Okanogan River Watershed

Freshwater Fish Contaminant Monitoring, 2017 Results

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Cover Photo:
Defunct powerhouse at Enloe Dam near Oroville, WA (taken by Keith Seiders/Patti Sandvik).

Okanogan River Watershed

Freshwater Fish Contaminant Monitoring, 2017 Results

by

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Abstract

The Washington State Department of Ecology's (Ecology's) Freshwater Fish Contaminant Monitoring Program (FFCMP) monitors toxic contaminants in freshwater fish statewide to inform public health, aquatic health, and environmental risk. The objectives of our monitoring efforts are to (1) characterize the extent and magnitude of contamination, (2) characterize long-term trends over time, (3) compare data to water quality and human health standards, and (4) inform the Washington State Department of Health in the development of fish consumption advisories.

The 2017 sampling focused on the Okanogan River. Studies conducted on the Okanogan River in the 1980s and 1990s showed that DDT and PCB contamination were persistent in the watershed. This led to a 303(d) listing under the federal Clean Water Act as well as a Total Maximum Daily Load study intended to reduce the amount of contamination entering the river. Subsequent sampling showed that levels of contamination were decreasing but without a level of statistical certainty.

Our 2017 results build off of previous studies to statistically substantiate ongoing trends. Over the previous nine to 16 years, we saw DDT concentrations decrease by 64% to 87% in the Okanogan River between Oroville, WA and Tonasket, WA. DDT also decreased by 38% to 66% between Tonasket and Omak, WA. We could not determine PCB trends over time.

Contaminant concentrations remain unchanged in Pateros and Osoyoos Lakes. Overall, concentrations continue to be higher than human health thresholds throughout the Okanogan River.

We recommend continued monitoring every ten years to verify if trends are ongoing. We also recommend a reevaluation of cleanup efforts for sites where contamination remains unchanged: Lake Osoyoos, Lake Pateros, and the lower Okanogan River.

Introduction

Monitoring contaminants in fish tissue informs us of environmental health and human health risks. In 2001, the Department of Ecology (Ecology) established the Freshwater Fish Contaminant Monitoring Program (FFCMP)[1], managed under the Environmental Assessment Program (EAP), to stay informed of toxic threats to humans and the environment. Prior to 2013, the monitoring program was called the Washington State Toxics Monitoring Program. The program focuses on characterizing persistent, bioaccumulative, and toxic chemicals (PBTs) in freshwater fish throughout the state. The objectives of this program are to:

- Measure trends of toxics in the environment over time and geographically.
- Conduct exploratory monitoring to establish baseline data for sites with little or no information, or for emerging contaminants.
- Compare data with Washington State water quality standards and health screening levels to support fish consumption advisories.

Since the program's beginning, we have collected and analyzed over 1000 samples throughout Washington. The study uses Washington's Persistent, Bioaccumulative, and Toxic (PBT) rules[3] to guide which contaminants we target during monitoring. These rules also establish criteria for identifying and prioritizing PBTs. Some of the contaminants we regularly sample for are:

- Polychlorinated biphenyls (PCBs)
- Polybrominated diphenyl ethers (PBDEs)
- Chlorinated pesticides
- Dioxins and furans (PCDD/Fs)
- Metals

Eating fish is a common exposure pathway for contaminants to humans. Exposure to contaminants has negative health effects on humans and wildlife. Contaminants can interfere with reproductive, immune, and neurological functions, and can cause cancer. To reduce the health risks of eating contaminated fish, the Washington State Department of Health (WADOH) issues fish consumption advisories for certain species and waterbodies in Washington. There is currently a statewide consumption advisory for bass (limit 2 meals per month) and northern pikeminnow (do not eat). There are also many site-specific advisories addressing isolated hotspots of contamination[3]. Results from the FFCMP program led to fish consumption advisories in the Spokane River, middle Columbia River, Wenatchee River, Snake River, Lake Washington, and Green Lake.

[1] https://ecology.wa.gov/Research-Data/Monitoring-assessment/toxics-monitoring/Freshwater-fish-contaminant-monitoring
[2] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals
[3] https://doh.wa.gov/community-and-environment/food/fish/advisories

The 2017 sampling focused on the Okanogan River watershed in northeastern Washington. We are interested in long-term monitoring of this watershed due to elevated concentrations of dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs). Initial findings by Hopkins (1985) and Davis and Serdar (1995) led to an impaired water listing under the US Environmental Protection Agency's (EPA's) Clean Water Act for these contaminants.

An Okanogan River Total Maximum Daily Load (TMDL) for DDT and PCBs was developed in response to fish tissue data collected during 1985-2001 (Peterschmidt 2003). The TMDL covers the entire mainstem river within Washington, including Lake Osoyoos but excluding Lake Pateros. Since then, TMDL effectiveness studies showed some decreases in contaminants, but there were not enough data to sufficiently show that water quality meets thresholds established by Ecology (Newell 2011). These effectiveness studies laid a good foundation for an enhanced statistical comparison of temporal trends. In 2017, the FFCMP collected additional samples for comparison with past data.

This 2017 study does not claim to evaluate TMDL effectiveness data. Sampling in 2017 did not include data on sources such as tributaries and wastewater treatment plants. These data are needed to show TMDL effectiveness. This report describes trends of contaminants in fish tissues only.

Okanogan River

Peterschmidt (2004) and Serdar (2003) provide a thorough description of the Okanogan River, much of which we summarize below. The Okanogan River originates in British Columbia, flows through north-central Washington, and terminates in the Columbia River near the town of Brewster. Forest and rangeland dominate the upper basin. The lower basin provides one of the most fertile orchard regions in British Columbia, Canada (B.C.) and Washington State. The river flows through a series of four lakes, three of which are in B.C.; the fourth, Lake Osoyoos, is in Washington but overlaps the Canadian border.

The Similkameen River flows into the Okanogan just downstream of Lake Osoyoos and the city of Oroville. The Similkameen River has a basin size nearly as large as the Okanogan River basin and contributes a significant portion of streamflow to the lower river. Approximately 20 smaller tributaries feed the Okanogan River within Washington's borders. Most of these are small or seasonal streams that do not contribute significantly to the Okanogan River's flow.

The climate along the Okanogan River is semi-arid receiving 10 to 20 inches of rain per year depending on elevation. The lower valley receives less than the upper range lands. Surface flows in the Okanogan River fluctuate seasonally according to snowmelt. The lowest flows typically occur September through March.

About 42,000 people live in Okanogan County as of the 2020 census. The county population has nearly doubled since 2010, but the population along the Okanogan River is relatively unchanged since the TMDL was implemented in 2003. Omak and Okanogan maintain a combined population of around 7,000 people. Oroville and Tonasket maintain populations of around 1,700 and 1,000 people, respectively.

The Colville Confederated Tribes (Colville Tribes) also reside in the Okanogan River watershed and use these lands as traditional hunting and fishing grounds. Members living near the river regularly consume fish from the river. Hence, members of Colville Tribes have a vested interest and concern over the presence of toxics in the Okanogan River and the effect it has on the health of people using the river's resources.

Sources of contaminants to the Okanogan River

Fruit orchards have a long history in the Okanogan River valley. The first orchards were planted in 1857. North of the United States border, the Okanogan has a similar composition of orchard lands. Okanogan valley orchards in Canada at one time provided 99.4% by weight of the tree fruits grown in British Columbia (Sinclair and Elliott, 1993). Apple orchards were heavily treated with DDT between 1946 and 1970. Blus (1987) estimated that between 30 kg and 73 kg of DDT were applied to fruit orchards per hectare per year.

Specific sources of DDT and PCB to Okanogan River fish are not entirely clear. In a source assessment conducted by Serdar (2003), they suspected DDT bound to agricultural soils makes its way to the Okanogan River and tributaries through rivulets caused by rainstorms, snowmelt, and irrigation. Serdar (2003) also implicated Lake Osoyoos as a source that continually doses the Okanogan River with contaminated sediments during high streamflows and seasonal lake turnover.

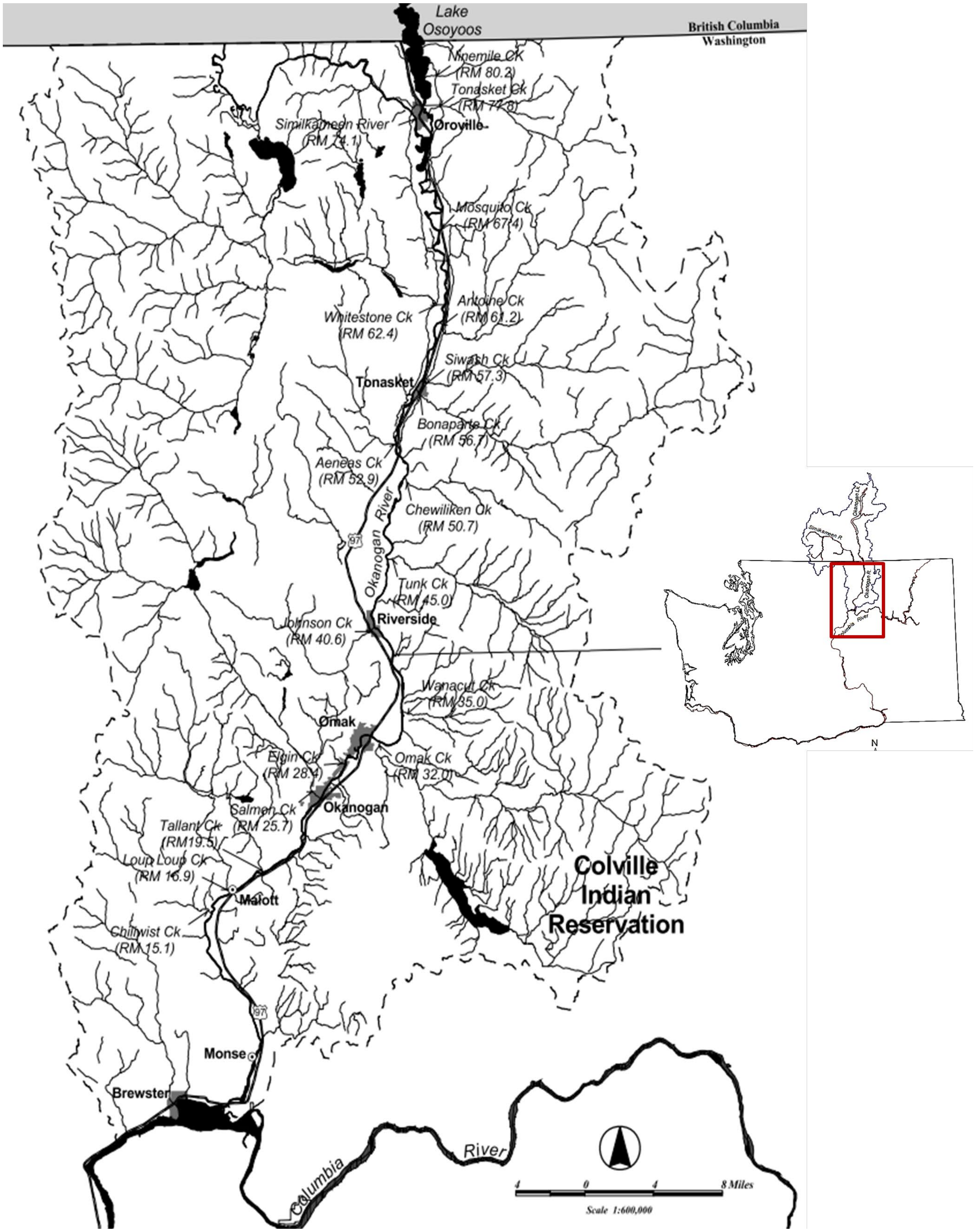

Figure 1. Detailed Map of the Okanogan River Basin (Serdar 2003).
Details represent the red square in Washington overview map.

Methods

Sample design, collection, preparation, and analytical methods followed those described in the quality assurance project plan (QAPP) and Addendum 6 to the QAPP (Seiders 2013; Seiders 2017). Our 2017 sampling was optimized to increase the likelihood of detecting change in contaminant levels over time.

Field

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 (Sandvik 2018a; Sandvik 2018b). Ecology's 2017 collection of fish adhered to federal and state Scientific Collection Permits.

Fish were collected using a 16' electrofishing boat. Ecology staff performed the collections with help by staff from the Washington Department of Fish and Wildlife (WDFW). Fish were collected and preserved on ice until they could be frozen at -20 degrees Celsius. Fish from each location were assigned to composite samples based on the sampling goals for individual sites. This involved grouping fish by size to match the sizes of fish used in historical samples. To create multiple composite samples of similar sized fish, individual fish meeting the size criteria were grouped by locations, then randomly assigned to composite samples. All fish met the 75% rule for composite samples; the smallest fish in the composite sample were not less than 75% of the total length of the largest fish in the sample.

Most composite samples consisted of skin-on fillets from three to five individual fish of a similar size of the same species per site. Largescale suckers were processed as whole fish, and carp were processed as fillets with skin-off to replicate past years' efforts. Eleven carp were processed as fillets with skin-on to compare the effect of skin tissue on contaminant concentrations in carp fillets.

Laboratory

Ecology's Manchester Environmental Laboratory (MEL) analyzed samples for lipids, PBDEs, PCB aroclors, mercury, and chlorinated pesticides (including DDT). Pacific Rim Laboratories in Surrey, B.C. analyzed results for dioxins/furans (PCDD/Fs). Laboratory methods were used as described in the QAPP Addendum 6 (Seiders 2017).

A total of 112 fish tissue samples were analyzed. Table 1 shows how many samples were analyzed for each site, species, and contaminant. Results are reported on a wet weight basis and standardized to ug/Kg.

Table 1. Number of composite samples for each type of analysis, 2017.

Reach / Site	Species[1]	Mercury	Chlorinated Pesticides	PBDEs	PCB Aroclors	Dioxins & Furans
1 Lake Osoyoos	CCP	3	7	3	7	3
	LSS	2	2	2	2	
	SMB	3	3		3	
2 Upper Okanogan	CCP	3	9	3	9	3
	SMB	8	8	2	8	
3 Similkameen	LSS	1	1	1	1	
4 Middle Okanogan	CCP	3	12	3	12	3
	LSS	3	3	3	3	
	MWF	3	7	3	7	3
	NPM	5	5	4	5	3
	SMB	12	12	4	12	1
5 Lower Okanogan	LSS	1	1	1	1	
	NPM	1	1		1	
	SMB	9	9	3	9	
6 Pateros	CCP	3	6	3	6	3
	LSS	3	6	3	6	
	LNS	3	3	3	3	
	NPM	9	9	5	9	4
	SMB	6	6	1	6	
	WAL	2	2	2	2	2

[1] CCP = common carp, SMB = smallmouth bass, NPM = northern pikeminnow, LSS = largescale suckers, MWF = mountain whitefish, WAL = walleye, LNS = Longnose sucker

Data Analysis

We enter and store all data into Ecology's Environmental Information Management (EIM) database. Data for this study are available under study ID "FFCMP17". We used R version 4.2.1 for all statistical analyses. (R Core Team 2022). We also used Excel and ArcGIS to manage and present data deliverables.

We aggregated individual contaminant results for PCB aroclors, DDTs, PBDEs, and dioxins and furans as the sum of all congeners. We reported these as total PCB aroclors, total DDT, total PBDEs, and TCDD-TEQ. We aggregate contaminant results to account for their additive effects and to simplify trends reporting. DOH thresholds are also based on aggregated results, so summing congeners simplifies comparisons.

To calculate total congener values, we simply sum the concentrations of all congeners. Samples with non-detect qualifiers (U, UJ, NJ, NUJ as defined by MEL) were set to zero for summing. If more than 10% of the concentration of addends are qualified, then we qualify the total value. If reporting limits are different, we used the highest reporting limit for the total value.

We aggregated dioxins and furans according to recommendations by EPA (2010) and the World Health Organization (Van den Berg et al. 2006). Each dioxin/furan addend is multiplied by a toxicity factor then summed. We report the result as TCDD-TEQ, the toxicity equivalent (TEQ) to the single congener 2,3,7,8-TCDD, which is the most toxic congener. TCDD-TEQ values can be compared to threshold values for the protection of human health established by Ecology, EPA, or WADOH.

Lipid Normalization

We do not lipid normalize our data because of a weak or inconsistent relationship between lipid and contaminant concentration. We found correlation between contaminants and lipids was $r^2 < 0.5$ for six out of seven contaminant groups, and R^2 was less than 0.7 in remaining contaminant group (Figures D-4 and D-5, Appendix D). Additionally, the ratio approach to lipid normalization can introduce bias by diminishing the precision of the data (Herbert 1995). Herbert recommends ANCOVA for lipid normalization. However, our data set does not meet the assumptions for normalization using ANCOVA. In this scenario, we believe a non-normalized approach is the most appropriate.

Trends Analysis

We conducted a qualitative and quantitative spatial analysis comparing Lake Osoyoos, Lake Pateros, and sites along the Okanogan River. We grouped sites along the river into upper, middle, and lower reaches.

Table 2. Okanogan River reach names and descriptions.

Reach	Description
Upper Okanogan	Between Lake Osoyoos and Tonasket, WA
Middle Okanogan	Between Tonasket and Omak, WA
Lower Okanogan	Between Omak the mouth at Brewster, WA

When defining the reaches, we take into consideration major river inputs, potential sources (such as wastewater treatment plants), and barriers that may prevent migration of fish.

We compared box plots and plotted points to qualitatively assess spatial differences and trends. Quantitatively, we used Kruskal-Wallis rank-sum test to determine differences between sites. We also reported the correlation effect using the eta^2 method as recommended for non-parametric analysis by Tomczak (2014). When differences between sites were observed, we did post-hoc analysis using the Dunn test with a Bonferroni adjustment to account for bias associated with the additive effects of pairwise comparison on p-values. Test statistics are reported in tables, and post-hoc results are reported for keystone differences between sites.

We analyzed temporal trends for years where we have at least seven total samples per year for comparison. Table 2 shows which years data were available at each location. Although tissue data are available since 1984, hypothesis testing cannot meaningfully detect trends with fewer than seven samples at the alpha level chosen for this study ($\alpha = 0.05$). Trends were assessed for total DDT, total PCB aroclors, mercury, and covariates such as lipid, size, and age.

We assessed temporal trends using the same methods and tools as spatial trends. However, when only two years of data are available for comparison, we use Mann-Whitney test and effect size instead of Kruskal-Wallis. Prior to hypothesis testing, we compared samples from different years for age and size comparability. Age data were not always complete, but overall, fish were of comparable size and age at all sites except Lake Pateros. Largescale suckers were bigger on average in 2017 than in 2013 but ages were comparable. Carp were older on average in 2017 than in 2013, but sizes were comparable.

Table 3. Number of samples available for temporal trends, 1995-2017.

Site	Species	Tissue Type	1995	2001	2008	2013	2017	n
Lake Osoyoos	CCP	F $_{\text{skin off}}$	4				7	11
Upper Okanogan	CCP	F $_{\text{skin off}}$		3	1		9	13
Upper Okanogan	SMB	F $_{\text{skin on}}$		3	2		8	13
Middle Okanogan	CCP	F $_{\text{skin off}}$		4	3		12	19
Middle Okanogan	MWF	F $_{\text{skin on}}$		4			7	11
Middle Okanogan	SMB	F $_{\text{skin on}}$		3	6		12	21
Lower Okanogan	SMB	F $_{\text{skin on}}$		3	3		9	15
Lake Pateros	CCP	F $_{\text{skin off}}$				3	6	9
Lake Pateros	LSS	W				5	6	11

F - fillet; W - whole fish

Comparison to Water Quality and Health Standards

We compare contaminant concentrations to various state thresholds of risk or action. When contaminants are above the threshold, consumption advisories or water quality protections are triggered. Ecology uses a tissue exposure concentration (TEC) threshold. Ecology's thresholds include fish contaminant concentrations that pose non-carcinogenic effects (TEC_n) and carcinogenic effects (TEC_c). TEC_c is typically a more stringent threshold because long-term exposure to PBTs, even at low levels, can cause cancer.

We also compare data to WADOH fish consumption screening values. WADOH also estimates risk at two levels: general consumption and high consumers. High consumers might include subsistence anglers or indigenous communities. General consumers include occasional recreational anglers. We compare results for 4,4'-DDE because it is the most frequently detected DDT metabolite and accounts for most of total DDTs found. Ecology uses a TEC_n threshold for each individual metabolite of DDT, while WADOH and EPA use screening levels for total DDT.

We may compare our 2017 results to EPA screening values in this report on a limited basis. Ecology's water quality criteria are generally more protective of human and aquatic health than federal standards. Comparing our data to EPA thresholds would likely not trigger any additional regulatory action. However, EPA screening values are used in comparison for PBDE because Ecology does not have a TEC threshold for that parameter. We do not compare to federal Food and Drug Administration (FDA) screening values.

Results

Data Quality Assessment

Laboratory case narratives from MEL were reviewed by Ecology's project staff to evaluate data for precision, bias, sensitivity, completeness, and overall usability. Results were qualified automatically based on reporting limits and manually based on measurement quality objectives (MQOs) described in our quality assurance (QA) project plan (Seiders 2013); we rejected 150 results due to severe matrix interference. The remaining results were deemed usable as qualified (n = 3728). Most qualifications were attributed to matrix interference, which can be common in matrices containing high lipid content.

Samples were qualified based on reporting limits and ability to meet QA objectives described in Seiders (2013). Reporting limits met quality control (QC) limits in most cases. Overall, most QA targets were well within the limits described.

Bias was measured by percent recovery of analytes in lab control samples (LCS), surrogates, and matrix spikes. LCS had excellent recovery on average (87%). However, two PBDE results and eight chlorinated pesticide results were qualified as estimates due to low LCS recovery. Matrix spike recoveries averaged 76%, and all matrix spike samples were within limits recommended by the lab (50-150%). Several analyses were affected by severe matrix interference causing poor surrogate recoveries in chlorinated pesticides. The contaminants affected were Chlorpyrifos, Dacthal, Heptachlor Epoxide, Endosulfan I, Endosulfan II, Endosulfan Sulfate, Endrin, Dieldrin, Endrin Aldehyde, Endrin Ketone, and Methoxychlor. A total of 150 of these results were rejected.

Precision was assessed with the relative percent difference (RPD) measured by duplicates. Lab control samples had a mean RPD of 8%, and all samples were well within QC targets. Lab duplicates had a mean RPD of 4%. Matrix spike duplicates had a mean RPD of 15%; however, 12 results were qualified due to exceedance of matrix spike RPD limits.

Lastly, eight mercury results were qualified as estimates for holding time exceedance. The holding time for mercury analysis is 6 months Holding time was exceeded by 4 to 6 days.

Fish capture goals were accomplished with mixed results. We did not meet our goals for carp in the lower Okanogan, mountain whitefish in the upper and lower Okanogan, or northern pikeminnow in Lake Osoyoos. We exceeded our capture goals for smallmouth bass and largescale sucker. Lab analysis plans were modified as needed to get the most value for characterization and trends analysis. Table 1 shows our fish capture results and adjusted analysis plan.

Data Summary

Mercury, DDTs, PBDEs, and TCDDs were detected in all samples. PCB aroclors were detected in more than one-half of all fillet and whole fish samples. Total chlordane was rarely detected in fillet samples and not detected in any whole fish samples. Whole fish samples were not analyzed for TCDDs. Tables 6 and 7 show detection frequencies and summary statistics for contaminants of interest.

Whole body largescale sucker samples had higher median levels of lipids and contaminants than fillet samples of other species (Tables 4 and 5). However, the maximum contaminant levels were higher in fillet samples of various species. The results of skin-on and skin off fillet samples are pooled and summarized in Table 6. Table E-1 in Appendix E shows a more detailed summary of contaminant concentrations grouped by species and tissue type.

Table 4. Summary statistics for contaminants in whole largescale suckers from the Okanogan River basin, FFCMP 2017

Contaminant	Total Samples	Number of Detects	Minimum Detected Concentration (ug/Kg ww)	Median Concentration (ug/Kg ww)	Maximum (ug/Kg ww)
Lipids[1]	16	16	3.78	8.65	13.7
t-DDT	16	16	295	463	2286
4,4'-DDE	16	16	267	417	1890
Mercury	13	13	33.4	85.3	212
t-PBDEs	13	13	2.18	10.2	22.2
t-PCB aroclors	16	10	4.42	31.3	68.8
Hexachlorobenzene	13	3	1.19	2.18	2.41

[1] Lipid results are provided because they are of interest in fish contaminant studies involving hydrophobic/ lipophilic contaminants.

Table 5. Summary statistics for contaminants in fillets of various species from the Okanogan River basin, FFCMP 2017

Contaminant	Total Samples	Number of Detects	Minimum Detected Concentration (ug/Kg ww)	Median Concentration (ug/Kg ww)	Maximum (ug/Kg ww)
Lipids[1]	96	96	0.19	1.73	14.6
t-DDT	96	96	7.54	108	4686
4,4'-DDE	96	96	7.54	98.5	4280
Mercury	70	70	36.3	88.6	338
t-PBDEs	36	36	0.60	1.94	28.3
tTCDD_TEQ	25	25	1.29×10^{-7}	2.52×10^{-5}	4.62×10^{-4}
t-PCB aroclors	96	73	0.86	9.42	216
t-Chlordane	36	5	0.30	0.59	2.38
Hexachlorobenzene	36	2	0.63	0.84	1.04

[1] Lipid results are provided because they are of interest in fish contaminant studies involving hydrophobic/ lipophilic contaminants.

Eleven carp samples were processed as skin-on fillets while the remaining samples were processed with skin on. We saw a moderate effect size between skin-on and skin-off fillets for DDT using Pearson's correlation coefficient and Mann-Whitney comparison ($r = 0.62$, $p < 0.05$, $n = 22$). No effect was observed for PCB concentrations between the two tissue types for PCBs (Figure 2).

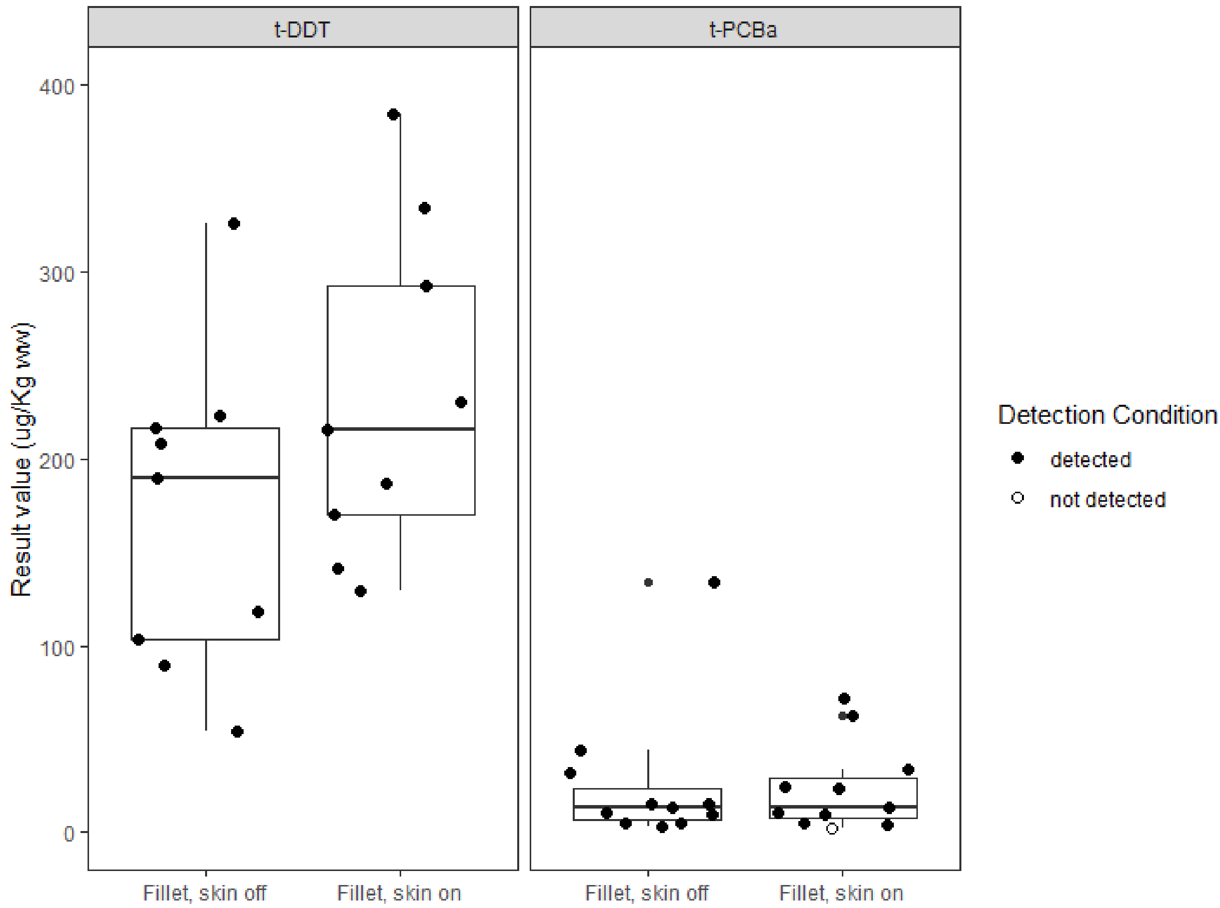

Figure 2. Comparison of DDT concentrations (left) and PCB concentrations (right) between skin-on and skin-off common carp fillets from Okanogan River, FFCMP 2017. Points are staggered to show variation. DDT outliers not shown to preserve scale.

Comparison to Health Standards

All fillet samples had total mercury concentrations above Ecology's human health threshold for methylmercury in fish tissue. Mercury results ranged from the 12^{th} to 87^{th} percentile (36.3 – 338 ppb) when comparing to statewide results from previous FFCMP studies. A total of 37% of fillet samples were above the WADOH screening level of 101 parts per billion.

DDE ranged from the 33^{rd} – 100^{th} percentile (7.54 ppb – 4280 ppb) of statewide FFCMP results. Two samples showed the highest concentrations yet found in Washington fish fillet tissue. A total of 14% of all fillet samples were above Ecology's tissue exposure concentration for non-carcinogenic effects (TEC_n) for 4,4'-DDE. All samples exceed the TEC_c. The 4,4'-DDE metabolites made up most of the total DDT measured. Figure 3 shows the cumulative frequency distribution of 2017 samples (in red) compared to all statewide FFCMP results. Cumulative distribution figures for other parameters are shown in Appendix A.

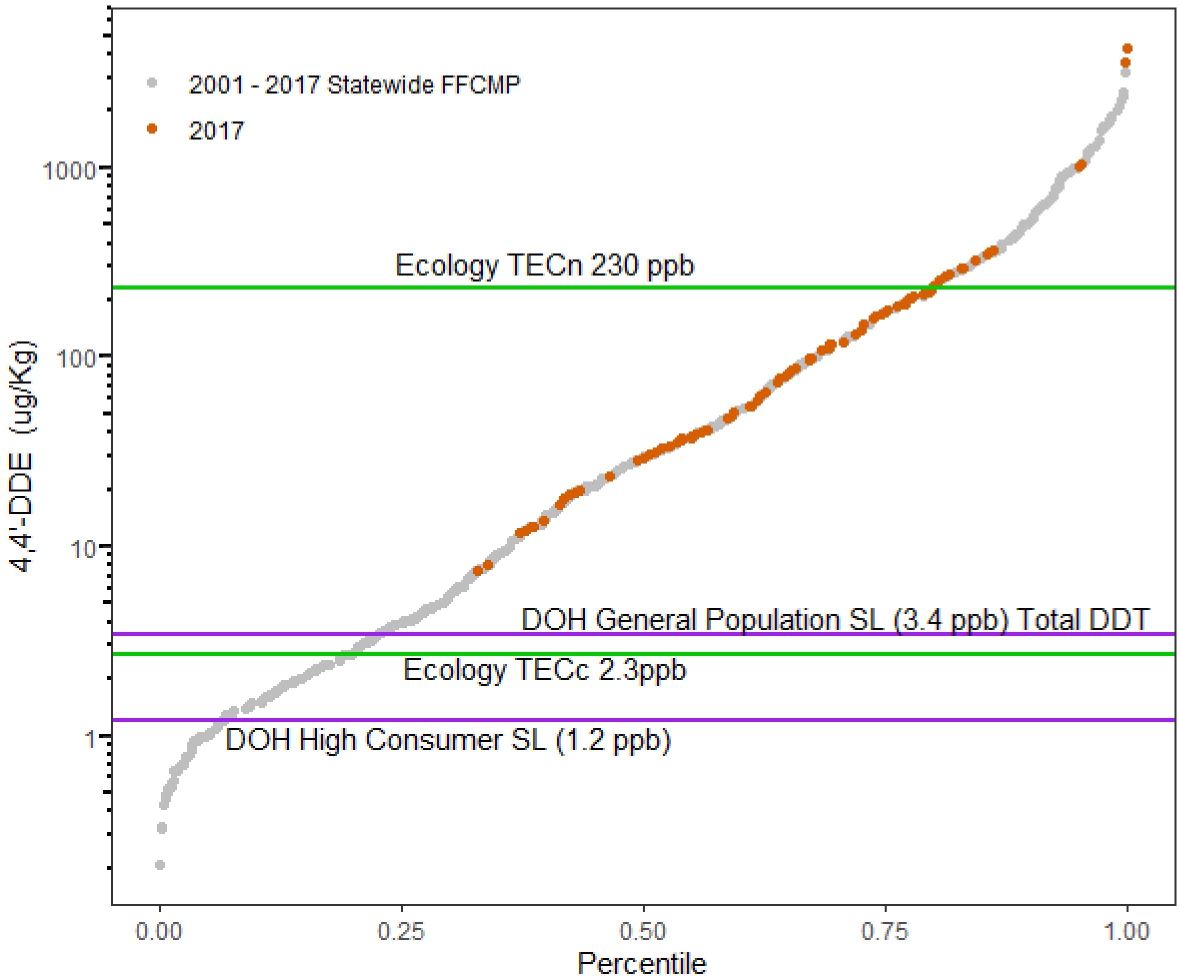

Figure 3. Cumulative frequency distribution of 2017 DDE results compared to statewide DDE results with common regulatory benchmarks for reference (n = 818).

PCBs were detected in all samples. The composition of aroclors in total PCBs varied but aroclors 1254, 1248, and 1260 typically made up most total PCBs. Total PCBs in fish fillets ranged from less than 1 to 98th percentile of statewide FFCMP results (0.86 ppb – 216 ppb). One-half of all fillet samples did not meet Ecology's TEC_n for total PCBs. All samples were above TEC_c and WADOH screening levels.

PBDEs were detected in all fillet samples. None of the samples were above WADOH screening levels. Ecology and EPA do not have screening levels for PBDE's. Sample concentrations ranged from the 15th - 88th percentile of statewide FFCMP results (0.60 – 28.27 ppb). PBDE-047 and PBDE-209 together made up the majority of total PBDEs. The remaining mix of congeners made up about one-half to two-thirds of the remaining concentration of total PBDEs.

Dioxins (PCDD/Fs) were detected in all samples. We found TCDD TEQ concentrations ranging from the less than 1 to 81st percentile (1.29×10^{-7} ppb to 4.62×10^{-4} ppb) of statewide FFCMP data. Two samples exceed Ecology's TEC_n for 2,3,7,8-TCDD TEQ and 84% of samples exceeded the WADOH high consumer screening level. In most samples, OCDD, TCDD, and 2,3,7,8 – TCDF made up most of all dioxins and furans in the sample.

Chlorinated pesticides were detected less frequently. We detected chlordane in five of 36 fillet samples. All five samples met Ecology's TEC_n threshold, and one sample exceeded TECc threshold. Results ranged between the 4th and 55th percentile (.31 ppb – 2.38 ppb) of statewide FFCMP data. We detected hexachlorobenzene in 2 of 36 fillet samples. One sample was above the WADOH screening level for the general population but below Ecology's TEC_n. Other chlorinated pesticides were not detected.

Frequency distributions for PCBs, mercury, TCDD-TEQ, PBDEs, and other contaminants are shown appendix A. Field replicates were not aggregated by location. We present individual sample results in the frequency distribution charts, which is consistent with how samples are treated in the water quality assessment (Ecology 2018). However, we include all samples, including whole fish tissue samples, which may not be comparable to how samples are used in the assessment because whole fish results may not necessarily trigger regulatory action.

Spatial Analysis

We analyzed spatial trends at four sites for common carp, five sites for smallmouth bass, and three sites for largescale suckers. Largescale suckers were collected at Lake Osoyoos, Okanogan middle reach, and Lake Pateros. Carp were collected at Lake Osoyoos, Lake Pateros, and the upper and middle Okanogan. Smallmouth bass were collected from Lake Osoyoos, all three reaches of the Okanogan, and Lake Pateros. We observed spatial trends for mercury, total DDT, and PCBs in all fish species.

In general, we detected the highest mercury concentrations in largescale suckers from the middle Okanogan. Lowest mercury concentrations were seen in largescale suckers and common carp from Lake Osoyoos. We found concentrations of organic contaminants are highest in bass and carp from Lake Osoyoos, Lake Pateros, and the lower Okanogan. The upper Okanogan River had the lowest concentrations of organic contaminants in carp and bass.

Below, we compare boxplots and statistics for each site-species-parameter combination. Figure 4 shows boxplots of sample results at each site with brackets indicating significantly different pairwise comparisons (Bonferroni adjusted p-value was < 0.05).

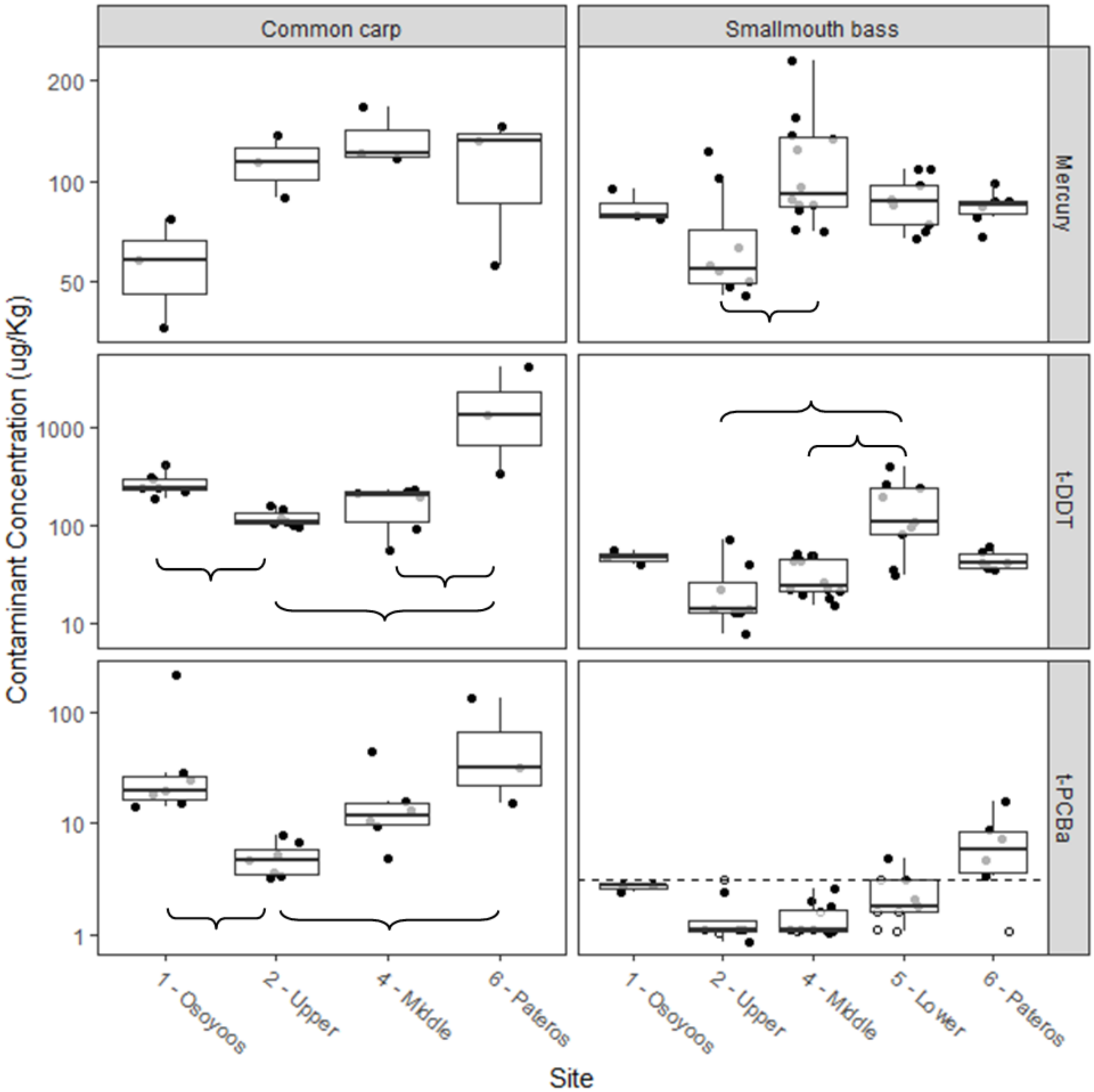

Figure 4. Contaminant concentrations in common carp and smallmouth bass at Okanogan River sites, 2017.
Empty dots represent non-detects, brackets indicate statistically different pairs, dots are staggered to show variation, sites are arranged from upstream (left) to downstream (right), and dotted line indicates reporting limit.

Location had a large effect (eta$^2 > 0.15$) on nearly all species and contaminant combinations. Kruskal-Wallis tests showed moderate to strong evidence that the effect size was significant for DDT and PCB concentrations for both carp and bass. Inferential testing supports spatial trends for mercury in smallmouth bass but not carp. Table 6 shows the eta^2 effect statistics and results of Kruskal-Wallis analysis of variance.

Table 6. Spatial effect sizes using eta^2 method and results of Kruskal-Wallis test.

Species	Contaminant	Effect Size	Magnitude	n	H - statistic	p
CCP	Mercury	0.26	large	12	5.05	0.168
	DDT	0.67	large	23	3.00	**0.001**
	PCB	0.64	large	23	15.22	**0.002**
	PBDE	0.26	large	12	3.00	0.164
	TCDD	0.43	large	12	3.00	0.092
SMB	Mercury	0.15	large	38	8.87	**0.064**
	DDT	0.40	large	38	17.36	**0.002**
	PCB	0.27	large	38	12.76	**0.013**
	PBDE	0.02	small	10	3.09	0.378
	TCDD	--	--	--	--	--
LSS	Mercury	0.85	large	8	6.25	**0.044**
	DDT	0.45	large	11	5.64	**0.060**
	PCB	0.05	small	11	2.41	0.300
	PBDE	0.23	large	10	5.15	0.273
	TCDD	--	--	--	--	--

Common carp

Mercury concentrations were relatively high in common carp at all locations where carp were captured. Mercury concentration was lowest at Lake Osoyoos (median = 58.1 ppb, range = 36.3 - 76.6 ppb). Spatial effect was largely based on eta^2 statistic, but Kruskal-Wallis statistics suggest that sites have similar concentrations.

Total DDT in common carp show an increasing trend in the downstream direction (Figure 4). Common carp from Lake Pateros had the highest median t-DDT levels of all sites (median = 1299 ppb, range = 326 – 3998 ppb). Common carp from upper Okanogan near Oroville, WA have the lowest concentrations (t-DDT: median = 108 ppb, range = 93.6 - 158 ppb).

Eta^2 effect size was large, and Kruskal-Wallis statistics show moderate to strong evidence for statistical differences between sites. DDT concentrations in Lake Pateros were seven times higher than middle Okanogan (p.adj = 0.05, n = 9) and 12 times higher than the upper Okanogan (p.adj < 0.01, n = 10). DDT concentrations in Lake Osoyoos were twice as high as in the upper Okanogan (p.adj = 0.024, n = 14).

Total PCBs in carp were highest in Lake Osoyoos and Lake Pateros. Concentrations increase in the downstream direction between upper Okanogan and Lake Pateros. Common carp from Lake Pateros have the highest median t-PCB concentrations of all sites (median = 32.0 ppb, range = 15.0 – 134 ppb). Common carp from upper Okanogan near Oroville, WA have the lowest t-PCB concentrations (median 4.74 ppb, range 3.21 - 7.91 ppb). Lake Osoyoos carp had four times higher PCB concentrations than in the upper Okanogan ($p < 0.01$, $n = 14$). Lake Pateros carp had seven times higher PCBs than in the upper Okanogan ($p = 0.01$, $n = 10$).

Smallmouth bass

Mercury concentrations were relatively high at all locations. The lowest mercury concentrations were in the upper Okanogan. Pairwise comparison showed mercury concentrations in the upper Okanogan were one-half as high as in the middle Okanogan ($p = 0.03$, $n = 20$).

Total DDT concentrations are lowest at the upper Okanogan River (median = 13.7 ppb, range = 7.54 – 71.4 ppb). DDT concentrations increase between upper and lower Okanogan sites peaking at the lower Okanogan (median = 108 ppb, range = 30.6 – 398 ppb). The lower Okanogan River had DDT concentrations five times higher than the middle Okanogan ($p = 0.026$, $n = 21$) and two times higher than the upper Okanogan ($p.adj = 0.001$, $n = 17$).

Detected total PCB concentrations appear to be lowest at the upper Okanogan River but variable detection limits make it difficult to quantify accurately. The highest detected PCB concentrations were in Lake Pateros (median = 5.96 ppb, range = 1.05 – 15.6 ppb).

Trends for total PCB could not be determined because most results are below or near the reporting limit. Data are censored according to Helsel and Hirsch (2002) using the highest reporting limit from the dataset. The dashed line in Figure 4 shows the highest reporting limit with most results falling below the line. Despite qualitative spatial trends in median point estimates, confidence in spatial t-PCB trends in smallmouth bass is low.

Largescale suckers

Figure 5 shows boxplots for largescale suckers. Location had a large effect on mercury, DDT, and PBDE concentrations and a small effect on PCB concentrations. Kruskal-Wallis results initially supported spatial correlation for mercury and DDT. Mercury was nearly five times higher at middle Okanogan than Lake Osoyoos ($p = 0.041$, $n = 5$). Lake Osoyoos had the lowest mercury concentrations.

DDT was relatively high at all sites. Pairwise comparisons of DDT concentrations in suckers showed weak evidence for spatial trends although eta^2 effect was large.

The highest PCB levels in largescale suckers were at Lake Pateros. Inferential testing shows no evidence for differences between sites. Five of 11 PCB results were non-detects, and reporting limits were high, likely due to high lipid content and matrix interference in analysis. Figure 5 shows the reporting limit for total PCBs as a dotted line with most sample results below the reporting limit.

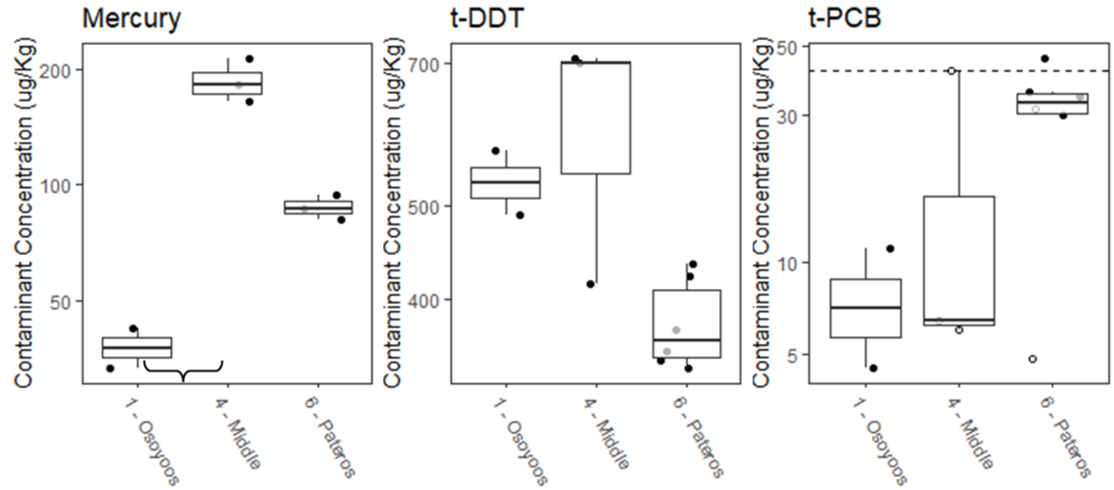

Figure 5. Spatial trends for mercury, total DDTs, and total PCB aroclors in largescale suckers from the Okanogan River, 2017.

Bracket indicates pairwise comparison with $p < 0.05$, points are staggered to show variation, and dotted line represents the reporting limit.

Temporal Trends

We evaluated trends for total DDT, PCBs, and mercury. For trends analysis, we grouped sites into river segments representing major reaches of the river (upper, middle, lower) Okanogan, Lake Osoyoos, and Lake Pateros. The years that each reach was visited by monitoring crews were inconsistent, so comparisons were made where data were available. Table 2 shows what data were available for trends analysis.

We measured a large effect size for total DDT concentrations at the upper and middle Okanogan River. Total DDT concentrations decreased by 64% in common carp fillets and by 87% in smallmouth bass fillets at the upper Okanogan between 2001 and 2017 (Figure 6). Total DDT concentrations decreased by 38% in common carp, 66% in mountain whitefish, and 60% in smallmouth bass at the middle Okanogan (Figure 7). Table 8 shows the median contaminant concentrations and test statics for each species-site-year combination.

Point estimates of total DDT appear to decrease at Lake Osoyoos and increase at the lower Okanogan and Lake Pateros sites. However, the effect size at these sites was moderate or small, and Kruskal-Wallis evidence was weak. Appendix C shows boxplots for all site and species combinations of DDT concentrations.

In 2017, total PCB concentrations appear to decrease in Okanogan River locations, but statistical evidence was weak. Thirteen of 18 smallmouth bass samples were non-detects, confounding correlations and Kruskal-Wallis comparisons. We observed a large effect size for total PCBs in smallmouth bass at the upper and middle Okanogan sites, but the effect could be related to reporting limits rather than PCB concentrations.

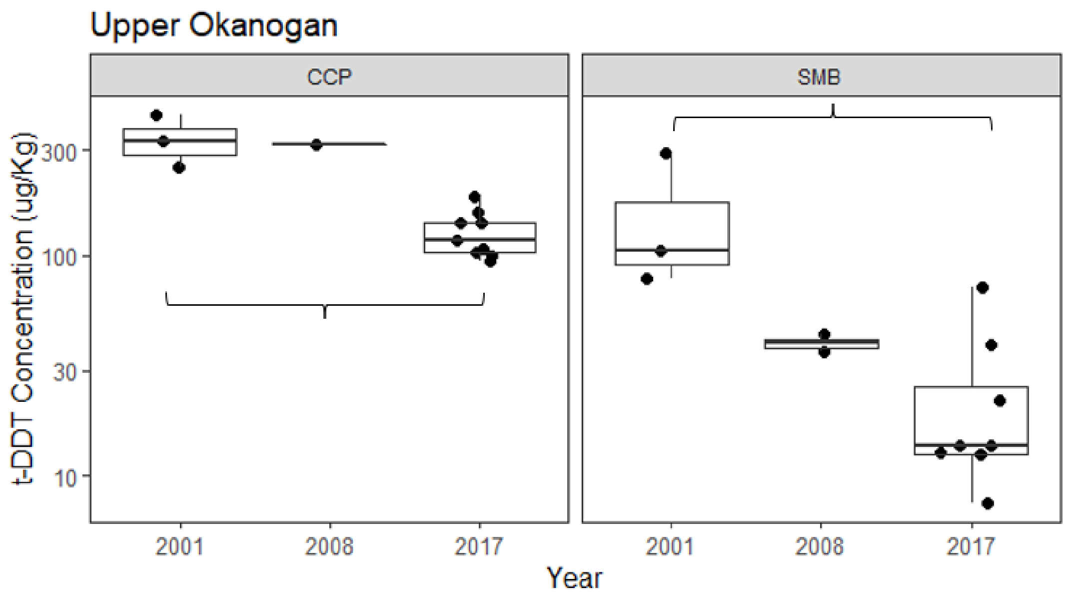

Figure 6. Box plots showing DDT trends over time in common carp (CCP) and smallmouth bass (SMB) at upper Okanogan River sites.

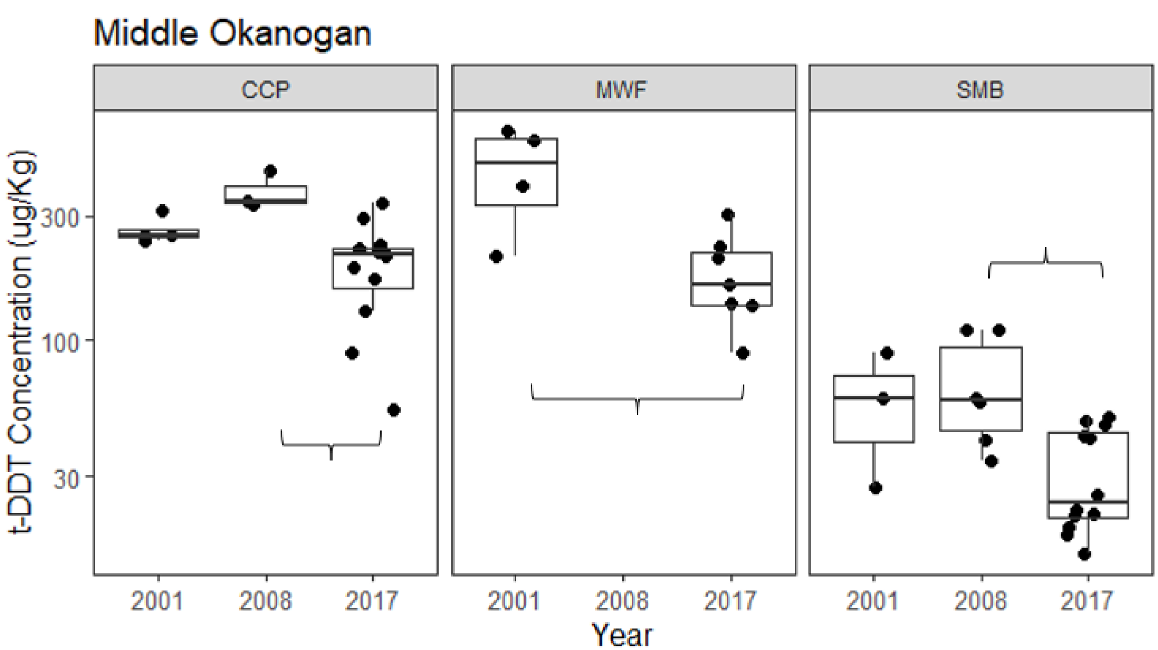

Figure 7. Boxplots showing DDT trends over time in common carp (CCP), mountain whitefish (MWF), and smallmouth bass (SMB) at middle Okanogan River sites.

We also found a large effect size in common carp from the middle and upper Okanogan, and in smallmouth bass from the upper Okanogan. However, we do not see any evidence from the Kruskal-Wallis test to support the correlation in carp. We saw a moderate or small effect in common carp from the lower Okanogan and Lake Pateros. No PCB data were available to assess temporal trends in Lake Osoyoos. Appendix C shows boxplots for all site and species combinations of PCB concentrations.

We had a limited amount of data to assess mercury trends in Lake Pateros and the middle Okanogan. Mercury concentrations increased by 96% in whole largescale suckers from Lake Pateros from 2013 to 2017. We did not see changes in mercury concentration in smallmouth bass or common carp.

Hypothesis testing also indicates a large effect for TCDD-TEQ reductions ($p = 0.1$) in Lake Pateros. Due to small sample sizes, temporal trends could not be measured for PBDEs, metals other than mercury, chlorinated pesticides other than DDT, or dioxins/furans from locations other than Lake Pateros.

Table 7. Median contaminant concentrations (ug/Kg) by year and Mann-Whitney /Kruskal-Wallis statistics

Site*	Species	Contaminant	Median contaminant concentration ug/Kg (ppb)[1]										
			1995	2001	2008	2013	2017	% Change	test Statistic	p	n_1, n_2, n_3	Eta^2 Effect Size	Magnitude of effect
Osoyoos	CCP	t-DDT	437				242		22	0.16	4, 7	0.46	moderate
Upper	CCP			329_{a}	320_{ab}		118_{b}	-64	8	**0.02**	3, 1, 9	**0.57**	**large**
Upper	SMB			105_{a}	40_{ab}		14_{b}	-87	7	**0.02**	3, 2, 8	**0.55**	**large**
Middle	CCP			252_{ab}	341_{a}		212_{b}	-38	10	**<0.01**	3, 12	**0.47**	**large**
Middle	MWF			483_{a}			164_{b}	-66	26	**0.02**	4, 7	**0.68**	**large**
Middle	SMB			60_{ab}	59_{a}		24_{b}	-60	8	**0.02**	3, 6, 12	**0.32**	**large**
Lower	SMB			103	79		109		0	0.84	3, 3, 9	-0.14	moderate
Pateros	CCP					1180	1283		6	0.55	3, 6	0.26	small
Pateros	LSS					203	363		6	0.13	5, 6	0.50	moderate
Upper	CCP	t-PCBa		10	4		5		5	0.08	3, 1, 9	**0.30**	**large**
Upper	SMB			2	3		1		4	0.11	3, 2, 8	**0.23**	**large**
Middle	CCP			29	20		13		4	0.11	4, 3, 12	**0.15**	**large**
Middle	MWF			37			18		21	0.23	4, 7	0.40	moderate
Middle	SMB			3	3		1		13	**<0.01**	3, 6, 12	**0.62**	**large**
Lower	SMB			3	3		2		3	0.21	3, 3, 9	0.09	moderate
Pateros	CCP					37	47		8	0.91	3, 6	0.09	small
Pateros	LSS					36	33		18	0.66	5, 6	0.17	small
Pateros	CCP	Mercury				99	133		3	0.70	3, 3	0.27	small
Pateros	LSS					44_{a}	87_{b}	96	0	**0.04**	5, 3	**0.79**	**large**

*Upper, Middle, Lower are sections of the Okanogan River.

Comparisons where Kruskal Wallis/Mann Whitney $p < 0.05$ are highlighted in bold; large effect size is also in bold.

$_{abc}$ subscripts show which medians are distinct from the others in pairwise comparison ($p < 0.05$)

Discussion

In previous sampling during 2001-2017, total-DDT declined in two of five locations in the Okanogan River watershed. The remaining locations have not seen measurable reductions. Overall, DDT remains above thresholds for human health. Other classes of contaminants (PCBs and mercury) continue to be prevalent.

More than 30% of samples exceeded Ecology's TEC_n for DDE and PCBs. Mercury was detected above ecology's human health threshold in all samples. An even greater proportion of samples exceeded thresholds when comparing to the more stringent TEC_c threshold. While contaminant concentrations remain elevated above thresholds, results of the 2017 survey substantiate downward trends for parts of the Okanogan River between Oroville and Omak.

In 2017, we saw total DDT and PCB concentrations decrease in the Okanogan River between Oroville and Omak when comparing to past data. Decreases in DDT are supported by measures of correlation and hypothesis testing. The strength of evidence from Kruskal-Wallis results do not always support measured correlations. But sample sizes could be too small for us to detect strong evidence for change. Large effect sizes could be meaningful even when p-values exceed 0.05.

We saw the highest contaminant concentrations in Lake Osoyoos, Lake Pateros, and the lower Okanogan River. Evidence for contaminant reductions was weak. A likely explanation for this is that lakes and reservoirs are the endpoint for sediment-bound contaminants such as DDT and PCB and can be a sink for contaminants (Schoellhamer et al. 2007; Mariani et al. 2008).

Contaminant sinks increase the likelihood for contaminants to enter the food web in lakes and reservoirs during seasonal lake turnover. The lower Okanogan River can share characteristics of a reservoir. Characteristics of rivers near the mouth are often slow flow and high sediment deposition, similar to lakes.

Additionally, fish migratory ranges are more likely to overlap between Lake Pateros and the lower Okanogan River. This could explain why we occasionally see elevated contaminant concentrations in the lower river. We do not see the same type of migratory connectivity between upper Okanogan reaches and Lake Osoyoos where Zosel Dam impedes migration (although it does not completely obstruct migration).

Our results reflect those of other watersheds. Johnson et al. (2007) and Seiders et al. (2016) found large reductions of DDE in fish tissues in the Yakima River. A terrestrial study in the Okanogan orchards in Canada showed 29% - 57% decreases in p,p'-DDE in American Robin eggs during 2000-2020 (Kesic et al. 2021). Because best management practices are intended to protect aquatic environments, it is interesting that Kesics' study also saw a large reduction in DDT compounds with no known conservation measures being applied to the terrestrial environment.

Covariates

Controlling for covariates such as fish size or lipids can be a challenge. ANCOVA methods cannot be applied because data do not meet the assumptions of the method. Data are non-parametric and sample sizes are too low due to the effort it takes to collect sufficient fish for composite sampling.

We attempt to control for fish size while collecting fish in the field. Lipids do not correlate strongly, and bias due to lipids seems low. We saw lipids increase in carp collected from the upper Okanogan during 2001-2017. Regardless, we see a measurable downward trend in total DDT and slight decreases in PCB over the same time frame.

Early studies show contaminant concentrations in fish correlating with lipid content (Mckay 1982; Muir 1990). More recent studies show the relationship between contaminant concentration and lipid content in fish is more nuanced. Polarity of contaminants, fatty acids, and even extraction solvents can affect relationships between contaminants and lipid content (Elksus 2005). Extraction efficiencies can differ widely between solvents (e.g., making it difficult to compare lipid concentrations).

Using different solvents can make lipid results vary by a factor of 2 or 3 (EPA 2000). Our extraction methods varied over the years and switched from using a methylene chloride solvent to a 1:1 acetone/hexane mix around 2010. Seiders et al. (2012) observed bias like that reported by EPA when comparing results after the switch. The increases in lipids during 2001- 2017 Okanogan results are also likely due to changes in extraction methods.

Lipid variation between fish species may play a greater role than lipid variation within a species. Lipid content can vary between species, as can fatty acid type. Ljubojevic et al. (2013) observed carp fillets having 1.5 – 4.5 times the lipid content of other inland species. We found that carp fillets had almost 6 times higher lipids percent than smallmouth bass fillets. Common carp also had the highest concentrations of DDT and other organic contaminants in our 2001-2017 study while bass had the lowest. However, trend direction is similar in both species over time.

We saw lipid content decrease in tandem with contaminant concentrations in smallmouth bass from the middle Okanogan. Trends in lipid content were not seen in other species-location comparisons over time, yet similar contaminant trends were seen. The mixed or non-existent relationships between lipid and contaminant concentration led us to conclude that contaminant trends overshadow in magnitude the effect of lipids as a covariate. That does not mean we should ignore the potential effect of lipid content. All data should be synthesized in future analyses.

Fish size was mostly consistent between years compared except in large scale suckers from Lake Pateros where 2017 fish were older and larger on average than 2013 fish. In this case trends could not be determined for DDT or PCBs. Fish size could have limited our ability to statistically detect trends in DDT and PCBs. Mercury increased slightly which could simply be due to fish size differences and not necessarily due to source input of mercury into the Okanogan River.

Conclusions and Recommendations

Results of this 2017 study support the following conclusions and recommendations.

Conclusions

- We found strong evidence that total DDT decreased in common carp and smallmouth bass by 38% to 87% in the Okanogan River between the towns of Omak and Oroville.
- We found that total PCBs decreased in common carp by 17% to 57% in the Okanogan River between Omak and Tonasket, but statistical evidence was weak.
- Contaminant concentrations remain unchanged in fish from Lake Osoyoos, Lake Pateros, and the lower Okanogan River downstream of Omak.
- DDT, PCBs, and mercury remain elevated above Ecology human health thresholds despite the observed decreases over time.
- The highest concentrations of contaminants measured were in fish from Lake Osoyoos and Lake Pateros.
- The high concentrations are likely due to lakes and reservoirs being the fate of sediment-bound contaminants like DDT, PCB, and others.

Recommendations

- Continue monitoring these water bodies on every ten years to confirm if trends continue.
- Re-evaluate methods of reducing toxic threats in locations where decreasing trends were small or not existent: Lake Osoyoos, Lake Pateros, and Okanogan River downstream of Omak.
- Use these 2017 sample results for the upcoming Water Quality Assessments.
- Investigate additional statistical methods that could reinforce or clarify contaminant trends over time.

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Glossary, Acronyms, and Abbreviations

Glossary

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.

Contaminant: A toxic chemical compound being measured in fish tissue or the environment. An analyte.

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; (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses; or (3) livestock, wild animals, birds, fish, or other aquatic life.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting water quality standards. A TMDL is equal to the sum of all the following: (1) individual waste load 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.

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

ADA	Americans with Disabilities Act
BMP	Best management practice
CCP	Common carp
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database

EPA	U.S. Environmental Protection Agency
FDA	United States Food and Drug Administration
FFCMP	Freshwater Fish Contaminant Monitoring Program
HUC	hydrological unit Code
LCS	laboratory control sample
LNS	longnose sucker
LSS	largescale sucker
MEL	Manchester Environmental Laboratory
MWF	mountain whitefish
NPM	northern pikeminnow
OCDD	octachlorodibenzodioxin
PBDE	polybrominated diphenyl ethers
PBT	persistent, bioaccumulative, and toxic substance
PCB	polychlorinated Biphenyls
PCDD	polychlorinated dibenzodioxins
PFAS	per- and polyfluoroalkyl substances
QAPP	quality assurance project plan
RPD	relative percent difference
SMB	smallmouth bass
SOP	standard operating procedures
TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin
TCDF	2,3,7,8-Tetrachlorodibenzofuran
TEC	tissue exposure concentration
TEQ	toxicity equivalent
TMDL	Total Maximum Daily Load (see glossary)
WADOH	Washington Department of Health
WAL	walleye
WRIA	Water Resource Inventory Area

Units of Measurement

mm	millimeters
µg/kg	micrograms per kilogram (parts per billion)
ww	wet weight

Appendices

Appendix A. Sample result cumulative frequency distributions

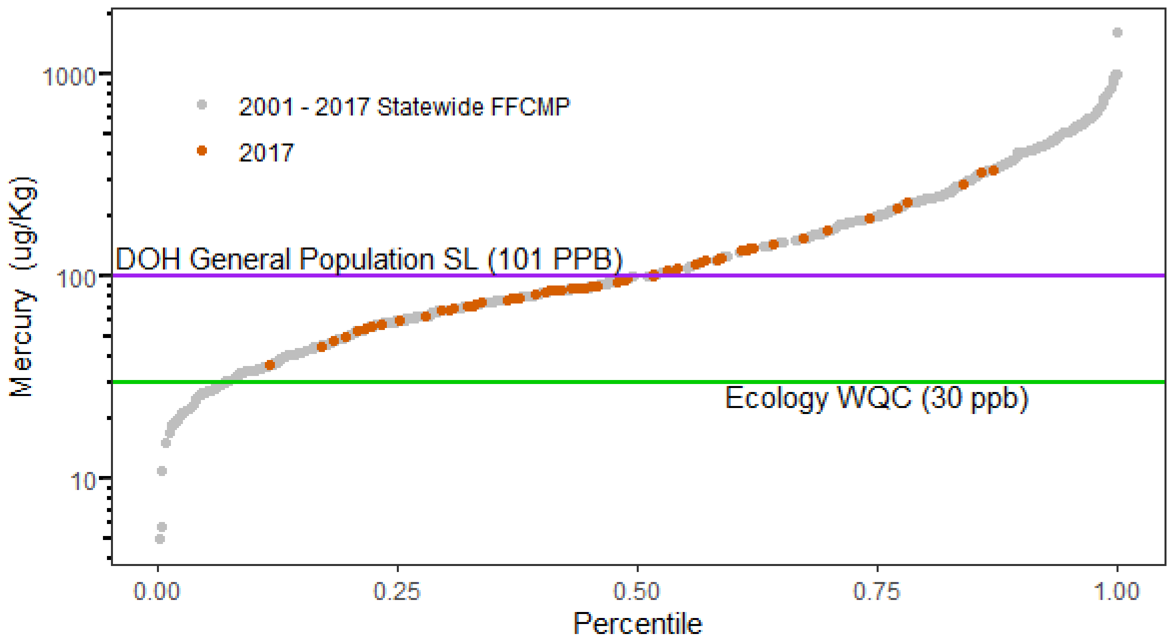

Figure A-1. Cumulative frequency distribution of mercury results in fillet tissue samples from Okanogan River 2017 (n = 762).

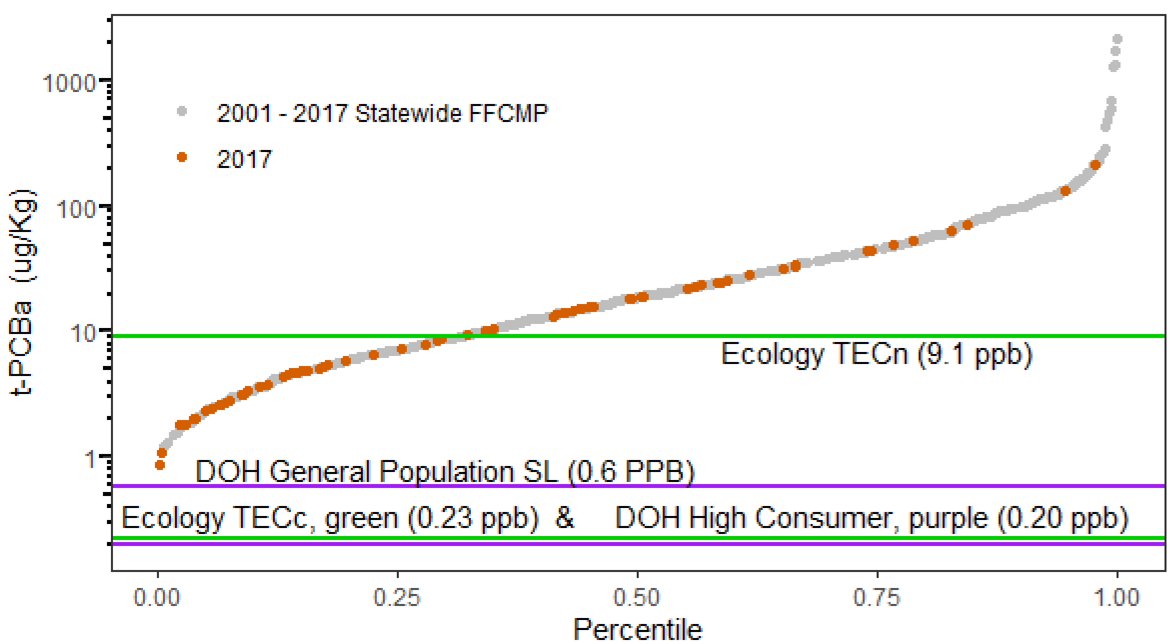

Figure A-2. Cumulative frequency distribution of total PCB results (sum of aroclors) in fillet tissue samples from the Okanogan River 2017 (n= 648).

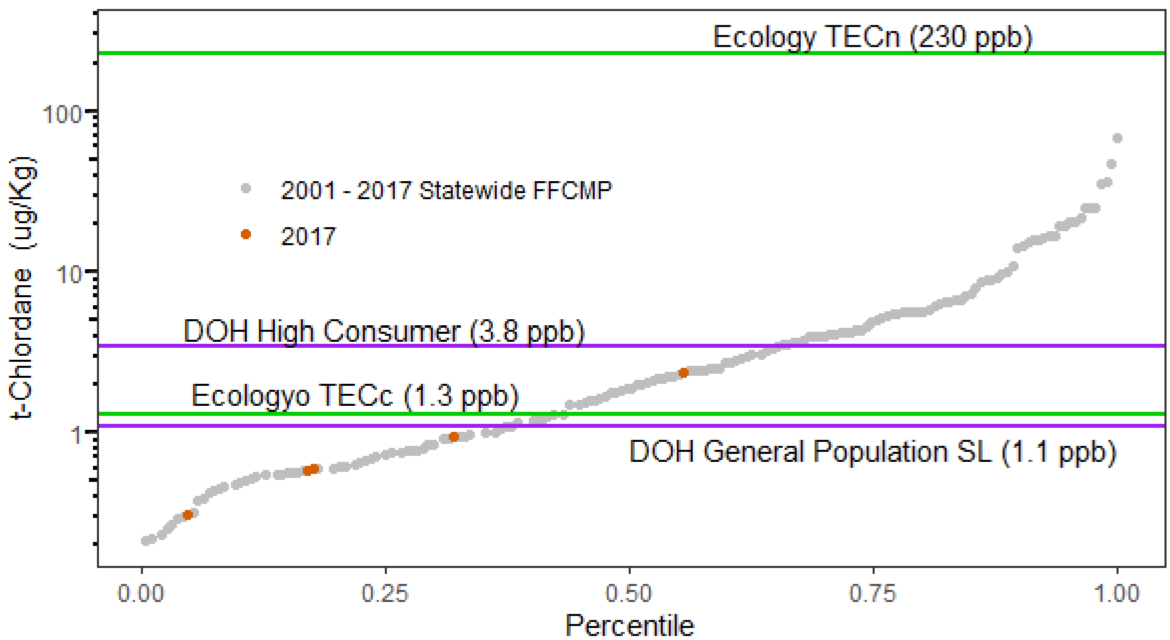

Figure A-3. Cumulative frequency distribution of t-Chlordane in fillet tissue samples, Okanogan River 2017 (n = 187).

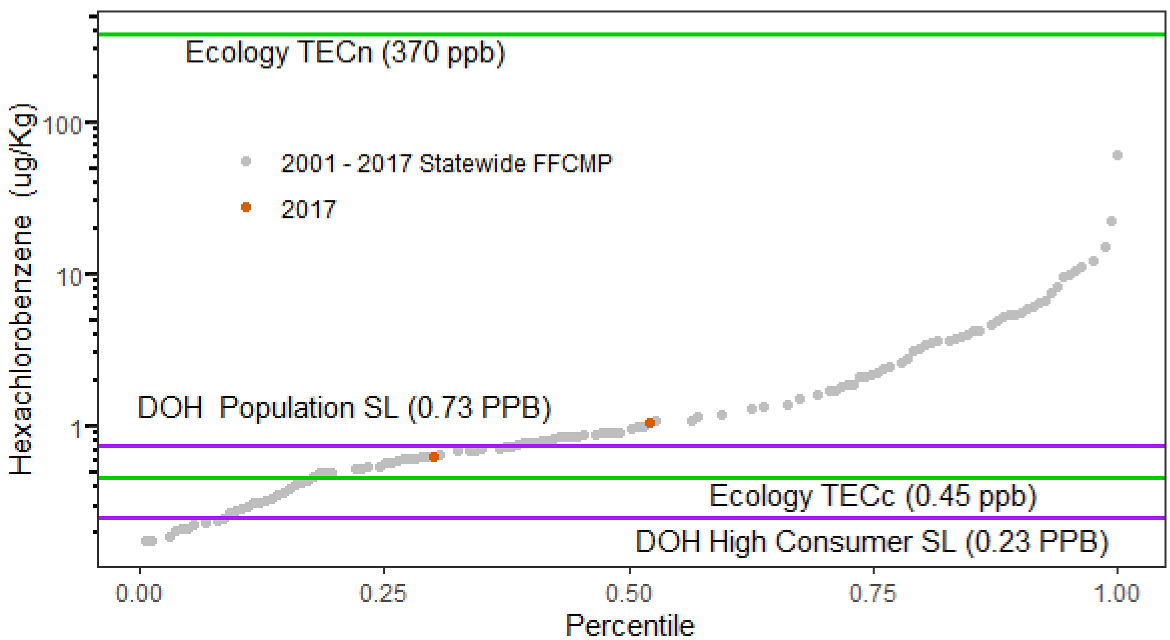

Figure A-4. Cumulative frequency distribution of Hexachlorobenzene results in fillet tissue, Okanagan River, 2017 (n = 163).

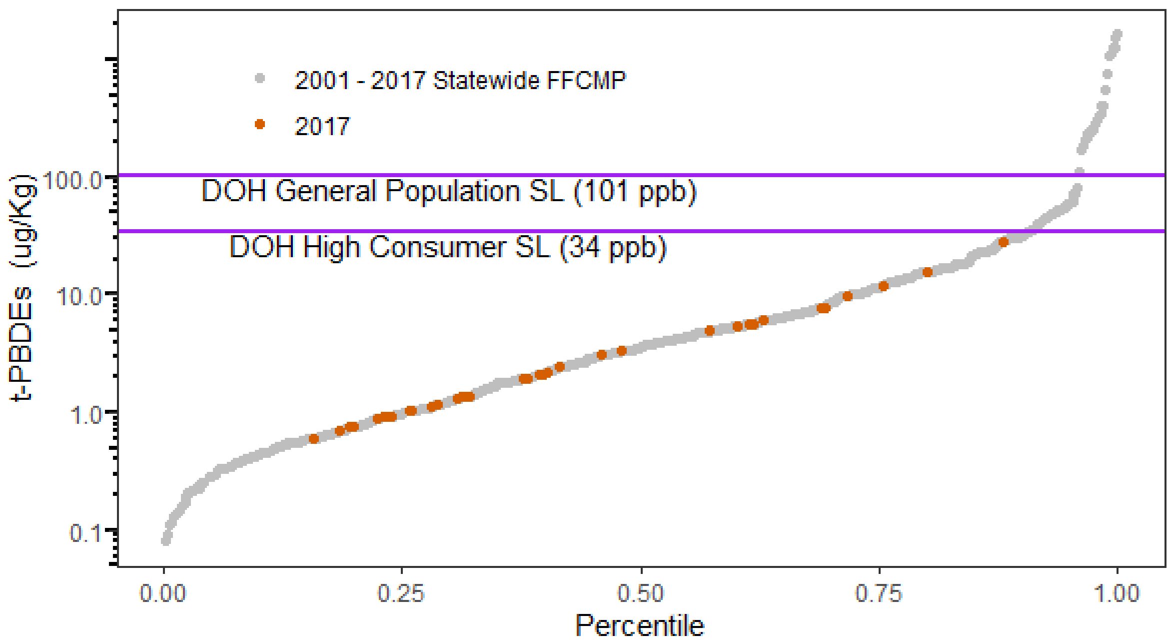

Figure A-5. Cumulative frequency distribution of total PBDEs in fillet tissue samples from Okanogan River 2017 (n = 543).

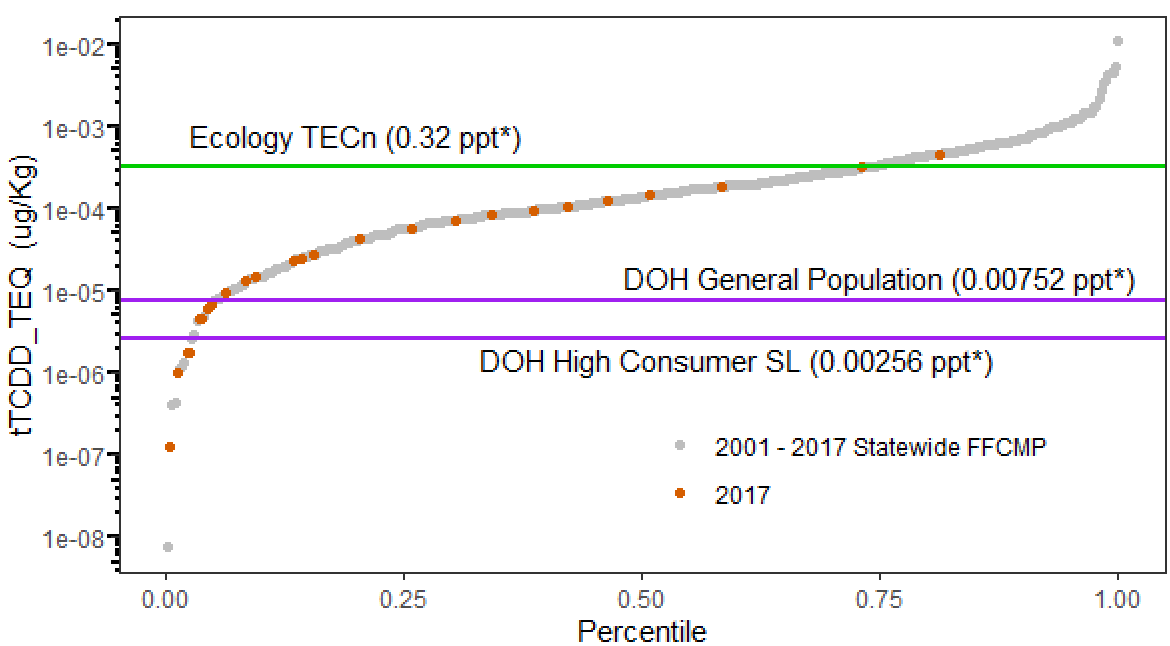

Figure A-6. Cumulative frequency distribution TCDD TEQ in fillet tissue samples from Okanogan River 2017 (n = 386).

Appendix B. Boxplots of DDT trends over time

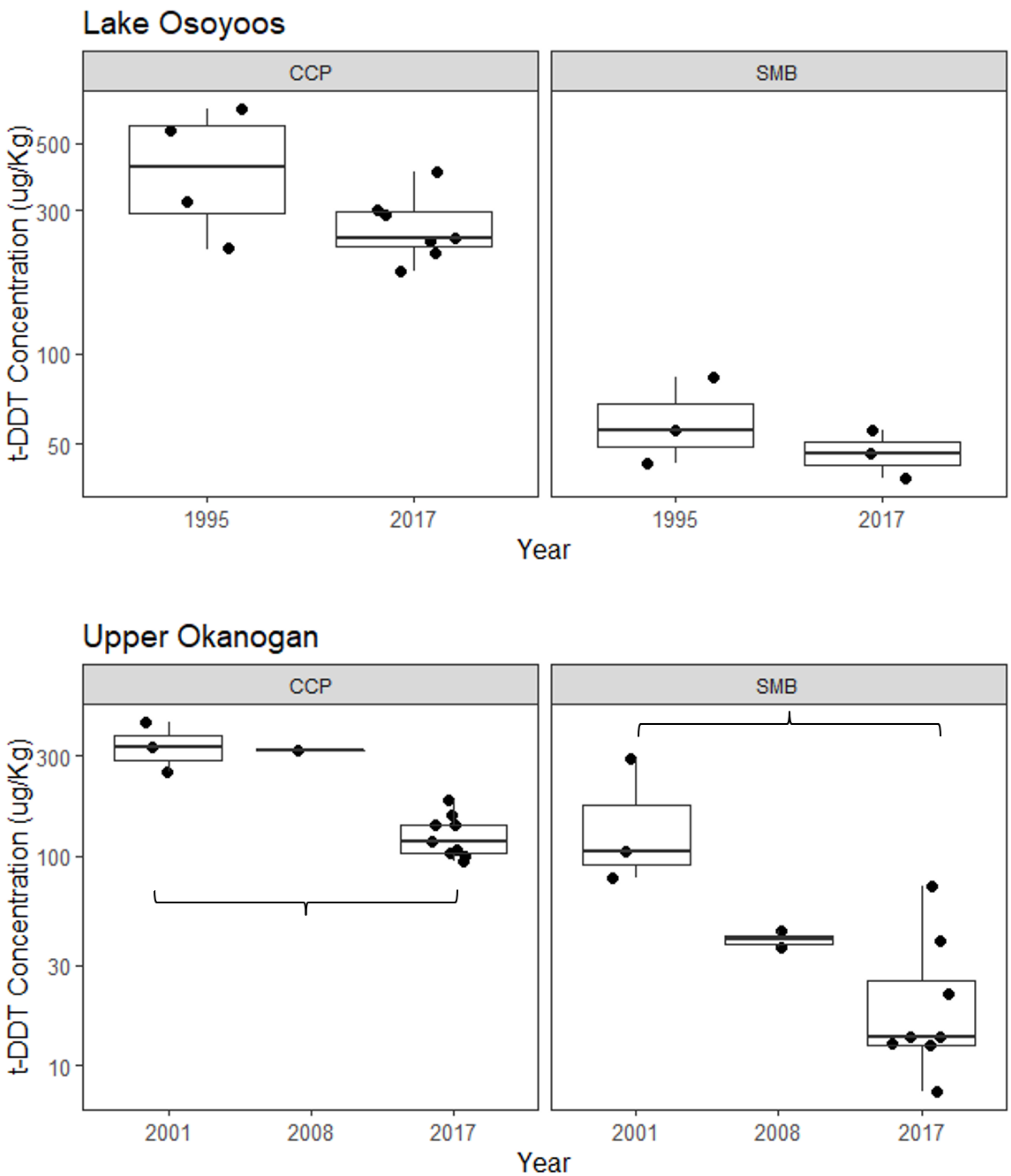

Figure B-1. Box plots comparing trends for total DDT in common carp (CCP) and smallmouth bass (SMB) in Lake Osoyoos and the upper Okanogan River.
Brackets indicate pairs where Bonferroni adjusted p-value < 0.05. Points staggered.

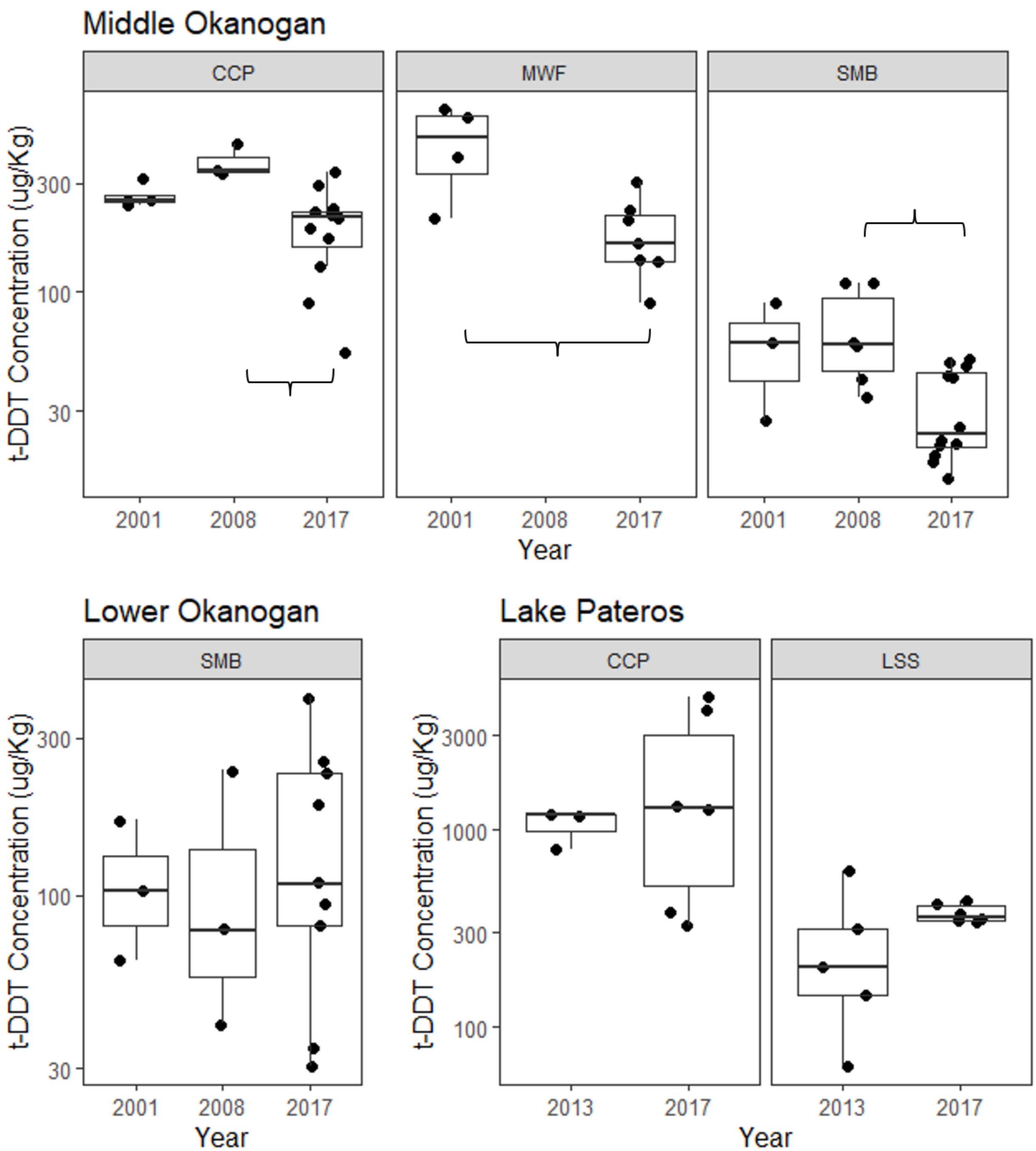

Figure B-2. Box plots comparing trends for total DDT concentrations in smallmouth bass (SMB), common carp (CCP), mountain whitefish (MWF), and largescale sucker (LSS) in the middle and lower Okanogan River and Lake Pateros.
Points staggered to show variation.

Appendix C. Boxplots of PCB trends over time

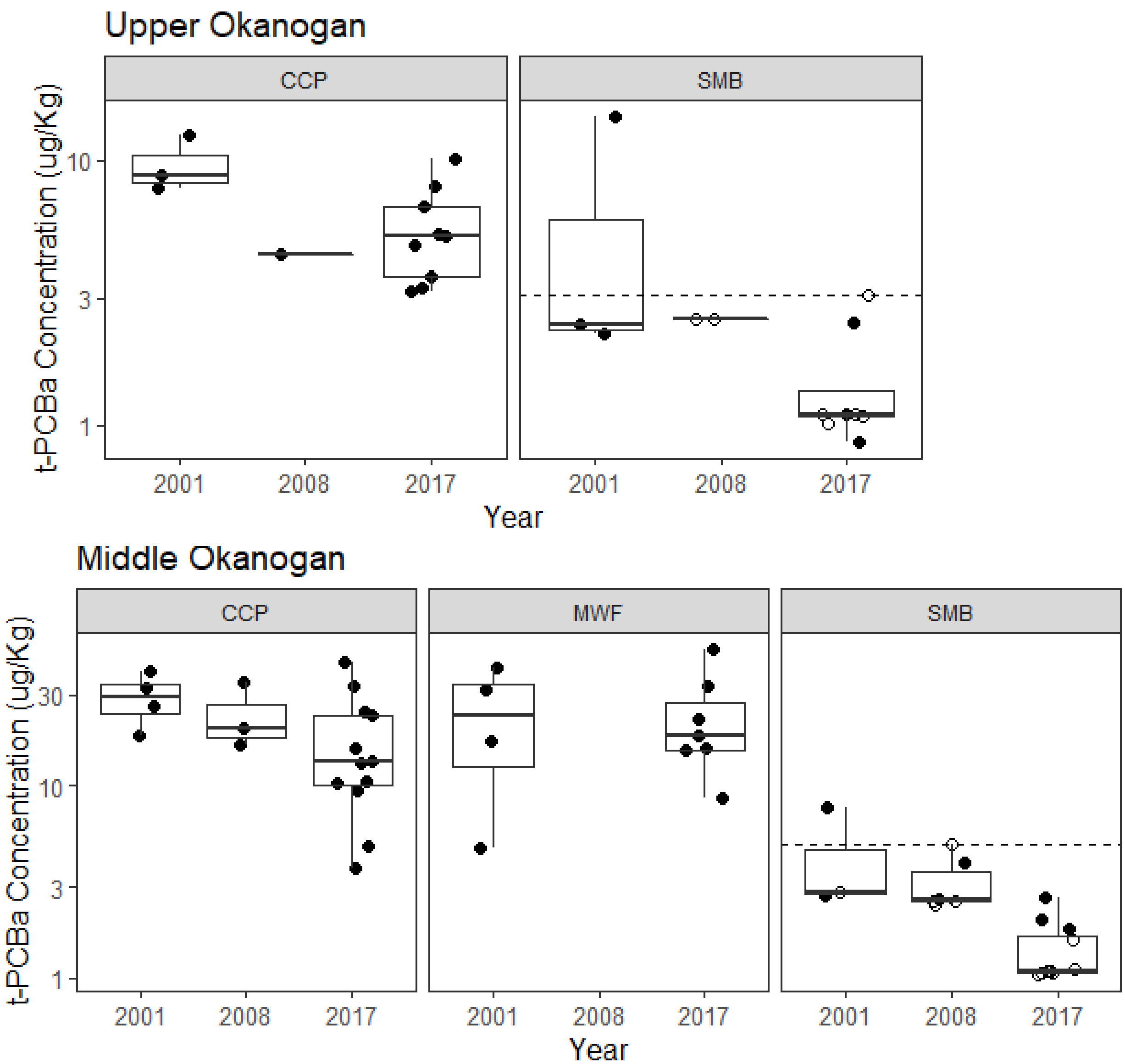

Figure C-1. Total PCB aroclor concentrations in the upper and middle Okanogan River in common carp (CCP), mountain whitefish (MWF), and smallmouth bass (SMB).
Dots represent individual sample concentrations. Empty circles indicate that PCB was not detected at that concentration. Points staggered to show variation. Dotted line shows reporting limit.

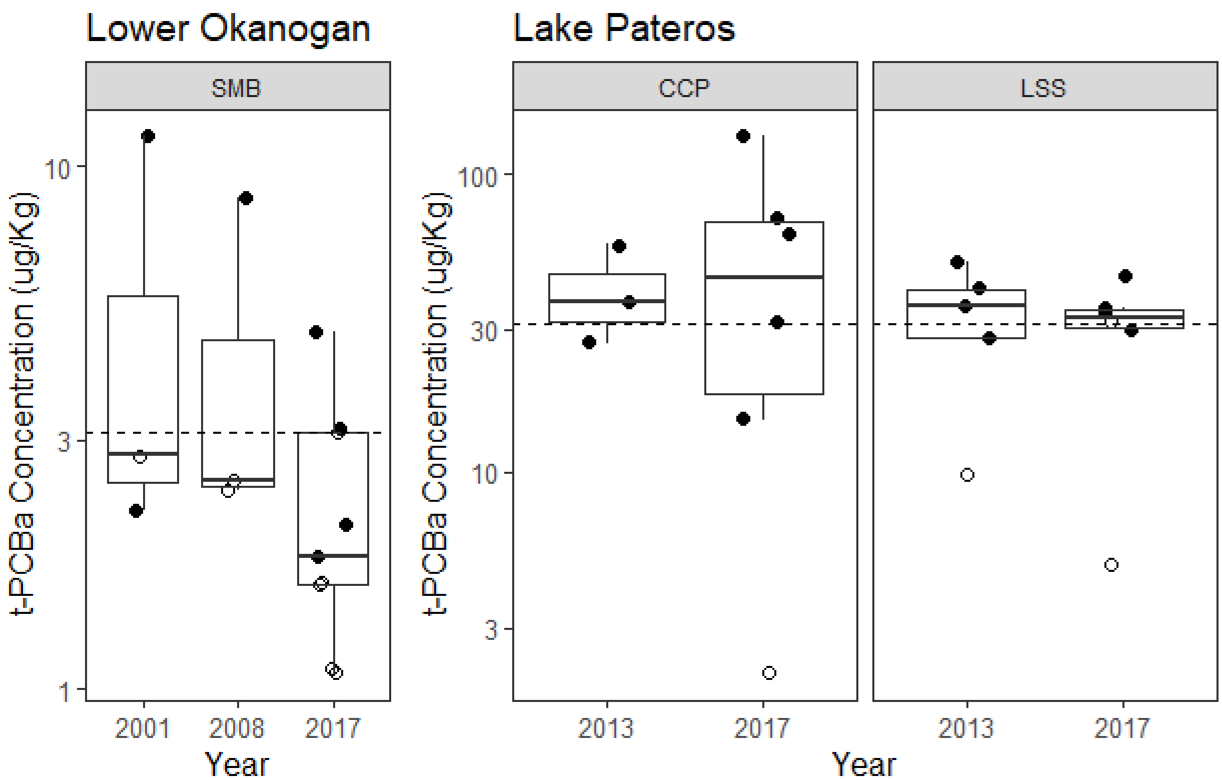

Figure C-2. Box plots showing total PCB aroclor concentration in the lower Okanogan River and Lake Pateros in common carp fillets (CCP), whole largescale sucker (LSS), and smallmouth bass fillets (SMB).

Dots represent individual sample concentrations; empty circles indicate that PCB was not detected at that concentration. Points staggered to show variation. Dotted line shows analytical reporting limit.

Appendix D. Fish covariates

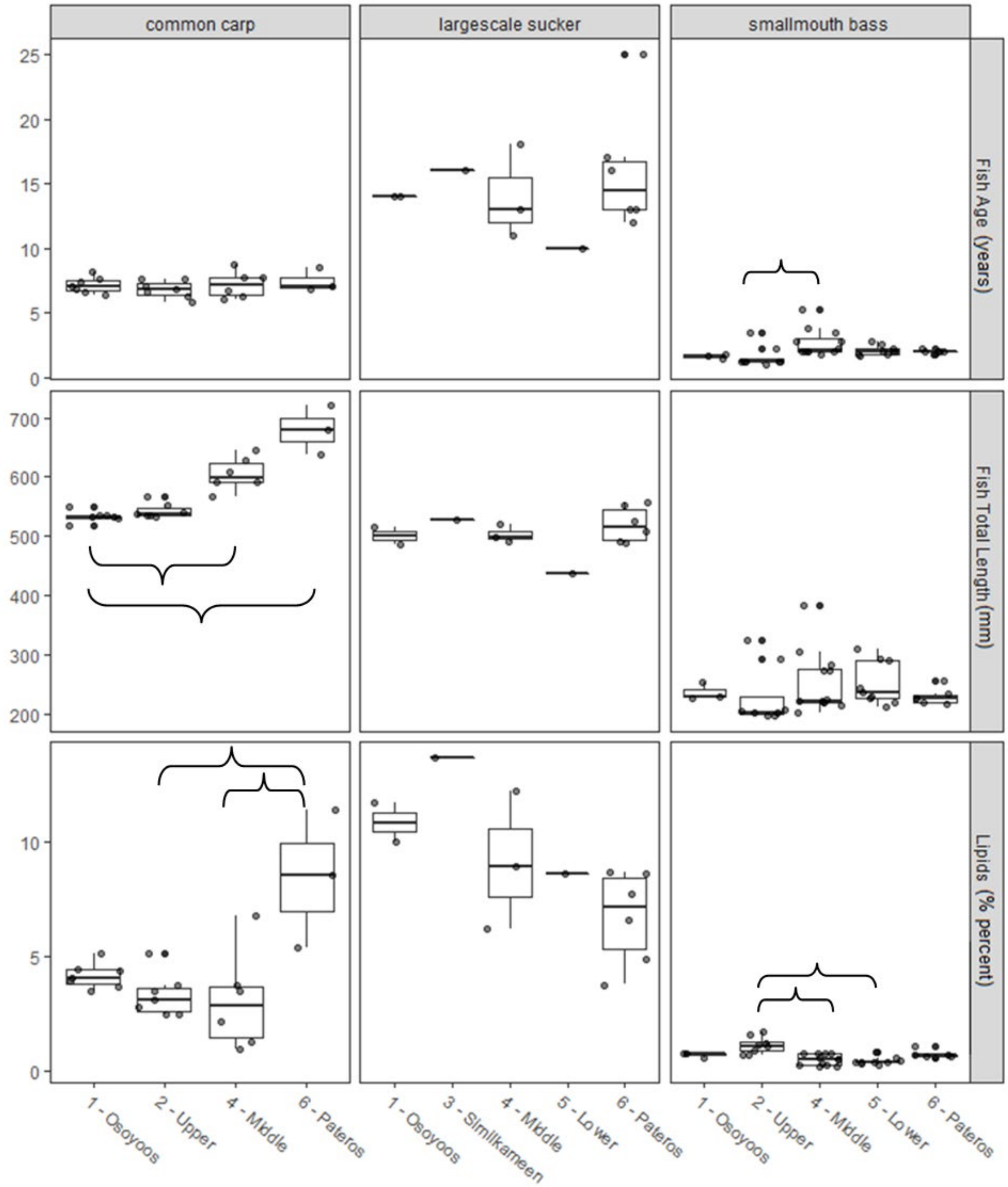

Figure D-1. Boxplot comparison of fish age, size, and percent lipids at Osoyoos and Pateros lakes and Okanogan River 2017.

Dots staggered to show variation. Brackets indicate pairwise comparison with strong evidence of statistical differences (p <0.05).

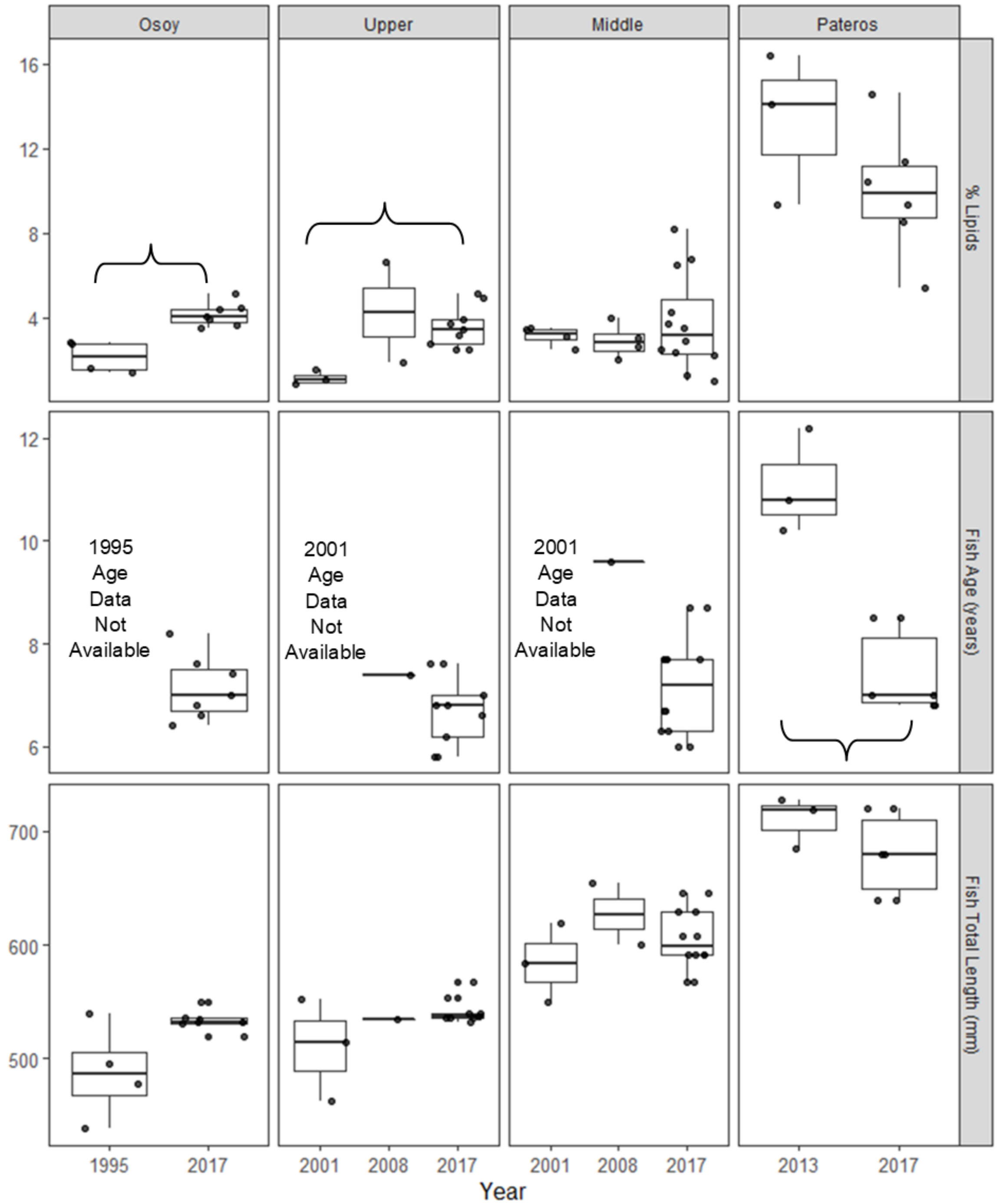

Figure D-2. Boxplot comparison of common carp age, size, and percent lipids for years and sites where time trends were assessed.
Dots staggered to show variation. Brackets indicate significant pairwise comparisons.

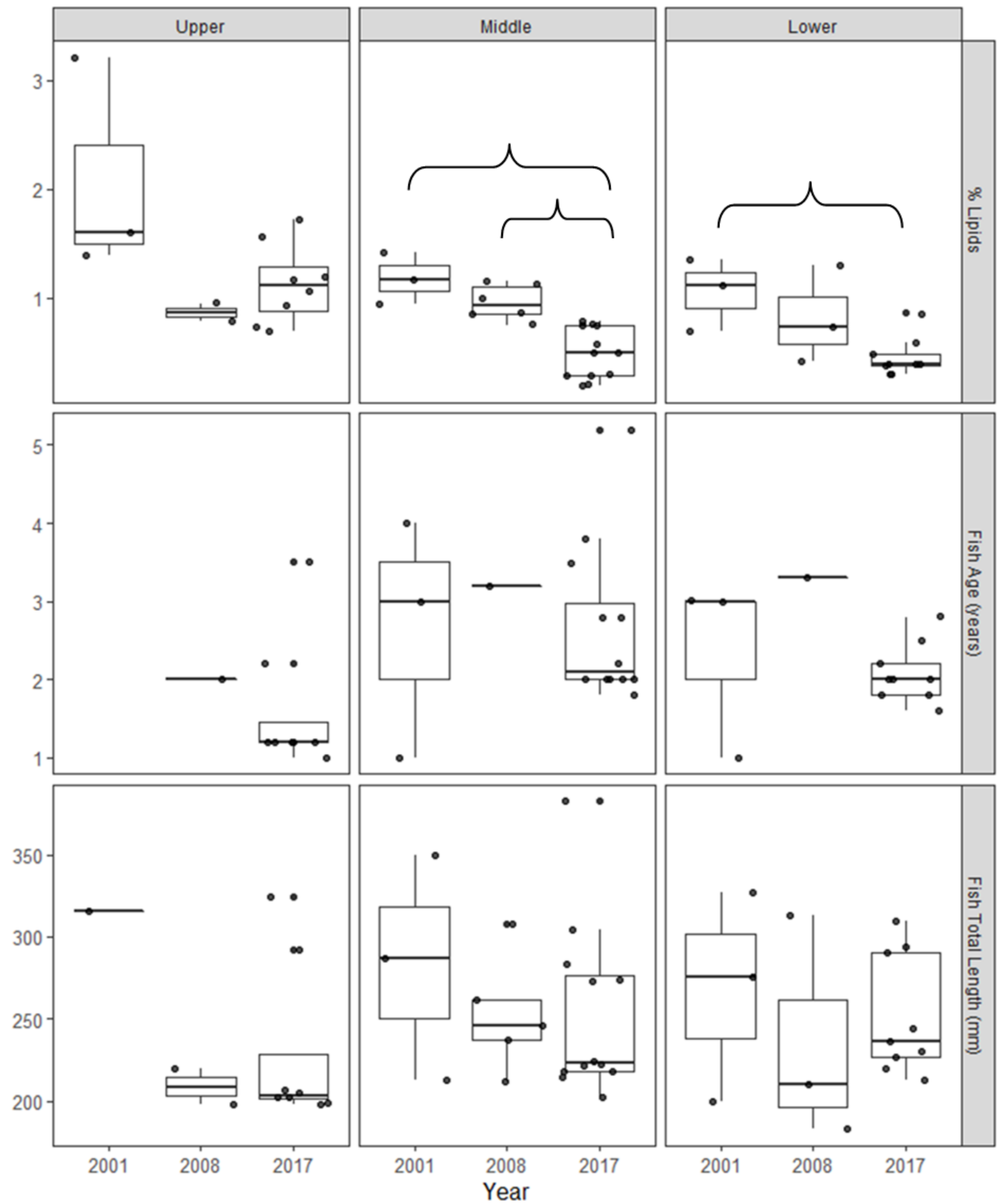

Figure D-3. Boxplot comparison of smallmouth bass age, size, and lipids for years and sites where time trends were assessed.
Points staggered to show variation. Significant differences indicated by brackets.

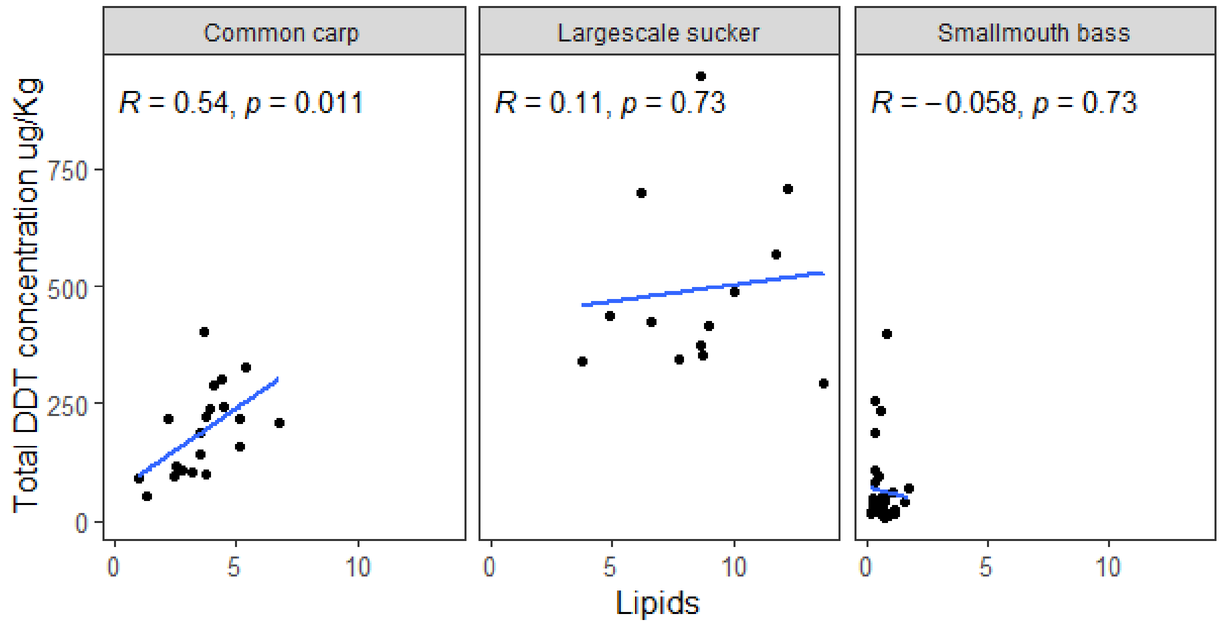

Figure D-4. Regressions for lipids and total DDT concentration in Okanogan fish species.

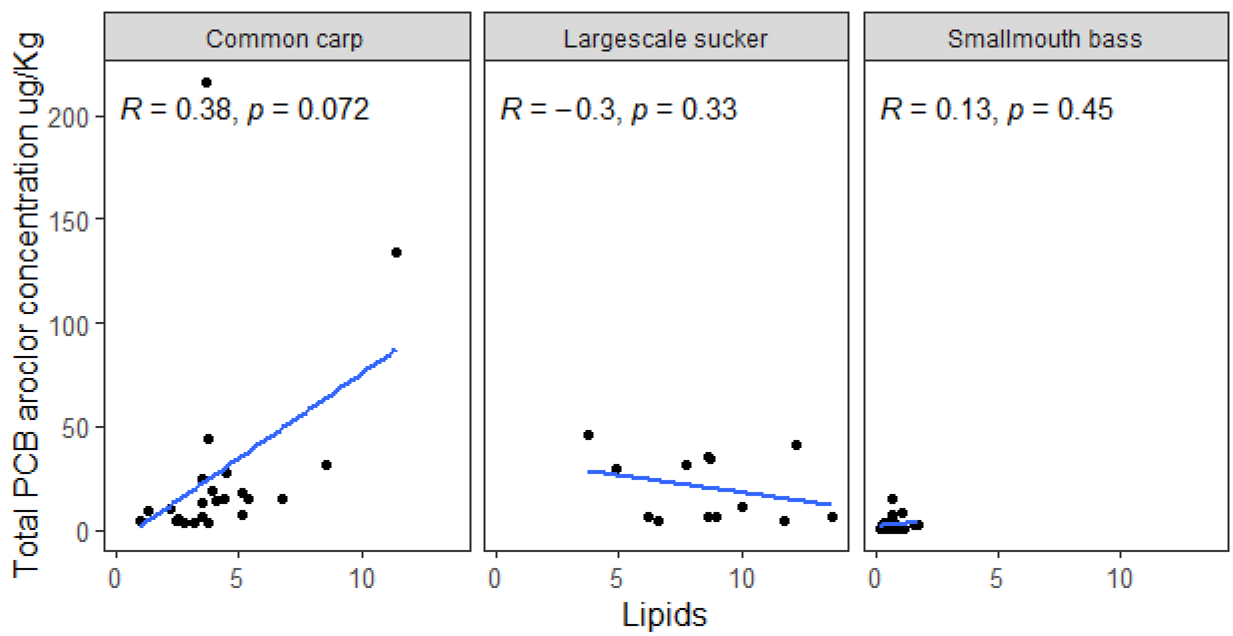

Figure D-5. Regressions for lipids and total PCB aroclor concentrations in Okanogan fish species.

Appendix E. Contaminant summary statistics grouped by fish.

Table E-1. Summary statistics detected results by species of interest.
Non-detects excluded

Result Parameter Name	Species	Tissue Type	n	minimum	median	maximum
Lipids	CCP	Fillet, skin off	23	1.0	3.7	11.4
	CCP	Fillet, skin on	11	2.3	4.9	14.6
	MWF	Fillet, skin on	7	1.7	4.3	4.7
	NPM	Fillet, skin on	15	0.5	1.8	3.1
	SMB	Fillet, skin on	38	0.2	0.7	1.7
	WAL	Fillet, skin on	2	0.6	1.9	3.2
Mercury	CCP	Fillet, skin off	23	54.5	208.2	3997.6
	CCP	Fillet, skin on	11	128.9	230.6	4686.0
	MWF	Fillet, skin on	7	88.8	164.0	300.9
	NPM	Fillet, skin on	15	34.8	114.1	318.1
	SMB	Fillet, skin on	38	7.5	39.8	398.4
	WAL	Fillet, skin on	2	8.9	40.3	71.7
4,4'-DDE	CCP	Fillet, skin off	23	48.2	191.0	3600.0
	CCP	Fillet, skin on	11	118.0	223.0	4280.0
	MWF	Fillet, skin on	7	79.3	140.0	265.0
	NPM	Fillet, skin on	15	30.6	108.0	295.0
	SMB	Fillet, skin on	38	7.5	35.8	358.0
	WAL	Fillet, skin on	2	8.0	36.8	65.7
t-DDT	CCP	Fillet, skin off	23	54.5	208.2	3997.6
	CCP	Fillet, skin on	11	128.9	230.6	4686.0
	MWF	Fillet, skin on	7	88.8	164.0	300.9
	NPM	Fillet, skin on	15	34.8	114.1	318.1
	SMB	Fillet, skin on	38	7.5	39.8	398.4
	WAL	Fillet, skin on	2	8.9	40.3	71.7
t-PBDEs	CCP	Fillet, skin off	12	1.3	2.8	12.0
	MWF	Fillet, skin on	3	7.8	15.3	28.3
	NPM	Fillet, skin on	9	0.9	1.4	9.9
	SMB	Fillet, skin on	10	0.7	0.9	4.9
	WAL	Fillet, skin on	2	0.6	1.4	2.2
t-PCBa	CCP	Fillet, skin off	23	3.2	14.2	216.0
	CCP	Fillet, skin on	10	3.8	18.4	71.4
	MWF	Fillet, skin on	7	8.7	18.3	52.1
	NPM	Fillet, skin on	13	2.7	8.7	48.5

Result Parameter Name	Species	Tissue Type	n	minimum	median	maximum
	SMB	Fillet, skin on	18	0.9	2.7	15.6
	WAL	Fillet, skin on	2	4.6	10.0	15.5
tTCDD_TEQ	CCP	Fillet, skin off	12	1.29 x $^{-7}$	2.05 x 10^{-5}	4.62 x 10^{-4}
	MWF	Fillet, skin on	3	1.76 x $^{-6}$	4.65 x 10^{-6}	1.48 x 10^{-5}
	NPM	Fillet, skin on	7	2.40 x 10^{-5}	8.40 x 10^{-5}	1.88 x 10^{-4}
	SMB	Fillet, skin on	1	6.90 x 10^{-6}	6.90 x 10^{-6}	6.90 x 10^{-6}
	WAL	Fillet, skin on	2	4.71 x 10^{-6}	6.46 x 10^{-5}	1.24 x 10^{-4}
t-Chlordane	CCP	Fillet, skin off	5	0.3	0.6	2.4
Hexachlorobenzene	CCP	Fillet, skin off	2	0.6	0.8	1.0