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Research Article

# Consumption of fish from a contaminated lake strongly affects the concentrations of polybrominated diphenyl ethers and hexabromocyclododecane in serum

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Very high concentrations of polybrominated diphenyl ethers (PBDE) have been reported in fish from Lake Mjøsa in Norway. This study was performed to examine the serum concentrations of PBDE and hexabromocyclododecane (HBCD) in consumers of fish from this lake and to investigate possible relationships between serum concentrations, self-reported fish intake and calculated total dietary PBDE exposure. Serum concentrations of the sum of the seven PBDE (BDE-28, 47, 99, 100, 153, 154 and 183) were significantly higher than those of a reference group of Norwegians eating only food with background levels of contamination (medians: 18 ng/g lipids men, 8.4 ng/g lipids women). The median dietary intake of Sum 7 PBDE was 2549 ng/day (30 ng/kg body weight/day), the highest dietary intake of PBDE reported. The contribution from fish caught from the contaminated lake comprised 98.7% of the total dietary exposure. For men, serum levels of PBDE were strongly correlated with the calculated dietary exposure, except for BDE-209. This suggests that sources other than the diet are important for human BDE-209 exposure. The median serum HBCD concentration was 4.1 and 2.6 ng/g lipids for men and women, respectively, and was also found to be associated with consumption of fish from Lake Mjøsa.

**Keywords:** Contaminated fish / Dietary exposure / Hexabromocyclododecane / Polybrominated diphenyl ethers / Serum levels

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## 1 Introduction

Brominated flame retardants (BFR) constitute a diverse group of compounds used to prevent or minimize the extent of a fire. The three main representatives are tetrabromobisphenol A, hexabromocyclododecane (HBCD) and polybrominated diphenyl ethers (PBDE). The BFR are incorporated into a number of consumer products, such as furniture, textiles, computers, household appliances, electronics and TV-sets. Several of the BFR have been shown to be widespread in the environment, in wildlife and in humans [1 – 4], and their toxicity has been reviewed [5, 6]. For some of the PBDE, neurotoxic effects [7] and effects on the thyroid hormone system [8, 9] have been shown in rodents, and there are indications that HBCD exposure can affect the liver and thyroid hormone system, and might cause neurobehavioral alterations [5, 6, 10]. The technical products PentaBDE and OctaBDE have been banned for production and use in the EU and in other countries, while DecaBDE and HBCD are still in use.

PBDE and HBCD are both lipophilic and able to bioaccumulate in food chains. Thus, fatty foods of animal origin are probably a major source of human exposure. Dietary intake estimates of PBDE in Sweden [11], Finland [12], Spain [13], Belgium [14], UK [15], USA [16] and Norway [17] range from about 23 to 107 ng/day. Seafood was found to be the main dietary source in Norway, Finland and Spain, while in the USA, meat was the major source to the dietary intake of PBDE. The body burden of PBDE in general populations has been found to be quite variable [2], and a recent study on 151 breast milk samples from the Norwegian pop-

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**Abbreviations: BFR**, brominated flame retardants; **HBCD**, hexabromocyclododecane; **LB**, lower bound; **PCB**, polychlorinated biphenyls; **PBDE**, polybrominated diphenyl ethers

ulation showed that 5% of the samples had a PBDE content exceeding five times the median [18]. So far, no clear associations between specific sources of exposure and body burdens have been established. Recently, BFR in indoor environments have also been suggested to make an important contribution to exposure, at least for some individuals [15, 19]. However, in a few studies, positive associations between consumption of fish contaminated with PBDE and blood concentrations of PBDE were found [20–22], and recently Wu *et al*. [23] found correlations between diet, house dust and contents of PBDE in breast milk.

In the largest lake in Norway, Lake Mjøsa, located in the southeastern part of the country, very high levels of PBDE have been reported in fish, *e.g*. concentrations of 353 ng/g wet weight (5283 ng/g lipids) have been found in trout [24]. In comparison, PBDE levels at least an order of magnitude lower have been measured in trout from other Norwegian lakes [24], which is in accordance with levels reported in trout from European high mountain lakes and Greenland [25], and the Great Lakes in North America [26]. In Lake Mjøsa, high PBDE levels were also found in perch, pike and burbot [27] (Table 1). All these fish species are part of the diet for many hobby anglers and their families living near the lake. The region around Lake Mjøsa is populated and sources of environmental contaminants like mercury, polychlorinated biphenyls (PCB) and BFR are identified both from atmospheric long-range transport and emissions from local industry and agricultural activities [28, 29].

The main objective of this study was to measure the serum concentrations of PBDE and HBCD in a group of high consumers of fish from Lake Mjøsa and investigate possible relationships between the serum concentrations and self-reported fish intake. Further, we wanted to calculate the total dietary intake of PBDE based on the reported food frequencies and PBDE levels in food for each participant and examine the predictive strength of the intake estimations on the serum levels.

## 2 Materials and methods

### 2.1 Study subjects and sampling

This study was conducted on high consumers of inland fish living in the region around a BFR contaminated lake in Norway, Lake Mjøsa. The participants were recruited among 122 local hobby fishermen and women, of whom 74 responded positively to the invitation. Of these 74, 66 persons provided serum samples, and filled in detailed questionnaires regarding personal background data and dietary habits, both concerning their regular diet and intake of fish from the lake. The study group consisted of 41 men and 25 women, with mean age 58 and 54 years, respectively (range 30–87 and 9–78 years). The mean body weight of the participants was 86 kg for men and 72 kg for woman, respectively (range 60–129 and 35–95 kg).

The participants scheduled an appointment with their family doctor for blood sampling. The family doctor was provided sampling equipment from the Norwegian Institute of Public Health. Venous blood was drawn into BD Vacutainer tubes (Becton Dickinson, Plymouth, UK). After coagulation, serum was obtained by centrifugation at 2000 rpm for 10–15 min, transferred to tubes of polypropylene (Sarstedt, Nümbrecht, Germany) and sent to the Norwegian Institute of Public Health by surface mail. Samples were stored at −20°C until analysis. The sampling was performed from October 2004 to May 2005. Informed consent was obtained from all the participants and the project was approved by the Regional Committee for Medical Research Ethics.

### 2.2 Analysis of serum

#### 2.2.1 Chemicals

The individual PBDE standards BDE-28, 37, 47, 85, 99, 119, 153, 154, 181, 183 and 209, as well as HBCD were from Cambridge Isotope Laboratories (Andover, MA, USA). BDE-18, 51, 103, and 138 were obtained from AccuStandard (New Haven, CT, USA), while BDE-100, 156 and $C_{13}$-labeled 209 were from Wellington Laboratories (Guelph, Ontario, Canada). All solvents used were of pesticide grade from sds (Peypin, France) and sulfuric acid, silica gel and sodium sulfate were from Merck (Darmstadt, Germany). The polychlorinated biphenyl CB-207 (AccuStandard) was used as syringe standard for estimation of the absolute recovery.

#### 2.2.2 Glassware

All glassware used in the serum analysis was washed in 2.5% RBS 25 foaming cleaner (Chemical Products, Brussels, Belgium) rinsed with distilled water, and subsequently heated at 450°C for 4 h (volumetric equipment was not heated).

#### 2.2.3 Sample preparation

The frozen serum samples were thawed in a refrigerator (4°C) and brought to room temperature before 5.0 g of each sample was added 30 μL of an internal standard solution containing 75 pg BDE-18, 51, 103, 156 and 181 (750 pg BDE-209). The samples were kept overnight in the refrigerator and subsequently extracted according to a previously described method [30]. In brief, the serum was diluted by formic acid, 2-propanol and water and applied to a pre-washed and conditioned SPE column (Oasis HLB custom-made, 540 mg/3 mL, Waters, Milford, MA, USA). After rinsing and drying, the BFR were eluted by 12 mL dichloromethane-methanol (7+3, v/v), and the extract subjected to clean-up using sulfuric acid-silica columns. Both extraction and clean-up were performed on an automated solid phase extractor (ASPEC XL4, Gilson, Middleton, WI, USA). The final extracts were concentrated under a gentle stream of nitrogen at 40°C (Tur-

 

boVap LV, Zymark, Hopkinton, MA, USA) to about 30 μL and added 30 μL syringe standard (CB-207) used for evaluation of recovery of internal standards.

The lipids (triglycerides, cholesterol and phospholipids) were determined enzymatically at Haukeland University Hospital (Bergen, Norway) and the total lipid content of the samples calculated according to the method described by Grimvall *et al*. [31].

#### 2.2.4 Instrumentation, analysis and quantification

The extracts were analyzed using a GC/MS (6890/5973 from Agilent) equipped with an HP 7683 autosampler. Samples of 2 μL were injected at 290°C in pulsed splitless mode with a pulsed pressure of 3.79 bar for 1.5 min. Helium (99.998%, Aga, Oslo, Norway) was used as a carrier gas, and the flow was constant at 1.2 mL/min. The separation was performed on a DB-5MS column (25-m length, 0.25-mm id, 0.25-μm film thickness, Agilent Technologies, CA, USA) subjected to the following temperature program; 90°C held for 1 min, 20°C/min to 190°C, 5°C/min to 230°C, 1°C/min to 235°C, 3.5°C/min to 250°C and finally 30°C/min to 325°C, which was held for 4 min. A deactivated retention gap of length 1.5 m and 0.32-mm id fused silica (Agilent) was used in front of the column. Octa- to decaBDE were separated on a shorter DB-5MS column (15-m length, 0.25-mm id, 0.10-μm film thickness, Agilent) using the temperature program described above.

The MS was operated in electron capture negative ionization mode using methane (99.99%, Aga) as buffer gas. The temperature of the interface, ion source and quadrupole was 300, 250 and 106°C, respectively, and the electron energy was about 120 eV. The PBDE (except BDE-209) were monitored on *m/z* 79 and 81, BDE-209 on *m/z* 484 and 486, ($^{13}C_{12}$-BDE-209 internal standard on *m/z* 494 and 496), HBCD on *m/z* 79, 81 and 160 and the recovery standard CB-207 on *m/z* 464. All measured ions were used for identification and quantification. Due to a matrix effect observed previously when determining HBCD in human serum, the calibration curves were made of matrix-matched standards of horse serum (H-1270, Sigma-Aldrich, St. Louis, MO, USA). HBCD was not found in the horse serum. For the PBDE, standard solutions of isooctane were applied. The calibration solutions covered the concentration range 4.8–6000 pg HBCD/g serum and 0.6–120 pg PBDE/g serum (6–1200 pg BDE-209/g serum). Internal standard calibration was used for quantification and the BDE-156 was used as internal standard for HBCD. The internal standards used for quantification of the individual PBDE have been presented earlier [30]. The recovery of the internal standards was above 40% for all the individual samples (mean 79%). The LOD, which is based on the lowest level in the calibration curve, was 6 pg/g serum (1 ng/g lipids) for BDE-209, 0.6 pg/g serum (~0.1 ng/g lipids) for the other PBDE and 4.8 pg/g serum (~1 ng/g lipids) for HBCD. Ten procedural blanks were included in the analysis series, in which BDE-47, 99 and 209 were found in all, at levels in accordance with those found in procedural blanks in other series of serum analysis performed at our laboratory. Due to lower absolute recovery and less GC-MS response, the analysis uncertainty of the procedural blanks (water) was higher compared to the serum samples. The mean blank level has previously been found to exceed the levels found in about one fourth of serum samples of background exposed Norwegians, indicating that the actual blank level is lower. The concentrations of BDE-47, 99 and 209 have thus been corrected by subtracting half of the blank level from all the individual measurements. The LOQ was set to a level equal to LOD for the other PBDE. Compounds not detected have been assigned concentration zero [lower bound (LB) approach].

The analytical laboratory participated in 2006 in the annual Interlaboratory Comparison on Dioxins in Food [32] and obtained concentrations within ± 1 SD of the consensus value for BDE-28, 47, 99, 100, 153 and 154 in halibut filet and breast milk (exception: BDE-28 within ± 2 SD in breast milk and BDE-154 within ± 2 SD halibut filet). BDE-209 was not measured. Regarding HBCD, our laboratory obtained concentrations within ± 1 SD of the consensus value in an interlaboratory comparison study on HBCD in samples of herring and cod liver oil [33].

### 2.3 Questionnaires

Two different questionnaires were applied in this study. The first was a 12-page semi-quantitative food frequency questionnaire that included 300 questions about food consumption the previous year. The frequency of consumption was reported by selecting one out of eight to ten frequencies ranging from never to several times monthly, weekly or daily. The questionnaires were optically read. The same questionnaire has been applied in two other recent surveys [17, 34]. A second questionnaire was developed to obtain additional personal background information and consumption data on fish caught exclusively from Lake Mjøsa. Questions about consumption frequencies of trout, whitefish, grayling, vendace, burbot, pike and perch were asked. For the four latter species, products of the fish (fish pâtés, fish ball etc.) were also included. As PBDE levels in trout has been shown to vary with the weight of the fish [35, 36], questions regarding trout consumption were divided into four weight categories, *i.e.* <0.8 kg, 0.8–3 kg, 3–6 kg and >6 kg.

### 2.4 Calculation of PBDE intake

An extensive database comprising PBDE concentrations in Norwegian foods has recently been established [17]. A separate database, with concentrations in different fish species from Lake Mjøsa, was also created (Table 1). Species or foods for which no PBDE measurements were available

 

**Table 1**. The concentration of Sum 5 PBDE[a)] in different fish species from Lake Mjøsa [35, 36] used for calculation of PBDE exposure

| Fish species | Sum 5 PBDE[a)] (ng/g wet weight) |
|---|---|
| Trout < 0.8 kg | 70.8 |
| Trout 0.8-3 kg | 151 |
| Trout 3-6 kg | 301 |
| Trout > 6 kg | 344 |
| Perch | 95.7 |
| Pike | 37.3 |
| Vendace | 51.5 |
| Grayling | not determined |
| Whitefish | not determined |
| Burbot | not determined |

a) Sum 5 PBDE comprises BDE-47, 99, 100, 153 and 154.

were assigned a lipid adjusted PBDE content based on a comparable food item. Food frequencies from both questionnaires were converted into consumption (g/day) by multiplying with gender-specific portion sizes [37]. The individual dietary intake of PBDE was calculated by multiplying the consumption with the PBDE level in the respective food. Compounds not detected were assigned the value zero (LB approach). The dietary intake of HBCD could not be calculated due to limited information on HBCD concentrations in fish from Lake Mjøsa. The questionnaires were filled in satisfactory by 65 of the participants, who all fulfilled the inclusion criteria of reporting a daily food consumption corresponding to between 1000 and 4000 kcal/day.

### 2.5 Statistics

The distribution of both the calculated PBDE intakes and serum levels were highly skewed. Thus, Mann-Whitney rank sum tests were used for comparison of the serum concentrations of PBDE in the study group, with a reference groups and two-tailed Spearman's tests for investigation of bivariate correlations in general. Furthermore, multiple linear regression analyses were used to investigate the impact of different parameters on the serum BFR levels. The adequacy of the final linear regression model was tested by checking whether the assumptions of the model: linear effects and constant variance (homoscedastic) were met by plotting residuals versus predicted values. The model was checked for co-linearity and for points with high influence. The statistical evaluations have been performed using the SPSS 14.0.2 software.

## 3 Results and discussion

### 3.1 BFR concentrations in serum

The participants in this study were 41 men and 25 women who had eaten fish caught from the contaminated Lake

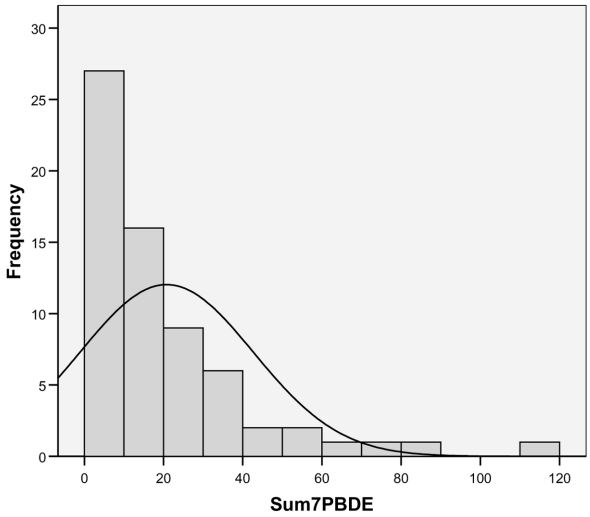


**Figure 1.** The frequency distribution of the Sum 7 PBDE in ng/g lipids in the 66 serum samples.

Mjøsa on a more or less regular basis. Altogether, ten PBDE and HBCD were measured in the serum from the 66 study participants as presented in Table 2. BDE-37 and 119 were not detected in any of the samples. The median of the sum of the seven PBDE (BDE-28, 47, 99, 100, 153, 154 and 183) was 18 and 8.4 ng/g lipids for men and women, respectively. The unusual frequency distribution of Sum 7 PBDE shown in Fig. 1 demonstrates the broad range of PBDE body burdens within the study group, with a considerable number at the high end. Both men and women had significantly higher ($p$ <0.05) Sum 7 PBDE serum concentrations, as well as serum BDE-47, 100 and 153 concentrations, compared with a reference group of 44 Norwegians eating only food with background levels of contamination [17], in which median Sum 7 PBDE was 3.7 ng/g lipids for both men and women, respectively. Serum BDE-99 was significantly higher only in men, while the difference in serum BDE-154 concentration was insignificant between the two groups. BDE-28, 85, 138 and 183 were detected in few samples and has not been evaluated. The median serum BDE-47 concentration observed in these high consumers of inland fish (7.0 ng/g lipids, men) exceeds BDE-47 levels reported in high consumers of fish from the Baltic Sea (2.2 ng/g lipids, men) [22]. The serum PBDE concentrations in the present study are in general higher than what has been reported in other studies in Norway [17, 30], Europe and Japan [2], however, they are of the same order of magnitude or slightly lower than that of North Americans [2].

The fully brominated BDE-209 as well as HBCD were detected in 59 and 49 of the samples, respectively (Table 2). The median concentrations of BDE-209 (men 1.7 and woman 1.5 ng/g lipids) are comparable with, or lower than levels reported in background exposed persons in Sweden and Belgium [38 – 40], while the HBCD concentrations (men 4.1 and woman 2.6 ng/g lipids) are higher than what

**Table 2**. Serum concentrations of the BFR in ng/g lipids in the 66 samples

| | Men (n = 41) | | | | | Women (n = 25) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | Min | Max | Det.[a)] | Mean | Median | Min | Max | Det.[a)] |
| BDE-28 | 0.30 | 0.29 | <LOQ | 0.58 | 19 | 0.33 | 0.37 | <LOQ | 0.46 | 5 |
| BDE-47 | 9.9 | 7.0 | 0.15 | 37 | 41 | 5.8 | 3.3 | 0.47 | 24 | 25 |
| BDE-85 | 0.43 | 0.31 | <LOQ | 1.1 | 9 | 0.26 | 0.24 | <LOQ | 0.36 | 5 |
| BDE-100 | 6.1 | 4.5 | <LOQ | 26 | 40 | 3.5 | 1.9 | 0.36 | 19 | 25 |
| BDE-99 | 2.9 | 1.3 | 0.04 | 22 | 41 | 1.5 | 0.98 | 0.14 | 5.7 | 25 |
| BDE-138 | 0.22 | 0.23 | <LOQ | 0.29 | 4 | 0.19 | 0.19 | <LOQ | 0.20 | 2 |
| BDE-154 | 1.3 | 0.60 | 0.08 | 14 | 41 | 0.69 | 0.25 | 0.11 | 3.3 | 25 |
| BDE-153 | 5.1 | 3.7 | <LOQ | 18 | 37 | 2.6 | 1.7 | 0.87 | 14 | 25 |
| HBCD | 9.6 | 4.1 | <LOQ | 52 | 31 | 3.7 | 2.6 | <LOQ | 18 | 18 |
| BDE-183 | 0.35 | 0.35 | <LOQ | 0.49 | 2 | 0.23 | 0.27 | <LOQ | 0.32 | 3 |
| BDE-209 | 2.4 | 1.7 | <LOQ | 11 | 35 | 2.3 | 1.5 | <LOQ | 14 | 24 |
| Sum 7 PBDE[b)] | 25 | 18 | 0.3 | 117 | 41 | 14 | 8.4 | 2.0 | 66 | 25 |

a) det. = Number of samples in which the congener was detected.
b) Sum 7 PBDE comprises BDE-28, 47, 99, 100, 153, 154 and 183.

**Table 3**. The mean and range of the participants' daily consumption (g/day) of the different fish species from Lake Mjøsa according to the questionnaires. The "*n*" shows the number of participants that reported eating the specific fish species

| | Men | | | Women | | |
|---|---|---|---|---|---|---|
| Fish species | Mean | Range | n | Mean | Range | *n* |
| Total trout | 30 | 3.6 – 101 | 37 | 15 | 1.4 – 57 | 22 |
| – Trout <0.8 kg | 9.5 | 1.8 – 47 | 12 | 3.7 | 1.4 – 14 | 12 |
| – Trout 0.8 – 3 kg | 23 | 1.8 – 94 | 35 | 10 | 1.4 – 36 | 20 |
| – Trout 3 – 6 kg | 5.6 | 1.8 – 18 | 29 | 3.8 | 1.4 – 14 | 17 |
| – Trout >6 kg | 2.1 | 1.8 – 7.2 | 16 | 1.4 | 1.4 – 1.4 | 9 |
| Perch and products of perch | 8.3 | 1.2 – 64 | 28 | 3.3 | 1.0 – 9.9 | 12 |
| Pike and products of pike | 3.9 | 1.6 – 16 | 20 | 4.3 | 1.5 – 15 | 9 |
| Vendace | 2.6 | 1.2 – 12 | 16 | 2.4 | 1.0 – 9.9 | 11 |
| Grayling | 4.7 | 1.2 – 32 | 11 | 2.5 | 1.0 – 9.9 | 6 |
| Whitefish | 1.2 | 1.2 – 1.2 | 4 | 1.0 | 1.0 – 1.0 | 3 |
| Burbot and products of burbot | 2.7 | 1.2 – 3.5 | 3 | 1.0 | 1.0 – 1.0 | 3 |
| Burbot liver | – | – | – | – | – | – |

has been reported in individuals without any specific known exposure (0.5 – 1.5 ng/g lipids) [41] and also higher than in another fish eating group from the East Coast of Sweden [42].

### 3.2 Fish consumption and correlation with serum levels

The participants in this study answered detailed questionnaires regarding personal background data and dietary habits concerning their regular diet and consumption of fish from the contaminated lake. The most frequently consumed fish was trout, followed by perch and pike (Table 3). The reported mean intake of trout was 30 g/day for men and 15 g/day for women with quite a wide range (0 – 101 g/day). The mean and median for both genders combined were 25 and 17 g/day, respectively. This is considerably higher than the average consumption of freshwater fish in the general population (4.4 g/day) [43]. A multiple linear regression was performed in order to investigate which food items, including fish species, influenced the serum levels significantly using intake of various food items in g/day obtained from the questionnaires. The fish species listed in Table 3 were used and other foods were divided into the following groups: dairy products, hen eggs, meat, lean fish, oily and semi oily fish, fish liver and roe, shellfish, vegetable oils and fats, seagull eggs, bread/cereals/nuts/greens and sweets/dry foods/beverages. As can be seen from Table 4, trout that weighed 0.8 to 3 kg was the most influential variable with regard to the participants' Sum 7 PBDE serum level. This confirms the first impression from the consumption data in Table 3 and PBDE levels in the respective fish species in Table 1. In addition, pike/products of pike and age were significantly related to the Sum 7 PBDE serum level. Trout that weighed 0.8 to 3 kg also influenced the HBCD serum levels, but perch/products of perch was the

 

**Table 4**. Significant relationships between the serum levels (ng/g lipids) and consumption data (g/day) from the questionnaires, obtained by linear regression

| Compound | Variable | B | Sign. | $R^2$ |
|---|---|---|---|---|
| Sum 7 PBDE | Intake of trout 0.8 – 3 kg | 0.63 | 0.000 | 0.593 |
| | Intake of pike and products of pike | 1.61 | 0.003 | |
| | Age | 0.31 | 0.028 | |
| BDE-209 | Intake of whitefish | 2.32 | 0.007 | 0.110 |
| HBCD | Intake of perch and products of perch | 0.51 | 0.000 | 0.825 |
| | Intake of trout 0.8 – 3 kg | 0.15 | 0.001 | |

**Table 5**. The mean calculated dietary intake of Sum 7 PBDE (ng/kg body weight/day) from different food groups

| | Mean (all) | Median (all) | Mean (men) | Median (men) | Mean (women) | Median (women) | Min | Max |
|---|---|---|---|---|---|---|---|---|
| Dairy products | 0.081 | 0.066 | 0.083 | 0.065 | 0.079 | 0.067 | 0 | 0.30 |
| Hen eggs | 0.025 | 0.018 | 0.024 | 0.018 | 0.027 | 0.020 | 0 | 0.10 |
| Meat | 0.068 | 0.063 | 0.068 | 0.067 | 0.067 | 0.054 | 0 | 0.16 |
| Fish, lean | 0.038 | 0.031 | 0.038 | 0.032 | 0.037 | 0.029 | 0 | 0.18 |
| Fish, oily and semi oily | 0.26 | 0.22 | 0.31 | 0.24 | 0.18 | 0.18 | 0 | 1.9 |
| Fish, liver and roe | 0.086 | 0.001 | 0.089 | 0.0007 | 0.082 | 0.0033 | 0 | 0.86 |
| Shellfish | 0.0017 | 0.0005 | 0.0019 | 0.0005 | 0.0013 | 0.0005 | 0 | 0.027 |
| Vegetable oils and fats | 0.014 | 0.013 | 0.016 | 0.014 | 0.012 | 0.0086 | 0 | 0.043 |
| Seagull eggs | 0.031 | 0 | 0.035 | 0 | 0.026 | 0 | 0 | 0.74 |
| Bread, cereals, nuts, greens | 0.0090 | 0.0066 | 0.0044 | 0.0029 | 0.016 | 0.013 | 0 | 0.039 |
| Sweets, dry foods, beverages | 0.0048 | 0.0029 | 0.0042 | 0.0027 | 0.0057 | 0.0042 | 0 | 0.024 |
| Fish from lake Mjøsa | 47 | 29 | 58 | 36 | 31 | 20 | 0 | 260 |
| Total diet | 48 | 30 | 58 | 37 | 32 | 20 | 0.3 | 260 |

most important variable for this compound. For BDE-209 on the other hand, whitefish was the only intake variable found to have significant impact on the serum level, but it explained only 11% ($R^2$) of the variance. Thus, this weak relationship should be interpreted with care. No associations were found between the subjects' serum BFR levels and smoking habits or level of education.

### 3.3 Calculated dietary exposure

The mean and median calculated dietary intake of Sum 7 PBDE from different food groups based on PBDE concentrations measured in food and food frequencies are presented in Table 5. The contribution from fish caught in the contaminated lake exceeds the other food groups by several orders of magnitude, comprising 98.7% of the total exposure. The mean calculated dietary intake of Sum 7 PBDE was 48 ng/kg body weight/day and the median 30 ng/kg body weight/day for the whole study group. In comparison, the corresponding mean intake of Sum 7 PBDE was found to be 1.1 ng/kg body weight/day in the reference group of 44 Norwegians eating only food with background levels of contamination [17]. The two studies utilized the same food frequency questionnaires and database containing PBDE levels in food for calculation of the exposure. In contrast, the calculated mean dietary intake of BDE-209 was in the same order of magnitude in the two groups of Norwegians, *i.e.* 1.1 ng/kg body weight/day in the present study and 1.4 ng/kg body weight/day in the other study, respectively. An almost equal BDE-209 exposure in the two groups was expected, since the fish in Lake Mjøsa was not particularly contaminated with BDE-209. For the anglers living around Lake Mjøsa, the second most important food sources of Sum 7 PBDE were commercial oily and semi-oily fish (0.54%), followed by fish liver and roe (0.18%) and dairy products (0.17%). This relative contribution is in accordance with the findings in the above-mentioned study [17].

The average daily dietary intake of PBDE has recently been estimated in several other countries in the range 23 to 107 ng/day [11 – 16]. The corresponding mean value for the local hobby fishermen and women is 3981 ng/day (median 2549 ng/day), which clearly shows their strongly elevated exposure due to consumption of fish from the contaminated Lake Mjøsa. In 2004, the Norwegian Food Safety Authority issued dietary advisories concerning consumption of fish from Lake Mjøsa, based on levels of dioxins and dioxin-like PCB measured in trout. The risk related to fish consumption was re-evaluated in 2005 by the Norwegian Scientific Committee for Food Safety (Risk assessment of PBDE, in Norwegian, http://www.vkm.no/eway/library/openForm.aspx?param1=16185&param5=read, accessed: March 2007), this time including exposure to PBDE. It was concluded that the fish advisories necessary to prevent exposure to dioxin-like compounds also covered the poten-

 

**Table 6**. Spearman's rank correlation coefficients between BFR concentrations in serum and the calculated dietary intake of the corresponding congener for males (M) and females (F)

| | | Calculated dietary intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | BDE-28 | BDE-47 | BDE-100 | BDE-99 | BDE-154 | BDE-153 | BDE-209 | Sum 7 PBDE |
| Serum concentration | | | | | | | | | |
| BDE-28 | M | 0.29 | 0.29 | 0.27 | 0.32[b] | 0.28 | 0.29 | 0.01 | 0.30 |
| | F | 0.24 | −0.16 | −0.17 | −0.21 | −0.18 | −0.17 | −0.36 | −0.18 |
| BDE-47 | M | 0.57[a] | 0.57[a] | 0.58[a] | 0.59[a] | 0.57[a] | 0.58[a] | −0.07 | 0.58[a] |
| | F | 0.45[b] | 0.50[b] | 0.48[b] | 0.47[b] | 0.48[b] | 0.47[b] | −0.36 | 0.49[a] |
| BDE-100 | M | 0.55[a] | 0.56[a] | 0.56[a] | 0.57[a] | 0.55[a] | 0.55[a] | −0.04 | 0.56[a] |
| | F | 0.31 | 0.32 | 0.30 | 0.29 | 0.30 | 0.28 | −0.19 | 0.31 |
| BDE-99 | M | 0.52[a] | 0.52[a] | 0.53[a] | 0.54[a] | 0.52[a] | 0.52[a] | −0.12 | 0.53[a] |
| | F | 0.44[b] | 0.48[b] | 0.47[b] | 0.45[b] | 0.47[b] | 0.45[b] | −0.20 | 0.47[b] |
| BDE-154 | M | 0.56[a] | 0.57[a] | 0.57[a] | 0.57[a] | 0.56[a] | 0.57[a] | −0.04 | 0.57[a] |
| | F | 0.17 | 0.13 | 0.12 | 0.09 | 0.12 | 0.08 | −0.15 | 0.13 |
| BDE-153 | M | 0.46[a] | 0.46[a] | 0.45[a] | 0.47[a] | 0.45[a] | 0.45[a] | 0.10 | 0.46[a] |
| | F | −0.002 | 0.004 | −0.02 | −0.04 | −0.02 | −0.04 | 0.04 | −0.01 |
| BDE-209 | M | −0.28 | −0.28 | −0.28 | −0.23 | −0.28 | −0.27 | 0.10 | −0.27 |
| | F | −0.03 | −0.01 | −0.005 | 0.02 | −0.01 | 0.02 | 0.05 | 0.002 |
| Sum 7 PBDEs[c] | M | 0.56[a] | 0.57[a] | 0.57[a] | 0.58[a] | 0.56[a] | 0.57[a] | −0.01 | 0.57[a] |
| | F | 0.27 | 0.28 | 0.26 | 0.25 | 0.26 | 0.24 | −0.33 | 0.27 |
| HBCD | M | 0.48[a] | 0.47[a] | 0.48[a] | 0.49[a] | 0.46[a] | 0.48[a] | −0.10 | 0.47[a] |
| | F | 0.23 | 0.25 | 0.23 | 0.22 | 0.23 | 0.23 | −0.15 | 0.24 |

a) Correlation is significant at the 0.01 level (two-tailed).
b) Correlation is significant at the 0.05 level (two-tailed).
c) Sum 7 PBDE comprises BDE-28, 47, 99, 100, 153, 154 and 183.

tial hazards posed by the presence of PBDE in Lake Mjøsa fish. The advice for the general population is to avoid eating Lake Mjøsa trout above 1 kg more often than once a month on average. About half of the hobby fishermen and women participating in this study reported eating such trout at least twice a month, some even up to 14 times per month.

### 3.4 Correlations between calculated dietary exposure and serum levels

The calculated exposure to Sum 7 PBDE of fish from Lake Mjøsa and the measured Sum 7 PBDE concentrations in serum are clearly correlated as shown in Fig. 2. The correlations between serum levels and the total calculated dietary exposure for all the individual BFR are presented in Table 6. For men, the calculated dietary exposure on congener basis correlated well with the measured serum level for the major congeners in the PentaBDE mixture, BDE-47, 99, 100, 153 and 154, both on individual congener basis and between the different congeners. The relationships were more pronounced than what was found in the previously mentioned study on persons eating only food with background levels of contamination [17], which is probably due to the relatively high exposure to the trout. The dietary exposure to HBCD was not calculated due to limited data on HBCD levels in fish from Lake Mjøsa. Nevertheless, HBCD serum levels correlated well with intakes of all PBDE except for BDE-209 (Table 6), indicating that

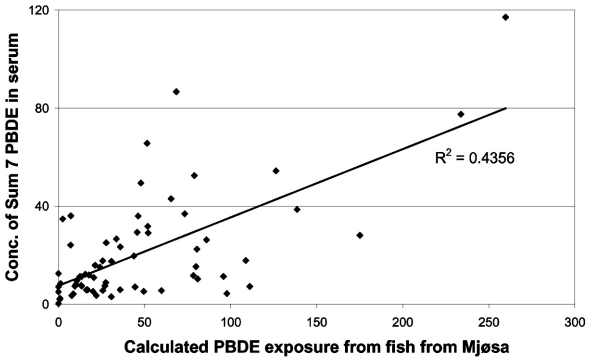


**Figure 2**. The relationship between calculated exposures to Sum 7 PBDE (ng/kg body weight/day) from fish from Lake Mjøsa and the Sum 7 PBDE concentrations in serum (ng/g lipids) ($p$ <0.01).

HBCD exposure occurs through the same pathways as the lower brominated PBDE. The BDE-209 serum level on the other hand, was correlated neither with the calculated BDE-209 dietary exposure nor to any of the exposure estimates for the other PBDE. This clearly suggests that sources other than the diet are important for human BDE-209 exposure. Several recent publications have pointed towards the indoor environment as a likely exposure source that should be further investigated [15, 19].

For women, only serum levels of BDE-47 and 99 were significantly correlated with the calculated dietary expo-

 

**Table 7**. Spearman's rank correlation coefficients between the BFR concentrations in serum

| PBDE | BDE-28 | BDE-47 | BDE-100 | BDE-99 | BDE-154 | BDE-153 | HBCD | BDE-209 |
|---|---|---|---|---|---|---|---|---|
| BDE-47 | 0.45[a)] | | | | | | | |
| BDE-100 | 0.37[a)] | 0.96[a)] | | | | | | |
| BDE-99 | 0.42[a)] | 0.95[a)] | 0.90[a)] | | | | | |
| BDE-154 | 0.25[b)] | 0.81[a)] | 0.85[a)] | 0.81[a)] | | | | |
| BDE-153 | 0.31[b)] | 0.76[a)] | 0.86[a)] | 0.72[a)] | 0.78[a)] | | | |
| HBCD | 0.39[a)] | 0.78[a)] | 0.85[a)] | 0.73[a)] | 0.70[a)] | 0.73[a)] | | |
| BDE-209 | −0.09 | −0.007 | 0.03 | −0.007 | 0.07 | 0.17 | −0.17 | |
| Sum 7 PBDE[c)] | 0.41[a)] | 0.97[a)] | 0.98[a)] | 0.94[a)] | 0.88[a)] | 0.86[a)] | 0.80[a)] | 0.05 |

a) Correlation is significant at the 0.01 level (two-tailed).
b) Correlation is significant at the 0.05 level (two-tailed).
c) Sum 7 PBDE comprises BDE-28, 47, 99, 100, 153, 154 and 183.

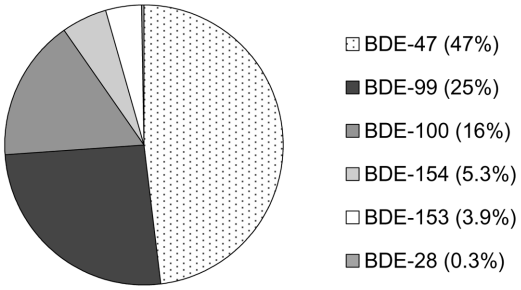


**Figure 3**. The contribution in% from the seven individual PBDE congeners to the mean dietary intake of Sum 7 PBDE.

sure (Table 6). We suspected that the striking and substantial differences between males and females might be caused by excretion of PBDE during lactation periods; however, we found no correlations between the numbers of breast-fed children and serum levels in this study. As shown in Tables 3 and 5, both fish consumption and the calculated dietary intake of Sum 7 PBDE were about twice as high for men compared to women, which might explain why weaker correlations are found between calculated dietary exposure and serum levels for women. One might also speculate that the discrepancy observed between men and women is related to differences in metabolism.

The significant correlations in Table 6 have been confirmed using adjusted linear regression, where also age and gender was taken into account. When including age and gender, a significant relation between the observed serum level and the calculated dietary exposure was found for BDE-28. In addition, age was positively and significantly related to the serum level for BDE-47, 99, 100 and 153, indicating accumulation with age, which is in contradiction to previous reports [22, 30].

### 3.5 Congener patterns

All the PBDE congeners in Sum 7 PBDE were significantly correlated ($p < 0.01$) in serum, with correlation coefficients ranging from 0.25 to 0.98 as can be seen from Table 7. The correlation coefficients were higher than those observed between PBDE in serum from background exposed Norwegians [17], and were generally higher for men than for women. HBCD was also strongly correlated with the seven individual PBDE, whereas BDE-209 did not correlate with any of the other BFR measured, supporting that different sources of exposure are more important for this compound than for the other PBDE. Of the seven PBDE, BDE-47 was found at highest concentration in all but six samples (where BDE-153 was highest) and contributed about 41% to the Sum 7 PBDE. The second most abundant PBDE observed was BDE-100 (23%), followed by BDE-153 (22%) and BDE-99 (10%). The congener pattern was similar in serum from men and women.

Interestingly, the contribution of BDE-100 to the Sum 7 PBDE was higher in the present study than in serum and breast milk from Norwegians without known exposure sources above background [17, 18]. In these studies, BDE-100 accounted only for about 8 and 10% of the Sum 7 PBDE, respectively. This may be explained by a higher contribution of BDE-100 to the dietary exposure for the participants eating contaminated fish. The contribution from BDE-100 to the diet for these study subjects was 16% (Fig. 3), which is somewhat higher than the 11% contribution that was calculated in the study on the general background exposed Norwegians [17]. Also seen in Fig. 3 is that BDE-153 only contributes to about 4% of the calculated dietary exposure, but constitutes 22% of the serum Sum 7 PBDE. This might be explained by a combination of longer half-life of BDE-153 compared to other PBDE in serum [44], and by additional sources than the diet.

The relative contribution of BDE-100 and BDE-153 as a function of Sum 7 PBDE concentrations is presented in Fig. 4, which shows a tendency for BDE-100 to increase and BDE-153 to decrease with increasing Sum 7 PBDE, respectively. These findings might be explained by the following: participants with low consumption of contaminated fish will have a dietary congener pattern more similar to the part of the population with only diffuse background exposure, and will thus have lower BDE-100 contribution to serum Sum 7 PBDE. If diet is a less important contributor to serum levels for BDE-153 than for BDE-100, which

 

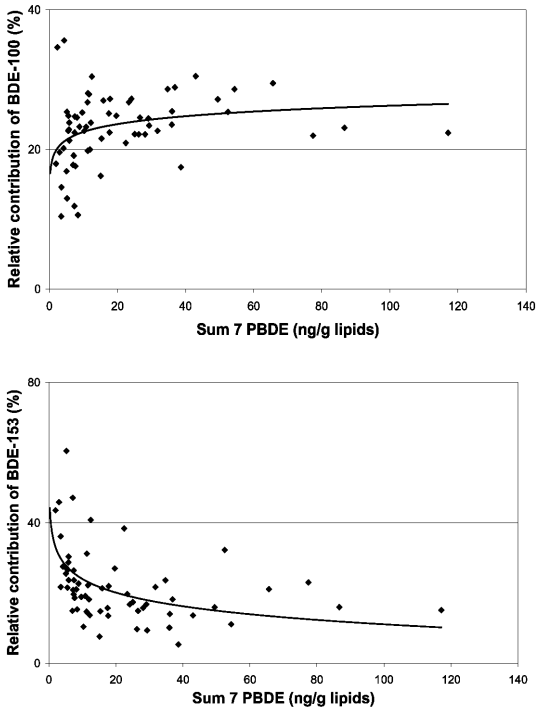


**Figure 4**. The relative contribution of BDE-100 and BDE-153 to the serum Sum 7 PBDE concentration.

Fig. 3 may indicate, one expects a higher contribution of BDE-153 to Sum 7 PBDE among those with lower PBDE serum concentration.

## 4 Concluding remarks

This study has demonstrated that consumption of fish from a BFR-contaminated lake influences the serum concentrations of BFR. Significant associations were found between the subjects' self-reported consumption of trout and pike from the lake and the serum levels of Sum 7 PBDE, and between serum HBCD levels and consumption of perch and trout, respectively. These fish species were consumed most frequently. Accordingly, the calculated dietary intake of Sum 7 PBDE showed that the total dietary PBDE exposure was almost exclusively determined by consumption of fish from the lake (98.7%). The results clearly demonstrate that the action plan for Lake Mjøsa put in force by national and local authorities is important for reducing the input of environmental contaminants into the lake.

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