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ACCUMULATION OF TRACE CONTAMINANTS IN FISHES RAISED IN RECIRCULATION SYSTEMS

by

H. Rosenthal[1], P.-D.Hansen[2] and H. Bergmann[3]

1) Biologische Anstalt Helgoland, Zentrale Hamburg
2000 Hamburg 50

2) Institut für Wasser-, Boden-und Lufthygiene des
Bundesgesundheitsamtes, Corrensplatz 1, 1000 Berlin 33

3) Bundesanstalt für Gewässerkunde, 5400 Koblenz

I N T R O D U C T I O N

In recent years the development of reciculatory systems has been discussed as a possible means of using limited water resources for intensive aquaculture production in industrialized countries (LIAO and MAYO 1972, 1974; MEADE 1973; SCHERB and BRAUN 1970, 1971; NÄGEL et al. 1976; ROSENTHAL and OTTE 1980; OTTE and ROSENTHAL 1979). Although the quasi-closed systems already available proved not to be continuously reliable (ROSENTHAL 1981), a few units are already in the position to market a small amount of fish produced. Trace contaminent accumulation by organisms grown in a waste water aquaculture system using secondarly treated sewage effluents as nutrient source has recently been reported by MANN and RYTHER (1979). These authors did not find any significant difference between organisms cultured in contaminant-free and effluent enriched regimes. Data on trace contaminants of aquacultural products fed on diets containing fish protein concentrates were reported by SIMON (1979).

Although there is still much to learn about safe operation and water quality control in intensive culture systems, it seems reasonable to study the uptake of environmentally hazardous elements under those culture conditions. Accumulation rates may not only depend on the trace elements contained in feeds but also on system performance (water quality) and associated stress on cultured species. The present study is a first attempt to provide some preliminary results on body burden

of fishes cultured at experimental and commercial sites.

MATERIAL AND METHODS

Fishes were collected from two fish culture recirculation systems in northern Germany, one being an experimental warm-water unit (25°C), and the other a commercial cold-water farm (17°C). Tilapia mossambica specimens of different age were taken from the warm-water system while rainbow trout (Salmo gairdneri) were obtained from the commercial plant. In both systems make-up water was added at regular intervals from nearby wells. Besides this well-water, commercially available pelleted feeds are the only other source through which trace contaminant can have entered the system. Since water quality varies considerably in recycling systems and trace contaminants added to it will probably be available for uptake much longer than in flow-through systems, body burdens of contaminants in cultured fish were determined in both liver and muscle tissue. The following contaminants were analysed: copper, cadmium, and chlorinated hydrocarbons including PCB, HCB, α-BHC, γ-BHC, DDE, DDD, Heptachlorepoxide and Dieldrin.

The method used for sample preparation and determination of heavy metals is described in details by KRISHNAMURTY (1976) and TÜLG and KOTZ (1972). The method used to extract the PCBs, HCB, Heptachlorepoxide, DDE, α-BHC, γ-BHC, Dieldrin and DDD from the tissues was desribed by ERNST et al. (1974); the frozen liver tissues were homogenized with quartz sand and calcined Na_2SO_4 p.a. (2h at 650°C) using a small grinding mill. The organochlorines were extracted from this tissue powder by a solvent mixture consisting of n-hexane/acetone (2:1) in a glass column. The muscle tissues were extracted diractly by the solvent mixture and purified by the calcined Na_2SO_4 and finally filtered over a layer of Na_2SO_4.

To separate the fat from the extracts two clean up processes were done, first with an Al_2O_3-column and secondly using a Florisil-column with 0.6-1.0% water content. Two extracts were obtained from the Florisil-column, one consisting of PCBs, DDE, HCB, Heptachlorepoxide and the other of α-BHC, γ-BHC, Dieldrin and DDD. The recovery rate of HCB was 80-90% and > 92% for the other compounds.

The gas-chromatographs used were a Packard-GC Model 428 and a Siemens L 350, both fitted with a ^{63}Ni electron capture detector. The Packard -GC was equipped with a glass column 6 ft long and with an interior diameter

of 2mm. It was packed with 3% CV-101 on Chromosorb WHP 100/120 mesh. For the Siemens-GC a compact glass column 1.5 m long and with an interior diameter of 2 mm was used, packed with 10% DC 200 on Gas-Chrom Q 100/120 mesh. The operating conditions were : column temperature, 230°C; detector, 260°C; injector, 240°C; N_2-flow rate, approximately 60 ml/min. The volume injected was 4-8 µl. The recorder was operated with a 1 mV full-scale deflection and the chart speed was 1 cm/min. For the calculation of the PCB-content the height of 3 peaks on the chromatogram were used. The gas chromatographic measurement tolerance amounted to 2.7%.

R E S U L T S

Heavy metals

The heavy metal content of liver and muscle tissue in the species investigated is shown in Table 1. There seems to be no relationship between the size of the fish and their heavy metal content. In muscle tissue copper concentrations ranged between 1.5 to 3.3 ppm in the warm-water fish and 0.9 to 1.7 ppm in rainbow trout from the cold water system. Cadmium levels in muscles were relatively low in both species, ranging from 0.01 to 0.06 ppm in Tilapia and attaining 0.02 ppm in trout. In contrast, copper accumulated to very high concentrations in the liver of both species (range: 353-988 ppm (Tilapia); 340-674 ppm (rainbow trout)). Cadmium values determined in the liver were slightly higher than in the muscle of both species (range: 0.28-2.90 ppm in Tilapia; 0.04-0.25 ppm in rainbow trout).

Chlorinated hydrocarbons

Trace contaminants were determined in both, muscle and liver tissue. As observed for heavy metals, data obtained so far show a considerable variation, which cannot simply be attributed to the differences in cultivation procedures. However, average PCB-levels determind in muscle are slightly higher in rainbow trout. Because of the high variability of the data, the number of specimens examined is too low to demonstrate whether any relationship exists between the size range of the fish and the concentration of trace contaminants in either muscle or liver (Tables 2 and 3).

PCB concentrations in muscle ranged between 9.9 and 22.3 ppb (wet weight basis) in warm-water fish and 30.8 to 193 ppb in the cold-water species. Tilapia livers contained much higher PCB concentrations than did trout liver.

α-HCH and γ-HCH were unusually high in large Tilapia specimens. DDD and DDE were present in fish from both systems.

Lindane concentrations were obviously higher in muscle and liver tissue of Tilapia than in comperable samples from rainbow trout.

It is important to note that the three highest PCB-values were found in stressed fish (trout with skeletal deformations; Tilapia under obvious social stress- dark colored fish, always pushed into the tank corner by other specimens and exhibiting reduced activity). These fish were specifically selected for trace element analysis (marked with asterics in Table 2).

D I S C U S S I O N

When comparing the body burdens of contaminants fish grown in intensive culture systems with those from wild fish grown in natural waters , it is obvious that there are no differences in cadmium concentrations, but that copper concentrations are higher in cultured fish. Cadmium levels in uncontaminated fresh water fish range from 0.0005 to 0.8035 ppm (n= 349) KÄFERSTEIN 1980. MÜLLER and PROSI (1978) determined cadmium in fish from the highly polluted Neckar-river-system (Germany) and found values between 0.002 and 0.088 ppm (muscle) and 0.02 and 2.28 ppm (liver). DAVIES (1981) stated that cadmium concentrations in most of the marine fin fish investigated were below the detection limit of the analytical technique employed.

Copper has been determined in fresh water fish within the range of 0.14 to 1.09 ppm in muscle tissue and 1.73 to 9.80 ppm in livers (MÜLLER and PROSI, 1978). These values are lower than most of those observed in fillet of cultured fish. Concentrations of copper determined in livers of fish from intensive culture systems are orders of magnitude higher than in those from wild fish. Since it is known that both, the warm-water and the cold-water recirculation systems studied here , did not contain any metal parts that would have been responsible for the release of substantial amounts of copper into the system, we conclude that most of the copper accumulated must have been entered the system via the make-up water, which was taken from the public water supply, although these supplies are considered to be safe with regard to health standards.

Chlorinated hydrocarbons did not accumulate substantially in either fillet and liver of culture fish. Data available from field studies indicate that in marine fish PCB-concentrations range from 0.155 to 0.281 ppm in fillet of the sole (Solea soles wet weight basis; GÖRKE et al. 1979) and 0.026 to 0.046 ppm in muscles of witch flounder (Glyptocephalus cynoglossus) EDER et al. 1976. SCHÄFER et al (1976) determined PCB-levels in muscles of dab (Limanda limanda) ranging between 0.03 and 0.06 ppm on a wet weight basis, and 0.38 to 0.74 ppm in livers of the same species.

In fresh water fish from German rivers, REUSCHENBETH (1977) found elevated levels in various species ranging from 0.205 to 9.300 ppm in muscle on a wet weight basis. Compared to these values, our observations of cultured fish from both systems indicate substantially higher accumulation rates. When compared with fresh water fish from German rivers, concentration factors vary between 2.4 to 48 for warm-water fish and 21 to 150 for fish from the cold-water system. Compared to sea water fish, concentrations in muscles are elevated by factors ranging between 144 and 380 (Tilapia in warm-water system) and 1,180 to 1,250 (trout in cold-water system).

The reason for the differences in PCB-accumulation in cold and warm-water systems are unexplained. One would expect the warm-water species to accumulate much more than fish maintained in the cold-water unit, since exposure was much longer (> 6 month in Tilapia compared to less than 3 month in trout). Possible reasons for this difference might be found in the different background levels of trace contaminants in feeds offered to both species. Lipid content in trout pellets is much higher than in the low protein diet offered to Tilapia. On the other hand, accumulation rates may be altered by general stress due to environmental conditions in the culture systems (pH, O_2, Ammonia, BOD, etc.).

Since intensive aquaculture development is increasingly using high density culture systems and non-conventional protein sources, attention has to be payed to the accumulation of trace contaminants under these culture conditions.

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Table 1. Heavy metal residues (ppm) in muscle and liver tissue of fish reared in recirculation systems. Data are calculated on dry weight basis and represent averages from two to three determinations; brackets indicate renge; A = warm water system; B = cold water system; * = below detection limit.

No of fish	System	Species	total lenght (cm)	total weight (g)	fat content (%) muscle	fat content (%) liver	Heavy metal content (ppm) muscle Cu	muscle Cd	liver Cu	liver Cd
1	A	Tilapia	11.6	34.0	4.5	7.7	3.25 (3.2-3.3)	0.010 -	-	-
2	A	Tilapia	12.4	41.5	1.9	5.4	3.20 (1.8-4.6)	0.040 (0.02-0.06)	-	-
3	A	Tilapia	14.2	54.4	3.5	6.3	1.55 (1.5-1.6)	0.015 (0.01-0.02)	-	-
4	A	Tilapia	23.4	260.0	-	3.2	-	-	388 (353-425)	2.70 (2.5-2.9)
5	A	Tilapia	28.9	400.0	1.0	8.2	2.60 (2.3-2.9)	0.025 (0.02-0.03)	963 (938-988)	0.62 (0.57-0.66)
6	A	Tilapia	29.3	460.0	1.9	14.7	4.45 (4.4-4.5)	0.020 -	405 (367-443)	0.38 (0.28-0.49)
7	A	Tilapia	29.1	480.0	1.4	12.7	1.75 (1.7-1.8)	0.020 -	449 (386-511)	0.47 (0.42-0.51)
8	A	Tilapia	29.8	580.0	-	6.6	-	-	629 (608-645)	1.03 (0.90-1.20)
9	B	Rainbow trout	25.0	283.0	6.6	5.0	1.55 (1.5-1.6)	*	668 (662-674)	0.25 (0.24-0.25)
10	B	Rainbow trout	27.0	297.0	11.7	4.0	1.65 (1.6-1.7)	0.020	371 (343-399)	0.07 (0.06-0.08)
11	B	Rainbow trout	29.5	358.0	4.9	3.9	1.35 (1.2-1.5)	0.020	370 (340-401)	0.05 (0.04-0.06)
12	B	Rainbow trout	31.0	407.0	8.2	3.3	1.10 (0.9-1.5)	0.020	533 (502-564)	0.045 (0.04-0.05)

Table 2. Chlorinated hydrocarbons accumulated in muscle of fish reared in recirculating systems. A= warm-water system, B= cold-water system. Values are given in ng/g wet weight. For corresponding size and weight of fish see Table 1. *= malformed or stressed fish.

No. of fish	System	Species	Residues (ng/g wet weight) PCB	HCB	Heptachlor-epoxid	DDE	α HBC	γ HBC	Dieldrin	DDD
1	A	Tilapia	16.5	<0.1	-	<0.1	13.0	22.4	1.5	4.6
2	A	" *	21.5	<0.1	<0.1	-	8.2	19.4	0.9	3.1
3	A	"	17.3	<0.1	<0.1	<0.1	1.0	4.1	1.3	2.7
4	A	"	-	-	-	-	-	-	-	-
5	A	"	9.9	<0.1	-	0.1	13.5	31.3	0.7	0.1
6	A	" *	22.3	21.5	113.4	202.6	5.2	9.4	0.8	1.6
7	A	"	14.6	<0.1	<0.1	<0.1	0.5	1.9	0.4	0.7
8	A	"	-	-	-	-	-	-	-	-
9	B	Rainbow trout	36.5	0.3	0.8	<0.1	0.8	1.9	1.6	1.9
10	B	" *	193.1	<0.1	0.1	<0.1	1.5	3.7	3.8	6.4
11	B	"	44.9	0.5	1.2	<0.1	0.7	1.7	1.4	2.1
12	B	"	30.8	0.4	-	<0.1	0.9	1.9	2.3	2.5

Table 3. Chlorinated hydrocarbons accumulated in livers of fish reared in quasi-closed recirculation systems. A= warm-water system, B= cold-water system. Values given in ng/g wet weight. For corresponding size and weight of fish see Table 1.

No. of fish	System	Species	Residues (ng/g wet weight)							
			PCB	HCB	Heptachlor-epoxid	DDE	α-HBC	γ-HBC	Dieldrin	DDD
1	A	Tilapia	41.0	<0.1	<0.1	<0.1	5.4	12.9	-	-
2	A	"	133.0	<0.1	3.1	4.0	8.9	14.7	-	-
3	A	"	21.7	<0.1	-	0.3	6.0	10.0	-	5.0
4	A	"	31.0	0.3	0.9	1.9	17.8	43.9	-	-
5	A	"	29.7	<0.1	-	<0.1	12.4	16.9	<0.1	4.8
6	A	"	44.7	<0.1	0.5	<0.1	3.6	6.1	4.6	6.3
7	A	"	38.8	0.14	-	<0.1	9.0	21.2	1.3	4.0
8	A	"	108.0	1.1	2.3	13.4	27.5	63.5	2.9	7.4
9	B	Rainbow trout	35.9	<0.1	-	0.1	1.3	2.4	3.6	2.6
10	B	"	34.0	-	-	0.7	1.0	2.7	5.8	4.8
11	B	"	15.8	<0.1	0.3	0.2	0.7	2.2	0.9	2.9
12	B	"	8.4	-	0.3	-	0.4	1.2	1.4	1.5