# Assessing Polybrominated Diphenyl Ether Accumulation in Farmed and Wild Salmon: How has it changed since 2004?

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## Introduction

Aquaculture is the fastest-growing animal-food-producing sector (FAO, 2013). Between 1980 and 2004, the global farmed salmon supply increased from 2% to 65% of total salmon production, and U.S. farmed salmon consumption increased from less than 25,000 metric tons in 1989 to over 175,000 metric tons in 2004 (Knapp, 2007; Claret, 2014). However, there are concerns in the scientific community and among consumers about elevated contaminant accumulation in farmed salmon (Claret, 2014). In 2004, Hites et al. investigated polybrominated diphenyl ether (PBDE) accumulation in farmed and wild salmon from eight regions across the globe (Hites, 2004). They found that farmed salmon had significantly higher levels of PBDEs than wild salmon, and that trophic status as well as geographic location had a strong influence on tissue concentrations. They attributed the large differences in PBDE accumulation to diet. At the time, farmed salmon were given feed high in fish oils and small pelagic fishes (Naylor, 2000). In 1990, 90% of Norwegian salmon feed was composed of marine biota, however, in 2013, fish meal and fish oil only composed 30% of salmon feed (Ytrestoyl, 2015). Given the dramatic change in feed composition since Hites' study in 2004, we hypothesize that this change could alter PBDE concentrations in farmed salmon. Therefore, the goal of this study was to measure PBDE concentrations in both farmed and wild salmon and compare these concentrations to Hites' data from 2004.

## Materials and Methods

Skin-on fillets of farmed Atlantic (n=9) and wild Sockeye Pacific (n=10) salmon (from distinct individual fish) were collected from two food stores in Durham, NC, USA, immediately frozen, and transported to the laboratory for analysis. Samples were first thawed and their wet mass was recorded. The fillet was then lyophilized for 36 hours and its dry mass was recorded. The dried fillet was cut in order to obtain an ~8 g subsample for analyses. The tissue was then homogenized using pre-cleaned sodium sulfate (~8 g) and a mortar and pestle until it became a fine powder. Each tissue was then submerged in 50:50 hexane:dichloromethane overnight to allow for complete solvent penetration. The preceding day, the tissue was sonicated for 20 minutes followed by centrifugation for 5 minutes at 3000 rpm. The solvent was then decanted and the extraction process was repeated twice more, yielding 45 mL of solvent, which was then concentrated to ~1 mL via nitrogen evaporation. A 100 µL aliquot was used for gravimetric lipid analysis while the remaining sample was passed through acidified silica columns three times to purifty the extract. Samples were concentrated to ~0.5 mL using nitrogen evaporation and PBDEs were quantified using gas chromatography with electron capture negative ion mass spectrometry (GC/ECNI-MS).

Statistical analyses were performed using SAS 9.4. Median concentrations of total PBDEs measured and reported in Hites et al. 2004 were compared to the levels quantified in these

samples. A liner regression of log-transformed total PBDE concentration (ng/g ww) was performed to evaluate the difference in the geometric means between fish type (farmed vs. wild) and year. Alpha < 0.05 was considered statistically significant.

**Results and Discussion**

Total PBDEs were significantly higher in farmed compared to wild salmon collected in 2016, although to a lesser degree than that observed in 2004. The total PBDE concentrations (ng/g ww) for farmed and wild salmon for years 2004 and 2016 are plotted in Figure 1.

A statistically significant difference in the geometric mean for total PBDE concentration across fish type (farmed vs. wild, $p < 0.0001$) as well as year (2004 vs. 2016, $p < 0.0003$) was observed. There was also a statistically significant difference between farmed salmon measured in 2004 and in 2016 ($p < 0.0006$), but there was not a statistically significant difference between wild 2004 and 2016 ($p = 0.056$). A general linear regression of fish type and year was plotted against log transformed total PBDE concentration (ng/g ww) in order to evaluate the magnitude of the difference in the geometric means. Table 1 presents the average lipid content, geometric mean for each fish type and year and $10^{\beta}$ relative to wild salmon in 2004 and 2016.

**Table 1.**

| | **Avg. lipid content (%)** | **Geo. Mean (ng/g ww)** | **$10^{\beta}$ (relative to 2004 wild)** | **$10^{\beta}$ (relative to 2016 wild)** |
|---|---|---|---|---|
| **Farmed 2004** | ----- | 2.311 | **9.651 *** | 6.084 ***** |
| **Wild 2004** | ----- | 0.229 | **Reference** | 0.6303 |
| **Farmed 2016** | 11.6 | 1.022 | 4.269 ***** | **2.691 *** |
| **Wild 2016** | 3.15 | 0.380 | 1.586 | **Reference** |

*** Indicates a statistically significant difference from reference (p< 0.05)**

Results from the model suggest there is a statistically significant difference between 2016 farmed and wild salmon ($p < 0.025$), with farmed concentrations being more than 2.5 times greater ($10^{\beta} = 2.691$, CI = 1.307 – 5.542) relative to total PBDE concentrations in wild salmon. However, 2004 farmed concentrations were nearly ten times higher ($10^{\beta} = 9.651$, CI = 7.393 – 12.60) relative to total PBDE concentrations in wild fish in 2004, indicating there has been a reduction in the magnitude of difference between farmed and wild salmon.

Our data indicate that although farmed salmon in 2016 had elevated total PBDE tissue concentrations relative to wild salmon, the magnitude of difference in the geometric mean was narrower than the magnitude of difference seen in 2004. A possible explanation is the reduction of marine biota composing salmon feed since 2004. Furthermore, a lack of similar decrease in total PBDE concentrations in wild salmon suggests that a decline in environmental levels of PBDEs is not a likely explanation for the decline in farmed salmon. However, unlike Hites' study, we did not quantify PBDE concentrations in salmon feed. In order to elucidate the possible mechanisms that are driving the reduction of total PBDE concentrations in farmed salmon, it would be useful to analyze salmon feed that is currently used in the aquaculture sector.

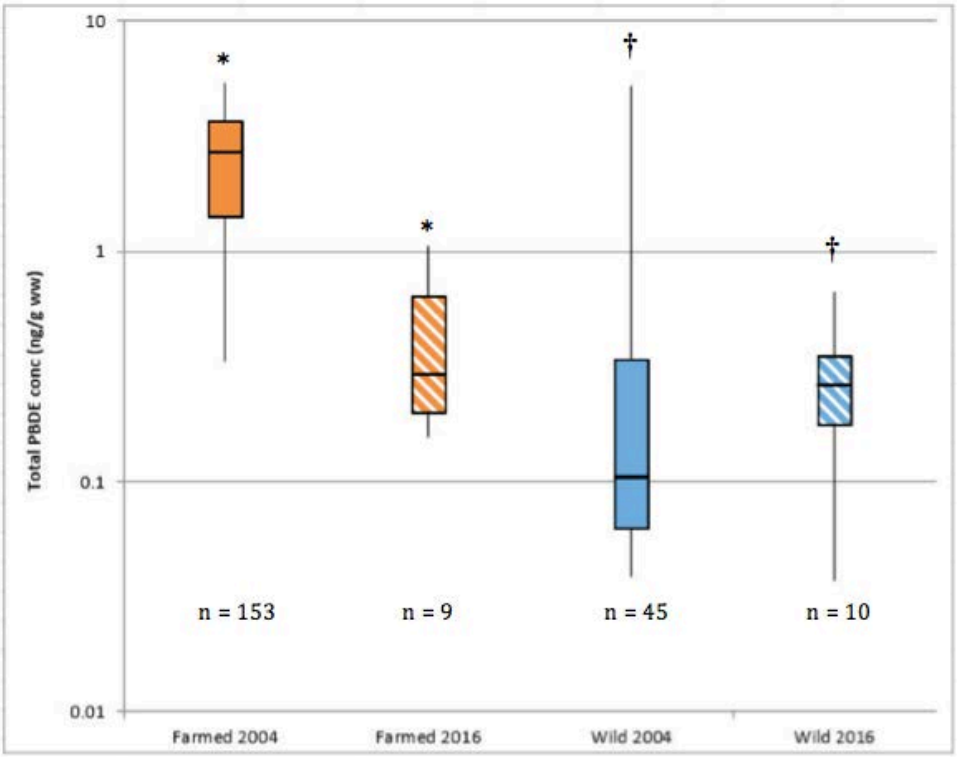


**Figure 1. Total PBDE concentrations (ng/g ww) found in farmed (orange) and wild (blue) salmon. Solid bars represent salmon analyzed in 2004, hashed bars represent salmon analyzed in 2016.**
*** Represents statistically significant difference from all other groups**
**† Represents statistically significant difference from farmed (both years) but not wild**

## References


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