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Accumulation of polychlorinated biphenyls in turbot *(Scophthalmus maximus)* from seawater sediments and food

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ABSTRACT: Juvenile turbot, *Scophthalmus maximus* (L.), were exposed to 0.58 μg 1^{-1} Aroclor 1254 in seawater, to sediments containing 100, 60 and 1 ppm or fed with cockle containing 20 ppm PCB (polychlorinated biphenyls). Concentration factors for liver and muscle were 10^4 and 10^3, respectively, for uptake of PCB from seawater. Contamination of muscle was similar to that of sediments containing 1 and 60 ppm PCB to which turbot were exposed, but less than the 20 ppm in their experimental diet. Contamination of flatfish in the North Sea area is compared with the levels of PCB in the flounder, *Platichthys flesus* (L.), in the River Thames and predictable values for uptake of PCB from different pathways discussed.

INTRODUCTION

Benthic fish of commercial importance are sampled during monitoring of nearshore ecosystems and, sometimes, attempts are made to evaluate different routes of entry of PCB (polychlorinated biphenyls) into fish by comparison of their residues with those of sediments, seawater or lower trophic levels (for review see Addison, 1976).

Seawater of the more contaminated areas in the northern hemisphere, for example, in the Gulf of Catalina, south of Los Angeles, contains 35.6 ng 1^{-1} (Scura & McClure, 1975) and, usually, sediments are more contaminated.

Trophic amplification of organochlorines, when concentrations are expressed as wet weight, is less apparent when concentrations are based on lipid weights (e. g. Ten Berge & Hillebrand, 1974; for review see Phillips, 1978). On the other hand, concentration factors for uptake of PCB from seawater in laboratory fish may be high, for example, 10^5 in sheepshead minnows, *Cyprinodon variegatus* (Hansen et al., 1975).

This paper deals with investigations of the uptake of PCB in turbot from various sources of contamination in laboratory systems. They are part of a wider programme of quantitative and qualitative studies of PCB's in shallow marine benthic ecosystems.

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MATERIAL AND METHODS

Cerastoderma edule (L.) collected from Southend-on-Sea, Essex (R 882847, Ordnance Survey Sheet 178) during 1977 were subsampled to determine field values of polychlorinated biphenyl (PCB) residues and the remaining animals were held at 10 °C ± 1 C° in a marine aquarium for about 6 days before use. Cockles were prepared as food containing PCB for experimental fish by placing them in silinised glass tanks of stirred seawater (30 revs min^{-1}) at 10 °C ± 1 C° containing 0.25 mg l^{-1} Aroclor 1254 (Monsanto Chemicals Ltd.) adsorbed to the surface of alumina particles after the method of Courtney & Denton (1976). The particulate feeding bivalves accumulated suitable quantities of PCB after 10 days when they were subsampled for residue analysis and the remainder stored at – 20 °C until required for dosing fish.

Small turbot, *Scophthalmus maximus* (L.) (weight 71–160 g) taken in shallow water near Lowestoft, Suffolk (R 542910, Ordnance Survey Sheet 134) were subsampled for analysis and the remainder placed in aerated stirred seawater in silinised glass tanks at 15 °C ± 1 C°. The fish were fed approximately 1/3 their body weight of cockles contaminated with Aroclor 1254 over a period of 8 to 14 days. It had been established that this weight of food approximated to the maintenance requirement of these animals under laboratory conditions. Residual cockle was removed from the tanks 15 min after feeding and the seawater was continuously filtered with a rotary pump (Eheim 383) containing 10 % by weight beads of expanded polystyrene foam in activated charcoal. Subsequently, some fish were held in filtered seawater for periods of up to 6 months during which time they were either starved or fed with fresh cockle. Fish were subsampled throughout the experiment; the seawater was changed each fortnight and the filters were recharged once a month.

Further turbot were exposed to 100, 60 and 1 ppm of Aroclor 1254 on sand prepared by a method similar to that used by Courtney & Denton (1976) to adsorb PCB onto alumina. These fish were sacrificed after 15 days in silinised glass tanks containing 3 kg of contaminated sand in 20 l of seawater. Fish liver and muscle were analysed together with water and sand residues.

Turbot were also analysed after 15 days exposure to seawater containing 0.58 $\mu g\ l^{-1}$ Aroclor 1254. Seawater was circulated continuously at 44 l h^{-1} over contaminated sand (60 ppm) and through the experimental tank, without sand, such that fish were exposed to 0.52 $\mu g\ l^{-1}$ initially rising slightly to 0.63 $\mu g\ l^{-1}$ after 15 days.

For comparison with laboratory results, the field data were supplemented by analysis of flounder (*Platichthys flesus* of 104–413 g, wet wt) taken from the screen of Thurrock Power Station on the Thames, Essex (R 592771, Ordnance Survey Sheet 177).

Residues extracted in hexane, were analysed with a Pye Series 104 Chromatograph with ^{63}Ni electron capture detectors and equipped with 83 × 0.3 cm (inner diameter) glass columns packed with 1.3 % Apiezon L + 0.2 % E1001 on Chromosorb G A/W DCMS. Operating conditions were: column 190 °C, detector 220 °C; gas flow, purified nitrogen, 60 ml min^{-1}. Quantification of PCB was by comparison of peak heights with standard solutions expressed as ppm wet weight unless otherwise stated.

Table 1. Organochlorine content (ppm ± 1 SD) of flounder from Thurrock Power Station and cockles from Southend

Organs	% Fat	PCB	DDE	DDD	DDT	Σ DDT	PCB/DDT
	Cerastoderma edule (n = 20)						
	2.57 ± 0.72	0.06 ± 0.03	0.0014 ± 0.0006	0.0011 ± 0.0002	0.0008 ± 0.0002	0.0033 ± 0.0007	11.4 ± 2.1
	Platichthys flesus (n = 10)						
Liver	34.0 ± 12.3	5.71 ± 4.39	0.30 ± 0.20	0.30 ± 0.23	0.19 ± 0.18	0.77 ± 0.50	7.3 ± 2.8
Gills	10.44 ± 4.89	1.05 ± 0.55	0.07 ± 0.05	0.07 ± 0.04	0.06 ± 0.04	0.20 ± 0.08	5.2 ± 2.0
Muscle	4.94 ± 6.47	0.60 ± 0.45	0.03 ± 0.02	0.04 ± 0.03	0.04 ± 0.03	0.11 ± 0.06	5.6 ± 2.2
Gonad	10.91 ± 11.66	0.57 ± 0.98	0.03 ± 0.04	0.02 ± 0.02	0.03 ± 0.03	0.07 ± 0.08	6.8 ± 2.9
Gut	4.93 ± 2.38	0.50 ± 0.36	0.04 ± 0.03	0.02 ± 0.01	0.03 ± 0.02	0.08 ± 0.04	6.2 ± 1.5

RESULTS

Cockles from Southend contain 0.06 ± 0.03 ppm (whole animal) PCB; this is more than 10 × the DDT content (Table 1). Thames flounder contain more PCB with 5.71 ± 4.39 ppm in the liver, which is more contaminated than all of the other tissues including muscle with 0.60 ± 0.5 ppm (Table 1). PCB : DDT ratios were lower in fish than in cockles ranging between 5.2 and 7.3 for different tissues.

High levels of PCB in flounder liver are associated with high lipid content and there is a correlation between PCB and lipid content in the different tissues of the flounder. Notably, although the values of PCB in the muscles of the flounder are 10 × that in whole cockles, the ratio of the respective ether/extractable fat levels is 2:1 (Table 1).

Cockles exposed to 0.25 mg l^{-1} Aroclor 1254 on alumina particles accumulated 19.87 ± 8.74 ppm PCB wet weight in their tissues after 10 days. When these were fed to turbot ($\bar{M}$ PCB in liver = 1.48 and muscle = 0.44 ppm) at 1/3 their body weight for a period of a fortnight, the fish developed residues of 33.95 ± 10.74 ppm PCB in the liver and 4.17 ± 2.11 ppm in the muscle (Table 2). Subsequently these levels were maintained in fish

Table 2. PCB content (ppm ± 1 SE) of turbot during post-exposure having been fed with cockle containing 20 ppm Aroclor 1254

Depuration	Turbot liver	Turbot muscle
2 days	33.95 ± 10.74	4.17 ± 2.11
1 month	50.67 ± 2.49 (19.00 ± 5.34)	6.56 ± 4.22 (1.95 ± 0.46)
3 months	38.64 ± 16.50	3.85 ± 1.42
6 months	– (9.35)*	– (1.75 ± 0.89)

Figures in parentheses relate to starved individuals

* n = 1

Table 3. PCB budgets when turbot held on contaminated sediments for 15 days

PCB in:	Sand	Water	Turbot liver	Turbot muscle	Turbot total	Total PCB
Initial	300 mg (100 ppm)	–	*	**		300 mg
Final	174 mg	24 μg	469.37 ± 125.39	43.48 ± 8.91	13.8 mg	187.8 mg = 63 % recovery
Initial	180 mg (60 ppm)	–	*	**		180 mg
Final	150.6 mg	12.6 μg	179.77 ± 39.85	58.64 ± 11.09	1.3 mg	151.9 mg = 84 % recovery
Initial	3 mg	–	*	**		3 mg
Final	1.1 mg	3 μg	21.84 ± 9.39	1.89 ± 0.36	0.2 mg	1.3 mg = 43 % recovery

Total PCB residues in turbot after exposure represents an estimate based on PCB content of the muscle and liver

* 1.48 and ** 0.44 ppm in pooled control animals

Table 4. Concentration factors for turbot tissues following uptake of PCB from different sources

External PCB level on day 1	Muscle (liver) concentration (ppm) on day 14/15	Concentration factor
0.58 $\mu g\ l^{-1}$ seawater	2 (25)	6 (50) $\times 10^3$
100 ppm sediment	43 (469)	0.4 (4.7)
60 ppm sediment	59 (180)	1 (3)
1 ppm sediment	2 (22)	2 (22)
20 ppm food	4 (34)	0.2 (1.7)

held for 3 months without food. However, fish which were fed on freshly collected cockles rid themselves of ¾ of their body load of PCB (Table 2).

Fish in tanks with sediment initially containing 100, 60 and 1 ppm Aroclor 1254 developed liver residues of 469.37 ± 125.39, 179.77 ± 39.85 and 21.84 ± 9.39 ppm PCB, respectively, after 15 days. By the end of the experiment the sediments contained 58, 50.2 and 0.35 ppm with 1.2, 0.63 and 0.15 $\mu g\ l^{-1}$ PCB in the seawater, respectively. Budgets for the contaminated sediments experiments given in Table 3 show that between 43 and 84 % of the PCB introduced into the aquaria was recovered.

Aroclor 1254 contaminated seawater prepared by passing seawater over sand containing PCB gave a $\overline{M}$ concentration of 0.52 $\mu g\ l^{-1}$ PCB in seawater. The $\overline{M}$ concentration of PCB in the seawater entering and leaving the tanks containing the fish was 0.58 $\mu g\ l^{-1}$ and turbot liver and muscle contained 24.88 ± 7.25 and 1.93 ± 0.08, respectively, after 15 days.

Concentration factors for liver and muscle of turbot contaminated with Aroclor 1254 by various methods are shown in Table 4.

DISCUSSION

Cockles and flounder of the outer Thames are slightly more contaminated with PCB than cockles and *Solea solea* in the Weser estuary (Goerke et al., 1979) although residues are of the same order of magnitude in both estuaries. PCB levels in flatfish of Swedish waters (Jensen et al., 1969), the Dutch Wadden Sea (Ten Berge & Hillebrand, 1974), the Skagerrak (Eder et al., 1976) and the North Sea (Ten Berge & Hillebrand, 1974; Schaeffer et al., 1976) contain less PCB than young turbot at Lowestoft. The liver of some very large specimens of flatfish from the English Channel (Ernst et al., 1976) is more contaminated.

PCB levels in the gut wall of *Platichthys flesus* taken at the Thurrock Power Station in May 1976 closely resemble levels in animals from the Medway estuary between March 1974 and April 1975 (Van den Broek, 1979).

Southend cockles have a similar level of PCB contamination to *Mytilis edulis* in the outer part of the Medway estuary (Wharfe & Van den Broek, 1978) entering the southern reach of the River Thames and also to *Mytilis edulis* in Liverpool Bay (Riley & Wahby, 1977). However, PCB residues are an order of magnitude greater in *Mytilis edulis* of the River Clyde (Holden, 1973), in New Brunswick waters (Zitko, 1971) and from the inner reaches of the Medway estuary (Wharfe & Van den Broek, 1978).

The solution of PCB obtained by passing seawater over Aroclor 1254 contaminated sand was an order of magnitude weaker than that obtained by mixing Aroclor 1254 and seawater using air (Courtney & Langston, 1978). This difference in aqueous concentration reflects the affinity of PCB for active sites on the sand in the former system. Young turbot from Lowestoft which are less contaminated than Thames flatfish – possibly due to differences in size (Bache et al., 1972; Ernst et al., 1976) – accumulated similar amounts of PCB in their tissues whether in 0.58 $\mu g\ l^{-1}$ seawater or on sand containing 1 ppm Aroclor 1254 initially.

These results are reminiscent of earlier work with *Arenicola marina* and *Nereis diversicolor* which contained 0.39 and 0.49 ppm, respectively, after 10 days on 1 ppm Aroclor 1254 in sand and accumulated similar body residues when held in 1.1 $\mu g\ l^{-1}$ Aroclor 1254 in seawater (Courtney & Langston, 1978).

Benthic fish, then, rapidly became contaminated with PCB from seawater with concentration factors of 10^4 and 10^3 for liver and muscle respectively (Table 4) compared with concentration factors of 10^2–10^4 for uptake of PCB from seawater in other fish (Hansen et al., 1971; Hattula & Karlog, 1973) and 10^2 for pink shrimp, *Penaeus duorarum* (Nimmo et al., 1971a) and for polychaetes (Courtney & Langston, 1978).

PCB levels in fish muscle were similar to respective sediment contamination of 1 or 60 ppm whereas the PCB content of the liver was one order of magnitude greater with concentration factors of 22 and 3, respectively. These residues are 1 or 2 orders of magnitude greater than PCB levels in polychaetes in 1 ppm sand (Courtney & Langston, 1978). *Penaeus duorarum* and *Uca mimax* differed by a factor of < 10 from contaminated laboratory sediments (Nimmo et al., 1971b).

The seawater, gently stirred by aeration of tanks of turbot on contaminated sediment, itself contained PCB though clearly the PCB in the fish tissues came from the sediment, at least in part, since body loads exceeded those which would arise from such concentrations of PCB in seawater alone (Table 4).

In part due to the level of feeding, the fish muscle residues were 1 order of magnitude less than the PCB content of the contaminated food which was similar to the liver residues. Subsequently, PCB body loads were reduced to pre-experimental levels in fish which were fed with clean cockle (0.06 ppm PCB) but not in starved animals (Table 2). In goldfish and pinfish the ½ life of PCB is 3 to 4 weeks (Hansen et al., 1971; Hattula & Karlog, 1973) although rainbow trout retain ⅔ of the PCB fed to them (Lieb et al., 1974).

In 1969 the liver of a dead flounder near the mouth of the Escambia River contained 187 ppm PCB wet weight and 76 and 4.5 ppm were present in the liver and muscle, respectively, of another dead specimen 5 km away in the Bay (Duke et al., 1970). A year later, levels in the sediments were 2.3 ppm and seawater levels averaged 0.6 $\mu g\ l^{-1}$ PCB during 1969–71. In all probability contaminated sediments contributed to these fish kills. However, the concentration factors for turbot tissues in contaminated seawater in the laboratory (Table 4) suggest that similar residues might arise by uptake of PCB from seawater alone in the Weser River, for example, which contains 11–114 ng l^{-1} PCB (unpublished data quoted in Goerke et al., 1979).

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