd (1.48) and Pb (1.54) and between Cu (0.80) and Zn (0.84) when only one pooled regression slope for Cd and another one for Cu was calculated for all animal sizes (Table 3). This means that a common slope for Cu and Zn (0.82) and another one for Cd and Pb (1.51) can be calculated (Zar, 1984) (Table 4).

Metal content (absolute quantity) in μg and metal concentration in μg g^{-1} tissue weight are, in fact, related. They have the same value when a 1 g individual is considered. The concentration/length plots (Fig. 3) generally indicate a similar idea about metal behaviour as content/weight plots do. However, their correlation coefficients are less than those obtained from content/weight plots (Table 3) and only one significant regression line for each metal over the whole animal sizes was possible. The two essential metals, Cu and Zn, were found to decrease with length and thus to have negative slopes of (−0.6) and (−0.48), respectively, while the two non-essential metals Cd and Pb increased

TABLE 4
Summary of the regression slopes of the four metals obtained from content/weight and concentration/length analysis in *Arctica islandica* from Süderfahrt in Kiel Bay in July 1992.

Metals	Slope (*b*) from Weight/content	Slope (*b*) from Length/concentration	Common (*b*)
Cu/Zn	0.82	−0.54	–
Cd/Pb	1.51	1.56	1.53

Shell length range: 30.1–73.7 mm. Dry body weight range: 0.15–2.89 g.

with length having positive slopes of (1.46) and (1.67), respectively (Table 3). Metal concentration is related to shell length by the following equation:

$$\text{concentration}\ (\mu g\ g^{-1}) = a(\text{length})^{b},$$

where b is a negative value for Cu and Zn and a positive one for Cd and Pb. Again, one common slope of (−0.54) was calculated for Cu and Zn, since their slopes are not significantly different from each other, and another common one of (1.56) for Cd and Pb was calculated for the same reason (Table 4). Moreover, the common slope of (1.51) obtained from the content/weight analysis for Cd and Pb and that of (1.56) obtained from the concentration/length analysis are not significantly different from each other. Consequently, one final regression slope of (1.53) for these two metals can be calculated (Table 4).

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