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Total Mercury Contamination of Selected Organisms in Puck Bay, Baltic Sea, Poland

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Abstract

The objective of this study was to recognize contamination by mercury of selected aquatic organisms such as algae, aquatic vascular plants, zooplankton, polychaetes, molluscs, crustaceans and fish collected from Puck Bay in 1995-1998. The mercury concentration was measured using cold vapour atomic absorption spectroscopy (CV-AAS). Some inter-species (in biota) and spatial differences in mercury concentration were observed, indicating that pollution comes from local land-based and non-point sources. However, noted mercury concentrations were relatively low and of the same magnitude as reported by other authors for other parts of the Baltic Sea.

Keywords: mercury, vascular plant, algae, zooplankton, polychaete, crustacean, mollusc, fish, Puck Bay, Baltic Sea

Introduction

Puck Bay is a sub-region of the Gulf of Gdańsk in the middle part of the Polish coast. The inner part of bay is protected from water activity of the Baltic Sea and the Gulf of Gdańsk by Hel Penisula and the Rybitwia Mielizna Sandbank. Area of Puck Bay is about 115 km^2 with an average water depth of 3.13 m, with a maximum depth in one of three natural cavities Jama Kuźnicka (9.4 m) [1]. The salinity of the bay is very low (0.005 ‰) as a result of the inflow of fresh water from rivers such as the Reda, Płutnica and Gizdepka and low exchange of water with the Gulf of Gdańsk [2]. The low depth and limited influence of the open Baltic facilitate growth of aquatic organisms in the bay. In the mid-1970s in the last century the ecological balance in the bay broke down, caused by the uncontrolled inflow of biogens into the bay. Bay water biodiversity decreased and species composition changed. The predominat species are *Pilayella litoralis* and fish such as *Gasterosteus aculeatus* and *Pungitius pungitius* [3, 4]. There are about 25 species of macroalgae and 8 species of aquatic vascular plants. The number of species of crustaceans and molluscs living in the bay reaches 30 [3].

No known natural deposits of mercury have yet been reported in the drainage area of the bay. It has been recognised that the main source of mercury in the bay's ecosystem is the atmosphere (1.1-3.8 kg/year). The input of

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*Corresponding author; e-mail: boszke@euv-frankfurt-o.de mercury from rivers inflowing into the bay has been estimated as 7-fold lower than that via the atmosphere [5]. The amount of mercury remobilised from the sediment to the water column is 0.25-1.25 kg annually, which has a significant impact on bioavailability of that element for aquatic biota [6]. However, an increase in the amount of mercury deposited in the bay (especially due to mobilization of the load adsorbed by the soil in the drainage area) accompanied by an increase in the rate of its remobilisation from the sediment, can result in a high increase in the mercury concentrations accumulated by the biota.

The main aim of the present study was to determine levels of mercury in biotic components of Puck Bay and to compare results with the data reported by other researchers for other parts of the Baltic.

Materials and Methods

Total mercury concentration was determined in the following algae: *Chara crinita, Cladophora glaucences, Cladophora rupestris, Enteromorpha compressa, Enteromorpha interstinalis, Pilayella litoralis* and *Ulva lactuca*; in aquatic vascular plants: *Batrachium baudotti, Mirophyllum spicatum, Potamogeton lucens, Ruppia maritima, Zanichella Palustris* and seagrass *Zostera marina*; in zooplankton; in polychaete *Nereis diversicolor*; in crustaceans such as brown shrimp *Crangon crangon*, prawn *Palaemon adspersus, Gammarus* sp. and *Idiotea baltica* as well as in tissues and organs of chinese crab *Eriocheir sinensis*; in bivalves such as: blue mussel *Mytilus trossulus, Cardium edule, Mya arenaria*; in gastropods *Theodoxus fluviatilis* and *Lymnea stagnalis*; in fish such as: *Gasterosteus aculeatus, Pungitius pungitius, Nerophis ophidion, Zoarces viviparous, Neogobius melanostromus, Pomatoschistus microps, Anquilla anquilla*, perch *Perca fluviatilis*, herring *Clupea harengus*, flounder *Platichthys flesus*, *Rutilus rutilus*, and bream *Abramis brama*.

Biological material was collected manually (algae, aquatic vascular plants, polychaete, molluscs) or caught using bottom sack at various sites of the bay in 1995–1998 (Figures 1-4). Samples of zooplankton were collected using a net with 160 µm mesh size. The organisms were placed in new polyethylene bags and were transported to laboratory, where they were deep frozen (-20^{0}C), except the samples of algae, aquatic vascular plants and zooplankton, which were dried at room temperature before analysis. The length and weight of the samples were measured prior to analysis. The samples were the muscle tissue of fish (except fish such as *Nerophis ophidion, Gasterosteus aculeatus, Pungitius pungitius, Pomatoschistus microps* - of which whole bodies were examinated), soft tissue (molluscs), whole body (polychaetes, crustaceans such as: *Palaemon adspersus, Crangon crangon*) pooled samples (zooplankton, *Idiothea baltica, Gammarus* sp.) or organs (*Mya arenaria, Eriocheir sinensis*).

About 0.5 to 1 g of sample material was moistened with 4 ml of concentrated nitric acid (65% Suprapur®, Merck), and left at room temperature for 24 hours. Next, the wet material was placed in a glass round-bottom flask connected to a partial condenser and a water cooler. The sample was digested at 200^{0}C for an hour, then left for 15 min. and moistened with 5 ml of doubly distilled water. The digestion was continued for a half-hour under the same conditions. The final determination of mercury concentration was performed by cold vapour atomic absorption spectrometry (CV-AAS) using a fully automated mercury analysis system (Mercury Monitor 3200, Thermo Separation Production, USA). The error inherent in the analytical method was estimated on the basis of determination of mercury in a certified material in our previous work [7, 8]. Analytical blanks did not indicate the presence of mercury concentrations interfering (<5%) with the lowest concentrations found in real samples.

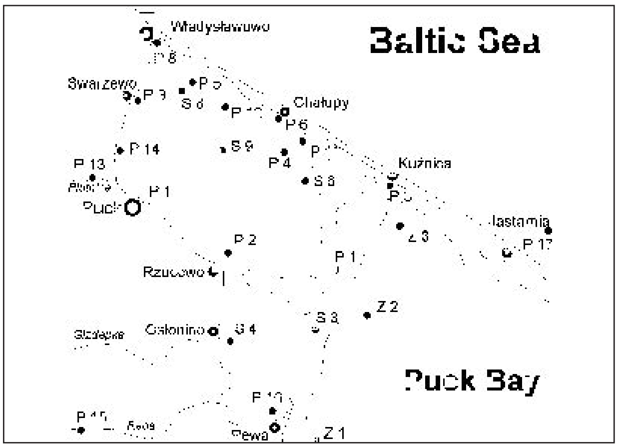

Fig. 1. Sample locations of molluscs, crustaceans and fish.

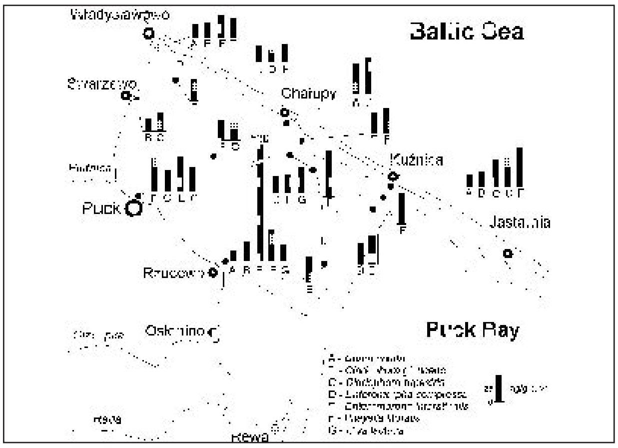

Fig. 2. Sample locations and total mercury concentrations in algae (ng/g dry weight).

Results and Discussion

Algae and Aquatic Vascular Plants

Aquatic plants of the estuarine ecosystems are very sensitive to environmental degradation. In Puck Bay aquatic plants were the first bioindicators that spectacularly responded to forthcoming environmental changes and damage. Recently, underwater meadows, once very characteristic of the bay and covering nearly the whole bottom, became extremely limited in space and their species' qualitative and quantitative composition has changed dramatically.

The range of mercury concentrations in algae and vascular plants was 15-512 ng/g dry weight (Table 1). Among species investigated the *Pilayella litoralis* (51±19 ng Hg/g dry weight), *Cladophora rupestris* (46±14 ng Hg/g dry weight) and *Enteromorpha interstinalis* (45±13 ng Hg/g dry weight) were characterised by concentrations of mercury higher than other organisms. In *Enteromorpha interstinalis*, collected at a particular site, up to 520 ng Hg/g dry weight were found. Vascular plants such as: *Potamogeton lucens* (27±7 ng/g dry weight), *Ruppia maritima* (29±8 ng/g dry weight), *Batrachium baudotti* (30±5 ng/g dry weight) showed relatively lower concentrations of mercury. The data on the mercury content in algae and vascular plants indicate slight differences in the spatial distribution of this element in the bay (Figures 1, 2), which can be related to the possible differences of mercury loads from local sources or differences in its bioavailability depending on the chemical species present in the sediment.

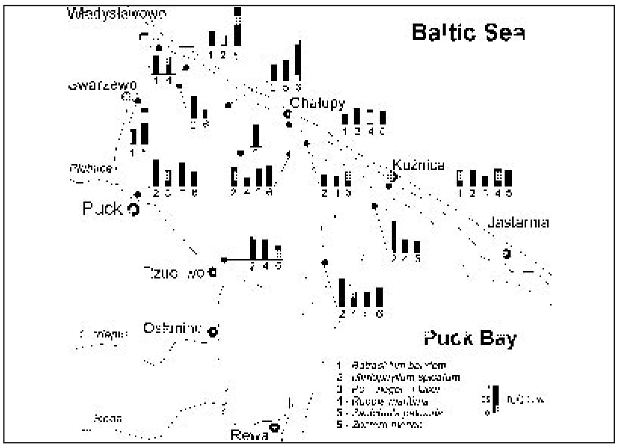

Fig. 3. Sample locations and total mercury concentrations in vascular plants (ng/g dry weigh).

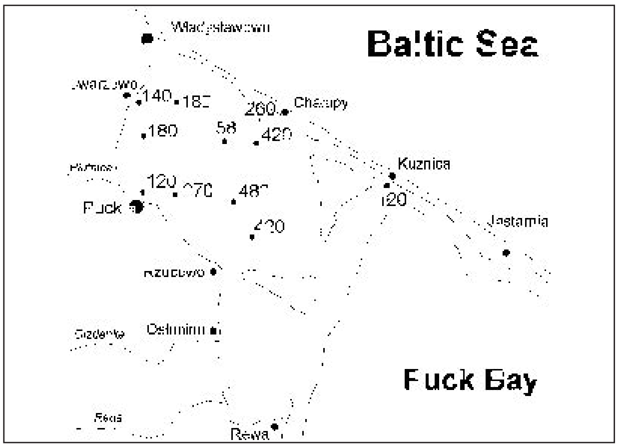

Fig. 4. Sample locations and total mercury concentrations in zooplankton (ng/g dry weight).

There are not many data available on the distribution of mercury in algae and vascular plants in the Baltic Sea. For example, total mercury concentration in algae varied from 1.4 to 24.8 ng/g dry weight in different parts of the Baltic Sea [9] and from 22 to 130 ng/g dry weight in algae and aquatic vascular plants from the bay and the Gulf of Gdańsk [10]. In vascular plants from Lake Paijanne (Finland) the average concentration of mercury was 54 ng Hg/g dry weight (range 8-122 ng/g d.w.) [11]. In other parts of the world higher levels of mercury were reported most often in algae and vascular plants. For example, in Lavaca Bay (USA) the concentration of mercury varied from 340 to 1430 ng/g dry weight [12] and in some areas in Finland vascular plants were contaminated with mercury from 10 to 6600 ng/g dry weight [13].

Zooplankton

Zooplankton can be a potential transporting agent of toxic substances in the aquatic ecosystems. Many toxic substances enter the water systems from the atmosphere and occur in higher concentrations in the surface microlayer. Such contaminants may associate with organic platelets and aggregates and may therefore be consumed by zooplankton. Zooplankton intake of contaminants is relatively fast compared to fish. Thus zooplankton may act as a biological sponge for contaminants freshly discharged into the waters.

The concentration of mercury in zooplankton ranged from 48 to 480 ng/g dry weight (Figure 4), and the average concentration was 240±140 ng/g dry weight. Some spatial differences in mercury contamination in zooplankton were observed. The level of mercury observed in the samples from middle part of the bay (420-480 ng/g dry weight) was higher than in the western part of the bay (120-180 ng/g dry weight). The reason for this spatial distribution can be the difference in composition of zooplankton between these areas and/or the presence of phytoplankton in samples. Since the organic matter transported from catchments to the bay is an important carrier of Hg, the terrigenous run-off may be an important source of bacteria, fungi and possibly zooplankton. This

Table 1. Total mercury concentration (ng/g dry weight) in algae and vascular plant from the Puck Bay.

Species		n	Hg	Range
Algae	Chara crinita	5 (9)*	34 ± 18	18 - 78
	Cladophora glaucences	3 (6)	36 ± 15	21 - 63
	Cladophora rupestris	2 (3)	46 ± 14	38 - 63
	Enteromorpha compressa	6 (7)	39 ± 16	25 - 68
	Enteromorpha intestinalis	6 (9)	45 ± 13 **	36 - 520
	Pilayella litoralis	12 (13)	51 ± 19	24 - 88
	Ulva lactuca	6 (11)	39 ± 15	16 - 58
Vascular plant	Batrachium baudotti	5 (7)	30 ± 5	20 - 36
	Mirrophyllum spicatum	11 (20)	40 ± 14	22 - 63
	Potamogeton lucens	2 (2)	27 ± 7	22 - 32
	Ruppia maritima	6 (12)	29 ± 8	17 - 41
	Zanichella palustris	11 (13)	41 ± 21	22 - 95
	Zostera marina	6 (8)	36 ± 19	17 - 77

* n – number of sampling sites and number of samples determined (in parentheses)
** without extreme values

terrigenous organic matter is characterised by low nutritive value. Therefore, in order to satisfy their food needs the zooplankton organisms must ingest large volumes of this matter, thus exposing themselves to a greater quantity of mercury [14]. However, in the bay the main source of mercury is the atmosphere, since the inflow of mercury with the rivers is 7-fold lower [5]. A uniform distribution of the low concentration of mercury in the bottom sediments of the bay, as well as positive relationship ($p<0.01$) between the organic matter and the mercury concentration in the sediments, indicate that plankton is a main source of mercury in the bottom sediments [6].

The levels of mercury concentrations in the zooplankton from Puck Bay were similar to those reported by other authors for the other parts of the Baltic. For example, in the samples of zooplankton from different Baltic sites the concentration of mercury varied from 20 to 720 ng/g dry weight [15] and in the southern part of the Baltic - 150 ng/g dry weight [16]. In the coastal zone of the Southern Baltic the concentration of mercury up to 870 ng/g dry weight in zooplankton was determined [16].

Polychaetes

The accumulation of mercury was significantly ($p<0.01$) higher in the organisms from organic-poor, sandy sediments than in those from organic-rich muddy sediments [17]. It seems that mercury strongly bound to organic matter in sediments reduces the availability of this element for bioaccumulation in nereids living in the contaminated sediments [17]. Moreover, the organisms living in contaminated sediments possibly regulate mercury more efficiently using a secretory system [18].

Among the polychaetes living in the bay only *Nereis diverdicolor* was accessible for this study. The average concentration of mercury in the whole body of nereids collected near Puck was 22±9 ng/g fresh weight (ranging between 8 and 37 ng/g fresh weight). As mentioned before, bioconcentration of mercury in worms living in sandy sediments was greater than in worms living in organic-rich sediments [17]. Thus, the higher concentration of mercury in *Nereis diversicolor* living in sandy sediments of Puck Bay may be expected. In the organic-rich sediments collected near Puck the concentrations of mercury were reported up to 350 ng/g dry weight, while in the organic-poor sediments, covering the greater part of the bay [19], values reached only a few ng/g dry weight [6].

The data on the concentrations of mercury in polychaetes are very limited. In *Nereis diversicolor* from the North Sea the concentration of mercury ranged from 30 to 40 ng/g fresh weight [20] and from the Scheld Estuary (Belgium) it ranged from 51 to 165 ng/g dry weight [17]. In polychaetes from Lavaca Bay (USA) mercury was determined in concentrations up to 19,400 ng/g fresh weight [12].

Molluscs

Molluscs are benthic organisms and because of the sedentary life style and relatively easy way of collection they are considered to be a useful matrix for biomonitoring the state of pollution of the aquatic ecosystems with mercury. Nevertheless, the data on chemical species and biotransformation of mercury accumulated by molluscs are limited. Accumulation of mercury by molluscs is species-specific and depends on the season, region and feeding habits [21].

The concentrations of mercury in soft tissues of molluscs ranged from 2 to 100 ng/g fresh weight (Table 2). The data indicated some species-specific differences in mercury concentration between the examined animals. The molluscs such as *Cardium edule* (from 12±3 to 65±38 ng/g fresh weight) saw and *Mytilus trossulus* (from 12±3 to 58±19 ng/g fresh weight) contained a high concentration of mercury, while *Theodoxus fluviatilis* (from 22±16 to 40 ng/g fresh weight) saw an intermediate concentration, and *Mya arenaria* (from 10±2 to 31±18 ng/g fresh weight) and *Lymnea stagnalis* (7-20 ng/g fresh weight) the lowest one. In *Mya arenaria* higher concentrations of mercury were noted in its hepatopancreas (from 22±23 to 26±9 ng/g fresh weight) than in the muscle tissue (from 13±3 to 19±12 ng/g fresh weight). This may indicate that the metal gets into the organisms mainly through the alimentary canal. At the majority of investigated sites a negative relationship was found between the concentrations of mercury and body length and weight.

The mercury concentrations in molluscs noted in this study were of the same magnitude, as reported by other authors for the other parts of the Baltic Sea. In the Gulf of Gdańsk the mercury concentration in *Mytilus edulis* varied from 7 to 50 ng/g fresh weight [10] and from 2 to 99 ng/g fresh weight [22]. In the same area in molluscs

Table 2. Biometric data and total mercury concentration in molluscs from Puck Bay.

Species and sampling sites	Date of sampling	n	Length (mm) x±SD (Range)	Weight (g) x±SD (Range)	Hg (ng/g fresh weight) x±SD (Range)
Mytilus trossulus					
P 3	15.09.95	28	25 ± 41 (9 – 34)	0.9 ± 0.4 (0.5 – 1.7)	58 ± 19 (19 – 100)
P 1	22.08.96	22	27 ± 6 (20 – 39)	0.7 ± 0.5 (0.2 – 2.5)	38 ± 23 (14 – 94)
P 4	24.08.96	11	31 ± 5 (25 – 41)	0.9 ± 0.5 (0.3 – 2.0)	25 ± 8 (12 – 38)
P 12	24.08.96	11	29 ± 4 (23 – 38)	0.7 ± 0.2 (0.3 – 1.2)	44 ± 18 (7 – 77)
S 3	16.07.97	12 (29)*	17 ± 5 (10 – 28)	0,7 ± 0.3 (0.3 – 1.5)	39 ± 16 (8 – 62)
S 6	16.07.97	4 (7)	21 ± 7 (15 – 32)	0.7 ± 0.5 (0.5 – 1.5)	49 ± 30 (21 – 91)
S 8	16.07.97	2 (4)	17 (12 – 20)	0.4 (0.3 – 0.5)	51 (19 – 83)
S 9	16.07.97	1 (2)	17 (16 – 18)	2.0	28
Z 3	26.02.98	17(20)	30 ± 6(18 – 36)	1.9 ± 1.0 (0.7 – 3.8)	12 ± 3 (6 – 21)
Z 2	26.02.98	22(30)	28 ± 8 (16 – 42)	2.3 ± 1.5 (0.5 – 6.0)	22 ± 9 (14 – 56)
Z 1	26.02.98	38(45)	30 ± 9 (4 – 46)	2.0 ± 0.9 (0.2 – 3.8)	18 ± 7 (6 – 36)
Cardium edule					
P 3	22.08.96	9	16±3 (13 – 23)	0.8 ± 0.3 (0.5 – 1.5)	50 ± 21 (28 – 98)
P 11	22.08.96	20	16±1 (13 – 19)	0.6 ± 0.1 (0.5 – 0.9)	42 ± 16 (21 – 79)
P 4	24.08.96	1	14	0.4	44
P 5	22.08.96	2	17 (14 – 19)	0.5 (0.4 – 0.7)	47 (44 – 50)
P 6	16.07.97	7 (19)	15±2 (12 – 18)	1.9 ± 0.4 (1.3 – 2.2)	28 ± 4 (23 – 32)
S 3	16.07.97	3 (8)	13±2 (10 – 16)	1.3 ± 0.5 (0.9 – 1.8)	65 ± 38 (25 – 100)
S 4	16.07.97	2 (5)	14 (13 – 17)	1.7 (0.9 – 2.4)	30 (26 – 34)
S 6	16.07.97	23 (64)	15±2 (10 – 18)	1.6 ± 0.4 (1.0 – 2.5)	35 ± 14 (13 – 66)
S 8	16.07.97	6 (18)	13±2 (10 – 18)	1.1 ± 0.5 (0.6 – 2.0)	53 ± 25 (26 – 92)
S 9	16.07.97	5 (13)	14±3 (10 – 18)	0.9 ± 0.5 (0.4 – 1.5)	43 ± 16 (25 – 65)
Z 3	26.02.98	7	15±1 (13 – 160)	1.3 ± 0.4 (0.8 – 2.1)	22 ± 10 (10 – 38)
Z 2	26.02.98	9	17±2 (14 – 20)	1.8 ± 0.5 (1.1 – 2.4)	20 ± 9 (13 – 27)
Z 1	26.02.98	3	14±2 (11 – 15)	1,2 ± 0,3 (0,9 - 1,5)	40 ± 24 (20 – 66)

Table 2 continues on next page

Mya arenaria					
P 3	17.05.97	13 13	43±6 (36 – 55)	9 ± 4 (5 – 19)	26 ± 9 (16 – 43 $^{(B}$ 19 ± 12 (5 – 40) $^{(C}$
Z 2	26.02.98 26.02.98 26.02.98	2 4 4	30 (31 – 29) 44 ± 9 (37 – 57)	2.2 (1.6 – 2.9) 10.6 ± 10.2 (5.2 – 25.9)	10 (8-11) $^{(A}$ 25 ± 5 (17 – 29) $^{(B}$ 16 ± 11 (5 – 32) $^{(C}$
Z 1	26.02.98 26.02.98 26.02.98	12 3 3	24 ± 2 (22 – 28) 41 ± 9 (32 – 49)	1.0 ± 0.4 (0.4 – 1.6) 6.3 ± 3.4 (2.5 – 9.2)	19 ± 12 (4 – 42) $^{(A}$ 22 ± 23 (7 – 48) $^{(B}$ 13 ± 3 (10 – 16) $^{(C}$
S 3	16.07.97	5 (7)	26 ±10 (15 – 42)	1.5 ± 2.1 (0.3 – 5.24)	31 ± 18 (11 – 54)
Theodoxus fluviatilis					
P 6	11.08.97	11(33)	11 ± 1 (9 – 14)	0.18 ± 0.06 (0.11 – 0.32)	33 ± 10 (18 – 56)
P 3	17.06.97	21(25)	10 ± 1 (9 – 12)	0.15 ± 0.04 (0.10 – 0.25)	30 ± 8 (20 – 51)
P 15	23.05.97	7	11 ± 3 (9 – 18)	0.24 ± 0.34 (0.09 – 1.02)	22 ± 16 (8 – 41)
P 9	11.08.97	12(33)	11 ± 1 (9 – 14)	0.19 ± 0.05 (0.09 – 0.26)	24 ± 9 (11 – 40)
P 8	19.08.98	27(130)	10 ± 2 (7 – 14)	0.14 ± 0.06 (0.05 – 0.27)	24 ± 16 (2 – 73)
P 14	19.08.98	27(99)	11 ± 2 (7 – 17)	0.21 ± 0.11 (0.04 – 0.48)	27 ± 16 (10 – 66)
P 13	31.08.98	1(2)	(9 – 11)		40
Lymnea stagnalis					
P 13	31.08.98	5	22 ± 4 (16 – 26)	0.65 ± 0.05 (0.56 – 0.73)	16 ± 6 (7 – 20)
P 10	02.09.97	1	30	1.14	9

* number of samples and number of specimens (in parentheses); x±SD - average value and standard deviation; ^{A}/ whole specimen; ^{B}/ hepatopancreas; ^{C}/ muscle tissue

such as: *Cardium edule*, *Mya arenaria* and *Macoma baltica* the mercury concentrations were between 9-46 ng/g, 6-43 and 13-20 ng/g fresh weight, respectively [22]. The data on the concentrations of mercury in gastropods are limited. In *Lymnea stagnalis* from the Gulf of Bothnia and in *Hydrobia ulvae* from the North Sea mercury was determined in concentrations of 10-1,300 ng/g and 46±7 ng/g fresh weight, respectively [20, 23]. In molluscs from mercury-contaminated water regions in Denmark, mercury was detected in concentrations up to 2341 ng/g fresh weight in *Mytilus edulis* and 1962±717 ng/g fresh weight in *Cardium edule* [21].

Crustaceans

There are large interspecies variations in the mercury concentrations among the crustaceans species inhabiting Puck Bay (Table 3). Total mercury at relatively high concentrations was found in *Gammarus Gammarus* sp. (from 27±18 to 80±12 ng/g fresh weight), whereas its levels were lower in *Idiothea baltica* (from 44±19 to 65±22 ng/g fresh weight), Brown Shrimp *Crangon crangon* (from 21±5 to 41±14 ng/g fresh weight) and *Palaemon adspersus* (from 12±5 to 19±9 ng/g fresh weight). Compared to the above-mentioned species, the higher concentrations of mercury were found in the tissues and organs of the crab *Erocheir sinensis* - 120-290 ng/g fresh weight in the muscle tissue and 120-220 ng/g fresh weight in gills, and lower in hepatopancreas (70-82 ng/g fresh weight) and gonads (25-28 ng/g fresh weight). The inter-species differences in mercury concentrations in the crustaceans can be related to different feeding habits of the species. For example, the benthic crustacean *Crangon crangon* is mainly exposed to mercury contained in the bottom sediment, while *Palaemon adspersus, Idiothea baltica* and *Gammarus* sp. are species living among aquatic plants. The crab *Eriocheir sinensis* is a predator and the main prey of this crustacean are molluscs [24]. The analysis of regression was applied to examine the relationship between total mercury concentration and the body weight and length of *Crangon crangon* and *Palaemon adspersus*. A negative relationship ($p<0.05$) between total mercury concentration and body length/weight was observed only for *Palaemon adspersus*. The number of specimens of crab *Eriocheir sinensis* available in this study was relatively small. Nevertheless, it seems that mercury concentration in the muscle tissue and gills depend on its body weight/length. For example, for crab *Cancer pagarus* from Azorean waters the positive relationship ($p<0.05$) between mercury concentration in gills and in muscle tissue and length of trunk of crabs were found, but no statistically significant relationship ($p>0.5$) was observed between the concentration of mercury in hepatopancreas and the length of the trunk [25].

The mercury concentrations in crustaceans from various parts of the Baltic Sea are of the same magnitude as these obtained in this study. In *Crangon crangon* from the Gulf of Gdańsk, reported concentration of mercury as 25 ng/g fresh weight [10] and 17±11 ng/g fresh weight [22]. In crustaceans such as *Saduria entomon, Gammarus* sp.

Table 3. Biometric data and the total mercury concentration in crustaceans from Puck Bay.

Species and sampling sites	Date of sampling	n	Length (mm) x±SD (Range)	Weight (g) x±SD(Range)	Hg (ng/g fresh weight) x±SD (Range)
Palaemon adspersus					
P 3	12.08.96	29	46 ± 9 (31 – 59)	0.9 ± 0.5 (0.2 – 1.9)	18 ± 9 (7 – 50)
P 2	22.08.96	9	50 ± 8 (39 – 58)	0.9 ± 0.3 (0.4 – 1.3)	15 ± 5 (11 – 25)
P 11	22.08.96	24	49 ± 7 (40 – 66)	1.0 ± 0.4 (0.4 – 1.8)	19 ± 9 (10 – 52)
S 4	16.07.97	11	50 ± 9 (40 – 61)	1.2 ± 0.7 (0.5 – 2.4)	1 2 ± 5 (4 – 20)
Crangon crangon					
P 3	12.08.96	20	45 ± 4 (36 – 56)	0.7 ± 0.2 (0.3 – 1.3)	41 ± 14 (14 – 76)
P 1	22.08.96	6	53 ± 12 (36 – 70)	1.1 ± 0.8 (0.3 – 2.2)	34 ± 8 (19 – 43)
P 2	22.08.96	5	49 ± 4 (46 – 54)	0.7 ± 0.3 (0.4 – 1.0)	38 ± 12 (25 – 52)
S 3	16.07.97	22	49 ± 9 (38 – 73)	0.9 ± 0.6 (0.4 – 2.8)	27 ± 8 (15 – 42)
S 6	16.07.97	3	53 ± 9 (43 – 59)	1.2 ± 0.7 (0.5 – 1.8)	21 ± 5 (16 – 27)
Idotea baltica					
P 3	12.08.96	16 (44)*	-	-	37 ± 16 (11 – 75)
S 3	16.07.97	14	20 ± 2 (16 – 22)	0.12 ± 0.03 (0.07 – 0.17)	44 ± 19 (21 – 88)
S 4	16.07.97	9	18 ± 2 (15 – 21)	0.09 ± 0.04 (0.06 – 0.18)	65 ± 22 (37 – 94)
S 6	16.07.97	2	17 (16 – 18)	0.06 (0.04 – 0.08)	45 (30 – 60)
Gammarus sp.					
P 3	16.06.97	21**	-	-	39 ± 13 (11 – 60)
S 3	16.07.97	5**	-	-	80 ± 12 (61 – 92)
P 6	25.08.97	12**	-	-	37 ± 16 (20 – 72)
P 16	20.08.98	11**	-	-	31 ± 18 (20 – 74)
P 14	19.08.98	16**	-	-	27 ± 18 (19 – 89)
P 8	19.08.98	9**	-	-	38 ± 17 (18 – 74)
P 9	19.08.98	1**	-	-	53
Eriocheir sinensis					
P 3	16.08.97	1	41	42	120 $^{(A}$
					120 $^{(B}$
					82 $^{(C}$
					25 $^{(D}$
P 17	04.09.97	1	59	134	290 $^{(A}$
					220 $^{(B}$
					70 $^{(C}$
					28 $^{(D}$

* number of samples and number of specimens (in parentheses); ** pooled samples; x±SD - average value and standard deviation; ^{A}/ muscle tissue; ^{B}/ gills; ^{C}/ hepatopancreas; ^{D}/ gonads

and *Carcinus means* from this same area, the concentrations of mercury were 11-55 ng/g, 12-37 ng/g and 18 ng/g fresh weight [10, 22], while in *Carcinus means, Crangon crangon* and *Palaemon adspersus* from the North Sea the concentrations of mercury were: 20-30 ng/g, 20-30 ng/g and 30-390 ng/g fresh weight [20, 26]. Higher levels of mercury in crustaceans than those obtained in this study were determined, for example, in specimens from the Lavaca Bay (USA) and Ligurian Sea (Italy), where they reach up to 1560 ng/g fresh weight [12] and from 100 to 10430 ng/g dry weight [27], respectively.

Fish

Perch were the fish most contaminated with mercury among the species examined with mean concentrations between 110±43 and 130±54 ng/g fresh weight. They were followed by eels (76±27 ng/g fresh weight) and roaches (81±13 ng/g fresh weight), while the three-spined sticklebacks (15±6 - 43±19 ng/g fresh weight), nine-spined stickleback (23±7 - 65±17 ng/g fresh weight), straightnose pipefish (28±8 - 52±8 ng/g fresh weight) and sand goby (30±15 - 53±4 ng/g fresh weight) were less contaminated with mercury (Table 4). There was a positive relationship ($p<0.05$) between total body length and weight and mercury concentrations in the muscle tissue only for the flounder collected at P3 and S3 sampling sites. For the flounder in all sampling sites a tendency of increasing concentration of mercury with increasing body length and weight was found. It was not observed for any other fish species. Statistically, a positive relationship ($p<0.5$) between biometric data and mercury concentration was noted in the three-spined stickleback collected in one of the six sites - P11.

The mercury concentrations in fish from Puck Bay were below a standard admissible residue limit of 300 ng/g fresh weight. Large specimens of predatory fish species (e.g. perch, brown trout or pike) were not available for examination. Nevertheless, on the basis of the data obtained it should be emphasised that occasional consumption of the muscle tissue of large specimens of predatory fish from the bay does not pose any real risk to consumers.

This same magnitude of the mercury level in fish as that obtained in this study was reported in fish from various parts of the Baltic [22, 28]. Generally, the concentration of mercury in fish from the Baltic examined in 1966-1985 was one order of magnitude higher [29]. A higher level of mercury in fish than that obtained in this study, was noted in specimens from areas contaminated with mercury e.g. of gold mining activity in Brazil and in Tokuyama Bay, where it ranged from 110±110 to 1300±890 ng/g fresh weight [30] and up to 800 ng/g fresh weight [31].

Spatial Distribution – Analysis of Variance (ANOVA)

Differences and similarities of the spatial distribution of mercury concentration in molluscs (*Mytilus trossulus, Cardium edule, Mya arenaria, Theodoxus fluviatilis* and *Lymnea stagnalis*), crustaceans (*Crangon crangon, Palaemon adspersus, Idiothea baltica* and *Gammarus* sp.) and fish (*Gasterosteus aculeatus, Pungitius pungitius,*

Table 4. Biometric data and total mercury concentration in crustaceans from Puck Bay.

Species and sampling sites	Date of sampling	n	Length (cm) x±SD (Range)	Weight (g) x±SD (Range)	Hg (ng/g fresh weight) x±SD (Range)
Zoarces viviparous					
P 3	29.04.97	27	23 ± 3 (17 – 28)	64 ± 19 (34 – 112)	49 ± 20 (16 – 84)
Anquilla anquilla					
P 3	28.06.96	29	43 ± 4 (38 – 53)	117 ± 30 (85 – 205)	76 ± 27 (32 – 144)
Clupea harengus					
P 3	26.08.97	8	20 ± 2 (17 – 23)	51 ± 13 (34 – 70)	49 ± 25 (22 – 97)
Rutilus rutilus					
P 3	26.08.97	3	20 ± 6 (12 – 24)	137 ± 107 (18 – 223)	81 ± 13 (69 – 94)
Abramis brama					
P 3	26.08.97	5	9.0 ± 0.2 (8.8 – 9.4)	11 ± 2 (9 – 13)	40 ± 9 (32 – 52)
Platichthys flesus					
P 3	15.09.95	6	14 ± 5 (11 – 23)	50 ± 53 (19 – 156)	53 ± 12 (38 – 70)
P 3	30.06.97	27	18 ± 3 (13 – 26)	78 ± 43 (23 – 211)	31 ± 19 (12 – 105)
S 3	26.08.97	26	19 ± 6 (11 – 30)	116 ± 94 (19 – 340)	37 ± 16 (15 – 73)
S 9	26.08.97	8	20 ± 3 (15 – 23)	99 ± 38 (35 – 152)	33 ± 14 (15 – 56)

Table 4 continues on next page

Perca fluviatilis					
P 3	12.07.97	32	13 ± 1 (11 – 17)	33 ± 11 (16 – 70)	110 ± 43 (23 – 210)
S 9	19.07.97	15	16 ± 2 (13 – 21)	51 ± 27 (22 – 12))	130 ± 54 (25 – 210)
P 8	19.07.97	9	17 ± 1 (16 – 19)	63 ± 13 (43 – 84)	120 ± 46 (44 – 200)
Neogobius melanostromus					
P 3	15.09.95	78	13 ± 2 (9 – 24)	37 ± 14 (13 – 84)	43 ± 21 (6 – 99)
S 3	15.08.97	19	13 ± 2 (11 – 17)	40 ± 21 (10 – 79)	51 ± 21 (18 – 78)
P 6	10.08.97	12	13 ± 1 (10 – 14)	30 ± 7 (22 – 46)	46 ± 20 (16 – 80)
S 9	26.08.97	12	13 ± 2 (10 – 16)	34 ± 13 (15 – 68)	50 ± 26 (10 – 106)
P 8	26.08.97	8	15 ± 2 (11 – 16)	54 ± 22 (25 – 75)	33 ± 17 (15- 70)
Pomatoschistus microps					
P 2	22.08.96	11	3.2 ± 0.4 (2.6 – 3.7)	0.3 ± 0.1 (0.1 – 0.5)	32 ± 12 (15 – 55)
S 3	16.07.97	8	4.3 ± 0.9 (2.3 – 5.0)	0.6 ± 0.2 (0.2 – 0.9)	30 ± 15 (14 – 57)
S 6	16.07.97	5	3.0 ± 0.2 (2.8 – 3.4)	0.3 ± 0.1 (0.2 – 4.0)	53 ± 4 (47 – 59)
Nerophis ophidion					
P 1	22.08.96	13	19 ± 2 (13 – 22)	0.5 ± 0.2 (0.1 – 0.9)	41 ± 9 (25 – 56)
P 11	22.08.96	13	19 ± 1 (17 – 21)	0.5 ± 0.1 (0.4 – 0.6)	52 ± 8 (41 – 64)
S 4	16.08.97	4	19 ± 3 (15 – 22)	0.5 ± 0.3 (0.2 – 1.0)	28 ± 8 (19 – 39)
S 9	16.08.97	3	18 ± 4 (16 – 23)	0.5 ± 0.4 (0.3 – 1.0)	30 ± 9 (20 – 38)
S 3	16.08.97	5	17 ± 4 (13 – 22)	0.4 ± 0.2 (0.2 – 0.8)	37 ± 12 (21 – 52)
S 8	16.08.97	3	16 ± 1 (15 – 17)	0.3 ± 1.0 (0.2 – 0.4)	43 ± 18 (23 – 54)
Gasterosteus aculeatus					
P 3	03.07.96	22	6.1 ± 0.5 (5.1 – 7.3)	1.6 ± 0.5 (1.0 – 2.9)	16 ± 4 (9 – 25)
P 2	22.08.96	10	5.6 ± 1.0 (4.3 – 6.9)	1.4 ± 0.7 (0.5 – 2.4)	43 ± 19 (16 – 66)
P 11	22.08.96	5	5.9 ± 0.6 (5.4 – 6.7)	1.7 ± 0.4 (1.2 – 2.2)	22 ± 5 (17 – 31)
S 3	19.07.97	14	6.1 ± 0.5 (5.3 – 7.1)	1.9 ± 0.5 (1.2 – 3.1)	18 ± 10 (11 – 51)
S 4	19.07.97	16	5.8 ± 1.1 (3.3 – 7.5)	1.9 ± 0.5 (1.0 – 2.4)	15 ± 6 (9 – 29)
S 6	19.07.97	5	5.3 ± 0.4 (4.9 – 5.8)	1.3 ± 0.3 (0.9 – 1.6)	14 ± 5 (9 – 23)
S 8	19.07.97	5	5.4 ± 0.7 (4.6 – 6.2)	1.4 ± 0.3 (1.0 – 1.8)	18 ± 5 (11 – 24)
S 9	19.07.97	8	5.4 ± 0.6 (4.8 – 6.3)	1.3 ± 0.4 (0.9 – 1.7)	16 ± 6 (9 – 23)
Pungitius pungitius					
P 1	22.08.96	4	4.4 ± 0.4 (3.9 – 4.7)	0.5 ± 0.1 (0.4 – 0.6)	65 ± 17 (48 – 89)
P 2	22.08.96	12	4.3 ± 0.6 (3.4 – 5.2)	0.5 ± 0.2 (0.3 – 1.0)	44 ± 9 (31 – 61)
P 11	22.08.96	9	4.8 ± 0.9 (3.1 – 6.4)	0.7 ± 0.4 (0.1 – 1.5)	55 ± 6 (45 – 65)
S 3	19.07.97	7	4.4 ± 0.6 (3.8 – 5.4)	0.5 ± 0.2 (0.4 – 0.8)	33 ± 8 (25 – 47)
S 4	19.07.97	18	4.0 ± 0.4 (3.4 – 4.8)	0.5 ± 0.1 (0.3 – 0.7)	23 ± 7 (4 – 36)
S 6	19.07.97	11	4.3 ± 0.7 (3.7 – 6.2)	0.5 ± 0.4 (0.3 – 1.8)	34 ± 10 (13 – 52)
S 8	19.07.97	14	3.9 ± 0.5 (3.4 – 4.8)	0.4 ± 0.1 (0.3 – 0.6)	42 ± 11 (30 – 67)
S 9	19.07.97	8	4.0 ± 0.3 (3.5 – 4.5)	0.4 ± 0.1 (0.3 – 0.6)	55 ± 13 (37 – 74)

n – number of specimens; x±SD – average value and standard deviation

Nerophis ophidion, Neogobius melanostromus, Pomatoschistus microps, Perca fluviatilis and *Platichthys flesus*) from various sites in Puck Bay were examined using analysis of variance (ANOVA) [32].

For most of the species the statistically significant ($p<0.05$) differences in spatial distribution were obtained. The most pronounced variation of the spatial distribution of mercury was found in *Mytilus trossulus* (F(10;154)=19,02; $p<0.0001$), gammarus (F(6;68)=7.86; $p=0.000002$) and nine-spined stickleback (F(7;77)=19.48; $p<0.0001$) and these species seem to be suitable bioindicators of mercury pollution of the bay for monitoring studies. Among the investigated species variations of spatial distribution of mercury were not found in T*heodoxus fluviatilis* (F(6;99)=1.06; $p<0.3904$), *Lymnea stagnalis* (F(1;4)=1.35; $p<0.3097$, *Mya arenaria* (F(2;16)=2.40; $p<0.123$), *Palaemon adspersus* (F(3;69)=2.58; $p<0.0604$), flounder (F(2;64)=1.18; $p<0.8321$), perch (F(2;53)=0.97; $p<0.3858$), and round goby (F(4;124)=1,3; $p<0.2722$).

Conclusions

The results of this study indicate relatively low mercury concentrations in living organisms in Puck Bay and of the same magnitude as reported by other authors for other parts of the Baltic. However, an increase in the amount of mercury deposited in the bay (especially due to mobilization of the load adsorbed by the soil in the drainage area) accompanied by an increase in the rate of its remobilisation from sediment can result in a significant increase in the concentrations accumulated by the biota.

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