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Per- and Polyfluoroalkyl Substances in Freshwater Fish, 2018

Lake Meridian, Lake Sammamish, and Lake Washington

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Cover Photo: Lake Washington with aquatic plants in foreground and forested hills in background. (Photo taken by Callie Mathieu)

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Lake Meridian, Lake Sammamish, and Lake Washington

by

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Acknowledgments

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Abstract

During 2008 and 2016, the Washington State Department of Ecology (Ecology) conducted statewide surveys of per- and polyfluoroalkyl substances (PFAS) in Washington State rivers and lakes. Findings from the two surveys showed elevated PFAS concentrations in freshwater fish collected from urban lakes, compared to other waterbodies in the state.

Because these statewide surveys were limited in scope, Ecology conducted follow-up sampling of freshwater fish from three urban lakes to gain a fuller understanding of PFAS levels in urban fish. During the fall of 2018, Ecology collected 328 fish from Lake Meridian, Lake Sammamish, and Lake Washington. Individual fish fillets were composited into 76 samples and analyzed for PFAS.

All of the study's 76 composite samples contained perfluorooctane sulfonate (PFOS). Species-specific concentrations of PFOS were similar across the three lakes. Largemouth bass contained the highest PFOS concentrations, followed by yellow perch, and then brown bullhead, with medians of 30.7 ng/g ww, 19.8 ng/g ww, and 2.1 ng/g ww, respectively. The consistency among species across these urban lakes may indicate diffuse sources associated with urban development.

The long-chain perfluoroalkyl carboxylates with carbon chain lengths of 10-14 were detected in all or almost all of the samples, at much lower concentrations (medians < 2 ng/g ww). Perfluorooctanoate (PFOA) and short-chain perfluoroalkyl acids were not detected in any of the fish tissue samples for this study.

This 2018 study confirmed findings from Ecology's 2008 and 2016 statewide surveys that PFOS is present in urban lake fish at elevated concentrations. PFOS concentrations in the 2018 study were (1) found to be similar to freshwater fish collected from other urban and industrial areas of the United States lacking point sources, and (2) generally higher than reference waterbodies in other states.

Introduction

Per- and Polyfluoroalkyl Substances (PFAS)

Per- and polyfluoroalkyl substances (PFAS) are a large group of chemicals used in many industrial and consumer applications, such as water-, stain-, and oil-repelling coatings, and aqueous film-forming foams (AFFFs) since the 1950s. In the 2000s, due to growing concerns over their toxicity and persistence in humans and the environment, manufacturers began phasing out specific compounds like perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), and their known precursors. The primary manufacturer of PFOS phased out production in 2002, and eight major companies committed to eliminate PFOA and other long-chain PFAS by 2015.

Nearly all people tested in the U.S. population have PFOS, PFOA, perfluorohexane sulfonic acid (PFHxS), and perfluorononanoic acid (PFNA) in their blood (CDC, 2018). Exposure to PFOA and PFOS at certain levels has been shown in animal studies to result in hepatotoxicity, tumor induction, developmental toxicity, immunotoxicity, neurotoxicity, and endocrine disruption (Lau, 2015). The U.S. Environmental Protection Agency (EPA) Health Advisory for PFOA and PFOS in drinking water is based on developmental effects to fetuses (e.g. low birth weight and accelerated pregnancy), testicular and kidney cancer, liver effects, immune effects, thyroid effects, and other adverse outcomes such as cholesterol changes (EPA, 2016).

Humans can be exposed to PFAS through drinking water, diet, house dust, food packaging, and consumer products (ITRC, 2020a). Drinking water and eating locally-caught fish are the primary contributors to PFAS body burdens in areas of contamination (Sunderland et al., 2019).

PFAS in the Environment

PFAS are ubiquitous in the environment. Giesy and Kannan (2001) first documented PFOS as a global contaminant, with detections in wildlife ranging from urban centers to remote regions of the Arctic. A review by Houde et al. (2011) concluded that PFOS and long chain perfluoroalkyl carboxylates (PFCAs) were still widespread in invertebrates, fish, reptiles, aquatic birds, and marine mammals throughout the globe. PFAS are also widespread in the abiotic environment and have been reported in surface water, groundwater, sediments, rainwater, and air (Vedagiri et al., 2018).

PFAS are released to the environment through manufacturing emissions, releases, or disposal of PFAS, as well as the use and disposal of products containing PFAS (ITRC, 2020b). Major pathways of specific PFAS compounds released to the environment have been identified as stormwater (Muller et al., 2011; Xiao et al., 2013), wastewater treatment plant (WWTP) effluent (Sinclair and Kannan, 2006), discrete releases from direct product use like AFFFs (Paul et al., 2009; Ahrens and Bundschuh, 2014), and atmospheric deposition (Stock et al., 2004; Prevedouros et al., 2006). Environmental monitoring in Washington has suggested that stormwater, WWTP effluent, and AFFF use are primary ways specific PFAS, such as perfluoroalkyl acids (PFAAs), are delivered to the state’s waterbodies (Ecology, 2021).

Previous Ecology PFAS Studies

Ecology has carried out several studies documenting the presence of PFAS in freshwater systems (Furl and Meredith, 2010; Johnson and Friese, 2012; Mathieu, 2013; Mathieu and McCall, 2017), commercial stormwater (Medlen, 2018), and marine sediments (Long et al., 2013; Dutch et al., 2014; Dutch et al., 2021).

In 2008 and 2016, Ecology conducted statewide studies to characterize levels of PFAS in rivers and lakes across the state (Furl and Meredith, 2010; Mathieu and McCall, 2017). The two studies assessed PFAS concentrations in surface water, WWTP effluent, freshwater fish tissue, and osprey eggs. The 2016 results showed a general decrease in detection frequencies and concentrations in surface water samples and WWTP effluent compared to 2008; however, no change was seen in fish tissue or osprey egg PFAS levels. The 2016 study concluded that PFAS – and in particular PFOS – continued to be a ubiquitous contaminant in aquatic biota.

PFAS concentrations measured in the 2016 fish fillet samples collected in Western Washington were highest in urban waterbodies. Six out of seven samples collected from three urban lakes (Angle Lake, Lake Meridian, and Lake Washington) contained PFOS concentrations higher than the Washington State Department of Health (DOH) provisional general population screening level for PFOS in edible fish tissue (23 ng/g at the time). The urban lakes were the only waterbodies to exceed the DOH provisional general population screening level at the time. Currently, there is no fish advisory for PFAS in Washington State. When finalized, screening levels will be used by DOH toxicologists when assessing a waterbody for fish consumption risk management and risk communication. The number of samples collected in 2016 was insufficient for DOH to assess the waterbodies.

Study Design

In 2018, Ecology collected freshwater fish samples from Lake Meridian, Lake Sammamish, and Lake Washington for analysis of PFAS in edible fillet tissue in order to gain a fuller understanding of PFAS levels in urban fish (Figure 1). Ecology revisited two of the waterbodies from the 2016 statewide survey (Lake Meridian and Lake Washington) where multiple fish tissue samples contained PFOS concentrations higher than the DOH provisional screening level. Angle Lake from the 2016 survey was not re-sampled because the fish community is not large enough to collect the target number of samples. Lake Sammamish was additionally selected to evaluate levels of PFAS in fish from the urban waterbody, as PFOS was reported in drinking water well samples in the lake's watershed between 2013 and 2016 (City of Issaquah, 2015).

This study's collection objectives were to obtain enough fish of each species to form 3–5 composite samples per site. Composite samples consisted of 3–5 individual fish per sample. The target fish species for each site included largemouth bass, yellow perch, and one additional species. This target was met for all sites, with the exception of Lake Meridian where only two composite samples of yellow perch were obtained. Brown bullhead were collected from all three lakes as the third species. Additionally, smallmouth bass, cutthroat trout, and kokanee were collected where encountered. Table 1 presents the fish species collected and number of composites analyzed for the study.

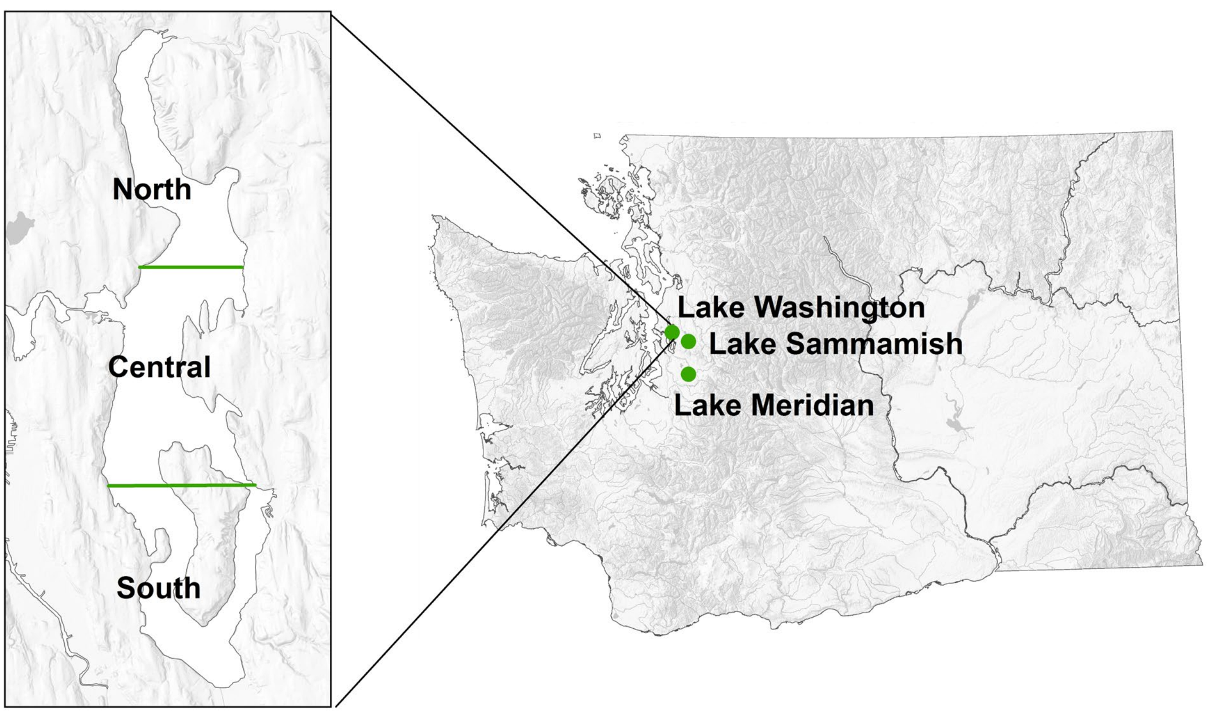

Figure 1. Study Locations.

Table 1. Sites, Collection Dates, and Number of Composites Analyzed by Species.

Site	Collection dates	# of BBH composite samples	# of YP composite samples	# of LMB composite samples	# of SMB composite samples	# of KOK composite samples	# of CTT composite samples
Lake Meridian	9/13/18 - 9/27/18	5	2	4	2	3	---
Lake Sammamish	10/15/18	5	5	5	---	---	---
Lake Washington - South	10/01/18 - 10/10/18	5	4	3	---	---	---
Lake Washington - Central	10/02/18 - 10/10/18	5	4	5	3	---	2
Lake Washington - North	10/8/18	5	4	5	---	---	---

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass
SMB = smallmouth bass; KOK = kokanee; CTT = cutthroat trout

Methods

Sample Collection and Preparation

Ecology field crews collected freshwater fish samples from Lake Meridian, Lake Sammamish, and Lake Washington in September and October of 2018. Fish were collected via boat electroshocking and gill-netting following Ecology's Standard Operating Procedure (SOP) EAP009: *Field Collection, Processing, and Preservation of Finfish Samples at the Time of Collection in the Field* (Sandvik, 2018a). Fish were collected under the following state and federal scientific collection permits: WDFW 18-158a, NOAA 1386-9R, and USFWS TE-058381-8. The Muckleshoot Indian Tribe provided several samples of cutthroat trout and smallmouth bass collected during their fishing events in early October.

Ecology staff processed and homogenized individual fish fillets into 3–5 fish composite samples at Ecology headquarters following SOP EAP007: *Resecting Finfish Whole Body, Body Parts, or Tissue Samples* (Sandvik, 2018b) and the Quality Assurance (QA) Project Plan for this study (Mathieu, 2018). All species were composited with the skin left on, except for brown bullhead, for which the skin was removed. Individual fish were de-slimed, descaled, and filleted. Individual fillets were then ground a minimum of two times until a consistent color and texture was reached. An equal aliquot of each fillet homogenate was combined to make up a composite, and then passed through the grinder a third time. Homogenized samples were placed in laboratory-provided, pre-cleaned high-density polyethylene (HDPE) jars, frozen at -20 C°, and sent to the laboratory on ice following Manchester Environmental Laboratory's (MEL's) chain of custody protocols.

After fillets were removed, the sex of the fish was determined and recorded. Fish aging structures (otoliths, scales, opercula, or pectoral spines depending on species) were removed and sent to WDFW biologists for age determination. Appendix A presents fish measurement data including length, weight, and age.

Laboratory Analysis

Ecology's MEL analyzed all fish tissue samples for a suite of 15 PFAS (see Appendix B for full list). Samples were extracted following a modification of method AOAC2007.01. This method is a QuEChERS based extraction procedure using acetonitrile and HPLC-MS grade water pH-adjusted with ammonium hydroxide. The method is based on partitioning the sample by salting-out and creating an equilibrium between an aqueous and organic layer. After extraction salts and acetonitrile are added, the sample is shaken and centrifuged, and the acetonitrile extract is removed. The extracts were cleaned prior to analysis using dispersive solid phase extraction (dSPE) and Extended Matrix Removal-Lipids (EMR-L).

Samples were analyzed following a modification of EPA Method SW8321B using liquid chromatography-tandem mass spectrometry (LC-MS/MS). Specific selected reactive monitoring (SRM) settings were developed for each analyte and utilized to maximize response and selectivity. Sample concentrations were determined by isotopic dilution quantification.

Data Quality

EcoChem reviewed and conducted an independent EPA Stage 4 Data Validation on all analytical results for this study as defined by EPA (2009). Data were electronically and manually reviewed in accordance with the technical specifications and quality assurance/quality control (QA/QC) requirements of the laboratory method and the study's QA project plan. EcoChem provided a case narrative and electronic data deliverable documenting the findings of the validation. MEL provided written case narratives to the project manager with a description of the quality of the data, including method of analysis, instrument calibration, and results of QC tests. All QC tests outlined in the QA project plan were performed for the analysis.

The PFAS analytical data were deemed usable for all purposes, as reported with qualifications. Data generally met measurement quality objectives (MQOs) outlined in the QA project plan with the following exceptions:

- PFTeA and PFTrA were found in two of the method blanks at concentrations of 0.02 – 0.13 ng/g ww. Ten PFTeA sample results were less than ten times the amount found in the method blank and were qualified "U" to indicate a non-detect. All other sample results were either non-detects or greater than 10 times the method blank contamination and not qualified. NEtFOSAA and NMeFOSAA were also detected in method blanks for two batches, but all associated samples were below detection limits.
- One NEtFOSAA sample was qualified as an estimate based on a high surrogate recovery (210%). Three other MeFOSAA and NEtFOSAA surrogates had high recoveries, but the associated sample results were below detection limits and therefore not qualified.
- Laboratory control samples for all batches had low recoveries of PFPeA, ranging from 50–67% recovery. All PFPeA results were below detection limits and no qualifications were made to the data.

Results below the method reporting limit (MRL) were reported as qualified "J" indicating an estimated value. PFHxA and PFPeA had very low or no confirming daughter ion and were not reported below the MRL, due to the difficulty of confirmation at low levels.

With the exception of PFPeA, laboratory control sample (LCS) recoveries across all analytes and batches ranged 78–124%, with an average of 98.2%. Matrix spike recoveries ranged 58–135% (average = 103%). The average relative percent difference in laboratory duplicates and LCS duplicates were 9.3% and 6.5%, respectively.

A standard reference material (SRM) certified for PFOS was analyzed with each batch. National Institute of Standards and Technology (NIST) 1947 SRM was used for this study. This SRM consists of Lake Michigan frozen lake trout homogenate with a known PFOS concentration of 5.9 ng/g ww. In this study, SRM recoveries of PFOS ranged from 110–116%, with an average of 112% across four batches. Quantitation limits outlined in the QA project plan were achieved for all samples, and generally below 0.5 ng/g ww.

Results

For this 2018 study, Ecology analyzed 76 fillet composite samples (consisting of 328 individual fish) collected from three urban lakes. Laboratory results are summarized in the following sections by study location. Appendix A presents the fish biological data for each composite sample and Appendix B provides the analytical results. Data can also be obtained through Ecology's Environmental Information Management (EIM) database at https://apps.ecology.wa.gov/eim/search/default.aspx.

Lake Meridian

Figure 2 and Table 2 present PFAS results of fish species collected from Lake Meridian.

PFOS and several long chain PFCAs (PFDA, PFUnA, PFDoA, PFTrA, and PFTeA) were present in all species and samples analyzed from Lake Meridian. PFNA was detected in only two of four largemouth bass samples and in all three kokanee samples.

PFOS was the dominant compound in all samples analyzed, making up 70–85% of the total PFAS concentration in yellow perch, largemouth bass, smallmouth bass, and kokanee. All other compounds made up less than 10% of the total PFAS concentration in those species. PFOS was the dominant compound in brown bullhead species as well, but with a much lower percent contribution. PFOS in brown bullhead ranged from 36–47% of the total, while PFDoA, PFUnA, PFDA, PFTrA, and PFTeA contributed 20%, 13%, 9%, 9%, and 8% of the total PFAS concentration, on average.

Two smallmouth bass samples contained the highest PFOS concentrations, at 60.0 and 64.1 ng/g ww, followed by largemouth bass samples (range = 19.2–31.4 ng/g ww). The two yellow perch samples contained PFOS concentrations of 10.7 and 10.8 ng/g ww, and kokanee were in the range of 6.40–7.88 ng/g ww. The lowest PFOS concentrations were found in brown bullhead (range = 0.94–1.60 ng/g ww).

The long-chain PFCAs were present in much lower amounts than PFOS across the species. PFDA was present at the highest concentrations of the long-chain PFCAs, in smallmouth bass (5.75 and 6.24 ng/g ww), and in other species ranging from 0.15–2.6 ng/g ww. PFUnA, PFDoA, PFTrA, and PFTeA were detected in all species and samples at concentrations of 0.11–2.9 ng/g ww. PFNA was detected at concentrations of 0.5 ng/g ww or less.

Comparison to statewide survey

PFOS concentrations in the 2018 Lake Meridian largemouth bass samples were very similar to levels found in the two largemouth bass samples collected in the 2016 statewide survey from Lake Meridian. The 2016 samples contained 24–40 ng/g ww of PFOS, while our 2018 samples were 19.2–31.4 ng/g ww. Concentrations of PFDA, PFUnA, and PFDoA were also very similar between years.

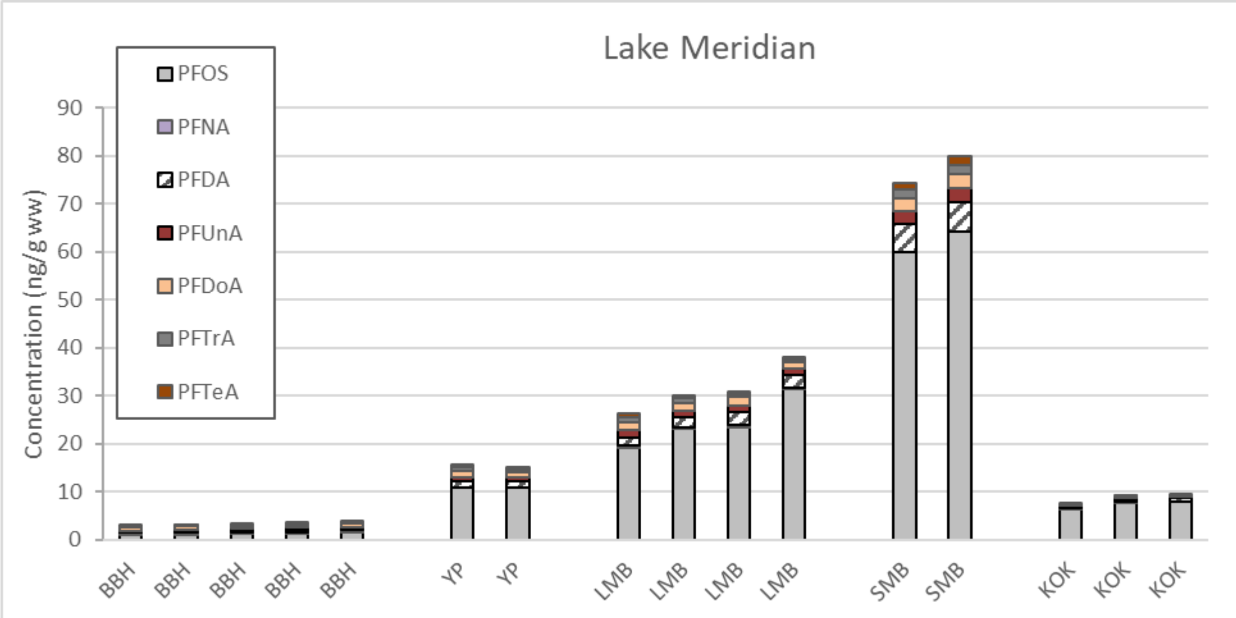

Figure 2. Fillet Composite Sample PFAS Concentrations in Fish Collected from Lake Meridian.

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass; SMB = smallmouth bass; KOK = kokanee

Table 2. Summary of PFAS Concentrations in Lake Meridian Fish Composites.

Species	Summary statistic	PFOS	PFNA	PFDA	PFUnA	PFDoA	PFTrA	PFTeA
BBH	Min.-Max. (ng/g)	0.94 – 1.60	ND	0.15 J – 0.39 J	0.33 J – 0.49	0.55 – 0.62	0.23 J – 0.33 J	0.17 J – 0.29 J
	Mean (ng/g)	1.17	---	0.26	0.39	0.58	0.27	0.23
	Median (ng/g)	1.13	---	0.27 J	0.38 J	0.58	0.28 J	0.24 J
	Det. Freq.*	5/5	0/5	5/5	5/5	5/5	5/5	5/5
YP	Min.-Max. (ng/g)	10.7 – 10.8	ND	1.29 – 1.39	0.89 – 0.92	1.1 – 1.4	0.53 – 0.71	0.41 J – 0.53
	Mean (ng/g)	10.8	---	1.34	0.90	1.23	0.62	0.47
	Median (ng/g)	10.8	---	---	---	---	---	---
	Det. Freq.*	2/2	0/2	2/2	2/2	2/2	2/2	2/2
LMB	Min.-Max. (ng/g)	19.2 – 31.4	ND – 0.5	1.65 – 2.85	1.25 – 1.54	1.23 – 1.83	0.65 – 1.06	0.52 – 0.79
	Mean (ng/g)	24.2	0.32	2.28	1.37	1.63	0.83	0.63
	Median (ng/g)	23.2	---	2.32	1.35	1.73	0.80	0.60
	Det. Freq.*	4/4	2/4	4/4	4/4	4/4	4/4	4/4
SMB	Min.-Max. (ng/g)	60 – 64.1	ND	5.75 – 6.24	2.76 – 2.87	2.76 – 2.94	1.67 J – 1.86 J	1.44 – 2.04 J
	Mean (ng/g)	62.1	---	6.00	2.82	2.85	1.77	1.74
	Median (ng/g)	---	---	---	---	---	---	---
	Det. Freq.*	2/2	0/2	2/2	2/2	2/2	2/2	2/2
KOK	Min.-Max. (ng/g)	6.40 – 7.88	0.09 J – 0.12 J	0.49 – 0.68	0.12 J – 0.17 J	0.11 J – 0.20 J	0.11 J – 0.21 J	0.17 J – 0.21 J
	Mean (ng/g)	7.32	0.10	0.62	0.15	0.15	0.16	0.18
	Median (ng/g)	7.67	0.10 J	0.68	0.15 J	0.15 J	0.17 J	0.17 J
	Det. Freq.*	3/3	3/3	3/3	3/3	3/3	3/3	3/3

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass; SMB = smallmouth bass; KOK = kokanee;
ND = non-detect. *number of detections/number of composites analyzed. J = reported result is an estimate.

Lake Sammamish

PFAS results of fish collected from Lake Sammamish are presented in Figure 3 and Table 3.

PFOS, PFUnA, PFDoA, PFTrA, and PFTeA were detected in all Lake Sammamish samples and species analyzed. PFDA was detected in all yellow perch and largemouth bass samples, and three out of five brown bullhead samples. PFNA was present in four out of five yellow perch and largemouth bass samples, and not detected in any of the brown bullhead samples. NEtFOSAA was only detected in one brown bullhead sample, and not in any other species.

The dominant compound in all samples was PFOS, with relative percent contributions averaging 57%, 82%, and 82% in brown bullhead, yellow perch, and largemouth bass, respectively. In the yellow perch and largemouth bass, the compound make up was similar, with average percent contributions of PFDA, PFUnA, and PFDoA ranging 4–6% and PFTrA, PFTeA, and PFNA ranging 0–2%. Similar to Lake Meridian, brown bullhead samples had higher relative contributions of compounds other than PFOS. In the brown bullhead samples, PFDoA had the second-highest relative contribution (average = 13%), followed by PFUnA (average = 11%), PFTrA (6%), PFTeA (5%), and PFDA (2%).

The highest concentrations of PFOS were observed in largemouth bass samples, ranging from 25.9–50.1 ng/g ww. Yellow perch followed the bass, with PFOS concentrations of 8.97–19.8 ng/g ww, and brown bullhead contained the lowest PFOS concentrations (range = 0.52–1.9 ng/g ww). All other detected compounds were present at less than 4 ng/g ww.

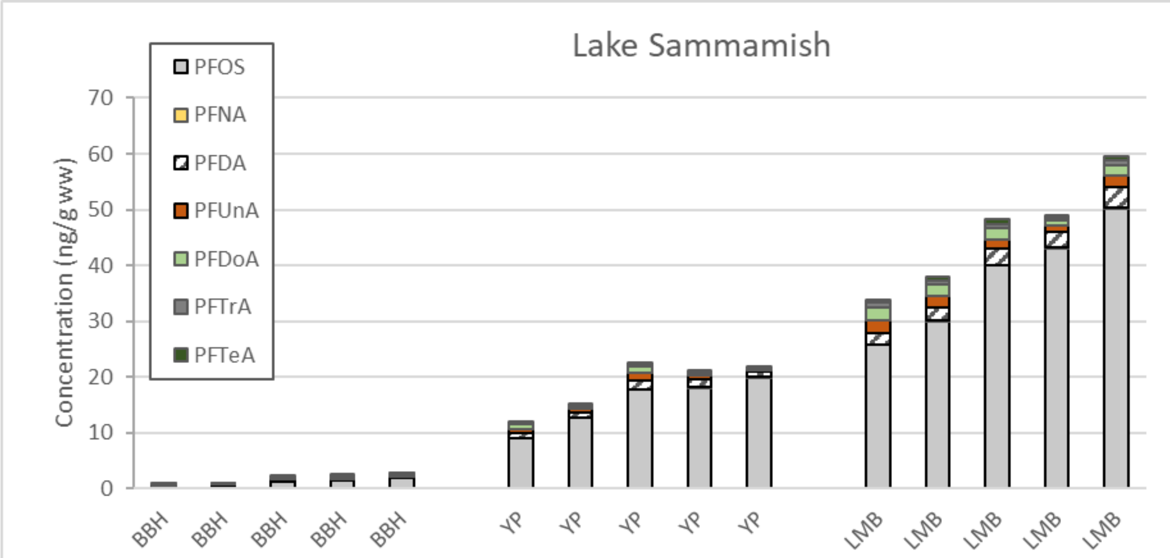

Figure 3. Fillet Composite Sample PFAS Concentrations in Fish Collected from Lake Sammamish.

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass

Table 3. Summary of PFAS Concentrations in Lake Sammamish Fish Composites.

Species	Summary statistic	PFOS	PFNA	PFDA	PFUnA	PFDoA	PFTrA	PFTeA
BBH	Min.-Max. (ng/g)	0.52 – 1.9	ND	ND – 0.12J	0.06J – 0.31J	0.13J – 0.36J	0.07J – 0.18J	0.07J – 0.13J
	Mean (ng/g)	1.11	---	0.10	0.21	0.25	0.12	0.09
	Median (ng/g)	1.16	---	0.11J	0.23J	0.30J	0.14J	0.10J
	Det. Freq.*	5/5	0/5	3/5	5/5	5/5	5/5	5/5
YP	Min.-Max. (ng/g)	8.97 – 19.8	ND – 0.23J	0.84 – 1.5	0.28J – 1.4	0.20J – 1.20	0.19J – 0.39J	0.15J – 0.23J
	Mean (ng/g)	15.4	0.15	1.15	0.74	0.64	0.28	0.19
	Median (ng/g)	17.8J	0.15J	1.00	0.72	0.51	0.24J	0.20J
	Det. Freq.*	5/5	4/5	5/5	5/5	5/5	5/5	5/5
LMB	Min.-Max. (ng/g)	25.9J – 50.1	ND – 0.19J	2.05J – 3.71	1.21 – 2.21J	0.96 – 2.3J	0.49 – 0.92	0.41J – 0.71
	Mean (ng/g)	37.8	0.13	2.74	1.88	1.80	0.79	0.60
	Median (ng/g)	40.0	0.13J	2.76	2.05	1.93	0.88J	0.61J
	Det. Freq.*	5/5	4/5	5/5	5/5	5/5	5/5	5/5

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass; ND = non-detect.
*number of detections/number of composites analyzed. J = reported result is an estimate.

South Lake Washington

Results of PFAS in fish collected from South Lake Washington are shown in Figure 4 and Table 4.

PFOS, PFDA, PFUnA, PFDoA, and PFTrA were detected in all samples analyzed from South Lake Washington. PFTeA was detected in all samples except for two yellow perch composites. PFNA was detected in two of four yellow perch samples and two of three largemouth bass samples, at very low concentrations.

PFOS was the dominant compound in all species and made up 70–85% of the total PFAS burden in yellow perch and largemouth bass, and 40–54% in brown bullhead. Other individual compounds made up 10% or less of the total PFAS concentration, with PFDA, PFUnA, and PFDoA having slightly higher percent contributions (3–10%) than PFTrA and PFTeA (0–4%) in yellow perch and largemouth bass. In brown bullhead, PFDoA was the second-most dominant compound, making up an average of 18% of the total, and other compounds were between 3% and 14%.

PFOS concentrations were in the range of 26.4–43.0 ng/g ww in largemouth bass, 12.7–19.6 ng/g ww in yellow perch, and 2.32–4.81 ng/g ww in brown bullhead. Other compounds followed the same pattern, with concentrations in the order of largemouth bass > yellow perch > brown bullhead. All detected compounds other than PFOS were present at concentrations of less than 5 ng/g ww.

Comparison to statewide surveys

Largemouth bass collected from South Lake Washington in 2008 and 2016 during the Ecology statewide surveys contained similar concentrations of PFOS, PFDA, PFUnA, and PFDoA to those observed in this study. Largemouth bass PFOS concentrations in 2008 and 2016 were 33.6 and 52.7 ng/g ww, respectively, and the 2018 samples contained 26.4–43.0 ng/g ww of PFOS.

Yellow perch collected in 2008 and 2016 contained slightly higher concentrations of PFOS than the 2018 perch samples; 22.5–26.9 ng/g ww in the statewide surveys compared to 12.7–19.6 ng/g ww in the 2018 study. Concentrations of PFDA, PFUnA, and PFDoA were similar among all three collection years.

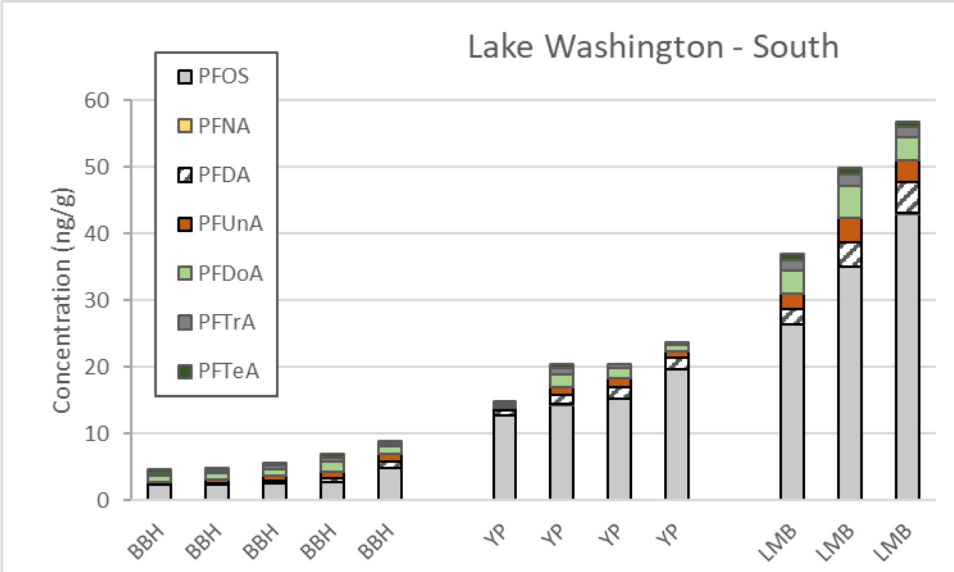

Figure 4. Fillet Composite Sample PFAS Concentrations in Fish Collected from South Lake Washington.
BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass

Table 4. Summary of PFAS Concentrations in South Lake Washington Fish Composites.

Species	Summary statistic	PFOS	PFNA	PFDA	PFUnA	PFDoA	PFTrA	PFTeA
BBH	Min.-Max. (ng/g)	2.32 – 4.81	ND	0.12 J – 1.07	0.36 J – 1.10	0.85 – 1.52	0.40 J – 0.68	0.30 J – 0.49
	Mean (ng/g)	2.99	---	0.46	0.73	1.10	0.53	0.42
	Median (ng/g)	2.60	---	0.37 J	0.67	1.07	0.54 J	0.44
	Det. Freq.*	5/5	0/5	5/5	5/5	5/5	5/5	5/5
YP	Min.-Max. (ng/g)	12.7 – 19.6	ND – 0.11 J	0.80 – 1.72	0.37 J – 1.37	0.42 J – 1.91	0.31 J – 0.88	ND – 0.64
	Mean (ng/g)	15.5	0.09	1.40	0.98	1.18	0.54	0.48
	Median (ng/g)	14.9	---	1.54	1.10	1.19	0.48 J	---
	Det. Freq.*	4/4	2/4	4/4	4/4	4/4	4/4	2/4
LMB	Min.-Max. (ng/g)	26.4 – 43.0	ND – 0.08 J	2.38 – 4.68	2.32 – 3.59	3.39 – 4.86	1.43 – 1.74	0.81 – 0.93
	Mean (ng/g)	34.8	0.07	3.59	3.09	3.88	1.58	0.86
	Median (ng/g)	35.0	---	3.72	3.35	3.40	1.56	0.83
	Det. Freq.*	3/3	2/3	3/3	3/3	3/3	3/3	3/3

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass; ND = non-detect.
*number of detections/number of composites analyzed. J = reported result is an estimate.

Central Lake Washington

Figure 5 and Table 5 present PFAS results of fish collected from Central Lake Washington.

PFOS, PFDA, PFUnA, PFDoA, and PFTrA were detected in all samples analyzed from Central Lake Washington. PFTeA was detected in all three smallmouth bass samples, and in at least one sample of brown bullhead, yellow perch, and cutthroat trout. PFNA was mostly undetected, and present only in the two cutthroat trout samples, at very low levels.

Individual compound profiles were very similar to other sites for yellow perch, largemouth bass, smallmouth bass, and cutthroat trout: PFOS was dominant, making up 66–84% of the total. PFDA, PFUnA, and PFDoA had relative percent compositions of 3–12%, and the other compounds had minor contributions.

PFOS concentrations in the Central Lake Washington smallmouth bass were the highest of all samples analyzed for this study, ranging 86.0–99.9 ng/g ww. These smallmouth bass samples were large (average length = 420–508 mm) and some of the older fish analyzed (average age = 5–9 years). However, largemouth bass analyzed from Central Lake Washington of similar size and age had about half the PFOS concentration: 28.6 ng/g ww. In general, PFOS concentrations did not appear to be correlated with fish size in this study (see Appendix C), as others have also found (Fair et al., 2019). The smallmouth bass samples also had the highest concentrations of PFDA, PFUnA, and PFDoA for this study, with median concentrations of 9.36, 10.7, and 9.19 ng/g ww, respectively.

Largemouth bass and cutthroat trout samples had similar PFOS concentrations, ranging from 19.1–44.1 ng/g ww. Yellow perch samples contained PFOS concentrations of 4.06–11.2 ng/g ww and brown bullhead PFOS concentrations were 1.33–2.04 ng/g ww. Concentrations of long chain PFCAs in the species other than smallmouth bass were less than 5 ng/g ww.

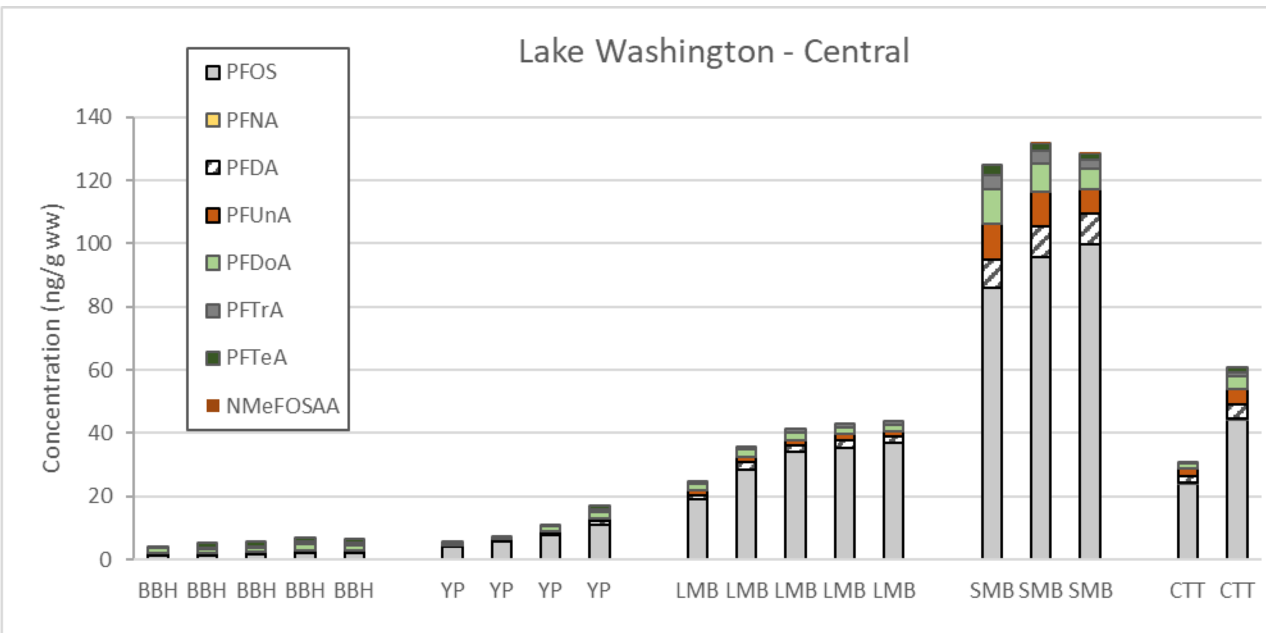

Figure 5. Fillet Composite Sample PFAS Concentrations in Fish Collected from Central Lake Washington.

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass; SMB = smallmouth bass; CTT = cutthroat trout

Table 5. Summary of PFAS Concentrations in Central Lake Washington Fish Composites.

Species	Summary statistic	PFOS	PFNA	PFDA	PFUnA	PFDoA	PFTrA	PFTeA
BBH	Min.-Max. (ng/g)	1.33 – 2.04	ND	0.17 J – 0.42	0.44 J – 0.68	1.17 – 2.00	0.60 J – 0.76 J	ND – 1.47
	Mean (ng/g)	1.73	---	0.24	0.50	1.53	0.68	1.35
	Median (ng/g)	1.83	---	0.20 J	0.46	1.58	0.66 J	1.34
	Det. Freq.*	5/5	0/5	5/5	5/5	5/5	5/5	5/5
YP	Min.-Max. (ng/g)	4.06 – 11.2	ND	0.32 J – 1.15	0.22 J – 0.89	0.57 – 1.75	0.42 J – 0.86 J	ND – 1.07
	Mean (ng/g)	7.28	---	0.66	0.47	1.07	0.61	1.07
	Median (ng/g)	6.92	---	0.59 J	0.39	0.98	0.58 J	ND
	Det. Freq.*	4/4	0/4	4/4	4/4	4/4	4/4	1/4
LMB	Min.-Max. (ng/g)	19.1 – 36.8	ND	1.30 – 2.42	1.46 – 1.95	2.21 – 2.56	0.81 J – 1.11 J	ND
	Mean (ng/g)	30.8	---	2.02	1.63	2.34	0.97	---
	Median (ng/g)	34.3	---	2.21	1.62	2.34	1.0 J	---
	Det. Freq.*	5/5	0/5	5/5	5/5	5/5	5/5	0/5
SMB	Min.-Max. (ng/g)	86.0 – 99.9	ND	9.07 – 10.0	7.72 – 11.3	6.75 – 10.6	2.79 J – 4.45 J	1.97 – 3.19
	Mean (ng/g)	93.8	---	9.48	9.91	8.85	3.69	2.60
	Median (ng/g)	95.5	---	9.36	10.7	9.19	3.8 J	2.64
	Det. Freq.*	3/3	0/3	3/3	3/3	3/3	3/3	3/3
CTT	Min.-Max. (ng/g)	23.9 – 44.1	0.37 J – 0.49	2.24 – 4.64	2.16 – 4.84	1.67 – 3.93	0.65 J – 1.41 J	ND – 1.36
	Mean (ng/g)	34.0	0.43	3.44	3.50	2.80	1.03	1.36
	Median (ng/g)	---	---	---	---	---	---	---
	Det. Freq.*	2/2	2/2	2/2	2/2	2/2	2/2	1/2

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass; SMB = smallmouth bass; CTT = cutthroat trout; ND = non-detect. *number of detections/number of composites analyzed. J = reported result is an estimate.

North Lake Washington

PFAS results of fish collected from North Lake Washington are shown in Figure 6 and Table 6.

PFOS, PFDA, PFUnA, and PFDoA were present in all samples analyzed from North Lake Washington. PFTrA and PFTeA were detected in all samples except for one brown bullhead composite. PFNA was only detected in three yellow perch samples, at low levels.

PFAS compound profiles for yellow perch and largemouth bass were similar to that observed at all other sites. PFOS dominated, making up 73–82% of the total, followed by contributions of PFDA, PFUnA, and PFDoA (4–10%), and minor contributions of PFTrA, PFTeA, and PFNA (3% or less). In the brown bullhead, PFOS made up 47–70% of the total PFAS, followed by PFUnA and PFDoA (9–19%), and PFTrA and PFTeA (7–9%).

PFOS concentrations showed a similar pattern to other sites. Largemouth bass, yellow perch, and brown bullhead contained PFOS concentrations of 22.8–38.1, 14.4–18.5, and 2.19–4.02 ng/g ww, respectively. Other compounds were present at less than 4 ng/g ww.

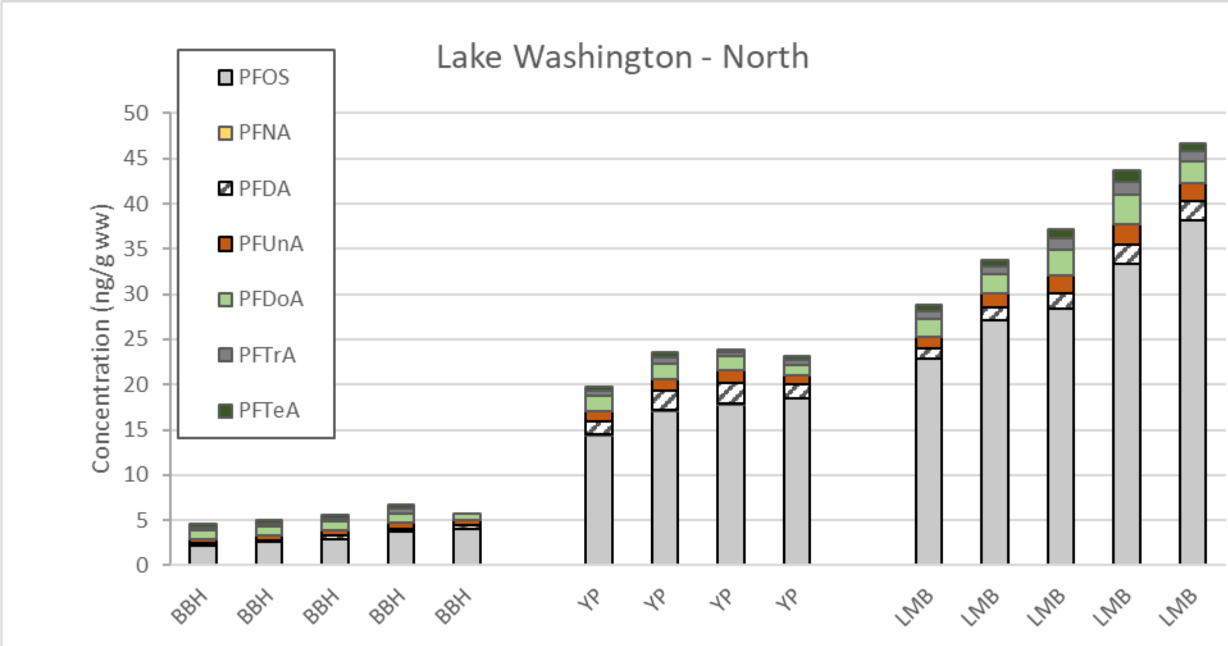

Figure 6. Fillet Composite Sample PFAS Concentrations in Fish Collected from North Lake Washington.
BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass

Table 6. Summary of PFAS Concentrations in North Lake Washington Fish Composites.

Species	Summary statistic	PFOS	PFNA	PFDA	PFUnA	PFDoA	PFTrA	PFTeA
BBH	Min.-Max. (ng/g)	2.19 – 4.02	ND	0.20 J – 0.48	0.50 – 0.71	0.73 – 0.99	ND – 0.49 J	ND – 0.44 J
	Mean (ng/g)	3.08	---	0.34	0.59	0.88	0.41	0.40
	Median (ng/g)	2.91	---	0.38 J	0.58	0.89	0.39 J	0.41 J
	Det. Freq.*	5/5	0/5	5/5	5/5	5/5	4/5	4/5
YP	Min.-Max. (ng/g)	14.4 – 18.5	ND – 0.18 J	1.46 – 2.32	0.95 – 1.45	1.12 – 1.68	0.48 J – 0.69 J	0.34 J – 0.62
	Mean (ng/g)	16.9	0.13	1.85	1.22	1.48	0.55	0.45
	Median (ng/g)	17.4	0.16 J	1.81	1.25	1.56	0.53 J	0.42 J
	Det. Freq.*	4/4	3/4	4/4	4/4	4/4	4/4	4/4
LMB	Min.-Max. (ng/g)	22.8 – 38.1	ND	1.25 – 2.22	1.24 – 2.24	1.97 – 3.18	0.86 J – 1.5 J	0.70 – 1.22
	Mean (ng/g)	30.0	---	1.75	1.78	2.50	1.13	0.90
	Median (ng/g)	28.4	---	1.69	1.94	2.43	1.14 J	0.85
	Det. Freq.*	5/5	0/5	5/5	5/5	5/5	5/5	5/5

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass; ND = non-detect.
*number of detections/number of composites analyzed. J = reported result is an estimate.

Discussion

The three lakes included in this 2018 study displayed very similar species-specific PFOS concentrations. Among all sites, the three main fish species contained PFOS concentrations in relatively tight concentration ranges. Largemouth bass contained the highest PFOS concentrations, followed by yellow perch, and then brown bullhead, with medians of 30.7, 19.8, and 2.1 ng/g ww, respectively, across all sites. The detection frequencies and concentrations of long chain perfluoroalkyl carboxylates were also similar for each species across sites. This consistency in PFAS accumulation within species across the urban waterbodies may suggest diffuse sources associated with urban development.

During the 2016 statewide survey, surface water PFOS concentrations were also very similar in Lakes Meridian and Washington (Mathieu and McCall, 2017). No water samples were collected for Lake Sammamish. In 2016, PFOS concentrations in surface water grabs collected in spring and fall ranged from 3.56–4.32 ng/L across the two sites, and PFOS concentrations in largemouth bass collected from the two sites the same year ranged from 23.5–52.7 ng/g ww. Angle Lake, the other urban lake sampled in 2016, contained surface water PFOS concentrations of 8.75–12.5 ng/L and a largemouth bass fillet PFOS concentration of 74.2 ng/g ww.

The 2018 study was limited to testing only fish tissue. In future studies, it would be helpful to test both surface water and fish tissue concurrently.

Ecological Relevance

Ecological protection guidelines

In the United States, no state or federal ecological or wildlife protection criteria currently exist for PFAS in fish tissue. Canada has issued federal guidelines for PFOS that serve as benchmarks to protect aquatic ecosystems (ECCC, 2018). Canada's PFOS federal fish tissue guideline is a whole body fish tissue concentration (9,400 ng/g ww) below which adverse effects to the fish themselves is not expected. Canada also has wildlife dietary guidelines for protection of mammals and birds that eat the fish. The wildlife diet guidelines for mammals (4.6 ng/g ww) and avian species (8.2 ng/g ww) are whole body concentrations in fish tissue below which adverse effects to the wildlife consuming the fish is unlikely to occur.

Comparison to ecological protection guidelines

Figure 7 compares the PFOS concentrations detected in our 2018 study's brown bullhead, yellow perch, and largemouth bass to Canada's fish tissue wildlife consumer guidelines. All species had PFOS concentrations well below Environment Canada's PFOS guideline for the protection of aquatic life, indicating that PFOS levels in these 2018 samples are not likely to harm the fish themselves.

Canada's PFOS guidelines for protection of mammalian and avian consumers of fish and other aquatic biota are much lower. PFOS concentrations in all largemouth bass samples from the three lakes were higher than Canada's mammalian and avian diet guidelines, indicating potential risk to wildlife that eat these fish. PFOS concentrations in smallmouth bass from Lake Meridian and Central Lake Washington, as well as cutthroat trout from Central Lake Washington, were also higher than Canada's wildlife diet guidelines.

Yellow perch collected from all sites, except for Central Lake Washington, contained PFOS concentrations higher than both mammal and avian wildlife diet guidelines. Two Central Lake Washington yellow perch exceeded the mammal diet guideline, but not the avian guideline, and one Central Lake Washington yellow perch sample had a PFOS concentration of 4.06 ng/g ww, below both of Canada's wildlife guidelines.

Brown bullhead from all sites contained low PFOS concentrations. All samples, except for one composite collected from South Lake Washington, had PFOS concentrations below Canada's mammal and avian diet guidelines. The sample from South Lake Washington had a concentration of 4.81 ng/g, which is higher than the mammal diet guideline but below the avian diet guideline.

Canada bases their guidelines on whole body concentrations, but our results represent concentrations in the fillet. This would lead to an underestimate of the total risk to wildlife, since PFOS concentrations in whole body are typically 2–3 times higher than in fillet (Fliedner et al., 2018; Fair et al., 2019).

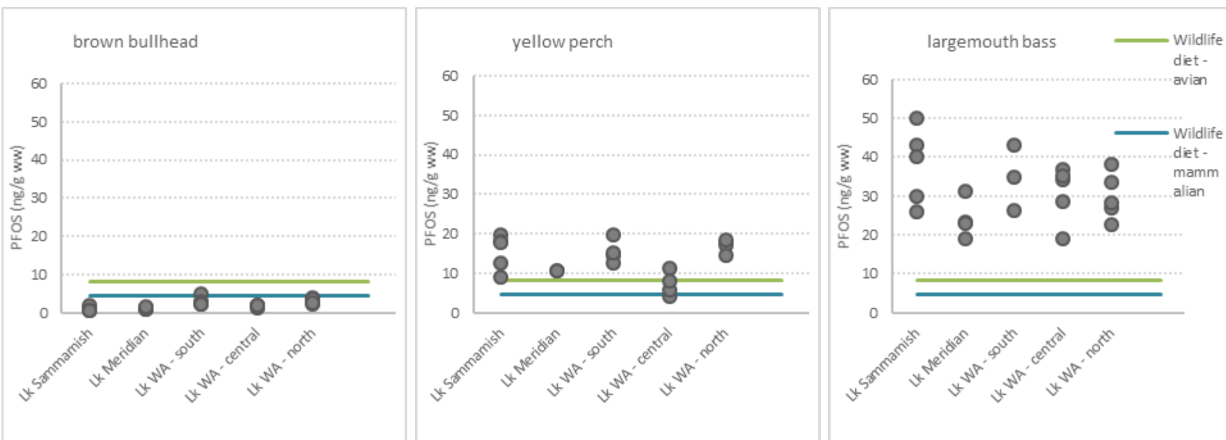

Figure 7. PFOS Concentrations in Brown Bullhead, Yellow Perch, and Largemouth Bass Fillet Samples Compared to Environment Canada's Federal Environmental Quality Guidelines (FEQG) for Whole Body Fish.

Green line = Environment Canada's FEQG for Avian Wildlife Diet
Dark blue line = Environment Canada's FEQG for Mammalian Wildlife Diet

Comparison to Other Fish in North America

A species-specific comparison to PFOS concentrations reported for other waterbodies in North America is given below. In general, during this 2018 study, PFOS concentrations detected in the collected species are lower than concentrations found near sites impacted by aqueous film-forming foams (AFFF) or manufacturing, and higher than concentrations found in reference waterbodies. This study's PFOS concentrations appear typical for freshwater fish collected in urban areas.

Largemouth bass

PFOS concentrations in largemouth bass fillet ranged from 19.1–50.1 ng/g ww (average of 31.6 ng/g ww) across all sites for this 2018 study. This is similar to PFOS concentrations found in skin-off fillet samples of largemouth bass collected in New Jersey rivers and lakes near industrial/urban centers (Goodrow et al., 2019), which were in the range of 21.2–39.3 ng/g ww, and skin-on fillets collected from Lake St. Clair (37.4–42.4 ng/g ww; MDEQ, 2020a). Other compounds were also similar to the New Jersey study, with average concentrations of long-chain PFCAs generally ranging from 0.5 to 5 ng/g ww.

In our 2018 study, PFOS concentrations in largemouth bass were higher than concentrations found in a reference site in New Jersey, and lower than AFFF-impacted sites in New Jersey (Goodrow et al., 2019). PFOS concentrations in our largemouth bass fillet were also higher than in largemouth bass fillet samples collected from Michigan reference waterbodies, but lower than maximum concentrations reported from Michigan waterbodies near known sources (MDEQ, 2015).

Yellow perch

PFOS concentrations in yellow perch fillets sampled for this 2018 study ranged from 4.06–19.8 ng/g ww (average = 13.5 ng/g ww) similar to that reported in skin-off perch samples collected in New Jersey industrial/urban waterbodies (average = 7.51 ng/g ww) (Goodrow et al., 2019). Our yellow perch PFOS concentrations were much lower than skin-off perch collected from an AFFF-impacted waterbody (average = 118.6 ng/g ww) (Goodrow et al., 2019). For this 2018 study, PFOS concentrations in yellow perch were also similar to levels found in yellow perch skin-off fillets collected from waterbodies far from sources in Ontario, Canada (Gewurtz et al., 2014). Average PFOS concentrations in yellow perch from this study and the Ontario study were 13.5 and 10 ng/g ww, respectively. This study's yellow perch were much lower in PFOS compared to yellow perch fillets collected near an airport with extensive historical AFFF use (Gewurtz et al., 2014).

Brown bullhead

Average PFOS concentrations in brown bullhead and yellow bullhead fillets from New Jersey forested watershed sites were 2.43 and 1.43 ng/g ww, respectively (Goodrow et al., 2019). This agrees well with our 2018 findings of PFOS concentrations in brown bullhead ranging 0.5–4.8 ng/g ww (average = 2.2 ng/g ww). Other states have found catfish to have lower PFOS accumulation than other fish species (Williams and Schrank, 2016). The reason for this lower accumulation potential is not clear. In our study, brown bullhead were the only species analyzed with the skin removed, which may have affected the PFOS concentrations. However, in the New Jersey study all species were analyzed as skin-off, and bullhead were still much lower in PFOS accumulation than other species.

Other species

While limited in sample sizes, PFOS concentrations in smallmouth bass and cutthroat trout collected for this 2018 study are within the range for those species reported in other areas of North America lacking manufacturing or AFFF point sources. Our smallmouth bass fillet samples contained PFOS concentrations comparable to PFOS levels in smallmouth bass skin-on fillets collected from the Mississippi River in 2012, with a mean of 81 ng/g ww compared to an average of 59 ng/g ww, respectively (MPCA, 2013). MDEQ (2020b) reported a much lower average PFOS concentration for smallmouth bass fillets collected from the St. Joseph River (21.7 ng/g ww), outside of an urban area and far from point sources.

In this 2018 study, cutthroat trout samples contained 23.9–44.1 ng/g ww of PFOS. Whereas, lake trout fillets collected from the Great Lakes contained a wide PFOS range of 0.68–46 ng/g ww (Guo et al., 2012). Chu et al. (2016) reported PFOS concentrations in whole body lake trout collected from the Great Lakes near industrial/urban centers of 9.2–140 ng/g (median = 58.3 ng/g ww). As PFOS concentrations in whole body samples are typically 2–3 times higher than in fillet samples, these earlier concentrations are in line with concentrations in our 2018 samples.

Summary and Conclusions

Results of this 2018 study support the following conclusions:

- During the fall of 2018, Ecology collected 328 individual fish from Lake Meridian, Lake Sammamish, and Lake Washington. Individual fish fillets were composited into 76 samples and analyzed for 15 PFAS analytes. Largemouth bass, yellow perch, and brown bullhead were collected from each lake. Three additional species were encountered in limited sample sizes: smallmouth bass from Lake Meridian and Central Lake Washington, cutthroat trout from Central Lake Washington, and kokanee from Lake Meridian.
- PFOS was detected in all samples. Species-specific concentrations were similar across all sites in the three lakes. Of the three fish species collected from each lake, largemouth bass contained the highest PFOS concentrations and the widest range (range = 19.1–50.1 ng/g ww; median = 30.7 ng/g ww), followed by yellow perch (range = 4.1–19.8 ng/g ww; median = 14.4 ng/g ww), and brown bullhead (range = 0.52–4.81 ng/g ww; median = 2.1 ng/g ww). This consistency in species-specific concentrations across the urban lakes may suggest a diffuse source to the waterbodies associated with urban development.
- Results of the 2018 sampling confirm findings from Ecology's statewide surveys in 2008 and 2016 that urban lake freshwater fish tissue contain elevated PFOS concentrations, relative to other waterbody types across Washington State.
- The long-chain perfluoroalkyl carboxylates, PFDoA and PFUnA, were detected in all samples at low levels, with median concentrations of 1.31 and 0.96 ng/g ww, respectively. PFDA, PFTeA, and PFTrA were also frequently detected in almost all samples, with median concentrations of 1.34, 0.46, and 0.65 ng/g ww, respectively. Similar to PFOS, the species-specific concentration similarity across all sampling sites did not suggest any particular point source of the compounds.
- PFOA and the short-chain perfluoroalkyl acids (PFBS, PFHxS, PFPeA, PFHxA, and PFHpA) were not detected in any of the samples. NEtFOSAA was detected in one sample, and NMeFOSAA was detected in two samples at very low concentrations, below the quantitation limit. This study supports our findings from the 2008 and 2016 statewide surveys that these shorter compounds are not accumulating in freshwater fish.
- None of the fish analyzed for this study contained PFOS concentrations that suggest harm to the fish themselves; however, some species contained PFOS levels that may be harmful to wildlife that consume the fish. All largemouth bass, smallmouth bass, and kokanee analyzed had PFOS concentrations that exceeded Canada's guideline for wildlife diet, indicating these concentrations may not be protective of wildlife consuming the fish. Yellow perch collected from all sites, except for Central Lake Washington, had PFOS concentrations higher than both of Canada's mammal and avian wildlife diet guidelines. PFOS concentrations in all but one of the brown bullhead samples were below both of Canada's wildlife consumer diet guidelines.
- In general, the PFAS concentrations and detection frequencies among the three lakes were similar to other urban and industrial areas of the United States. The samples analyzed contained PFAS concentrations higher than in samples collected from reference waterbodies in other states, but lower than typically found in areas of contamination from manufacturing or AFFF releases.

Recommendations

Results of this 2018 study support the following recommendations:

- The Washington State Department of Health should review the data collected for this study. Their review will assess the potential human health effects of PFOS concentrations found in edible fish fillets of the species tested and determine suitable guidance for fish consumption for these three urban lakes.
- PFOS concentrations documented by this study confirm the need for investigation into sources and pathways of PFOS and other PFAS to urban waterbodies in Washington. This type of research would help identify potential inputs of PFOS and precursors that may inform where to make PFAS reductions in waterbodies and ultimately in fish. Ecology started this work in 2020 and is currently planning for a final report to be completed in 2023.
- Brown bullhead appear to be poor indicators of overall PFAS concentrations in freshwater systems. Future monitoring of PFAS should focus on other fish species and should include top predator species such as bass. Additional information on diet and trophic levels of fish sampled would be helpful for interpreting PFOS accumulation differences between similar species, such as largemouth and smallmouth bass.
- Follow-up monitoring of PFAS levels in urban-lake fish tissue should be considered in 5–10 years to assess potential declines in PFOS and other phased-out PFAS. Surface water should be collected concurrently with fish tissue for PFAS analysis.

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Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector, such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

AFFF	aqueous film-forming foam
BBH	brown bullhead
CTT	cutthroat trout
DOH	Washington State Department of Health
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
FEQG	Federal Environmental Quality Guidelines
KOK	kokanee
LMB	largemouth bass
LOQ	limit of quantitation
MEL	Manchester Environmental Laboratory
MQO	measurement quality objective
NEtFOSAA	N-ethyl perfluorooctanesulfonamidoacetate
NMeFOSAA	N-methyl perfluorooctanesulfonamidoacetate
PBT	persistent, bioaccumulative, and toxic substance
PFAA	perfluoroalkyl acid
PFAS	per- and polyfluoroalkyl substance
PFBS	perfluorobutane sulfonate
PFCA	perfluoroalkyl carboxylic acid
PFDA	perfluorodecanoate
PFDoA	perfluorododecanoate
PFHpA	perfluoroheptanoate
PFHxA	perfluorohexanoate
PFNA	perfluorononanoate

PFOA	perfluorooctanoate
PFOS	perfluorooctane sulfonate
PFPeA	perfluoropentanoate
PFSA	perfluoroalkyl sulfonate
PFTeA	perfluorotetradecanoate
PFTrA	perfluorotridecanoate
PFUnA	perfluoroundecanoate
QA	quality assurance
QC	quality control
SMB	smallmouth bass
SOP	standard operating procedure
T-	total-
USGS	U.S. Geological Survey
WRIA	Water Resource Inventory Area
WWTP	Wastewater treatment plant
YP	yellow perch

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
g	gram
km	kilometer
mm	millimeter
ng/g	nanograms per gram (parts per billion)
ww	wet weight

Appendices

Appendix A. Ancillary Data on Fish Samples

Table A-1. Biological and composite data on fish samples collected from Lake Sammamish and Lake Meridian.

Sample ID	Site	Species	Collection date	Number in composite	Ave. total length (mm)	Ave. field weight (g)	Ave. fish age (years)
1812019-01	Lake Sammamish	brown bullhead	10/15/2018	4	246	184	2.5
1812019-02		brown bullhead	10/15/2018	4	267	249	3
1812019-03		brown bullhead	10/15/2018	4	281	283	3
1812019-04		brown bullhead	10/15/2018	3	300	345	3
1812019-05		brown bullhead	10/15/2018	3	331	451	5.5
1812019-06		yellow perch	10/15/2018	5	165	56	1
1812019-07		yellow perch	10/15/2018	4	182	63	1.5
1812019-08		yellow perch	10/15/2018	3	203	90	2
1812019-09		yellow perch	10/15/2018	3	216	97	2.3
1812019-10		yellow perch	10/15/2018	3	244	165	2.3
1812019-11		largemouth bass	10/15/2018	5	200	107	1
1812019-12		largemouth bass	10/15/2018	5	227	165	1
1812019-13		largemouth bass	10/15/2018	5	269	299	1.4
1812019-14		largemouth bass	10/15/2018	5	391	1016	3.2
1812019-15		largemouth bass	10/15/2018	4	458	1417	4.5
1812019-16	Lake Meridian	brown bullhead	9/27/2018	5	218	146	1
1812019-17		brown bullhead	9/13/2018	5	264	264	1.8
1812019-18		brown bullhead	9/27/2018	5	297	370	2
1812019-19		brown bullhead	9/27/2018	5	331	562	3
1812019-20		brown bullhead	9/27/2018	5	352	681	3.5
1812019-21		largemouth bass	9/27/2018	4	213	134	1
1812019-22		largemouth bass	9/27/2018	5	236	182	1
1812019-23		largemouth bass	9/27/2018	5	280	346	1
1812019-24		largemouth bass	9/27/2018	3	425	1286	6
1812019-25		smallmouth bass	9/27/2018	4	390	918	3
1812019-76		smallmouth bass	9/27/2018	3	430	1287	5
1812019-26		kokanee	9/27/2018	4	263	200	1
1812019-27		kokanee	9/27/2018	4	290	280	1
1812019-28		kokanee	9/27/2018	4	309	297	1
1812019-29		yellow perch	9/27/2018	5	199	74	2.2
1812019-30		yellow perch	9/27/2018	5	221	110	2.5

Table A-2. Biological and composite data on fish samples collected from Lake Washington South and Central sites.

Sample ID	Site	Species	Collection date	Number in composite	Ave. total length (mm)	Ave. field weight (g)	Ave. fish age (years)
1812019-31	Lake Washington - South	brown bullhead	10/9/2018	5	186	93	1.4
1812019-32		brown bullhead	10/9/2018	5	237	164	2.6
1812019-33		brown bullhead	10/9/2018	5	255	208	3.4
1812019-34		brown bullhead	10/1/2018	5	279	286	3.4
1812019-35		brown bullhead	10/1/2018	5	303	361	4.3
1812019-36		largemouth bass	10/9/2018	5	192	88	1
1812019-37		largemouth bass	10/10/2018	5	219	146	1.2
1812019-38		largemouth bass	10/10/2018	3	332	491	2.3
1812019-39		yellow perch	10/1/2018	5	167	60	1
1812019-40		yellow perch	10/1/2018	4	184	79	1
1812019-41		yellow perch	10/1/2018	4	197	91	1.8
1812019-42		yellow perch	10/1/2018	3	233	137	3
1812019-43	Lake Washington - Central	brown bullhead	10/9/2018	5	184	82	1
1812019-44		brown bullhead	10/9/2018	5	214	132	1.8
1812019-45		brown bullhead	10/9/2018	5	263	225	3.2
1812019-46		brown bullhead	10/9/2018	5	275	291	3
1812019-47		brown bullhead	10/9/2018	5	306	381	3.4
1812019-48		cutthroat trout	10/4/2018	4	490	1365	3
1812019-49		cutthroat trout	10/4/2018	4	528	1790	3.7
1812019-50		largemouth bass	10/10/2018	5	207	141	1
1812019-51		largemouth bass	10/10/2018	4	215	149	1
1812019-52		largemouth bass	10/10/2018	4	222	165	1
1812019-53		largemouth bass	10/10/2018	4	246	235	1
1812019-54		largemouth bass	10/10/2018	4	446	1596	4.8
1812019-55		smallmouth bass	10/4/2018	3	420	1223	5
1812019-56		smallmouth bass	10/2/2018	3	436	1456	5
1812019-57		smallmouth bass	10/4/2018	3	508	1949	9
1812019-58		yellow perch	10/10/2018	5	173	64	1
1812019-59		yellow perch	10/10/2018	5	183	73	1.2
1812019-60		yellow perch	10/10/2018	5	217	118	2.2
1812019-61		yellow perch	10/10/2018	5	242	159	3

Table A-3. Biological and composite data on fish samples collected from Lake Washington North sites.

Sample ID	Site	Species	Collection date	Number in composite	Ave. total length (mm)	Ave. field weight (g)	Ave. fish age (years)
1812019-62	Lake Washington - North	brown bullhead	10/8/2018	5	170	71	1
1812019-63		brown bullhead	10/8/2018	5	221	147	1.6
1812019-64		brown bullhead	10/8/2018	4	260	231	2.8
1812019-65		brown bullhead	10/8/2018	5	272	301	3
1812019-66		brown bullhead	10/8/2018	4	308	380	3
1812019-67		largemouth bass	10/8/2018	5	185	133	1
1812019-68		largemouth bass	10/8/2018	5	193	179	1
1812019-69		largemouth bass	10/8/2018	5	208	178	1
1812019-70		largemouth bass	10/8/2018	5	232	228	1.2
1812019-71		largemouth bass	10/8/2018	5	267	302	1.4
1812019-72		yellow perch	10/8/2018	5	150	50	1
1812019-73		yellow perch	10/8/2018	5	153	53	1
1812019-74		yellow perch	10/8/2018	4	165	59	1
1812019-75		yellow perch	10/8/2018	4	210	107	2.3

Appendix B. Laboratory Results

Table B-1. PFAS concentrations (ng/g ww) in fish fillet composite samples collected in fall 2018.

Site/species	Sample ID 1812019-	NEtFOSAA	NMeFOSAA	PFBS	PFHxS	PFOS	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrA	PFTeA
Sammamish BBH	-01	0.47 U	0.47 U	0.47 U	0.47 U	**1.38**	0.47 U	0.47 U	0.47 U	0.47 U	0.47 U	**0.068 J**	**0.308 J**	**0.338 J**	**0.175 J**	**0.13 J**
Sammamish BBH	-02	0.429 U	0.429 U	0.429 U	0.429 U	**1.16**	0.429 U	0.429 U	0.429 U	0.429 U	0.429 U	**0.117 J**	**0.312 J**	**0.355 J**	**0.136 J**	**0.096 J**
Sammamish BBH	-03	0.473 U	0.473 U	0.473 U	0.473 U	**1.86**	0.473 U	0.473 U	0.473 U	0.473 U	0.473 U	**0.108 J**	**0.233 J**	**0.299 J**	**0.142 J**	**0.102 J**
Sammamish BBH	-04	**0.332 J**	0.474 U	0.474 U	0.474 U	**0.607 J**	0.474 U	0.474 U	0.474 U	0.474 U	0.474 U	0.474 U	**0.059 J**	**0.125 J**	**0.07 J**	**0.07 J**
Sammamish BBH	-05	0.486 U	0.486 U	0.486 U	0.486 U	**0.523**	0.486 U	0.486 U	0.486 U	0.486 U	0.486 U	0.486 U	**0.113 J**	**0.136 J**	**0.066 J**	**0.072 J**
Sammamish YP	-06	0.437 U	0.437 U	0.437 U	0.437 U	**19.8**	0.437 U	0.437 U	0.437 U	0.437 U	**0.226 J**	**0.981**	**0.275 J**	**0.198 J**	**0.191 J**	**0.196 J**
Sammamish YP	-07	0.458 U	0.458 U	0.458 U	0.458 U	**12.6**	0.458 U	0.458 U	0.458 U	0.458 U	**0.112 J**	**1.0**	**0.559**	0.506	**0.242 J**	**0.178 J**
Sammamish YP	-08	0.446 U	0.446 U	0.446 U	0.446 U	**8.97**	0.446 U	0.446 U	0.446 U	0.446 U	**0.064 J**	**0.844**	**0.755**	**0.817**	**0.394 J**	**0.23 J**
Sammamish YP	-09	0.404 U	0.404 U	0.404 U	0.404 U	**18**	0.404 U	0.404 U	0.404 U	0.404 U	**0.178 J**	**1.41**	**0.718**	**0.472**	**0.207 J**	**0.154 J**
Sammamish YP	-10	0.459 U	0.459 U	0.459 U	0.459 U	**17.8 J**	0.459 U	0.459 U	0.459 U	0.459 U	0.459 U	**1.53**	**1.38**	**1.2**	**0.365 J**	**0.209 J**
Sammamish LMB	-11	0.463 U	0.463 U	0.03 U	0.463 U	**25.9 J**	0.463 U	0.463 U	0.463 U	0.463 U	0.463 U	**2.05 J**	**2.21 J**	**2.28 J**	**0.883 J**	**0.613 J**
Sammamish LMB	-12	0.446 U	0.446 U	0.446 U	0.446 U	**30**	0.446 U	0.446 U	0.446 U	0.446 U	**0.098 J**	**2.33**	**2.15**	**1.97**	**0.788**	**0.576**
Sammamish LMB	-13	0.49 U	0.49 U	0.49 U	0.49 U	**43**	0.49 U	0.49 U	0.49 U	0.49 U	**0.19 J**	**2.76**	**1.21**	**0.96**	**0.49**	**0.411 J**
Sammamish LMB	-14	0.466 U	0.466 U	0.466 U	0.466 U	**50.1**	0.466 U	0.466 U	0.466 U	0.466 U	**0.162 J**	**3.71**	**2.05**	**1.88**	**0.915**	**0.702**
Sammamish LMB	-15	0.481 U	0.481 U	0.481 U	0.481 U	**40**	0.481 U	0.481 U	0.481 U	0.481 U	**0.054 J**	**2.86**	**1.76**	**1.93**	**0.885**	**0.712**
Meridian BBH	-16	0.414 U	0.414 U	0.414 U	0.414 U	**1.14**	0.414 U	0.414 U	0.414 U	0.414 U	0.414 U	**0.391 J**	**0.49**	**0.623**	**0.281 J**	**0.247 J**
Meridian BBH	-17	0.432 U	0.432 U	0.432 U	0.432 U	**1.02**	0.432 U	0.432 U	0.432 U	0.432 U	0.432 U	**0.277 J**	**0.335 J**	**0.621**	**0.232 J**	**0.209 J**
Meridian BBH	-18	0.463 U	0.463 U	0.463 U	0.463 U	**1.13**	0.463 U	0.463 U	0.463 U	0.463 U	0.463 U	**0.285 J**	**0.411 J**	**0.545**	**0.235 J**	**0.172 J**
Meridian BBH	-19	0.448 U	0.448 U	0.448 U	0.448 U	**0.936**	0.448 U	0.448 U	0.448 U	0.448 U	0.448 U	**0.154 J**	**0.33 J**	**0.552**	**0.299 J**	**0.244 J**
Meridian BBH	-20	0.468 U	0.468 U	0.468 U	0.468 U	**1.6**	0.468 U	0.468 U	0.468 U	0.468 U	0.468 U	**0.204 J**	**0.376 J**	**0.579**	**0.326 J**	**0.288 J**
Meridian LMB	-21	0.483 U	0.483 U	0.483 U	0.483 U	**23.3**	0.483 U	0.483 U	0.483 U	0.483 U	**0.503**	**2.64**	**1.54**	**1.73**	**0.715**	**0.534**
Meridian LMB	-22	0.475 U	0.475 U	0.475 U	0.475 U	**31.4**	0.475 U	0.475 U	0.475 U	0.475 U	**0.131 J**	**2.85**	**1.25**	**1.23**	**0.65**	**0.521**
Meridian LMB	-23	0.488 U	0.488 U	0.488 U	0.488 U	**23**	0.488 U	0.488 U	0.488 U	0.488 U	0.488 U	**1.99**	**1.33**	**1.72**	**0.887**	**0.674**
Meridian LMB	-24	0.495 U	0.495 U	0.495 U	0.495 U	**19.2**	0.495 U	0.495 U	0.495 U	0.495 U	0.495 U	**1.65**	**1.36**	**1.83**	**1.06**	**0.786**
Meridian SMB	-25	2.27 U	2.27 U	2.27 U	2.27 U	**64.1**	2.27 U	2.27 U	2.27 U	2.27 U	2.27 U	**6.24**	**2.87**	**2.94**	**1.86 J**	**2.04 J**
Meridian SMB	-76	0.478 U	0.478 U	0.478 U	0.478 U	**60**	0.478 U	0.478 U	0.478 U	0.478 U	0.478 U	**5.75**	**2.76**	**2.76**	**1.67 J**	**1.44**
Meridian KOK	-26	0.493 U	0.493 U	0.493 U	0.493 U	**7.88**	0.493 U	0.493 U	0.493 U	0.493 U	**0.118 J**	**0.678**	**0.152 J**	**0.148 J**	**0.168 J**	**0.17 J**
Meridian KOK	-27	0.421 U	0.421 U	0.421 U	0.421 U	**6.4**	0.421 U	0.421 U	0.421 U	0.421 U	**0.094 J**	**0.488**	**0.116 J**	**0.114 J**	**0.113 J**	**0.17 J**

Site/species	Sample ID 1812019-	NEtFOSAA	NMeFOSAA	PFBS	PFHxS	PFOS	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrA	PFTeA
Meridian KOK	-28	0.406 U	0.406 U	0.406 U	0.406 U	**7.67**	0.406 U	0.406 U	0.406 U	0.406 U	**0.102 J**	**0.682**	**0.172 J**	**0.2 J**	**0.208 J**	**0.213 J**
Meridian YP	-29	0.495 U	0.495 U	0.495 U	0.495 U	**10.8**	0.495 U	0.495 U	0.495 U	0.495 U	0.495 U	**1.29**	**0.886**	**1.1**	**0.529**	**0.41 J**
Meridian YP	-30	0.474 U	0.474 U	0.474 U	0.474 U	**10.7**	0.474 U	0.474 U	0.474 U	0.474 U	0.474 U	**1.39**	**0.917**	**1.35**	**0.71**	**0.526**
WA - South BBH	-31	0.414 U	0.414 U	0.414 U	0.414 U	**4.81**	0.414 U	0.414 U	0.414 U	0.414 U	0.414 U	**1.07**	**1.1**	**1.19**	**0.402 J**	**0.298 J**
WA - South BBH	-32	0.415 U	0.415 U	0.415 U	0.415 U	**2.8**	0.415 U	0.415 U	0.415 U	0.415 U	0.415 U	**0.516**	**0.973**	**1.52**	**0.677**	**0.491**
WA - South BBH	-33	0.442 U	0.442 U	0.442 U	0.442 U	**2.6**	0.442 U	0.442 U	0.442 U	0.442 U	0.442 U	**0.369 J**	**0.673**	**1.07**	**0.56**	**0.444**
WA - South BBH	-34	0.447 U	0.447 U	0.447 U	0.447 U	**2.41**	0.447 U	0.447 U	0.447 U	0.447 U	0.447 U	**0.247 J**	**0.529**	**0.854**	**0.497**	**0.422 J**
WA - South BBH	-35	0.419 U	0.419 U	0.419 U	0.419 U	**2.32**	0.419 U	0.419 U	0.419 U	0.419 U	0.419 U	**0.121 J**	**0.355 J**	**0.873 J**	**0.538 J**	**0.456 J**
WA - South LMB	-36	0.457 U	0.457 U	0.457 U	0.457 U	**35**	0.457 U	0.457 U	0.457 U	0.457 U	**0.064 J**	**3.72**	**3.59**	**4.86**	**1.74**	**0.83**
WA - South LMB	-37	0.493 U	0.493 U	0.493 U	0.493 U	**26.4**	0.493 U	0.493 U	0.493 U	0.493 U	0.493 U	**2.38**	**2.32**	**3.39**	**1.56**	**0.931**
WA - South LMB	-38	0.403 U	0.403 U	0.403 U	0.403 U	**43**	0.403 U	0.403 U	0.403 U	0.403 U	**0.084 J**	**4.68**	**3.35**	**3.4**	**1.43**	**0.813**
WA - South YP	-39	0.417 U	0.417 U	0.417 U	0.417 U	**14.4**	0.417 U	0.417 U	0.417 U	0.417 U	**0.105 J**	**1.38**	**1.18**	**1.91**	**0.881**	**0.639**
WA - South YP	-40	0.446 U	0.446 U	0.446 U	0.446 U	**12.7**	0.446 U	0.446 U	0.446 U	0.446 U	0.446 U	**0.797**	**0.373 J**	**0.422 J**	**0.314 J**	**0.312 J**
WA - South YP	-41	0.471 U	0.471 U	0.471 U	0.471 U	**19.6**	0.471 U	0.471 U	0.471 U	0.471 U	**0.068 J**	**1.72**	**1.01**	**0.919**	**0.403 J**	0.345 U
WA - South YP	-42	0.434 U	0.434 U	0.434 U	0.434 U	**15.3**	0.434 U	0.434 U	0.434 U	0.434 U	0.434 U	**1.7**	**1.37**	**1.47**	**0.559 J**	0.375 U
WA - Central BBH	-43	0.409 U	0.409 U	0.409 U	0.409 U	**2**	0.409 U	0.409 U	0.409 U	0.409 U	0.409 U	**0.424**	**0.678**	**2**	**0.764 J**	**1.26**
WA - Central BBH	-44	0.443 U	0.443 U	0.443 U	0.443 U	**2.04**	0.443 U	0.443 U	0.443 U	0.443 U	0.443 U	**0.236 J**	**0.497**	**1.65**	**0.752 J**	**1.47**
WA - Central BBH	-45	0.445 U	0.445 U	0.445 U	0.445 U	**1.33**	0.445 U	0.445 U	0.445 U	0.445 U	0.445 U	**0.192 J**	**0.46**	**1.58**	**0.652 J**	1.01 U
WA - Central BBH	-46	0.443 U	0.443 U	0.443 U	0.443 U	**1.45**	0.443 U	0.443 U	0.443 U	0.443 U	0.443 U	**0.168 J**	**0.438 J**	**1.27**	**0.599 J**	**1.3**
WA - Central BBH	-47	0.413 U	0.413 U	0.413 U	0.413 U	**1.83**	0.413 U	0.413 U	0.413 U	0.413 U	0.413 U	**0.195 J**	**0.445**	**1.17**	**0.656 J**	**1.38**
WA - Central CTT	-48	0.394 U	0.394 U	0.394 U	0.394 U	**23.9**	0.394 U	0.394 U	0.394 U	0.394 U	**0.372 J**	**2.24**	**2.16**	**1.67**	**0.645 J**	0.618 U
WA - Central CTT	-49	0.403 U	0.403 U	0.403 U	0.403 U	**44.1**	0.403 U	0.403 U	0.403 U	0.403 U	**0.49**	**4.64**	**4.84**	**3.93**	**1.41 J**	**1.36**
WA - Central LMB	-50	0.432 U	0.432 U	0.432 U	0.432 U	**19.1**	0.432 U	0.432 U	0.432 U	0.432 U	0.432 U	**1.3**	**1.46**	**2.21**	**0.808 J**	0.81 U
WA - Central LMB	-51	0.43 U	0.43 U	0.43 U	0.43 U	**36.8**	0.43 U	0.43 U	0.43 U	0.43 U	0.43 U	**2.3**	**1.47**	**2.24**	**0.889 J**	0.717 U
WA - Central LMB	-52	0.467 U	0.467 U	0.467 U	0.467 U	**34.3**	0.467 U	0.467 U	0.467 U	0.467 U	0.467 U	**1.87**	**1.62**	**2.56**	**1.03 J**	0.73 U
WA - Central LMB	-53	0.418 U	0.418 U	0.418 U	0.418 U	**35.3**	0.418 U	0.418 U	0.418 U	0.418 U	0.418 U	**2.42**	**1.95**	**2.34**	**0.999 J**	0.759 U
WA - Central LMB	-54	0.44 U	0.44 U	0.44 U	0.44 U	**28.6**	0.44 U	0.44 U	0.44 U	0.44 U	0.44 U	**2.21**	**1.63**	**2.36**	**1.11 J**	0.76 U
WA - Central SMB	-55	0.429 U	0.429 U	0.429 U	0.429 U	**86**	0.429 U	0.429 U	0.429 U	0.429 U	0.429 U	**9.07**	**11.3**	**10.6**	**4.49 J**	**3.19**
WA - Central SMB	-56	0.487 U	**0.136 J**	0.487 U	0.487 U	**95.5**	0.487 U	0.487 U	0.487 U	0.487 U	0.487 U	**10**	**10.7**	**9.19**	**3.8 J**	**2.64**
WA - Central SMB	-57	0.45 U	**0.209 J**	0.45 U	0.45 U	**99.9**	0.45 U	0.45 U	0.45 U	0.45 U	0.45 U	**9.36**	**7.72**	**6.75**	**2.79 J**	**1.97**
WA - Central YP	-58	0.459 U	0.459 U	0.459 U	0.459 U	**4.06**	0.459 U	0.459 U	0.459 U	0.459 U	0.459 U	**0.316 J**	**0.248 J**	**0.698**	**0.492 J**	0.459 U
WA - Central YP	-59	0.45 U	0.45 U	0.45 U	0.45 U	**5.92**	0.45 U	0.45 U	0.45 U	0.45 U	0.45 U	**0.422 J**	**0.222 J**	**0.573**	**0.416 J**	0.45 U

Site/species	Sample ID 1812019-	NEtFOSAA	NMeFOSAA	PFBS	PFHxS	PFOS	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrA	PFTeA
WA - Central YP	-60	0.496 U	0.496 U	0.496 U	0.496 U	**7.92**	0.496 U	0.496 U	0.496 U	0.496 U	0.496 U	**0.752**	**0.522**	**1.26**	**0.668 J**	0.714 U
WA - Central YP	-61	0.438 U	0.438 U	0.438 U	0.438 U	**11.2**	0.438 U	0.438 U	0.438 U	0.438 U	0.438 U	**1.15**	**0.886**	**1.75**	**0.861 J**	**1.07**
WA - North BBH	-62	0.475 U	0.475 U	0.475 U	0.475 U	**4.02**	0.475 U	0.475 U	0.475 U	0.475 U	0.475 U	**0.477**	**0.549**	**0.733**	0.475 UJ	0.475 U
WA - North BBH	-63	0.446 U	0.446 U	0.446 U	0.446 U	**2.91**	0.446 U	0.446 U	0.446 U	0.446 U	0.446 U	**0.375 J**	**0.627**	**0.917**	**0.375 J**	**0.389 J**
WA - North BBH	-64	0.482 U	0.482 U	0.482 U	0.482 U	**2.19**	0.482 U	0.482 U	0.482 U	0.482 U	0.482 U	**0.264 J**	**0.495**	**0.892**	**0.389 J**	**0.422 J**
WA - North BBH	-65	0.448 U	0.448 U	0.448 U	0.448 U	**3.7**	0.448 U	0.448 U	0.448 U	0.448 U	0.448 U	**0.381 J**	**0.705**	**0.994**	**0.485 J**	**0.44 J**
WA - North BBH	-66	0.459 U	0.459 U	0.459 U	0.459 U	**2.59**	0.459 U	0.459 U	0.459 U	0.459 U	0.459 U	**0.198 J**	**0.581**	**0.88**	**0.397 J**	**0.355 J**
WA - North LMB	-67	0.41 U	0.41 U	0.41 U	0.41 U	**22.8**	0.41 U	0.41 U	0.41 U	0.41 U	0.41 U	**1.25**	**1.24**	**1.97**	**0.856 J**	**0.699**
WA - North LMB	-68	0.421 U	0.421 U	0.421 U	0.421 U	**27.1**	0.421 U	0.421 U	0.421 U	0.421 U	0.421 U	**1.49**	**1.51**	**2.08**	**0.882 J**	**0.721**
WA - North LMB	-69	0.437 U	0.437 U	0.437 U	0.437 U	**28.4**	0.437 U	0.437 U	0.437 U	0.437 U	0.437 U	**1.69**	**1.95**	**2.84**	**1.25 J**	**1.02**
WA - North LMB	-70	0.414 U	0.414 U	0.414 U	0.414 U	**33.4**	0.414 U	0.414 U	0.414 U	0.414 U	0.414 U	**2.11**	**2.24**	**3.18**	**1.53 J**	**1.22**
WA - North LMB	-71	0.498 U	0.498 U	0.498 U	0.498 U	**38.1**	0.498 U	0.498 U	0.498 U	0.498 U	0.498 U	**2.22**	**1.94**	**2.43**	**1.14 J**	**0.845**
WA - North YP	-72	0.488 U	0.488 U	0.488 U	0.488 U	**17.7**	0.488 U	0.488 U	0.488 U	0.488 U	**0.178 J**	**2.32**	**1.45**	**1.46**	**0.475 J**	**0.34 J**
WA - North YP	-73	0.467 U	0.467 U	0.467 U	0.467 U	**17.1**	0.467 U	0.467 U	0.467 U	0.467 U	**0.148 J**	**2.03**	**1.3**	**1.68**	**0.687 J**	**0.618**
WA - North YP	-74	0.411 U	0.411 U	0.411 U	0.411 U	**14.4**	0.411 U	0.411 U	0.411 U	0.411 U	**0.074 J**	**1.46**	**1.19**	**1.65**	**0.539 J**	**0.426**
WA - North YP	-75	0.458 U	0.458 U	0.458 U	0.458 U	**18.5**	0.458 U	0.458 U	0.458 U	0.458 U	0.458 U	**1.58**	**0.952**	**1.12**	**0.518 J**	**0.423 J**

BBH = brown bullhead; YP = yellow perch; LMB = largemouth bass; SMB = smallmouth bass; KOK = kokanee; CTT = cutthroat trout.
Full analyte names are spelled out in the Glossary, Acronyms, and Abbreviations section.
U = Analyte not detected at or above the reported value.
J = Analyte was positively identified and the associated value is an estimated concentration.

Appendix C. Correlations

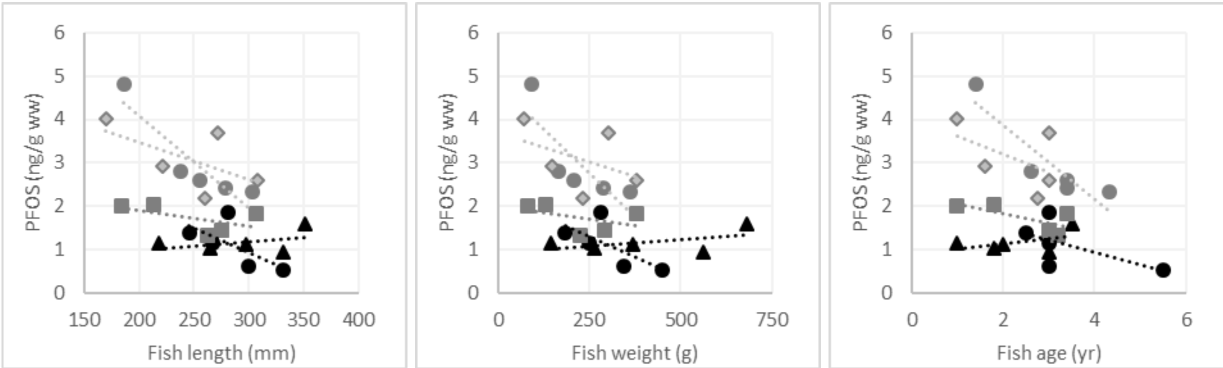

Figure C-1. Brown bullhead correlations between PFOS concentrations and fish size/age.

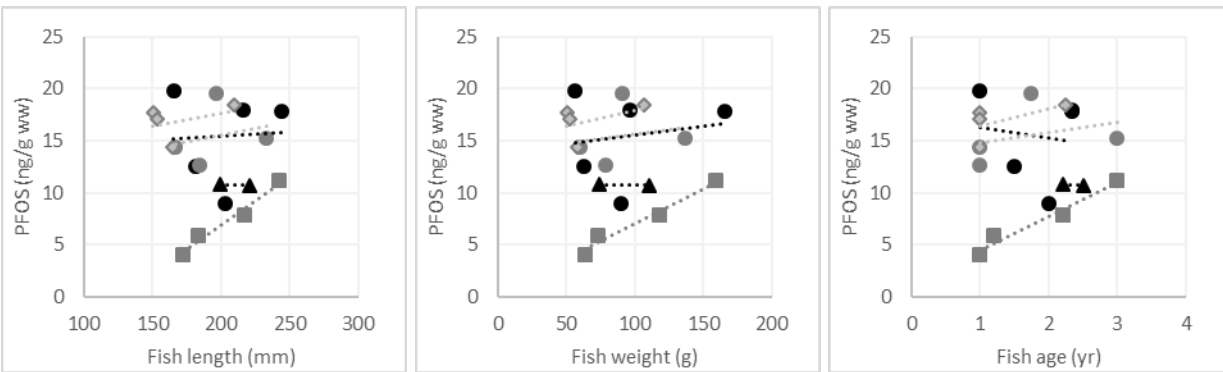

Figure C-2. Yellow perch correlations between PFOS concentrations and fish size/age.

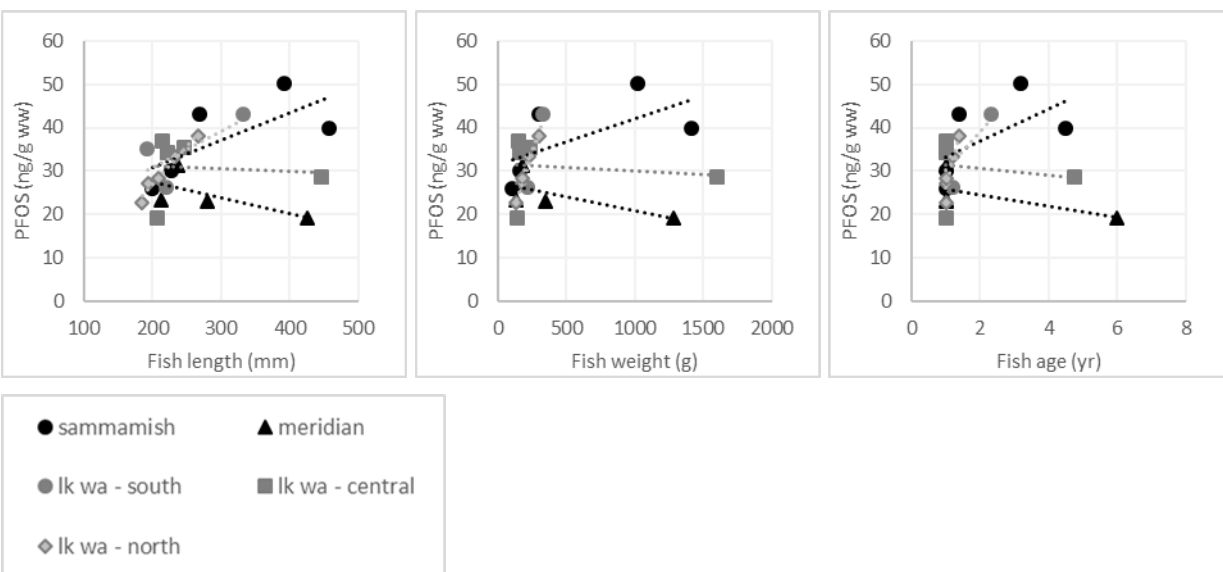

Figure C-3. Largemouth bass correlations between PFOS concentrations and fish size/age.