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Mercury in benthic invertebrates of the Elbe estuary

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ABSTRACT: Hg concentrations in benthic invertebrates of the Elbe estuary were analyzed by atomic absorption spectrophotometry and instrumental neutron activation analysis. In general Hg levels in organisms decreased from the limnic region to the marine environment. Highest Hg levels were found in *Asellus aquaticus* and *Radix balthica* taken from the Elbe upstream of Hamburg (0.35 and 0.34 ppm wet weight). The concentrations in gammarid species decreased from 0.20 ppm (limnic region) to 0.02–0.05 ppm (brackish and marine environment). Hg levels in organisms from the brackish region proved to be 0.08–0.16 ppm *(Littorina littorea)*, 0.04–0.09 *(Crangon crangon)* 0.05–0.10 *(Corophium volutator)* and 0.04–0.08 ppm (wet weight) *(Nereis diversicolor)*. Some factors which may influence the heavy metal concentrations in aquatic organisms are discussed, such as: food chain, weight of organisms, and elimination via moulting products in the case of crustaceans.

INTRODUCTION

Information about heavy metal contamination in the estuary of the River Elbe is available in papers of Nauke (1974; sediments and suspended matter), Müller & Förstner (1975; clay fractions of the sediments), Harms (1974; fish) and Karbe et al. (1975). In general, relatively high values for several elements (including Hg) were reported in the region upstream of Hamburg with a marked tendency to decrease in the region downstream of Hamburg.

Information on the degree to which natural populations of benthic invertebrates in the Elbe estuary are contaminated by heavy metals is still missing. The present study represents an attempt to establish the current level of Hg in naturally occurring populations of invertebrates and to discuss some factors which may influence Hg concentrations in these organisms.

AREA AND ORGANISMS STUDIED

The investigation was carried out in the estuary of the Elbe, concentrating on the brackish-water region; salinities ranged from 5–18 ‰ (according to the "Venice-System"; cf. Caspers, 1959). A characterization of the localities is summarized in Table 1; their geographical position is shown in Figure 3. A summary of organisms

Table 1

Locations of the sampling stations in the Elbe estuary (see Fig. 3)

Station	River (km)	Region	Locality
Oberelbe	upstream of Hamburg	limnic	Hitzacker–Hamburg
1	643	limnic	Hamburg/Wedel
2	645	limnic	Haseldorfer Marsch
3	665	limnic	Schwarztonnensand
4	709	brackish	Belum
5	712	brackish	Otterndorf
6	720	brackish	Altenbruch
7	725	brackish	Cuxhaven/Alte Liebe
8	727	marine	Cuxhaven/Kugelbake
9	—	marine	Trischendamm

collected during spring (May), summer (July–September) and autumn (October till November) of the year 1974 is given in Table 2.

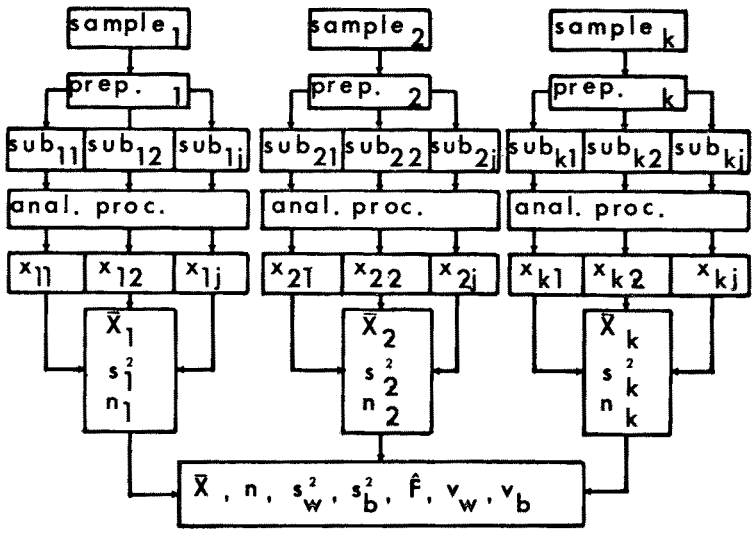

Fig. 1: Diagram of the preparation of the samples and the statistical analysis. Mathematical equations according to Sachs (1973, chapter 73). $sample_{1;\,2,\,k}$: sample consisted of organisms either taken from the same locality at $time_{1;\,2,\,k}$ or from $locality_{1,\,2,\,k}$ at comparable times; prep.: preparation of the samples (cleaning, freezing or freeze-drying); sub_{ij}: subsamples consisted of several to hundreds individuals; anal. proc.: analytical procedure; x_{ij}: Hg-concentration of one subsample; $\bar{x}_i$: mean Hg-concentration of one sample; s^2_i: variance of one sample; n_i: number of determinations; $\bar{X}$: weighted mean of all observations $= \frac{1}{n} \sum_{i=1}^{k} n_i \cdot \bar{x}_i$; s^2_w: variance within sample $= \frac{1}{n-k} \sum_{i=1}^{k} s^2_i\,(n_i-1)$; n: $\sum_{i=1}^{k} n_i$; s^2_b: variance between samples $= \frac{1}{k-1} \sum_{i=1}^{k} n_i\,(\bar{x}_i-\bar{X})^2$; F: quotient of variances $= s^2_b : s^2_w$; v_w: degree of freedom $= n-k$; v_b: degree of freedom $= k-1$

Table 2

Species sampled in the Elbe estuary for Hg analysis and substrata from which the organisms were collected

Taxa	Species	Station	Substratum
Crustaceans	*Asellus aquaticus* (L.)	Oberelbe	stones beneath the water surface
	Gammarus zaddachi Sexton	1, 2, 3	stone groyne, artificial substratum
	G. salinus Spooner		
	G. oceanicus Segerstrale	6, 7, 9	stone groyne, *Fucus* sp.
	Crangon crangon (Fabr.)	4, 5, 6, 8, 9	shallow waters, tide pools
	Corophium volutator (Pallas)	4, 5	mud flats
Gastropods	*Radix balthica* Drap.	Oberelbe, 2	stones beneath the water surface
	Littorina littorea (L.)	6, 7, 8, 9	stone groyne
Bivalves	*Macoma balthica* Leach	6, 8, 9	mud flats
	Cardium edule (L.)	8	mud flats
	Mya arenaria (L.)	9	mud flats
Polychaetes	*Nereis diversicolor* O. F. Müller	4, 6, 8, 9	mud flats
	Nephtys hombergii Lamarck	8	mud flats
	Arenicola marina (L.)	6, 8, 9	mud flats
Fish	*Platichthys flesus* (L.)	4, 6	shallow waters
	Zoarces viviparus (L.)	7	shallow waters

METHODS

Preparation of the samples and statistical analysis

After collection the organisms were washed at the sampling site. The gastropods and bivalves were kept in water from the sampling site for 48 h, the polychaetes were kept under wet filter paper for 24 h to allow purging. After that the samples were stored frozen at – 18° C. All other organisms were frozen immediately after sampling. Only the soft parts of gastropods and bivalves were used for Hg determination. In the case of all other organisms the whole body was prepared for further analysis. The samples were analyzed either as wet material or after freeze-drying, which was carried out for 48 h at – 25° C and a pressure of approximately 0.5 torr above the ice.

A diagram of the preparation of the samples and the statistical analysis is given in Figure 1. The analysis of variance was carried out according to Sachs (1973, chapter 73). The null hypothesis of equality of means is to be rejected, if the quotient of variances (F) exceeds a tabulated value F which is depended on the level of significance (in this paper the 5 % level) and the degrees of freedom (Sachs, 1973)*. Thus the mercury levels of given species taken at different times from one locality were tested as well as the levels of given species taken from different localities.

Analytical procedure

Hg was analyzed by wet digestion (using mixtures of HNO_3/H_2SO_4 and $HNO_3/HClO_4$) and flameless atomic absorption spectrophotometry (AAS) as outlined by Antonacopoulos (1974), using a Coleman MAS-50 or a Perkin-Elmer AAS-300. The element concentrations of 13 subsamples were determined by instrumental neutron activation analysis (INAA). Irradiation of the freeze-dried samples and gamma-spectroscopy was done at the reactor station of the GKSS at Geesthacht (FRG). The integral flux of neutrons proved to be $8 \cdot 10^{18}$ n/cm² (for details see Zauke, 1975). Only the results obtained for Hg will be discussed in this paper.

Comparison of results obtained by different procedures

A comparison of the results of the Hg analysis by AAS and INAA is shown in Figure 2 A. The potential systematic errors of the analytical methods used are quite different. The fact that both methods yield nearly identical Hg values indicates that a bias in the analytical procedures (starting after freeze-drying) is quite unlikely. A

* This procedure presumes normal distributed values. The Hg values obtained for *Littoria littorea* collected in May–September were tested according to Sachs (1973, p. 252) as an example. There is no objection to the normal distribution hypothesis on the 10 %-level of significance ($\chi^2 = 10.49 < \chi^2_{10\,\%} = 14.68$).

comparison of values obtained by AAS using either wet or dry material is given in Figure 2 B. Data are converted to ppm wet weight. In this case statistical parameters also indicate good agreement of results from both procedures. Therefore, a bias introduced by freeze-drying is not significant as is pointed out by La Fleur (1973), who found maximum errors of 5 % being introduced by freeze-drying.

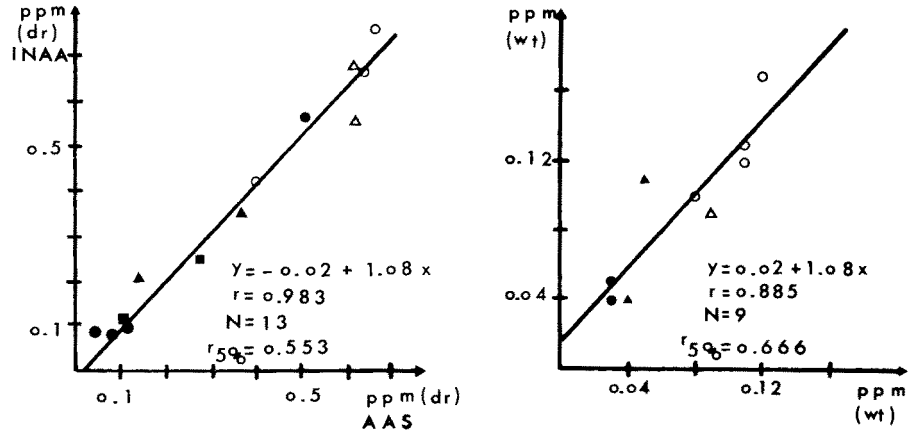

Fig. 2: Correlation analysis: comparison of analytical procedures. (A) Hg determination in benthic invertebrates from the Elbe estuary performed by atomic absorption spectrophotometry, AAS, (x-axis) and instrumental neutron activation analysis, INAA, (y-axis). Values given in ppm (dry weight). (B) Hg determination carried out by AAS using wet (x-axis) and dry (y-axis) material. Data converted to ppm (wet weight). Symbols: ○ *Littorina littorea*, ■ *Nereis diversicolor*, △ *Corophium volutator*, ▲ *Crangon crangon*, ● gammarids. In both cases the correlation coefficients r are significant at least on the 5 %-level as they exceed tabulated values $r_{5\,\%}$ which are dependent on the degrees of freedom (Sachs, 1973; p. 330)

Furthermore, as the analysis of the freeze-dried material was carried out several months later, together with the samples taken in October and November, it is evident that the procedure yielded constant values over the period of investigation. This fact will be important when discussing the possibility of seasonal fluctuations (see below).

RESULTS AND DISCUSSION

Hg concentrations in invertebrates from the Elbe estuary

The results obtained by the procedures described are presented in Tables 3–7 and are summarized in Figure 3 for some important organisms. All Hg concentrations are given in ppm wet weight unless otherwise indicated.

Some of the obtained F values for *Littorina littorea* (c, e, g, Table 3b) indicate different Hg levels in samples taken in July and October/November at nearly all stations, which might be interpreted as seasonal fluctuation. Assuming this, Hg concentrations tend to decrease from spring and summer to late autumn.

Table 3a

Mercury concentrations in *Littorina littorea* from the Elbe estuary and analysis of variance. Water content, mean weight of organisms and Hg concentrations. Values given in ppm (wet weight). 95 %-confidence interval calculated as 1.96 $s_{\bar{x}}$

Number	Station	Sampling date (1974)	H_2O (%)	Mean weight (mg)	Number of determinations	ppm Hg (wet weight) Range	Mean	95 %:confidence interval	$s^2 \times 10^{-7}$
1	6	May	76.6	690	4	0.14–0.16	0.150	0.008	667
2	6	May	—	680	7	0.11–0.18	0.133	0.017	5238
3	6	July	—	780	9	0.12–0.20	0.156	0.018	7528
4	6	July	—	190	5	0.09–0.12	0.110	0.011	1500
5	6	Nov.	80.9	90– 960	8	0.08–0.09	0.088	0.003	214
6	7	May	76.8	10–1000	4	0.12–0.14	0.130	0.008	667
7	7	May	84.8	380– 570	6	0.10–0.13	0.112	0.008	967
8	7	Oct.	79.2	120– 750	4	0.07–0.08	0.075	0.006	333
9	8	July	76.5	500– 770	5	0.09–0.10	0.094	0.004	300
10	8	July	76.5	270	2	0.06	0.06	—	—
11	8	Oct.	81.3	70– 560	6	0.06–0.09	0.082	0.009	1367
12	9	July	75.6	560–1630	10	0.10–0.15	0.118	0.012	3511
13	9	Nov.	78.5	110– 920	6	0.08–0.11	0.095	0.010	1500

Table 3b

Analysis of variance performed between samples referred to in Table 3a (according to Fig. 1)

Number	Between samples	Weighted mean	Variance within samples ($\times 10^{-7}$)	Variance between samples ($\times 10^{-7}$)	F	$F_{5\,\%}$
a	3, 4	0.139	5519	66 705	12.1	4.75
b	1, 2, 3	0.147	5509	10 450	1.90	3.59
c	3, 5	0.124	4115	196 160	47.7	4.54
d	6, 7	0.119	855	8 067	9.43	5.32
e	7, 8	0.097	729	32 267	44.2	5.32
f	9, 11	0.087	893	4 148	4.65	5.12
g	12, 13	0.109	2793	19 838	7.10	4.60
h	3, 9, 12	0.125	4071	78 071	19.2	3.42
i	5, 8, 11, 13	0.086	842	3 667	4.35	3.10

Table 4a

Mercury concentrations in *Crangon crangon* from the Elbe estuary and analysis of variance. Water content, mean weight of organisms and Hg concentrations. Values given in ppm (wet). 95 %-confidence interval calculated as $1.96\ s_{\bar{x}}$

Number	Station	Sampling date (1974)	H_2O (%)	Mean weight (mg)	Number of determinations	Range	ppm Hg (wet weight) Mean	95 %-confidence interval	$s^2 \times 10^{-7}$
14	4	Sep.	75.0	45	2	0.08–0.09	0.085	0.010	500
15	4	Aug. (75)	77.8	30– 120	7	0.08–0.12	0.093	0.014	3571
16	5	Aug.	74.2	330	5	0.05–0.11	0.080	0.025	8000
17	5	Oct.	77.0	270	1	0.05	—	—	—
18	6	July	—	140– 470	4	0.07–0.09	0.083	0.009	917
19	6	Nov.	76.7	220–1115	5	0.05–0.06	0.056	0.005	300
20	8	July	—	140	2	0.04–0.05	0.045	0.010	500
21	8	Oct.	77.0	300– 430	3	0.04–0.05	0.043	0.007	333
22	9	July	74.8	120– 450	12	0.03–0.06	0.043	0.006	1114
23	9	Nov.	76.4	70– 420	3	0.04–0.05	0.043	0.007	333

Table 4b

Analysis of variance performed between samples referred to in Table 4a (according to Fig. 1)

Number	Between samples	Weighted mean	Variance within samples ($\times 10^{-7}$)	Variance between samples ($\times 10^{-7}$)	F	$F_{5\ \%}$
k	15, 16	0.088	5343	4 821	0.902	4.96
l	18, 19	0.068	564	15 606	27.7	5.69
m	22, 23	0.043	994	17	0.02	4.67
n	16, 18, 20, 22	0.058	2500	26 804	10.7	3.13
o	19, 21, 23	0.049	218	2 188	10.0	4.46

Table 5a

Mercury concentrations in *Corophium volutator* from the Elbe estuary and analysis of variance. Water content, mean weight of organisms and Hg concentrations. Values given in ppm (wet). 95 %-confidence interval calculated as 1.96 $s_{\bar{x}}$

Number	Station	Sampling date (1974)	H_2O (%)	Mean weight (mg)	Number of determinations	Range	Hg (wet weight) ppm Mean	95 %-confidence interval	$s^2 \times 10^{-7}$
24	4	May	—	10	1	0.09	—	—	—
25	4	July	—	10	1	0.08	—	—	—
26	4	Nov.	84.0	—	4	0.04–0.07	0.058	0.015	2250
27	5	Aug.	83.3	4	8	0.07–0.13	0.103	0.014	4214
28	5	Oct.	87.9	—	4	0.04–0.06	0.048	0.009	917

Table 5b

Analysis of variance performed between samples referred to in Table 5a (according to Fig. 1)

Number	Between samples	Weighted mean	Variance within samples ($\times 10^{-7}$)	Variance between samples ($\times 10^{-7}$)	F	$F_{5\,\%}$
p	27, 28	0.084	3225	80 667	25.0	4.96
q	26, 28	0.053	1584	2 000	1.26	5.99

Table 6

Mercury concentrations of *Nereis diversicolor, Nephthys hombergii, Arenicola marina, Macoma balthica, Cardium edule, Mya arenaria, Asellus aquaticus* and *Radix balthica* from the Elbe estuary. Water content and mean weight of the organisms indicated

Species	Number	Station	Sampling date (1974)	H_2O (%)	Mean weight (mg)	Number of determinations	ppm Hg (wet weight) Range	Mean
Nereis diversicolor	29	4	July	—	—	1	0.08	—
Nereis diversicolor	30	4	Aug. (1975)	85.2	110	2	0.06–0.07	0.065
Nereis diversicolor	31	4	Nov.	85.6	90	5	0.04–0.06	0.052
Nereis diversicolor	32	6	Sep.	78.5	—	2	0.03–0.05	0.04*
Nereis diversicolor	33	6	Nov.	85.5	220	5	0.03–0.04	0.038
Nereis diversicolor	34	8	Oct.	82.0	500	2	0.04	0.04
Nereis diversicolor	35	9	July	78.5	—	4	0.07–0.08	0.075
Nereis diversicolor	36	9	Nov.	83.6	360	2	0.05	0.05
Nephthys hombergii	34a	8	Oct.	80.8	150	3	0.01	0.010
Arenicola marina	37	6	July	—	280	2	0.05	0.05
Arenicola marina	38	6	Nov.	87.8	3090	2	0.05	0.05
Arenicola marina	39	8	July	—	4280	3	0.04	0.040*
Arenicola marina	40	8	Oct.	86.7	620–1900	5	0.02–0.03	0.026
Arenicola marina	41	9	July	—	3160	2	0.07	0.07
Arenicola marina	42	9	Nov.	87.4	680–1790	7	0.01–0.02	0.019
Macoma balthica	43	6	Nov.	87.0	320	2	0.07	0.07
Macoma balthica	44	8	Oct.	87.6	270	2	0.03	0.03
Macoma balthica	45	9	Nov.	85.5	180	2	0.03–0.04	0.035
Cardium edule	46	8	July	—	630	2	0.04	0.04
Cardium edule	47	8	Oct.	88.7	1200	2	0.03	0.03
Mya arenaria	48	9	Nov.	89.9	840	1	0.04	—
Asellus aquaticus	61	Oberelbe	Apr./July	81.3	—	8	0.22–0.56	0.35
Radix balthica	62	Oberelbe	Apr./May	86.1	—	6	0.25–0.40	0.34
Radix balthica	63	2	Aug.	82.3	60	2	0.08–0.09	0.085

* Probably too low due to loss of body fluid

Table 7a

Mercury concentrations in gammarids from the Elbe estuary and analysis of variance. Water content, mean weight of organisms and Hg concentrations. Values given in ppm (wet). 95 %-confidence interval calculated as 1.96 $s_{\bar{x}}$

Number	Station	Sampling date (1974)	H_2O (%)	Mean weight (mg)	Number of determinations	Range	ppm Hg (wet weight) Mean	95 %-confidence interval	$s^2 \times 10^{-7}$
49	1	Aug.	72.2	–	2	0.20	0.20	–	–
50	2	Oct.	75.7	–	2	0.12–0.13	0.125	–	–
51	3	Aug.	77.2	–	5	0.11–0.15	0.132	0.014	2700
52	6	May	79.8	55	4	0.04–0.05	0.048	0.005	250
53	6	July	–	30	2	0.04–0.05	0.045	–	–
54	6	Sep.	75.0	–	5	0.01–0.03	0.020	0.006	500
55	6	Nov.	76.0	30	2	0.03	0.03	–	–
56	7	May	80.5	60	4	0.03–0.05	0.040	0.008	667
57	7	May	79.8	60	5	0.02–0.05	0.034	0.012	–
58	7	July	–	20	2	0.03–0.04	0.035	–	–
59	7	Oct.	74.9	20	4	0.02–0.03	0.023	0.005	250
60	9	Nov.	74.8	–	3	0.03	0.030	–	–

Table 7b

Analysis of variance performed between samples referred to in Table 7a (according to Fig. 1)

Number	Between samples	Weighted mean	Variance within samples (x 10^{-7})	Variance between samples (x 10^{-7})	F	$F_{5\,\%}$
r	52, 53, 54, 55	0.032	361	6712	18.6	3.86
s	56, 57, 58, 59	0.033	950	2161	2.27	3.59
t	49, 50, 51, (54+55), 59, 60	0.072	967	176765	182	2.77
u	(54+55), 59, 60	0.024	380	625	1.65	3.98

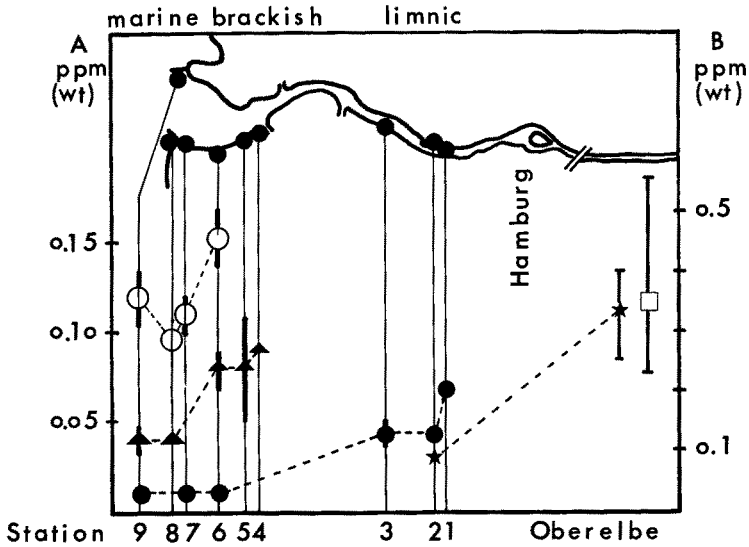

Fig. 3: Mean Hg concentrations of some important invertebrates from the Elbe estuary collected in May–September (see Tables 3—7). Values given in ppm (wet weight) for: (A) ○ *Littorina littorea*, ▲ *Crangon crangon*, (B) □ *Asellus aquaticus*, ★ *Radix balthica*, ● gammarids. I 95 %-confidence interval = 1.96 $s_{\bar{x}}$; I range

This also seems to be true for *Crangon crangon* from Station 6 (l, Table 4b), *Corophium volutator* from Station 5 (p, Table 5b) and gammarids from Station 6 (r, Table 7b). In other cases lack of significance might be either due to low number of observations and appreciable variance within a sample or to the fact that no seasonal fluctuation occurs. From other F values it may be concluded that Hg concentrations differ when considering various localities. In general it can be seen that Hg levels in benthic invertebrates tend to decrease from the region upstream of Hamburg to the marine environment (Stations 8 and 9). This is demonstrated by the values for *Radix balthica* and *Asellus aquaticus* sampled upstream of Hamburg and found to have relatively high amounts of Hg (0.34 and 0.35 ppm respectively, see Table 6), as well as by the results for gammarid species which tend to decrease from the limnic region (Station 1, 0.20 ppm) to the brackish and more marine environments (0.02–0.05 ppm; t, Table 7b). This tendency is also apparent within the brackish region when considering the results for *Littorina littorea* (h, Table 3b) and *Crangon crangon* (n, Table 4b) collected in summer, but not for gammarids (u, Table 7b). On the other hand, this tendency is not so conspicuous in organisms collected in October/November. In the case of *Littorina littorea* even a slight change toward a more marine environment (Station 9) may be concluded (i, Table 3b and o, Table 4b).

The geographical distribution of Hg in crustaceans (*Asellus aquaticus* and gammarids) is similar to that of the clay fraction of the sediment (analyzed by Müller & Förstner, 1975), which may reflect the actual presence of Hg in this ecosystem (Table 8).

Table 8

Relative Hg levels in the clay fraction of the sediments and in the crustaceans (*Asellus aquaticus* and gammarids) from the Elbe estuary. Values calculated by setting data of Müller & Förstner (1975) and from Table 6 and 7 obtained for the brackish region as one. Regions: a = Oberelbe, b = Hamburg (station 1), c = lower limnic region (station 2, 3), d = brackish region (station 6, 7)

Regions	a	:	b	:	c	:	d
Sediment (< 2 μm)	14	:	5	:	3	:	1
Crustaceans	12	:	7	:	4	:	1

Mercury contamination of the Elbe estuary as compared with other localities

The mean Hg concentrations of invertebrates from the Elbe estuary are summarized in Table 9 and compared with results reported from other localities (see Table 9 for references).

Information on the Hg contamination of fresh water benthic invertebrates is very scarce. Only unspecific data are available. Hg levels in organisms from the River Elbe seem to be somewhat higher than results from Clay Lake (Ontario, Canada) which was contaminated by the effluents of a chlorine alkali plant (Armstrong & Hamilton, 1973) or a Swedish freshwater biotope situated above a paper mill (Johnels et al., 1967). On the other hand these values are markedly lower than those in organisms from sites below the paper mill effluent.

In the brackish region of the Elbe estuary, as is apparent in Table 9, Hg levels in organisms are generally of the same order of magnitude as reported for other localities. As for *Littorina*, only results from the Tay Region (Great Britain) and the Fjord of Kiel (Baltic Sea) seem to be somewhat lower. On the other hand, Hg levels in *Crangon crangon* from some British waters and from the Mediterranean Sea tend to be higher. In the case of the Mediterranean Sea the effluents of a titanium dioxide plant are suspected to be of some significance (see Table 9).

The results of this comparison of organisms from the limnic region of the River Elbe show a slightly increased Hg level, a fact that corresponds with the findings of Förstner & Müller (1974) when comparing the clay fraction of sediment in important German rivers. Moreover, Müller & Förstner (1976) pointed out that the Hg levels of the sediment at Stade (limnic region) increased by a factor of 3 from 1973 to 1975. It is obvious that further investigation is required, especially when one considers that the sources of the present Hg levels are unknown and that on the other hand an intensive process of industrialization is going on in this region which may contribute to further contamination.

Table 9

Comparison of mean Hg levels of invertebrates from the Elbe estuary and from other localities. If necessary, data were converted to ppm (wet) according to the water content of the organisms indicated by the authors

Organisms	Locality	Biotope	ppm Hg (wt)	References
Asellus aquaticus	Oberelbe	limnic	0.35	this paper
Radix balthica	River Elbe	limnic	0.09 – 0.34	this paper
Gammarids	River Elbe	limnic	0.13 – 0.20	this paper
Asellus aquaticus	South Sweden	limnic	0.06*– 1.9**	Johnels et al. (1967)
Trichoptera	South Sweden	limnic	0.05*–11/17**	Johnels et al. (1967)
Plecoptera	South Sweden	limnic	0.07*– 2.4**	Johnels et al. (1967)
Zooplankton	Clay Lake (Canada)	limnic	0.01 – 0.08	Armstrong & Hamilton (1973)
Cladocerans	Clay Lake (Canada)	limnic	0.04 – 0.09	Armstrong & Hamilton (1973)
Gastropods	Clay Lake (Canada)	limnic	0.08 – 0.18	Armstrong & Hamilton (1973)
Littorina littorea	Elbe estuary	brackish	0.08 – 0.16	this paper
Littorina littorea	Helgoland	marine	0.05	Haar (1975)
Littorina littorea	Southampton Water	brackish	0.15	Leatherland & Burton (1974)
Littorina littoralis	Severn estuary	—	0.06	Leatherland & Burton (1974)
Littorina littorea	Tay Region	brackish	0.04	Jones et al. (1972)
Littorina littorea	Fjord of Kiel (Baltic)	brackish	0.01 – 0.05	Hablizel (1975)
Nereis diversicolor	Elbe estuary	brackish	0.04 – 0.08	this paper
Nereis diversicolor	Southampton Water	brackish	0.06	Leatherland & Burton (1974)
Arenicola marina	Elbe estuary	brackish	0.02 – 0.07	this paper
Arenicola marina	various European coastal aeras	—	0.05 – 0.08	according to Bouquiaux (1974)
Crangon crangon	Elbe estuary	brackish	0.04 – 0.09	this paper
Crangon crangon	German Bight	marine	0.08	Haar (1975)
Crangon crangon	Belgian Coast	—	0.10	Herman & Bouquiaux (1973)
Crangon crangon	Coast of Netherland	—	0.1	Korringa & Hagel (1974)
Crangon crangon	Belgian Coast	marine	0.10 – 0.25	De Clerk et al. (1974)
Crangon crangon	Oslo Fjord	—	0.09	Andersen & Neelakantan (1974)
Crangon crangon	British Waters	—	0.15 – 0.21	Ministry of Agriculture, Fisheries and Food (1971) according to Herman & Bouquiaux (1973)
"Crevettes"	Cap Corse (Mediter.)	—	0.35 – 0.64	according to Aubert & Donnier (1974)
Crangon crangon (edible part)	Norddeich (Germany)	marine	0.01	Günther et al. (1972)
Cardium edule	Elbe estuary	brackish	0.03 – 0.04	this paper
Cardium edule	Southampton Water	brack./mar.	0.12	Leatherland & Burton (1974)
Cardium edule	Poole Dorset	—	0.16	Leatherland & Burton (1974)
Cardium edule	Solvay Firth	—	0.01	Leatherland & Burton (1974)
Cardium edule	Oslo Fjord	—	0.08	Andersen & Neelakantan (1974)
Mya arenaria	Elbe estuary	brackish	0.04	this paper
Mya arenaria	Oslo Fjord	—	0.07	Andersen & Neelakantan (1974)

* above a paper mill ** below a paper mill

Discussion of factors which may influence mercury concentrations in aquatic invertebrates

From the results obtained in this investigation (some of which only are of preliminary character) the following factors will be discussed: (a) position of organisms in aquatic food chains, (b) weight of organisms, (c) elimination e. g. via moulting products in the case of crustaceans.

Food chain

Several of the invertebrates from the brackish region which were analyzed can be seen as components of brackish water food chains. For example, *Corophium volutator, Nereis diversicolor* and to some extent gammarids are important food items of *Crangon crangon* (Tiews, 1967), in turn *Crangon crangon* is regarded as a relevant food source for various fishes (Kühl, 1961). Hg levels in these organisms are summarized in Figure 4.

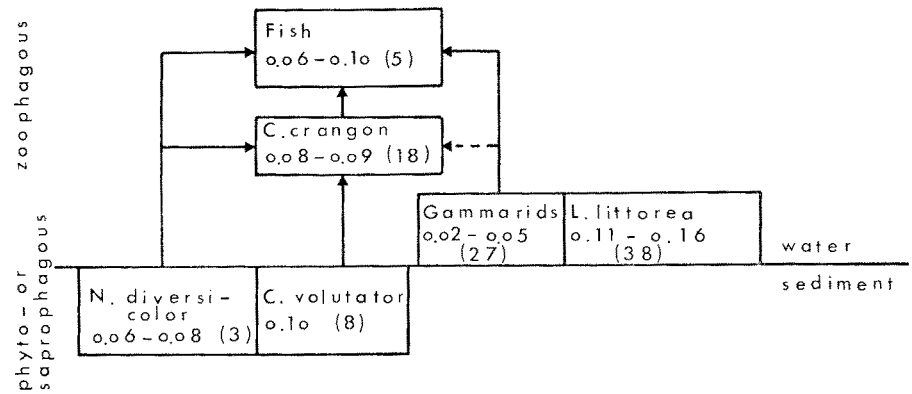

Fig. 4: Mean Hg levels in organisms of a brackish water food chain from the Elbe estuary. Samples taken in May–September at Stations 4–7 (see Tables 3–7). Values given in ppm (wet weight), (i) indicates number of determinations

From this figure it can be seen that Hg concentrations appear to be of the same order of magnitude in all trophic levels (but it should be kept in mind that only a few samples of small fishes, young *Platichthys flesus* and *Zoarces viviparus,* were analyzed). Only the concentrations of Hg in gammarids tend to be somewhat lower. The highest levels observed occur in individuals of the phytophagous snail *Littorina littorea.*

Data from the Wadden sea (The Netherlands) reported by de Goeij et al. (1972, according to van Genderen, 1974) are in good agreement with the preliminary results presented here. They found similar Hg contamination in invertebrates and fish. This also proved to be true for marine pelagic food chains, as reported by Leatherland et al. (1973), who found equal Hg levels in fish, some copepods and euphausids. Regarding other heavy metals, the concentrations of As, Cd, Sb and Zn analyzed by the same authors even tend to decrease from plankton to fishes of higher trophic levels. Such depletion of Zn, As and Cu in the food chain was also reported by Windom et al. (1973) as regards marine pelagic fishes.

On the other hand, data from Armstrong & Hamilton (1973) and Bligh (1971), regarding limnic ecosystems, can either be interpreted as increased Hg accumulation in higher trophic levels or in benthic organisms as compared with pelagic species. Results from Potter et al. (1975) indicate increasing Hg concentrations in a limnic food chain. Jernelöv & Lann (1971) calculated that only a minor part of the Hg (less than 25 %) was transferred from bottom fauna to bottom feeding fish, the major amount being accumulated directly from the water.

Weight of organisms

As mentioned above, some of the material was analyzed for correlations between Hg concentrations and mean weight (w) of the organisms. In two cases correlations were found to be significant (*Crangon crangon:* ppm Hg = 0.032 + 0.060 w, N = 6, r = 0.996, r 5 % = 0.811; *Littorina littorea:* ppm Hg = 0.091 + 0.094 w, N = 10, r = 0.913, r 5 % = 0.632; see also a, Table 3).

Correlations between the heavy metal concentrations of aquatic invertebrates and their size or weight have been reported by several authors, e. g. Armstrong & Hamilton (1973), Bryan & Hummerstone (1973) and Leatherland & Burton (1974). The heavy metal concentration may either increase or decrease with size or weight of the organisms, depending on the species and heavy metal in question. Therefore any data should be characterized by the weight or size of the organisms analyzed to allow comparison of results from various sources.

Elimination via moulting products

The Hg concentrations in moulting products of *Crangon crangon* have been analyzed in two cases and were found to be about 17 % of the value which was obtained for the entire body, a fact which is almost in agreement with results (about 12 %) of Herman & Bouguiaux (1973).

The Hg concentrations in carapaces of crayfish were found to be 12 % (Armstrong & Hamilton, 1973) and 19 % (Johnels et al., 1967) of the abdominal muscle, also indicating that an appreciable amount of Hg is accumulated in the skeleton of crustaceans. Fowler et al. (1971) observed an important transfer of radionuclides via moulting products of euphausids. Furthermore, the rate of elimination depends on the way in which the substances have been introduced into the animals. For instance, 0.3–2 % of the Zn-65 which has been accumulated in experiments is eliminated when it had been introduced by contaminated food, whereas about 18 % is eliminated when it had been introduced by contaminated water.

It can be concluded from these findings that a decontamination of heavy metals may occur in crustaceans such as *Crangon crangon* or gammarids due to moulting. It may be possible that the relatively uniform Hg levels in *Crangon crangon* reported from several localities (see Table 9) are influenced by this fact. This effect is probably intensified by migrations of *Crangon crangon* into deeper waters in winter (Tiews, 1967), where concentrations of Hg are lower.

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