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Original Research

Bioaccumulation of DDT and Its Metabolites in the Międzyodrze Ecosystem, Poland

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Abstract

The aim of this study was to estimate the degree of DDT and its metabolite bioaccumulation (*biota-sediment accumulation factor*, BSAF and *biota-water accumulation factor*, BCF) in certain aquatic biota collected from the lower Oder River. The study comprised surface water and sediments, as well as soft tissue of compressed river mussel (*Anodonta complanata*) and certain organs of roach (*Rutilus rutilus*) and spinycheek crayfish (*Orconectes limosus*). Regarding a 30-year-old ban on DDT use in Poland, relatively low concentrations of the compound were expected. DDT and its metabolites were detected in all the examined samples. ΣDDT levels in water and sediments averaged 0.157 ± 0.068 μg/dm^3 and 11.478 ± 2.292 μg/kg d.w., respectively. Roach organs contained higher levels of these compounds than crayfish and bivalves. DDT was accumulated mainly in the liver and gonads (45.823 ± 9.845 and 19.815 ± 4.854 μg ΣDDT/kg w.w., respectively). In roach organs *p,p'* DDE predominated. BSAF values for *p,p'* DDE and *p,p'* DDD in the liver and *p,p'* DDE in the gonads exceeded the predicted theoretical value (2.4). In water and sediment samples from several sites, the DDT/DDE ratio was higher than 1, which indicated fresh input of DDT in the studied area or inhibition of its breakdown.

Keywords: BSAF, log BCF, DDT, aquatic biota, the Oder River

Introduction

Organochlorine pesticides, including DDT (*p,p'*-dichloro(diphenyl)trichloroethane), are some of the major pollutants of aquatic and terrestrial ecosystems. DDT was widely used due to its high toxicity to insects and high efficiency in insect pest control (agriculture) and disease vector control (malaria, typhus). During several decades, significant amounts of this pesticide were introduced to the natural environment, which resulted in serious pollution due to its high toxicity. DDT was categorized by the Governing Council of the United Nations Environment Programme as one of the twelve Persistent Organic Pollutants (POPs). POPs are organic compounds that have potentially significant impacts on human health and the environment. They are persistent in all compartments of the environment, bioaccumulate in human and animal tissues, are capable of long-range transport, and are distinguished by low water solubility and high lipid solubility [1].

A wide range of literature data indicates that despite a three-decades-long ban on the use of organochlorine pesticides, DDT and its metabolites are still detected in the aquatic environment [2-8]. Aquatic biota accumulate DDT as a result of bioconcentration (from water) and/or bioaccumulation (from food) [9]. The degree of bioaccumulation is determined by many factors, such as lipid content, rate of

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body mass increase, xenobiotic elimination rate, exposure duration, food chain structure and a species' trophic position [10].

Bioaccumulation of organochlorine compounds, including DDT, results from a variety of physical and biochemical processes that occur in the environment. A necessary condition is, however, predominance of absorption rate over elimination rate in the body [11].

The Oder is one of the longest rivers in Europe and the second longest river in Poland (741.9 km). In Widuchowa, the Oder forks into its eastern and western branches, enclosing an area of Międzyodrze that is legally protected as the Lower Oder Valley Landscape Park. The Międzyodrze is one of the largest fens in Europe with unique flora and fauna. Pollution of the Oder results from intensive agriculture and big industrial-municipal agglomerations located in its catchment area, as well as from significant loads of pollutants from industrialized areas in the Czech Republic, Germany, Upper Silesia and Lower Silesia [12].

The aim of this study was to estimate the degree of DDT and its metabolites bioaccumulation (biota-sediment accumulation factor, BSAF and biota-water accumulation factor, BCF) in certain aquatic biota collected from the lower reaches of the Oder. Because of a three-decades-long ban on DDT use in Poland, relatively low concentrations of the compound were expected.

Experimental Procedures

The study comprised surface water, sediments, soft tissue of compressed river mussel (*Anodonta complanata*), certain organs of female roach (*Rutilus rutilus*) – gonads, gills (gill lamellae), muscles, liver, and certain organs of female spinycheek crayfish (*Orconectes limosus*): gills, gastrointestinal tract, and muscles. Body weight, body length and lipid content in the tissues of fish, crayfish and mussel are presented in Table 1.

All samples (N=5 from each site) were collected in spring 2003 from 5 sites located in the lower reaches of the Oder, in the Międzyodrze area (Fig. 1).

All fish, bivalves, crayfish and sediment samples were frozen (-20ºC) and stored in a laboratory until analysis. Water samples were kept at -4ºC until extraction.

Sediments

Sediments were collected with a Van Veen grab sampler (0-5 cm) to glass containers. In the laboratory, the collected sediment samples were dried at ambient temperature, ground in a mortar and 2-mm sieved. Subsamples of 30 g were taken for analysis. Extraction of pesticides and purification of extracts were performed according to methods described by Jensen and Reutengardh [13]. Organic carbon content in the sediments was determined using Tiurin's method [14].

Water

At each site, 10 dm^3 of surface water was collected to a 2.5-dm^3 dark glass bottle containing 300 cm^3 n-hexane. In the laboratory, the analyzed compounds were extracted with n hexane in a separator. The extract was dried over anhydrous sodium sulphate (Na_2SO_4) and concentrated to 2 cm^3 in a rotary vacuum evaporator at 50ºC. Next, the extract was purified with 6 cm^3 of fuming sulphuric acid (7% SO_3 in concentrated H_2SO_4). After layers separation, the upper (n-hexane) layer was quantitatively transferred to a 10-cm^3 test tube, washed three times with deionized water and dried over anhydrous sodium sulphate in an 8-cm^3 LiChrolut® glass column.

Fish, Bivalves and Crayfish

Subsamples of 7-30 g were taken for analysis. Each subsample was spiked with 50 µl of internal standard (Pesticides Surrogate Spike Mix) of 80 µg/dm^3 concentration, and the

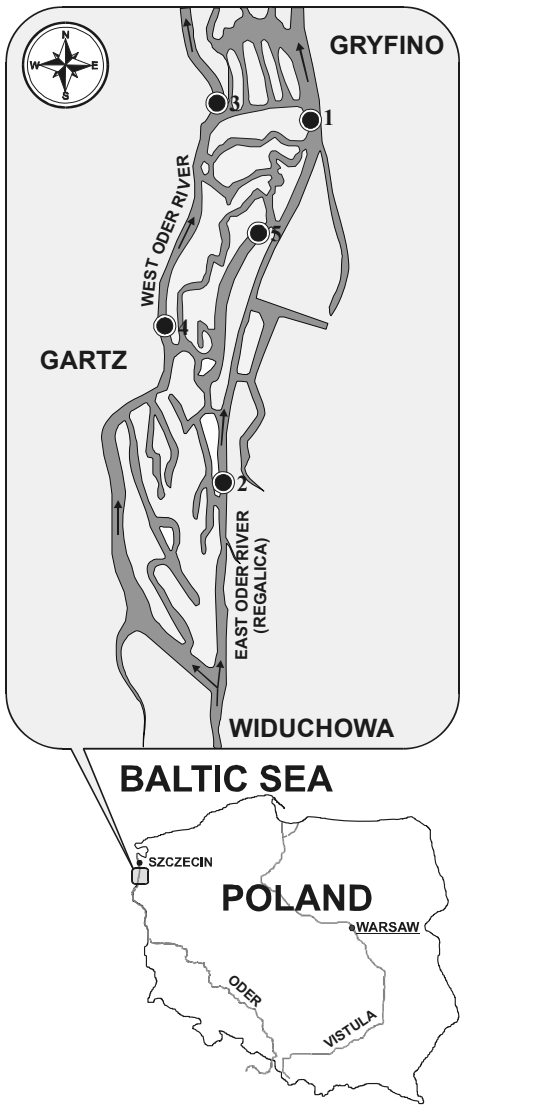

Fig. 1. Location of sample collection sites at the Międzyodrze, the lower Oder, Poland.

Table 1. Body weight, body length and lipid content in the tissues of fish, crayfish and mussel from the lower Oder, Poland.

Samples	Parameter	Value
roach (*Rutilus rutilus*) n=25	body weight (g)	369.6 ± 32.0
	body length (cm)	22.6 ± 3.1
	content of lipids (%):	
	gonads	1.02 ± 0.36
	gills	3.15 ± 0.23
	liver	1.52 ± 0.28
	muscles	2.02 ± 0.41
spinycheek crayfish (*Orconectes limosus*) n=25	body weight (g)	34.2 ± 4.8
	body length (cm)	7.4 ± 0.9
	content of lipids (%):	
	gills	0.48 ± 0.11
	gastroint. tract	3.85 ± 0.79
	muscles	1.41 ± 0.37
compressed river mussel (*Anodonta complanata*) n=25	content of lipids (%):	
	soft tissue	1.92 ± 0.32

Table 2. Analytical conditions for gas chromatography/mass spectrometry analysis.

Parameter	Condition
Sample volume	3 µl
Injection mode	Pulsed Splitless
Injector temperature	250°C
Carrier gas	Helium
Flow rate	1.0 $cm^3 \cdot min^{-1}$
Capillary column	HP-35 (30 m×320 µm×0.15 µm)
Detector operating system	MSD, SIM
Ion source temperature	230°C
Quadrupole temperature	150°C
Temperature program	140°C (0.5 min); 5°C/min; 200°C (5 min); 10°C /min; 280°C (10 min); 30°C/min; 300°C (1 min)

whole was ground with anhydrous sodium sulphate in a mortar to a loose homogenous substance. Next, the sample was quantitatively transferred to a 300-cm^3 conical flask with a ground glass stopper and the examined compounds, together with lipids, were extracted first with 50 cm^3 of acetone:n-hexane mixture (2.5:1, v/v) and next with 50 cm^3 of n-hexane:ethyl ether mixture (9:1, v/v). The extract obtained was concentrated to 2 cm^3 in a rotary vacuum evaporator at 50ºC, and quantitatively transferred to a dry pre-weighed 10-cm^3 test tube with a ground glass stopper. To determine percentage lipid content, the solvent was evaporated under a nitrogen stream and the residue was dried to a constant weight at 80ºC. Next, the test tube content was redissolved in 2 cm^3 of n hexane and purified first with 6 cm^3 of fuming sulphuric acid (7% SO_3 in concentrated H_2SO_4), and next with a 5% solution of KOH in 96% ethanol. After layers separation, the upper (n-hexane) layer was washed with deionized water and dried over anhydrous sodium sulphate.

Chromatographic Analysis

Previously prepared extracts were concentrated to 0.5 cm^3 in nitrogen atmosphere, and subjected to chromatographic separation in a gas-liquid system by capillary gas chromatography-mass spectrometry method in a GC MSD HP 6890/5973 apparatus. The chromatographic analysis conditions are presented in Table 2.

The accuracy of methods applied was checked by the addition of internal standard Pesticides Surrogate Spike Mix, Supelco. Recoveries of the analyzed compounds ranged within 76-94% in biological material, 70-88% in water, and 75-96% in sediments. All determinations were performed in triplicate, and the results are presented as arithmetic means of concentrations from all collection sites.

Biota-Sediment Accumulation Factors (BSAF) and Bioconcentration Factors (BCF)

Biota-sediment accumulation factors (BSAF) and bioconcentration factors (BCF) were calculated according to the following equations [15-17]:

$$BSAF = \frac{[DDT]_{organism(lipids)}}{[DDT]_{sediment(C_{org})}} \quad (1)$$

$$BCF = \frac{[DDT]_{organism(lipids)}}{[DDT]_{water}} \quad (2)$$

The bioaccumulation (BSAFs) and bioconcentration (log BCFs) factors for DDT and its metabolites were estimated on the basis of equilibrium partitioning theory (EPT) [18]. The calculations were made using the following relationships [14-16]:

$$BCF = K_{OW} \quad (3)$$

$$BSAF = \frac{BCF}{K_{OC}} \quad (4)$$

$$K_{OC} = 0.41 \cdot K_{OW} \quad (5)$$

where:

K_{OC} – is the organic-carbon normalized sediment/water distribution coefficient;

K_{OW} – is the octanol/water partition coefficient.

The predicted level of bioaccumulation factor for DDT and its metabolites equals 2.4. The predicted value of log BCF is equivalent to octanol-water partition coefficient (log K_{OW}), which ranges from 2.25 for *p,p'* DDD to 2.54 for *p,p'* DDT.

Statistical Analysis

Statistical analysis of the results was carried out using Statistica 6.1. Mean values ($\bar{x}$), standard deviations (SD) and correlation coefficients were determined. The significance of differences was determined by Student's t-test.

Results

Levels of DDT and its metabolites detected in the examined samples are presented in Table 4. In water, ΣDDT levels averaged 0.157 ± 0.068 μg/dm^3 and varied between the sampling sites from 0.077 ± 0.020 μg/dm^3 (site 4) to 0.262 ± 0.026 μg/dm3 (site 5). The dominant compound was *p,p'* DDT, whose concentration averaged 0.064 ± 0.029 μg/dm^3, while the less abundant was *p,p'* DDD. Statistical analysis revealed that differences between aquatic concentration of *p,p'* DDD and concentrations of the other compounds were statistically significant ($P < 0.05$). Similar relationships were observed in sediments, where concentrations of *p,p'* DDT, *p,p'* DDE and *p,p'* DDD averaged 5.313 ± 2.449, 4.122 ± 2.356 and 2.043 ± 1.305 μg/kg dry weight, respectively. The ratio of *p,p'* DDT/*p,p'* DDE higher than 1 was observed in the water and sediments of sites 1 and 3 located on the eastern Oder and in the sediments of site 4 located on the western Oder.

In the aquatic biota, levels of DDT and its metabolites varied and were species-specific. Roach organs contained higher levels of these compounds than crayfish and bivalves. DDT accumulated mainly in the liver (45.823 ± 9.845 μg DDT/kg w.w.) and gonads (19.815 ± 4.854 μg ΣDDT/kg w.w.), while the lowest levels were found in the gills and muscles – 6.549 ± 1.005 and 9.073 ± 3.248 μg ΣDDT/kg w.w., respectively. In all roach organs *p,p'* DDE predominated and its concentrations ranged from 4.911 ± 0.402 μg/kg w.w. in gills to 18.740 ± 4.522 μg/kg w.w. in liver.

In crayfish gills and muscles, levels of DDT and its metabolites were significantly lower ($P < 0.05$) than in gills and muscles of roach. The highest ΣDDT level (5.822 ± 0.859 μg/kg w.w.) was found in the crayfish gastrointestinal tract, being an order of magnitude higher than the average levels in the other organs. In both crayfish and mussels, concentrations of the examined compounds formed a decreasing sequence: *p,p'* DDE > *p,p'* DDT > *p,p'* DDD.

In mussels, levels of *p,p'* DDT, *p,p'* DDE and *p,p'* DDD in the soft tissue averaged 0.368 ± 0.191, 0.424 ± 0.178 and 0.072 ± 0.057 μg/kg w.w., respectively.

Although levels of *p,p'* DDD in roach liver was significantly lower than levels of the other compounds, factors of bioaccumulation (BSAF) and bioconcentration (BCF) for this compound were higher than factors calculated for *p,p'* DDT and *p,p'* DDE (Fig. 2). However, in the case of gonads, gills and muscles, the highest BSAF and log BCF were found for *p,p'* DDE (2.63, 1.87, 0.93 and 2.92, 2.77, 2.47, respectively). In all organs, the lowest BSAFs were calculated for *p,p'* DDT.

The highest values of BSAF for the examined compounds were obtained for the liver (1.71 to 2.90) and gonads (0.19 to 2.63). DDT and its metabolites were the least bioaccumulated in the gills (BSAF from 0.15 to 1.87) and muscles (BSAF from 0.33 to 0.93). Analysis of the data obtained in this study revealed that bioconcentration factors were less varied among organs than bioaccumulation factors, and ranged from 1.79 (*p,p'*DDT in the gills) to 2.96 (*p,p'*DDD in the liver). BSAFs for *p,p'* DDE and *p,p'* DDD in the liver and *p,p'* DDE in the gonads exceeded the predicted theoretical value (2.4).

In crayfish gills and muscles, BSAF and BCF values were evidently lower than values obtained for roach (Fig. 3), and for muscles the difference was statistically significant ($P < 0.05$). Crayfish accumulated the examined compounds mainly in the gastrointestinal tract (BSAF: 0.07-0.45), and to a lower extent also in the gills (BSAF: 0.04-0.10) and muscles (BSAF: 0.03-0.15). In both crayfish and bivalves, bioaccumulation and bioconcentration of *p,p'* DDE was the most intensive. The lowest BSAF and log BCF values in crayfish organs were obtained for *p,p'* DDT. BSAFs for *p,p'* DDT varied from 0.03 (muscles) to 0.07 (gastrointestinal tract), while log BCF values ranged from 1.1 (muscles) to 1.5 (gastrointestinal tract). Differently in bivalve tissue, the lowest BSAF and log BCF values were measured for *p,p'* DDD – 0.02 and 0.60, respectively.

Discussion

Studies on concentrations of polychlorinated hydrocarbons in the Oder river estuary have been conducted for three decades [19-22]. Despite a ban on DDT use which has been in effect in the last 30 years, the compound is still detected in various compartments of the environment. Of all persistent organic pollutants, this compound dominates in bottom sediments, together with PCBs [23]. Our study revealed that DDT levels in the sediments of the lower Oder

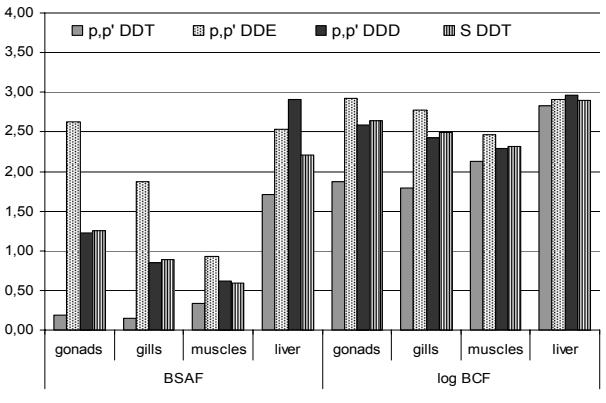

Fig. 2. Factors of bioaccumulation (BSAF) and bioconcentration (log BCF) for DDT and its metabolites in organs of roach (*Rutilus rutilus*) in the lower Oder, Poland.

Table 3. Concentrations of DDT and its metabolites in water (μg/dm³) and sediments (μg/kg d.w.), organic carbon content (%) and DDT/DDE ratio in the lower Oder, Poland.

Sample	Site	Concentration					*p,p'* DDT/*p,p'* DDE ratio*
			p,p' DDT	*p,p'* DDE	*p,p'* DDD	∑ DDT	
surface water	1		0.057 ± 0.009	0.037 ± 0.008	0.024 ± 0.005	0.112 ± 0.015	1.823 ± 0.171
	2		0.038 ± 0.005	0.082 ± 0.013	0.038 ± 0.008	0.157 ± 0.015	0.473 ± 0.100
	3		0.098 ± 0.006	0.049 ± 0.007	0.028 ± 0.013	0.174 ± 0.012	2.086 ± 0.529
	4		0.034 ± 0.011	0.032 ± 0.010	0.010 ± 0.004	0.077 ± 0.020	1.033 ± 0.091
	5		0.094 ± 0.006	0.116 ± 0.017	0.052 ± 0.011	0.262 ± 0.026	0.827 ± 0.144
$\bar{x}$ ± SD			0.064 ± 0.029	0.062 ± 0.036	0.037 ± 0.017	0.157 ± 0.068	
		C_{org}, %	*p,p'* DDT	*p,p'* DDE	*p,p'* DDD	∑ DDT	
sediment	1	4.61 ± 0.58	5.824 ± 0.647	3.173 ± 0.248	0.437 ± 0.213	9.434 ± 0.606	1.835 ± 0.487
	2	5.40 ± 0.56	3.693 ± 0.228	4.652 ± 0.642	2.653 ± 0.512	10.998 ± 0.412	0.793 ± 0.852
	3	3.76 ± 0.49	4.058 ± 0.751	2.391 ± 0.547	1.086 ± 0.192	7.535 ± 0.636	1.697 ± 0.398
	4	4.77 ± 0.30	3.658 ± 0.404	2.382 ± 0.303	2.304 ± 0.227	8.172 ± 0.403	1.535 ± 0.384
	5	7.21 ± 0.36	9.391 ± 0.419	8.042 ± 0.451	3.739 ± 0.254	21.172 ± 0.512	1.167 ± 0.244
$\bar{x}$ ± SD		5.15 ± 1,27	5.313 ± 2.449	4.122 ± 2.356	2.043 ± 1.305	11.478 ± 2.292	

* Underlined values of *p,p'* DDT/*p,p'* DDE ratio indicate fresh input of DDT or inhibition of its degradation.

varied depending on sediment type (Table 3). Organic matter-rich (muddy) sediments accumulated more DDT than sandy (mineral) deposits, which was confirmed by a high positive correlation between ΣDDT levels and organic matter (C_{org}) content in the sediments (Fig. 4). Such a relationship was also observed in previous studies of other authors [17, 20].

Average content of ΣDDT in the sediments of the Oder river ranged from 7.535 ± 0.636 (site 3) to 21.172 ± 0.512 μg/kg d.w. (site 5; Table 3). The determined values were similar to the levels reported by Protasowicki et al. [22] for this area and by da Silva et al. [24] for the Piracicaba River, Brazil (range n.d.-20 μg ΣDDT/kg d.w.). However, in comparison with sediment ΣDDT levels in the Pearl River, China, varying within 1.36-8.99 μg ΣDDT/kg d.w. [25], the Oder River sediments were more contaminated.

In our study, concentrations of *p,p'* DDT in the water and sediments from several sites on the Oder river were higher than concentrations of its metabolite (Table 3). This may indicate fresh input of DDT or inhibition of its degradation. DDT breakdown in the environment depends on many factors, including sediment pollution, e.g. with toxic metals which may directly influence activity of microorganisms taking part in this process [26]. According to Rochkind and Blackburn [27], DDT breakdown can occur under both aerobic and anaerobic conditions, but intensive dehydrohalogenation occurs mainly under anaerobic conditions.

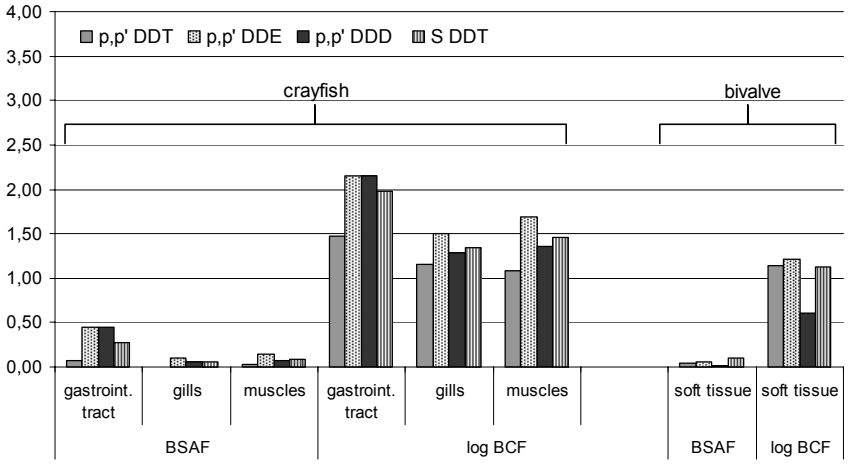

Fig. 3. Factors of bioaccumulation (BSAF) and bioconcentration (log BCF) for DDT and its metabolites in organs of spinycheek crayfish (Orconectes limosus) and soft tissue of compressed river mussel (Anodonta complanata) in the lower Oder, Poland.

Table 4. Concentrations of DDT and its metabolites in certain organs and tissues of fish, mussels and crayfish (µg/kg w.w.) in the lower Oder, Poland.

Samples		N	Pesticides			
			p,p' DDT	*p,p'* DDE	*p,p'* DDD	Σ DDT
Rutilus rutilus		25				
gills			0.528 ± 0.224	4.911 ± 0.402	1.110 ± 0.366	6.549 ± 1.005
gonads			1.381 ± 0.288	14.970 ± 2.514	3.464 ± 0.994	19.815 ± 4.854
muscles			2.343 ± 0.871	5.060 ± 1.997	1.670 ± 0.151	9.073 ± 3.248
liver			16.415 ± 1.578	18.740 ± 4.522	10.672 ± 2.395	45.823 ± 9.845
Orconectes limosus		25				
gills			0.113 ± 0.084	0.241 ± 0.054	0.073 ± 0.032	0.427 ± 0.168
gastrointestinal tract			0.725 ± 0.132	3.417 ± 0.242	1.680 ± 0.469	5.822 ± 0.859
muscles			0.109 ± 0.076	0.422 ± 0.103	0.101 ± 0.046	0.632 ± 0.230
Anodonta complanata						
soft tissue	site 1	5	0.414 ± 0.042	0.312 ± 0.023	0.026 ± 0.011	0.782 ± 0.071
	site 2	5	0.436 ± 0.161	0.289 ± 0.049	0.079 ± 0.023	0.854 ± 0.094
	site 3	5	0.190 ± 0.098	0.141 ± 0.081	0.051 ± 0.028	0.391± 0.062
	site 4	5	0.257 ± 0.107	0.517 ± 0.112	0.075 ± 0.032	0.986 ± 0.054
	site 5	5	0.635 ± 0.072	0.861 ± 0.098	0.157 ± 0.044	1.722 ± 0.107
	$\bar{x}$	25	0.368 ± 0.191	0.424 ± 0.178	0.072 ± 0.057	0.863 ± 0.180

In fish, DDT and its metabolites accumulated mainly in the liver and gonads, while in the gills and muscles their content was several-fold lower. ΣDDT levels in roach muscle tissue averaged 9.073 ± 3.248 µg/kg w.w. The results were similar to the data of Protasowicki et al. [5]. Differently, higher ΣDDT levels of 23.7 ± 1.60 µg ΣDDT/kg w.w. were found in roach from the Szczecin Lagoon [2]. Moreover, in fish from the lower Oder *p,p'* DDE predominated, while in roach specimens from Szczecin Lagoon the most abundant was *p,p'* DDT. In organs of roach from the Oder, DDT content was lower than concentrations reported for organs of fish from the Gulf of Gdańsk [28], Szczecin Lagoon [2], Baltic Sea [29], and the Dniester [3].

ΣDDT content in the soft tissue of compressed river mussel averaged 0.863 ± 0.480 µg/kg w.w. and was lower than reported by Pikkarainen [29]. The author observed that bivalves from the Baltic Sea contained from 1.4 to 4.4 µg ΣDDT/kg w.w. Evidently higher ΣDDT levels of 1.9-79.0 µg ΣDDT /kg w.w. were also found in molluscs from the Pearl River estuary [6].

Crayfish are often used as biological indicators in monitoring environmental pollution with organic compounds [30]. In this study we observed that ΣDDT content in crayfish muscles was significantly lower ($P < 0.05$) than in fish muscles or bivalve soft tissue. However, in comparison to the data of Schilderman et al. [30], crayfish in the Oder River contained more DDT than crayfish in the River Meuse.

The degree of accumulation of organic compounds varies among species, due to dissimilarity of physiological and biochemical processes that determine uptake, distribution and elimination of xenobiotics and their trophic levels. In the examined fish, DDT and its metabolites accumulated mainly in lipid-rich organs, i.e. liver and gonads (Fig. 2). BSAF values in fish livers and gonads ranged within 1.7-2.9 and 0.2-2.6, respectively. Values of log BCF in fish

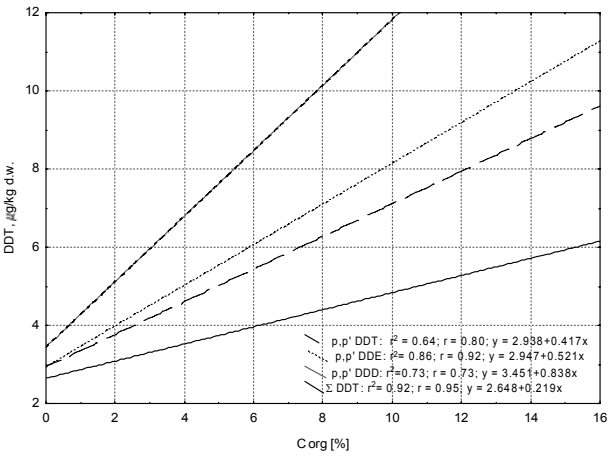

Fig. 4. Relationships between organic matter content and levels of DDT and its metabolites in the sediments of the lower Oder, Poland.

organs varied between 1.8 (*p,p'* DDT, gills) and 2.96 (*p,p'*DDD, liver). Much higher log BCF values of 3.5-5.4 were observed for fish in the river Qiantang [7]. But BSAFs for fish from the river Qiantang [8] were comparable to BSAFs for roach obtained in this study.

According to Ozkoc et al. [4], BSAFs for molluscs harvested from the Black Sea averaged 2.9, while in this study BSAFs for bivalves from the Oder did not exceed 0.1. Worth noticing is that DDT levels in the Black Sea molluscs averaged 14 µg/kg w.w., while in the bivalves from the Oder – only 0.863µg/kg w.w.

The observed differences in BSAF and BCF values in the examined aquatic biota were probably the effect of differences in DDT absorption from the polluted food (biomagnification) and/or the rate and effectiveness of the compound elimination from the body. Factors of bioaccumulation (BSAF) and bioconcentration (BCF) depend largely on bioavailability of organochlorine compounds, as this determines their partitioning among water, organic fraction of sediments (C_{org}) and lipids of the body [31]. Muir et al. [32] have suggested that a decline in absorption of hydrophobic compounds by aquatic biota may reflect their low bioavailability due to strong sorption on surface of sediment particles. Our study revealed, however, that higher BSAFs occurred in bivalves harvested from sites with sediments more polluted with organic compounds and richer in organic matter (C_{org}). Similar relationships were observed by Zhou et al. [8] in aquatic biota from the river Qiantang. This might imply that sediments, being an absorbent of/for organic compounds, also become a source of chemicals for other ecosystem elements.

Conclusions

To summarize, DDT and its metabolites were present in water, sediments and all the examined organs and tissues of aquatic biota from the lower reaches of the Oder river. Roach accumulated DDT and its metabolites mainly in the gonads and liver. BSAFs for *p,p'* DDE and *p,p'* DDD in the liver and *p,p'* DDE in the gonads exceeded the predicted theoretical value. In the aquatic biota, a high proportion of DDT was transformed into DDE. In water and sediment samples from sites 1, 3 and 4, the DDT/DDE ratio was higher than 1, which indicated fresh input of DDT in the studied area or inhibition of its breakdown.

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