Quantitative Analysis of the Benefits and Risks of Consuming Farmed and Wild Salmon[1]

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ABSTRACT Contaminants in farmed Atlantic and wild Pacific salmon raise important questions about the competing health benefits and risks of fish consumption. A benefit-risk analysis was conducted to compare quantitatively the cancer and noncancer risks of exposure to organic contaminants in salmon with the (n-3) fatty acid–associated health benefits of salmon consumption. Recommended levels of (n-3) fatty acid intake, as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), may be achieved by consuming farmed or wild salmon while maintaining an acceptable level of noncarcinogenic risk. However, the recommended level of EPA+DHA intake cannot be achieved solely from farmed or wild salmon while maintaining an acceptable level of carcinogenic risk. Although the benefit-risk ratio for carcinogens and noncarcinogens is significantly greater for wild Pacific salmon than for farmed Atlantic salmon as a group, the ratio for some subgroups of farmed salmon is on par with the ratio for wild salmon. This analysis suggests that risk of exposure to contaminants in farmed and wild salmon is partially offset by the fatty acid–associated health benefits. However, young children, women of child-bearing age, pregnant women, and nursing mothers not at significant risk for sudden cardiac death associated with CHD but concerned with health impairments such as reduction in IQ and other cognitive and behavioral effects, can minimize contaminant exposure by choosing the least contaminated wild salmon or by selecting other sources of (n-3) fatty acids. J. Nutr. 135: 2639–2643, 2005.

KEY WORDS: • *benefits* • *risks* • *salmon*

Assessments of contaminants in salmon (1–4) have raised health risk concerns, which are particularly important given the considerable increasing trend in salmon consumption, especially of farmed salmon (5). Over half the salmon sold globally is now farm-raised, and the annual global production of farmed salmon (predominantly Atlantic salmon) has risen from 2.7×10^4 to $>1.3 \times 10^6$ metric tons during the past 2 decades (6). Contaminant-associated health risks are important because they may detract from the health benefits (prevention of cardiac death) of consuming (n-3) PUFA that occur in tissues of salmon as well as other fatty fish (7–14).

As we reported previously (1–4), concentrations of dioxins, polychlorinated biphenyls (PCB),[3] polybrominated diphenyl ethers, and some pesticides are significantly higher in farm-raised Atlantic salmon than in wild Pacific salmon, and salmon raised on European farms have significantly higher contaminant concentrations than those raised on North and South American farms. As a result, the health risks of consuming farmed salmon are greater than the risks of consuming the less contaminated wild salmon. It is unclear, however, whether the higher concentrations of (n-3) fatty acids in farmed salmon (15) outweigh or balance contaminant-associated health risks.

Here we present the results of a quantitative analysis of the competing benefits and risks of consuming farmed Atlantic and wild Pacific salmon. This analysis is critically important for public health officials charged with encouraging fish consumption and, concurrently, with developing advice for consumption restrictions because of contaminants in fish tissues (16–18). It is also important for the general public, often confused by conflicting advice to consume fish for its health benefits and to avoid fish because of elevated contaminant concentrations.

MATERIALS AND METHODS

A benefit-risk ratio was developed that compares cancer and noncancer risks associated with cumulative exposure to organic con-

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[3] Abbreviations used: AHA, American Heart Association; BCRR, benefit carcinogenic risk ratio; BNRR, benefit noncarcinogenic risk ratio; CHD, coronary heart disease; CSF, cancer slope factor; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; IOM, Institute of Medicine; PCB, polychlorinated biphenyls; RfD, reference dose; U.S. EPA, U.S. Environmental Protection Agency.

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taminants in salmon with the quantities of (n-3) fatty acids, measured as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) that result from salmon consumption. The ratios were derived from 245 composite samples (3 fillets each) collected in 2001 (1). The data included 153 observations from farmed salmon purchased from wholesalers, 48 from fillets of farmed salmon purchased from retail markets in 16 cities, and 44 from wild-caught Pacific salmon.

Assessment of risk. The risk portion of the benefit carcinogenic risk ratio (BCRR) and benefit noncarcinogenic risk ratio (BNRR) is based on the methods of the U.S. Environmental Protection Agency [U.S. EPA (19)] for developing fish consumption advisories. Quantitative estimates of carcinogenic risk associated with exposure to PCBs, dioxin, and the dioxin-like compounds, dieldrin and toxaphene, in farmed and wild salmon were presented previously (1,4). For this analysis, we developed quantitative estimates of cumulative carcinogenic risk for a majority of the contaminants reported by Hites et al. (1) in farmed Atlantic and wild Pacific salmon (**Table 1**). Cumulative carcinogenic risk was expressed as a probability of additional (above background) deaths from cancer associated with lifetime exposure to mixtures of organic contaminants in salmon for which cancer slope factors (Table 1) were established by the U.S. EPA (20). An acceptable risk level for carcinogens was established as 1×10^{-5} increased probability of death from cancer, the middle of the U.S. EPA's acceptable cancer risk range (21).

Noncarcinogenic risk was based on U.S. EPA Reference Doses (RfD; Table 1) for contaminants in farmed and wild salmon. An elevated noncarcinogenic risk occurs when the ratio of cumulative contaminant exposures to cumulative chemical-specific RfDs is >1. A ratio of exposures to RfDs < 1 indicates a generally acceptable or de minimus risk (21). For calculation of cumulative noncarcinogenic risk, we adopted the conservative assumption that all contaminants in farmed and wild salmon exert their toxicity via a similar mechanism of action.

For both carcinogenic and noncarcinogenic risk, we followed U.S. EPA (19) guidance by assuming that an average meal size was 227 g and that an average adult weighed 70 kg and was exposed to contaminants over a 70-y lifetime.

Assessment of benefit. The benefits of consuming farmed or wild salmon derive from intake of (n-3) fatty acids in these fish (**Table 2** [see (15) for detailed analysis of (n-3) and (n-6) concentrations in salmon tissues]. There is convincing evidence that the long-chain (n-3) fatty acids (EPA and DHA) and their precursor, α-linolenic acid, play important roles in preventing arrhythmia following myocardial infarction and sudden death (7,22). The evidence supporting the connection between (n-3) fatty acids and coronary heart disease (CHD) comes from epidemiologic studies (12), prospective cohort studies (10,11), and randomized clinical trials (13). The outcomes of these studies, although not perfectly consistent, demonstrate a clear protective effect of α-linolenic acid, DHA, and EPA on death from coronary disease (7).

There is also evidence from prospective cohort studies that the (n-3) fatty acids, and DHA in particular, may be beneficial in delaying the effects of Alzheimer's disease (23,24). Other studies suggest that (n-3) fatty acids may slow the progression of chronic inflammation such as rheumatoid arthritis, asthma, autoimmune diseases, and diabetes (25–27). Although the empirical evidence for these benefits is less complete than that for CHD, it suggests that some benefits are achieved at roughly the same rates of consumption as the benefits of reduced CHD. Consequently, we focused on the levels related to prevention of sudden death associated with CHD rather than benefits associated with improved quality of life.

To achieve these benefits, the WHO (28) recommends that individuals obtain 1–2% of their energy intake from (n-3) fatty acids. For an 8374 kJ diet, WHO's recommendation translates to ~2–3 g/d of (n-3) fatty acids. The American Heart Association (AHA) (7) recommends consumption of 1g/d of EPA+DHA, preferably from fatty fish for individuals without coronary heart disease. The U.S. Institute of Medicine (IOM) (22) recommends an intake rate ranging from 0.5 g/d of (n-3) fatty acids (for children < age 1 y) to 1.6 g/d (for males > 14 y of age).

The benefit-risk ratio. Benefit-risk ratios [benefit cancer risk ratio (BCRR) and benefit noncancer risk ratio (BNRR)] for farmed and wild salmon, or subgroups of salmon, represent the benefits and risks of repeated consumption from within a group of sources. The ratios are expressed as:

$$BCRR = \frac{\sum_{i-1}^{n} C_{N-3,i}}{\sum_{i-1}^{n}\sum_{k=1}^{K} C_{k,i}\, CSF_k/70 \times 10E-5}$$

$$BNRR = \frac{\sum_{i=1}^{n} C_{N-3,i}}{\sum_{i=1}^{n}\sum_{k=1}^{K} C_{k,i}/70 \times RfD_k}$$

where $C_{(N\text{-}3),i}$, and $C_{k,i}$ are the concentrations of EPA+DHA and contaminant k, respectively (in mg/kg) from fish source i; the CSF_k and RfD_k are the Cancer Slope Factor in $(mg \cdot kg^{-1} \cdot d^{-1})^{-1}$ and Reference Dose [mg/(kg · d)] for contaminant k (Table 1), and 70 is the weight in kilograms of a typical adult. Because the rate of EPA+DHA intake and the risk are proportionate to meal size and meal frequency, these factors do not appear in the ratios. The ratios presented in **Figure 1** represent the rates of consumption of EPA+DHA (g/d) while controlling for the level of acceptable carcinogenic or noncarcinogenic risk.

The population values of BCRR and BNRR represent the long-run trade-off of benefits and risks over repeated consumption. The statistical properties of the ratios of sums are not well established and there is no expectation that the distribution of our estimates of BCRR

TABLE 1

RfD and CSF for contaminants in farmed and wild salmon[1]

Contaminant	RfD mg/(kg · d)	CSF $(mg \cdot kg^{-1} \cdot day^{-1})^{-1}$
PCB	0.00002[2]	2.0
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin	NA[3]	1.50×10^5
Hexachlorobenzene	0.0008	1.6
Hexachlorocyclohexane	0.0003	1.8
Chlordane	0.0005	0.35
Total dichlorodiphenyltrichloroethane	0.0005	0.34
Mirex	0.0002	NA
Endosulfan	0.006	NA
Methoxyclor	0.005	NA
Dieldrin	0.00005	16.0
Endrin	0.0003	NA
Toxaphene	NA	1.1
Aldrin	0.00003	17.0
Heptaclor	0.0005	4.5
Heptaclor epoxide	0.000013	9.1
Methylmercury	0.0001	NA

[1] All values from U.S. EPA (20).
[2] RfD for Aroclor 1254.
[3] NA, not available.

TABLE 2

Lipid and fatty acid concentrations in wild Pacific salmon, Atlantic salmon purchased directly from farms, and store-bought farmed Atlantic salmon[1]

	Wild Pacific salmon	Farmed Atlantic salmon	Supermarket Atlantic salmon
Lipid, *g/100 g body*	6.44 ± 3.27	16.59 ± 2.91	14.47 ± 3.49
(n-6) Fatty acids, *mg/g body weight*	1.28 ± 0.55	8.80 ± 3.83	8.18 ± 3.27
(n-3) Fatty acids, *mg/g body weight*	12.22 ± 4.57	33.73 ± 6.32	30.47 ± 7.20

[1] Values are means ± SD.

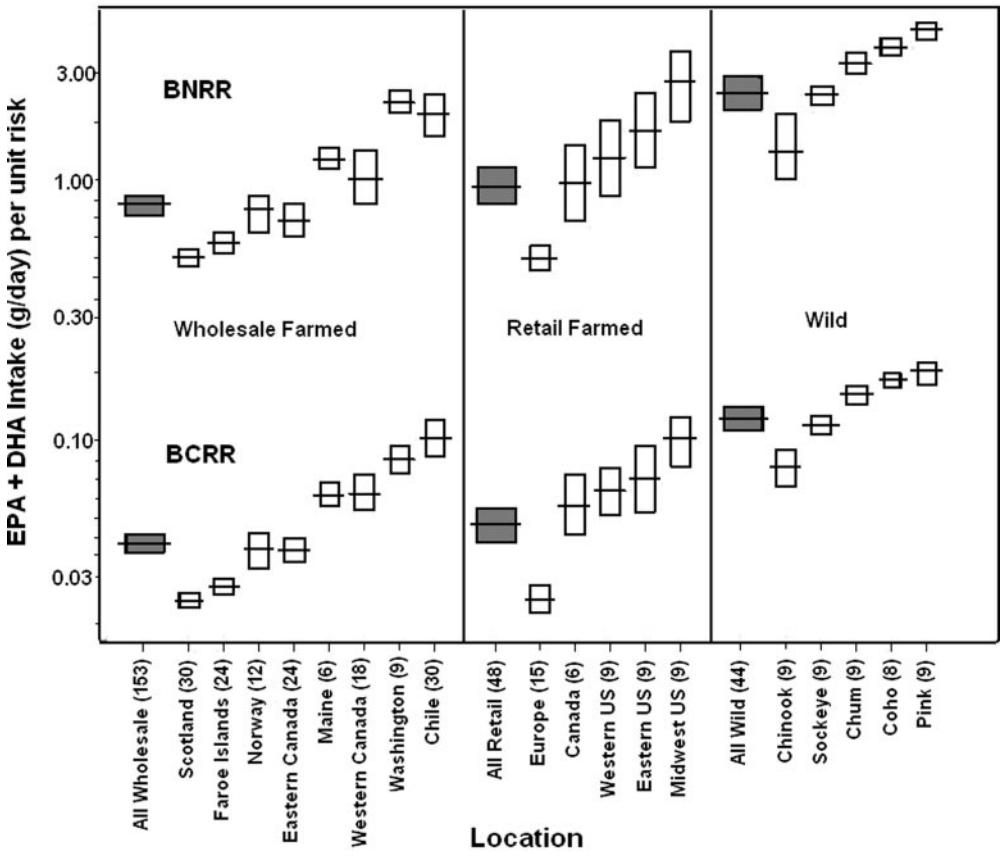

FIGURE 1 BCRR (lower bars) and BNRR (upper bars) for farmed Atlantic salmon purchased wholesale, farmed Atlantic salmon fillets purchased from retail markets, and wild Pacific salmon. The tops and bottoms of boxes represent the upper and lower 95% confidence limits for the benefit-risk ratios, and the horizontal line represents the value of the ratio estimate. Grey bars are ratios for groups. Numbers in parentheses are sample sizes. Unit risk for carcinogens is 1×10^{-5} increased probability of death from cancer. Unit risk for noncarcinogens is the ratio of cumulative contaminant exposures to cumulative chemical-specific RfDs equal to 1.

and BNRR are normal or that traditional CI estimation or hypothesis testing tools apply. As a result, we constructed the upper and lower 95% confidence limits for the population values of the BCRR and BNRR (represented by the top and bottom of the boxes in Fig. 1) using bootstrap methods with 10,000 replications. Point estimates in this figure are represented by the horizontal line through the box.

To test hypotheses about the equality of the BCRR and BNRR across the 3 groups (wholesale farmed, retail farmed, and wild), we constructed permutation tests following Good (29). Approximate *P*-values are constructed using 10,000 randomly selected permutations of the data. The statistical differences for BCRR and BNRR across the farmed, retail, and wild caught groups are not subtle (as also evidenced by the disparity of the CI for each of the ratio estimates). None of the 10,000 replications generated values of the statistic that were as large as those from the actual data and indicate that we can clearly reject hypotheses at levels of 0.01% or higher.

The benefits associated with acceptable (carcinogenic or noncarcinogenic) risk can be compared with recommended rates of (n-3) fatty acid consumption established by WHO (28), AHA (7), and IOM (22). These organizations base their recommendations on various forms of (n-3) fatty acids, whereas we focus on EPA+DHA because its connection to benefits in reducing deaths from CHD is reasonably well established (7). We did not assess benefits associated with (n-6) fatty acid consumption nor the (n-6):(n-3) ratio because the benefits of (n-6) consumption are inconclusive (30) and both the IOM (22) and AHA (7) concluded that current (n-6) consumption rates are far above levels at which additional benefits would accrue from increased consumption.

RESULTS

Both farmed and wild salmon can be consumed at rates that provide at least 1 g/d EPA+DHA per unit noncarcinogenic risk (Fig. 1). However, there are clear differences in the benefit-risk ratio for noncarcinogens among wholesale farmed salmon, farmed salmon fillets purchased from retail markets, and wild salmon ($P < 0.0001$). Based on the benefit-noncarcinogenic risk ratio, wild salmon can be consumed at rates that approach the higher levels of (n-3) fatty acid intake recommended by the WHO (28) and AHA (7). Salmon from farms in the Faroe Islands and Scotland provide the least amount of EPA+DHA per unit noncarcinogenic risk, even though these fish contain some of the highest concentrations of fatty acids (15). Similarly, farmed salmon sold in European retail markets provide the least EPA+DHA per unit noncarcinogenic risk, suggesting that these fish derive from farms in the European north Atlantic. Of the farmed salmon, those from Chile and Washington State, and those sold in retail markets in the United States provide the highest EPA+DHA intake per unit noncarcinogenic risk.

Neither farmed nor wild salmon can be consumed at rates that provide 1 g/d EPA+DHA while maintaining an acceptable level of carcinogenic risk (1×10^{-5}), although there are differences ($P < 0.0001$) in the benefit-risk ratio for carcinogens among wholesale farmed, retail market, and wild salmon. When salmon are consumed at rates that provide 1 g/d EPA+DHA, cumulative cancer risk for farmed salmon is 24 times the acceptable cancer risk level, whereas the cumulative cancer risk for wild salmon is only 8 times the acceptable risk level.

Regional patterns in the benefit-risk ratio for carcinogens mirror those of the benefit-risk ratio for noncarcinogens with wild salmon, salmon from Chilean and Washington farms, and farmed salmon from retail markets in the United States providing the highest benefit per unit risk. These farmed salmon provide benefits per unit carcinogenic risk on a par with some wild salmon, indicating high concentrations of beneficial fatty acids and relatively lower concentrations of carcinogenic contaminants in these fish.

Meal frequencies associated with a benefit-risk ratio constrained to 1 U of carcinogenic risk (the more restrictive of the risk estimates) are <0.25 meal/mo for farmed fish from Scotland, Norway, Eastern Canada, the Faroe Islands, and purchased from European markets; 0.25–0.5 meal/mo for farmed salmon from Maine, Western Canada, Washington, and purchased from markets in North American stores other than in the Midwest United States; and just over 0.5 meal/mo for farmed fish from Chile or purchased from markets in the Midwestern U.S. Wild-caught species can be consumed at rates of nearly 4 meals/mo for Chum; ~2 meals/mo for Pink, Sockeye, and Coho; and just under 1 meal/mo for Chinook.

DISCUSSION

As we demonstrated previously (1,4), wild salmon have significantly lower contaminant concentrations than farmed salmon from any region; however, fatty acid concentrations in farmed salmon are significantly higher than those in wild salmon (15). As a result, risk associated with exposure to noncarcinogenic contaminants in farmed and wild salmon may, in some cases, be outweighed by the fatty acid–associated health benefits of consuming these fish. Further, the relatively lower contaminant concentrations in Chilean and North American farmed fish (compared with farmed fish from other regions) appear to balance the benefit-risk ratios for these fish compared with their wild counterparts. However, the benefit-risk ratios for carcinogens are an order of magnitude lower than ratios for noncarcinogens. As a result, cancer risk drives fish consumption advice, and approaches other than selection of particular types or sources of salmon may be necessary to reduce cancer risk to acceptable levels while achieving recommended levels of fatty acid intake.

We chose a conservative approach to develop the risk component of the ratios for noncarcinogens, which requires the assumption of a common mechanism of toxicity for compounds for which an RfD was established. Because this assumption may not be true for all compounds, noncarcinogenic risk may be overestimated. Conversely, reference doses do not, in many cases, include or address a suite of recently identified neurobehavioral effects associated with exposure to PCBs, dioxins, and other compounds in farmed and wild salmon (31,32). These effects appear to be irreversible (31) and therefore can cause life-long disability. As a result, the degree of conservatism in the noncarcinogenic risk estimates may be lessened considerably. Development of cumulative cancer risk estimates based on risk additivity does not require an assumption of mechanistic similarity (33).

This analysis compares benefits of recommended EPA+DHA intake levels with risks that are assessed via an RfD or the increased probability of death from cancer. Another approach in comparing benefits and risks is via a comparison of health outcomes. Although this approach is speculative with variable results and wide CI, prospective cohort studies and clinical trials suggest that consumption of (n-3) fatty acids reduces the risk of sudden death from heart attacks by ~50% (7,10,11). With a death rate from CHD of 28,500/100,000 individuals (34) and assuming that half of CHD mortality results from sudden death (35), the number of lives saved is ~7100/100,000 individuals ($0.5 \times 0.5 \times 28{,}500$). The cumulative cancer risk for farmed salmon at a consumption rate that provides 1 g/d EPA+DHA is 2.4×10^{-4} (the reciprocal of the ratio in Fig. 1) or 24 additional deaths from cancer per 100,000 exposed individuals. Therefore, the number of lives saved per 100,000 individuals is nearly 300 times greater than the number of excess deaths from cancer when farmed salmon are consumed at a rate that provides 1 g/d EPA+DHA. Consumption of wild salmon provides benefits that are ~900 times greater than the cancer-associated risks.

Individuals at risk for CHD-associated sudden death can maximize benefit while reducing contaminant-associated risk by choosing wild salmon, farmed salmon such as those from Chile, or other species of fish with lower contaminant concentrations. However, these individuals may choose to ignore contaminant-associated health risks and simply consume salmon with the highest concentrations of (n-3) fatty acids, such as those from European farms. The evidence for beneficial effects of (n-3) fatty acids in preventing cancer is not supported by epidemiologic studies (36,37); thus, individuals concerned primarily with reducing cancer may choose wild salmon or farmed salmon with lower contaminant concentrations such as those from Chilean farms. Similarly, young children, women of child-bearing age, pregnant women, and nursing mothers not at significant risk for sudden cardiac death associated with CHD but concerned with health impairments such as reduction in IQ and other cognitive and behavioral effects, can minimize contaminant exposure by choosing the least contaminated wild salmon or by selecting other sources of (n-3) fatty acids.

Differences in the benefit-risk ratios for farmed vs. wild salmon, and differences for farmed salmon by region, support our earlier recommendations (1) for informative labeling (e.g., farmed vs. wild; country of origin) of seafood to aid consumer decisions. Our previous analyses (1,2) indicated that the feed of farmed salmon is the probable source of most contaminants in these fish, and we have recommended that the salmon farming industry take steps to reduce contaminants in feed. Substantial reductions of contaminant concentrations in feed should result in lower contaminant concentrations in farmed fish, consistent with IOM (38) recommendations to interrupt the cycle of dioxin-like compounds through forage, animal feed, and food-producing animals. However, actions to reduce contaminants in feed such as substituting vegetable oil for fish oil may also reduce concentrations of beneficial fatty acids (39), thus having little net effect on the benefit-risk ratio. Only actions that reduce contaminants in the tissues of farmed salmon while maintaining elevated concentrations of (n-3) fatty acids will reduce the influence of contaminant-associated risk on the benefit-risk ratio, and only in that case will all farmed salmon become a highly desirable, low risk source of beneficial (n-3) fatty acids.

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