Contaminants in Whole Fish

Formerly Indicator #0121

Overall Assessment

Status: Fair

Trend: Deteriorating

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Lake Trout and Walleye in all the Great Lakes and declining. Total Hg concentations, although still below the target of 0.5 µg/g ww in all lakes, appear to be increasing across the basin.

Lake-by-Lake Assessment

Lake Superior

Status: Fair

Trend: Deteriorating

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Lake Trout in Lake Superior and declining. Total Hg concentrations, although still below the target of 0.5 µg/g ww, have returned to levels observed in the 1980s and appear to be increasing.

Lake Michigan

Status: Fair

Trend: Unchanging

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Lake Trout from the lake and declining. Total Hg concentrations are similar to observations in the other lakes but there is not enough data from recent years to confirm a significant trend.

Lake Huron

Status: Fair

Trend: Deteriorating

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Lake Trout in Lake Huron and declining. Total Hg concentrations, although still below the target of 0.5 µg/g ww, have returned to levels observed in the 1980s and are increasing.

Lake Erie

Status: Fair

Trend: Deteriorating

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Walleye from Lake Erie and declining. Total Hg concentrations, although still below the target of 0.5 µg/g ww, have returned to levels observed in the 1980s and are increasing.

Lake Ontario

Status: Fair

Trend: Unchanging

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Lake Trout from Lake Ontario and declining. Total Hg concentrations are no longer declining and may be increasing as observed in fish from Lakes Superior, Huron and Erie.

Purpose

- To describe temporal and spatial trends of bioavailable contaminants in representative open water fish species from throughout the Great Lakes
- To infer the effectiveness of remedial actions related to the management of critical pollutants
- To identify the nature and severity of new and emerging pollutants of concern

Ecosystem Objective

Great Lakes waters should be free of toxic substances that are harmful to fish and wildlife populations and the consumers of this biota. Data on status and trends of contaminant conditions, using fish as biological indicators, support the requirements of the Great Lakes Water Quality Agreement (GLWQA, United States and Canada 1987) Annexes 1 (Specific Objectives), 2 (Remedial Action Plans and Lakewide Management Plans), 11 (Surveillance and Monitoring), and 12 (Persistent Toxic Substances).

Ecological Condition

Background

Long-term (greater than 25 years), basin-wide monitoring programs that measure whole body concentrations of contaminants in top predator fish (Lake Trout and/or Walleye) are conducted by both the U.S. Environmental Protection Agency (U.S. EPA) Great Lakes National Program Office through the Great Lakes Fish Monitoring and Surveillance Program, and Environment Canada's (EC) Water Quality Monitoring Surveillance Division, through the Fish Contaminants Monitoring and Surveillance Program, to identify the risk of contaminants to wildlife consumers of fish and to monitor trends in time. EC reports annually on contaminant burdens in similarly aged Lake Trout (4+ through 6+ year range) and Walleye (Lake Erie) as well as in Rainbow Smelt (*Osmerus mordax*), a common forage species. The U.S. EPA monitors contaminant burdens in similarly sized lake trout (600-700 mm total length) and walleye (Lake Erie, 400-500 mm total length) annually from alternating locations by year in each lake. Monitoring stations for both EC and U.S. EPA are shown in Figure 1. More information on the monitoring programs at http://www.epa.gov/glnpo/monitoring/fish/index.html and http://www.ec.gc.ca/scitech/default.asp?lang=en&n=828EB4D2-1. One additional difference between the EC and U.S. EPA programs, which limits the combination of data for statistical analyses, is that EC measures contaminants in individual fish and U.S. EPA measures contaminants in composite samples. As a result of these differences, all analyses and summary statistics are reported separately for each dataset. Unless stated otherwise, trends through time were assessed using first-order log-linear regression models of annual median concentrations to estimate percent annual declines. Trends were deemed significant if the slope of model was greater or less than zero at α = 0.05. When applicable, contaminant concentrations and trends are compared to criteria established in the GLWQA or other relevant guidelines developed to protect ecosystem quality. The GLWQA, first signed in 1972, renewed in 1978, and amended in 1987, expresses the commitment of Canada and the United States to restore and maintain the chemical, physical and biological integrity of the Great Lakes basin ecosystem. At present, negotiations between the governments of Canada and the United States to develop a new agreement are underway. When a new agreement is reached, the fish contaminant monitoring programs will be evaluated and modified to meet new requirements and objectives.

Chemical Concentrations in Whole Great Lakes Fishes

Since the late 1970s, concentrations of legacy organochlorine contaminants such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT) have declined in most monitored fish species. Conversely, the declines in concentrations of total mercury in fish through the 1980s have reversed in most lakes and are now increasing to levels observed at the onset of monitoring in the basin. In recent years, contaminants, such as polybrominated diphenyl ethers (PBDEs) and perfluorooctane sulphonate (PFOS), have garnered the attention of monitoring and regulatory agencies in the Great Lakes Basin. In general, the levels of regulated compounds are slowly declining or have stabilized in the tissues of Great Lakes top predatory fish. Basin wide, the changes are often lake-specific as they are dependant, in part, on the physio-chemical characteristics of the contaminants, hydrological characteristics of the lake, and the biological composition of the fish community and associated food webs.

Total polychlorinated biphenyls (PCBs)
Basin Wide Status: Fair; Improving

Total PCB concentrations in Great Lakes top predator fish have continuously declined since their phase-out in the 1970s (Figure 2). Median PCB concentrations in Lake Trout in Lakes Superior, Huron, and Ontario and Walleye in Lake Erie continue to decline; however, they are still above the target of 0.1 µg/g ww in the GLWQA (Table 1). Log-linear regression of Environment Canada data show the continued long-term annual declines of 5% in Lake Trout from Lake Superior and 7% in Lakes Huron and Ontario while PCBs in Lake Erie Walleye are declining by 3% per year. Similar analyses of U.S. EPA data show no significant annual declines of total PCB in Lake Trout from Lake Superior and 4%, 6%, 7%, and 4% annual declines in total PCB in Lake Trout from Lakes Huron, Michigan, Ontario, and Lake Erie Walleye, respectively. Data collected since the last SOLEC indicator report (2006-2009), show that total PCB concentrations in composited Rainbow Smelt measured by Environment Canada were all less than 0.1 µg/g ww in Lakes Superior and Huron. In Lake Erie, total PCB measured in 83% of Rainbow Smelt were below 0.1 µg/g ww, compared to only 34% of measurements in smelt from Lake Ontario. In Lake Ontario, total PCB concentrations in Rainbow Smelt are declining by ~8% per year since monitoring began in 1977.
Recent studies have suggested that rates of decline of PCB residues in fish are slowing or have stopped in some lakes in recent years (Bhavsar et al. 2007; Carlson et al. 2010). Despite potential changes in annual rates of decline, first-order log-linear regression models are still a good fit to observed concentrations in the lakes through time (Figure 2). Results generated in the next few years of monitoring should clarify whether or not the rates of decline are slowing and statistical methods to assess trends will be altered as required.

Dichlorodiphenyltrichloroethane (DDT) and metabolites
Basin Wide Status: Good; Improving

The concentration of opDDT and its metabolites, opDDD and opDDE, (sumDDT) in Great Lakes top predator fish have continuously declined since the use of the chemical was banned in 1972. Concentrations measured since the last indicator report (2006-2009) remain well below the GLWQA target of 1.0 µg/g ww across the basin (Table 2). Based on data collected at EC monitoring locations, annual rates of decline are 6.8% in L. Superior, 7.1% in L. Huron, 7.5% in L. Erie, and 7.3% in L. Ontario. Since the last indicator report, the rates of decline appear to be consistent with historical trends. Annual rates of decline determined using U.S. EPA data are slightly lower at 4.5% in L. Superior, 5.9% in L. Michigan, 5.9% in L. Huron, 6.0% in L. Erie, and 6.7% in L. Ontario. Rates of decline at the U.S. monitoring stations in the years since the last indicator report appear to be increasing (i.e. declining faster) in lakes Michigan, Huron, and Ontario compared to historical trends while rates remain consistent with historical trends in Lakes Superior and Erie.

Total mercury
Basin Wide Status: Good; Deteriorating

There have been several studies on spatial and temporal trends of mercury in fish in the Great Lakes region since the last SOLEC indicator report (Bhavsar et al 2010; Monson et al. in press; Zananski et al. accepted). Both studies found that generally, the declines in mercury concentrations observed up until approximately 1990 have ceased and that mercury concentrations in fish have started to increase. EC and U.S. EPA data were used in the analyses of both studies and correspond with their findings (Figure 3). Concentrations of mercury are similar across all fish in all Great Lakes consistent with the assumption that concentrations of mercury in top predator fish are atmospherically driven and the recent increases may be a reflection, in part, of increased global mercury emissions (Pacyna et al. 2006). It is important to note that since the last indicator report (2006-2009) median concentrations of mercury in all top predator fish collected in Lakes Ontario, Erie, Huron and Michigan are below the GLWQA guideline of 0.5 µg/g and exceedances of the guideline only occurred in ~4% of the Lake Trout captured in Lake Superior (Table 3). Mercury concentrations in top predator fish are currently equal to or approaching the concentrations measured at the inception of the monitoring program in the late 1970s. Two segment linear piecewise regression of the EC dataset show that declines in mercury ceased in the late 1980s in lakes Superior and Huron and the early 1990s in lakes Erie and Ontario. Following the change points in each lake, mercury levels have been stable in lakes Huron and Ontario and appear to be increasing in lakes Superior and Erie. Mercury levels at U.S. EPA monitoring locations since 1999 mirror the EC results with one exception, in Lake Huron there has been a significant annual increase of mercury in Lake Trout of ~7%. Similar temporal patterns in mercury concentrations are also observed in Rainbow Smelt, a common forage fish for many fish and birds in the Great Lakes basin (Figure 4). The observed trend reversal in mercury concentrations in fish is consistent with recent findings (Monson 2009; Bhavsar et al. 2010; Monson et al. in press) of mercury. Unfortunately, the data gap from the mid to late 1990s does not leave a sufficient number of data points to determine the current rates increase due to low statistical power. Continued monitoring of Hg levels in fish is required to definitively determine the rate of increase in mercury in all the lakes and adequately assess the future risk to wildlife consumers of fish in the Great Lakes basin.

Cis- & trans-Chlordane

Basin Wide Status: Good; Unchanging

Concentrations of cis- + trans-chlordane in whole Lake Trout and Walleye have consistently declined since the chemical was banned by the U.S. EPA in 1988. In recent years, the concentrations in fish appear to have reached a steady state with no significant increases or decreases. The highest observed median concentrations since the last indicator report (2006-2009) are in Lake Trout from Lake Michigan (0.018 µg/g ww), followed by Lake Ontario (0.012 µg/g ww). Median concentration in Lakes Superior, Huron, and Erie are all below 0.01 µg/g ww. There is no target for chlordane in whole fish in the GLWQA. A report on the levels of chlordane in fish will not appear in future SOLEC indicator reports as focus is shifted to contaminants with established environmental quality guidelines or targets.

Mirex

Basin Wide Status: Good; Improving

Mirex is regularly detected only in fish from Lake Ontario due to historical releases in the Niagara River and other locations within the lake’s watershed. Since the last indicator report (2006-09), median concentrations in Lake Trout were 0.061 µg/g ww (EC) and 0.041 µg/g ww (U.S. EPA). Declines in the concentration of mirex in Lake Trout from Lake Ontario are still declining at historical rates of between 4 and 12 % annually.

Dieldrin

Basin Wide Status: Good; Improving

The highest concentrations of dieldrin (and related compounds endrin and andrin) in top predator fish are observed in Lake Michigan (median = 0.034 µg/g ww) and Lake Ontario (median = 0.021 ug/g ww). Concentrations have declined substantially since monitoring began in the lakes and are still declining basin wide at rates ranging from 2 to 18% annually. There is no guideline for dieldrin in whole fish in the GLWQA. This will be the last report on the levels of dieldrin and related compounds SOLEC as focus is shifted to contaminants with established environmental quality guidelines or targets.

Toxaphene
Basin Wide Status: Fair; Improving

Decreases in toxaphene concentrations have been observed throughout the Great Lakes in all media following its ban in the mid-1980s. A recent study on toxaphene trends in Great Lakes fish show that concentrations remain the highest in Lake Superior (up to ~480 ng/g) and lowest in Lake Erie (up to ~50 ng/g) (Xia et al. in press). Concentrations of toxaphene in Lake Trout and Walleye continue to exhibit exponential temporal declines in all of the Great Lakes; however, concentrations appear to level off starting in 2007 (Xia et al in press). Continued monitoring of toxaphene in top predator fish in the coming years should confirm whether toxaphene concentrations have reached a steady state in Great Lakes fish.

Polybrominated Diphenyl Ethers (PBDEs)
Basin Wide Status: Fair; Improving

The production and use of three popular commercial formulations of PBDE have or are being voluntarily phased out by industry in North America. The phase out of the more toxic penta- and octa-BDE compounds started in 2004 and by 2012, the use of deca-BDE formulations will also cease (http:/www.bsef.com). In a national survey of PBDE concentrations in top predator fish from lakes across Canada, the highest concentrations were observed in fish from the Great Lakes and >95% of the PBDE compounds in the fish were tetra-, penta-, or hexa-BDEs (Gewurtz et al. 2011). Federal Environmental Quality Guidelines (FEQG) have been developed by Environment Canada for these three homologue groups which are meant to provide targets for acceptable environmental quality, assess the significance of observed concentrations, and to measure the success of risk management activities. The FEQGs to protect wildlife consumers of fish for tetra-, penta- and hexa-BDEs are 88, 1.0, and 420 ng/g ww respectively (Environment Canada 2010). Routine monitoring of PBDEs in whole top predator fish from the Great Lakes combined with retrospective analyses of archived samples by the U.S. EPA (Zhu & Hites, 2004) and Environment Canada have provided a complete picture of PBDE contamination in Great Lakes fish from 1977 to the present day. Concentrations of PBDEs in Lake Trout and Walleye rose continuously through to the early 2000s then began to decline as shown for penta-BDE in Figure 5**.** Log-linear regression of PBDE concentrations in Lake Trout and Walleye (U.S. EPA; Lake Erie), show significant declining trends of 5.8%/year for tetra-BDEs, 6.4% for penta-BDEs, and 3.4% for hexa-BDEs in Lake Ontario and annual declines of 19% for tetra-BDEs and 17% for penta-BDEs from Lake Michigan. PBDE concentrations in Lakes Superior, Huron, and Erie also appear to be declining as the slopes of the regressions are all negative; however, the slopes are not signi*ficantly different from zero at* $\alpha = 0.05$ with a power of 80%. The majority of tetra-BDE and all hexa-BDE concentrations reported for Lake Trout and Walleye in 2009 from all the Great Lakes are below Environment Canada's FEQGs; however, all measured penta-BDE concentrations are well above the FEQG of 1.0 ng/g ww (Figure 6).

Other Contaminants of Emerging Interest

Perfluorinated acids

Perfluorooctane sulfonate (PFOS) is a synthetic substance belonging to a larger class of organic fluorochemicals that are either partially or completely saturated with fluorine. PFOS, perfluorocarboxylates and their precursors are used primarily in water, oil, soil, and grease repellents for paper and packaging, carpets, and fabrics, as well as in aqueous film forming foam (AFFF) for fighting fuel fires. PFOS was voluntarily phased-out of production by their primary supplier in 2002. However, PFOS use in Canada and the US continues due to specific use exemptions. Routine monitoring of PFOS in whole Lake Trout from the Great Lakes combined with retrospective analyses of archived samples from EC's National Aquatic Biological Specimen Bank have provided information on PFOS contamination in Lake Ontario Great Lakes fish from 1979 to 2008 (Figure 7). Concentrations of PFOS in Lake Trout rose continuously at a rate of 5.9%/year through to the late 1980s/early 1990s, after which no consistent change in time was observed. This contradicts trends observed in ringed seals in the Canadian Arctic, where significant PFOS declines were observed within the year following voluntary phase-outs (Butt et al. 2007). This contradiction may be due to continued inputs into Lake Ontario. Perfluorooctanoic acid (PFOA) is another common fluorochemical and major manufacturers have voluntarily agreed to a 99% phase-out by 2015. However, PFOA is not highly bioaccumulative and time trends were not reliably measured in fish. Conversely, the concentration of two other fluorochemicals, perfluorodecane sulfonate (PFDS) and Perfluorooctane sulfonamide (PFOSA), have declined consistently in Lake Trout from Lake Ontario since 1992 at rates of 4.4% and 6.2% per year, respectively.

Synthetic Musks

The GLFMSP has begun screening for synthetic musks in fish tissue. These compounds are typically used in perfumes, colognes, shampoos, detergents, disinfectants and enter water through wastewater discharge and atmospheric deposition. The classes of synthetic musks that are of interest include: nitro-musks, polycylic musks, macrocyclic musks, alicyclic musks. To date, analytical results have indicated that two synthetic musks in particular, galoxolide and tonalide, are the most abundant musks found in GLFMSP samples. Concentrations of musks are highest in Lake Ontario followed by Lake Superior, Lake Huron, Lake Michigan, and Lake Erie. There is currently insufficient data to fully explain the spatial pattern in the Lakes; however, this could be evidence of significant atmospheric transport of musks. Detection of these chemicals is extremely difficult due to their presence in numerous products, including laundry detergent, soaps, shampoos, deodorants, body sprays, cleaning supplies, etc. Experimental techniques, such as fragarance-free rooms for analysis may be employed for future analyses. Additional results for musks, and other emerging chemicals, will be reported in subsequent SOLEC indicator reports.

Linkages

Contaminant levels in Lake Trout and Walleye are dependant on complex biological and physiochemical interactions both within and outside of the Great Lakes basin as these apex predators integrate contaminant inputs from water, air, sediment, and their food sources. A changing climate and associated changes to precipitation and wind currents will alter the influx of contaminants from sources outside of the basin and may alter food webs and the contaminant transfer through them. Aquatic invasive species also alter food webs and change energy and contaminant dynamics in the lakes. They also may introduce new pathways by which sediment contaminant pools could be mobilized and transferred to fish. Many new contaminants of concern are components of consumer products, personal care products, or pharmaceuticals, as a result, wastewater treatment effluents are an important source of contamination which is growing along with the human population of the basin.

Management Challenges/Opportunities

Much of the current, basin wide, persistent toxic substance data that is reported focuses on legacy chemicals whose use has been previously restricted through various forms of legislation but that continue to be the source of the highest levels of contaminants detected in fish, eg. PCBs. However, both the U.S. and Canadian programs are making efforts to incorporate the monitoring and surveillance of emerging chemicals into their routine work. Chemicals of interest are identified through scientific studies (eg. Howard & Muir 2010), and general screening of annual samples and also though risk assessments by regulatory bodies. As chemicals are identified through this process, they will be reported out through SOLEC, particularly those chemicals with established criteria. Environmental Specimen Banks containing tissue samples are a key component of both the U.S. and Canadian monitoring programs, allowing for retrospective analyses of newly identified chemicals of concern to develop long-term trends in the short-term.

Fostering collaboration between U.S. and Canadian monitoring programs for various media will be beneficial, especially in times of fiscal restraint. In 2009, an ad-hoc binational group was formed to bring together government representatives and researchers working on identifying new chemicals in the Great Lakes ecosystem with the objective to facilitate best management practices and sharing of information and resources. The group provides a forum for agencies and researchers to seek and provide information on emerging contaminant surveillance, monitoring, chemical methods development, and provides a place to collaborate on similar chemicals, or classes of chemicals, in different media. Collaboration among research in differing media also provides an excellent opportunity for cost sharing, an accelerated rate of discovery, and a validation of results among the Great Lakes research and monitoring community.

Assessing Data Quality

Insert “x” under the statement that best corresponds with each data characteristic

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization						
2. Data are traceable to original sources						
3. The source of the data is a known, reliable and respected generator of data						
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin						
5. Data obtained from sources within the U.S. are comparable to those from Canada						
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report						
Clarifying Notes:						

Acknowledgments

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List of Tables

List of Figures

Last Updated

State of the Lakes Ecosystem Conference (SOLEC) 2011

	N	Median (IQR) µg/g ww	% measurements above target[3]
Lake Superior[1]			
Env. Canada	324	0.21 (0.08 – 0.41)	72
U.S. EPA	35	0.37 (0.18 – 0.55)	100
Lake Michigan[1]			
Env. Canada	-	-	-
U.S. EPA	40	0.92 (0.78 – 0.99)	100
Lake Huron[1]			
Env. Canada	101	0.20 (0.16 – 0.26)	89
U.S. EPA	40	0.73 (0.50 – 0.85)	100
Lake Erie[2]			
Env. Canada	142	0.77 (0.53 – 1.3)	100
U.S. EPA	40	0.49 (0.38 – 0.79)	100
Lake Ontario[1]			
Env. Canada	324	0.85 (0.66 – 1.1)	100
U.S. EPA	38	0.87 (0.74 – 1.0)	100

[1] whole body Lake Trout
[2] whole body Walleye
[3] 0.1 µg/g ww (GLWQA Annex 1)

Table 1. Summary of total PCB concentrations for individual (Env. Canada; Arochlor 1254) and composited (U.S. EPA; total congeners) whole body Lake Trout or Walleye collected from the each of the Great Lakes measured since the last SOLEC indicator report (2006-2009).

	N	Median (IQR) µg/g ww	% measurements above target[3]
Lake Superior[1]			
Env. Canada	255	0.04 (0.03 – 0.07)	0
U.S. EPA	37	0.09 (0.05 – 0.16)	0
Lake Michigan[1]			
Env. Canada	-	-	-
U.S. EPA	41	0.27 (0.21 – 0.32)	0
Lake Huron[1]			
Env. Canada	55	0.11 (0.07 – 0.14)	0
U.S. EPA	43	0.21 (0.15 – 0.25)	0
Lake Erie[2]			
Env. Canada	142	0.06 (0.05 – 0.08)	0
U.S. EPA	42	0.05 (0.04 – 0.05)	0
Lake Ontario[1]			
Env. Canada	200	0.21 (0.12 – 0.30)	0
U.S. EPA	40	0.24 (0.19 – 0.29)	0

[1] whole body Lake Trout
[2] whole body Walleye
[3] 1.0 µg/g ww (GLWQA Annex 1)

Table 2. Summary of the concentrations of opDDT and its metabolites (opDDD and opDDE) in individual (Env.

Canada) and composited (U.S. EPA) whole body Lake Trout or Walleye collected from the each of the Great Lakes measured since the last SOLEC indicator report (2006-2009).

	N	Median (IQR) µg/g ww	% measurements above target[3]
Lake Superior[1]			
Env. Canada	266	0.18 (0.12 – 0.29)	4
U.S. EPA	17	0.21 (0.14 – 0.33)	0
Lake Michigan[1]			
Env. Canada	-	-	-
U.S. EPA	19	0.15 (0.13 – 0.18)	0
Lake Huron[1]			
Env. Canada	101	0.10 (0.08 – 0.14)	0
U.S. EPA	20	0.24 (0.20 – 0.28)	0
Lake Erie[2]			
Env. Canada	91	0.15 (0.13 – 0.17)	0
U.S. EPA	20	0.11 (0.10 – 0.13)	0
Lake Ontario[1]			
Env. Canada	252	0.13 (0.11 – 0.15)	0
U.S. EPA	20	0.10 (0.10 – 0.13)	0

[1] whole body Lake Trout
[2] whole body Walleye
[3] 0.5 µg/g ww (GLWQA Annex 1)

Table 3. Summary of total mercury concentrations in individual (Env. Canada; 2006-2009) and composited (U.S. EPA; 2006-2007) whole body Lake Trout or Walleye collected from the each of the Great Lakes measured since the last SOLEC indicator report.

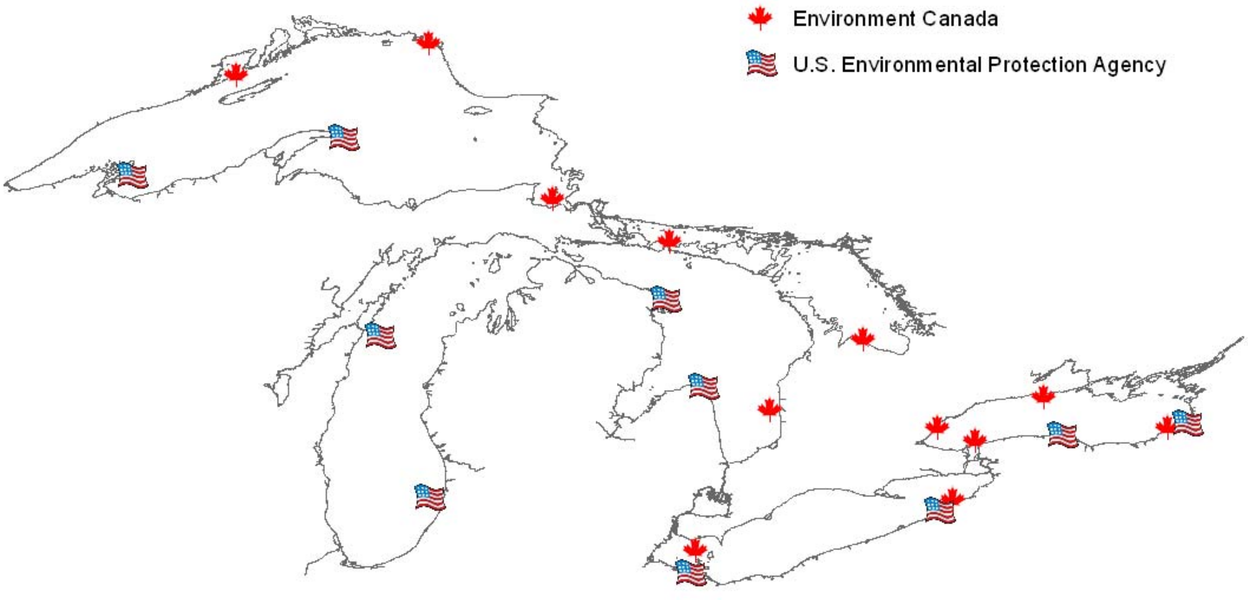

Figure 1. Map of Great Lakes showing Environment Canada and U.S. Environmental Protection Agency monitoring stations for fish contaminants.

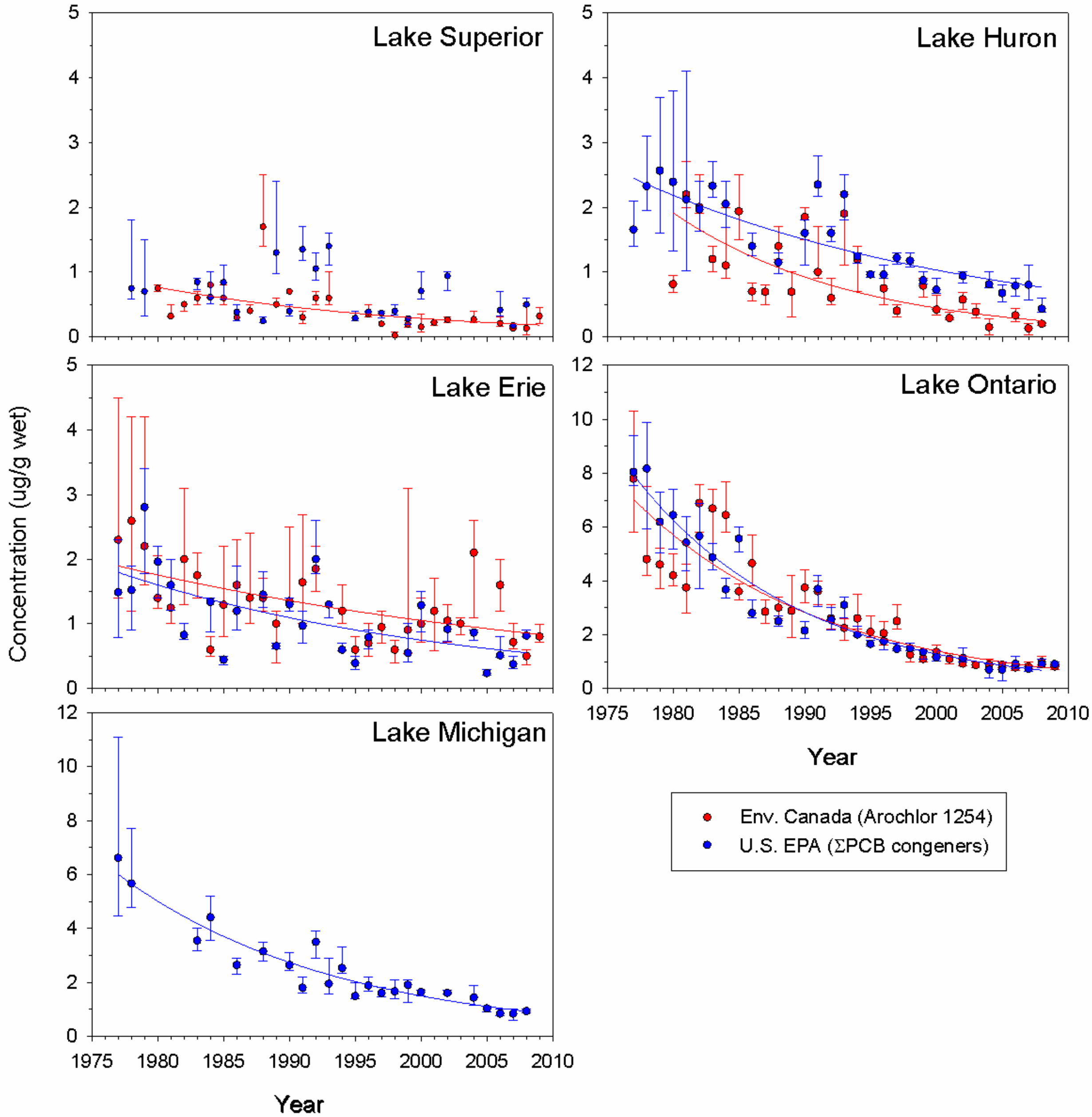

Figure 2. Total PCB concentrations (median & IQR) for individual (Environment Canada) and composited (U.S. Environmental Protection Agency) whole body Lake Trout or Walleye (Lake Erie) collected from each of the Great Lakes. Dashed lines show log-*linear regression model if annual change is significantly different from zero (α =* 0.05).

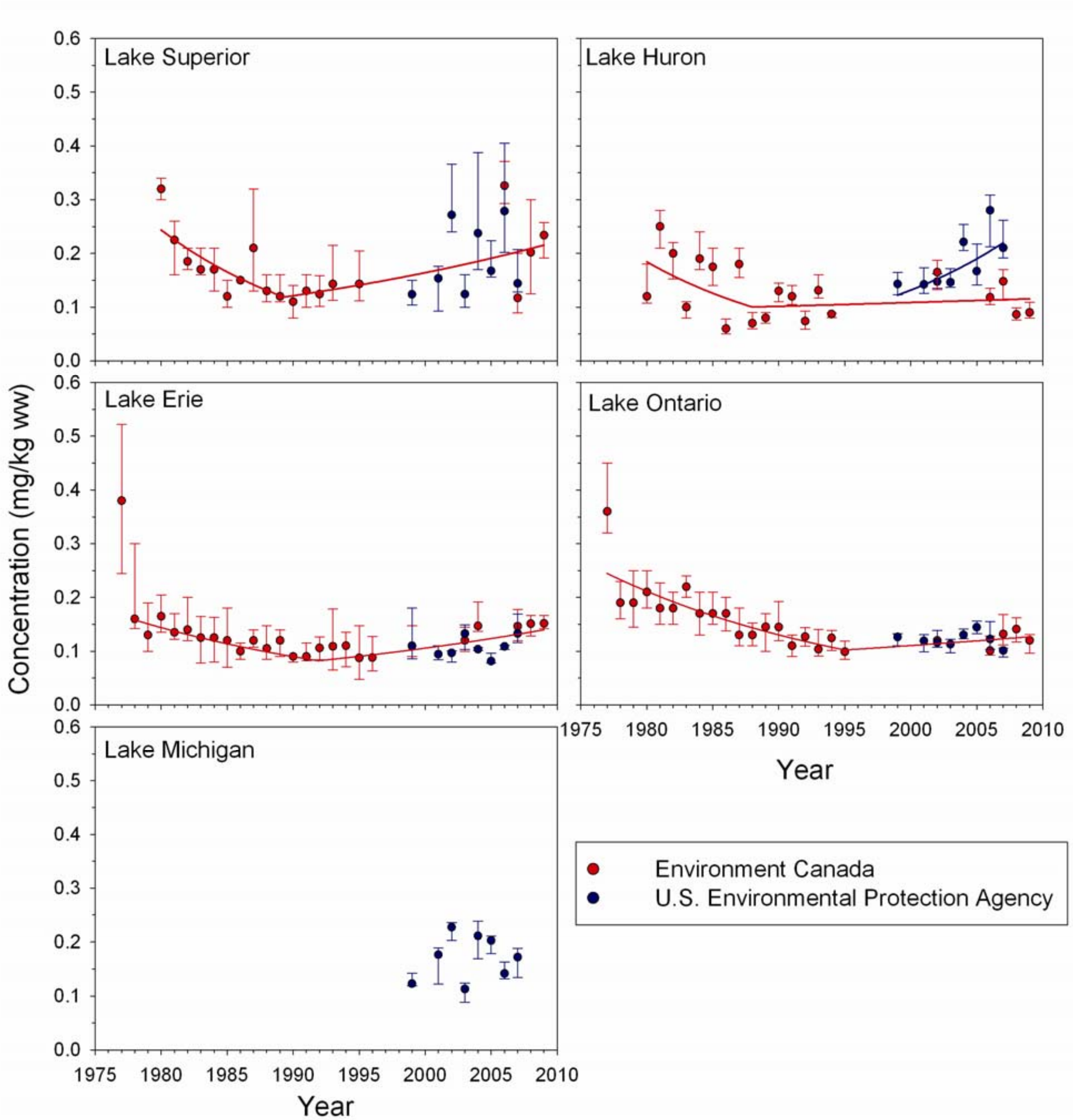

Figure 3. Total mercury concentrations (median & IQR) for individual (Environment Canada) and composited (U.S. Environmental Protection Agency) whole body Lake Trout or Walleye (Lake Erie) collected from each of the Great Lakes. Results of 2-segment linear piecewise regression (solid red line) or log-linear regression (solid blue line) models.

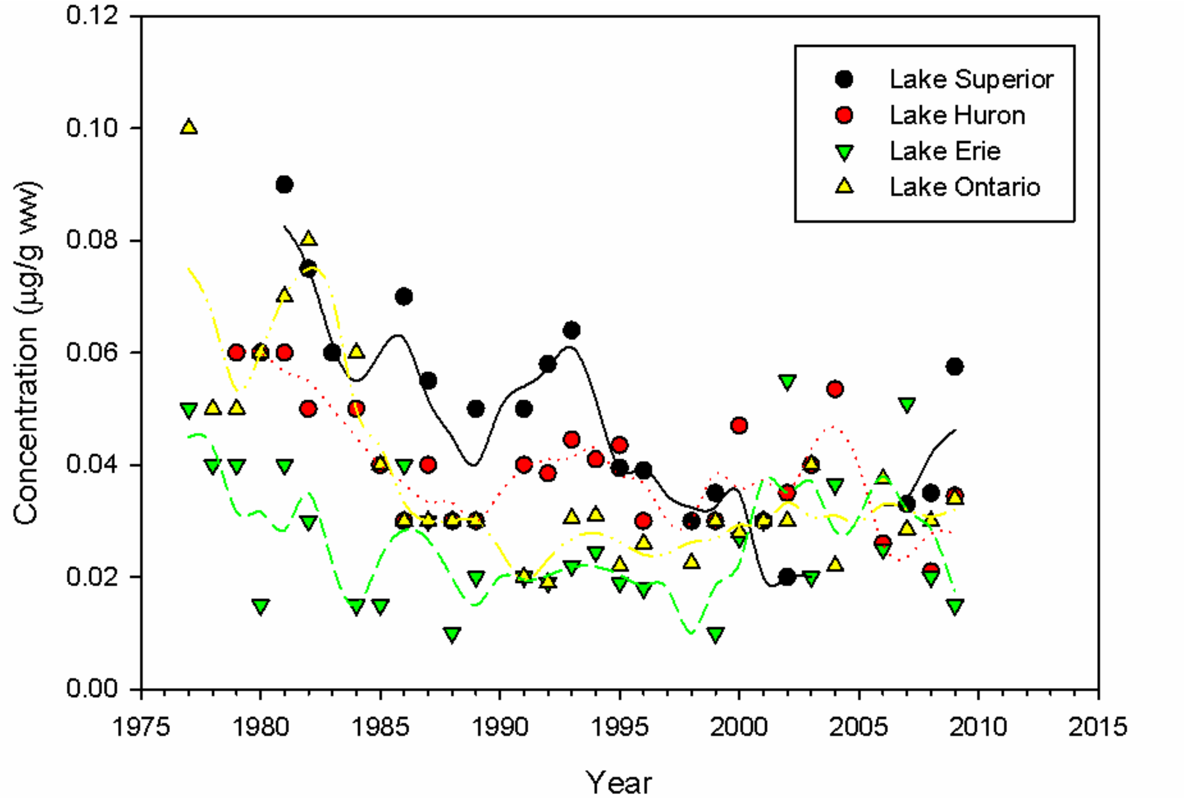

Figure 4. Median total mercury concentrations in composited Rainbow Smelt collected from the Canadian waters of the Great Lakes by Environment Canada. Lines denote 3 year moving average.

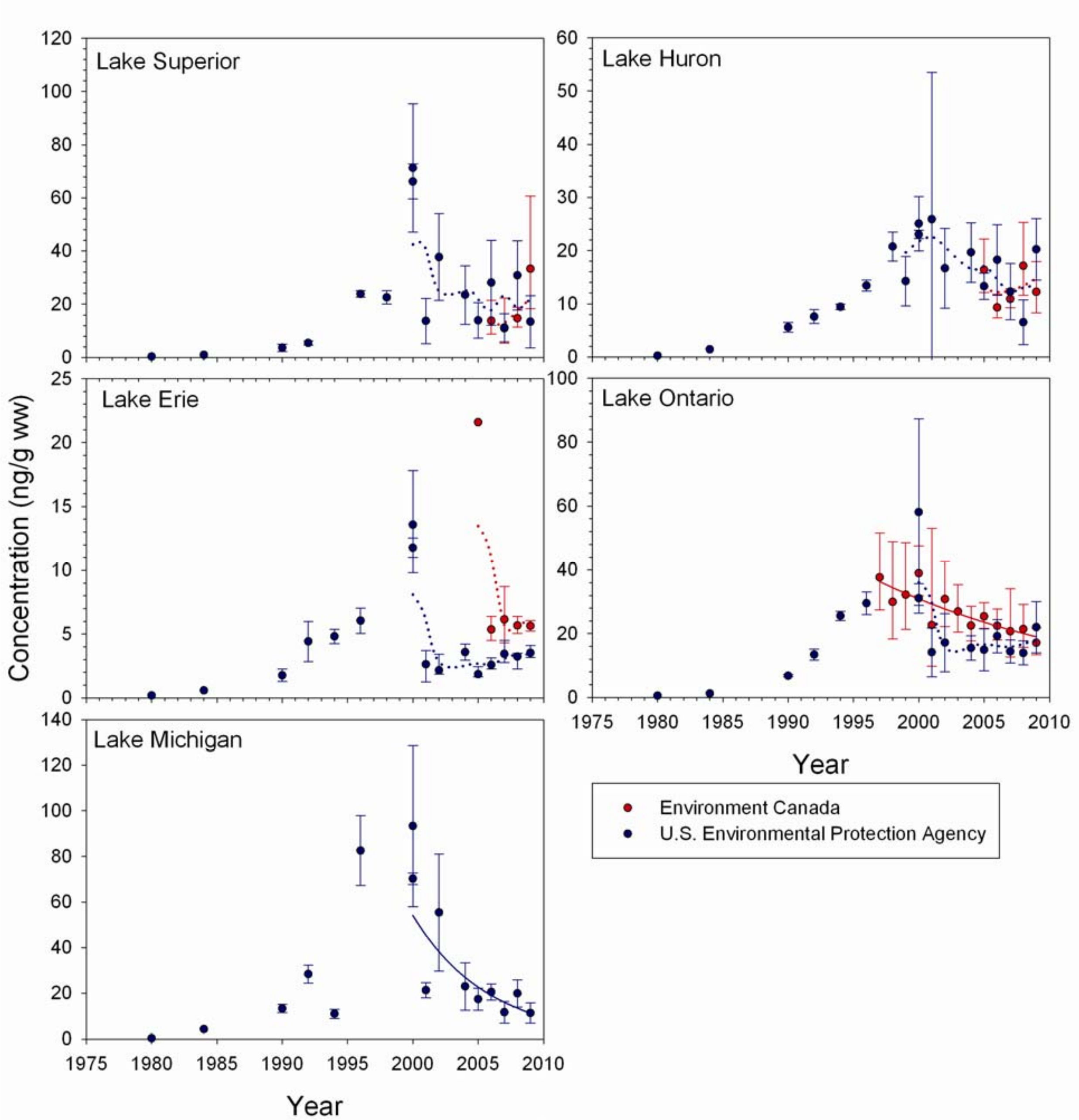

Figure 5. Mean (± stdev) penta-BDE concentrations in Great Lakes fish measured by Environment Canada, U.S. Environmental Protection Agency and Zhu & Hites (2004). Solid lines denote significant log-linear regressions. Dotted lines denote 3 year moving average when log-linear regression is not significant.

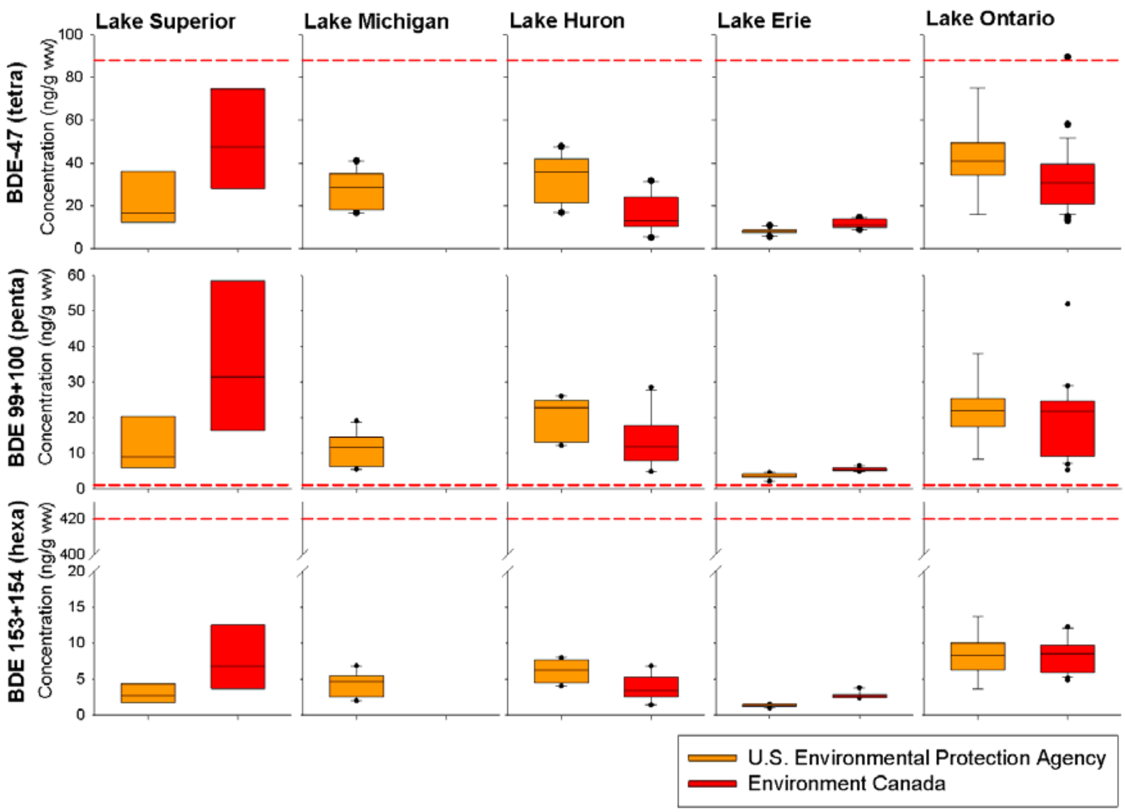

Figure 6. Concentrations of the dominant PBDE congeners (ng/g ww) in whole body Lake Trout and Walleye (U.S. EPA; Lake Erie) in each of the Great Lakes measured in 2009 relative to the Federal Environmental Quality Guidelines developed by Environment Canada (red dashed line).

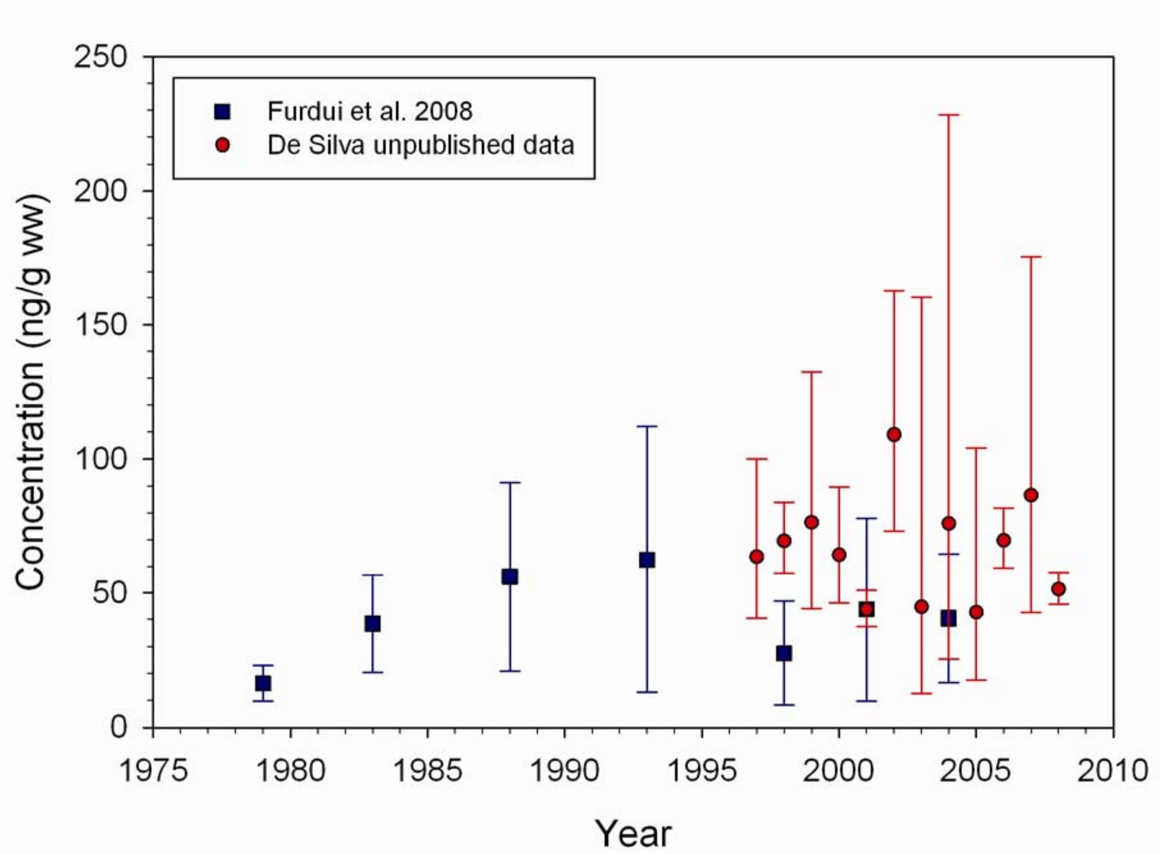

Figure 7. Temporal trends of PFOS concentrations (geometric mean ± 95% confidence interval) in Lake Ontario Lake Trout measured by Environment Canada (De Silva, unpublished data) and Ontario Ministry of the Environment (Furdui et al. 2008).

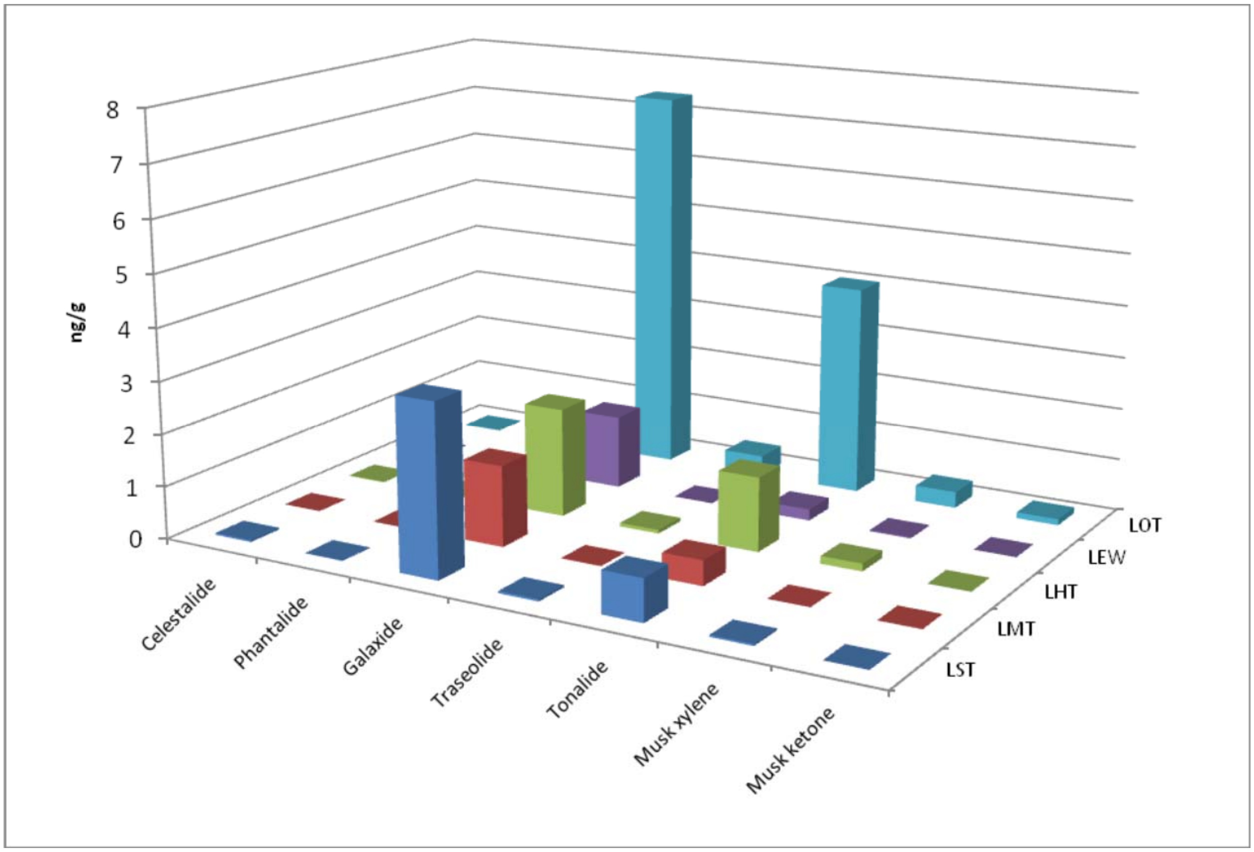

Figure 8. Average synthetic musk concentrations (ng/g ww) in whole body Lake Trout and Walleye (U.S. EPA; Lake Erie) in each of the Great Lakes measured in 2009.