Bilag 61

Available online at www.sciencedirect.com
SCIENCE DIRECT
Marine Pollution Bulletin 52 (2006) 100–103
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Note

PCB-containing paint and plaster caused extreme PCB-concentrations in biota from the Sørfjord (Western Norway)—A case study

Anders Ruus [a,*], Norman W. Green [a], Amund Maage [b,c], Jens Skei [a]

[a] Norwegian Institute for Water Research (NIVA), P.O. Box 173, Kjelsås, N-0411 Oslo, Norway
[b] Hardanger Miljøsenter, Alex Stewart Environmental Services AS, N-5750 Odda, Norway
[c] National Institute of Nutrition and Seafood Research, P.O. Box 176, Sentrum, 5804 Bergen, Norway

Abstract

The Sørfjord (Western Norway) has a long history of industry and pollution, and has been monitored for several decades. The environmental monitoring has comprised analyses of different contaminants in sea water, mussel, fish, seaweed and sediments. Measurements of polychlorinated biphenyls (PCBs) in blue mussels (*Mytilus edulis*) some 17 years ago indicated a local source. In 2001 severe concentrations were measured in blue mussels and further investigations disclosed the primary source of PCBs in the Sørfjord. In 2002, extreme PCB-concentrations were found in cod (*Gadus morhua*) from the same area. However, no induction of EROD activity was detected, indicating the limitations of this assay as marker for PCB contamination. A future scientific challenge will be to understand the specific mechanisms and effects of such PCB accumulation in fish.

Keywords: Sørfjord; PCB; Polychlorinated biphenyls; Cod; Blue mussels; Environmental monitoring

1. Introduction

The unique nature in the area of Odda and the Sørfjord (Western Norway) has rendered this area a tourist attraction since the end of the 19th century. The waterfalls from the mountain plateau Hardangervidda in combination with the deep and ice-free fjord have also made it possible for profitable industry in Odda. The hydro-electric power company A/S Tyssefaldene was established in 1906, and soon new industries were founded in the vicinity of Odda, producing calcium carbide (since 1908), calcium cyanamide (since 1909), aluminium (1916–1982), zinc (since 1929) and titanium oxide (since 1986). Environment concerns were to follow and the Sørfjord was at one time considered as one of the most metal polluted fjords in the world (Skei et al., 1972). Remedial actions in the area have included disposal of metal containing sludge in mountain caverns and containment of contaminated sediment by the use of sheet pilings or capping.

The Norwegian State Pollution Monitoring Programme (NSPMP) in the Sørfjord and Hardangerfjord has been continuous since 1979, with the objective of monitoring the environmental changes following remedial actions, to support the environmental authorities in their assessment of potential needs for further remedial actions and to produce a foundation for the food safety authorities in their evaluation of the edibility of fish and shellfish. The programme has comprised analyses of different contaminants in sea water, mussels, fish, seaweed and sediments. The Sørfjord has also been monitored since 1987, through the international *Joint Assessment and Monitoring Programme* (JAMP) administrated by the Oslo–Paris Convention (OSPAR). Through this programme, some biological effect parameters (biomarkers) are also monitored (since 1997; Ruus et al., 2003).

* Corresponding author. Tel.: +47 22185100; fax: +47 22185200.
E-mail address: anders.ruus@niva.no (A. Ruus).

0025-326X/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2005.11.010

Industrial activities in the Odda area have been the major source of contamination of metals (mercury, cadmium, lead, zinc and copper), polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). The point sources of the contaminants have been well known, except for PCBs.

2. Materials and methods

2.1. Study area

The Sørfjord is a southern branch of the Hardangerfjord in Western Norway. The municipality of Odda is located at the head of the fjord (N 60° 05′; E 06° 31′).

2.2. Sampling

Blue mussels (*Mytilus edulis*) were sampled annually in shallow waters at several stations in the Sørfjord (through NSPMP and JAMP; Ruus and Green, 2002; Green et al., 2003). Pooled samples (of usually 50 individuals) were prepared for each station. Cod (*Gadus morhua*) were sampled annually (by trawling) in the inner Sørfjord (near Tyssedal, N 60° 07′; E 06° 33′; Green et al., 2003). Individual livers were sampled for analysis of PCBs and hepatic ethoxyresorufin-*O*-deethylase (EROD) activity (frozen at −20 °C and in liquid nitrogen, respectively).

2.3. Analyses

Analyses of PCBs were performed at NIVA's laboratory according to the method described by Brevik (1978), with some modifications. EROD activity was assayed fluorimetrically (Burke and Mayer, 1974) and normalised to protein content in the microsomal fraction, determined according to Lowry et al. (1951).

3. Results and discussion

The results of the monitoring of the Sørfjord early suggested the presence of a local source of PCB, as blue mussels near one site (Tyssedal) accumulated high concentrations ($\sum$PCB = 86 ng/g wet wt.; Skei et al., 1989). In 1990, a sediment survey and analyses of oil from electrical transformers previously used in the area were conducted to identify the potential source of the PCB. No specific PCB source was, however, found (Skei and Klungsøyr, 1990). Then, in 2000, semi-permeable membrane devices (SPMDs) were deployed at different localities in the Sørfjord and the highest amounts of PCBs were found at the station near Tyssedal (Skei and Tellefsen, 2000).

The PCB-concentrations in blue mussels near Tyssedal showed large variability through the years, and in 2001 a severe contamination was measured ($\sum PCB_7$ = 1132 ng/g wet wt.; 59584 ng/g lipid wt.; Ruus and Green, 2002). For comparison, a suggested Norwegian reference "high background" concentration for blue mussels is $\sum PCB_7$ = 3 ng/g wet wt. (Green and Knutzen, 2003). The time of sampling corresponded with the renovation of the old power station of Tyssefaldene A/S, which was designated a national historical monument the year before. Old paint and plaster were removed from ≈1500 m^2 of the facade of the 175 m long building, which is located on the shore of the fjord. A fibre sheet was applied to prevent release of waste material to the environment, however, some paint and plaster waste still entered the fjord.

Analysis of paint/plaster from the power station showed high concentrations of PCB ($\sum PCB_7 \geqslant$ 336 030 ng/g). During the 1960s the power station was painted with a product containing an unknown PCB-mixture. The PCB-profiles (relative concentrations of the congeners) of blue mussels sampled in 2001 and 2002 were similar to the PCB-profile of the paint/plaster, thus it was concluded that the paint/plaster was likely the main source of PCB in the Sørfjord biota (Ruus and Green, 2002).

In 2002, four (out of 25) cod sampled near Tyssedal had extremely high hepatic PCB-concentrations (Table 1). The individual with the highest PCB content ($\sum PCB_7$ = 427 100 ng/g wet wt.) had an amount of PCB in the liver corresponding to 3.6‰ of the weight of the hepatic lipid. For comparison, a suggested Norwegian reference "high background" concentration for cod-liver is $\sum PCB_7$ = 500 ng/g wet wt. (Green and Knutzen, 2003). Interestingly, the other 21 individuals did not show PCB-concentrations deviating from the concentrations common in this area (Green et al., 2003). Furthermore, these 21 individuals showed different PCB-profiles than the cod with the extreme PCB-concentrations, which were more similar to the profiles in the paint/plaster from the power station. Higher percentages of PCB-101 and −118, and lower percentages of −138, −153, and −180 were measured in the most contaminated cod, as compared to common PCB-mixtures (Frame et al., 1996) and to profiles in organisms at different trophic levels (Ruus et al., 2002; Fig. 1). A review of the profiles in cod-liver samples from Tyssedal 1999 to 2001 did not indicate such similarity to the paint/plaster profile (Green et al., 2003).

EROD is a measure of cytochrome P450 1A activity, which is induced by planar compounds, such as specific PCBs (primarily non-*ortho* substituted congeners), PAHs and polychlorinated dibenzo-*p*-dioxins (PCDDs) (Goksøyr and Förlin, 1992). Cod accumulating extreme PCB-concentrations generally did not show any elevated EROD activity in the present study (Table 1). This finding indicates the limitations of this assay as a biomarker of PCB contamination (at least for this combination of congeners), as discussed by Kennedy et al. (2003). The results are also in correspondence with findings of Besselink et al. (1998), who showed inhibition of TCDD-induced EROD activity by PCBs in flounder (*Platichthys flesus*).

A challenge will be to understand the specific mechanisms leading to the accumulation of such extreme PCB-concentrations in fish, as presented here, and effects on these indi-

Table 1
Length, weight, liver lipid content, liver-PCB-concentrations and hepatic ethoxyresorufin-*O*-deethylase (EROD) activity in 25 cod caught in Sørfjorden (Western Norway) October 2002 (sorted with increasing PCB-concentrations)

Length (mm)	Weight (g)	Liver lipid (%)	∑PCB[a] (ng/g wet wt.)	$\sum PCB_7$[b] (ng/g wet wt.)	EROD (pg/min/mg prot.)
320	228	2.9	51.1	47.3	196.0
320	275	3.0	160.2	153.6	95.1
370	516	3.1	226.9	202.2	20.6
360	513	26.0	252.1	235.9	112.5
330	324	5.1	346.5	313.2	102.2
390	358	2.5	370.1	344.8	16.0
410	536	4.4	383.5	346.2	27.8
360	384	6.6	460.0	417.7	127.6
310	329	10.0	540.3	521.6	89.8
435	916	61.0	596.0	546.5	278.1
410	700	33.0	770.9	710.9	87.3
420	694	26.0	812.7	749.7	12.1
340	330	17.0	1052.7	955.7	155.7
390	536	54.0	1106.6	1006.0	223.3
330	360	23.0	1545.0	1470.0	32.3
670	2890	25.0	1965.1	1813.1	117.2
470	900	17.0	2148.2	1972.6	83.2
480	1095	30.0	2519.5	2421.5	174.0
350	459	38.0	2695.2	2414.7	93.9
490	1044	3.5	5989.3	5318.9	67.5
380	502	15.0	8860.7	7940.0	9.0
510	1058	12.0	160404.4	142703.4	41.1
440	797	8.6	316304.6	281303.3	60.3
410	679	8.0	373704.8	332703.2	460.1
440	796	12.0	478100.9	427100.0	121.6

[a] Sum of 10 congeners: PCB-28, -52, -101, -105, -118, -138, -153, -156, -180, -209.
[b] Sum of 7 congeners: PCB-28, -52, -101, -118, -138, -153, -180.

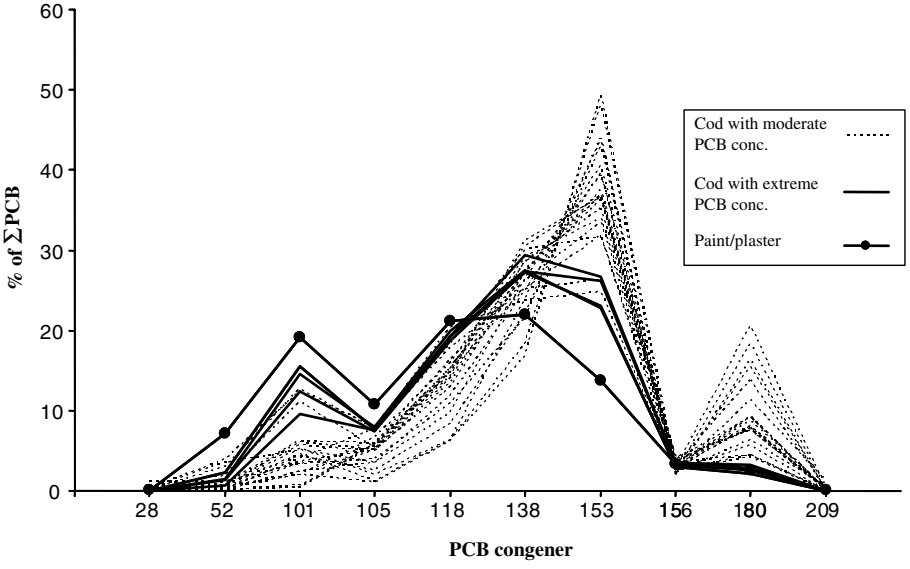

Fig. 1. PCB-profiles (% of sum concentration of 10 congeners) in paint/plaster from the old power station in Tyssedal (Western Norway), and in 25 cod caught in the Sørfjord (near Tyssedal) 2002. The PCB-concentrations in the cod-liver samples are presented in Table 1.

viduals. Dietary accumulation is a most likely mechanism (Thomann and Connolly, 1984). However, in the Sørfjord it is uncertain if prey organisms (or which prey organisms) have accumulated exceptionally high PCB-concentrations before being consumed by cod. There is also a possibility that some cod (feeding opportunistically) have consumed paint/plaster particles when it was in the water column.

Acknowledgement

The Norwegian State Pollution Monitoring Programme in the Sørfjord is carried out by NIVA, under contract from the Norwegian Pollution Control Authority (SFT), and with Alex Stewart Environmental Services AS as subcontractor. Besides SFT and the local authorities in Odda

and Ullensvang, the following companies have funded the monitoring during the last years: Outokumpu Norzink A/S (now Boliden Odda AS), Odda Smelteverk A/S, Tinfos Titan & Iron K/S. The *Joint Assessment and Monitoring Programme* (JAMP) is administrated by the Oslo–Paris Convention (OSPAR) and the Norwegian activity is carried out by NIVA, under contract from SFT.

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