Global Assessment of Organic Contaminants in Farmed Salmon: Geographical Differences and Health Risks

Summary. Analysis of more than two metric tons of salmon from around the globe reveals that concentrations of organochlorine contaminants, including polychlorinated biphenyls, dioxins, toxaphene, and dieldrin, are significantly higher in farmed salmon than in wild, significantly higher in European farmed salmon as compared to those from North and South America, and occur at levels that may present a human health risk if farmed salmon are consumed more than once or twice per month.

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Abstract. The annual global production of farmed salmon has increased by a factor of 40 during the past two decades. Salmon from farms in northern Europe, North America, and Chile are now available widely year-round at relatively low prices. Salmon farms have been criticized for their ecological effects, but the potential human health risks of farmed salmon consumption have not been examined rigorously. Analyzing over two

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metric tons of farmed and wild salmon from around the world for organochlorine contaminants, we show that concentrations of these contaminants are significantly higher in farmed salmon than in wild. European-raised salmon have significantly greater contaminant loads than those raised in North and South America, indicating the need for further investigation into the sources of contamination. Risk analysis indicates that consumption of more than one or two meals per month of farmed salmon may pose elevated and unacceptable risks.

Between 1987 and 1999, salmon consumption increased annually at a rate of 14% in the European Union and 23% in the US (*1*). Currently, over half the salmon sold globally is farm-raised in Northern Europe, Chile, Canada, and the United States, and the annual global production of farmed salmon (predominantly Atlantic salmon, *Salmo salar*) has risen from ~24,000 to over 1 million metric tons during the past two decades (*2*). The health benefits of eating fish such as salmon have been well documented (*3*, *4*). However, salmon are relatively fatty, carnivorous fish that feed high in the food web, and as such, they bioaccumulate contaminants (*5*). The potential risks of eating contaminated farmed salmon have not been evaluated well. Three previous studies reporting contaminants in salmon are inconclusive because of their very small sample sizes and narrow geographic representation (*6*-*8*). As a result, the extent of this problem and the potential risks remain unclear and raise major human health questions.

In this study, we measured organochlorine contaminants in approximately 700 farmed and wild salmon (totaling ~2 metric tons) collected from around the world. We do not report on other important contaminants, such as methylmercury, because our prelimi-

nary study (manuscript in preparation) showed no significant difference in methylmercury levels between farmed and wild salmon. Using the data on organochlorine contaminants, we assessed the variation of contaminant loads between farmed and wild salmon and among geographic regions, and we calculated the human health risks of salmon consumption. Farmed Atlantic salmon from eight major producing regions in the northern and southern hemispheres were purchased from wholesalers; in addition, farmed Atlantic salmon fillets were purchased at supermarkets in 16 large cities in North America and Europe. For comparison, samples of five wild species of Pacific salmon [chum *(Oncorhyncus keta)*, coho *(O. kisutch)*, chinook *(O. tshawytscha)*, pink *(O. gorbuscha)*, and sockeye *(O. nerka)*] were obtained from three different geographic regions. Wild Atlantic salmon were not studied because few are available commercially; nor did we analyze farmed Pacific salmon because they are not raised in any substantial amounts (*2*, *9*).

A total of 594 individual whole salmon were purchased from wholesalers and filleted; an additional 144 fillets were purchased from retailers in Boston, Chicago, Denver, Edinburgh, Frankfurt, London, Los Angeles, New Orleans, New York, Oslo, Paris, San Francisco, Seattle, Toronto, Vancouver, and Washington DC. Composites of fillets from whole salmon were made on the basis of the location where they were produced (farmed salmon) or purchased (wild salmon). Composites of fillets from retailers were made on the basis of the retail outlet where they were purchased. Each composite sample consisted of fillets from three salmon per location or three fillets per retail outlet, giving 246 measured samples. All samples were homogenized and analyzed by gas chromatographic high resolution mass spectrometry (*10*). Strict quality assurance/quality control procedures were

81 followed (*10*). Thirteen samples of salmon feed were purchased from the European, North
82 American, and South American outlets of the two major fish feed companies, which to-
83 gether have ~80% of the global market for fish feed (*11*).

84 Contaminant concentrations in farmed and wild salmon were compared by analysis
85 of variance. In comparing wild and farmed salmon, farmed salmon were considered as a
86 single group. In addition, locations at which salmon were farmed were compared by
87 analysis of variance with multiple comparisons of means to test for differences among lo-
88 cations in contaminant levels. In all analyses of variance, the replicate composites from
89 each source were not assumed to be independent observations. Differences between
90 farmed and wild salmon and differences among farming locations were consistently sub-
91 stantial and highly significant.

92 Figure 1 shows the concentrations of 14 organochlorine contaminants in the sam-
93 ples of farmed, supermarket, and wild salmon. Thirteen of these contaminants were sig-
94 nificantly more concentrated in the farmed salmon as a group (red bars) than in the wild
95 salmon (green bars) [$F = 3.75$, $p = 0.0573$ for lindane; $F = 9.93$, $p = 0.0025$ for HCB; $F \geq$
96 11.71, $p \leq 0.001$ for the other 12 contaminants, with $df = (1, 64)$ for all]. Concentrations in
97 farmed salmon from Europe and from North America were significantly higher than those
98 in wild salmon for all 14 contaminants [$p < 0.05$ for all 28 comparisons]. Concentrations
99 in farmed salmon from South America were significantly higher than those in wild salmon
100 for six contaminants (PCBs, dioxins, dieldrin, *cis*-nonachlor, total DDT, and mirex) but
101 significantly lower for two contaminants (HCB and lindane) [$p < 0.05$ for each]. In addi-
102 tion, concentrations of all contaminants in farmed salmon from Europe were significantly

greater than concentrations in farmed salmon from both North and South America [F = 8.31 to 65.87, with df = (2, 48); $p < 0.001$ for all 14 contaminants].

We focused additional analysis on PCBs, dioxins, toxaphene, and dieldrin because the patterns of their occurrence in farmed and wild salmon are similar to the patterns of all contaminants evaluated in this study and because an abundance of human health risk information is readily available for these compounds (*12-18*). The average measured concentrations for these four contaminants are shown in Figure 2a-d as a function of location. As noted above, total PCBs, dioxins, toxaphene, and dieldrin were consistently and significantly more concentrated in the farmed salmon as a group (red bars) than in the wild salmon (green bars) [F = 60.53, 26.80, 15.03, and 32.22, with df = (1, 64) for all; $p \leq 0.0003$ for all]. Salmon fillets obtained from commercial outlets in the various cities (yellow bars) generally clustered with the farmed samples, not with the wild samples.

PCB, dioxin, toxaphene, and dieldrin concentrations were highest in farmed salmon from Scotland and the Faroe Islands and lowest in farmed salmon from Chile and Washington state. Salmon produced in Europe had significantly higher contaminant levels than those produced in both North and South America [F = 26.15, 23.36, 64.42, and 59.26, with df = (2, 48) for all; $p < 0.0001$ for all]. Even the least contaminated farmed salmon, from Chile and Washington state, had significantly higher contaminant loads of PCBs, dioxins, and dieldrin than wild salmon [F = 28.55, 8.61, and 4.66, with df = (1, 26); $p < 0.0001$, $p = 0.0069$, and $p = 0.0402$]. Farmed salmon fillets purchased from supermarkets in Frankfurt, Edinburgh, Paris, London, and Oslo were generally the most contaminated, although those purchased in Boston and San Francisco approached these concentrations. Those purchased in New Or-

leans and Denver were the least contaminated of the store-bought samples. The concentrations of PCBs, dioxins, toxaphene, and dieldrin in salmon fillets purchased in cities in Europe were significantly higher than those purchased in cities in North America [$F = 22.08$, 31.46, 116.80, and 36.50, with $df = (1, 14)$; $p < 0.0001$ for all]. Most of the salmon sold in European stores comes from European farms, which produce the more contaminated salmon, while much of the salmon sold in US stores comes from Chile and Canada (*19*, *20*).

Some of the concentrations in the store-bought farmed samples were quite variable. For example, dieldrin concentrations in the three samples purchased in Washington DC were 4.63, 0.61, and 0.46 ng/g wet weight. Based on information from the retailer, the two Washington DC samples with the lowest concentrations came from farms in Chile, and the one with the highest concentration came from a farm in Iceland. This is further evidence that farmed salmon from the North Atlantic have higher contaminant concentrations than those from Chile and Canada.

The large differences between the farmed and wild salmon contaminant concentrations are most likely a function of their diet. Farmed salmon are fed a concentrated feed high in fish oils and fish meal, which is obtained primarily from small pelagic fishes (*21*). We analyzed 13 samples of commercial salmon feed (Figure 3). Although the concentrations in these feed samples were quite variable, they were generally similar to or greater than those in the farmed salmon. The concentrations in feed purchased from Europe were significantly higher than those in feed purchased from North and South America [$F = 7.05$, 11.16, 31.35, and 6.78, with $df = (1, 11)$; $p = 0.022$, 0.007, 0.001, and 0.024]. This may reflect higher contaminant concentrations in forage fish from the industrialized waters of Europe's North At-

147 lantic compared to forage fish from the waters off North and South America – the primary
148 sources of fish harvested for fish meal and fish oil (*22*). Uptake of organic contaminants
149 from water to fish is a minor accumulation pathway (*23*), so we did not analyze contami-
150 nants in water where farmed and wild salmon live.

151 The human health effects of exposure to PCBs, dioxins, toxaphene, and dieldrin in
152 salmon tissues are a function of contaminant toxicity, concentration in fish tissues, and fish
153 consumption rates. We used the approaches of the U.S. Environmental Protection Agency
154 (EPA) (*24*) and the World Health Organization (WHO) (*25*) to assess comparative health
155 risks of consuming farmed and wild salmon. Individual contaminant concentrations in
156 farmed and wild salmon do not exceed U.S. Food and Drug Administration action or toler-
157 ance levels for PCBs, toxaphene, and dieldrin (*26*). However, FDA action/tolerance levels
158 are not strictly health based, do not address health risks of concurrent exposure to more
159 than one contaminant, and do not provide guidance for dioxins in fish tissue (*27*, *28*). The
160 U.S. EPA approach (*24*) is designed to manage health risks by providing risk-based con-
161 sumption advice for contaminated fish (for example, one should limit consumption of a par-
162 ticular species to a specified number of meals per month or week). The WHO uses an expo-
163 sure-based approach for dioxins by issuing thresholds for contaminant intake rather than fish
164 consumption advice; for consistency, we converted WHO intake levels for dioxins to fish
165 consumption rates (*10*).

166 The combined concentrations of PCBs, toxaphene, and dieldrin trigger EPA con-
167 sumption advice for all samples of farmed salmon purchased from wholesalers and most
168 samples of store-bought farmed fillets. This advice is much more restrictive than con-

sumption advice triggered by contaminants in the tissues of wild salmon (Figures 4a and 4b). The most restrictive advice (<1 meal of salmon per month), which reflects the highest health risks, was generated for farmed salmon fillets purchased from stores in Frankfurt, Germany, and for farmed salmon from Scotland and the Faroe Islands. The concentrations of PCBs, toxaphene, and dieldrin trigger EPA consumption advice of no more than 1-2 meals per month for all samples of farmed salmon, including farmed salmon from South America.

Patterns in consumption advice generated by the WHO Tolerable Daily Intake for dioxins (Figures 4c and 4d) are consistent with patterns in consumption advice for the other contaminants. Generally, consumption of farmed salmon at a rate of 1-2 meals/week [the American Heart Association's recommended dietary guideline for fish consumption (*29*)] would result in dioxin intake levels that reach or exceed the WHO limit of total human intake from all sources (*25*), while consumption of wild salmon at rates as high as 14 meals/week would be required to achieve the same dioxin intake levels (Figure 4c).

The methods used to develop this consumption advice for PCBs, toxaphene, and dieldrin are based on estimates of potential cancer risks and on an assumption of risk additivity (*24*). A variety of non-cancer health effects have also been associated with exposure to PCBs (*18*), dioxins (*25*), toxaphene (*30*), dieldrin (*31*), and other contaminants found in salmon. Some of these non-cancer endpoints, such as adverse neurobehavioral and immune effects and endocrine disruption, occur at lower concentrations than those implicated in cancer (*16*). However, these hazards were not considered in the present analysis because quantitative risk or threshold levels are not available for these effects.

Our data indicate that farmed salmon have significantly higher contaminant burdens than wild salmon and that farmed salmon from Europe are significantly more contaminated than farmed salmon from South and North America. Fish that is not contaminated is a healthy food, high in nutrients, such as omega-3 polyunsaturated fatty acids, that are known to have a variety of beneficial human health effects (*3*, *4*). However, this study suggests that consumption of farmed salmon may result in exposure to a variety of persistent bioaccumulative contaminants with the potential for an elevation in attendant health risks. In some cases, consumption of more than one or two meals of farmed salmon per month may exceed acceptable contaminant levels. This study also demonstrates the importance of labeling salmon as farmed and identifying the country of origin. Further studies of contaminant sources, particularly in feeds used for farmed carnivorous species such as salmon, are needed.

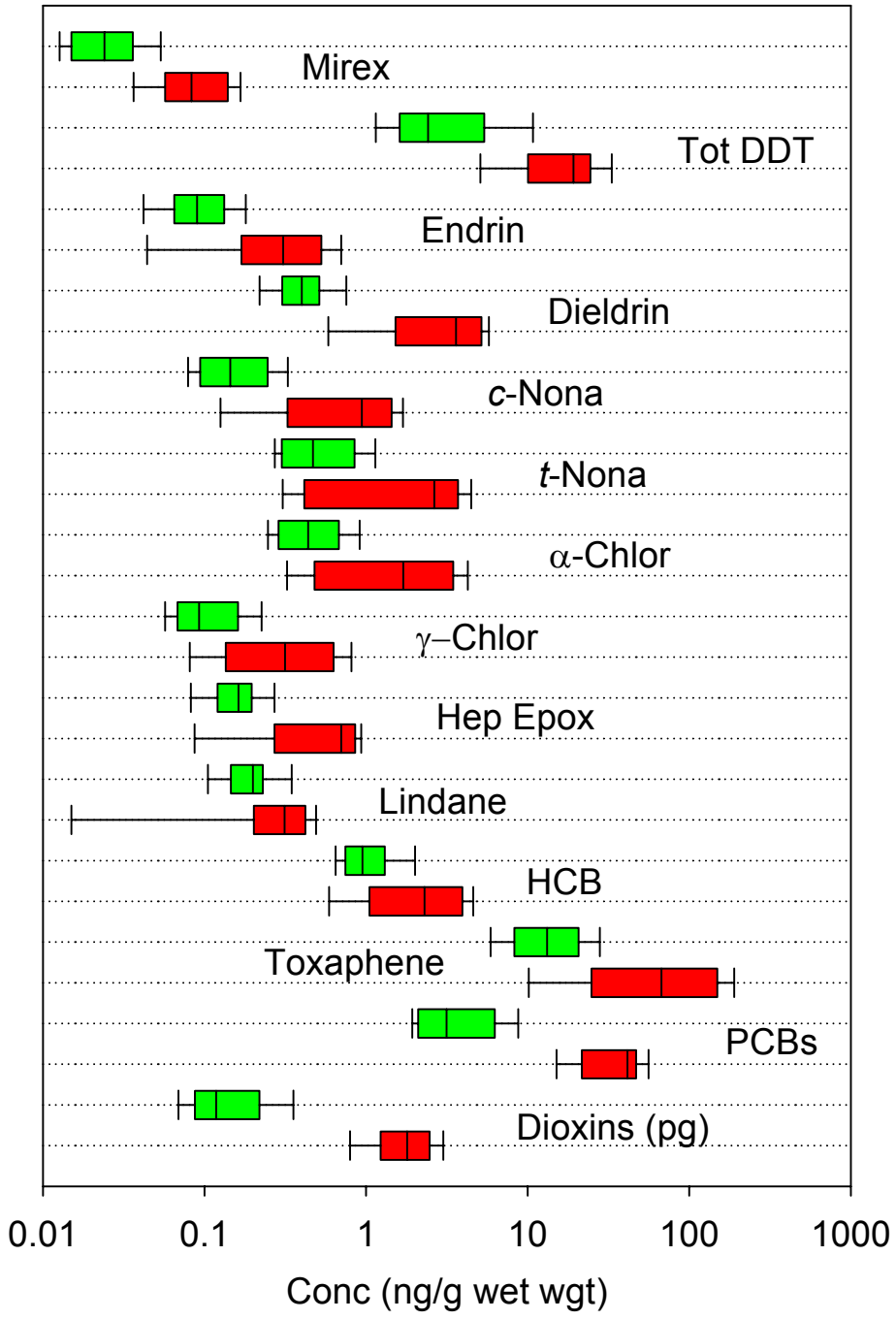
Figure Captions

1. Concentrations (in ng/g wet weight, except dioxins) of 14 contaminants found in farm-raised (red bars) and wild (green bars) salmon. The vertical lines represent the 10^{th}, 50^{th}, and 90^{th} percentiles, and the boxes represent the 25^{th} to 75^{th} percentiles. Dioxins are in pg WHO toxic equivalents (WHO-TEQs) per g wet weight and include polychlorinated dibenzo-*p*-dioxins and dibenzofurans and dioxin-like PCBs. Typically 75% of the total TEQ was due to the dioxin-like PCBs. Other abbreviations: HCB, hexachlorobenzene; Hep Epox, heptachlor epoxide; Chlor, chlordane; Nona, nonachlor; and Tot DDT, the *p,p*' and *o,p'* isomers of DDT, DDD, and DDE.

2. Concentrations of **(a)** PCBs in ng/g wet weight, **(b)** dioxins (for detail, see Figure 1) in pg WHO-TEQ/g wet weight, **(c)** toxaphene in ng/g wet weight, and **(d)** dieldrin in ng/g wet weight in farmed, supermarket, and wild salmon. The concentrations are all given as functions of the locations where the salmon were grown or purchased. Red represents farmed salmon, green represents wild salmon, and yellow represents salmon purchased at supermarkets. The error bars represent standard errors. The number of samples is given in parentheses after the location identifier. The locations are sequenced by average contaminant rank.

3. Concentrations of **(a)** PCBs in ng/g wet weight, **(b)** dioxins (for detail, see Figure 1) in pg WHO-TEQ/g wet weight, **(c)** toxaphene in ng/g wet weight, and **(d)** dieldrin in ng/g wet weight in commercial fish meal purchased at facilities in various countries at various times of the year. Each bar represents the analysis of one sample of fish meal, and the country from which it was obtained is indicated. The concentrations are given as functions of the locations where the salmon were grown or purchased. Fish feed purchased in Europe is indicated by red, and fish feed purchased in North or South America is indicated by gray.

4. Consumption rate advisories based on **(a)** US EPA cumulative risk assessment methods for PCBs, toxaphene, and dieldrin (meals/month) for farmed (red) and wild (green) salmon and for **(b)** supermarket salmon (yellow). **(c)** WHO intake limits for dioxin TEQs (meals/week) for farmed (red) and wild (green) salmon and for **(d)** supermarket salmon (yellow). The country in which the salmon was produced or the city from which it was purchased is indicated.



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237 **FIGURE 1**

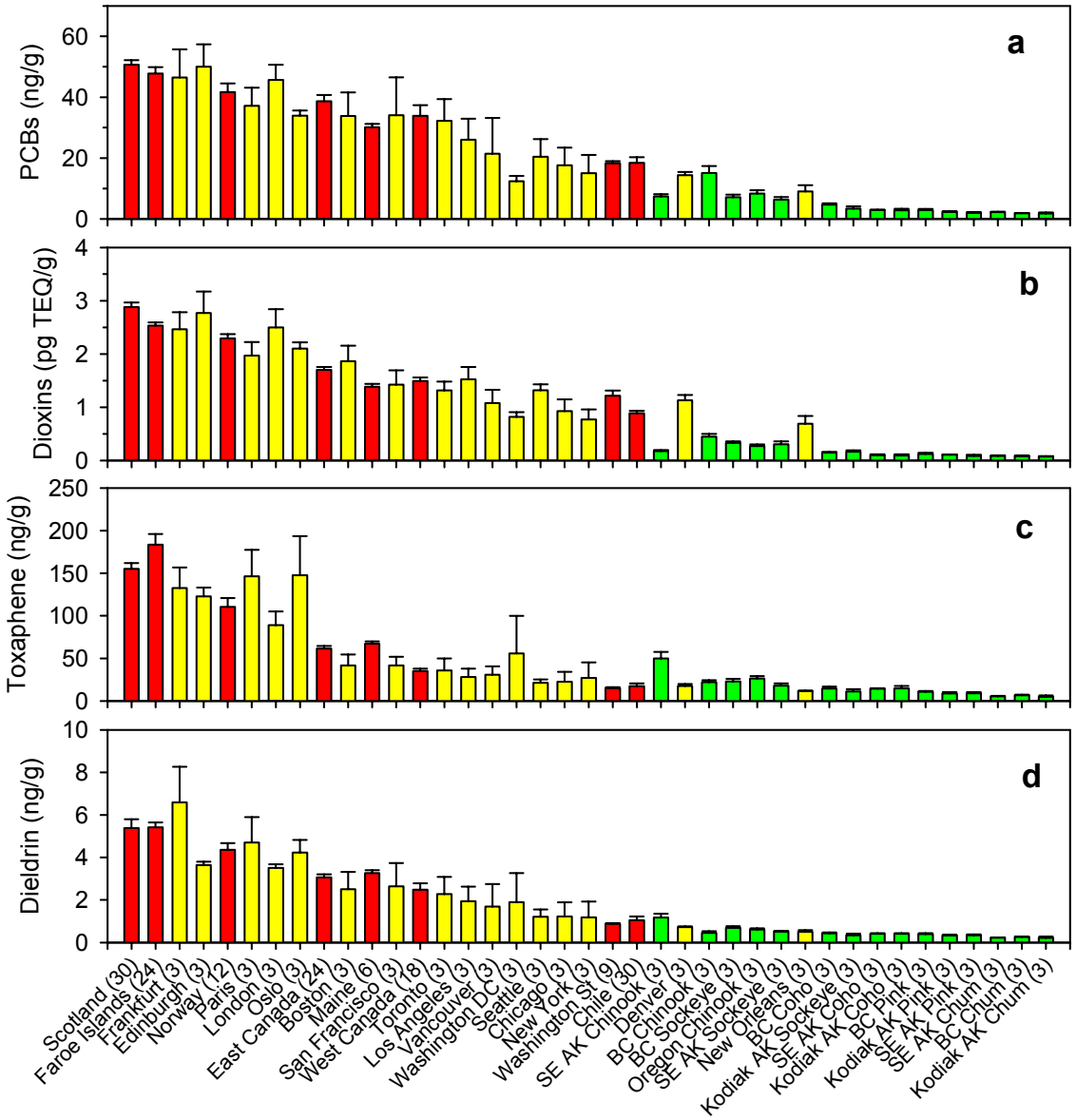
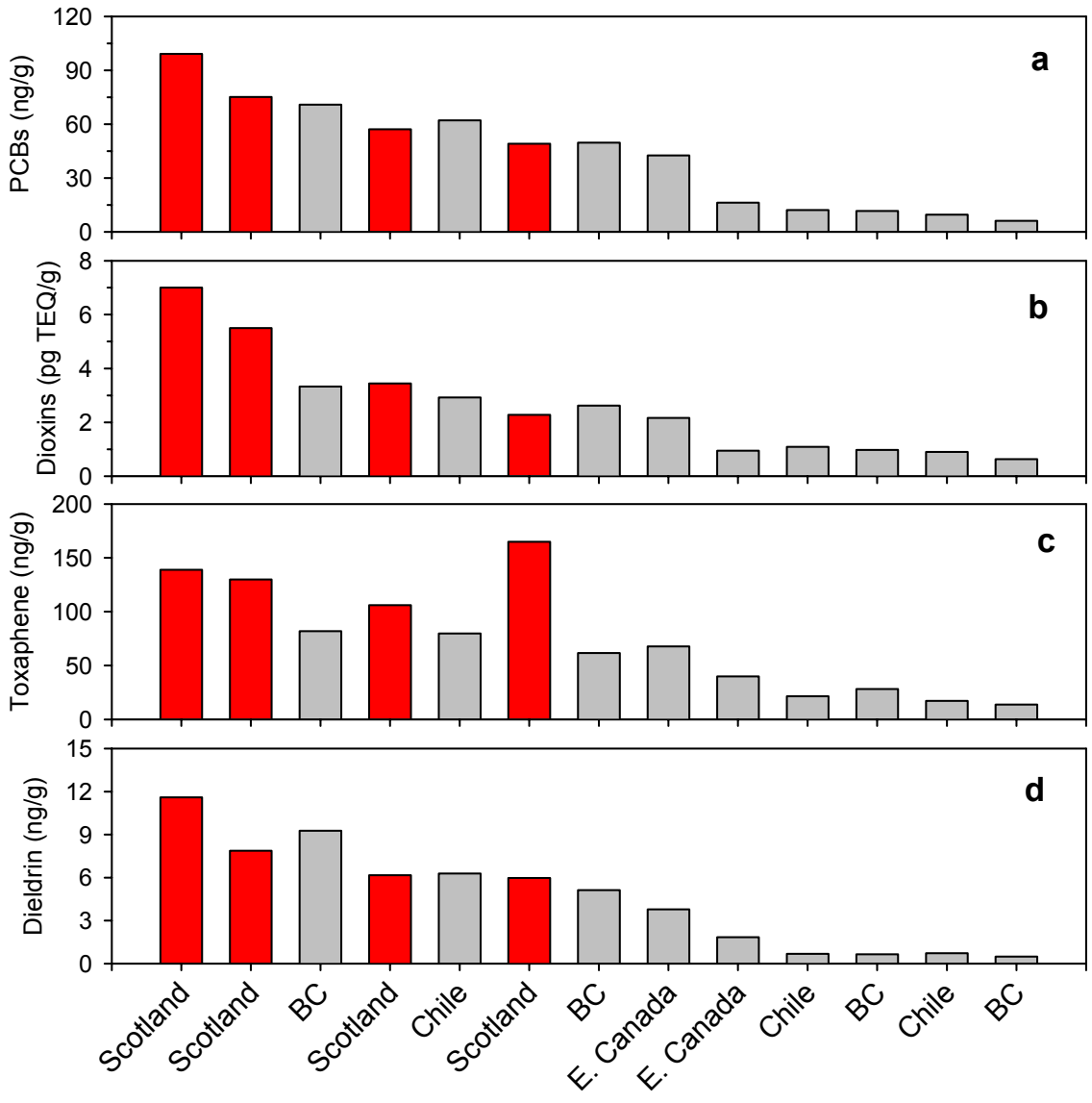
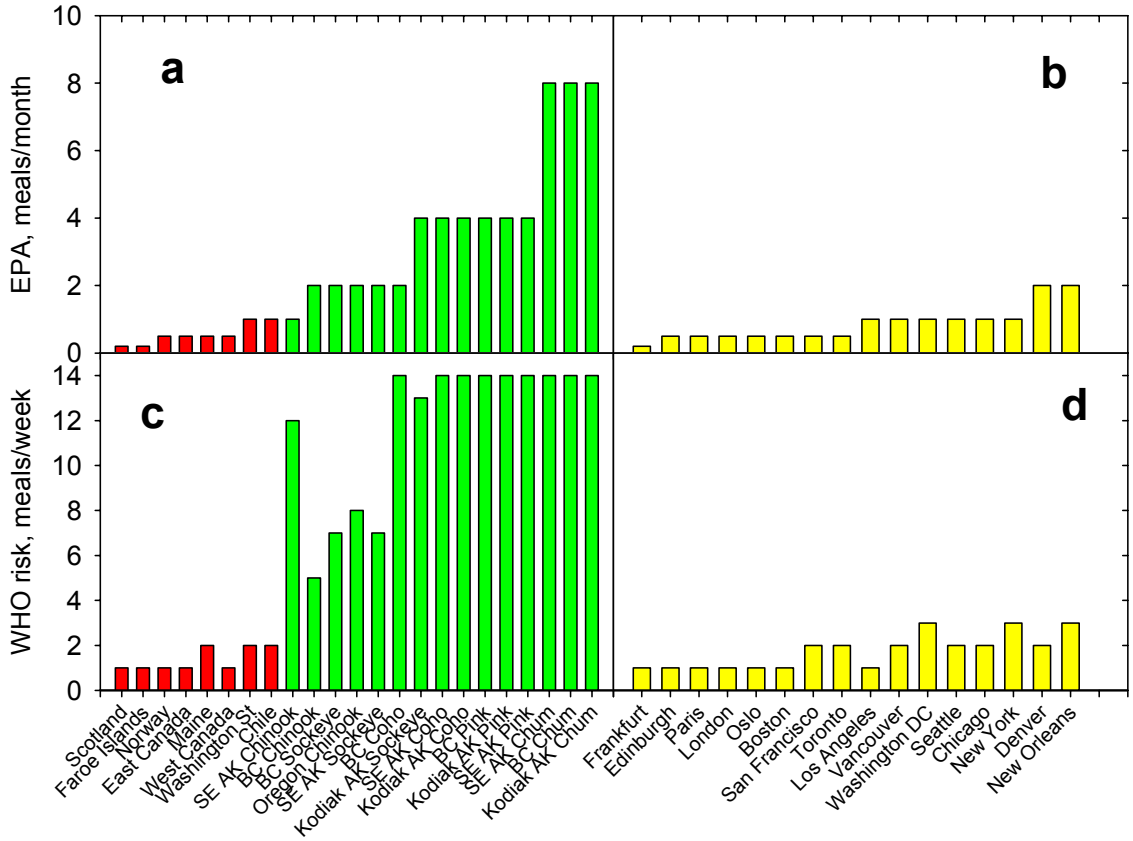

a
PCBs (ng/g)
0
20
40
60
b
Dioxins (pg TEQ/g)
0
1
2
3
4
c
Toxaphene (ng/g)
0
50
100
150
200
250
d
Dieldrin (ng/g)
0
2
4
6
8
10
Scotland (30)
Faroe Islands (24)
Frankfurt (3)
Edinburgh (3)
Norway (12)
Paris (3)
London (3)
Oslo (3)
East Canada (24)
Boston (3)
Maine (6)
San Francisco (3)
West Canada (18)
Toronto (3)
Los Angeles (3)
Vancouver (3)
Washington DC (3)
Seattle (3)
Chicago (3)
New York (3)
Washington St (9)
Chile (30)
SE AK Chinook (3)
Denver (3)
BC Chinook (3)
Oregon Chinook (3)
SE AK Sockeye (3)
New Orleans (3)
BC Sockeye (3)
BC Coho (3)
Kodiak AK Sockeye (3)
SE AK Coho (3)
Kodiak AK Coho (3)
BC Pink (3)
Kodiak AK Pink (3)
SE AK Pink (3)
SE AK Chum (3)
BC Chum (3)
Kodiak AK Chum (3)

FIGURE 2



240

241 **FIGURE 3**



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244 **FIGURE 4**

245 **References**

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Supporting On-line Material: Methods

The farmed Atlantic salmon (*Salmo salar*) were purchased from wholesale suppliers in the United States, the United Kingdom, Norway, and Canada and directly from retail outlets in 16 cities in Europe and North America. All such samples were purchased in the period from March through December 2002. Wholesale salmon were selected to include salmon farmed in British Columbia, Chile, Eastern Canada, the Faroe Islands, Maine, Norway, Scotland, and Washington state. The farms reflect those farms from which suppliers could obtain Atlantic salmon of the appropriate size within the sampling period. The number of farms sampled per region and the corresponding total production per region in 2000 are presented in Table l. One to three wholesale suppliers provided fish from each of these eight regions for a total of 51 farms. Suppliers provided information on the origin of the fish (region and farm) by including the original labels from the farm source where possible, or filling in labels we provided to them for this purpose. When necessary for clarification, we confirmed the written information verbally or by E-mail with the suppliers. Ten fish were obtained from each farm, nine of which were randomly grouped into three composites of three fish each. Most individual fish weighed ~4-6 kg. A total of 459 farmed salmon from wholesalers was used to produce 153 samples for analysis. Viscera and gills were removed from the fish before shipment, but the heads were left on. Three whole fillet samples were obtained from each of three retail outlets in 16 cities (Boston, Chicago, Denver, Edinburgh, Frankfurt, London, Los Angeles, New Orleans, New York, Oslo, Paris, San Francisco, Seattle, Toronto, Vancouver, and Washington DC); composites were made

of these 144 fillets by retail outlet to give three samples for each city, for a total of 48 samples for analysis. Between September 2001 and August 2002, other suppliers provided 135 wild fish representing five wild species of Pacific salmon: chum *(Oncorhyncus keta)*, coho *(O. kisutch)*, chinook *(O. tshawytscha)*, pink *(O. gorbuscha)*, and sockeye *(O. nerka)*. Samples of each species were purchased from suppliers located in different geographic regions who purchase locally-caught fish, including Kodiak, Alaska; Southeast Alaska; British Columbia, and Oregon. Three composites of three fish for each species at each of three different locations resulted in a total of 45 samples for analysis.

All samples came to the analytical laboratory (AXYS Analytical in Sidney, British Columbia) fresh or frozen on ice or gel-packs. Fish were thawed and inspected by a fisheries biologist to verify species. Each fish was weighed, its length measured, and filleted to give two skin-on fillets. We analyzed skin-on fillets because most salmon are sold at retail outlets with the skin on. In each case, the fillets from three fish were ground and re-ground together to make a homogenous composite.

We used U.S. EPA methods to measure the concentrations of dioxins and PCBs. Other organochlorine pesticides were measured using analogous procedures. All methods were based on gas chromatographic high resolution mass spectrometry (GC/HRMS) with isotopically labeled internal standards. Chlorinated dibenzo-*p*-dioxins and dibenzofurans were measured using EPA Method 1613, which was calibrated with an extra standard that was one-fifth the concentration of the method requirement. The dioxin concentrations were reported as toxic equivalents (TEQs) assuming non-detects were zero (to be conservative) and using WHO toxic equivalent factors. PCBs were quantitated using EPA Method 1668A;

this technique is an isotope-dilution, congener-specific method for the twelve dioxin-like congeners and an internal standard method for the remaining 197 congeners. The dioxin-like PCB concentrations were reported as TEQs assuming non-detects were zero (to be conservative) and using WHO toxic equivalent factors. Total dioxin TEQs were the sum of the TEQs from dioxins plus those from dioxin-like PCBs. Analysis of the concentrations and pattern of PCB congener distributions will be the subject of a future publication. The organochlorine pesticides were measured using a GC/HRMS isotope dilution method analogous to the EPA methods used for dioxin and PCB analyses. Toxaphene was measured by gas chromatographic mass spectrometry operated in the electron capture negative ion mode. Quantification of total toxaphene was achieved using ^{13}C-labeled PCB-180 as the internal standard and Hercules toxaphene as the reference. Quantification of dieldrin was achieved using ^{13}C-labeled dieldrin as the internal standard.

Fish feed samples were purchased from European and North and South American outlets of the two major fish feed companies. For the first company, two samples of feed, purchased three to four months apart, were obtained from facilities in Scotland, Eastern Canada, British Columbia, and Chile. For the second company, two samples of feed, purchased three to four months apart, were obtained from facilities in Scotland and British Columbia, and one sample from a facility in Chile. Where possible, two samples per location were purchased several months apart in order to account for possible seasonal variations in the fish feed formulation.

All analyses were conducted in accordance with AXYS's accredited QA/QC program. Each analysis batch of nine samples also included a procedural blank, a "known" or

laboratory control sample, and an analysis duplicate. The sample results were reviewed and evaluated in relation to the QA/QC samples worked up at the same time. The sample internal standard recoveries and detection limits, procedural blank data, and laboratory control sample data were evaluated against method criteria to ensure data quality. All instrument QA specifications for EPA Methods were adhered to and applied to all analyses conducted for this study. All data met the QA/QC specifications. In general, duplicate measurements differed from each other by < 15%. Reported concentrations were adjusted for the recoveries of the internal standards. All blank measurements were near or below the detection limits (typically <0.02 pg/g for dioxins/furans, <0.2 pg/g for dioxin-like PCBs, 0.001 ng/g for dieldrin, and 0.1 ng/g for toxaphene); hence, blank values were not subtracted from the sample measurements. Certified reference samples (NIST SRMs or Radian CRMs) were analyzed periodically to demonstrate analytical accuracy.

Risk-based consumption advice for PCBs, toxaphene, and dieldrin was generated using contaminant concentrations found in farmed and wild salmon, the U.S. EPA Cancer Slope Factors for each compound, and an acceptable risk level of 1×10^{-5} (*24*). The WHO uses an exposure-based approach for dioxins by issuing thresholds for contaminant intake rather than fish consumption advice (*25*). This assessment stressed that the upper range of the TDI (4 pg TEQ/kg b.w.) should be considered a maximal tolerable intake on a provisional basis and that the ultimate goal is to reduce human intake levels below 1 pg TEQ/kg body weight/day. Consumption advice for dioxins was generated using an intake level of 2 pg/kg/day, which is consistent with tolerable intakes established by the WHO (*25*). For consistency, we converted WHO intake levels for dioxins to fish consumption rates. For

all risk estimates and consumption calculations, it was assumed that an average meal size was 227 g (0.5 pounds) and the body weight of an average individual was 70 kg.

The statistical analyses are based on the analysis of variance, using the model

$$y_{ijk} = \mu + \tau_i + e_{ij} + d_{ijk}$$

where

y_{ijk} = the observed value of a response variable (one of the 14 contaminants)

μ = the overall (grand mean) value

τ_i = the effect of kind i – depending on the specific analysis, this could represent wild, farmed, farmed in North America, or other such groups

e_{ij} = the effect of source j of kind i – depending on the specific analysis, this could represent a batch of salmon from a particular location, from which a set of 3 composites was formed

d_{ijk} = the effect of composite (observation) k of source j of kind i, where k = 1,2,3 for each source, because there were always 3 replicate composites per source

To make inferences about the terms τ_i, the effects of different kinds of salmon, relative to one another, the appropriate measure of variability is source-to-source variation, not variation among composites. The statistical tests for differences between kinds of salmon are *F*-tests, with degrees of freedom based on the number of sources present in the analysis (not the number of composites). For example, in an analysis of differences among the three farming continents, there are 153 observations, which represent 51 sources, so the statistical *F*-tests involve 2 (= 3 – 1) degrees of freedom in the numerator for differences in

means among the three regions and 48 (= 51 – 3) degrees of freedom in the denominator for differences among sources. (For a general exposition of *F*-tests, *p*-values, and the model used here, see, for example, Sections 2.10, 2.11, and 5.9 of *Statistical Principles of Research Design and Analysis*, 2nd edition, Robert O. Kuehl, 2000, Duxbury Press.)

Table 1. Production levels from regions

Region	Number of farms sampled	Production in region in 2000 (mt)	Sources
Norway	3	437,000	Food and Agriculture Organization/Fisheries Global Information Systems (www.fao.org)
Chile	10	167,000	Food and Agriculture Organization/Fisheries Global Information Systems (www.fao.org)
Scotland (UK)	10	130,000	Food and Agriculture Organization/Fisheries Global Information Systems (www.fao.org)
British Columbia	6	39,100	Government of British Columbia, Ministry of Agriculture, Food and Fisheries, Fisheries Statistics (www.agf.gov.bc.ca/fish_stats/aqua-salmon-2000.htm)
Eastern Canada	8	29,100	Government of Nova Scotia, Agriculture and Fisheries Statistics (www.gov.ns.ca/nsaf/aquaculture/stats/2000.htm); Government of New Brunswick, Fisheries, Aquaculture and Agriculture 2000-2001 Annual Report (Available through www.gnb.ca); Government of Newfoundland and Labrador, Fisheries and Aquaculture Statistics (www.gov.nf.ca/Fishaq/Statistics/aqua2000.stm)
Faroe Islands	8	28,300	Food and Agriculture Organization/Fisheries Global Information Systems (www.fao.org)
Ireland:	0	20,000	Commodity Update – Salmon, Globefish, Food and Agriculture Organization of the United Nations. 2002. Rome, Italy.
Maine, USA	2	16,400	Maine Department of Marine Resources, Lease inventory (www.state.me.us/dmr/aquaculture/lease_inventory/inventorylist.htm)
Washington, USA	3	6,100	Personal communication, Lee Hoines, Washington Department of Fish and Wildlife.
Iceland	0	2,600	Food and Agriculture Organization/Fisheries Global Information Systems (www.fao.org)