Freshwater Fish Contaminant Monitoring Program

2015 Results

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Cover photo: Electrofishing boat at Green Lake in Seattle.

Freshwater Fish Contaminant Monitoring Program

2015 Results

by

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Water Resource Inventory Area (WRIA) and 12-digit Hydrologic Unit Code (HUC) numbers for the study area:

WRIAs

- Lake Washington: 08 Cedar Sammamish
- Green Lake: 08 Cedar Sammamish
- Ross Lake: 04 Upper Skagit

HUC numbers

- Lake Washington: 171100120400
- Green Lake: 171100120400
- Ross Lake: 171100050602

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Abstract

The Department of Ecology's Freshwater Fish Contaminant Monitoring Program analyzed fish collected from three lakes in 2015: Washington, Ross, and Green. Key results are described for these lakes. Goals were to characterize: (1) contaminant concentrations in fish tissue and (2) temporal patterns.

- In Lake Washington (King County), multiple species of fish continue to have high concentrations of contaminants, especially PCBs, PBDEs, dioxins/furans, DDTs, chlordanes, and mercury. Concentration of some of these contaminants appear to have decreased between 2005 and 2015. Yet only large-sized cutthroat trout showed statistically significant changes for t-PCB, t-PBDE, t-DDT, and mercury; with mean concentrations decreasing by 55-75%, 69%, 54%, and 40%, respectively.
- In Green Lake (Seattle), multiple species have elevated levels of various contaminants, especially PCBs, dioxin/furans, chlordanes, and hexachlorobenzene.
- In Ross Lake (North Cascades National Park), contaminant concentrations remained low. Concentrations of metals in Ross Lake fish appeared similar to those found across Washington.

Temporal trends were not determined for Green and Ross Lakes because of the low numbers of samples in historic data sets. The 2015 sample sets should serve as a good baseline for future comparisons.

Based on the 2015 results for Lake Washington and Green Lake, the Washington Department of Health did not revise the Fish Consumption Advisories for these lakes.

Recommendations include sampling again for temporal trends in 10-15 years, targeting key species and size ranges, and collecting five to seven field replicates in order to increase the sensitivity of trend detection.

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Introduction

Freshwater Fish Contaminant Monitoring Program

Since 2001, the Washington State Department of Ecology's (Ecology) Freshwater Fish Contaminant Monitoring Program (FFCMP)[1] has characterized persistent, bioaccumulative, and toxic chemicals (PBTs) in freshwater fish statewide with analysis of over 730 fish tissue samples from 170 sites. The FFCMP has two broad goals: (1) long-term monitoring for temporal trends and (2) exploratory monitoring to characterize the extent of contamination in areas of interest.

Results from fish contaminant monitoring are used for a variety of purposes, such as water quality assessments, health risk assessments, determining total maximum daily load (TMDL) effectiveness, and evaluating spatial and temporal trends. Target analytes are most often mercury, polychlorinated biphenyls (PCBs), dioxins and furans (polychlorinated dibenzo-p-dioxins and -furans, or PCDD/Fs), chlorinated pesticides (CPs), such as dichloro-diphenyl-trichloroethane (DDT) and its breakdown products (DDD and DDE), and polybrominated diphenyl ethers (PBDEs). More information about some of these and other chemicals is at https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals.

The accumulation of contaminants can have a variety of health effects on humans and wildlife, such as reproductive abnormalities, neurological problems, and behavioral changes. A primary route of exposure for people is through the consumption of contaminated food, particularly fish. The Washington State Department of Health (Health) currently has a statewide fish consumption advisory (FCA) for mercury in bass and northern pikeminnow. There are also 16 site-specific advisories due to contamination of fish by various chemicals: www.doh.wa.gov/CommunityandEnvironment/Food/Fish.aspx.

The 2015 sampling focused on Lake Washington and Ross Lake in order to take advantage of other fish-related research in these waterbodies. The 2015 plan also included Green Lake in Seattle which had been sampled in 2001. Figure 1 shows the general sampling locations while Appendix A shows sample location coordinates and a map of Lake Washington fish collection sites. A review of historical data from these lakes helped determine the species, analytes, and sample sizes to meet the goals of the ongoing monitoring project. The original plan to sample the Walla Walla River in 2015 was abandoned because the statewide drought led to low flows and high temperatures which would have hampered sample collection.

Lake Washington and Green Lake were original target sites for long-term monitoring because of their high contaminant levels and the presence of fish consumption advisories. Sampling at Ross Lake helps support National Park Service concerns about potential mining activities in part of the watershed that lies within the province of British Columbia, Canada. Monitoring or data analyses to measure statistically significant temporal changes have not been pursued in any of these areas with one exception: King County developed a long-term fish tissue monitoring plan

[1] https://ecology.wa.gov/Research-Data/Monitoring-assessment/toxics-monitoring/Freshwater-fish-contaminant-monitoring

in 2010 (King County, 2010) for several areas, including Lake Washington. Challenges for long-term monitoring programs have been small sample sizes, high variability associated with fish tissue, and high costs associated with laboratory analyses for organic contaminants.

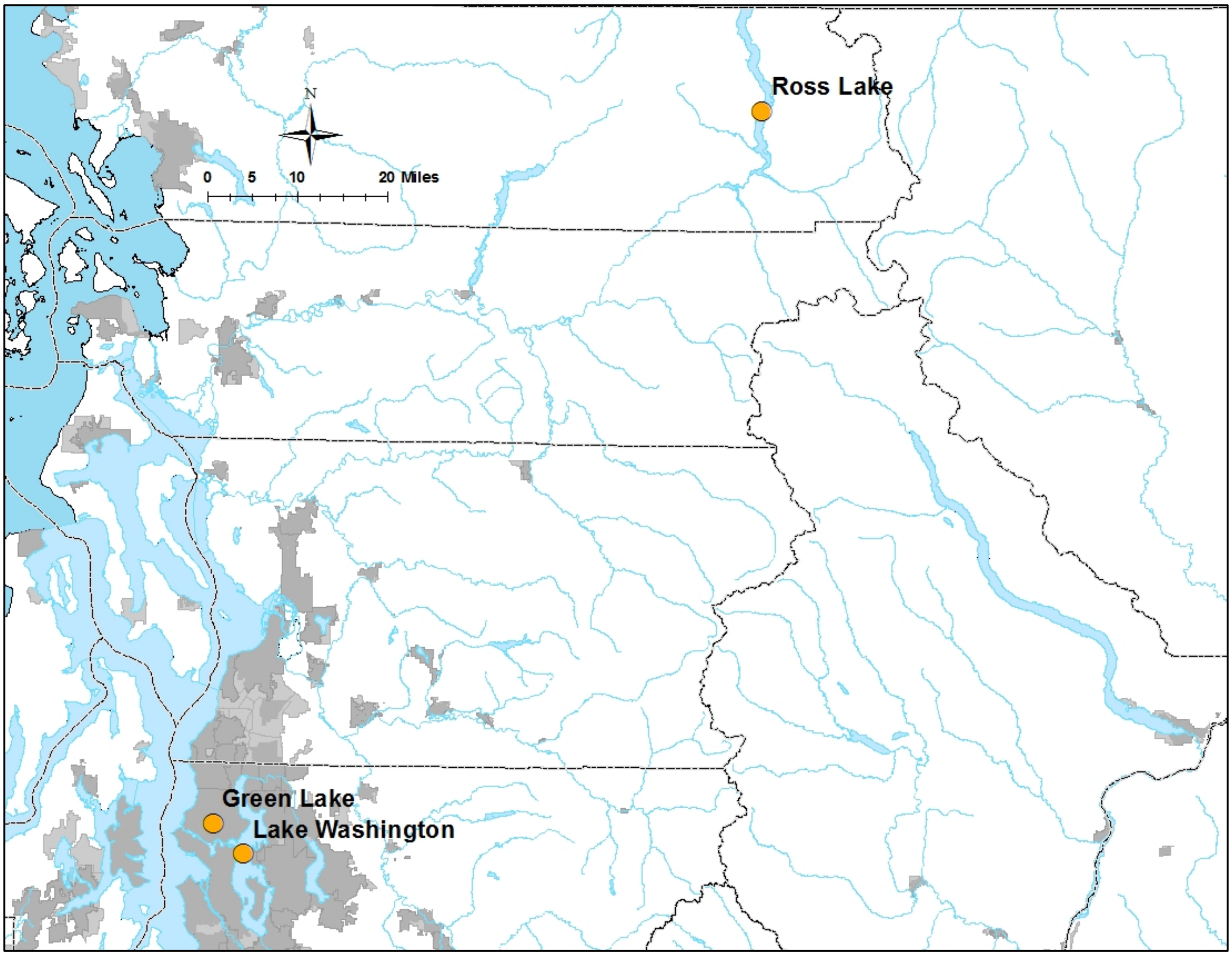

Figure 1. Sample locations for the 2015 FFCMP.

Our 2015 monitoring targeted sites and species that were sampled historically in order to gain a temporal perspective where possible. The goal of the 2015 monitoring was to develop a robust data set of contaminant levels in fish from Lake Washington, Green Lake, and Ross Lake in order to:

- Compare results to water quality standards.
- Support fish consumption risk assessments by health jurisdictions.
- Characterize temporal trends by comparisons to historical and future monitoring data.
- Inform future work such as developing pollution control programs.

Lake Washington

Several fish tissue monitoring projects in Lake Washington have been conducted since 2003 and were summarized in the project plan (Seiders, 2015). These projects characterized the nature and extent of contaminants in various species of fish. While these studies shared similar goals, the different objectives and levels of effort resulted in a historical data set that is a mix of species, tissue types, target analytes, analytical methods and collection seasons.

Contaminants of concern include various organic compounds. Concentrations of PCBs (10-1339 ug/kg) and PCDD/Fs (4.6-11.9 ng/kg as Toxic Equivalent [TEQ] to the most toxic PCDD/F congener which is 2,3,7,8-tetra-chloro dibenzo-p-dioxin, or TCDD) in fillet tissue from common carp, cutthroat trout, and northern pikeminnow are among the highest found in Washington. Other compounds showing relatively high levels among different species include PBDEs, DDTs, chlordanes, and mercury. Concentration of PCBs in fish is of particular interest for trend detection because of the Fish Consumption Advisory (Figure 2) and work by King County to address PCBs (King County, 2010, 2013, 2014a, 2014b).

Figure 2. Fish consumption advisory sign for Lake Washington.

These past projects yielded information that supported key actions by state and local jurisdictions. These actions included:

- Fish Consumption Interim Advisory in 2004 for PCBs and mercury (Hardy and McBride, 2004); https://www.doh.wa.gov/CommunityandEnvironment/Food/Fish/Advisories.
- Clean Water Act Section 303(d) listings for PCBs, chlorinated pesticides, dioxin, and mercury beginning in 2004 (https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d).

This 2015 FFCMP study compares results to those obtained in 2005. In 2005, Health obtained fish from Washington Department of Fish and Wildlife's sampling activity in Lake Washington and analyzed fillet tissues for various contaminants (McBride, 2005). A subset of these samples were analyzed by Ecology for additional parameters (Seiders et al., 2007). In 2015, Ecology obtained fish from Lake Washington which were collected by the Washington Cooperative Fish and Wildlife Research Unit at the University of Washington to support a predation study (Clark and Beauchamp, 2015).

Green Lake

Green Lake, in Seattle, was sampled in 2001 by the Washington State Toxics Monitoring Program (WSTMP), the forerunner of the FFCMP. Common carp was the only species analyzed for organic contaminants and results led to a Fish Consumption Advisory because of high levels of PCBs. Other chemicals detected in fillet tissue were chlordanes, DDTs, dioxins/furans, mercury, and PBDEs.

Green Lake has a history with undesirable aquatic plant infestations and treatments, often with mechanical removal and applications of alum to reduce internal phosphorus loading. Mueller and Downen (2000) summarize this history and describe how the increasing population of common carp contributed to these water quality problems. King County (2014c; http://green2.kingcounty.gov/smalllakes/LakePage.aspx) and Herrera Environmental Consultants, Inc. (2017) continue to address water quality concerns associated with phosphorus loading. Green Lake is a popular park used by many for boating, swimming, and fishing. The recreational fishery at Green Lake is managed for several species, with stocked rainbow trout being very popular (WDFW, 2015: http://wdfw.wa.gov/fishing/washington/22/).

Ross Lake

Ross Lake lies in North Cascades National Park and is now a reservoir formed by Ross Dam. Concerns about future contamination from a proposed copper mine in the watershed led Park staff to ask Ecology to analyze trout samples for metals. Park staff identified cadmium and chromium to be of particular concern. Other metals of concern include arsenic, copper, lead, mercury, silver, and zinc.

Trout collected from Ross Lake in 2007 and 2012 were previously analyzed by the FFCMP. Results from 2007 showed that PCBs, 4,4'-DDE, PBDEs, and PCDD/Fs were present at low levels in two samples of bull and rainbow trout. In 2012 samples, concentrations of chromium, copper, selenium, and zinc in samples from three trout species were detected at levels typically seen in other fish fillet tissue samples across Washington. (Seiders and Deligeannis, 2009; Seiders et al., 2014).

In 2015, Park staff collected nearly 70 rainbow trout and native char for Ecology to analyze. A larger number of composite samples (five) for each species were formed and analyzed for metals and other contaminants. The native char that were collected could have been either bull trout or Dolly Varden: taxonomic identification to the species level would require DNA analysis which was not performed.

Methods

Field and Laboratory Methods

Sample design, collection, preparation, and analytical methods followed those described in the project plan and Addendum 4 for the FFCMP (Seiders, 2013 and 2015). The sampling design was crafted to help reduce the effects of high variability of pollutant levels often seen in fish tissue. In general, the sampling design addresses sample representativeness, sample size, comparability of results to other studies, frequency of sampling, and other factors that can affect the usability of the data. For example, a sampling frequency of about 10 years allows for sampling a different generation of fish (for most species) than was historically sampled.

Fish collection by Ecology was conducted under several scientific collection permits. These were: National Marine Fisheries Service permit # 1386-7A; U.S. Fish and Wildlife Permit # TE058381-8; Washington Department of Fish and Wildlife Permit # 12-298-F, and Seattle Parks and Recreation Permit # 342397. Lake Washington fish were collected from multiple sites throughout the entire lake by gill net and purse seiner (Figure 3) during a predation study conducted by the University of Washington, School of Fisheries (Clark and Beauchamp, 2015). Green Lake was sampled with gillnets and electrofishing (Figure 3). Ross Lake fish were obtained from throughout the lake by North Cascades National Park Service staff (Anthony, 2015).

Figure 3. Fish collection methods: *left*- purse seiner; *right*- electrofishing boat.

A total of 66 samples of fish tissue were analyzed for some or all of these chemicals: chlorinated pesticides, mercury, PBDEs, PCBs, and PCDD/Fs. All results were reported on a wet-weight basis. For PCBs, all samples were analyzed for Aroclors while a subset of samples were analyzed for all 209 congeners using EPA Method 1668c. Aroclor results were used in this report because the Aroclor method was used for all 2015 samples and in samples from historical studies.

Results for congeners are not discussed in this report: these analyses were done to supplement data that can address broader interests than the scope of the FFCMP. These interests include evaluating comparisons to other fish samples (statewide) having PCB Aroclor or congener data and informing statewide strategies for addressing PCB contamination in the environment.

Multiple composite samples of the same species were collected at most sites in order to reduce address sampling variability and improve the strength of statistical tests to determine spatial or temporal trends. We tried to obtain five to seven composite samples for each species and size range. These numbers of composite samples have been found to reduce variability at manageable sampling and analytical costs. As we learn more about the variability in the sampled population, we should consider using various algorithms to optimize sampling approaches, such as those suggested by Rohlf et al. (1996) and Zar (1984).

Review of historical data helped determine the species and fish sizes to be collected that would improve the comparability of results among sites and studies. Most composite samples consisted of skin-on fillets from five individual fish of a similar size of the same species per site, except for largescale suckers which were processed as whole fish. Appendix B describes sample collection and processing in more detail.

Table 1 shows the number of composite samples that were analyzed for each species and size class in each waterbody.

Table 1. Sites, species, samples, and analyses of composite samples, FFCMP, 2015.

Sites	Species and size code	Number of Composite Samples for Each Analysis						
		Total number of samples	Hg	Metals (13)	3 PCB Aroclors, 3 DDTs, lipid	Cl Pest, PCB Aroclor, PBDE, lipid	PCB congener	PCDD/F
Lake Washington	CCP-L	1	1			1	1	1
	CCP-M	2	2			2	2	2
	CCP-S	1	1			1	1	1
	CTT-L	5	5		2	3	3	3
	CTT-S	3	3			3		
	LSS	7	7		4	3		
	NPM	7	7		4	3	3	3
	SMB-L	5	5		2	3	3	3
	SMB-S	3	3			3		
	YP	3	3			3		
Green Lake	BBH	3	3			3		
	CCP-L	3	3			3		
	CCP-S	5	5		2	3		3
	RBT-L	1	1			1	1	1
	RBT-S	3	3			3	3	3
	RKB	3	3			3		
	YP	1	1			1		
Ross Lake	NC-L	1	1	1		1		
	NC-M	3	3	3		3	3	
	NC-S	1	1	1		1		
	RBT	5	5	5		5	3	
Total # analyses		66	66	10	14	52	23	20

Species codes: BBH: Brown bullhead; CCP: Common carp; CTT: Cutthroat trout; LSS: Largescale sucker; NC: Native char; NPM: Northern pikeminnow, RBT: Rainbow trout; RKB: Rock bass; SMB: Smallmouth bass; YP: Yellow perch. Relative size groups: L-large size, M-Medium size; S-small size.

Data Quality Assessment

General

The quality of laboratory results from the 2015 study was assessed by reviewing laboratory case narratives, analytical results, and field replicate data. Quality control procedures included a mixture of analyses such as method blanks, calibration and control standards, matrix spikes, matrix spike duplicates, surrogate recoveries, laboratory duplicates, and field replicates.

All laboratory analyses were completed and only 33 results were rejected, which results in a 99.7% completion value for laboratory analyses. The rejected results were acid-labile chlorinated pesticides in three field replicates of whole largescale suckers: pesticides which we've rarely detected in fish tissue. Results from laboratory analyses were heavily qualified, which is common with the analytical interferences associated with the matrix of fish tissue. Overall, most of the 2015 data met measurement quality objectives and other data quality targets described in the project plans (Seiders, 2013 and 2015). All results were deemed usable as qualified.

The field sampling came close to meeting the original goal for completeness. While some species were not found as anticipated, other species that were collected were used instead (e.g. rock bass used instead of largemouth bass in Green Lake). Overall, adequate samples were collected to meet project objectives.

As with many fish tissue studies, the sampling methods result in fish that were collected from multiple locations and habitats across the entire waterbody. The samples from each of the lakes were thus deemed to be representative of the entire waterbody.

The quality and comparability of historical data were examined by reviewing the individual study reports with emphasis on field, laboratory, and quality assurance procedures. Most of the historical studies were in Ecology's Environmental Information Management (EIM) system, and in most cases, data from historical studies were deemed acceptable as qualified for use in this report. Further assessment of data quality is beyond the scope of this report, except for the following section on comparability of PCB results. Additional quality assurance information is available by contacting the authors of this report.

Comparability of PCB Results

Results from PCB analyses were examined more closely in order to evaluate the comparability of PCB data generated from two different methods, and to evaluate the usability of N-flagged PCB Aroclor results in this report. These efforts are summarized below and described further in Appendix C.

Results from two PCB analytical methods, EPA 8082 and EPA 1668, were evaluated to determine the comparability of data produced by the different methods. Analysis of PCB congeners using EPA Method 1668 has been done numerous times for the FFCMP since 2004. The congener analyses were done on a subset of each year's samples since 2004 which allows the evaluation of accuracy and comparability of results from the Aroclor analyses (EPA Method 8082) performed by MEL since 2004. Analyses for PCB Aroclors in fish tissue presents many challenges, such as poor pattern matches to standards because of weathering or degradation as well as interference due to high lipids content or the presence of other analytes.

Findings from this two-method comparison suggest that the methods yield adequately comparable data for most needs of this project (as described in the project plans), including for trends analyses. However, the congener method may be preferable to use in cases where lower concentrations (e.g. < 10 ug/kg) in samples will be compared to numerical thresholds that trigger important decisions, such as 303(d) listings. Appendix C describes the evaluation of results from the two methods.

In order to maximize the use of historical PCB Aroclor data for trends analyses in Lake Washington (i.e. to increase sample n), the data qualifiers associated with Health's 2005 results were examined along with PCB congener results from samples that were analyzed by both methods. Some of the 2005 PCB Aroclor results were qualified as NJ, the "N" indicating the lack of positive identification of PCB Aroclors 1254 and 1260 which can be challenging to distinguish from one another in some samples. The overlap of the two Aroclor patterns was more common in samples with elevated levels of PCBs samples. Other factors in this interference include the extent of Aroclor "weathering", lipids, or other analytes present in the matrix. The examination of these data, described in Appendix D, suggests that some "N" qualified results could be used in trends analyses, recognizing that such results may be biased high.

While current and past PCB Aroclor analyses often reference the same method (e.g. EPA 8082), slight changes in the analytical procedures can affect the comparability of data when used for long-term monitoring programs. King County (2016) examined the effects of changes in extraction techniques, solvents, and cleanup methods for PCB Aroclor analyses. They reported that such changes do affect results and can introduce bias into the analyses for temporal trends. For example, apparent downward trends in PCBs in yellow perch and smallmouth bass were modestly dependent on extraction processes and highly dependent on quantitation methods.

Sampling Precision

Contaminant concentrations in individual fish can be influenced by many factors, such as: size, age, lipid content, trophic position, diet, sex, exposure to contaminants, and sample preparation and analysis. These factors lead to high variability in sample results. A challenge for monitoring programs is to obtain reliable measurements of some parameter in order to inform decisions, such as protecting the protecting consumers of fish (i.e. people, wildlife). Commonly used strategies to reduce variability include the use of composite samples and multiple samples. Generally, as one increases the number of fish used in samples and the number of samples, one increases the confidence and reliability of measurements.

One way to estimate the uncertainty associated with a sample statistic (e.g. the mean) is to calculate the confidence interval. Di Stefano (2004) argues that the confidence interval is an informative way of characterizing sampling precision, especially where uncertainty may complicate important decisions to be made using the data. The confidence interval is based on the mean value, the standard error, and the critical t-value associated with the desired level of confidence. Figure 4 shows the mean values of t-PCB for field replicates and the 95% confidence interval around each mean.

The confidence interval is the range within which the true mean of the population would be found in 95% of repeated sampling efforts. As can be seen in Figure 4, the high variability in some field replicates leads to large confidence intervals. For example, the confidence interval for the three replicates in the group “GR-CCP-L” ranges from about 40 to nearly 400 ug/kg. The true mean t-PCB for this population of large carp from Green Lake is somewhere between these two values. Other replicate groups have much smaller confidence intervals, for example, the group “GR-CCP-S” consisted of five replicate samples which yielded a 95% confidence interval from about 23 to 42 ug/kg.

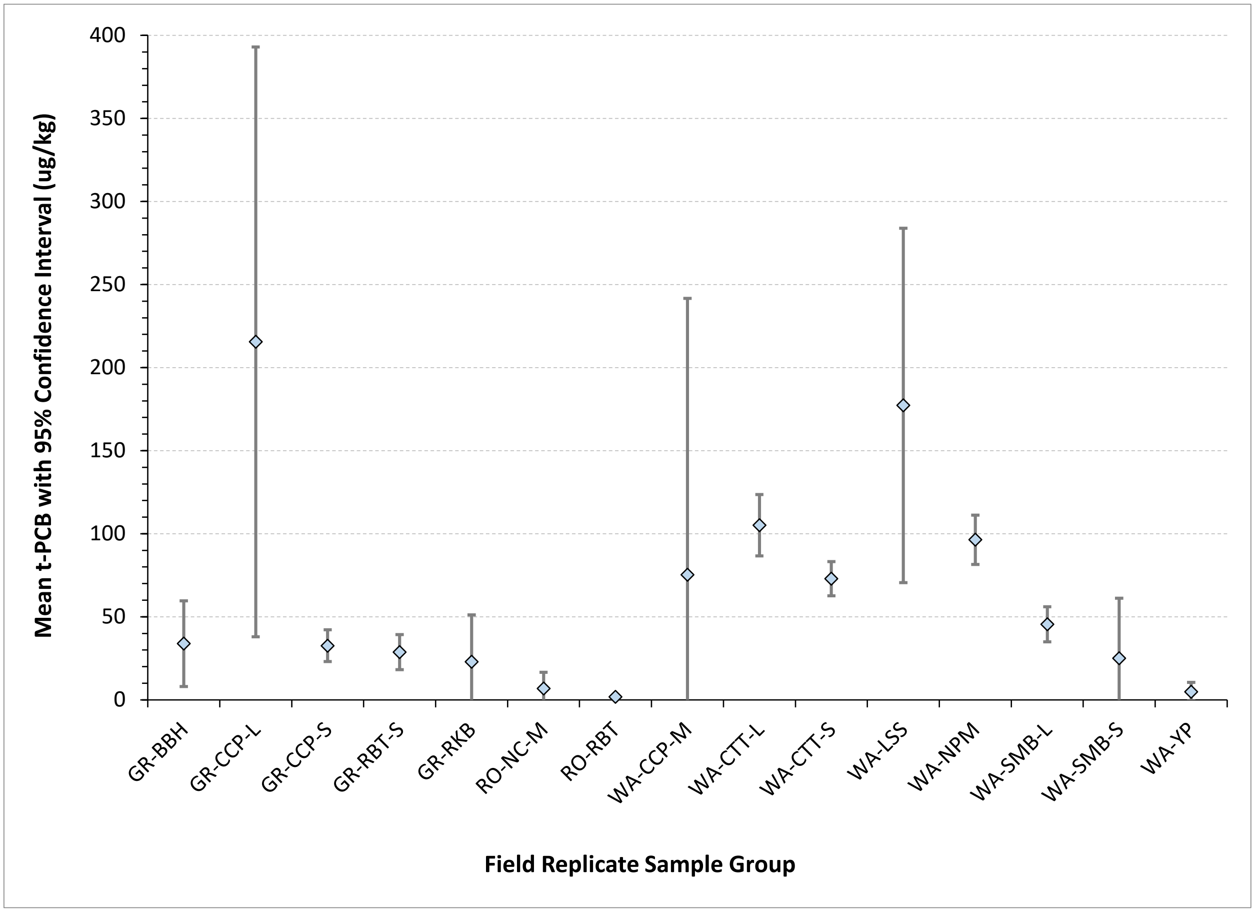

Figure 4. Mean and 95% confidence intervals for t-PCBs from field replicate samples.

Site Codes: GR-Green Lake; RO-Ross Lake; WA-Lake Washington.   Species codes: CCP: Common carp; CTT: Cutthroat trout; NPM: Northern pikeminnow, YP: Yellow perch.   Relative size groups: L-large size, M-Medium size; S-small size.

Data Reduction, Trends Analyses, Water Quality Criteria

Data Reduction

Data reduction and management procedures followed practices described in the project plan for the FFCMP (Seiders, 2013). Results from some groups of target analytes were summed in order to account for their additive effects and for simplicity of comparison to various criteria and to other data. Summed values in this report are noted using the prefix "t-", as in t-PCB. Procedures for summing followed Ecology's internal guidance for the Water Quality Assessment process.

For dioxins and furans, a cumulative toxicity concentration for the 17 toxic dioxin and furan congeners was calculated following EPA (EPA, 2010) and the World Health Organization (Van den Berg et al., 2006). The cumulative toxicity is expressed as TCDD-TEQ, the toxicity equivalent (TEQ) to the single congener 2,3,7,8-TCDD which is the most toxic congener. The TCDD-TEQ values can be used for comparisons to various benchmarks for the protection of human health, such as EPA Screening Values described later.

For PCBs, all samples were analyzed for Aroclors while a subset of samples were analyzed for all congeners. Aroclor results were used in this report because the Aroclor method was used for all samples and in the historical studies. Results for congeners are discussed briefly in this report because the congener analyses were done to supplement other data that can address broader interests than the scope of the FFCMP. These interests include evaluating comparisons to other fish samples (statewide) having PCB Aroclor or congener data and informing statewide strategies for addressing PCB contamination in the environment.

Contaminant concentrations in fish can be influenced by many factors, such as: species, tissue type, size, age, lipid content, collection location, collection season, and analytical method. These factors were considered while choosing samples for various comparisons. The results were plotted to examine relationships between each of three analytes (t-PCB, t-DDT, and mercury) to fish length, weight, age, and lipids. Simple linear regression was used to help determine the existence and strength of relationships. These plots showed that relationships among these parameters were non-existent, inconsistent, or too weak (Coefficient of Determination, or r^2, < 0.7) to use in normalizing the data or performing other adjustments using co-variance. Such adjustments could potentially increase the sensitivity of statistical tests for differences among sites or between years.

Trends Analyses

Temporal trends were examined for Lake Washington only because historical data from Green and Ross Lakes are insufficient for meaningful comparisons. The 2015 results for Green and Ross Lakes should be adequately robust for future trend analyses. For Lake Washington, results from the 2005 studies (McBride, 2005; Seiders et al, 2007) were used for comparison to the 2015 results. Although King County sampled fish in 2010 and 2014, the characteristics of the available data (e.g. sample size, species, fish size, tissue type) were deemed insufficient to include in trend analysis at this time.

Several data sets from the Lake Washington 2005 and 2015 studies were selected for trends analyses. These were data sets where multiple samples (field replicates) of individual fish species of common size ranges existed. These data were graphically examined and where boxplots suggested there might be statistically significant differences between cases of interest, statistical testing was pursued. Data sets usually failed assumptions for normal distribution or equality of variances, so parametric tests for comparisons were not pursued. Data were not transformed prior to conducting the statistical tests described below. For sample results that were reported as non-detect, the value of the detection limit was used in these tests.

Data from the 2005 and 2015 were tested for temporal differences using the non-parametric two-sample Mann-Whitney test using SYSTAT (2012) and Zar (1984). The generalized null hypothesis was that data sets did not differ. For these tests, alpha levels of 0.05 was chosen, meaning that there was a 5% chance that the outcome of the test was due to chance.

Water Quality Criteria

Results from this 2015 fish tissue study are not compared to Washington's new 2016 human health criteria because the policy on how to use environmental data for assessing compliance with these criteria will not be completed until mid-2018 or later. However, Appendix E shows the draft threshold concentrations that would be used in determining whether the designated use of fish harvest is met. The next Water Quality Assessment process, which may be completed in 2019, will determine whether the sampled water bodies meet water quality standards.

Other water quality benchmarks that organizations use for evaluating the risks of consuming contaminated fish are EPA's Screening Values for Subsistence and Recreational Fishers. Some results from 2015 are compared to these values to provide context. Appendix E describes these benchmarks in more detail, along with other benchmarks such as EPA's Recommended Water Quality Criteria and Health's Screening Values. Appendix F describes the different approaches used by Ecology and Health in evaluating risks to human health from exposure to contaminants in fish.

Results and Discussion

Results for each monitoring site are summarized and discussed below. All results are available from Ecology's Environmental Information Management database (EIM) at https://ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database under the Study ID FFCMP15.

Lake Washington

Results from 2015

Table 2 summarizes results for chemicals detected in fillets from five species collected in 2015: common carp, cutthroat trout, northern pikeminnow, smallmouth bass, and yellow perch. Because the fillet data were pooled, these statistics are not representative of any single species. One chemical not in Table 2 is the pesticide beta-BHC. This analyte was detected in only one sample (medium sized common carp with lab ID of 1601009-32) at a concentration of 0.52 ug/kg. Chemicals with high frequencies of detection in fillets were PCBs, dioxin/furans, PBDEs, DDTs, chlordanes, and mercury. Results for largescale suckers were excluded from Table 2 because these fish were analyzed whole, rather than as fillets.

Table 2. Summary statistics for chemicals detected in fish: Lake Washington, FFCMP 2015.

Parameter	Count	Mean	Median	Min	Max	SD	95% CL	Detect Freq
t-PCBa	30	72.8	72.2	3.1	284.0	54.2	20.2	100%
t-PCBc	12	101.0	81.4	28.6	393.2	98.6	62.6	100%
TCDD-TEQ (ng/kg)	12	1.095	0.971	0.017	4.725	1.271	0.807	100%
t-PBDE	24	13.8	12.8	0.32	34.6	10.7	4.5	96%
t-DDT	30	39.5	37.6	0.90	228	42.6	15.9	100%
t-Chlordane	24	13.5	14.3	0.49	47.0	10.9	4.61	88%
Hexachlorobenzene	24	1.10	1.00	0.48	2.47	0.57	0.24	8%
Dieldrin	24	0.68	0.27	0.24	2.29	0.67	0.28	42%
Mercury	30	276	229	27	683	163	61	100%
Lipids (%)	30	2.8	2.5	0.20	6.8	1.9	0.73	-
Total Length (mm)	30	407	418	230	751	108	40	-
Weight (g)	30	1041	782	163	5935	1135	424	-
Age (yr)	30	4.7	3.7	1.0	12.3	2.3	0.9	-

Values are in ug/kg unless otherwise specified.

Figure 5 shows the range of PCBs and dioxin/furans (as TCDD-TEQ) in fish from Lake Washington. These boxplots graphically summarize the data set using various statistical descriptors. The lower and upper ends of the box represent the lower and upper quartiles (i.e. the 25^{th} and 75^{th} percentile values), with the line dividing the box depicting the median, or 50^{th} percentile. The whiskers extending beyond the box represent the range of observed values that fall within 1.5 times the interquartile range. Outliers are shown as asterisks – those values between 1.5 and 3 times the interquartile range, and open circles – those values greater than 3 times the interquartile range.

The highest concentrations of these contaminants in fillet tissue are in common carp, cutthroat trout, and northern pikeminnow. High levels are also seen in whole largescale suckers. Boxplots for other contaminants and field data are in Appendix G.

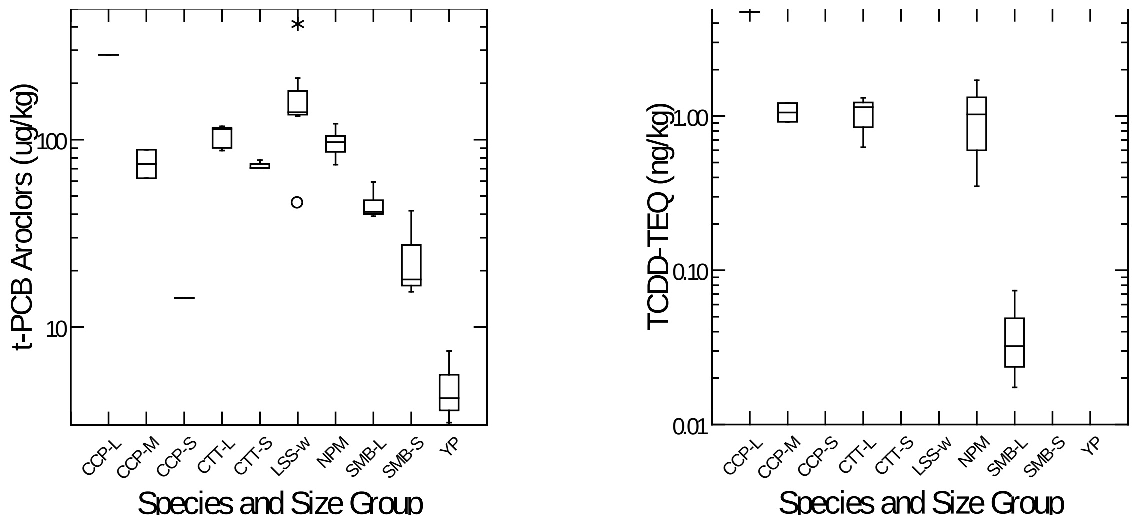

Figure 5. Boxplots for PCBs and dioxin/furans in Lake Washington fish, FFCMP 2015.

Species codes: CCP: Common carp; CTT: Cutthroat trout; LSS: Largescale sucker; NPM: Northern pikeminnow; SMB: Smallmouth bass; YP: Yellow perch, w: whole fish. Relative size groups: L-large size, M-Medium size; S-small size.

Figure 6 shows results for t-PCBs, TCDD-TEQ, mercury, and t-PBDEs in fillet tissue from multiple species of fish collected across Washington during the FFCMP since 2001. Results from 2015 and 2005 for Lake Washington are indicated with circle and square symbols. Where multiple field replicates were taken, the symbols show the mean value of those replicates. For context regarding human health, EPA's Screening Values (SVs) for Subsistence and Recreational Fishers (EPA, 2000a) are shown for PCBs, TCDD-TEQ, and mercury.

Fish from Lake Washington continue to show elevated levels of multiple contaminants. Fillet tissue from common carp, cutthroat trout, and northern pikeminnow continue to have some of the highest concentrations of PCBs and dioxins/furans found in Washington. Most samples also showed levels of PBDEs that are above the statewide median of 3.2 ug/kg. Mercury concentrations in 2015 were above the median value (114 ug/kg) found during the FFCMP 2001-2015. The highest values were in northern pikeminnow (443-683 ug/kg), smallmouth bass (150-420 ug/kg), yellow perch (150-243 ug/kg), and cutthroat trout (119-239 ug/kg). Health reviewed these results and decided to keep the current Fish Consumption Advisory for PCBs.

The draft TEC thresholds in Table D-1 were often exceeded by contaminants found in multiple samples and species. These contaminants include: chlordane, 4,4'-DDE, dioxin (2,3,7,8-TCDD), mercury, and PCBs.

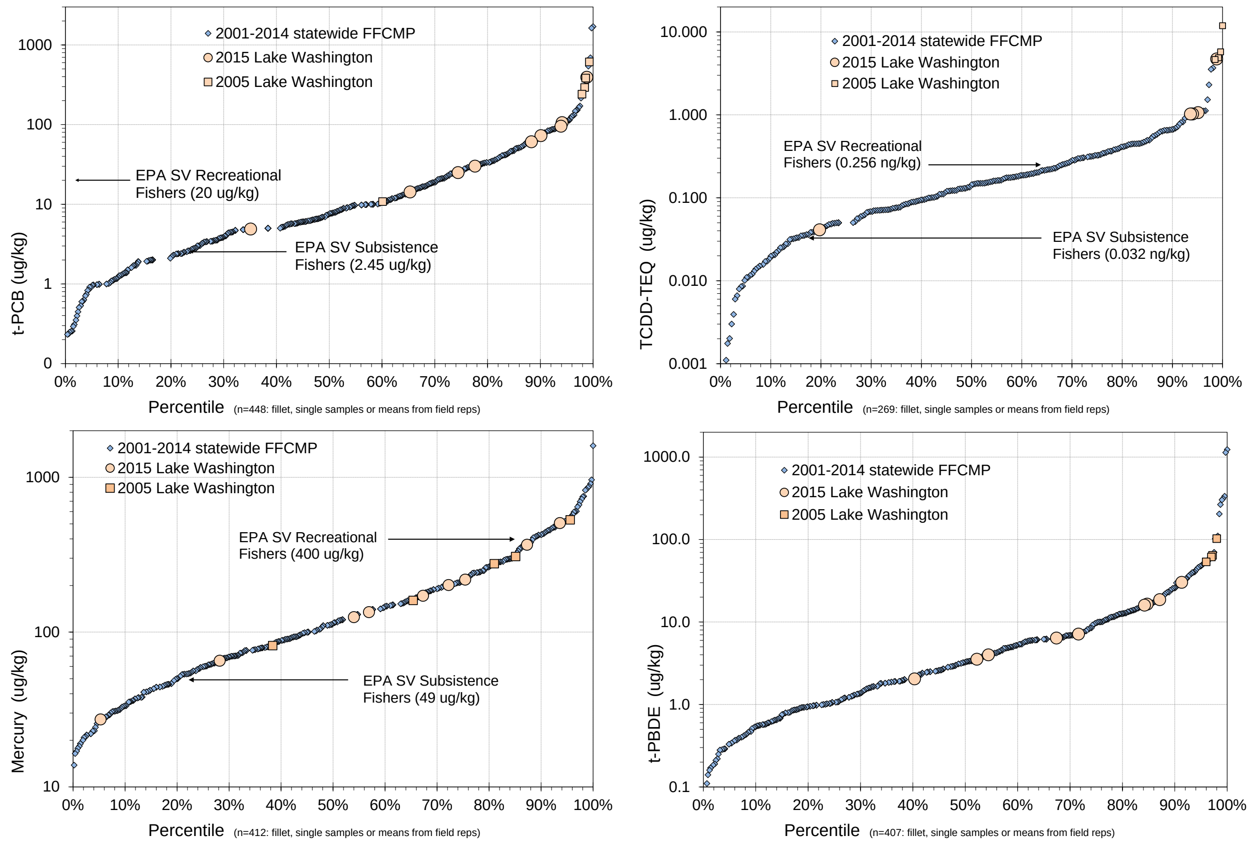

Figure 6. Cumulative frequency distributions for t-PCB, TCDD-TEQ, mercury, and t-PBDE in fillet tissue from Washington.

Should the current draft of Ecology’s Policy 1-11 be adopted, it is likely that the next Water Quality Assessment will find only a small part (< 10%) of Lake Washington impaired and placed on state’s 303(d) list for contaminants in fish. The current draft of assessment procedures consider only the assessment unit (grid cell) where the centroid of the fish collection sites for each sample is recorded in EIM – and not the entire lake which the samples represent. As such, only 16 of the lake’s 192 grid cells would be included in the next assessment. Appendix A shows where the 2015 fish were collected, the centroids for composite samples, and current grid cells for Lake Washington.

Temporal Trends

Several data sets from Lake Washington were selected for trends analyses. These data sets had multiple samples (field replicates) of individual fish species of common size ranges: cutthroat trout with two size ranges, northern pikeminnow, and yellow perch. Cutthroat trout and northern pikeminnow tend to accumulate some contaminants to higher concentrations due to their trophic position in the food web which makes them suitable for detecting downward trends. Parameters that were examined were: t-PCB, t-PBDE, t-DDT, t-Chlordane, mercury, lipids, age, total length, and weight. These data were graphically examined and where boxplots suggested there might be statistically significant differences between years, statistical testing was pursued. Common carp were also plotted even though only one sample was available for one of the years.

Figure 7 shows boxplots of t-PCB results from the 2005 and 2015 fillet samples. These boxplots suggest that t-PCBs in 2015 are lower than those found in 2005 for all species except yellow perch. The results for cutthroat trout, northern pikeminnow, and yellow perch were then tested for differences between years. The other parameters were also plotted and are shown in Appendix H.

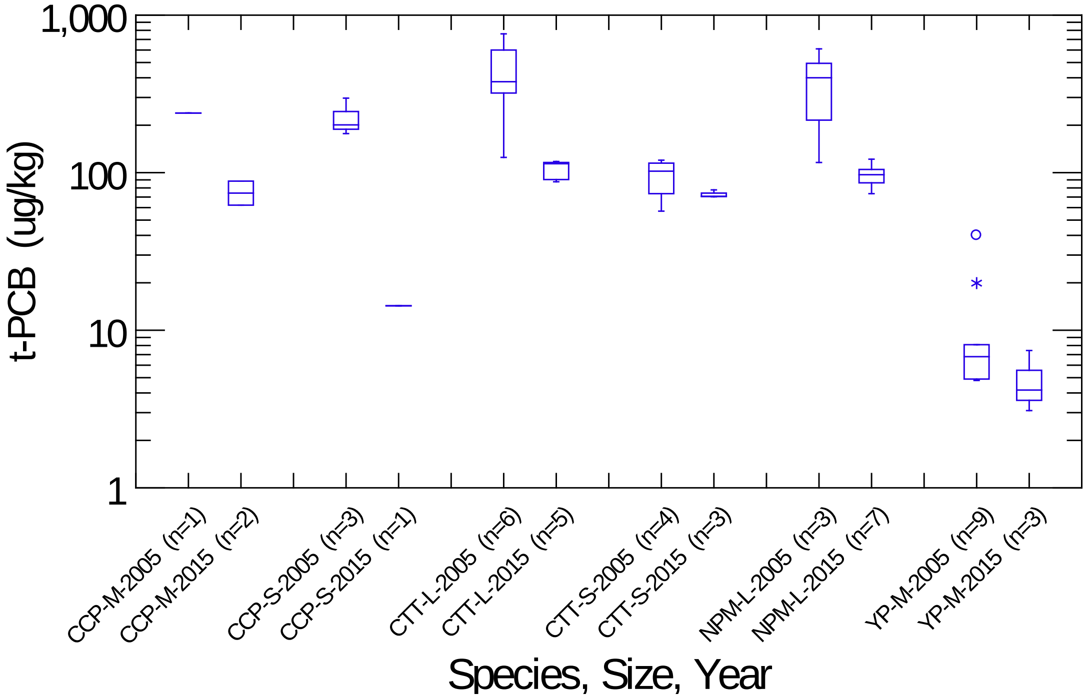

Figure 7. Boxplots comparing PCB concentrations between 2005 and 2015 in common carp, cutthroat trout, northern pikeminnow, and yellow perch from Lake Washington.

Species codes: CCP: Common carp; CTT: Cutthroat trout; NPM: Northern pikeminnow, YP: Yellow perch. Relative size groups: L-large size, M-Medium size; S-small size.

Data from the 2005 and 2015 were tested for temporal differences using the non-parametric two-sample Mann-Whitney test. The generalized null hypothesis was that data sets did not differ. For these tests, an alpha level of 0.05 was chosen, meaning that there was a 5% chance that the outcome of the test was due to chance. Parametric tests for comparisons were not pursued because data sets usually failed assumptions for normal distribution or equality of variances. Data were not transformed prior to conducting the Mann-Whitney test. For sample results that were reported as non-detect, the value of the detection limit was used in these tests.

Statistically significant differences (a=0.05, p=0.006) were found only for large-sized cutthroat trout for four parameters. The mean concentrations of t-PCB, t-PBDE, t-DDT, and mercury are estimated to have decreased by 55-75%, 69%, 54%, and 40%, respectively (Table 3). Increased sensitivity of trend detection in other species and size ranges would be helped by larger sample sizes or larger differences in concentrations between years. Many of the species/size groups had only three samples for use in one year or the other. Note that the lower concentrations in yellow perch would make it difficult to detect temporal trends in this species.

Table 3. Changes in mean concentrations for four chemicals in large cutthroat trout from Lake Washington between 2005 and 2015.

Feature	n	t-PCB (NJ=J)	t-PCB (NJ=ND)	t-PBDE	t-DDT	Mercury
2005	6	427.5	233.5	98.4	122.4	364.2
2015	5	105.1	105.1	30.3	56.8	218.2
Difference		322.4	128.4	68.0	65.6	146.0
% Change		75%	55%	69%	54%	40%
Significant at a=0.05?		Yes	No	Yes	Yes	Yes

% Change = difference between 2005 and 2015, divided by the 2005 value.
NJ=J: when t-PCB calculation treats NJ qualified results as J-qualified, and thus included in the calculation.
NJ=ND: when t-PCB calculation treats NJ qualified results as non-detects (ND), and thus uses the detection limit in the calculation.

As described in the Data Quality Assessment section above, and in Appendix D, some t-PCB Aroclor mean values were calculated two ways:

- Treating NJ qualified results as J-qualified, and thus including these values the calculation. This likely results in a mean value that is biased high.
- Treating NJ qualified results as non-detects (ND), and thus using only the given detection limit in the calculation. This likely results in a mean value that is biased low.

When the t-PCB calculation treats NJs as non-detects, the t-PCB mean value is lower (233.5 ug/kg) than when the NJs are treated as J-qualified results (427.5 ug/kg). The actual mean value of t-PCBs in the 2005 data may lie between these two values, which suggests a decrease of 55-75% between 2005 and 2015. These two approaches also yielded different results when the Mann-Whitney test was applied to the data sets (Table 3, bottom row): the difference was statistically significant for one case but not for the other.

The interpretation of PCB Aroclor data can be especially challenging due to the nature of PCBs in the environment and techniques to quantify them in fish tissue. King County's (2016) experience with changes in laboratory techniques found that such changes can introduce bias and thus hamper attempts to determine changes in PCBs over time. Despite such challenges, King County's monitoring program suggests that PCB concentrations in Lake Washington fish are declining – and the results from this FFCMP study support this.

Green Lake

Table 4 shows selected results from Green Lake fish for 2001 and 2015. The results in the first row are for a common carp (CCP) composite sample collected in 2001 and are shown for temporal comparison purposes. For 2015, concentrations of PCBs, dioxin/furans, DDT, chlordane, and mercury were elevated in carp, bullhead, rainbow trout, rock bass, and yellow perch, (bold values). The chlorinated pesticides delta-BHC and gamma-BHC (lindane) were detected, and one of the three 2015 carp samples had the highest concentration (60.3 ug/kg) of hexachlorobenzene (HCB) found in Washington fish. Green Lake carp also have some of the highest concentrations of PCBs and chlordane in Washington fish. Health reviewed these results and has not revised the Fish Consumption Advisory for PCBs.

Comparison of results from 2001 to those from 2015 are limited to a cursory review of several analytes found in carp: a more thorough analysis of temporal trends is not possible because only a single sample from 2001 is available. Considering the size and age of fish collected (the 2001 fish were between the size and age values of the 2015 samples), the results suggest there is no difference between the two sampling periods for PCBs, t-DDT, t-chlordane, and mercury.

Results for dioxin-furans (as TCDD-TEQ) in the 2015 small carp (CCP-S in Table 4) show that the 2015 mean concentration of 0.283 ng/kg is nearly four times lower than the 2001 concentration of 1.11 ng/kg. It's unlikely that there has been a true decline in dioxin-furan levels in Green Lake carp when variability and fish size are taken into account. The upper 95% confidence limit for the mean of the 2015 result is 1.016 ng/kg – only 0.1 ng/kg less than the 2001 result from a single composite sample. Also, the fish used in the 2015 analyses were less than half the weight of the 2001 fish and had an average age of 1.0 years compared to 5.6 years for the 2001 fish. Concentrations of dioxin-furans in the small sized carp collected in 2015 remain elevated: the mean value from three samples, 0.283 ng/kg, ranks at the 70th percentile among fish across Washington.

Table 4. Results for key parameters for Green Lake from 2001 and 2015.

Study Year	Species and Size	t-PCBa (ug/kg)		TCDD TEQ (ng/kg)		TCDD (ng/kg)		t-PBDE (ug/kg)		t-DDT (ug/kg)		HCB (ug/kg)		t-Chlordane (ug/kg)		Hg (ug/kg)		Lipid MEL (%)		Mean Total Length (mm)		Mean Weight (g)		Mean Age (yr)	
2001	CCP-M	**132**		**1.11**		**0.300**	J	2.1		**63.3**		1.1		**36**		**76.2**	c	3.8		549		2879		5.6	
2015	CCP-L	**216**	m					4.5	m	**82.8**	m	**21**	m	**24**	m	**90.1**	m	3.7	m	615	m	3939	m	10.9	m
2015	CCP-S	**32.6**	m	**0.283**	m	0.044	m,NJ	0.54	m	11.0	m	0.55	m	4.9	m	17.7	m	1.4	m	427	m	1300	m	1.0	m
2015	RBT-L	**15.9**		**0.160**	J	0.026	J	0.28	J	7.76		0.69		2.8	J	**35.4**		2.2		375		495		3.0	
2015	RBT-S	**28.8**	m	**0.425**	m	**0.140**	m	0.18	m	8.62	m	0.49	m,U	2.9	m	20.8	m	1.5	m	222	m	124	m	1.0	m
2015	RKB	**22.9**	m					0.37	m	7.48	m	0.50	m,U	2.0	m	**70.0**	m	0.4	m	206	m	182	m	3.2	m
2015	YP	**7.91**	J					0.08	J	1.97		0.49	U	0.25		**33.0**		0.2		260		238		1.0	
2015	BBH	**33.8**	m					0.57	m	13.2	m	0.63	m	5.6	m	22.9	m	0.7	m	289	m	307	m	1.5	m

Bold values represent elevated concentrations: these may not meet thresholds for protecting designated uses.
Species codes: BBH: Brown bullhead; CCP: Common carp; RBT: Rainbow trout; RKB_ Rock bass; YP: Yellow perch. Relative Size Groups: L-large size, M-Medium size; S-small size.
Qualifiers: c=value estimated using a conversion factor because of bias in an older analytical; m=mean of field replicates; J=estimated value; NJ=tentative identification of analyte, concentration estimated; U= not detected at or above the reported value.

Ross Lake

Fish from Ross Lake were analyzed for chlorinated pesticides, PCBs, PBDEs, and metals. Concentrations of chlorinated pesticides, PCBs were low and comparable to levels seen in waterbodies deemed to have little apparent human impact (Johnson et al, 2010, 2013). Table 5 summarizes results for commonly detected analytes from 2015, 2012, and 2007. Concentrations of PCBs, PBDEs, and DDTs remain low over all years and species.

Metals in fish tissue was a primary interest to help address concerns that North Cascades National park staff had about potential impacts of mining in that watershed. Of the 13 metals analyzed for, only four were consistently detected in fish fillets: copper, mercury, selenium, and zinc. Lead was detected in only one sample and at a level near the reporting limit. Chromium was not detected in 2015 yet was detected in 2012. Results for the four consistently detected metals show no clear differences among years – likely due to the inherent variability of contaminants in fish tissue. Also, only a single composite sample result was available for comparison to 2007 and 2012. Results for all metals are given in Appendix I.

The concentrations of metals in the 2015 samples appear to be typical. Levels of copper were within or slightly above ranges (0.37-2.18 mg/kg, respectively) found in other studies in Washington (Energy, 2012; EPA, 2002a). Concentrations of mercury in 2015 (0.147-0.600 mg/kg) seem typical for the size, age, and trophic level for the native char and rainbow trout that were analyzed. Levels of selenium were detected just above the reporting limit and were within a guideline of 3 mg/kg for the protection of piscivorous wildlife (MacDonald, 1994). Concentrations of zinc were also similar to the median value (8.2 mg/kg) for fish fillets across Washington as reported by Serdar and Johnson (2006). Further discussion of the impact of these concentrations on fish or population health is beyond the scope of this report.

Table 5. Results for key parameters for Ross Lake from 2007, 2012, and 2015.

Sort	Year	Field ID	PCBa (ug/kg)		PCBc (ug/kg)		PBDE (ug/kg)		t-DDT (ug/kg)		Cr (ug/kg)		Cu (ug/kg)		Pb (ug/kg)		Hg (ug/kg)		Se (ug/kg)		Zn (ug/kg)		Lipids (%)	Mean Age (yr)	Mean Total Length (mm)	Mean Weight (g)
1	2015	RO-NC-L	6.94	J			0.797	J	2.64		0.494	U	1.960		0.099	U	0.600		0.494	U	6.20		1.19	5.8	617	1948
2		RO-NC-M1	10.86	J	2.82		0.639	J	3.73		0.494	U	1.290		0.099	U	0.560		0.533		6.70		1.89	4.4	526	1239
3		RO-NC-M2	6.5	J	1.81		0.089	J	2.66		0.465	U	1.340		0.106		0.451		0.524		6.53		1.49	4.8	523	1187
4		RO-NC-M3	3.02	J	1.94		0.135	J	2		0.476	U	1.500		0.095	U	0.549		0.516		7.59		1.89	4.3	511	1084
5		RO-NC-S	2.53	J			0.094	J	1.53		0.496	U	1.210		0.099	U	0.298		0.496	U	8.06		1.76	3.2	370	432
6	2012	ROSS-BLT	3.5	J			1.0	J	2.1		2.28		1.49		0.100	U	0.415		0.581		6.76		0.83	3.2	367	451
7	2007	ROSSBLT	5.1	J	3.0	J	1.2	J	3.1								0.219						4.24	5.0	376	476
8	2015	RO-RBT-1	1.93	U	1.29		0.079	J	0.99		0.489	U	0.717		0.098	U	0.189		0.560		7.50		2.39	4.0	381	487
9		RO-RBT-2	1.98	U	1.14		5.51	U	0.99		0.466	U	0.701		0.093	U	0.246		0.527		7.27		3.07	4.0	368	495
10		RO-RBT-3	1.99	U	0.844		4.062	J	1		0.500	U	0.518		0.100	U	0.147		0.500	U	6.79		2.70	3.0	352	419
11		RO-RBT-4	1.98	U			0.075	J	1.11		0.488	U	1.59		0.098	U	0.258		0.488	U	9.05		3.03	4.2	533	1271
12		RO-RBT-5	1.09	J			0.059	J	0.83		0.486	U	1.07		0.097	U	0.169		0.487		7.19		2.05	2.5	336	521
13	2012	ROSS-RBT	2.4	UJ			6.2		1.1		3.17		0.835		0.100	U	0.188		0.495	U	6.85		1.13	3.4	384	493
14	2007	ROSSRBT	1.4	U	0.40	J	0.16	J	1.0	U							0.063						3.60	5.0	504	1184
15	2012	ROSS-EBT	1.6	J			0.76	J	1.4		1.09		2.29		0.100	U	0.188		0.746		7.80		3.07	2.8	328	339

Species codes: BLT=Bull trout (a native char); EBT=Eastern brook trout; NC-Native char (bull trout or Dolly Varden); RBT: Rainbow trout.
Relative size group codes: L-large size, M-Medium size; S-small size.
Qualifiers: J=estimated value; U= not detected at or above the reported value; UJ= not detected at or above the estimated reported value.

Conclusions

Results of this 2015 study support the following conclusions:

- Multiple species of fish in Lake Washington continue to show elevated levels of various contaminants, especially PCBs, PBDEs, dioxins/furans, DDTs, chlordanes, and mercury.
- Concentrations of key contaminants in Lake Washington fish appear to be decreasing, yet only large-sized cutthroat trout showed statistically significant changes for t-PCB, t-PBDE, t-DDT, and mercury, with mean concentrations decreasing by 55-75%, 69%, 54%, and 40%, respectively.
- Multiple species of fish in Green Lake continue to show elevated levels of various contaminants, especially PCBs, dioxin/furans, chlordanes, and hexachlorobenzene.
- Based on these 2015 results for Lake Washington and Green Lake, the Washington State Department of Health did not revise the Fish Consumption Advisories for these lakes.
- Contaminant concentrations remain low in fish from Ross Lake. Concentrations of metals in fish tissue appeared similar to concentrations found across Washington State.
- Temporal trends were not determined for Green and Ross Lakes because of low numbers of samples in historic data sets. The 2015 sample results should serve as a good baseline for future comparisons.
- The current Clean Water Act 303(d) listings for Lake Washington and Green Lake remain in effect until a new Water Quality Assessment is performed. Likely candidates for new 303(d) listings include PCBs, dioxin, DDTs, chlordane, dieldrin, hexachlorobenzene, and mercury.

Recommendations

Results of this 2015 study support the following recommendations:

- Results of this study should be included in the next section 303(d) Water Quality Assessment conducted by Ecology.
- Based on contaminant concentrations and the ages of fish sampled in 2015, re-sampling fish at a frequency of about 10-15 years seems appropriate for temporal trends analyses.
- Future sampling of fish for temporal trend analyses should focus on the sites, species, and fish size ranges that are comparable to samples from this 2015 effort. For Lake Washington, the species and size ranges used in King County's fish monitoring program should also be considered.
- Fish species of greatest value in detecting temporal trends would be those that are abundant in each waterbody (which allows larger sample sizes) and known to accumulate target contaminants (which allows greater chance of detecting change). The use of multiple species helps increase the weight of evidence for true trends (i.e. true signals from the environment rather than false signals that could be due to sampling or analytical procedures).
- Larger sample sizes, such as five to seven field replicate composite samples of a single fish species per site, will likely be needed in future monitoring where the goal is detection of temporal trends.

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Appendices

Appendix A. Sampling Site Information

Table A-1. Sample Location Information (NAD83HARN).

Sample Field ID	Sample Lab ID: 1601009-nn	EIM Location ID Name	EIM Centroid Location ID Latitude	EIM Centroid Location ID Longitude
All Green Lake	01-19	GREEN-F	47.67832	-122.33834
RO-NC-L	20	ROSSLK-F-I0E2	48.84359	-121.02766
RO-NC-M1	21	ROSSLK-F-H0J4	48.79933	-121.04906
RO-NC-M2	22	ROSSLK-F-I0E2	48.84359	-121.02766
RO-NC-M3	23	ROSSLK-F-H0J4	48.79933	-121.04906
RO-NC-S	24	ROSSLK-F-I0E2	48.84359	-121.02766
RO-RBT-1	25	ROSSLK-F-I0I4	48.88097	-121.04216
RO-RBT-2	26	ROSSLK-F-I0I4	48.88097	-121.04216
RO-RBT-3	27	ROSSLK-F-I0D4	48.83330	-121.04170
RO-RBT-4	28	ROSSLK-F-H0J4	48.79933	-121.04906
RO-RBT-5	29	ROSSLK-F-I0I4	48.88097	-121.04216
WA-CCP-L	30	WashLk-F-G2H4	47.67063	-122.24268
WA-CCP-M1	31	WashLk-F-G2H4	47.67063	-122.24268
WA-CCP-M2	32	WashLk-F-G2F6	47.65016	-122.26160
WA-CCP-S	33	WashLk-F-F2G4	47.56824	-122.24871
WA-CTT-L1	34	WashLk-F-G2B4	47.61587	-122.24738
WA-CTT-L2	35	WashLk-F-G2B4	47.61587	-122.24738
WA-CTT-L3	36	WashLk-F-G2B4	47.61587	-122.24738
WA-CTT-L4	37	WashLk-F-G2H4	47.67063	-122.24268
WA-CTT-L5	38	WashLk-F-G2A4	47.60082	-122.24798
WA-CTT-S1	39	WashLk-F-G2A6	47.60520	-122.26265
WA-CTT-S2	40	WashLk-F-G2B4	47.61587	-122.24738
WA-CTT-S3	41	WashLk-F-G2A6	47.60520	-122.26265
WA-NPM-1	42	WashLk-F-G2F6	47.65016	-122.26160
WA-NPM-2	43	WashLk-F-G2B5	47.61809	-122.25805
WA-NPM-3	44	WashLk-F-G2A4	47.60082	-122.24798
WA-NPM-4	45	WashLk-F-G2B5	47.61809	-122.25805
WA-NPM-5	46	WashLk-F-G2A4	47.60082	-122.24798
WA-NPM-6	47	WashLk-F-G2B5	47.61809	-122.25805
WA-NPM-7	48	WashLk-F-F2B1	47.51827	-122.21888
WA-SMB-L1	49	WashLk-F-F2G4	47.56824	-122.24871
WA-SMB-L2	50	WashLk-F-G2A6	47.60520	-122.26265
WA-SMB-L3	51	WashLk-F-F2J3	47.59713	-122.23747
WA-SMB-L4	52	WashLk-F-G2F6	47.65016	-122.26160
WA-SMB-L5	53	WashLk-F-F2G4	47.56824	-122.24871
WA-SMB-S1	54	WashLk-F-G2C5	47.62221	-122.25381
WA-SMB-S2	55	WashLk-F-G2C5	47.62221	-122.25381
WA-SMB-S3	56	WashLk-F-G2C5	47.62221	-122.25381

Sample Field ID	Sample Lab ID: 1601009-nn	EIM Location ID Name	EIM Centroid Location ID Latitude	EIM Centroid Location ID Longitude
WA-LSS-1	57	WashLk-F-G2F6	47.65016	-122.26160
WA-LSS-2	58	WashLk-F-F2J5	47.59412	-122.25858
WA-LSS-3	59	WashLk-F-F2D4	47.53316	-122.24487
WA-LSS-4	60	WashLk-F-G2A6	47.60520	-122.26265
WA-LSS-5	61	WashLk-F-F2J2	47.59668	-122.22572
WA-LSS-6	62	WashLk-F-F2E3	47.54840	-122.23878
WA-LSS-7	63	WashLk-F-G2C4	47.62693	-122.24468
WA-YP-1	64	WashLk-F-G2C4	47.62693	-122.24468
WA-YP-2	65	WashLk-F-F2E0	47.54864	-122.20676
WA-YP-3	66	WashLk-F-G2B4	47.61587	-122.24738

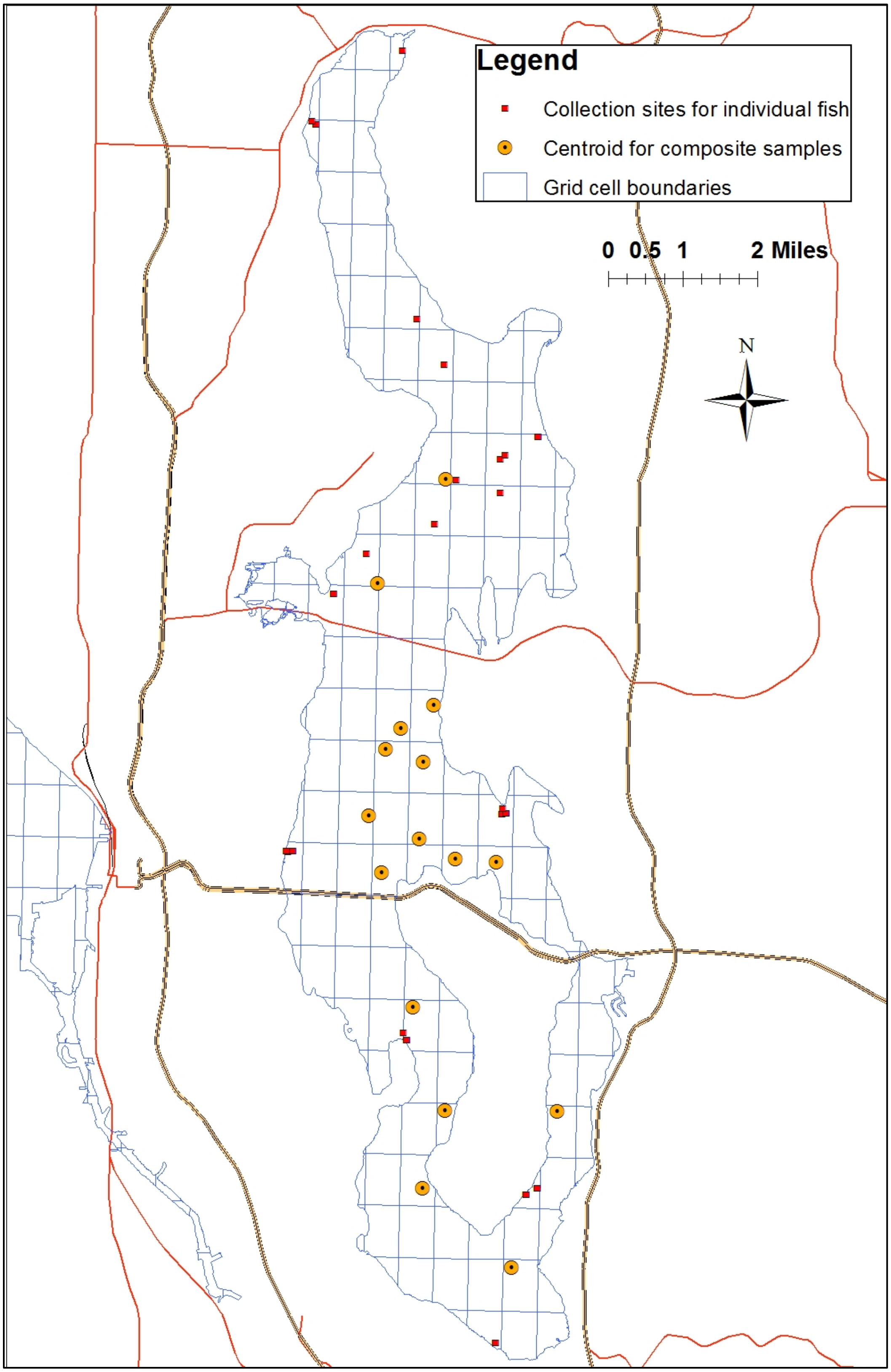


Figure A-1. Fish collection sites, sample centroid location, and grid cells for Lake Washington.

Appendix B. Field Collection and Preservation Methods

The collection, handling, and processing of fish tissue samples for analyses were guided by methods described by EPA (2000) and Ecology's standard operating procedures (SOPs) (Sandvik, 2006 a, b, c). The collection of fish by Ecology in 2015 adhered to these federal and state Scientific Collection Permits: USFWS # TE-058381-8, NOAA # 1386-7A, and WDFW # 12-298f.

Fish Collection

Information from historical work helped determine the sampling goals for each site. Goals for each site consisted of specific fish species and specific size ranges of fish (i.e. length and weight). The 2015 monitoring aimed to increase the number of samples (compared to historical work) available for analyses in order to reduce variability and improve the ability to detect spatial and temporal trends. Fish were collected between June and October in order to match the timeframes in which fish were collected in previous studies and to take advantage of cooperative efforts by the University of Washington and the National Park Service.

Fish were collected by several organizations. Fish from Lake Washington were collected during a study led by Casey Clark of the University of Washington: collection methods involved gill netting and purse seining.   Fish from Ross Lake were collected with gillnet during a study led by Hugh Anthony of the National Park Service at North Cascades National Park. Ecology collected fish from Green Lake using gillnets and a 16' electrofishing boat (cover photo). Captured fish were identified to species, and target species were retained while non-target species were released. Retained fish were inspected to ensure that they were acceptable for further processing (e.g., proper size – smallest fish at least 75% the length of largest fish in the sample, no obvious damage to tissues, skin intact).

Field preservation of each retained fish involved assigning unique identification code, measuring length and weight, wrapping in foil and Ziploc bags or large plastic bags, and placing on ice for transport to freezer for storage at -20 °C. Fish collected by the University of Washington were kept on ice for one to two days before being picked up by Ecology staff for transport to Ecology freezers in Olympia. Fish collected by North Cascades National Park were frozen at NPS facilities in Newhalem and later picked up by Ecology staff for transport to Ecology freezers in Olympia. Fish were processed at a later date to form samples that were sent to the laboratory for analysis.

Sample Preparation

Frozen fish were processed at Ecology's headquarters several months after collection. Individual fish were first assigned to composite samples based on the sampling goals for individual sites. This involved grouping fish by size, usually by total length, to match sizes of fish used in historical samples and make use of available fish. To create multiple composite samples of similar sized fish, individual fish meeting the size criteria were randomly assigned to composite samples. For example, where five composite samples of five fish each were to be created, each of the 25 individual fish was randomly assigned to one of the five composite samples.

Most composite samples consisted of skin-on fillets from five individual fish of the same species per site of a similar size (i.e., the smallest fish was at least 75% the length of the largest fish in the composite sample). Fillets of largescale suckers were not used; all samples of this species were processed as whole fish. For fish (species or size) that did not match historical collections, composite samples were created using fish of similar size. Composite samples were used because they reduce the variability in contaminant levels that are often seen in individual fish, and they provide adequate tissue material for varied laboratory analyses.

Individual fish selected for a specific composite sample were processed at the same time. Fish were partially thawed before further processing. For fillet samples, fillets were removed and cut into smaller pieces. One or both fillets were removed from the fish, depending on the fish size and sample mass required for laboratory analysis. Pieces of fillet tissue were then passed through a Kitchen-Aid food processer into a stainless steel bowl three times in order to grind and homogenize the tissue sample (Figure B-1). Whole fish were passed through a larger, commercial-grade Hobart meat grinder in a similar fashion. Equal amounts of the ground and homogenized tissue from each fish were then combined and homogenized to form a single composite sample. This composite was then passed once again through the grinder.

Figure B-1. Left: grinding fish fillet tissue. Right: removing otolith to determine age.

An aliquot (30-90 grams) of the homogenized composite tissue was put in pre-cleaned jars (I-Chem 200 or 300) labeled for specific analyses and stored frozen until transport to the Ecology/EPA Manchester Environmental Laboratory (MEL).

For fillet samples, the abdominal cavity of the fish was opened to determine gender after fillets were removed from the fish. Fish scales, otoliths, opercula, or other structures were removed for age determination by Washington Department of Fish and Wildlife (WDFW) biologists in Olympia, WA. All utensils used for tissue processing were cleaned to prevent contamination of the samples. The cleaning procedure involved soap and water washes followed by acid and solvent rinses. Sample collection and processing details are described in SOPs. (Sandvik, 2006 a, b, c).

Appendix C. Comparison of Results from PCB Aroclor and Congener Analyses

Results from PCB analyses were examined more closely in order to evaluate the comparability of PCB data generated from two different methods, and to evaluate the usability of N-flagged PCB Aroclor results in this report. These efforts are summarized below and described further in the Appendices.

PCB congeners were analyzed in a subset of each year's samples since 2004. Congener analysis was pursued in order to evaluate the accuracy and comparability of Aroclor analysis for meeting the needs of this monitoring program. Analyses for PCB Aroclor often had challenges such as poor pattern matches to standards because of weathering or degradation as well as interference due to high lipids content or the presence of other analytes. These factors added to the difficulty of achieving the desired reporting limits of 2 ug/kg. However, lower reporting limits for Aroclors have recently been achieved more consistently at MEL with additional cleanup methods and changes in sample extraction methods.

Figure C-1 shows that total PCB Aroclor values compare fairly well with total PCB congener values over three orders of magnitude. Viewing the relationship between the two sets of values, Aroclor values appear to be a bit higher than congener values and may overestimate the true concentration of PCBs in the samples (assuming the PCB congener analysis yields the "truer" value). This difference is likely due to differences in analytical methods: Aroclor analysis is based on matching patterns of mixtures of selected congeners whereas the congener method is a direct measurement of all PCB congeners present. The differences in results produced by the two methods are likely negligible such that Aroclor analysis would be adequate to meet this project's needs.

Advantages and disadvantages to each method for quantifying PCBs which need to be considered in monitoring projects (Bernhard and Petron, 2001). Congener analysis provides a more accurate quantification at lower reporting limits (0.005 – 0.02 ug/kg) than Aroclor analysis (5.0 - 20.0 ug/kg). Analytical costs per sample are higher for congener analysis ($800 - $1000) than for Aroclor analysis ($200). PCB congener analysis also requires substantial work to validate and verify the data and prepare it for loading into Ecology's EIM data base. The time between sample submittal and readiness to load data into EIM is longer for congener data (minimum 8-14 months) than for Aroclor data (minimum 4-8 months).

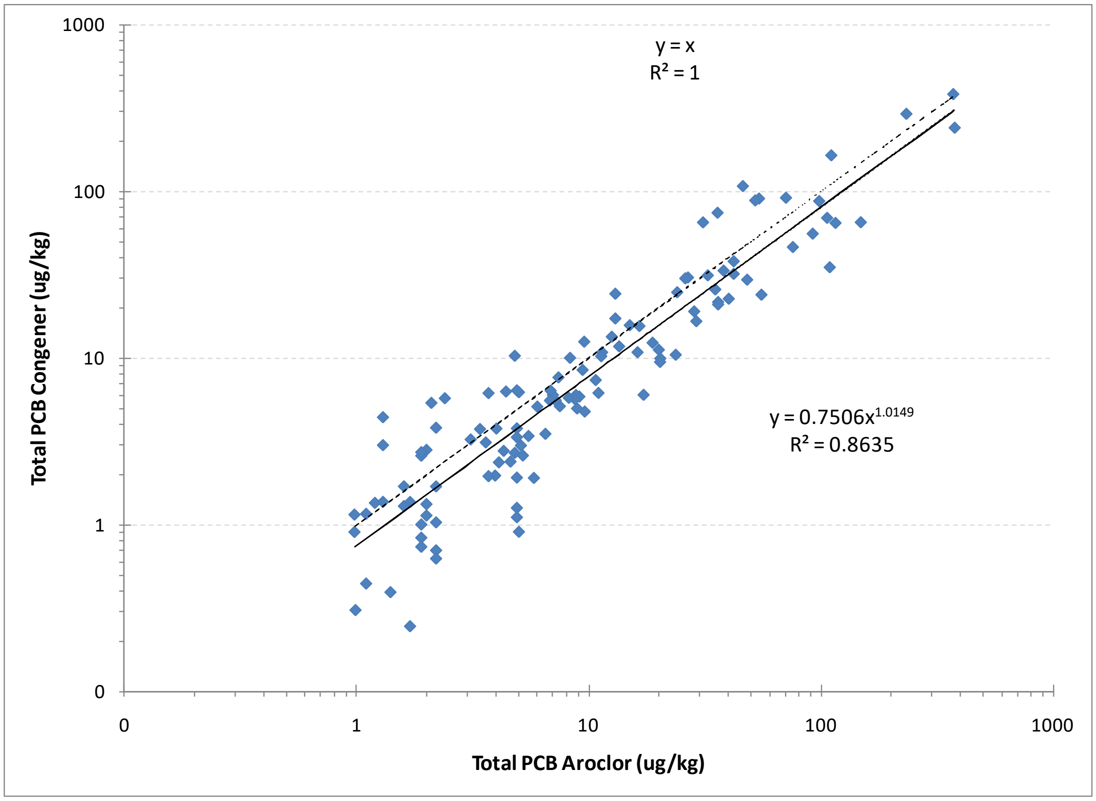


Figure C-1. Total PCB Aroclors versus Total PCB Congeners, WSTMP 2001-2008 (n=120).

The consequences of underestimating or overestimating PCB levels in fish tissue for this monitoring program is likely negligible because the levels are so high. Also, little or no action has been taken in cases where PCB levels in fish exceeded the previous water quality standard, expressed as a Fish Tissue Equivalent Concentration, or FTEC) of 5.3 ug/kg by factors ranging from 2-10, and even higher. In most of these cases, the PCB level as estimated by Aroclor analysis is likely adequate. Further actions to increase certainty would likely involve using larger sample sizes and the congener method to obtain a better estimate of the level of PCBs in fish tissue.

Given the factors described above, the use of PCB Aroclor analysis in the FFCMP would meet project needs at lower laboratory costs, lower data processing costs, and quicker turnaround times between sampling and data upload to EIM. Results from this two-method comparison suggest that values from the two different methods are adequately comparable for most needs of this project, including for trends analyses in many cases. However, the congener method may be preferable to use in cases where lower concentrations (e.g. < 10 ug/kg) in samples will be compared to numerical thresholds that trigger important decisions, such as 303(d) listings.

Appendix D. Evaluating the Utility of N-Flagged PCB Results in Selected Samples

In order to maximize the use of historical PCB Aroclor data for trends analyses in Lake Washington, the qualification of Health's' DOH 2005 results was examined along with PCB congener results from samples that were analyzed by both methods. Some of the DOH 2005 PCB Aroclor results were qualified as NJ, the "N" indicating the lack of positive identification of the analyte. Some of the PCB Aroclor 1254 and 1260 were so qualified because of challenges in distinguishing the two Aroclor patterns in some samples. Factors contributing to this interference include the extent of Aroclor "weathering", lipids, and other analytes present in the matrix. The examination of these data, described below, suggests that some "N" qualified results could be cautiously used in trends analyses, recognizing that such results may be biased high.

Table D-1 shows results for PCB Aroclors and congeners from samples that were analyzed by both methods. PCB Aroclor analysis was done on individual samples from the 2005 Health study. The 2005 WSTMP study had combined archive tissue from some of Health's samples to form a new sample that was then analyzed for PCB congeners. The t-PCB Aroclor results from the samples that were combined for congener analysis were averaged, and this arithmetic average assumed to be representative of the t-PCB Aroclor concentration of the combined samples. This Aroclor average was then compared to the t-PCB congener result and the Relative Percent Difference (RPD) was calculated.

This combining and congener analysis routine was performed on three groups of samples. Only results for Aroclors 1254 and 1260 were used because other Aroclors have not been detected in freshwater fish during Ecology's monitoring efforts, except for Aroclor 1248 which has rarely been detected.

The RPDs of 23%, 4%, and 44% for the Aroclor and congener analyses are within the commonly used limit of 50% for laboratory duplicates for such analyses. This consolidation and comparison of sample results suggests that the use of N-flagged Aroclor results in calculating t-PCB Aroclor values for the 2005 data may be appropriate for use in trend analyses. This approach will introduce high bias to some of the 2005 t-PCB Aroclor results which should be considered in interpreting trends.

Table D-1. PCB Aroclor and congener results from samples that were consolidated and analyzed by two analytical methods (PCB values in ug/kg).

Study_ID	Trend Group	Note	Sample Lab ID	PCB-1254	q	PCB-1260	q	t-PCBa w NJ as J	q	mean t-PCBa w NJ as J for t-PCBc comparison	t-PCBc	RPD: mean of t-PCBa w NJ as J, t-PCBc	mean t-PCBa for Trend Group w NJ as J	t-PCBa w NJ as ND	q	mean t-PCBa w NJ as ND for t-PCBc comparison	t-PCBc	RPD: mean of t-PCBa w NJ as ND, t-PCBc	mean t-PCBa for Trend Group w NJ as ND
DOHLW05	CTT-L-2005		5138745	200	J	400	NJ	600	J				427.5	200	J				233.5
		A	5138746	120	NJ	200	NJ	320	J	370.0		4%		200	NJ	220.0		54%	
			5138747	180	NJ	240	NJ	420	J					240	NJ				
WSTMP05			5524733								383.6						383.6		
DOHLW05	CTT-L-2005		5138773	210	NJ	550	NJ	760	J					550	NJ				
		B	5138774	180	NJ	160		340	J	232.5		23%		160		105.5		94%	
			5138775	74	NJ	51		125	J					51					
WSTMP05			5524732								292.2						292.2		
DOHLW05	NPM-L-2005	C	5138754	65		51		116		375.3		44%	375.3	116		255.3		6%	255.3
			5138755	190	NJ	210	NJ	400	J					210	NJ				
			5138757	170	NJ	440	NJ	610	J					440	NJ				
WSTMP05			5524734								241.2						241.2		
DOHLW05	CTT-S-2005		5138763	60	NJ	57		117	J	168			168	57					95.5
			5138769	120	NJ	110		230	J					110					
			5138776	110	NJ	120		230	J					120					
			5138786	52		43	J	95						95	J				

A - Sample IDs 05138774 and 05138775 in EIM User Study ID DOHLW05 were combined to form sample # 05524732 in EIM User Study ID WSTMP05
B - Sample IDs 05138746 and 05138747 in EIM User Study ID DOHLW05 were combined to form sample # 05524733 in EIM User Study ID WSTMP05.
C - Sample IDs 05138754, 05138755, and 05138757 in EIM User Study ID DOHLW05 were combined to form sample # 05524734 in EIM User Study ID WSTMP05.
t-PCBa = total PCB Aroclors.
t-PCBc = total PCB congeners.
RPD = Relative Percent Difference.
NJ = The analysis indicates the presence of the analyte, has been tentatively identified and the associated numerical value is the approximate concentration. Identification needs further confirmation.
J = The analytes was positively identified and the associated numerical value is the approximate concentration of the analyte in the sample.
ND = Not detected. Q = qualifier code.

Appendix E. Water Quality Criteria and Screening Values

Various criteria for the protection of human health exist because of changing knowledge about the toxic effects of chemicals and subsequent risks to consumers of fish. These different criteria and screening values are often based on different assumptions used in determining risk, such as daily consumption rates, toxicological data used in calculations, and risk levels. The criteria summarized below are Washington's water quality standards via the current proposed implementation policy, EPA's recommended criteria, and EPA's screening values.

Table E-1 shows Washington's proposed thresholds (as Tissue Equivalent Concentrations, or TECs) along with other EPA criteria and screening values for the most frequently detected contaminants in the 2015 study. Appendix F describes how Ecology and Health evaluate fish tissue data.

Washington's Current Water Quality Standards and Proposed Policy for Implementation

Ecology adopted new human health criteria which were incorporated into Washington's water quality standards (WAC Chapter 173-201A) in August 2016. Water quality criteria are designed to minimize the risk of health effects from ingesting contaminants found in drinking water and fish/shellfish obtained from surface waters in Washington. The water quality criteria, if met, will generally help ensure that public health advisories for drinking water or eating fish are not needed. Washington's previous water quality criteria for toxic contaminants were originally issued to the state by EPA through the 1992 National Toxics Rule (NTR) found at 40 CFR 131.36.

Ecology uses its Water Quality Program Policy 1-11 to assess water quality and determine impairments: impairments lead to waterbodies being added to a list as required by Section 303(d) of the Clean Water Act. Revisions to Policy 1-11 are expected to be complete in the spring of 2018.

The most recent draft of Policy 1-11 (Public Review Draft dated 1/30/18) uses a Tissue Equivalent Concentration (TEC) concept to evaluate whether the use of harvest (fish and shellfish consumption) is met in a waterbody. This approach includes risks from both cancer and non-cancer health effects for most chemicals having criteria. Incorporating both types of risks leads to chemicals having one or two numerical values. These numerical values are termed the TECc for carcinogenic effects thresholds; and the TECn for non-carcinogenic effects thresholds.

In order to determine whether the designated use of harvest is met, sample results would be compared to these TECs. The draft policy incorporates requirements for sample size and magnitude of result in determining whether uses are met. More information about Ecology's new TEC thresholds and other revisions to Policy 1-11 are available at https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d/Assessment-policy-1-11.

Table E-1. Water Quality Standards Criteria and Guidelines Used for the Protection of Human Health for Contaminants Detected in Fish Tissue, FFCMP 2015.

Analyte (ppb ww)[1]	Fish Tissue Thresholds to Evaluate Use Attainment			EPA Screening Values			
				Subsistence Fishers		Recreational Fishers	
	draft TECn (2018)	draft TECc (2018)	Old FTEC (2016)	Non-carcino-gens	Carcino-gens	Non-carcino-gens	Carcino-gens
2,3,7,8-TCDD [3]	0.32	-	0.065	-	-	-	-
2,3,7,8-TCDD TEQ [3, 4]	0.32	-	-	-	0.0315	-	0.256
4,4'-DDD	230	1.9	44	-	-	-	-
4,4'-DDE	230	2.7	32	-	-	-	-
4,4'-DDT	230	1.3	32	-	-	-	-
Total DDT [5]	-	-	-	245	14.4	2000	117
Beta-BHC	-	0.25	1.8	-	-	-	-
Chlordane [6]	230	1.3	8.0	245	14.0	2000	114
Dieldrin	23	0.029	0.65	24	0.307	200	2.5
gamma-BHC (Lindane)	2100	-	2.5	147	3.78	1200	30.7
Hexachlorobenzene (HCB)	370	0.45	6.5	393	3.07	3200	25.0
Mercury	30	-	770	49	-	400	-
PBDEs	-	-	-	-	-	-	-
Total PCBs [2]	9.1	0.23	5.3	9.83	2.45	80	20
Toxaphene	160	0.42	9.6	122	4.46	1000	36.3

FTEC: Fish Tissue Equivalent Concentration.

TEC: Tissue Equivalent Concentration; c=for carcinogenic effect; n=for non-carcinogenic effects,

1 - Values in parts per billion wet-weight (ug/kg ww) unless otherwise noted.
2 - Total PCBs is sum of Aroclors or congeners.
3 - Values in parts per trillion wet-weight (ng/kg ww).
4 - The cumulative toxicity of a mixture of congeners in a sample can be expressed as a TEQ to 2,3,7,8-TCDD. EPA (2010) states that the criterion for dioxin is expressed in terms of 2,3,7,8-TCDD and should be used in conjunction with the international convention of TEFs and TEQs to account for the additive effects of other dioxin-like compounds. When the TEQ is used, the toxicity of the single congener 2,3,7,8-TCDD is incorporated.
5 - Total DDT is the sum of 2,4'- and 4,4'- isomers of DDD, DDE, and DDT. DDD: 4,4'-dichlorodiphenyldichloroethane. DDE: 4,4'-dichlorodiphenyldichloroethylene. DDT: 4,4'-dichlorodiphenyltrichloroethane. Where data for the 2,4' isomers are lacking, the sum of the 4,4'- isomers is used.
6 - The criterion for chlordane is interpreted as the sum of five chlordane components; these can be individually quantified through laboratory analyses while chlordane cannot. The EPA screening values are for "Total Chlordanes" which is the sum of five compounds: cis- and trans- chlordane, cis- and trans- nonachlor, and oxychlordane.

EPA Screening Values

EPA developed screening values (SVs) for carcinogenic and non-carcinogenic effects of substances to help prioritize areas that may present risks to humans from fish consumption. The EPA SVs are considered guidance only; they are not regulatory thresholds (EPA, 2000). The approach EPA used to develop the SVs was similar to the approach it to develop some of the new criteria adopted by Washington in August 2016. However, the SVs differ in two key assumptions:

- A cancer risk level of 10^{-5}.
- Two consumption rates: 17.5 grams/day for Recreational Fishers, and 142.4 grams/day for Subsistence Fishers.

A difference between the EPA SVs and Ecology's Policy 1-11 relating to PCDD/Fs is that the SVs use the dioxin/furan TEQ value while Ecology has used, and proposes to continue to use, the single congener (TCDD) for 303(d) assessments (Ecology, 2012).

Washington State Department of Health (Health) Screening Levels

Screening levels (SLs) for the carcinogenic or non-carcinogenic effects of toxic substances were developed by Health to help determine whether a full risk assessment is needed. Health uses varied consumption rates, cancer/non-cancer risk levels, and other assumptions that may depend on the location of the waterbody and population to be protected. Such risk assessments may or may not lead to a fish consumption advisory for a specific site and species. More information about the health benefits of eating fish and fish consumption advisories in Washington are at Health's website: www.doh.wa.gov/ehp/oehas/fish/.

Appendix F. Fish Tissue Data Evaluation: Ecology and Health

Several state and federal agencies collect and evaluate fish tissue data in Washington State. These include the Ecology, Health, and Washington Department of Fish and Wildlife; the U.S. Environmental Protection Agency (EPA); and the U.S. Geological Survey. Tissue data are evaluated differently by these agencies because their mandates and roles are varied. These multiple evaluations often lead to confusion and misunderstanding among agencies and the public on how fish tissue data are used and interpreted. Adding to potential confusion are the numerous criteria or screening values derived to provide guidance for determining the risks of consuming contaminated fish and protecting public health.

Most tissue contaminant data from Washington fish and shellfish, regardless of who conducted the study, make their way to Health for evaluation regarding the safety of consuming fish. Health provides information about the heathy benefits of fish as well as advice regarding Fish Consumption Advisories at: www.doh.wa.gov/CommunityandEnvironment/Food/Fish.aspx.

For the FFCMP and many other Ecology studies, fish tissue data are evaluated primarily to determine if (1) Washington State water quality standards are being met, and (2) potential risks to human health from consuming contaminated fish warrant further study and/or development of a fish consumption advisory. Ecology's role is to determine whether water quality standards are met and to begin the process to correct problems where standards are not met. Health and local health departments are responsible for developing fish consumption advisories in Washington. There is some overlap in these evaluations because the water quality standards that fish tissue data are compared to were developed for the protection of human health.

The following is an overview of how Ecology and Health evaluate fish tissue data to meet different needs.

Washington State Water Quality Standards

For the protection of human health, Washington's water quality standards criteria for toxic contaminants were originally issued to the state in EPA's 1992 National Toxics Rule (NTR) (40 CFR 131.36). In 2016, Ecology revised its water quality standards which included the adoption of a number of criteria promulgated by EPA. All of the criteria are designed to minimize the risk of effects occurring to humans from chronic (long-term) exposure to substances through the ingestion of drinking water and consumption of fish obtained from surface waters. The water quality criteria, if met, will generally ensure that public health concerns do not arise and that fish advisories are not needed.

The criteria are thresholds that, when exceeded, may lead to action to address sources of pollution. When water quality standards are not met, the federal Clean Water Act requires that the water body be put on a list and that a Water Cleanup Plan be developed for the pollutant causing the problem. This list is known as the 303(d) list, and the Water Cleanup Plan results from a study (such as a Total Maximum Daily Load, or TMDL) which identifies sources of pollution; and a public involvement process which identifies actions to correct the sources of pollution. Ecology uses the TMDL program to control sources of the particular pollutant in order to bring the water body back into compliance with the water quality standards.

How the new criteria will be used to assess waterbodies is documented in Ecology Water Quality Program Policy 1-11. The revision of Policy 1-11 is expected to be complete in spring 2018. Policy 1-11, Chapter 1 describes the methods for how water bodies will be assessed to determine whether they meet surface water quality standards described in Chapter 173-201A of the Washington Administrative Code. Water bodies are then placed in various categories based on the methodologies described in this policy. Water bodies that do not meet standards are listed as Category 5 (the 303(d) list) which requires that action be taken to address the pollution problem.

Risk Management Decisions

While Health supports Ecology's use of various criteria for identifying problems and controlling pollutant sources so that water quality will meet standards, Health may not use the same criteria to establish fish consumption advisories (McBride, 2006).

Health uses an approach similar to that in EPA's Guidance for Assessing Chemical Contaminant Data for use in Fish Advisories Vol. 1-4 for assessing mercury, PCBs, and other contaminants (EPA, 2000). These guidance documents provide a framework from which states can evaluate fish tissue data to develop fish consumption advisories. The framework is based on sound science and established procedures in risk assessment, risk management, and risk communication. Neither Ecology's criteria nor the screening values found in the EPA guidance documents described above incorporate all of the varied risk management decisions essential to developing fish consumption advisories. Risk management concepts include:

- **Risk Assessment** involves calculating allowable meal limits based on known fish contaminant concentrations. These calculations are conducted for both non-cancer and cancer criteria using the appropriate Reference Dose (RfD) or Cancer Slope Factor (CSF), if available. These initial calculations are the starting point for evaluating contaminant data to determine whether a fish advisory is warranted. Additionally, known or estimated fish consumption rates help determine the potential magnitude of exposure and highlight the sensitive groups or populations that may exist due to elevated consumption rates.
- **Risk Management** includes (but is not limited to) consideration of contaminant background concentrations, reduction in contaminant concentrations through preparation and cooking techniques, known health benefits from fish consumption, contaminant concentrations, health risks associated with replacement foods, and cultural importance of fish. Other considerations are the possible health criteria associated with a contaminant, the strength or weakness of the supporting toxicological or sampling data, and whether effects are transient or irreversible.
- **Risk Communication** is the outreach component of the fish advisory. The interpretation of the data from the risk assessment and risk management components drives how and when the fish advisory recommendations are issued to the public, dependent on whether the message is targeted toward a sensitive group or a population or the general public. Health's dual objective is (1) how best to provide guidance to the public to increase fish consumption of fish low in contaminants to gain the benefits of eating fish, while (2) steering the public away from fish that have high levels of health-damaging contaminants.

Appendix G. Boxplots for Selected Parameters from Lake Washington Fish, 2015

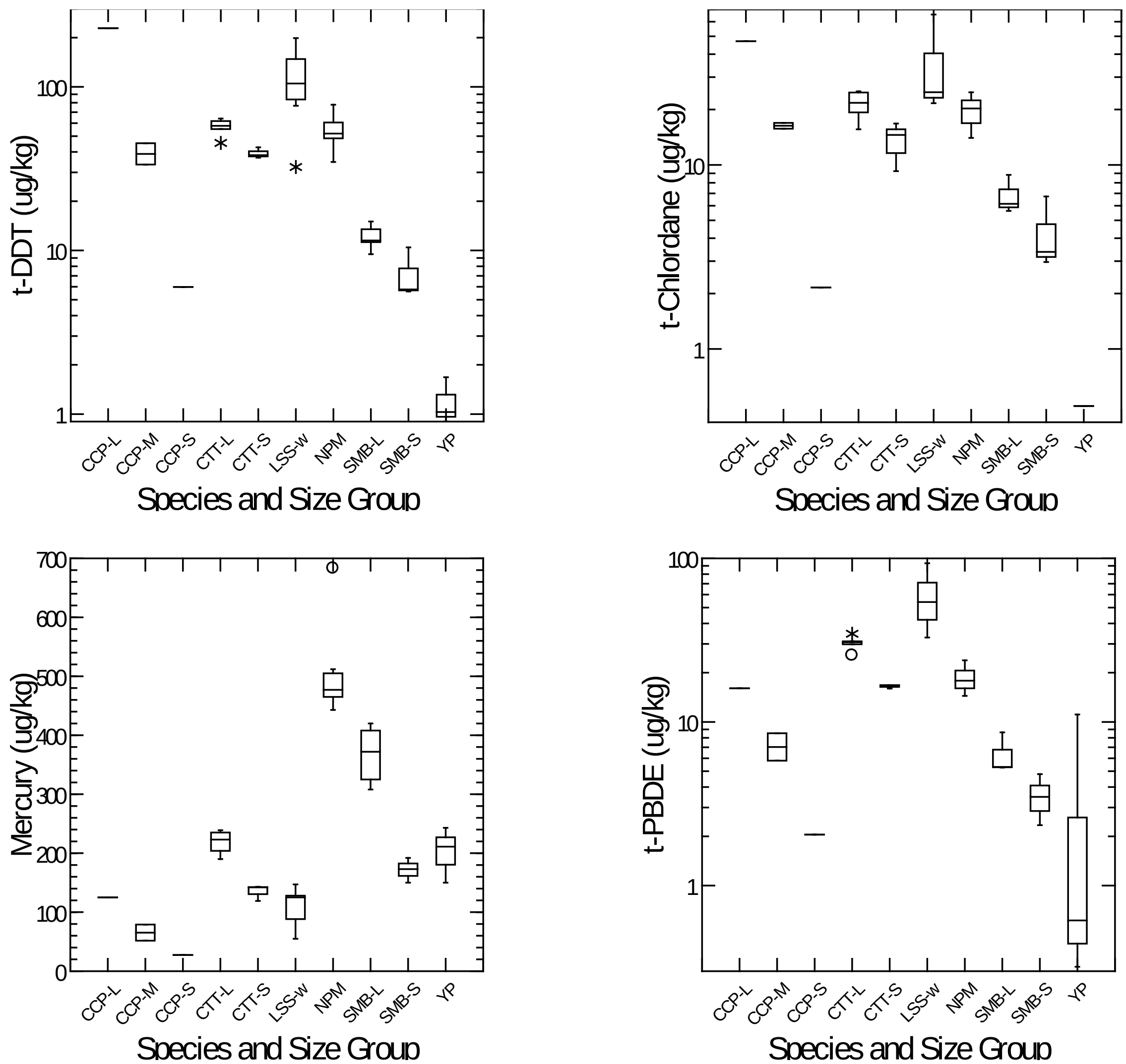


Figure G-1. Boxplots for selected parameters for Lake Washington Fish, 2015.

Species codes: CCP: Common carp; CTT: Cutthroat trout; LSS: Largescale sucker; NPM: Northern pikeminnow; SMB: Smallmouth bass; YP: Yellow perch.

Relative size groups: L-large size, M-Medium size; S-small size; W-whole fish.

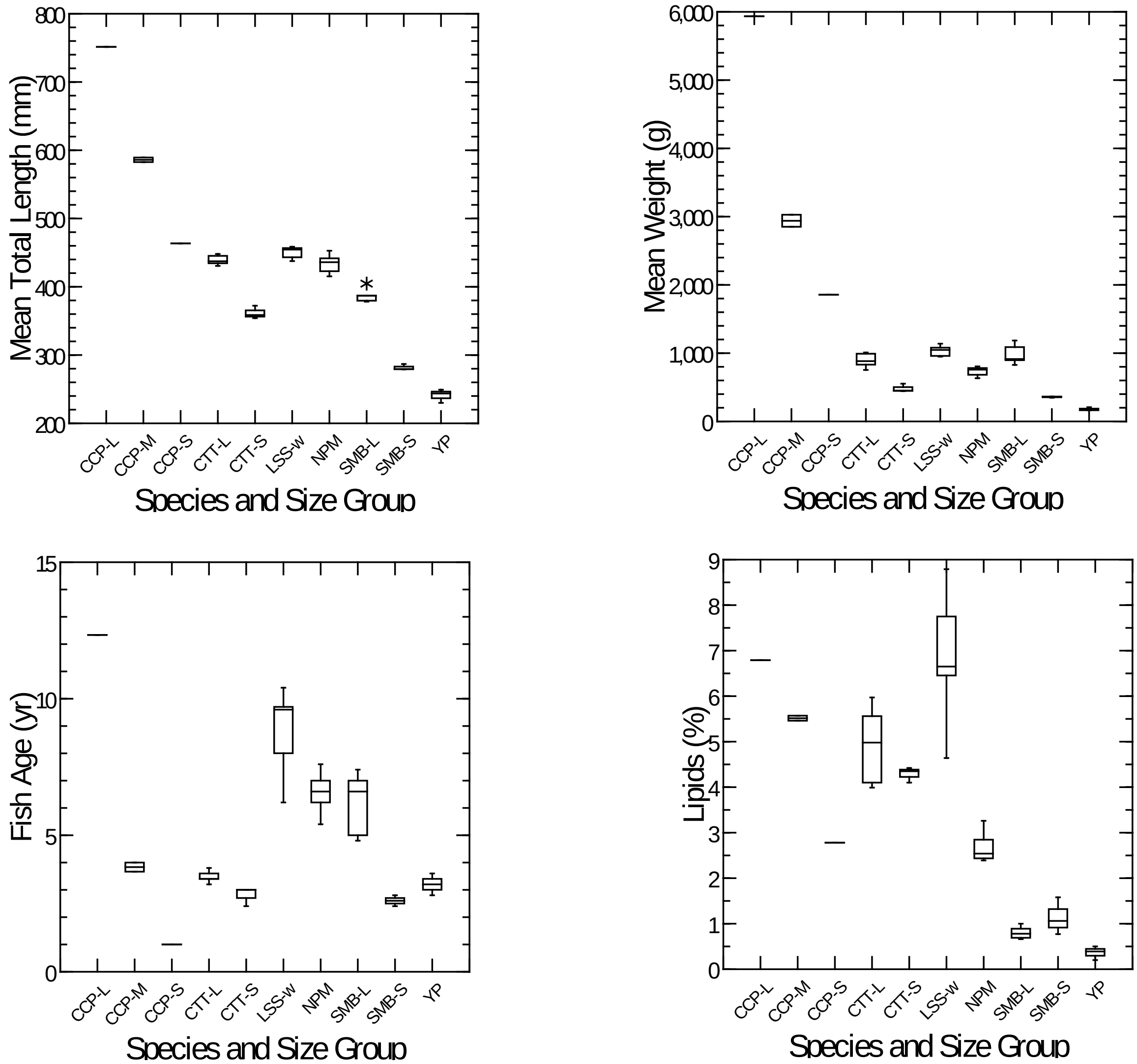
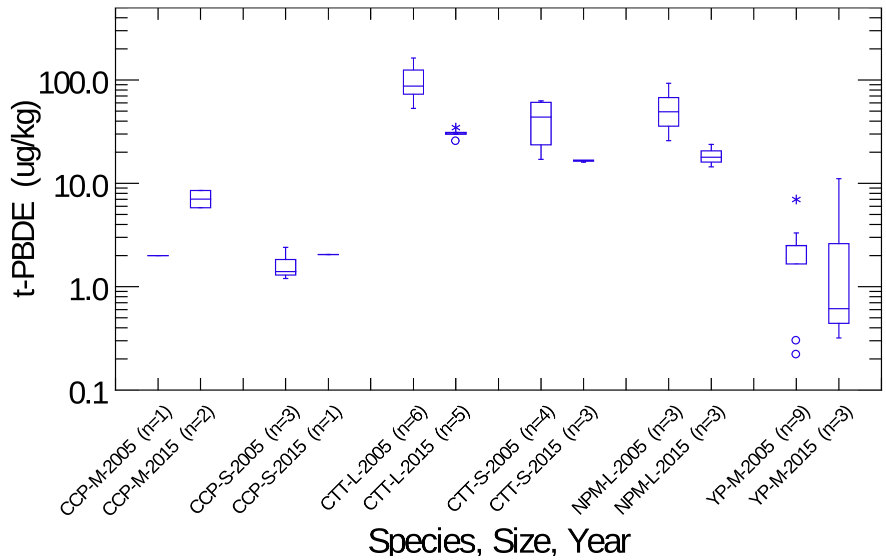


Figure G-1…continued.

Appendix H. Boxplots Comparing 2005 and 2015 Results for Selected Parameters from Lake Washington Fish



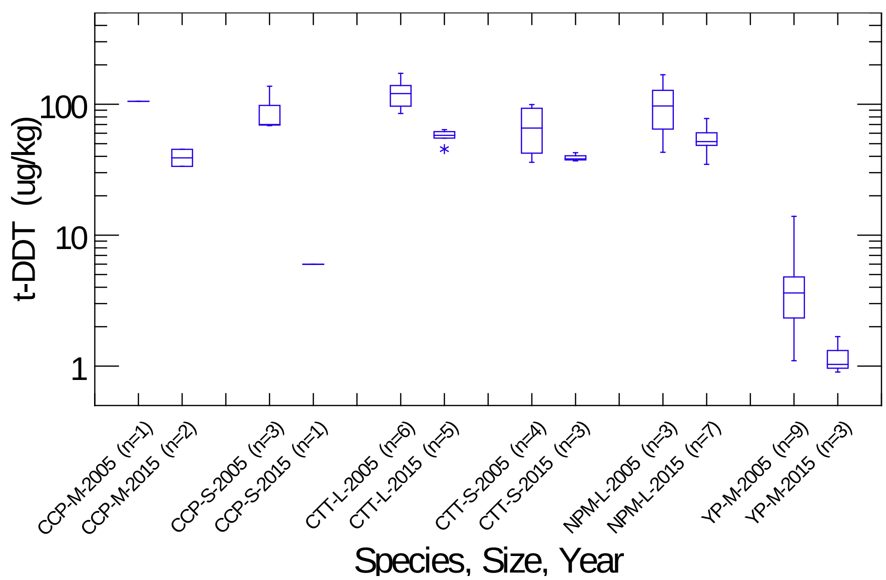


Figure H-1. Boxplots comparing selected parameters for Lake Washington Fish over time.

Species codes: CCP: Common carp; CTT: Cutthroat trout; NPM: Northern pikeminnow; YP: Yellow perch.
Relative size groups: L-large size, M-Medium size; S-small size; W-whole fish.

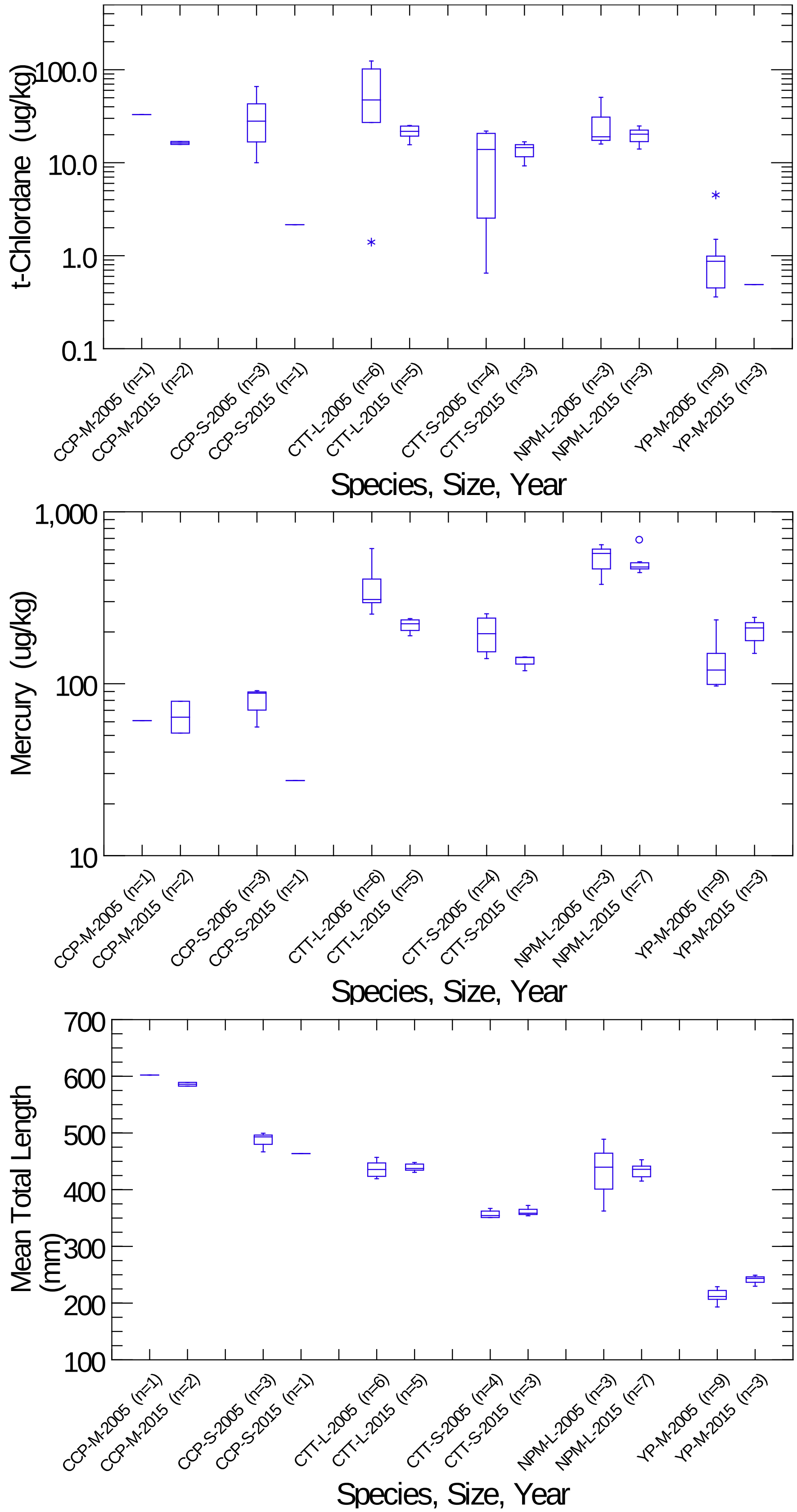


Figure H-1… continued.

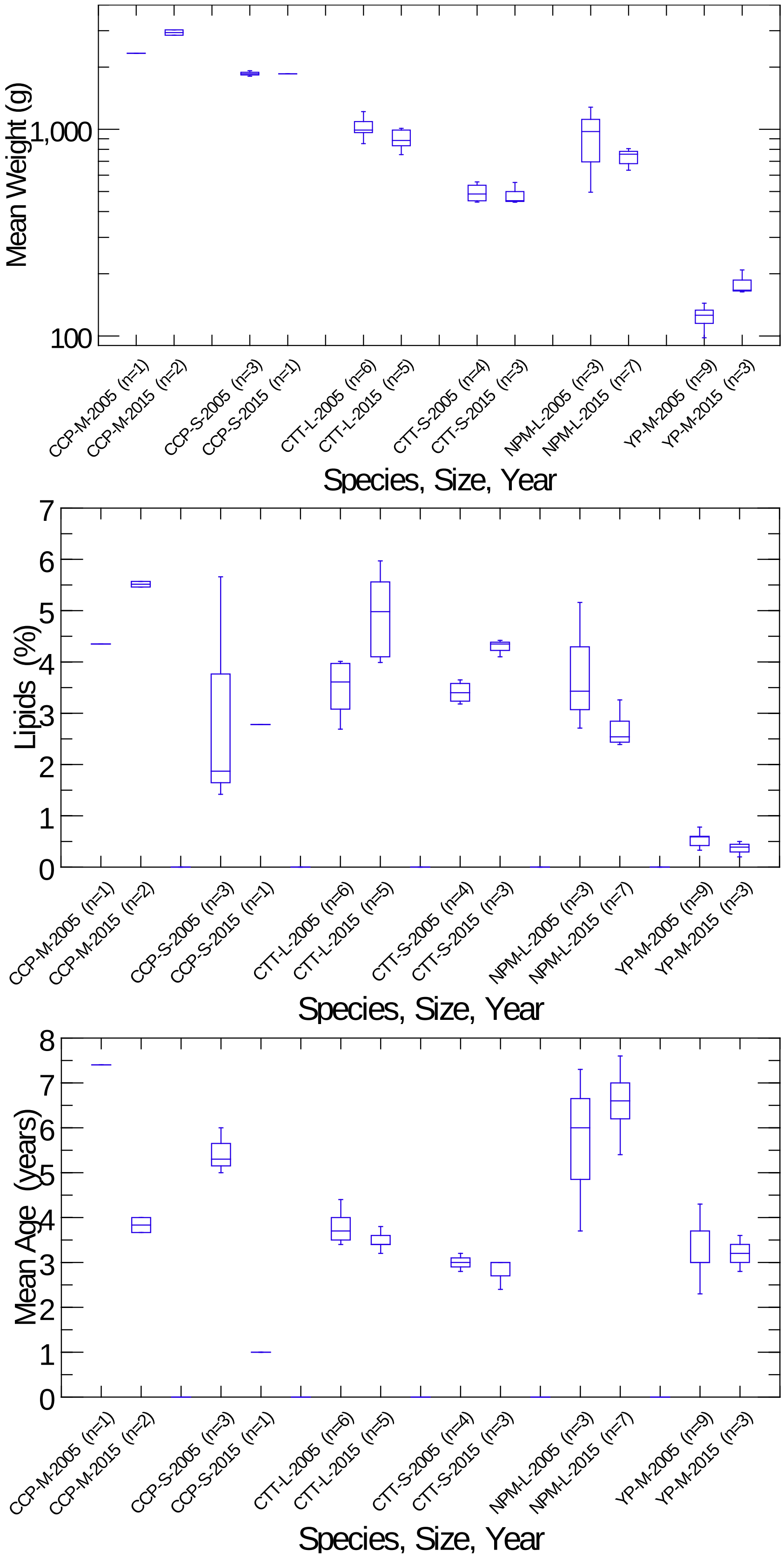


Figure H-1… continued.

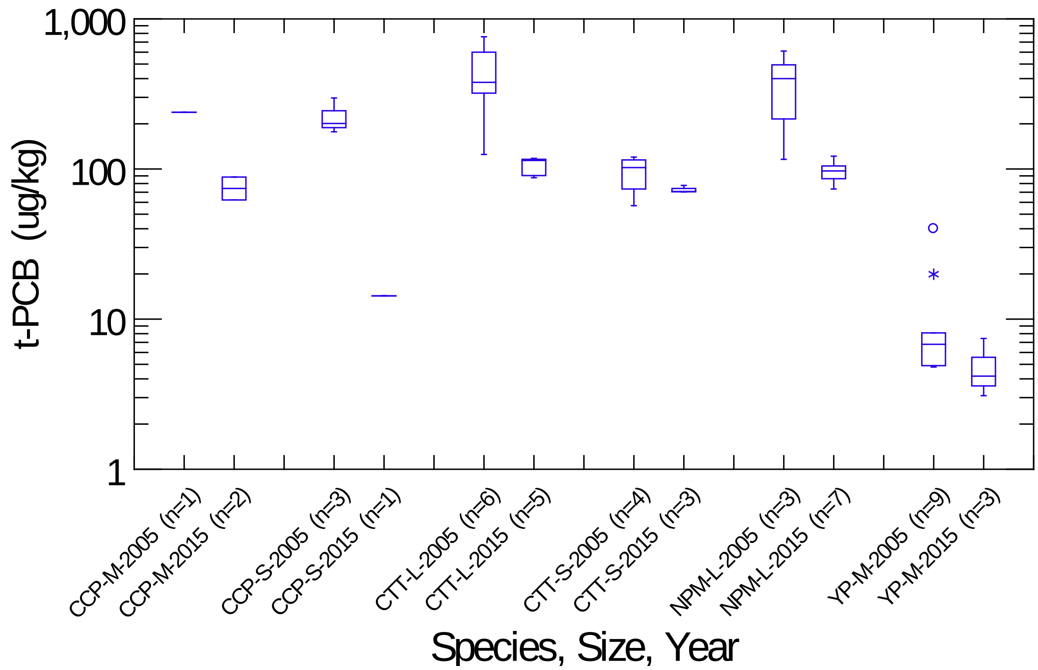


Figure H-2. Boxplots for t-PCB Aroclors where NJ-qualifier values were treated as J (estimate), and thus included in calculating t-PCB (only for 2005 CCT-L and NPM-L).

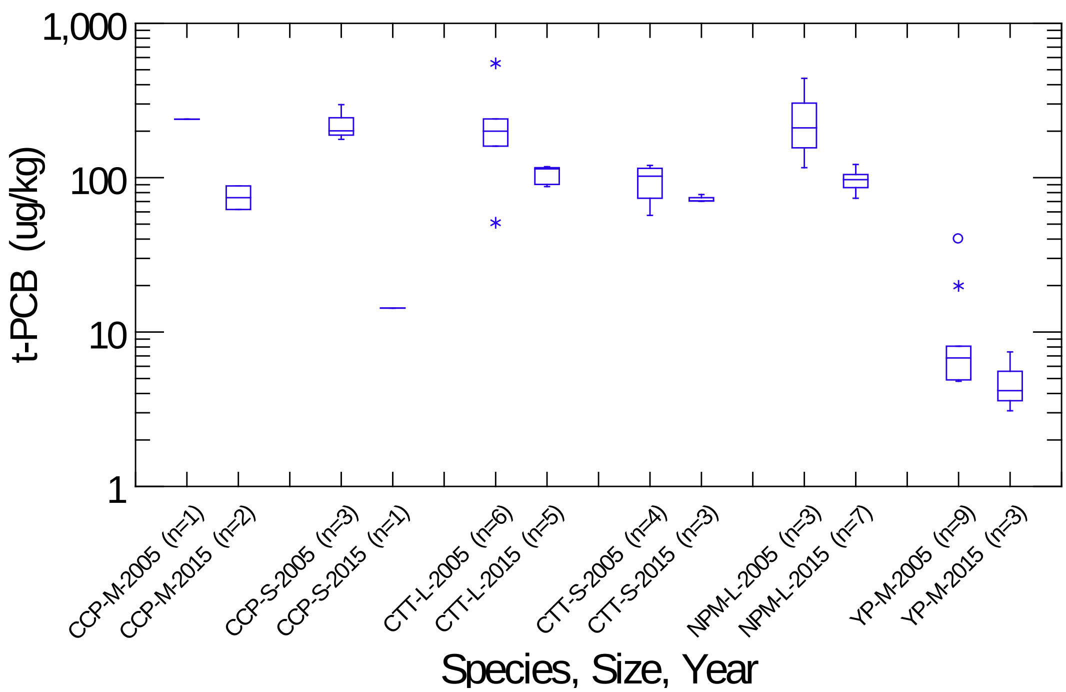


Figure H-3. Boxplots for t-PCB Aroclors where NJ-qualifier values were treated as Non-Detects, and thus excluded when calculating t-PCB (only for 2005 CCT-L and NPM-L).

Appendix I. Results for Metals in Ross Lake Fish

Table I-1. Results for metals (ug/kg ww) in fish fillets from Ross Lake.

Sort	Year	Field ID	Sb		As		Be		Cd		Cr		Cu	Pb		Hg	Ni		Se		Ag		Tl		Zn
1		RO-NC-L	0.198	U	0.099	U	0.099	U	0.099	U	0.494	U	**1.960**	0.099	U	**0.600**	0.099	U	0.494	U	0.099	U	0.099	U	**6.20**
2		RO-NC-M1	0.198	U	0.099	U	0.099	U	0.099	U	0.494	U	**1.290**	0.099	U	**0.560**	0.099	U	**0.533**		0.099	U	0.099	U	**6.70**
3	2015	RO-NC-M2	0.186	U	0.093	U	0.093	U	0.093	U	0.465	U	**1.340**	**0.106**		**0.451**	0.093	U	**0.524**		0.093	U	0.093	U	**6.53**
4		RO-NC-M3	0.190	U	0.095	U	0.095	U	0.095	U	0.476	U	**1.500**	0.095	U	**0.549**	0.095	U	**0.516**		0.095	U	0.095	U	**7.59**
5		RO-NC-S	0.198	U	0.099	U	0.099	U	0.099	U	0.496	U	**1.210**	0.099	U	**0.298**	0.099	U	0.496	U	0.099	U	0.099	U	**8.06**
6	2012	ROSS-BLT	0.198	U	0.099	U	0.099	U	0.099	U	**2.28**		**1.49**	0.100	U	**0.415**	0.099	U	**0.581**		0.099	U	0.100	U	**6.76**
7	2007	ROSSBLT														**0.219**									
8		RO-RBT-1	0.196	U	0.098	U	0.098	U	0.098	U	0.489	U	**0.717**	0.098	U	**0.189**	0.098	U	**0.560**		0.098	U	0.098	U	**7.50**
9		RO-RBT-2	0.187	U	0.093	U	0.093	U	0.093	U	0.466	U	**0.701**	0.093	U	**0.246**	0.093	U	**0.527**		0.093	U	0.093	U	**7.27**
10	2015	RO-RBT-3	0.200	U	0.100	U	0.100	U	0.100	U	0.500	U	**0.518**	0.100	U	**0.147**	0.100	U	0.500	U	0.100	U	0.100	U	**6.79**
11		RO-RBT-4	0.195	U	0.098	U	0.098	U	0.098	U	0.488	U	**1.59**	0.098	U	**0.258**	0.098	U	0.488	U	0.098	U	0.098	U	**9.05**
12		RO-RBT-5	0.195	U	0.097	U	0.097	U	0.097	U	0.486	U	**1.07**	0.097	U	**0.169**	0.097	U	**0.487**		0.097	U	0.097	U	**7.19**
13	2012	ROSS-RBT	0.198	U	0.099	U	0.099	U	0.099	U	**3.17**		**0.835**	0.100	U	**0.188**	0.099	U	0.495	U	0.099	U	0.100	U	**6.85**
14	2007	ROSSRBT														**0.063**									
15	2012	ROSS-EBT	0.199	U	0.099	U	0.099	U	0.099	U	**1.09**		**2.29**	0.100	U	**0.188**	0.099	U	**0.746**		0.099	U	0.100	U	**7.80**

Species codes: BLT=Bull trout (a native char); EBT=Eastern brook trout; NC-Native char (bull trout or Dolly Varden); RBT: Rainbow trout.
Relative size group codes: L-large size, M-Medium size; S-small size.
Qualifiers: U= not detected at or above the reported value.

Appendix J. Glossary, Acronyms, and Abbreviations

Glossary

Analyte: A substance or constituent being measured in an analytical procedure (parameter). A physical, chemical, or biological property whose measured value help determine the characteristics of something of interest.

Aroclor: A trade name under which a commercial mixture of individual PCB congeners was marketed by Monsanto Company in North America. Different mixtures, or Aroclors, were used for different applications. Aroclors are the most common form of PCBs targeted in laboratory analyses.

Char: Char (genus *Salvelinus*) are distinguished from trout and salmon by the absence of teeth in the roof of the mouth, presence of light colored spots on a dark background, absence of spots on the dorsal fin, small scales, and differences in the structure of their skeleton. (Trout and salmon have dark spots on a lighter background.) In Washington, native char refer to fish that are called Dolly Varden and bull trout: these two species are identical in appearance and need DNA testing to determine the species.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Congener: In chemistry, congeners are related chemicals. For example, polychlorinated biphenyls (PCBs) are a group of 209 molecules that are related by a similar structure and are called congeners. Laboratory analysis for all PCB congeners is complex and expensive.

Fish Tissue Equivalent Concentration (FTEC): The FTECs is a tissue contaminant concentration previously used by Ecology to determine whether surface water human health criteria were being met. The FTEC was an interpretation of Washington's water quality criterion for a specific chemical for the protection of human health: the National Toxics Rule (40 CFR 131.36). Fish tissue sample concentrations that were lower than the FTEC suggested that the uses of fishing and drinking from surface waters were being met for that specific contaminant. Where a FTEC was not met (i.e., concentration of a chemical in fish tissue is greater than the FTEC), that water body was then placed into Category 5 during Washington's periodic Water Quality Assessment (https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d). Category 5 listings become part of Washington's 303(d) list during the assessment process. The FTEC was calculated by multiplying the contaminant-specific Bio-Concentration Factor (BCF) times the contaminant-specific Water Quality Criterion found in the National Toxics Rule.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

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

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Salmonid: Fish that belong to the family *Salmonidae*. Species of salmon, trout, or char.

Spatial: Relating to space, location, and distance, such as between two sampling sites.

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.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Temporal: Relating to time, such as between one year and another.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Trend: A meaningful change or difference that can be measured and differentiated from measurement error. Often used in the context of time (temporal trend) or space (spatial trend).

Water Quality Assessment (WQA): Washington's Water Quality Assessment lists the water quality status for water bodies in the state. This assessment meets the federal requirements for an integrated report under Sections 303(d) and 305(b) of the Clean Water Act. The assessed waters are grouped into categories that describe the status of water quality. The 303(d) list comprises those waters that are in the polluted water category, for which beneficial uses– such as drinking, recreation, aquatic habitat, and industrial use – are impaired by pollution.

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.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

ANOVA	Analysis of Variance
BBH	Brown bullhead (*Ameiurus nebulosus*)
CCP	Common carp (*Cyprinus carpio*)
CTT	Cutthroat trout *(Oncorhynchus clarki)*
DDE	Dichloro-diphenyl-dichloroethylene
DDT	Dichloro-diphenyl-trichloroethane
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FCA	Fish Consumption Advisory
FFCMP	Freshwater Fish Contaminant Monitoring Program
FTEC	Fish tissue equivalent concentration
Health	Washington State Department of Health
J	estimated value
LSS	Largescale sucker (*Catostomus macrocheilus*)
MEL	Manchester Environmental Laboratory
NJ	The analysis indicates the presence of the analyte has been tentatively identified, and the associated numerical value is the approximate concentration. Identification needs further confirmation.
NOAA	National Oceanic and Atmospheric Administration
NPM	Northern pikeminnow (*Ptychocheilus oregonensis*)
NTR	National Toxics Rule
PBDE	Polybrominated diphenyl ether
PCB	Polychlorinated biphenyl
PCDD/F	Polychlorinated dibenzo-p-dioxin and -furan
RBT	Rainbow trout (*Oncorhynchus mykiss*)
RKB	Rock bass (*Ambloplites rupestris*)
SMB	Smallmouth bass (*Micropterus salmoides*)
SV	Screening value
t-DDT	Total DDTs
t-PCB	Total PCBs
t-PBDE	Total PBDEs
TCDD	2,3,7,8-tetra-chlorinated dibenzo-p-dioxin
TEQ	Toxicity equivalent
TMDL	Total Maximum Daily Load
U	Not detected at the reported value

UJ	Undetected at the estimated reported value
USFWS	United States Fish and Wildlife Service
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WQA	Water Quality Assessment
WRIA	Water Resource Inventory Area

Units of Measurement

=	equal to
>	greater than
<	less than
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
mg	milligram
mm	millimeter
ng/kg	nanograms per kilogram (parts per trillion)
ug/kg	micrograms per kilogram (parts per billion)