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# Risk and benefits from consuming salmon and trout: A Canadian perspective

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**Abstract**

Recent reports on the presence of persistent organic chemicals in wild and farmed salmon have left consumers and health professionals confused regarding the safety of regular fish consumption. The objectives of this study were (1) to compare concentrations of key contaminants and the essential nutrients omega-3 fatty acids between farmed and wild salmon and trout, and (2) to balance risks and benefits from regularly consuming these species. Concentrations of mercury, polychlorinated biphenyls, dioxins and furans as well as omega-3 fatty acids were determined in fillets from farmed salmon and trout bought in various markets located in Quebec, Canada, as well as in fillets from wild salmonids obtained from fishermen and various Canadian agencies. While differences were observed between market (farmed) and wild fish with regard to the concentrations of mercury and polychlorinated biphenyls, overall the concentrations of contaminants were low, such that the regular consumption of these fish would not cause tolerable daily intakes to be exceeded. Our results indicate that salmon and trout sold in Quebec markets, which as in markets located elsewhere in North America originate for the most part from Chilean farms, can be consumed regularly to achieve optimal nutritional benefits from omega-3 fatty acids, without incurring significant contaminant related health risks.


*Keywords:* Salmon; Trout; Polychlorinated biphenyls; Methylmercury; Dioxins; Omega-3 fatty acids

## 1. Introduction

In order to prevent cardiovascular diseases, the American Heart Association (AHA) recommends eating fish (preferably fatty species) twice a week for the general population (Kris-Etherton et al., 2002). Fish consumption is largely recognized as beneficial for brain development and protective against cardiovascular diseases, mental disorders and various inflammatory conditions such as bowel diseases, asthma, and arthritis (Uauy et al., 2001; Kris-Etherton et al., 2002; Ruxton et al., 2004). Long-chain omega-3 polyunsaturated fatty acids (n-3 PUFAs), more specifically eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are believed to be responsible for these beneficial effects. On the other hand, fish flesh also contains persistent and bioaccumulative chemicals such as polychlorinated biphenyls (PCBs), polychlorinated dioxins/furans (PCDD/Fs) and methylmercury and as a result, fish advisories are regularly issued by governmental agencies to limit the consumption of certain species. One example is the most recent advisory issued by the US Food and Drug Administration (USFDA) and the US Environmental Protection Agency (USEPA) informing women of reproductive age to avoid the consumption of four species

*Abbreviations*: DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; PCBs, polychlorinated biphenyls; PCDD/Fs, polychlorinated dibenzo-*p*-dioxins and dibenzofurans; n-3 PUFAs, omega-3 polyunsaturated fatty acids; TDI, tolerable daily intake; TEQ, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin toxic equivalents.

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that are highly contaminated by methylmercury: King mackerel, Shark, Swordfish and Tilefish (USDHHS-USEPA, 2004). At the same time these agencies recommend for these women a weekly consumption of up to 360 g (12 oz) of a variety of other fish species. Clearly, the consumption of species with high nutrient content and low concentrations of contaminants should be favored.

Salmonid species would appear a healthy choice because they are high in EPA and DHA while containing much lower concentrations of methylmercury than long-lived, large predatory fish species. However, a recent series of reports revealing the presence of organochlorine contaminants in farmed and wild salmon and warning about putative cancer risks have likely detracted the public from consuming this species (Hamilton et al., 2005; Hites et al., 2004a, 2004b; Foran et al., 2005a,b; Huang et al., 2006). The objectives of the present study were to measure concentrations of key contaminants and fatty acids in fillets from Atlantic salmon and Rainbow trout, both farmed and wild, and to qualitatively assess the risks and benefits of regularly consuming these species, according to widely accepted reference values.

## 2. Material and methods

### 2.1. Materials

Solvents were of pesticide grade. Alumina and silica gel were obtained from EM Science. Hydrochloric, nitric and sulfuric acids were of Baker Instra-Analyzed grade. All others reagents were of analytical grade. The mercury standard used was traceable to NIST.

### 2.2. Samples

In 2003, we obtained samples from 46 farmed and 10 wild Atlantic salmon (*Salmo salar*) as well as 37 farmed and 10 wild Rainbow trout (*Oncorhynchus mykiss*). Farmed salmon were bought from 30 supermarkets located in 20 municipalities and Rainbow Trout from 27 markets located in 16 municipalities of the Province of Québec (Canada). Wild fish were obtained from fishermen of the Gaspé Peninsula and from various Canadian agencies (*Centre interuniversitaire de recherche sur le saumon atlantique*, *Ministère des ressources naturelles, de la faune et des parcs du Québec* and the Freshwater Fisheries Society in British Columbia). Samples were kept frozen at −20 °C until time of analysis. Analyses were conducted on raw, skinless fillets (more representative of people consumption), excluding other type of fat such as subcutaneous or mesenteric fat. Tissue samples were homogenized to obtain a uniform texture with an Omni Macro ES homogenizer fitted with an all-titanium blade assembly.

### 2.3. Analysis of mercury

Total mercury concentration was measured by cold vapor atomic absorption after digesting the samples in acid and reducing mercury with stannous chloride. Accurately weighed portions of about 5 g of tissue homogenates were digested in 85-ml glass digestion tubes on a programmable 40 position heating block. Digestion was carried out in two phases. Concentrated nitric acid (20 ml) was first added to the sample which was digested at 100 °C. After cooling, concentrated sulfuric acid (10 ml) was added and heating resumed in order to attain 130 °C. After cooling, 0.2 ml of 10% potassium dichromate was added as a preservative and the solution diluted to 75 ml.

The samples were analyzed by flameless atomic absorption using a Varian VGA-76 accessory that allows the mixing of the sample with the reducing agent. A gas–liquid separator cell recovers the mercury vapors which are measured by passing through a 15-cm path length quartz-windowed cell installed on a Perkin Elmer model 1100B atomic absorption spectrophotometer. Absorption was measured at a 253.7 nm wavelength. Calibration was performed in the 0–50 ng/ml range.

### 2.4. Analysis of PCBs

Samples were analyzed for 44 PCB congeners using capillary column gas chromatography (HP5890) with detection by high-resolution mass spectrometry (Autospec, Fisons). In brief, $^{13}$C-labelled internal standards of PCB congeners IUPAC nos. 77, 105, 169, 180 and 194 were added to the homogenized sample (10 g). Samples were extracted with a mixture hexane:dichloromethane using a Polytron agitator. Extracts were treated with sulfuric acid and transferred onto a chromatographic column containing silica gel and sodium sulfate. Compounds were eluted with 50 ml of hexane, the eluate was evaporated to 4 ml and then submitted to gel permeation chromatography using an Envirosep 350 mm × 21.2 mm ABC column and an Envirosep 60 mm × 21.2 mm guard column at a flow of 5 ml/min of dichloromethane. The eluate was evaporated down to 1 ml, fortified with $^{13}$C-labelled PCB 138 and injected on the GC-MS.

Separation of PCB congeners was effected on a DB-5 capillary column (30-m long, 0.25-mm internal diameter and 0.25-μm film thickness). Operating conditions were as follows: injector temperature 290 °C; oven temperature held at 100 °C for 1 min, then increased to 170 °C at 15 °C/min and held 3 min; temperature increased to 220 °C at 17 °C/min and held 10 min; temperature increased to 260 °C at 10 °C/min and held 10 min. The carrier gas was helium at a column flow rate of 1 ml/min.

### 2.5. Analysis of PCDD/Fs

Samples were analysed for 17 PCDD/F congeners using capillary column gas chromatography (HP5890) with detection by high resolution mass spectrometry (Autospec, Fisons). In brief, $^{13}$C-labelled internal standards of the 17 PCDD/Fs were added to homogenized samples (10 g). Samples were extracted with a mixture of hexane and dichloromethane using a Polytron agitator. Extracts were treated with sulfuric acid and transferred onto a chromatographic column containing silica gel, potassium silicate and sodium sulfate and a second column containing activated charcoal. The extract was eluted with 125 ml of a mixture of hexane and dichloromethane. The charcoal was moved to a soxhlet extractor and heated with toluene for 2 h. The eluate was evaporated to 1 ml and transferred onto a chromatographic column containing acid silica gel, cesium silicate and acid alumina. PCDD/Fs were eluted with 10 ml dichloromethane:hexane (50:50). After evaporating this eluate to dryness, 20 μl of an iso-octane solution containing two $^{13}$C-labelled PCDD/F congeners was added to the sample and the resulting solution was injected on the GC-MS.

PCDD/F separation was achieved on a DB-5 capillary column (30-m long, 0.25-mm internal diameter and 0.25-μm film thickness). Operating conditions were as follows: injector set at 290 °C; oven temperature held at 80 °C for 1 min, then increased to 200 °C at 30 °C/min, subsequently to 280 °C at 5 °C/min, and finally to 300 °C at 15 °C/min, at which temperature it was held during 5 min. The carrier gas was helium at a column flow rate of 1 ml/min.

Concentrations of the following 2,3,7,8-chlorosubstituted PCDD/Fs were determined in fish samples: 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD,1,2,3,4,7,8-HxCDD, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, OCDD, 2,3,7,8-TCDF, 1,2,3,7,8-PeCDF, 2,3,4,7,8-PeCDF, 1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, 2,3,4,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDF, 1,2,3,4,6,7,8-HpCDF, 1,2,3,4,7,8,9-HpCDF; OCDF. Concentrations of individual compounds were multiplied by their respective toxic equivalency factor (relative to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin) and added up to yield the total toxic equivalent (TEQ) concentration (Van den Berg et al., 1998).

### 2.6. Analysis of lipids

The method for measuring total lipid and fatty acid content of fish fillets was described in detail elsewhere (Blanchet et al., 2005). Briefly, total lipids were measured gravimetrically, whereas the fatty acid composition of fish fillets was determined by gas chromatography of the methyl ester derivatives (Lepage and Roy, 1986; Holub and Skeaff, 1987).

### 2.7. Statistical analysis

A concentration equal to half the detection limit was assumed for samples with concentrations below the limit of detection of the analytical method. We used the Wilcoxon rank-sum test to compare concentrations of contaminants and n-3 PUFA between market (farmed) and wild fish. A non-parametric test was selected because of the skewed distributions and the small sample sizes. The level of statistical significance was set at $p \leqslant 0.05$. Statistical analyses were conducted using the SAS/STAT (version 9.0).

## 3. Results

Concentrations of total mercury in fillets of farmed salmonids were about 3-fold lower than those determined in their wild counterparts ($P < 0.05$; Table 1). PCDD/F concentrations also appeared lower in farmed compared to wild salmonids, although statistically significant differences were not observed. In contrast, the mean total PCB concentration in farmed Atlantic salmon fillets was approximately double ($P < 0.05$) that of their wild counterparts. Such a difference was not observed between farmed and wild Rainbow trout.

Concentrations of total lipids and EPA + DHA in farmed Rainbow trout fillets were respectively 5.9 and 3.2-fold higher ($P < 0.05$) than those in their wild counterparts (Table 1). In contrast, we found no difference in lipid content and fatty acid composition between farmed and wild Atlantic salmon. Detailed data on fatty acids profiles were presented elsewhere (Blanchet et al., 2005).

Current EPA + DHA daily intakes average between 100 and 200 mg/day in Canada and USA (Kris-Etherton et al., 2000; Dewailly et al., 2001), values well below the lower limit of 500 mg/day recommended by the AHA and ISSFAL (Kris-Etherton et al., 2002; Cunnane et al., 2004). Data in Table 2 indicate that this recommendation could be met by eating approximately two 180-g portions of farmed salmon or trout weekly. Because farmed salmon is more widely available in supermarkets than Rainbow Trout, we focused on farmed salmon for the assessment of risks and benefits.

Daily intakes of mercury, PCBs and PCDD/Fs resulting from consuming farmed salmon meals at different frequencies are also presented in Table 2. According to the latest Canadian data available, the mean dietary exposure to mercury in women of reproductive age (20–39 years) is 0.019 μg/kg BW/day (Dabeka et al., 2003). Assuming a 60-kg body weight (BW), the mercury intake corresponding to two farmed salmon meals per week (0.015 μg/kg BW/day), added to the mean current intake, would amount to 17% of the most restrictive Canadian TDI for methylmercury, which is applicable to pregnant women and women of childbearing age (0.2 μg/kg BW/day).

The average dietary intake of PCBs for Canadian women in the 20–39 years old age group is 0.002 μg/kg BW/day (Health Canada, 2003). The PCB intake resulting from the nutritionally-optimal salmon intake (0.012 μg/kg BW/day), added to the average intake from the current diet, amounts to 11% of the new Canadian tolerable daily intake (TDI) of 0.13 μg/kg BW/day.

The latest data on dietary intake of PCDD/Fs in Canadians indicate that the average adult intake is 0.62 pg TEQ/kg BW/day (Health Canada, 2004). Adding this average dietary intake to that resulting from eating salmon twice a week (0.07 pg/kg BW/day), the PCDD/F intake would reach 69% of the lower limit of the range of TDI proposed by WHO (1 pg TEQ/Kg BW/day).

The calculation of total dioxin-like dietary exposure from fish consumption should include the contribution of dioxin-like PCBs (Judd et al., 2004). Unfortunately, some dioxin-like PCBs, namely the non-ortho coplanar PCBs, were not measured in the present study, thus preventing us from calculating the total TEQ concentrations in fish fillets. However, because dioxin-like PCBs represent typically 75% of total TEQ in farmed salmon (Hites et al., 2004a), we estimate that the total TEQ intake from eating two salmon meals weekly would reach 0.28 pg/kg BW/day. Dairy products and meat are major contributors to dietary PCB exposure of Canadians (Newsome et al., 1998). Based on the proportion of total PCBs represented by dioxin-like

Table 1
Concentrations of selected contaminants and lipids in wild and farmed Rainbow trout and Atlantic salmon

| | Rainbow trout | | | | | Atlantic salmon | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *N* | Farmed | *N* | Wild | *P*-value[a] | *N* | Farmed | *N* | Wild | *P*-value |
| *Compound* | | | | | | | | | | |
| Total mercury (μg/kg) | 37 | 21 ± 9 | 10 | 45 ± 26 | 0.005 | 42 | 18 ± 7 | 10 | 56 ± 13 | <0.001 |
| ΣPCBs (μg/kg) | 37 | 6 ± 3 | 8 | 6 ± 5 | 0.757 | 40 | 14 ± 9 | 8 | 6 ± 7 | 0.024 |
| ΣPCDD/Fs (pg TEQ/kg) | 37 | 41 ± 38 | 8 | 98 ± 101 | 0.187 | 40 | 82 ± 99 | 9 | 150 ± 139 | 0.061 |
| *Lipid content (mg/100 g)* | | | | | | | | | | |
| Total lipids | 37 | 5576 ± 3517 | 10 | 953 ± 386 | <0.001 | 46 | 7421 ± 3836 | 10 | 6967 ± 3757 | 0.578 |
| EPA + DHA | 37 | 731 ± 294 | 10 | 232 ± 48 | <0.001 | 46 | 855 ± 261 | 10 | 749 ± 157 | 0.358 |

Concentrations in fillets on a wet weight basis. Values are mean ± SD for *N* samples.
[a] *P*-value for Wilcoxon rank-sum test comparing wild and farmed fish.

Table 2
Daily intakes of n-3 PUFAs and selected contaminants according to the frequency of farmed Atlantic salmon meals

| | Farmed Atlantic salmon meal frequency | | | | | | Reference values |
|---|---|---|---|---|---|---|---|
| | 1/month | 1/week | 2/week | 3/week | 4/week | 1/day | |
| *Compounds* | | | | | | | |
| Mercury (μg/kg BW/day) | 0.002 | 0.007 | 0.015 | 0.023 | 0.030 | 0.054 | 0.1–0.47[a] |
| PCBs (μg/kg BW/day) | 0.001 | 0.006 | 0.012 | 0.018 | 0.024 | 0.042 | 0.02–0.13[b] |
| PCDD/Fs (pg TEQ/kg BW/day) | 0.008 | 0.035 | 0.070 | 0.105 | 0.140 | 0.246 | 1–4[c] |
| EPA + DHA (mg/day) | 55 | 220 | 440 | 660 | 880 | 1540 | 500–1800[d] |

We assumed a 180-g portion of fish per meal and an average body weight of 60 kg to calculate contaminants daily intakes.

[a] The lower limit is the tolerable daily intake (TDI) for methylmercury proposed in the US by the National Research Council (NRC, 2000) and the upper limit is the Canadian TDI for the general population (Health Canada, 1998). In between lies the Canadian TDI for pregnant, child bearing age women and children of 0.2 μg/kg BW/day (Health Canada, 1998) and the TDI of 0.23 μg/kg BW/day derived from WHO's provisional tolerable weekly intake of 1.6 μg/kg BW (WHO, 2004).

[b] The lower limit is the maximum recommended level from ATSDR (2000) and the upper limit is the TDI recently put forward by Health Canada (Food Directorate, Health Canada, personal communication).

[c] This range of TDI was proposed by WHO (Van Leeuwen et al., 2000). It encompasses the value of 1 pg/kg BW/day proposed in Europe (SCF, 2000) and in the US by ATSDR (1999).

[d] Range of recommended daily values for EPA + DHA proposed by the American Heart Association (Kris-Etherton et al., 2002). The lower intake is recommended for the general population, whereas the highest is recommend for patients with existing ischemic disease.

PCBs in butter (Weiss et al., 2005), which was applied to the average daily PCB intake of Canadian adults (0.002 μg/kg/day), we estimate at 0.02 pg TEQ/kg BW/day the average dietary intake of dioxin-like PCBs in adults, bringing the average dioxin-like compound exposure to 0.64 pg TEQ/kg BW/day. Hence, when PCDD/Fs and dioxin-like PCBs are considered in the calculation, the average total dioxin-like compound exposure corresponding to the nutritionally-optimal salmon intake would reach 0.92 pg TEQ/kg BW/day, or 92% of the lowest TDI.

## 4. Discussion

We determined the concentrations of key contaminants in two fatty fish species, salmon and trout, both farmed and wild, in order to qualitatively assess contaminant-related health risks and balanced them with the benefits of n-3 PUFAs. Our results indicate that while some differences were observed between market (farmed) and wild fish with regard to the concentrations of mercury and polychlorinated biphenyls, overall the concentrations of key contaminants were low, such that the regular consumption of these fish would not cause significant health risks.

This conclusion is based on the fact that the additional doses of methylmercury, PCBs and PCDD/Fs resulting from the consumption of farmed salmon twice a week would not cause the average daily intakes to exceed TDIs proposed by the various governmental agencies. The same can be said of trout consumption since concentrations of contaminants in trout fillets were similar to or lower than those measured in salmon fillets. However, eating farmed salmon twice a week would likely cause the mean total intake of dioxin-like compounds, including PCDD/Fs, non-ortho and mono-ortho PCBs to approach the lowest TDI established by the WHO (1 pg TEQ/kg BW/day). Although this might be viewed with some concern, one must consider that the PCDD/Fs dietary intake estimate was obtained from the Total Diet Study conducted in two Canadian cities during 1998–1999. In all likelihood, levels in the diet have continued to decrease following the introduction of measures to control the major sources of dioxin emission to the environment, especially waste incineration.

Our results are in contrast to those recently reported by Foran et al (2005b), who concluded that neither farmed nor wild salmon can be consumed at rates that provide the recommended intake of EPA + DHA while maintaining an acceptable level of risk. This disagreement between our studies is not primarily due to differences in concentrations of contaminants measured in fish fillets. Foran's group reported total PCB concentrations in farmed or retail market salmon from different countries and cities varying between 10 and 50 ng/g wet weight (Huang et al., 2006), compared to 14 ng/g for salmon from markets in Quebec. For dioxins and furans, Foran's group measured concentrations ranging from 0.1 to 0.8 pg TEQ/g wet weight (Huang et al., 2006), compared to 0.08 pg TEQ/g for farmed salmon bought in Quebec markets. The major difference between our studies lies with the method used for assessing health risks. Foran et al. calculated quantitative estimates of cumulative carcinogenic risks for 11 contaminants measured in salmon using the cancer slopes factors developed by the USEPA (2005). The acceptable level of risk was set at $1 \times 10^{-5}$. This approach which assumes a linear-non threshold relation between risk and low dose exposure is not appropriate for the type of carcinogens found in salmon i.e. epigenetic carcinogens (Pitot and Dragan, 2001; Cole et al., 2003; Fukushima et al., 2005). We rather focused our assessment on PCBs, dioxins, and methylmercury, which might induce adverse reproductive and developmental effects at low dose, and TDIs that were developed to protect the population from these and other non-cancer health effects.

The mean total lipid content of fatty fish in the present study ranged from 1.0% for wild trout to 7.4% for farmed salmon. By comparison, animal products regularly consumed by Canadians such as regular ground meat and pork chops contain respectively 20% and 12.7% total fat (USDA, 2002). Hence, salmon and trout fillets, either from farmed or wild fish, can be considered as lean and healthy choices based on their total lipid content. Their high omega-3 fatty acid content adds even more to the nutritional value of these fish. Our risk-benefit analysis is based on the consumption of skinless fillets, trimmed of any subcutaneous or mesenteric fat. The consumption of these fish without removing the fat would adversely affect the balance between risk and benefits.

Between 60 and 85% of the Atlantic salmon fillets sold in Quebec markets originates from Chilean farms; with the balance being supplied by Canadian farms (Richard Morin, MAPAQ, personal communication). In the US, 87% of farm salmon fillets imported in the US in 2005 originated from Chile (Harvey, 2006). Chile continues to be the price leader for filleted products by a wide margin. In the first half of 2005, the average price for Chilean imports was 30% less than imports from most other suppliers (CAIA, 2006). In as much as fish with relatively low contaminant burden, such as that observed in the present study, continues to be available in North American markets, eating two salmon or trout meals per week can be recommended to increase EPA and DHA intake towards optimal values, without worrying about the putative health risks. We support initiatives that will reduce the contaminant burden of farmed fish, without compromising its nutritional value.

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