

**Polychlorinated Biphenyl and Organochlorine Pesticide Concentrations in
Whole Body Mummichog and Banded Killifish from the Anacostia River
Watershed: 2018-2020**

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EXECUTIVE SUMMARY

The Anacostia River is one of three Chesapeake Bay Regions of Concern designated by the US Environmental Protection Agency (USEPA) due to contamination of water, sediment, and biota. In 2020, the District of Columbia Department of Energy and Environment (DOEE) issued an Interim Record of Decision (IROD) for the Anacostia River Sediment Project (ARSP). The IROD was based on a Remedial Investigation/Feasibility Study (RI/FS) and DOEE-funded investigations of contaminant sources. The ARSP Study Area includes the tidal Anacostia River in Washington, DC and Maryland, Kingman Lake, and Washington Channel. The IROD calls for sediment remediation of Early Action Areas (EAAs) with greater than 600 parts per billion (ppb) total polychlorinated biphenyl (PCB) congeners. The IROD identified the following Constituents of Concern (COCs) — PCB congeners, dioxin-like PCBs, dioxins and furans, and chlordane, an organochlorine (OC) pesticide. DOEE is addressing the control of ongoing loading of COCs through a multi-government Source Control Workgroup.

Here we describe forage fish monitoring which relates to IROD Remedial Action Objective (RAO) 1 (reduce risks associated with human consumption of COCs in fish) and has the potential to relate to RAO 4 (reduce risks associated with COCs to levels protective of fish). The objectives are to: 1) determine 2018 through 2020 pre-remedial PCB (including dioxin-like congeners) and chlordane concentrations in forage fish from the ARSP Study Area, Anacostia tributaries, and the Potomac River; 2) compare these concentrations between locations and collections (samples of one species at one location in one year); 3) interpret patterns in PCB homologs; and 4) provide recommendations for future monitoring.

We chose to monitor mummichog (*Fundulus heteroclitus*, MC) and banded killifish (*F. diaphanus*, BK) because of their small home range (~ 0.8 km), 3 to 4-year lifespan, and wide distribution. We collected 216 composite samples, consisting of 1503 individual fish. For each species, samples consisted of 2 to 18 similar-sized fish to obtain ≥ 20 grams wet weight. We analyzed three of the four COCs, excluding dioxins and furans due to cost considerations. The rationale for this choice is described in detail in the report.

Six Anacostia River tributaries were sampled: Northwest Branch (NW), Northeast Branch (NE), Lower Beaverdam Creek (LB; locations LB1, LB1.5, LB2), Hickey Run (HR), Watts Branch (WB), and Nash Run (NR). In the mainstem Anacostia, we sampled: across from Bladensburg Waterfront Park (BL), across from the mouth of Dueling Creek (DC), Pepco Cove (PC), north of the CSX Bridge (A2), between the 11th St. Bridge and Sousa Bridge (11A), and near Poplar Point (A1). In Kingman Lake, we sampled the area between the East Capitol Bridge and footbridge to Heritage Island (KL); along Heritage Island near the footbridge (KH); and along the northern mainland shore of Langston Golf Course (KG). Four Potomac River locations were sampled: the northern shore of Theodore Roosevelt Island (P3); about 0.8 km upstream of Key Bridge (KB); near Fletchers Cove (P4); and in Dyke Marsh (DM).

In the tributaries, there was a 20-fold difference in mean total PCBs in BK and a 15-fold difference in MC. Mean total PCBs were highest in LB1 and LB2 (both near source areas under

investigation) and lower at LB1.5 (remote from these areas). Mean concentrations at LB1 ranged from 313 to 1110 parts per billion (ppb) wet weight, varying between species and sampling year. PCB homologs were enriched in di-, tr-, and tetra-chlorinated congeners in LB fish, suggesting current releases of PCBs. Lower total mean PCB concentrations (47.9 to 76.5 ppb) were detected in NW and NE forage fish. These findings are consistent with those from investigations of suspended sediments, passive samplers, and freshwater mussels. Together these provide a weight of evidence implicating LB as a continuing source of PCBs to the tidal Anacostia.

In the mainstem Anacostia, mean total PCBs were lowest in collections from upstream locations BL and DC, ranging from 29.3 to 119 ppb. The remaining Anacostia collections (except Pepco Cove) had mean total PCB concentrations that ranged from 109 ppb to 458 ppb. Multiple collections from Pepco Cove, a Potential Environmental Cleanup Site, ranged from 252 to 476 ppb. Samples from Kingman Lake ranged from 181 ppb to 376 ppb. The lowest mean total PCB concentrations were in BK from the Potomac River location near Fletchers Cove (P4, at 29.3 ppb and 42.3 ppb). Based on food chain modeling, we propose risk-based forage fish whole body categories of green (<50 ppb), yellow (50 to 200 ppb), orange (200 to 400 ppb), and red (>400 ppb).

We used a linear model to investigate possible covariates; for both total PCBs and total chlordane, higher lipid content was a statistically significant covariate for higher contaminant concentrations. Lipid-adjusted means were compared separately for BK and MC and in a combined species model. For PCBs, based on Holm multiple comparison tests, LB1 and LB2 were in the highest statistical groupings and NW, NE, and P4 in the lowest.

A power analysis provided sample size recommendations for future pre- and post-remedial monitoring, based on total PCBs. The ability to detect a statistically significant decrease was strongest at the highest total PCB concentrations. A 25 percent decrease can be detected with 80 percent power at $\alpha = 0.05$ in BK at LB2 (average lipid-adjusted mean of 875 ppb total PCBs) with a sample size of 15. A 50 percent decrease can be detected with a sample size of 5. For DM, average of 95.4 ppb, there is 0 power to detect even a 75 percent decrease with a sample size of 15.

We recommend investigation of MC and BK as fish health indicator species to monitor progress towards RAO 4. Pilot studies in progress compare liver and gonad histopathology in 2020 MC and BK samples from Lower Beaverdam Creek (high PCBs) and Bladensburg (low PCBs). Embryo-larval laboratory tests are currently comparing the effects of site sediments on hatching success, larval length, and prevalence of abnormalities in MC and sheepshead minnow (*Cyprinodon variegatus*). Depending on the ongoing study results, these or other procedures related to fish health should be considered for inclusion in the forage fish monitoring program.

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List of Abbreviations

11A: Anacostia sampling location between 11th St. and Sousa Bridges

A1: Anacostia sampling location near Poplar Point

A2: Anacostia sampling location above CSX Railroad Bridge

ARSP: Anacostia River Sediment Project

BHC: Benzene hexachloride

BK: Banded killifish

BL: Bladensburg sampling location

CSO: Combined Sewer Outfall

COCs: Constituents of Concern

CV: Coefficient of Variation

DC: Dueling Creek sampling location

DDD: Dichlorodiphenyldichloroethane

DDE: Dichlorodiphenyldichloroethylene

DDT: Dichlorodiphenyltrichloroethane

DM: Dyke Marsh (sampling location)

DOEE: Department of Energy and Environment

EAA: Early Action Area

GC: Gas Chromatography

HR: Hickey Run (sampling location)

IROD: Interim Record of Decision

KB: Key Bridge (Potomac sampling location upstream of Key Bridge)

KG: Kingman Lake sampling location along the northern section of Langston Golf Course

KH: Kingman Lake sampling location on Heritage Island near the footbridge

KL: Kingman Lake sampling location between East Capitol Bridge and footbridge

LB: Lower Beaverdam Creek (sampling locations LB1, LB1.5, LB2)

LR: Low resolution

MC: Mummichog

MDE: Maryland Department of Environment
MS: Mass spectrometry
NR: Nash Run (sampling location)
NE: Northeast Branch (sampling location)
NW: Northwest Branch (sampling location)
P3: Potomac sampling location at northern tip of Theodore Roosevelt Island
P4: Potomac sampling location along the shoreline at Fletchers Cove
PC: Pepco Cove (sampling location)
PAH Polynuclear Aromatic Hydrocarbon
PCB: Polychlorinated Biphenyl
PECS: Potential Environmental Cleanup Site
QA: Quality Assurance
QC: Quality Control
RAO: Remedial Action Objective
RI/FS: Remedial Investigation/ Feasibility Study
TEF: Toxic equivalency factor
TEQ: Toxic Equivalents
UMBC: University of Maryland Baltimore County
USEPA: United States Environmental Protection Agency
USFWS: U.S. Fish and Wildlife Service
USGS: U.S. Geological Survey
WB: Watts Branch (sampling location)

Definitions

Collection: samples of one species (BK or MC) from one location in one year

Location/year: samples of all species (BK and/or MC) collected from one location in one year

Total PCBs: sum of all PCB congeners or co-eluting congeners; this value is calculated by the analytical laboratory

Total chlordanes: sum of alpha and gamma chlordanes, cis and trans nonachlor, and oxychlordanes

INTRODUCTION

Background

The Anacostia River is one of three Chesapeake Bay Regions of Concern designated by the US Environmental Protection Agency (USEPA) due to contamination of water, sediment, and biota. The river and watershed cover 460 sq kilometers (sq km equal to 176 sq miles) in Montgomery and Prince George's County, Maryland and most of the eastern half of Washington, D.C. Within the District of Columbia, fish advisories have been in place since 1989 (Government of the District of Columbia, Department of Consumer and Regulatory Affairs 1989), warning the public to restrict their consumption, largely due to polychlorinated biphenyl (PCB) contamination (Pinkney 2014, 2018a). The current (2016) advisory

(https://doee.dc.gov/sites/default/files/dc/sites/ddoe/service_content/attachments/Fish%20Advisory%202-2-2016.pdf) warns the public not to consume striped bass (*Morone saxatilis*), carp (*Cyprinus carpio*), and American eel (*Anguilla rostrata*) and to limit consumption of other game fish, including several catfish species.

In 2013, the District of Columbia Department of Energy and Environment (DOEE) started the Anacostia River Sediment Project (ARSP, <https://www.anacostiasedimentproject.com/>) to address toxic contamination in the 14-km (9-mile) tidal Anacostia River, Kingman Lake, and Washington Channel (ARSP Study Area). ARSP studies followed the USEPA guidance documents for the Superfund Program, including a Remedial Investigation/Feasibility Study (RI/FS; Tetra Tech 2019a,b,c). The RI assessed the nature and extent of contamination in the Study Area and included human health and ecological risk assessments. The FS evaluated potential remedial actions.

Building on these results and source identification studies, DOEE issued an Interim Record of Decision (IROD; DOEE 2020), which identified four Constituents of Concern (COCs): total PCB congeners, dioxin-like PCBs, dioxins and furans (as Toxic Equivalents, TEQs), and chlordane, an organochlorine (OC) pesticide. The IROD focused on the remediation of Early Action Areas (EAAs) delineated as areas with surface sediment total PCBs ≥ 600 $\mu\text{g/kg}$ (parts per billion (ppb)). It also described 15 Potential Environmental Cleanup Sites (PECS). A PECS is “an area bordering the Anacostia River where current activities, documented previous activities, or suspected previous activities include or included storage, handling, use, and potential release of hazardous substances or petroleum products.” Separate investigations are ongoing at PECS including Pepco Benning Road Facility, Washington Gas Light, and Washington Navy Yard.

The IROD established the following Remedial Action Objectives (RAOs):

RAO 1. Reduce risks associated with the consumption of COCs in fish from the tidal Anacostia River by people with the highest potential exposure.

RAO 2. Reduce risks associated with direct exposure of people to surface sediment in shallow water (fringe sediment) in the tidal Anacostia River.

RAO 3. Reduce risks associated with COCs in sediment to levels protective of benthic and aquatic invertebrates based on direct chronic exposure to surface sediment and surface water.

RAO 4. Reduce risks associated with COCs in surface sediment to levels protective of fish based on direct contact with and ingestion of surface water, sediment, and prey.

DOEE also funded studies that quantified contaminant loading from the watershed into the tidal river. Such data are critical to ensure that cleanup actions taken in the ARSP Study Area are long-lasting and not subject to re-contamination from tributary loadings. Wilson (2019) measured contaminant loads in high and low flow periods throughout 2017 at gage stations of the five largest tributaries— Northwest Branch (NW), Northeast Branch (NE), Lower Beaverdam Creek (LB), Watts Branch (WB), and Hickey Run (HR). The sediment load was driven by the discharge (which follows the size of the watersheds) with NW providing 50 percent, NE 33 percent, LB 14 percent, WB 2 percent, and HR 1 percent. Total PCB loads, however, had a different pattern, with an estimated 75 percent from LB, 12 percent from NW, 7 percent from NE, 3 percent from WB, and 2.5 percent from HR.

Ghosh et al. (2020) deployed passive samplers and caged freshwater mussels (*Elliptio complanata*) in 2016 and 2017 to estimate the freely dissolved and bioavailable concentrations of PCBs, OC pesticides, and polynuclear aromatic hydrocarbons (PAHs) in the same tributaries. Consistent with Wilson (2019), LB contributed 72 percent of the total load of freely dissolved PCBs per year with the remainder coming primarily from NE (13 percent) and NW (9 percent).

DOEE is developing a monitoring program to assess the effectiveness of the remediation to be performed in the EAAs and the actions to reduce ongoing inputs of COCs (Tetra Tech 2022). To support DOEE, Pinkney and Ghosh (2021) designed a Strategic Approach to help assess: 1) baseline and post-remedial conditions; 2) suggest targets for monitoring the progress towards the RAOs to enable feedback for adaptive management; and 3) help refine the conceptual site model (CSM) that guides the overall remediation. The abiotic media to be monitored include sediment, pore water, and surface water. Biota monitoring is focused on forage fish, game fish, and benthic invertebrates including caged freshwater mussels.

Approach

The current study provides the approach, objectives, methods, and results of forage fish monitoring conducted in 2018 through 2020 relevant to IROD RAO 1 and has the potential to be relevant to RAO 4. An ideal forage fish species for the ARSP would be widely distributed, with site fidelity, and a relatively short lifespan. In developing the plan, we initially focused on the mummichog (MC; *Fundulus heteroclitus*, Figure 1), which has been frequently used in contaminant monitoring studies along the East Coast of the U.S. related to PAHs (Vogelbein et al. 1990, Vogelbein and Unger 2006), PCBs (e.g., Black et al. 1998), and mercury (e.g., Buckman et al. 2021). Information provided by the DOEE Fisheries Research Branch (D. Ryan, DOEE, personal communication) emphasized that spatial coverage was incomplete with mummichogs alone and that

collection of banded killifish (BK; *F. diaphanus*, Figure 1) was also required. Thus, we targeted both species for the three-year study.

Mummichogs in a tidal creek in Delaware, had an estimated summer home range of 36 m, with a few fish moving 375 m (Lotrich 1975, Abraham 1985). Teo and Able (2003) estimated a home range of 15 ha in a tidal marsh in New Jersey monitored from April through November. Valley et al. (2010) estimated the median displacement distances for banded killifish of 228 m (2005) and 355 m (2006) in a Minnesota Lake. The aerial home ranges were 1.25 ha in 2005 and 1.95 ha in 2006. No home range estimates for banded killifish in rivers were identified in the literature. Pinkney and McGowan (2006), however, compared concentrations of DDT isomers in whole body BK collected from the tidal 78-ha Quantico embayment of the Potomac River and nearby creeks. They found a similar, elevated ratio of p,p'-DDD: p,p'-DDE concentrations in embayment sediments and fish; this ratio was not observed in nearby creeks. They concluded that there was site fidelity for banded killifish in the embayment. The embayment is in the shape of a half circle with a diameter of 1.6 km (radius of 0.8 km) at its border with the main river. Thus, for the current study, we estimated that for both species there is site fidelity in a river segment with a length of 0.805 km (0.5 mi) and an area of 50 ha (124 ac).

The life span of both species is three to four years (Abraham 1985, Phillips et al. 2007). This is advantageous in that new cohorts are representative of recent exposure, facilitating before and after monitoring studies. In general, longer fish are older although age-length relationships reported for these species have varied (Fritz and Garside 1975; Valiela et al. 1977; Phillips et al. 2007). In addition to contaminant investigations, MC have been used in fish health studies because of their propensity to develop liver tumors and pre-neoplastic lesions. Such tumor surveys have been conducted in the Elizabeth River, Virginia (Vogelbein et al. 1990, Vogelbein and Unger 2006) and in Hershey Run, Delaware (Pinkney and Harshbarger 2006). Although no liver tumor surveys have been performed with BK, both species would be suitable for fish health studies (V. Blazer, USGS, personal communication) that evaluate histopathology of the liver and gonads (e.g., Blazer 2002; Blazer et al. 2009).

Objectives

The objectives are to: 1) determine 2018 through 2020 pre-remedial PCB (including dioxin-like congeners) and chlordane concentrations in forage fish from the ARSP Study Area, Anacostia tributaries, and the Potomac River; 2) compare these concentrations between locations and collections (samples of one species at one location in one year); 3) interpret patterns in PCB homologs; and 4) provide recommendations for future monitoring.

METHODS

Sampling Locations and Collection Procedures

Sampling locations (Table 1, Figure 2) were chosen to obtain pre-remedial concentrations of MC and BK in Anacostia tributaries, Kingman Lake, and main stem Anacostia areas near and remote from PECS. In addition, we sampled in the Potomac River, including the

5.1 km (3.2 mi) reach from Key Bridge to Chain Bridge that was used as background for sediment contamination in the RI (Tetra Tech 2019a). Forage fish were also collected from Dyke Marsh (DM), a 154-hectare freshwater tidal wetland maintained by the National Park Service about 5 km (3.1 mi) downriver of the Wilson Bridge to provide regional context. Fish were collected in September and October 2018, June through August 2019, and June through November 2020. Four locations — in the Anacostia at A1 (near Poplar Point) and A2 (above CSX Bridge, near the mouth of Fort Dupont Creek) and Potomac at P3 (northern tip of Theodore Roosevelt Island) and P4 (adjacent to Fletchers Cove) — are monitored by DOEE Fisheries Research Branch who provided some of the 2018 and 2019 samples. The remaining samples were collected by U.S. Fish and Wildlife Service, Chesapeake Bay Field Office (CBFO) biologists with beach seines, baited minnow traps fished overnight, or backpack electroshocking. Over the course of the study, stations were added to expand spatial coverage, others were repeated to investigate differences between years.

Six tributaries (Table 1, Figure 2) were sampled, five of which (NW, NE, LB, HR, and WB) provide the greatest flow to the mainstem Anacostia. These tributaries were sampled near USGS gages, close to the locations of Ghosh et al. (2020). The sixth tributary, Nash Run (NR), was sampled in 2020, about 100 meters from its mouth in Kenilworth Marsh. In LB, two locations were chosen near contaminant sources currently under investigation by the Maryland Department of the Environment (MDE). The collection area of LB1, includes areas adjacent to and downstream from the Joseph Smith & Sons Scrap Yard. The upstream location, LB2, is downriver of the Pennsy Drive area which has been investigated as a potential PCB source by MDE (E. Green, MDE, personal communication). In 2020, we added a middle location near Jesse Warr Recreation Center (LB1.5), which Ghosh et al. (2020) reported was less contaminated than LB1 or LB2.

There were six mainstem sites (Table 1, Figure 2) in the tidal Anacostia River: Bladensburg Waterfront Park (BL); across from the mouth of Dueling Creek (DC); Pepco Cove (PC, a PECS); A2; 11A (about halfway between the 11th Street Bridge and Sousa Bridge); and A1. Kingman Lake (KL) was sampled across an area from the East Capitol Bridge north to the footbridge in 2018. In 2020, due to limited success at KL, sampling was moved to a small beach on Heritage Island near the footbridge (KH), and to the northern edge of Kingman Lake along the mainland portion of Langston Golf Course (KG). In the District of Columbia portion of the Potomac River, we collected from P3, P4, and about 0.805 km (0.5 mi) upstream of Key Bridge (KB) along both shores. In 2020, we added DM.

Fish Processing

Fish were euthanized by immersion in a >0.5 mg/L solution of tricaine methanesulfonate (MS-222, Tricaine-S, 99.5 %, Western Chemical, Ferndale, WA), buffered to a pH of 7.0 to 7.5 with sodium bicarbonate (American Veterinary Medical Association (AVMA 2013, 2020). Whole-body MC and BK were double wrapped in aluminum foil and stored frozen in plastic bags. They

were labeled with the location, species, and date. At the CBFO laboratory, fish from a single location were thawed, unwrapped, rinsed with deionized water, blotted dry, weighed to the nearest 0.1 gram, and measured for total length to the nearest mm. Species were confirmed with field guides.

Single species composites (in chemically clean glass jars) consisted of three length classes. For MC, the small (S) class was 45 to 65 mm, the large (L) class was 66 to 84 mm, and the jumbo (J) class was ≥ 85 mm. The same length classes were used for BK, except the small class was from 50 to 65 mm. To the extent possible, fish lengths within a sample had the smallest fish at least 75 percent of the largest fish, based on USEPA (2000) guidance. This was met for all samples except four small class MC samples with percentages ranging from 70 percent to 74 percent. If possible, composite samples had ≥ 20 grams of wet tissue to allow the laboratory to easily meet its detection limits. The composites consisted of 8 to 18 small, 3 to 9 large, and 2 to 5 jumbo fish. In 2018 and 2019 samples were mixed sex. In 2020, single sex samples were collected to be able to evaluate sex as a possible covariate (see Data Analysis).

Samples were coded as follows: location (2 digits), species (2 digits), sex (2020 only), year (two digits), size class, sample number (2 digits; e.g., BLBKF20L01). All samples of one species at one location in one year were termed a collection (e.g., BLBK20). For the mixed species model described below and other analyses, samples of BK and/or MC from a location in a single year were termed a “location/year” (e.g., BL20).

Chemical Analyses

Organic analyses of 209 PCBs by congener and OC pesticides—which includes three of the four COCs—were performed by SGS AXYS Analytical Services, Ltd. (Sidney, British Columbia, Canada), contracted by the Service’s Analytical Control Facility (ACF). The decision not to analyze for dioxins and furans, is evaluated in the Discussion section. A summary of SGS AXYS Method MLA-007 for PCBs and OC pesticides is provided in Appendix A.

Samples were shipped on dry ice and documented with chain of custody forms. Fish samples were analyzed for lipid and moisture content, organochlorine pesticides, total PCBs, and 209 PCB congeners (see Table 2, for analyte list and typical detection limits, and Appendix A for a full description of Method MLA-007). As part of the method, two fractions are analyzed. The first fraction consisting of PCB congeners, aldrin, alpha benzene hexachloride (BHC), alpha chlordane, beta BHC, cis-nonachlor, gamma BHC, gamma chlordane, heptachlor, hexachlorobenzene (HCB), mirex, o,p'-DDD, o,p'-DDE, o,p'-DDT, oxychlordane, p,p'-DDD, p,p'-DDE, p,p'-DDT, toxaphene, and trans-nonachlor, was analyzed by Low Resolution Gas Chromatography/Mass Spectrometry (LRGC/MS). The second fraction—delta BHC, dieldrin, endrin, endrin aldehyde, endrin ketone, Endosulphan I, Endosulphan II, Endosulphan sulfate, heptachlor epoxide, and methoxychlor—was analyzed by GC with an Electron Capture Detector also according to AXYS method MLA-007. The LRGC/MS PCB analysis is equivalent to EPA method 1628 (USEPA 2021), which AXYS helped develop. Results, including the ACF Quality Review are presented in Appendix A in pdf format, with the Data Validation Report included as Appendix B. Data with descriptive statistics are summarized in Table 3 and provided in spreadsheets in Appendix C.

Quality Assurance

A Quality Assurance Project Plan (Pinkney 2018b) was prepared according to USEPA (2001, 2002a) guidance. Quality control/quality assurance procedures included the analysis of standard reference materials, laboratory duplicates, procedural blanks, internal standards, surrogates, and matrix spikes. A QA review of the data was performed by ACF chemists, Brenda Bryant and Steve Boateng and included in the laboratory reports (Appendix A). Two duplicates were prepared at the SGS AXYS laboratory from samples with double the usual weight of sample so that relative percent difference (RPD) could be calculated. A full data validation (USEPA Stage 4, according to USEPA 2017 guidance) was conducted by EcoChem, Inc. (Seattle, WA; Appendix B).

Data Analysis

We focused the data analysis on total PCB congeners, dioxin-like PCB congeners, PCB homologs, and total chlordane—as well as three other OC pesticides that were frequently detected (total DDT, dieldrin, and heptachlor epoxide). All data (including model-based estimates) were reported to three significant digits in wet weight parts per billion (ppb = $\mu\text{g/kg}$). PCBs were calculated as the sum of all 209 congeners, including some that co-eluted. Total chlordane was the sum of alpha- and gamma-chlordane, cis- and trans-nonachlor, and oxychlordane (USEPA 2000). Total DDT was the sum of all six o,p'- and p,p'-DDD, DDE, and DDT isomers. For calculating these totals, non-detects were counted as zeros. Separate bar graphs show the mean (+ one standard deviation) for each collection for total PCBs and total chlordane for the Anacostia Tributaries, mainstem Anacostia and Kingman Lake, and the Potomac River. The di- through octa-chlorinated homologs were summed and the percentage of di-through octa was calculated (the other homologs had minimal contributions to the total and were not tabulated to simplify the graphs).

Although these are whole fish samples, RAO 1 relates to protection of the health of consumers of game fish that accumulate contaminants partially through eating forage fish. We, therefore, calculated and apportioned cumulative human health risk for each collection based on mean concentrations of total PCBs, dioxin-like PCB congeners, total chlordane, total DDT, heptachlor epoxide, and dieldrin (see Table 3). We used the Toxic Equivalency Factors (TEFs) of Van Den Berg et al. (2006) and apportioned risk according to the Delaware Department of Natural Resources and Environmental Control (DNREC) and Department of Health and Social Services fish advisory guidance document (DNREC/DHSS 2017) and risk calculator provided by J. Cargill (DNREC, personal communication). Although both cancer and non-cancer risks are calculated, in all cases within the Delaware fish data base, meal advisories based on cancer risk were far more restrictive. Thus, after verifying that this was the case with the current data, risk apportionment (Table 4) was based on cancer risk.

For total PCBs and total chlordane, we developed linear models (Zuur et al. 2009) to take into consideration covariates for comparisons across collections and locations (see Appendix D for statistical analyses). The lack of co-occurrence of both species at all locations led to an unbalanced two-way design for models that included both species and location. To avoid possible model biases associated with this unbalanced two-way model, the most rigorous comparisons among collections were obtained by analyzing the species

separately using a one-way design. The adjusted means were presented along with standard error, and upper and lower 95th percentile confidence limits. The standard error of the predicted value is a composite of all the residuals from the model as accumulated in the mean squared error term and is justified by the homogeneous variance assumption. The confidence intervals are for predicted values from the fitted linear model (not based on the mean and standard deviation from a sample population at one location). The data were also analyzed using a combined species model using a two-way design in order to obtain a ranking of location/years. Pairwise comparisons based on the combined species model were considered less reliable, and therefore, we did not calculate confidence limits.

To identify the impact of outliers on the linear models, we first performed the modeling using the entire data set. A second analysis was performed after identifying outliers with Rosner's test (Gilbert 1987). This test requires the user to specify the number of suspected outliers prior to application. We computed the studentized residuals (Zuur et al. 2009) from the linear models of the entire data base. Observations with studentized residuals greater than 2.5 were identified as potential outliers. The outliers were then removed for both the individual species and combined species models. We present the model results with the outliers included and with outliers removed to show their effects on model parameters. For model-based multiple comparison tests, outliers were retained because there was no scientific basis for their exclusion.

Two potentially confounding variables, median fish length and percent lipids were considered for inclusion as covariates in the model. Both have been positively correlated with PCB concentration (Sadraddin et al. 2011, Gewurtz et al. 2011). These relationships were explored by plotting the location adjusted residuals of total PCBs and total chlordane against length residuals and percent lipid residuals. An additional variable, sex, was examined for the 2020 data only, in which single sex composites were analyzed. The analysis was restricted to locations with both male and female samples (13 for BK, 9 for MC) and the same linear model approach was applied. These analyses allowed us to prepare separate length and lipid residual plots for males and females and more fully examine lipid and length relationships (see Appendix D for statistical output).

The initial analysis produced slightly negative coefficients for the median length covariate which indicated an inverse relation to each COC. For BK, it appears to be driven by a negative relationship between fish length and lipids. For MC, there was a U-shaped relationship between length and lipid. A negative length relationship is not consistent with our scientific understanding of bioaccumulation of PCBs (e.g., Sadraddin et al. 2011, Gewurtz et al. 2011). Because of these uncertainties, length was not included as a covariate. Lipid content (as a percent) was centered by subtracting the mean by species for ease of interpretation of model parameters. Estimates of mean concentration by location were adjusted to mean percent lipids for each species.

Linear models were fitted using the `lm()` [linear model] function of the R statistical programming environment (R Core Team 2021). For each species, the linear model included location as a factor variable and percent lipids as a covariate. Following the linear model analysis, adjusted mean concentrations for pairs of locations were compared using a t-statistic computed as a linear function of the parameter vector (Rao 1973). The null hypothesis was that the difference between locations equals zero. Two methods were considered to adjust p-values for multiple comparisons: the method of controlling the false

discovery rate (FDR) (Benjamini and Hochberg 1995) and Holm's method for controlling the family-wise false positive rate (Holm 1979). We chose Holm's method, because it is more conservative in assigning statistical groups and is analogous to a Tukey's test for one way ANOVA in that both procedures control the family-wise false positive rate (Westfall and Young 1993). Collection comparisons were presented using compact letter display tables, in which groups with different letters are significantly different at $p < 0.05$.

Provisional Categories

For total PCBs, we developed provisional categories based on a color scheme from highest to lowest: red, orange, yellow, and green (Table 5). The categories were intended to be relevant to RAO 1, i.e., reducing risks to people consuming game fish that feed on the forage fish. Progress towards RAO1 would occur if forage fish concentrations decline such that a particular location could be considered to have moved down a color category, such as from yellow to green. Ideally the thresholds dividing the categories would be based on a site-specific food chain model developed for MC and BK. Since the food chain model is still under development, (M. Bokare, University of Maryland Baltimore County (UMBC), personal communication), we relied on literature values. Thus, we used a species multiplier of 2 and the ratio between whole body PCBs and fillet PCBs in game fish of 2.5 (M. Bokare, UMBC, personal communication). Used together, there is a ratio of 0.8 between forage fish whole-body total PCBs (e.g., 50 ppb) and game fish fillet PCBs (40 ppb).

To develop the thresholds and categories, we used the game fish meal thresholds provided by MDE (Table 5) as a starting point. Thus, we estimated if game fish fed on whole body forage fish averaging 50-ppb total PCBs, the game fish fillet concentration would be 40-ppb. This is nearly equal to the 42.49 ppb MDE threshold that allows the general population to consume 4 meals per month (i.e., >42.49 means < 4 meals/month). Thus, MC and BK with <50 ppb were placed in the lowest risk green category. Higher color thresholds are yellow (≥ 50 to <200 ppb), orange (≥ 200 to <400 ppb), and red (≥ 400 ppb, Table 4) and consistent with more restrictive meal advisories. Currently data are inadequate to develop tissue-effect categories for MC and BK, which would be applicable to RAO 4 (i.e., fish health).

RESULTS

Samples, Collections, Lab-generated Duplicates, and Data Validation

Over the three years (2018–2020), there were 47 collections resulting in 216 samples and 1503 fish (Table 3, Appendices A and C). There were 28 BK collections resulting in 135 composite samples, containing a total of 987 individuals. There were 19 MC collections, resulting in 81 samples and 516 individuals. Banded killifish were collected from the tributaries, mainstem Anacostia, Kingman Lake and the Potomac. Mummichogs were collected from all areas except the Potomac River.

Relative percent difference (RPD) was calculated for the two lab-generated duplicates (11ABKL03-A and -B; A2BKF20L03-A, and -B) for total PCBs and total chlordane. The RPDs for the 11ABKL03 samples were 4.0 percent for total PCBs and 5.7 percent for total chlordane; for the A2BKF20L03 samples the RPDs were 5.7 percent for PCBs and 7.0 percent for

chlordan. The mean values (designated as 11ABKL03M and A2BKF20L03M) were used for all calculations. This level of precision is acceptable since it is below the ACF limit of 8.64 percent for samples well above the limit of detection (D. Homer, ACF, personal communication). The Data Validation reports (Appendix B) indicated that all samples were acceptable according to USEPA (2017) guidance.

Outliers

Based on lipid-adjusted means, there were three outliers for total PCBs in BK (LB2BKM20L01 (adjusted mean of 1207 ppb), LB2BKF20S01 (adjusted mean of 577 ppb), and P3BKM20L02 (adjusted mean of 688 ppb), and none in MC (Table 6). For total chlordan, there was one outlier for BK (LB2BKM20L01 adjusted mean of 221 ppb) and three outliers for MC—LB2MCF20S01 (adjusted mean of 133 ppb), LB2MCF20S02 (adjusted mean of 139 ppb), and LB2MCM20S03 (adjusted mean of 346 ppb).

Total PCBs and PCB TEQs

Raw data

Across the six tributaries, there was a 20-fold difference in mean total PCB concentrations in BK and a 15-fold difference in MC (Table 3, Figure 3). The highest were in samples from LB and for the locations that were sampled in both 2018 and 2020, LB1 and LB2, there were higher concentrations in 2018. In 2020, when an intermediate location (LB1.5) was sampled for the first time, BK mean total PCB concentrations were highest at LB2 (834 ± 239 ppb), somewhat lower at LB1 (588 ± 133 ppb), and lowest at LB1.5 (327 ± 110 ppb). The next highest tributaries were NR (2020 only: BK= 354 ± 32 ppb; ppb, MC= 308 ± 83 ppb) and WB (2018 only: BK= 272 ± 38 ppb; MC= 314 ± 79 ppb). The lowest mean total PCB concentrations for BK were from NW (54.0 ± 4.3 ppb in 2018) and NE (76.5 ± 9.3 ppb in 2018). For MC, the lowest mean total PCB concentration was from NE (47.9 ± 7.0 ppb in 2018).

In the mainstem Anacostia, the lowest total PCB concentrations were in the two most upstream locations, BL and DC, Table 3, Figure 4). Mean total PCBs ranged from 29.3 ± 13.2 ppb to 119 ± 50 ppb. At A2 just above the CSX Bridge, mean total PCBs ranged from 109 ppb to 320 ppb, with higher concentrations in BK vs. MC in both 2018 and 2020. In the lower Anacostia, at location 11A, BK total PCBs were similar in 2019 (193 ± 40 ppb) and 2020 (196 ± 92 ppb). At A1, we detected the highest mean total PCB concentrations in the mainstem Anacostia (458 ppb in 2018, with no samples in later years). In Kingman Lake, mean total PCB concentrations ranged from 181 ppb to 376 ppb range, with higher concentrations in BK vs. MC at locations where both were sampled.

In the Potomac River, low mean total PCB concentrations were reported at P4 in 2019 (29.3 ± 16.1 ppb) and 2020 (42.3 ± 2.6 ppb). Total PCBs at KB and P3 were higher and more variable. At KB, the mean in 2019 was 48.8 ± 22.6 ppb but was much higher in 2020 at 167 ± 62 ppb with a maximum of 276 ppb. Only one sample was collected at P3 in 2019 (89.5 ppb). The samples from 2020 were higher with a mean total PCB concentration of 238 ± 236 ppb, including a maximum of 688 ppb in P3BKM20L02, identified as an outlier. The mean total PCB concentration without the outlier was 148 ppb. The mean total PCB concentration in BK from Dyke Marsh was 95.5 ± 45.6 ppb (Table 3, Figure 5).

For all 216 samples, on a concentration basis dioxin-like congeners comprised a mean of 6.7 ± 1.9 percent of total PCBs. In the tributaries, mean PCB TEQs (based on TEFs of Van den Berg et al. 2006) ranged from 0.0065 ± 0.0012 in NWBK18 to 0.0751 ± 0.0184 ppb in LB1BK18 (Table 3). In the mainstem Anacostia, mean PCB TEQs ranged from 0.0089 ± 0.0043 ppb in BLMC20 to 0.0784 ± 0.0162 ppb in PCMC18. Kingman Lake samples ranged from 0.0286 ± 0.0045 ppb in KGMC20 to 0.0449 ppb from the single composite sample at KLBK18. For the Potomac, the lowest PCB TEQs were in P4 samples (P4BK19: 0.0040 ± 0.0043 ppb; P4BK20: 0.0085 ± 0.0012 ppb) and highest in P3BK20 samples (0.0573 ± 0.0606 ppb).

PCB homologs

There were substantial differences in mean PCB homolog patterns between the collections, with lower chlorinated homologs dominant at LB. For example, di- chlorinated homologs ranged from 1.1 percent to 4.7 percent in LB fish, 1.3 percent (MC) and 2.0 percent (BK) from NR, and less than 1 percent at all other tributary locations (total = sum of di- through octa-chlorinated homologs). At LB, MC and BK had primarily, di-, tri- and tetra- chlorinated homologs (Figure 6). The total of these three homologs was highest in LB2 samples (means of 67.9 percent to 70.2 percent), and less at LB1 (44.7 percent to 59.1 percent) and LB1.5 (39.5 percent), with similar distributions for BK and MC. A large contribution of these three homologs was also present in NR fish (49.8 percent in BK and 39.2 percent in BK). In all other tributaries, di-, tri- and tetra-chlorinated homologs accounted for 9.9 to 17.2 percent of total PCBs in forage fish. In those tributaries, penta- and hexa-chlorinated homologs were dominant.

In the mainstem Anacostia River, the di-, tri-, and tetra- chlorinated homologs comprised 8.8 percent to 30.3 percent of the total PCBs (Figure 7). In Kingman Lake, the range was 22.0 percent to 34.1 percent. In the Potomac, all collections except KBBK20 (26.4 percent) were in the 4 to 10 percent range (Figure 7).

Model results for location differences and effects of lipid

For BK, linear model results showed a strong collection effect on PCB concentrations ($p < 0.0001$) but a weaker positive effect of lipid as a covariate ($p = 0.15$; Table 7). Removing the three outliers, the collection effect p value was still < 0.0001 , but the lipid relationship was stronger with a new p value of 0.0002. As noted, the comparisons are based on the model that included the outliers. The highest concentration statistical group (Group A) consisted of LB1BK18 (adjusted mean of 1104 ppb) and LB2BK18 (911 ppb, Table 8), which were significantly higher than all other collections. For 2020, LB2BK was in groups A and B and LB1BK was in group B only. There were many overlapping groups for collections with adjusted mean total PCB concentrations ranging from 64.7 ppb to 480 ppb. The following collections were in (the lowest concentration) Group D: KBBK19 (52.4 ppb), NWBK18 (50.7 ppb), P4BK19 (30.2 ppb), and P4BK20 (14.7 ppb).

For MC, collection was significant at $p < 0.0001$; lipid content had a significant positive effect ($p = 0.007$, Table 7). Model-based results for MC, yielded four groups (Table 9) with the highest (A group) consisting of the 2018 collections at LB1MC (735 ppb) and LB2MC (715 ppb). For 2020, LB2 was in groups A and B (585 ppb) and LB1 was in both groups B and C at 361 ppb. MC from Pepco Cove in 2018 had an adjusted mean total PCB estimate of 466 ppb and was in the B group, statistically different from PCMC19 (C group) at 282 ppb; PCMC20 was in both B

and C groups at 327 ppb. The following collections were in group D only: DCMC20 (125 ppb), BLMC20 (82.7 ppb), HRMC18 (70.0 ppb), NEMC18 (59.6 ppb), and BLMC18 (45.7 ppb).

For the combined species model (Table 7) there was a significant location/year effect ($p < 0.0001$), a p value of 0.08 for a positive lipid effect, but little effect for species ($p = 0.65$). With the outliers removed, the p values were < 0.0001 for location/year, 0.0003 for lipid, and 0.084 for species. Using the combined species model (Table 7), with the outliers included, statistical groups (Table 10) were similar to those for the single species models (Tables 8 and 9). Thus, in the combined species model, LB1 (888 ppb) and LB2 (817 ppb) in 2018 were in Group A, significantly different from all other location/years. The lowest concentration group included five of the seven Potomac collections: DM20 (59.2 ppb), P319 (42.2 ppb), with KB19, P419, P420 all estimated at less than 0 ppb. Two tributary collections, NE18 (48.7 ppb) and NW18 (< 0 ppb), and one mainstem location/year (BL20 at 71.0 ppb) were in the lowest concentration group (Table 9).

Model results for effects of sex

For BK, the model results indicated that sex ($p = 0.0077$) was a significant covariate, with males having an overall average lipid-adjusted total PCB concentration 64 ppb higher than females. This relationship, however, was not consistent across locations, with males higher at ten locations and females higher at three. There were large differences at two locations. At LB2, males had an adjusted mean of 975 ppb with females at 762 ppb. In contrast, at PC the average for females (539 ppb) was higher than that for males (311 ppb). For MC, the model was not significant for sex ($p = 0.62$); males were higher at five locations and females were higher at four.

Provisional thresholds

Based on lipid-adjusted total PCBs, there were six red category (> 400 ppb) location/years including several LB1 and LB2 collections, PC18, and PC20 (Table 11). There were no red category location/years in the other tributaries, Kingman Lake, or any other mainstem locations. There were nine orange category (200 to 400 ppb) location/years spread among the mainstem, tributaries, and Kingman Lake. For the yellow category (50 to 200 ppb), there were ten location/years including the mainstem, tributaries, Kingman Lake, and Potomac (P320, KB20, and DM20). The following six location/years were in the green category (< 50 ppb): NE18, NW18 and Potomac collections KB19, P319, P419, and P420.

Total Chlordane

Raw data

In the tributary collections, mean total chlordane concentrations had a six-fold difference between the highest and lowest locations (Table 3, Figure 8). The highest concentrations were reported from NE, NW, and LB2. For BK, the range was from 51.6 ± 19.0 ppb at LB1.5BK20 to 174 ± 49 ppb at LB2BK20. For MC, the range in the tributaries was from 32.2 ± 16.1 ppb at LB1MC20 to 199 ± 85 ppb at LB2MC20. NE and NW total chlordane concentrations ranged from 102 ± 31 ppb for NEMC18 to 165 ± 40 ppb for NWBK18.

In the mainstem and Kingman Lake BK mean total chlordane concentrations (Table 3, Figure 9) ranged from 53.9 ± 18.4 ppb in KGMC20 to 218 ± 12 ppb at A1BK18. For MC, the range was from 25.9 ± 4.1 for BLMC20 to 66.0 ± 23.0 ppb for BLMC18. In the Potomac River, where only

BK were collected, mean total chlordane concentrations ranged from 17.7 ± 7.1 ppb for DMBK20 to 91.8 ± 9.3 ppb for KBBK20 (Table 3, Figure 10).

Model results for location differences and effects of lipid

Model-based results for total chlordane (Table 12) were similar for BK with and without the single outlier (LB2BKM20L01, 221 ppb) with both collection and a positive lipid coefficient significant at $p < 0.0001$. For MC, removal of the three outliers (Table 6) reduced the p value for positive lipid effect from 0.0031 to < 0.001 . For the combined species model with and without outliers, the model yielded p values of < 0.0001 for collection, lipid, and species.

For BK, there were four statistical groups (Table 13) with A118BK (197 ppb), NW18 (161 ppb), and LB2MC20 (159 ppb) in the highest group. There were multiple collections in overlapping statistical groups. The lowest concentration group (D) consisted of P3BK20 and P4BK20, both with adjusted mean concentrations of less than zero.

For MC, there were only two statistical groups (Table 14), with LB2BK20 in the highest concentration (A) group, adjusted mean total chlordane concentration of 170 ppb. NEBK18 was in both A and B groups at 107 ppb. All other collections were in the B group, ranging from 32.7 ppb in HRMC18 to 91.8 ppb in LB2MC18.

With the combined species model, there were four statistical groups (Table 15) with A118 (185 ppb) and LB220 in the highest (A) group. Two location/years were in the AB groups: NW18 (148 ppb) and NE18 (130 ppb). The lowest group (D) consisted of three Potomac collections: KB19 (13.9 ppb), P420 (0 ppb), and P320 (0 ppb).

Model results for effects of sex

For BK, the model results indicated that location ($p < 0.0001$), sex ($p < 0.0001$), lipid ($p < 0.0001$), and location/sex interaction ($p = 0.0001$) were significant covariates with males having average total chlordane concentrations 23 ppb higher than females. This relationship was not consistent across locations with males higher at eight, females higher at three, and two locations within 2 ppb. For MC, both sex and the location–sex interaction were not significant covariates, with males having higher concentrations at five locations, females at two locations, and means within 2 ppb at two locations (see Appendix D).

Human health risk apportionment for PCBs and organochlorine pesticides

Using the DNREC/DHSS (2017) approach, PCBs were determined to be the major risk driver across all locations (Table 4), with an overall average of 91.9 percent of cumulative risk for the 47 collections. The three collections with the lowest risk attributed to PCBs were NEBK18 (64.6 percent), NEMC18 (59.8 percent), and NWBK18 (58.7 percent), all of which had low mean total PCB concentrations. In nearly all collections, more than three quarters of the risk attributed to PCBs was due to dioxin-like congeners (Table 4). One location, LB2, had a different allocation, with only 54.4 percent to 65.5 percent attributed to dioxin-like congeners.

For the OC pesticides, dieldrin was the greatest contributor to cumulative risk at an average of 5.8 percent (Table 4). Heptachlor epoxide ranked second at 1.5 percent, followed by chlordane at 0.6 percent, and DDT at 0.2 percent.

DISCUSSION

PCBs in Forage Fish from Anacostia Tributaries

The highly elevated total PCB concentrations in LB forage fish compared with NW, NE, WB, and HR was consistent with previous data for freshwater mussels, surface water, pore water, surface sediment, and suspended sediments (The Johnson Company 2019; Wilson 2019, Ghosh et al. 2020). Those studies did not include NR. The ranking of the five major tributaries in forage fish for total PCBs—LB1&LB2>WB>HR>NE=NW—was similar to that in suspended sediment concentrations in 2017 (Wilson 2019) with HR and WB reversed. The rankings for pore water and surface water total PCB concentrations were LB1&LB2>WB>HR=NW=NE (Ghosh et al. 2020). In 2016 and 2017 sampling, surface water total PCB concentrations in LB were 7 to 77 times those in NW and NE; in pore water LB concentrations were 9 to 66-fold higher. The same elevation in LB was observed by Ghosh et al. (2020) for 2016 and 2017 deployments of caged Eastern Elliptio (*Elliptio complanata*).

Within LB, concentrations were highest in fish collected close to sources areas currently being investigated by MDE: Joseph Smith & Sons Scrap Yard adjacent to LB1 (~ 0.8 km (0.5 mi) upstream from the mouth of the Creek) and unknown sources along Pennsy Drive, about 0.3 km (0.2 mi) upstream of LB2 (4.8 to 5.1 km (3.0 to 3.2 mi) from the Creek mouth). Somewhat lower total PCB concentrations were determined in BK from an intermediate location, LB1.5 (1.3 km (0.8 mi) upstream of LB1 and 2.4 km (1.5 mi) downstream of LB2). Higher total PCB concentrations near LB1 and LB2, and lower concentrations near LB1.5 were also reported in the Ghosh et al. (2020) passive sampler and mussel deployments.

A similar geographic pattern was also reported in surface sediments collected in 2019 and 2020 by MDE (2021). Total PCBs were 2510 ppb at the upstream edge of LB2, 21 ppb near LB1.5, and 2410 ppb at the upper edge of LB1. MDE concluded that these two reaches (near LB1 and LB2) were near source areas that warranted further investigation, which is continuing. A similar pattern in surface sediment was reported by The Johnson Company (2019) in 2018 samples in approximately the same areas, although concentrations were far lower.

The similarities in concentration and homolog distributions in forage fish with those for deployed freshwater mussels and passive samplers support the concept of tributary-specific populations of MC and BK. Furthermore, the similarities in the geographic pattern of total PCB concentrations in LB sediments and forage fish support the concept there is some overlap in fish populations between LB1 and LB1.5, but little overlap between LB2 and the other two LB locations. The distance between LB1 and LB1.5 is about 1.3 km (0.8 mi) and between LB1.5 and LB2 about 2.4 km (1.5 mi). PCB homolog patterns are similar in LB1 and LB1.5 and very different in LB2 (see Figure 6). These observations are consistent with the home range estimate of about 0.8 km (0.5 mi).

In addition to concentration data, patterns in the contribution of PCB homologs to total PCBs can be used as a tracer. Since the lower chlorinated congeners are more water soluble, more volatile, and more likely to biodegrade (Beyer and Biziuk 2009), their presence in water, sediments, and biota provides evidence of current or recent PCB sources (U. Ghosh, UMBC, personal communication). The dominance of lower chlorinated homologs in forage fish from all three LB locations compared to other tributaries was also observed in caged *Elliptio complanata* mussels

and passive samplers deployed at the same NW, NW, LB1, LB1.5, LB2, HR, and WB locations in 2016 and 2017 by Ghosh et al. (2020). They reported the combined percent of di, tri, and tetra homologs in mussels was 35.7 to 63.0 percent in the three LB locations compared with 6.3 to 21.1 percent in the other tributaries. Surface water passive samplers had di through tetra homologs comprising 89.7 to 97.3 percent in the three LB locations compared with 38.3 percent to 60.1 percent in the other tributaries. A similar pattern was reported for the pore water passive samplers (see Table S-1 for a full listing of homolog distribution for all media). Thus, both the concentration and homolog data in the current study and their consistency with abiotic and biotic media serve as a weight of evidence (see Menzie et al. 1996) implicating LB as containing one or more sources of current (and bioavailable) PCBs.

Lower Beaverdam Creek, the only tributary where BK and MC sampling was conducted in both 2018 and 2020, tended to have lower concentrations in 2020. These were apparent in both the raw data (Figure 3) and the lipid-adjusted means (Tables 7-9). Statistically significant decreases occurred for both species at LB1, whereas the differences were not significant at LB2. The homolog distributions between 2018 and 2020 collections were similar for both species, however, which suggests that they were still being exposed to the lower chlorinated homologs. Further sampling is needed to track whether this decrease will be sustained.

PCBs in Forage Fish from the Mainstem Anacostia, Kingman Lake, and Potomac River

The relatively low total PCB concentrations in forage fish from the upstream (Maryland) tidal Anacostia appear to reflect the low forage fish concentrations in NW and NE as well as the low PCB loadings from these tributaries. Sampling in the mainstem Anacostia just below the mouth of Lower Beaverdam Creek will add data on the effects of LB loading; a small sampling effort was completed in the fall of 2021 and awaits analysis.

For the remainder of the ambient locations in the mainstem Anacostia, there was no clear upstream to downstream pattern. Nor was there a pattern in concentrations across time. The only location with a statistically significant difference between years was Pepco Cove (MC only). Lipid-adjusted MC concentrations were significantly higher in 2018 vs. 2019; 2020 concentrations however were not statistically different from 2018 or 2019.

In Kingman Lake samples, there was also a wide range of total PCB concentrations, from the mean concentration of 181 ppb at KHMC20 to 376 ppb in the single sample at KLBK18. It is difficult to evaluate year to year changes because the KL location, which was difficult and time consuming to sample was replaced by the two other locations. Repeat sampling at KG and KH is advised for the year before remediation.

For the Potomac, BK samples at Dyke Marsh, which is a protected area, were 95.5ppb mean total PCBs, and continued sampling would provide regional context for the monitoring. By far the consistently lowest mean total PCB concentrations were near Fletchers Cove (P4), the most upstream location. Both sides of this area of the river have forested buffers and are protected natural areas. In contrast, the downstream sampling areas (KB and P3) are more urbanized. There are two combined sewer outfalls (CSOs) north of Key Bridge near KB and five south of Key Bridge across from Theodore Roosevelt Island (P3). Modeling for the tidal Potomac and Anacostia River Total Maximum Daily Load (TMDL; Haywood and Buchanan 2007) determined that CSOs contribute about 8 percent of the loading. No PCB concentration data,

however, were identified for the Potomac CSOs. We anticipate a decreased loading of raw sewage and runoff in general in this area through the DC Water Long Term Control Plan (DC Water 2015). For the Potomac, the plan includes Green Infrastructure, separation of CSOs, and construction of a tunnel to reduce overflows, with completion scheduled for 2027.

Total Chlordane in All Locations

For the tributaries, the highest total chlordane concentrations in forage fish were found in the same three tributaries that contributed the bulk of the 2017 chlordane loadings: NE (38 percent), NW (28 percent), and LB (28 percent; Wilson 2019). Within LB, mean chlordane concentrations were far higher at LB2 (97.3 to 199 ppb) compared with LB1.5 (51.6 ppb), and LB1 (32.2 to 105 ppb). Ghosh et al. (2020) also reported a similar pattern in which total chlordane concentrations in deployed freshwater mussels were twice as high in LB2 compared with LB and LB1.5. These authors, however, did not report substantially higher total chlordane concentrations in pore water or surface water samples in LB2, compared with LB1 or LB1.5. Current MDE-led investigations in Lower Beaverdam Creek are focused on determining possible contaminant sources, with a focus on areas near LB1 and LB2.

For the mainstem Anacostia and Kingman Lake, there was a narrow range of mean total chlordane concentrations in MC and BK (25.9 ppb to 120 ppb), with one exception (218 ppb at A1, near Poplar Point). Potomac forage fish samples were consistently low in total chlordane (<35 ppb), at all locations except KB. At that location, there were higher mean concentrations in 2020 (98.9 ppb) vs. 2019 (29.1), but lipid-adjusted means were not significantly different.

Uncertainties

In any monitoring program, there is a conflict between sampling effort in terms of labor and analytical cost and the desire for greater statistical power to detect differences across space and time. In addition, regulatory agencies must consider the health of the species and may be reluctant to issue permits for thousands of fish to be collected and sacrificed. The availability of technicians affects the sampling schedule. In this study, in 2018 all samples were collected in September and October. In 2019, fish were obtained from late June through August; and in 2020 from late June through early November. Mummichogs spawn on a lunar cycle in late spring through early September in Maryland tidal waters (L. Yonkos, University of Maryland, personal communication). The spawning behavior of banded killifish in mid-Atlantic streams has not been documented in the literature. Thus, it is possible that seasonal differences may have affected contaminant concentrations over the course of the study.

Model uncertainties are reflected in some of the changes in the model parameters resulting from the elimination of the outliers (three for total PCBs, four for total chlordane). In most cases, removing outliers strengthened the positive relationship between lipid and contaminant concentrations. Six of the seven outliers were from LB2, which is under investigation as a source area by Maryland Department of Environment (E. Green, personal communication). It is possible that several of these fish may be feeding to a large extent in one or more hot spot areas.

Uncertainties are present in the development of the provisional forage fish thresholds. Completing the food chain model will improve the estimated relationships between forage fish and game fish concentrations. In addition, the generic whole body: fillet ratio of 2.5 (M. Bokare,

UMBC, personal communication) will be refined after 2021 Anacostia River whole body and fillet samples of game fish are analyzed (DOEE-funded work in progress). The calculations are based on the assumption that the public is following the DC Fish Consumption Advisory https://doee.dc.gov/sites/default/files/dc/sites/ddoe/service_content/attachments/Fish%20Consumption%20Advisory%202016.pdf which recommends that consumers discard the inner organs, skin the fish, trim away the fat, and discard the belly flap. It is possible that some cooks will disregard the advice and prepare the fish without removing the skin, fat, and belly flap.

Forage Fish Monitoring Recommendations

Species, Size, and Sex

MC and BK are appropriate species because of their small home range, ~3- to 4-year lifespan, and wide distribution throughout the Anacostia mainstem, tributaries, Kingman Lake, and Potomac River. Because sex was not a significant covariate that resulted in consistent differences between males and females, the added sampling effort to collect single sex composite samples is not warranted and should not be continued.

The only area where these species are difficult to locate is Washington Channel which has little shallow water habitat. CBFO's fall 2021 efforts using boat electroshocking and minnow traps were not successful in obtaining BK or MC. Since there is a need for forage fish monitoring of the remediation, the site-specific work plan for Washington Channel will require biologists to identify one or more species (at appropriate sizes) that do not move outside of the waterbody. Perhaps young of the year sunfish such as bluegills may be available in sufficient number. The site-specific plan would include identifying the same species in the designated reference locations.

Background/Reference Areas

For the ARSP, Tetra Tech (2019a) used the reach of the tidal Potomac River between Key Bridge and Chain Bridge as a background area for sediment contaminant analyses and toxicity tests. Thus, for the Potomac, we sampled in two locations within that reach (P4 and KB), just downriver of the reach (P3), and at DM, about 5 km (3 mi) below the Woodrow Wilson Bridge. Our results for P4 clearly indicate its suitability as total PCB concentrations in both years were less than 50 ppb, our provisional threshold to define the green or cleanest category. The more variable concentrations at KB (within the reach) are in the green (39.3 ppb, 2019) and yellow (151 ppb, 2020) categories, possibly influenced by the urban nature of the area near Key Bridge that includes two CSOs. Based on the sampling results, we recommend the area near Fletchers Cove as a suitable background area for portions of the Study Area.

Two Anacostia tributaries, Northwest Branch and Northeast Branch, are suitable background areas for monitoring forage fish in relation to source control efforts in Lower Beaverdam Creek. . In addition to monitoring forage fish in NW and NE, we recommend evaluating suspended sediment concentrations and freely dissolved concentrations at the gage stations as a method of tracking the loadings to the lower river.

Two mainstream Anacostia locations—across from the mouth of Dueling Creek and Bladensburg—should be considered as possible background areas for site-specific work plans.

Both locations are upstream of the mouth of Lower Beaverdam Creek such that total PCB concentrations may be largely reflective of the influence of NW and NE.

Analytes

Selection of analytes for a monitoring program is based on balancing information needs with cost considerations. The goal is to select analytes as *indicators* that are vital for the Adaptive Management process, not to select all COCs. The IROD (page 4) states, “Performance monitoring activities will include key indicators for assessing progress toward the RAOs, monitoring and sampling activities, data interpretation methods, criteria that will indicate attainment or nonattainment of an RAO, and potential follow-on actions in the EAAs or other locations in the river.”

In this report, we chose to analyze three of the four COCs, with an emphasis on total PCB congeners as the major risk driver and the COC used to delineate the EAAs. To determine whether this approach is appropriate for pre- and post-remedial monitoring, we applied the DNREC/DHSS (2017) risk apportionment approach. Since dioxins and furans were not measured in the current study, we evaluated the Tetra Tech (2019a, Appendix K) RI whole body and fillet fish data. All duplicate and triplicate samples from a single location were averaged. To simplify the calculations, we estimated that dioxin-like congeners comprise 10 percent of total PCBs in each sample. This estimate is consistent with the findings of Bhavsar et al. (2007) who reported an average of 8.5 ± 5.4 percent of total PCBs in 912 fillet samples of 22 game species from the Great Lakes. It is also consistent with the current study mean of 6.7 ± 1.9 percent for dioxin-like PCBs in whole body samples.

After averaging duplicates and triplicates from the same location, we apportioned risk (Table 16) for the RI fillet data (n=18) and the 2014/2015 (n=122) and 2016 (n=38) whole body data from Appendix K. For the fillet data, PCBs contributed an average of 86.2 percent of cumulative risk, dioxins and furans (as TEQs) contributed 8.8 percent, and total chlordane 5.0 percent. For the 2014 and 2015 whole body data, PCBs contributed 96.5 percent, dioxins and furans 2.4 percent, and chlordane 1.1 percent. For the 2016 whole body data, PCBs contributed 84.8 percent, dioxins and furans contributed 9.6 percent, and total chlordane contributed 5.7 percent

These 2014 through 2016 samples include total PCB concentrations ranging from 33.3 to 1858 ppb (Table 16). Regarding dioxin and furan apportionment, we found that 15 of the 160 samples had an apportionment of 10.0 percent or greater, with none of these having a total PCB concentration above 271 ppb. Thus, it appears that the contribution of dioxin to total human health risk is not a major factor with the more highly PCB-contaminated fish. The Delaware fish tissue advisories, DNREC (2017, J. Cargill, personal communication) list only chemical classes responsible for at least 10 percent of cumulative risk as risk drivers. Using that procedure and the average risk apportionment for the fillet and whole body RI data, only total PCBs would be listed as risk drivers. Adding dioxins and furans would more than double the per sample cost (N. Corso, SGS AXYS, personal communication). We conclude that the low contribution of dioxins and furans to cumulative risk does not merit their added cost.

Although chlordane is the only OC pesticide listed in the IROD, in the current study we determined that a greater percentage of average cumulative human health risk is attributable to

dieldrin (5.8 percent), and heptachlor epoxide (1.5 percent) compared with chlordane (0.6 percent; Table 4). Thus, we recommend measuring *all* OC pesticides for assessing risk and communicating relevant results to the scientific community. We note that there is no added analytical cost for measuring all OC pesticides versus chlordane alone (N. Corso, SGS AXYS, personal communication).

Numbers of samples

We conducted a power analysis with computer simulation (Arnold et al. 2011) to determine the number of samples needed to detect decreases of 25 percent, 50 percent, and 75 percent in forage fish PCB concentrations at a particular location. The current data allow us to estimate the variance parameters for the simulation. The data for each location were combined across years with separate analyses conducted for each species. Using the Pre and Post data, an analysis of covariance was conducted where the factor variables are Location and Before/After remediation and the covariate is lipid content (standardized with 0 as the overall mean content). The post-remediation PCB standard deviations were simulated to be equal to those for pre-remediation levels by location. For each location, post-remediation lipid content was simulated to have the same mean and standard deviation as pre-remediation content. Power was determined for post-remediation sample sizes of 3, 5, 10, and 15 uniformly across locations. Analysis of covariance was performed for each set of simulated data and pre to post comparisons were computed using the expected marginal means within location adjusting to the mean lipid content. This pre to post comparison was done using the Holm (1979) procedure which adjusts the significance level for multiple comparisons across all locations. The simulation was repeated 1000 times and power computed as the proportion of the 1000 simulations that resulted in statistically significant differences for each test procedure by location. Power was determined using $\alpha=0.05$ and $\alpha=0.10$.

Sample size recommendations for future pre- and post-remedial monitoring (Tables 17, 18, and 19; Appendix D) revealed that the ability to detect a statistically significant decrease was strongest at the highest total PCB concentrations. This is logical in that a 25 percent decrease from 800 ppb is a decrease of 200 ppb, where a 25 decrease from 80 ppb is only 20 ppb. For BK at LB2 (average lipid-adjusted mean of 875 ppb total PCBs), a 25 percent difference can be detected (all results presented here with 80 percent power, $\alpha=0.05$) with a sample size of 15. A 50 percent difference for LB2BK can be detected with a sample size of 5. For DM, with an average total PCB concentration of 95.4 ppb, there is 0 power to detect even a 75 percent change with a sample size of 15. These results can be used in developing site specific pre-and post-remedial sampling plans. It would be most efficient to collect about 5 samples per species at locations with low total PCBs and about 10 or 15 per species at those with moderate and high total PCBs. The designations of low, moderate, and high would be based on the current results, acknowledging that concentrations can change over time.

Assessing Fish Health

Monitoring forage fish has the potential to help address RAO 4—Reduce risks associated with COCs in surface sediment to levels protective of fish based on direct contact with and ingestion of surface water, sediment, and prey. Lacking site-specific data, currently we rely on the work conducted by Berninger and Tillitt (2019) who performed a meta-analysis of PCB-induced adverse effects data in many fish species to develop tissue concentration-based effects

thresholds. The endpoints were increased mortality, decreased reproduction, and impaired growth, all of which can result in deleterious effects on fish populations. The authors used 31 studies to perform regression analyses. Two of the studies in the database used MC whereas none used BK. Both MC studies estimated rather than measured whole body residues. In one study, fish were dosed by injection. Because of these uncertainties, we relied on the regression equations developed for all species.

The regressions predicted that a whole-body total PCB concentration of 100 ppb would not result in increased mortality, but was associated with a 6 percent decrease in growth, and a 27 percent inhibition of reproduction. Total PCBs at 500 ppb would result in a 10 percent increase in mortality, a 12 percent inhibition of growth, and 35 percent inhibition of reproduction. A whole body residue of 1000 ppb would result in a 17 percent increase in mortality, a 15 percent inhibition of growth, and a 39 percent inhibition of reproduction. This concentration range (100 to 1000 ppb) overlaps with total PCB concentrations detected in many of our collections. Based on the tissue-effects database, our greatest likelihood of adverse effects would be in Lower Beaverdam Creek fish. Of the three endpoints, the greatest concern is for inhibition of reproduction.

We recommend site-specific investigations of MC and BK as possible fish health indicator species to monitor progress towards RAO 4. Pilot studies in progress are comparing liver and gonad histopathology in 2020 MC and BK samples from Lower Beaverdam Creek (high PCBs) and Bladensburg (low PCBs; V. Blazer, USGS, personal communication). We are also conducting pilot embryo larval sediment toxicity tests, based on USEPA (2002b) with fertilized MC and sheepshead minnow (*Cyprinodon variegatus*) eggs at these locations (L. Yonkos, University of Maryland College Park, personal communication). The tests compare the effects of site sediments on hatching success, larval length, and prevalence of abnormalities. Depending on the ongoing study results, these or other procedures related to fish health should be considered for inclusion in the forage fish monitoring program.

Monitoring Schedule and Timing of Sampling

Forage fish monitoring of PCBs and OC pesticides can be applied at Early Action Areas and PECS locations as well as Lower Beaverdam Creek, identified as a continuing source of PCB loading. The studies aimed at tributary inputs should include the tributary background locations (NE and NW) and BL, DC, and just below the mouth of Lower Beaverdam Creek to determine the impact of tributary sources on mainstem forage fish. Before and after monitoring should be planned for Pepco Cove, other PECS locations that are PCB and OC pesticide sources, and EAA areas. The schedule would depend on the timing of the remediation and source control actions and the 3- to 4-year lifespan of the forage fish. For example, if a sediment cleanup at an EAA is conducted and completed in the summer of 2023, pre-remedial monitoring should occur in fall 2022 and be repeated in fall 2027 and fall 2028. Fish become difficult to collect in the winter when water temperatures are low. We would like to avoid the possible influence of fish being in spawning condition. Thus, we recommend a 2-month window from mid-September to mid-November for having successful collections with less likelihood that fish are still spawning.

REFERENCES

- Abraham, B.J. 1985. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (mid-Atlantic): Mummichog and striped killifish. U.S. Army Corps of Engineers, Biological Report 82(11.40). 23 p.
- American Veterinary Medical Association (AVMA). 2013. AVMA Guidelines for Euthanasia in Animals —2013 Edition. AVMA, Schaumburg, IL.
- American Veterinary Medical Association (AVMA). 2020. AVMA Guidelines for Euthanasia in Animals —2020 Edition. AVMA, Schaumburg, IL.
<https://www.avma.org/sites/default/files/2020-02/Guidelines-on-Euthanasia-2020.pdf>
- Arnold, B.F., D.R. Hogan, J.M. Colford Jr, and A.E. Hubbard. 2011. Simulation methods to estimate design power: an overview for applied research. *IBMC Medical Research Methodology* 11:94; 10 p.
- Benjamini, Y. and Y. Hochberg. 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society, Series B* 57:289–300.
- Berninger, J.P. and D.E. Tillitt. 2019. Polychlorinated biphenyl tissue-concentration thresholds for survival, growth, and reproduction in fish. *Environmental Toxicology and Chemistry* 38:712–736.
- Beyer, A. and M. Biziuk. 2009. Environmental fate and global distribution of polychlorinated biphenyls. *Reviews of Environmental Contamination and Toxicology* 201:137–158.
- Bhavsar, S.P., R. Fletcher, A. Hayton, E.J. Reiner, and D. A. Jackson. 2007. Composition of dioxin-like PCBs in fish: an application for risk assessment. *Environmental Science and Technology* 41:3096–3102.
- Black, D.E., R. Gutjahr-Gobell, R.J. Pruell, B. Bergen, L. Mills, and A.E. McElroy. 1998. Reproduction and polychlorinated biphenyls in *Fundulus heteroclitus* (Linnaeus) from New Bedford Harbor, Massachusetts, USA. *Environmental Toxicology and Chemistry* 17:1405–1414.
- Blazer, V.S. 2002. Histopathological assessment of gonadal tissue in wild fishes. *Fish Physiology and Biochemistry* 26:85-101.
- Blazer, V.S., S.D. Rafferty, P.C. Baumann, S.B. Smith, and E. C. Obert. 2009. Assessment of the “fish tumors or other deformities” beneficial use impairment in brown bullhead (*Ameiurus nebulosus*): II. Liver neoplasia. *Journal of Great Lakes Research* 35:527-537.
- Buckman, K.L., R. P. Mason, E. Seelen, V.F. Taylor, P.H. Balcom, J. Chipman, and C.Y. Chen. 2021. Patterns in forage fish mercury concentrations across Northeast US estuaries. *Environmental Research* 194:110629.
- DC Water 2015. Clean Rivers Project Long Term Control Plan modifications for Green Infrastructure. Prepared by Program Consultants Organization, Washington, DC. 890 p.
- Delaware Department of Natural Resources and Environmental Control (DNREC) and Department of Health and Social Services (DHSS) Delaware Fish Contaminants Committee

- (2017). Technical Procedures for Evaluating Human Health Risks Associated with the Consumption of Chemically Contaminated Fish and Shellfish, Dover, DE. 43 p.
- Department of Energy and Environment (DOEE). 2020. Interim Record of Decision (ROD). Early Action Areas in the main stem, Kingman Lake, and Washington Channel. Anacostia River Sediment Project, Department of Energy and Environment, Washington, DC.
- Fritz, E.S. and E.T. Garside. 1975. Comparison of age composition, growth, and fecundity between two populations each of *Fundulus heteroclitus* and *F. diaphanus* (Pisces: Cyprinodontidae). *Canadian Journal of Zoology* 53:361–369.
- Gewurtz, S.B., S.P. Bhavsar, and R. Fletcher. 2011. Influence of fish size and sex on mercury/PCB concentration: Importance for fish consumption advisories. *Environment International* 37:425–434.
- Ghosh, U., N. Lombard, M. Bokare, A. Pinkney, L. Yonkos, and R. Harrison. 2020. Passive samplers and mussel deployment, monitoring, and sampling for organic constituents in Anacostia River tributaries: 2016-2018. Year 2 Final Report (January 2020). University of Maryland Baltimore County, U.S. Fish and Wildlife Service, University of Maryland College Park. Report to District of Columbia, Department of Energy and Environment, Washington, DC.
- Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold, New York. 320 p.
- Government of the District of Columbia, Department of Consumer and Regulatory Affairs. 1989. Public Health Advisory. Commissioner of Public Health urges limited consumption of Anacostia and Potomac River catfish. New Release, July 31, 1989.
- Haywood, C.H. and C. Buchanan. 2007. Total maximum daily loads of polychlorinated biphenyls (PCBs) for tidal portions of the Potomac and Anacostia rivers in the District of Columbia, Maryland, and Virginia. Interstate Commission on the Potomac River Basin. ICPRB Report 07-7. Rockville, MD. October 2007.
- Holm, S. 1979. A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics* 6:65–70.
- Johnson Company, 2019. NPS Tributary Sediment Sampling Study Report, Anacostia River Sediment Project Site, National Capital Region. Prepared for the National Park Service, National Capital Region, Washington, DC. September 2019.
- Lotrich, V.A. 1975. Summer home range and movements of *Fundulus heteroclitus* (Pisces: Cyprinodontidae) in a tidal creek. *Ecology* 56:191-198.
- Maryland Department of Environment (MDE). 2021. Technical Memorandum: 2020 Sampling Report Lower Beaverdam Creek Polychlorinated Biphenyl (PCB) Source Trackdown Study Land Restoration Program, Baltimore, MD. June 2021.
- Menzie, C., M.H. Henning, J. Cura, K. Finkelstein, J. Gentile, J. Maughan, D. Mitchell, S. Petron, B. Potocki, S. Svirsky, and P. Tyler. 1996. Special report of the Massachusetts weight-of-evidence workgroup: A weight-of-evidence approach for evaluating ecological risks. *Human and Ecological Risk Assessment* 2: 277-304.

- Phillips, E.C., Y. Ewert, and P.S. Speares. 2007. Fecundity, age and growth, and diet of *Fundulus diaphanus* (banded killifish) in Presque Isle Bay, Lake Erie. *Northeastern Naturalist* 14: 269-278.
- Pinkney, A.E. 2014. Analysis of contaminant concentrations in fish tissue collected from the waters of the District of Columbia. U.S. Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD. Final Report. CBFO-C14-03.
- Pinkney, A.E. 2018a. Contaminant concentrations in fish tissue collected from the waters of the District of Columbia: 2017-2018. U.S. Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD. CBFO-C18-02.
- Pinkney, A.E. 2018b. Quality Assurance Project Plan. Analysis of polychlorinated biphenyls and organochlorine pesticides in whole body samples of mummichog and killifish from the Anacostia and Potomac River watersheds: 2018-2019. U.S. Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD.
- Pinkney, A.E. and U. Ghosh. 2021. Strategic Approach for Baseline and Performance Monitoring and Refining the Conceptual Site Model for the Anacostia River Sediment Project. (Draft). Prepared for District of Columbia Department of Energy and Environment, Washington, DC.
- Pinkney, A.E. and J.C. Harshbarger. 2006. Tumor prevalence in mummichogs from the Delaware Estuary watershed. *Journal of Aquatic Animal Health* 18:244-251.
- Pinkney, A.E. and P.C. McGowan. 2006. Use of the p,p'-DDD: p,p'-DDE concentration ratio to trace contaminant migration from a hazardous waste site. *Environmental Monitoring and Assessment* 120:559-574.
- R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Rao, C. R. 1973. Linear Statistical Inference and Its Applications, 2nd Ed. John Wiley & Sons, New York. 625 p.
- Sadraddini, S., M.E. Azim, Y. Shimoda, S.P. Bhavsar, K.G. Drouillard, S.K. Backus, and G.B. Arhonditsis. 2011. A Bayesian assessment of the PCB temporal trends in Lake Erie fish communities. *Journal of Great Lakes Research* 37:507-520.
- Teo, S.L.H. and K.W. Able. 2003. Habitat use and movement of the mummichog (*Fundulus heteroclitus*) in a restored salt marsh. *Estuaries* 26:720-730.
- Tetra Tech 2019a. Remedial Investigation Report. Anacostia River Sediment Project, Washington, D.C. Prepared for Government of the District of Columbia, Department of Energy and Environment. Tetra Tech. Chantilly, VA.
- Tetra Tech 2019b. Focused Feasibility Study Report, Early Action Areas in Main Stem, Kingman Lake, and Washington Channel, Anacostia River Sediment Project, Washington DC, prepared for the District Department of Energy and Environment, December.
- Tetra Tech 2019c. River-wide Feasibility Study Report, Anacostia River Sediment Project, Washington DC, prepared for the District Department of Energy and Environment, December.

- Tetra Tech 2022. Anacostia River Sediment Project, Baseline and Performance Monitoring Work Plan. Prepared for the District Department of Energy and Environment, January.
- U.S. Environmental Protection Agency (USEPA) 2000. Guidance for assessing chemical contaminant data for use in fish advisories, Volume 1, Fish sampling and analysis, third edition. EPA 823-B-00-007, Office of Water, Washington, DC.
- U.S. Environmental Protection Agency (USEPA) 2001. EPA requirements for Quality Assurance Project Plans. EPA QA/R-5. EPA/240/B-01/003.
- U.S. Environmental Protection Agency (USEPA) 2002a. Guidance for Quality Assurance Project Plans. EPA QA/G-5. EPA/240/R-02/009.
- U.S. Environmental Protection Agency (USEPA) 2002b. Sheepshead Minnow, *Cyprinodon variegatus* Embryo-Larval Survival and Teratogenicity Test: Chronic Toxicity. 3rd edition. Office of Water. EPA-821-R-02-014.
- U.S. Environmental Protection Agency (USEPA) 2017. National functional guidelines for organic Superfund methods data review. OLEM 9355.0-135. EPA-540-R-2017-001.
- U.S. Environmental Protection Agency (USEPA) 2021. Method 1628 Polychlorinated Biphenyl (PCB) congeners in water, soil, sediment, biosolids, and tissue by Low-resolution GC/MS using selected ion monitoring. Office of Science and Technology, EPA 821-R-21-002.
- Valiela, I., J.E. Wright, J.M. Teal, and S.B. Volkmann. 1977. Growth, production and energy transformations in the salt-marsh killifish *Fundulus heteroclitus*. *Marine Biology* 40:135-144.
- Valley, R.D., M.D. Habrat, E.D. Dibble, and M.T. Drake. 2010. Movement patterns and habitat use of three declining littoral fish species in a north-temperate mesotrophic lake. *Hydrobiologia* 644: 385-399.
- Van den Berg, M., L.S. Birnbaum, M. Denison, M. De Vito, W. Farland, M. Feeley, H. Fiedler H. Hakansson, A. Hanberg, L. Haws, and M. Rose. 2006. The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological Sciences* 93:223-241.
- Vogelbein, W.G. and M.A. Unger. 2006. Liver carcinogenesis in a non-migratory fish: The association with polycyclic aromatic hydrocarbon exposure. *Bulletin of the European Association of Fish Pathologists* 26:11-20.
- Vogelbein, W.K., J.W. Fournie, P.A. Van Veld, and R.J. Huggett. 1990. Hepatic neoplasms in the mummichog *Fundulus heteroclitus* from a creosote-contaminated site. *Cancer Research* 50:5978-5986.
- Westfall, P. H. and S. S. Young. 1993. Resampling-Based Multiple Testing. Examples and Methods for p-Value Adjustment. John Wiley & Sons, Inc., New York. 340 p.
- Wilson, T.P. 2019. Sediment and Chemical Contaminant Loads in Tributaries to the Anacostia River, Washington, District of Columbia, 2016-17, USGS Scientific Investigations Report 2019-5092.

Zuur, A.F., E.N. Ieno, N. Walker, A.A. Saveliev, and G.M. Smith. 2009. *Mixed Effects Models and Extensions in Ecology with R*. Springer, New York, 574 p.

TABLES

Table 1. Location coordinates, descriptions, abbreviations, and sampling methods.

Waterbody, Location	Loc. Code	Description/	Methods	Range description					
		Tidal (T), Non-tidal (NT)			Start Lat.	Start Lon.		Stop Lat.	Stop Lon.
2018 Collections									
Anacostia R., Bladensburg, MD	BL	Gravel bar north of Boat Ramp + inlet (T)	Seine, traps	gravel bar (seining)	38.93630	-76.94038	inlet (traps)	38.9373	76.94042
Anacostia trib, Northwest Branch, MD	NW	Downstream of USGS gage (NT)	Shock	Start east (downriver)	38.95095	-76.96091	End west (upriver)	38.9534	-76.96163
Anacostia trib, Northeast Branch, MD	NE	Downstream of USGS gage (T)	Shock	Start south (downriver)	38.95541	-76.9287	End north (upriver)	38.9569	-76.92790
Anacostia trib, Watts Branch, DC	WB/ WC ^a	Upstream of USGS gage (NT)	Shock	Start east (upriver)	38.89886	-76.9403	End west (downriver)	38.8992	-76.94049
Anacostia trib, Hickey Run, DC	HR	Downstream of USGS gage (T)	Shock, traps	Start east (downriver)	38.91148	-76.9639	End west (upriver)	38.9122	-76.96530
Anacostia trib, Lower Beaverdam Creek, MD	LB1	Near USGS gage; Route 201(T)	Shock, traps	Start east (upriver)	38.91612	-76.93181	End west (downriver)	38.9163	-76.93389
Anacostia trib, Lower Beaverdam Creek, MD	LB2	Downstream of Route 202 and Cabin Branch (NT)	Shock, traps	Start east (upriver)	38.928424	-76.894427	End west (downriver)	38.9271	-76.89760
Kingman Lake, DC	KL	E. Capitol Br. north to footbridge (T)	Seine, traps	Start north (upriver) seining	38.89403	-76.9659	End south (downriver) traps	38.8902	-76.96567
Anacostia R., DC	A2	Above CSX Bridge (east side of river) (T)	Seine	Single area	38.88432	-76.96668			
Anacostia R., DC	PC	Pepco Cove (along south edge) (T)	Seine	Single area	38.90124	-76.96044			
Anacostia R., DC	A1	Near Poplar Point (T)	Seine	Single area	38.86929	-76.997			

Table 1 (continued)									
Waterbody, Location	Loc. Code	Description	Methods	Range description					
		Tidal (T), Non-tidal (NT)			Start Lat.	Start Lon.		Stop Lat.	Stop Lon.
2019 Collections									
Anacostia R., DC	11A	Between 11th St. and Sousa Br. (11A) (T)	Seine	Single area	38.87324	-76.98543			
Anacostia R., DC	PC	Pepco Cove (along South edge) (T)	Seine	Single area	38.90124	-76.96044			
Potomac R., DC	P3	Theo Roosevelt I. (T)	Seine	Single area	38.89985	-77.0662			
Potomac R., DC	P4	Fletchers Cove (T)	Seine	Single area	38.91805	-77.10309			
Potomac R., DC	KB	Upstream of Key Bridge (T)	Seine	VA side	38.90238	-77.0794	DC side	38.9049	-77.07908
2020 Collections									
Anacostia R., Bladensburg, MD	BL	Gravel bar north of Boat Ramp + inlet (T)	Seine	Single area	38.935065	-76.93992			
Anacostia R., MD	DC	Across from mouth of Dueling Crk (T)	Seine	Single area	38.92155	-76.93859			
Anacostia trib, Lower Beaverdam Creek, MD	LB1	From USGS gage to just upstream of Route 201(T)	Shock, traps	Start east (upriver)	38.91612	-76.93181	End west (downriver)	38.91631	-76.93431
Anacostia trib, Lower Beaverdam Creek, MD	LB1.5	Near Jesse Warr Rec. Center (NT)	Seine	3 areas close together	38.91379	-76.917394			
Anacostia trib, Lower Beaverdam Creek, MD	LB2	Along Country Club Lane (NT)	Seine, shock, traps	Start east (upriver)	38.928300	-76.894478	End west (downriver)	38.92723	-76.89757
Anacostia R., DC	NR	Nash Run (100 m from mouth) (T)	Seine	Single area	38.91216	-76.94596	Near footbridge		

Table 1 (continued)									
ID	Loc. Code	Description	Methods	Range descript.					
		Tidal (T), Non-tidal (NT)		Start Lat.	Start Lon.		Stop Lat.	Stop Lon.	
Anacostia R., DC	PC	Pepco Cove (along South edge) (T)	Seine	Single area	38.90124	-76.96044			
Anacostia R., DC	A2	Above CSX Bridge (east side of river) (T)	Seine	Single area	38.88432	-76.96668			
Anacostia R., DC	11A	Between 11th St. and Sousa Br. (11A) (T)	Seine	Single area	38.87324	-76.98543			
Kingman Lake, DC	KH	Heritage Island near footbridge (T)	Seine	Single area					
Kingman Lake, DC	KG	Along mainland, northern tip of Langston Golf Course (T)	Seine	Single area					
Potomac R., DC	P3	Theo. Roosevelt Island (T)	Seine	Single area	38.89985	-77.0662			
Potomac R., DC	P4	Fletchers Cove (T)	Seine	Single area	38.91623	-77.10175			
Potomac R., DC	KB	North of Key Bridge (T)	Seine	DC side	38.90488	-77.07908			
Potomac R., VA	DM	Dyke Marsh (T)	Boat shock	In marsh channels	38.76172	77.048005			

^a Watts Branch (WB) samples are designated as WC in all lab samples. In the text of the report WB is used.

Table 2. List of analytes and sample detection limits for SGS AXYS Method 007^a.

PCBs: Individual and Co-Eluting Congeners						
1	30	58	95/93	129	156	184
2	31	74/61	94	130	157	185
3	35	65/62	96	131/142	158/160	186
4/10	36	63	98/102	132/168	159	188
8/5	37	66/80	99	133	161	189
6	38	67	100	134/143	162	191
7/9	39	69	103	144/135	165	193
11	40	70/76	104	136	166	194
12/13	41/71/64/68	72	105/127	137	167	195
14	42/59	77	118/106	138/163/164	169	196/203
15	49/43	78	107/109	149/139	170/190	197
16/32	44	79	110	140	171	198
17	45	81	111/117	141	172/192	199
18	46	82	112	145	173	200
19	47/48/75	83/108	113	146	174/181	201
33/20/21	50	84	114	147	175	202
22	51	85/120	119	148	176	204
34/23	52/73	97/86	122	150	177	205
24/27	53	87/115/116	123 ¹	151	178	206
25	54	88/121	124	152	179	207
26	55	90/101/89	125	153	180	208
28	56/60	91	126	154	187/182	209
29	57	92	128	155	183	
<i>E1 Pesticides</i>			<i>E2 Pesticides</i>			
Hexachlorobenzene		Nonachlor, cis-		HCH, delta		
HCH, alpha		2,4'-DDD		Heptachlor Epoxide		
HCH, beta		4,4'-DDD		alpha-Endosulphan		
HCH, gamma		2,4'-DDE		Dieldrin		
Heptachlor		4,4'-DDE		Endrin		
Aldrin		2,4'-DDT		beta-Endosulphan		
Chlordane, oxy-		4,4'-DDT		Endosulphan Sulphate		
Chlordane, gamma (tr)		Mirex		Endrin Aldehyde		
Chlordane, alpha (cis)		Technical Toxaphene		Endrin Ketone		
Nonachlor, trans-				Methoxychlor		

^a Typical sample detection limits (ppb wet weight tissue based on 10 grams): PCB congeners with 3 to 9 chlorines = 0.1 ppb; Congeners with 1, 2, or 10 chlorines = 0.5 ppb; E1 OC pesticides by GC/MS = 0.1 to 0.5 ppb except trichlorobenzenes and dichlorobenzenes = 1.0 ppb and technical toxaphene = 15 ppb; E2 OC pesticides by GC/ECD = 0.1ppb, except methoxychlor = 0.5 ppb. A summary of Method 007 is included in Appendix A.

Table 3. Collection data including lipid (percent), total PCBs, PCB TEQ, total chlordane, dieldrin, total DDT, and heptachlor epoxide data (parts per billion wet weight). TEQ: Toxic equivalents, BK: Banded killifish, MC: Mummichog, S: Small, L: Large, J: Jumbo. Sample IDs with F or M in position 5 indicate sex (2020 only). See text and Table 1 for location/collection descriptions and abbreviations

Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordane	Total DDT	Dieldrin	Heptachlor Epoxide
A1BK18	A1BKL01	9/18/18	69	6	19.77	3.32	472	0.0673	227	75.9	32.3	12.6
	A1BKS01	9/18/18	58.5	8	14.8	3.65	443	0.0599	210	73.2	15.4	11.0
					Mean	3.49	458	0.0636	218	74.6	23.9	11.8
					Stdev	0.23	21	0.0054	12	1.9	12.0	1.1
11ABK19	11ABKJ01	6/27/19	86.5	4	27.13	2.23	166	0.0234	58	31.1	7.7	2.76
	11ABKJ02	6/27/19	85.5	4	29.04	2.38	158	0.0026	57.8	33.1	8.32	2.54
	11ABKL01	6/27/19	74	6	27.71	2.63	204	0.0260	78.6	36.3	9.84	3
	11ABKL02	6/27/19	72.5	6	26.67	2.00	193	0.0313	70.7	37.1	6.77	2.15
	11ABKL03M ^a	6/27/19	78	6	30.06	2.34	174	0.0268	75.4	36.3	8.06	2.61
	11ABKL04	6/27/19	71	6	25.25	2.5	211	0.0327	80.4	33.7	9.92	3.25
	11ABKL05	6/27/19	74	6	28.82	2.18	146	0.0226	55.8	23.8	7.75	2.75
	11ABKL06	6/27/19	71.5	6	26.1	2.44	181	0.0217	70.4	29.1	7.2	3.42
	11ABKL07	6/27/19	73	6	26.41	1.91	127	0.0187	51.3	24.6	5.81	1.92
	11ABKL08	6/27/19	73.5	6	27.14	2.31	250	0.0344	85.5	37.9	9.16	2.65
	11ABKL09	6/27/19	75	6	28.75	2.62	196	0.0299	79.7	34.4	9.38	3.59
	11ABKL10	6/27/19	73.5	6	29.34	2.37	244	0.0396	96	48	9.73	3.67
	11ABKS01	6/27/19	65	10	26.93	2.41	255	0.0331	93.6	36.6	7.36	2.91
					Mean	2.33	193	0.0302	73.3	34.0	8.23	2.86
					Stdev	0.21	40	0.0068	14.4	6.2	1.30	0.52
11ABK20	11ABKF20J01	7/15/20	87	4	26.72	1.48	97.5	0.0129	39.3	17.2	4.01	1.89
	11ABKF20J02	7/15/20	88.5	4	27.44	1.85	127	0.0206	44.9	19.7	5.66	1.91
	11ABKF20L01	7/15/20	72.5	6	24.29	2.46	233	0.0442	72.6	27.5	7.88	2.48
	11ABKF20L02	7/15/20	75	5	23.87	1.67	137	0.0210	60.3	25.3	4.9	1.19
	11ABKM20L01	7/15/20	70	5	19.26	1.95	338	0.0630	96.1	52.1	6.1	1.76
	11ABKM20L02	7/15/20	77	8	20.67	1.59	246	0.0508	73.0	32.4	3.74	0.09

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordane	Total DDT	Dieldrin	Heptachlor Epoxide
					Mean	1.83	196	0.0354	64.4	29.0	5.38	1.55
					Stdev	0.35	92	0.0201	20.8	12.5	1.53	0.83
A2BK18	A2BKL01	9/18/18	69	9	30.28	2.4	222	0.0280	84.1	40.6	9	4.71
	A2BKS01	9/18/18	62	13	26.72	3.93	364	0.0412	132	69.7	15.7	7.44
	A2BKS02	9/18/18	55	18	28.9	3.65	333	0.0410	121	62.4	15.9	6.77
	A2BKS03	9/18/18	60	18	32.46	4.23	359	0.0405	141	65.2	20.0	8.84
					Mean	3.55	320	0.0377	120	59.5	15.2	6.94
					Stdev	0.80	66	0.0065	25	12.9	4.6	1.72
A2BK20	A2BKF20L01	7/9/20	70	8	27.88	2.43	172	0.0240	70	26.8	8.11	3.87
	A2BKF20L02	7/9/20	79.5	6	29.81	1.8	129	0.0174	46.5	17.4	5.57	2.78
	A2BKF20L03M ^b	7/9/20	72.5	8	30.77	1.95	122	0.0182	51.2	23.2	5.53	2.49
	A2BKM20L01	7/9/20	69	7	23.83	2.64	299	0.0493	122	55.6	8.64	3.3
	A2BKM20L05	7/9/20	81	6	31.11	2.44	293	0.0559	115	54.4	7.88	3.06
	A2BKM20S01	7/9/20	59	13	29.19	3.63	328	0.0529	130	52.6	11.9	5.05
					Mean	2.48	224	0.0363	89.1	38.4	7.94	3.42
					Stdev	0.65	93	0.0183	37.5	17.7	2.35	0.93
A2MC18	A2MCL01	9/7/18	71	5	22.92	2.83	179	0.0290	51.3	40.1	8.7	5.06
	A2MCL02	9/7/18	70	5	22.35	3.46	180	0.0288	58.2	40.6	10.3	5.79
	A2MCS01	9/7/18	56	10	23.97	3.57	231	0.0391	69.4	52.5	12.0	6.79
	A2MCS02	9/7/18	57	14	28.73	3.62	233	0.0396	64.5	51.9	10.7	5.4
					Mean	3.37	206	0.0341	60.8	46.3	10.4	5.76
					Stdev	0.37	30	0.0061	7.8	6.9	1.4	0.75
A2MC20	A2MCF20L01	8/10/20	76	6	26.67	2.11	65.5	0.0126	23.6	14	4.25	2.14
	A2MCM20L01	8/10/20	69	5	22.02	2.1	153	0.0315	43.7	25.8	4.79	2.67
					Mean	2.11	109	0.0221	33.6	19.9	4.52	2.41
					Stdev	0.01	62	0.0134	14.2	8.3	0.38	0.37

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordane	Total DDT	Dieldrin	Heptachlor Epoxide
PCBK19	PC19BKL01	7/19/19	70	5	17.01	2.58	345	0.0388	80.5	30	10.2	5.54
	PC19BKL02	7/19/19	70.5	4	20.2	3.04	422	0.0555	93.2	33.5	10.4	4.62
	PC19BKS01	7/19/19	53.5	10	20.2	2.9	399	0.0614	63.9	25.4	9.55	3.72
	PC19BKS02	8/6/19	63	10	17.79	2.66	85	0.0166	40.8	20.4	6.62	1.65
					Mean	2.80	313	0.0431	69.6	27.3	9.19	3.88
					Stdev	0.21	155	0.0202	22.6	5.7	1.75	1.66
PCBK20	PCBKF20S02	9/22/20	62	14	20.01	3.49	445	0.0528	115	35.8	12.8	6.32
	PCBKF20L02	10/8/20	77	4	20.49	1.9	519	0.0822	67.6	25.1	5.71	2.03
	PCBKF20L03	10/8/20	76	5	22.66	1.84	497	0.0766	62.6	28.3	5.07	1.66
	PCBKF20L04	10/8/20	70	5	17.28	2.45	628	0.0906	103	43.9	8.12	2.85
	PCBKF20S01	10/8/20	54.5	14	22.23	3.73	595	0.0685	118	49.3	11.5	3.18
	PCBKM20L01	8/7/20	72	5	18.83	1.64	284	0.0552	70.5	36.9	5.67	2.33
	PCBKM20S01	8/7/20	50	12	20.62	2.31	361	0.0525	51.9	25.1	6.67	2.24
					Mean	2.48	476	0.0684	84.0	34.9	7.93	2.94
					Stdev	0.82	123	0.0156	27.0	9.4	3.06	1.57
PCMC18	PCMCS01	10/15/18	57	9	18.9	2.99	415	0.0669	58.8	26.8	10.1	6.09
	PCMCS02	10/15/18	58	8	21.38	2.76	373	0.0639	53.4	26	9.03	5.5
	PCMCS03	10/15/18	62	6	17.01	2.2	470	0.0844	45.9	21.9	6.71	3.44
	PCMCS04	10/15/18	64.5	6	15.61	2.22	615	0.0985	78.0	38.9	9.58	4.87
					Mean	2.54	468	0.0784	59.0	28.4	8.86	4.98
					Stdev	0.40	106	0.0162	13.7	7.3	1.50	1.14
PCMC19	PC19MCL01	7/19/19	72.5	4	21.3	1.78	205	0.0253	40.5	15.7	7.82	2.36
	PC19MCL02	7/19/19	70	3	16.88	2.19	223	0.0307	43.9	17.6	8.35	3.42
	PC19MCS01	7/19/19	48	11	17.05	2.58	329	0.0511	51.9	20.6	7.53	5.21
					Mean	2.18	252	0.0357	45.4	18.0	7.90	3.66
					Stdev	0.40	67	0.0136	5.9	2.4	0.42	1.44

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordane	Total DDT	Dieldrin	Heptachlor Epoxide
PCMC20	PCMCF20L01	8/10/20	68	5	22.05	2.71	279	0.0576	42.6	16.6	6.62	1.84
	PCMCF20L02	8/10/20	72	4	20.05	1.98	275	0.0558	29.8	13.4	4.75	1.17
	PCMCM20L01	9/22/20	69	5	22.26	1.83	211	0.0491	20.7	10.8	2.95	0.9
	PCMCM20S01	10/8/20	53.5	8	17.54	2.06	420	0.0389	32.8	14.2	4.51	2.75
					Mean	2.15	296	0.0503	31.5	13.8	4.71	1.67
					Stdev	0.39	88	0.0087	9.0	2.4	1.50	0.82
DCMC20	DCMCF20L01	8/10/20	67	6	25.13	2.82	108	0.0235	44.6	25.9	7.94	3.3
	DCMCF20L02	8/10/20	69.5	6	27.72	2.63	98.9	0.0213	36	17.5	7.05	2.7
	DCMCM20L01	8/10/20	69	4	21.46	1.9	82.0	0.021	26.2	12.4	4.22	2.08
	DCMCM20L02	8/10/20	75	4	22.9	1.25	80.0	0.0208	22.2	10.8	3.26	1.87
	DCMCF20S02	8/10/20	58	7	21.24	2.78	116	0.0275	40.7	17.5	8.78	4.32
	DCMCF20S03	8/10/20	63	6	21.64	2.78	94.6	0.0185	38.8	15.1	10.1	6.37
	DCMCM20S01	8/10/20	62	6	21.3	1.78	84.9	0.0223	22.4	9.2	4.8	2.28
	DCMCM20S02	8/10/20	62	6	22.58	2.07	127	0.0340	31.7	14	6.06	2.67
					Mean	2.25	98.9	0.0237	32.8	15.3	6.53	3.20
					Stdev	0.59	17.1	0.0050	8.6	5.2	2.37	1.50
BLBK18	BLBKJ01	10/18/18	88	4	23.65	2.22	65.3	0.0101	95.3	17.1	24.3	11.2
	BLBKJ02	10/18/18	87.5	4	24.74	1.76	47.3	0.0081	55.4	13.1	15.6	5.82
	BLBKL01	10/18/18	73	7	25.8	1.81	139	0.0182	91.4	26.4	16	7.07
	BLBKL02	10/18/18	75	7	26.63	1.69	151	0.0221	88.2	27	16.9	7.24
	BLBKS01	10/18/18	55.5	18	29.41	3.66	160	0.0221	134	30.6	24.1	13.1
	BLBKS02	10/18/18	57	18	29.53	3.43	154	0.0195	132	33.9	21.7	12.4
					Mean	2.43	119	0.0167	99.4	24.7	19.8	9.47
					Stdev	0.89	50	0.0061	29.7	8.0	4.1	3.12
BLBK20	BLBKF20J02	7/29/20	91	3	27.26	2.75	67.9	0.0108	79.1	12.4	17	14.9
	BLBKM20L02	7/29/20	81	5	27.94	2.33	116	0.0279	80.7	16.5	12.8	6.93

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordanes	Total DDT	Dieldrin	Heptachlor Epoxide
	BLBKF20J01	7/11/20	94	3	28.04	2.96	61.8	0.0149	98.6	15.7	15.7	8.27
	BLBKF20L02	7/11/20	67	7	24.07	2.87	89.8	0.0194	96.6	18.3	14.3	6.6
	BLBKM20J01	7/11/20	90	3	34.35	2.1	112	0.0308	81.6	19.9	8.9	3.73
	BLBKM20L01	7/11/20	67	7	24.18	2.92	172	0.0407	112.3	30	14.3	7.29
					Mean	2.66	103	0.0241	91.5	18.8	13.8	7.95
					Stdev	0.36	40	0.0112	13.2	6.1	2.8	3.73
BLMC18	BLMCL01	10/15/18	69	5	25.24	3.15	68.5	0.0136	49.6	13.9	16.4	9.84
	BLMCL02	10/15/18	82	3	22.22	3.24	56.5	0.0001	45.7	13.7	24.9	12.1
	BLMCS01	10/15/18	57	9	23.42	3.75	99.2	0.0169	95.1	26.6	28	15.1
	BLMCS02	10/15/18	58	11	24.46	3.95	84.6	0.0150	73.6	20.9	21.5	12.8
					Mean	3.52	77.2	0.0112	66.0	18.7	22.7	12.5
					Stdev	0.39	18.6	0.0075	23.0	6.2	5.0	2.2
BLMC20	BLMCF20L01	7/11/20	79	4	24.58	2.11	22.7	0.0069	29.5	7.67	7.49	3.8
	BLMCF20L02	7/11/20	83	3	23.04	1.57	14.1	0.0039	20	4.25	5.16	2.84
	BLMCM20L01	7/11/20	69	3	16.15	1.42	37.8	0.0120	26.2	7.78	4.64	1.84
	BLMCM20S01	7/11/20	64	7	24.15	1.55	42.6	0.0129	27.7	7.76	4.94	2.07
					Mean	1.66	29.3	0.0090	25.9	6.87	5.56	2.64
					Stdev	0.31	13.2	0.0043	4.1	1.74	1.31	0.89
KLBK18	KLBKS01	9/18/18	58	9	14.5	3.98	376	0.0449	116	60.5	12.9	7.37
KLMC18	KLMCL01	10/15/18	69	4	16.54	2.36	196	0.0293	40.3	29.8	6.78	3.4
	KLMCS01	10/15/18	55.5	10	20.09	2.64	262	0.0426	57.2	31.9	7.88	4.15
	KLMCS02	10/15/18	54	10	19.58	2.56	240	0.0318	63.4	28.8	8.78	4.87
					Mean	2.34	234	0.0346	53.7	30.2	7.81	4.14
					Stdev	0.14	34	0.0071	12.0	1.6	1.00	0.74
KHBK20	KHBKF20S01	10/9/20	51	16	21.35	3.97	348	0.0475	86.9	46.8	9.45	4.37

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordanes	Total DDT	Dieldrin	Heptachlor Epoxide
	KHBKM20S01	10/9/20	52	8	13.82	3.34	241	0.0332	48.3	39.6	7.24	3.19
					Mean	3.66	295	0.0404	67.6	43.2	8.35	3.78
					Stdev	0.45	76	0.0101	27.3	5.1	1.56	0.83
KHMC20	KHMC20L01	9/23/20	77	3	19.69	2.45	172	0.0326	37.2	28.5	4.74	1.71
	KHMC20L02	9/23/20	77	4	23.09	2.48	178	0.0273	43.2	33.6	5.36	2.14
	KHMC20L03	9/23/20	69.5	4	18.84	2.56	164	0.0219	37.7	30.4	5.02	2.18
	KHMC20L01	9/23/20	74.5	4	22.13	2.56	138	0.0226	31.4	23.7	4.32	1.8
	KHMC20L02	10/8/20	66	5	18.77	2.37	174	0.0283	33.5	26.5	4.49	1.84
	KHMC20S01	10/8/20	52.5	10	20.51	3.2	260	0.0398	50.4	39.7	6.56	3.27
					Mean	2.60	181	0.0287	38.9	30.4	5.08	2.16
					Stdev	0.30	41	0.0068	6.9	5.7	0.81	0.58
KGBK20	KGBK20L01	9/23/20	67	5	21.36	2.22	201	0.0350	55.4	26.5	6.5	2.89
	KGBK20L02	9/23/20	67	5	22.79	2.59	278	0.0416	81.1	29.2	9.58	4.74
	KGBK20S01	9/23/20	62.5	6	19.18	2.24	175	0.0300	45.2	19.3	5.9	2.94
	KGBK20S01	9/23/20	51	12	21.29	3.61	243	0.0301	76	28	10.8	6.33
					Mean	2.67	224	0.0342	64.4	25.7	8.20	4.23
					Stdev	0.65	45	0.0056	17.0	4.4	2.37	1.65
KGMC20	KGMC20L01	9/23/20	78.5	4	21.21	3.22	270	0.0352	86.6	28.9	10.8	5.81
	KGMC20L03	9/23/20	72	5	22.18	2.64	222	0.0331	61.3	23.7	7.89	3.09
	KGMC20S01	9/23/20	62	7	22.29	2.21	187	0.0270	53	21.7	6.16	3.44
	KGMC20L01	9/23/20	70	5	20.1	2.35	173	0.0257	47.6	19	6.15	2.62
	KGMC20L03	9/23/20	72	5	20.14	1.93	149	0.0261	38	15	5.12	2.29
	KGMC20S01	9/23/20	64	7	22.83	1.99	151	0.0244	37.1	14.8	5.18	2.16
					Mean	2.39	192	0.0286	53.9	20.5	6.88	3.24
					Stdev	0.48	47	0.0045	18.4	5.4	2.16	1.35
HRMC18	HRMCJ01	10/18/18	85	3	29.14	5.11	105	0.0160	58.2	41.2	18.7	8.05

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordanes	Total DDT	Dieldrin	Heptachlor Epoxide
	HRMCJ02	10/18/18	88.5	2	21.56	4.73	164	0.0232	77	50.2	22.3	8.93
	HRMCL01	10/18/18	73	6	39.58	4.47	122	0.0151	60.4	37.6	15.1	6.25
	HRMCL02	10/18/18	72.5	6	34.23	3.94	86.5	0.0135	53.2	46.1	18.4	7.02
	HRMCS01	10/18/18	59.5	10	25.88	3.04	159	0.0241	64.6	32.1	12.3	5.45
					Mean	4.26	127	0.0186	62.7	41.4	17.4	7.14
					Stdev	0.80	34	0.0050	9.0	7.1	3.8	1.39
WCBK18 ^c	WCBKL01 ^a	10/18/18	82	4	17.34	3.48	299	0.0139	117	54.5	45.6	14.9
WCBK18 ^c	WCBKL02 ^a	10/18/18	83	3	16.57	2.49	245	0.0106	86.2	36.8	27.5	11
					Mean	2.99	272	0.0123	102	45.6	36.6	13.0
					Stdev	0.70	38	0.0023	22	12.5	12.8	2.8
WCMC18 ^c	WCMCJ01 ^a	10/18/18	90.5	2	20.93	4.16	270	0.0123	75.7	53.7	34.2	14
WCMC18 ^c	WCMCL01 ^a	10/18/18	80	2	16.21	4.44	406	0.0236	94.1	78.2	50.6	30.8
WCMC18 ^c	WCMCL02 ^a	10/18/18	73	3	17.84	2.67	267	0.0128	88	35.6	31.1	11.5
					Mean	3.76	314	0.0162	85.9	55.8	38.6	18.8
					Stdev	0.95	79	0.0064	9.4	21.4	10.5	10.5
NRBK20	NRBKF20L01	11/10/20	68.5	6	21.22	3.34	331	0.0275	86.6	40.7	15	11.6
	NRBKF20S01	11/10/20	52.5	12	20.45	3.88	376	0.033	64.5	28.1	13.6	8.42
					Mean	3.61	354	0.0312	75.6	34.4	14.3	10.0
					Stdev	0.38	32	0.0039	15.6	8.9	1.0	2.2
NRMC20	NRMCF20J01	11/10/20	90.5	2	24.52	3.66	380	0.0342	84.8	49.4	13.5	9.46
	NRMCF20L01	11/10/20	72.5	4	20.15	3.54	388	0.0465	102.6	61.7	20.5	15
	NRMCF20L02	11/10/20	72	4	18.02	2.95	213	0.0217	36.5	17.5	6.46	4.97
	NRMCM20L01	11/10/20	78	4	20.99	3.48	308	0.0311	57.1	26.8	12.2	7.57
	NRMCM20L02	11/10/20	82	3	19.18	3.8	356	0.0429	73.2	39.2	12.4	8.34
	NRMCM20L03	11/10/20	72	5	23.21	3.2	200	0.0244	54.4	32.5	9.4	7.82
					Mean	3.44	308	0.0335	68.1	37.9	12.4	8.86

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordane	Total DDT	Dieldrin	Heptachlor Epoxide
					Stdev	0.31	83	0.0099	23.7	15.9	4.7	3.35
LB1BK18	LB1BKL01	10/18/18	69	7	24.2	2.32	1050	0.0653	81.5	22.8	15.2	7.89
LB1BK18	LB1BKL02	10/18/18	71.5	4	14.25	3.48	1020	0.0637	122	27.3	20	12.3
LB1BK18	LB1BKS01	10/18/18	55	10	16.05	3.13	1260	0.0963	110	21.4	18.4	11.1
					Mean	2.98	1110	0.0751	105	23.8	17.9	10.4
					Stdev	0.60	131	0.0184	21	3.1	2.4	2.3
LB1BK20	LB1BKF20L01	8/10/20	73	7	26.91	1.13	373	0.0333	28	5.79	3.24	1.88
	LB1BKF20S01	8/10/20	61	7	15.28	1.47	624	0.0444	32.8	7.09	4.3	3.13
	LB1BKM20L01	7/31/20	71.5	6	21.67	1.38	613	0.0572	68.7	22.4	5.89	3.11
	LB1BKM20L02	7/31/20	75	6	22.42	1.22	512	0.0561	58.9	16.3	4.32	2.27
	LB1BKM20L03	8/10/20	74	6	21.75	0.96	640	0.0438	20.4	5.7	2.34	1.27
	LB1BKM20S01	7/31/20	60	12	24.67	1.8	767	0.0671	60.2	16	6.08	3.52
					Mean	1.33	588	0.0503	44.8	12.2	4.36	2.53
					Stdev	0.29	133	0.0125	20.1	7.0	1.46	0.87
LB1MC18	LB1MCL01	10/18/18	72	5	24.79	2.57	755	0.0480	51	20.9	12.4	6.71
	LB1MCS01	10/18/18	60.5	6	16.83	2.29	674	0.0377	29.2	10.2	7.92	4.42
	LB1MCS02	10/18/18	51	11	17.42	3.45	844	0.0471	86.4	32.6	18.3	11.8
	LB1MCS03	10/18/18	47	9	15.96	2.51	716	0.0441	54.5	21.8	12.2	6.3
	LB1MCS04	10/18/18	51.5	8	15.35	2.57	639	0.0324	49.7	19.8	10.9	6.25
					Mean	2.68	726	0.0419	54.1	21.1	12.3	7.10
					Stdev	0.45	79	0.0067	20.6	7.9	3.8	2.77
LB1MC20	LB1MCF20L01	7/31/20	67.5	6	23.92	1.99	313	0.0273	33.8	6.13	4.65	2.59
	LB1MCF20L06	8/10/20	75.5	4	21.4	1.53	199	0.0180	22.6	4.74	2.92	1.9
	LB1MCF20S01	8/10/20	59	7	19.47	2.32	348	0.0263	61.9	8.56	5.7	3.34
	LB1MCM20L01	8/10/20	67	7	27.5	1.68	328	0.0364	23.7	8.38	3.63	2.27
	LB1MCM20L04	8/10/20	74	5	27.5	1.23	293	0.0375	16.6	4.96	2.72	1.35

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordanes	Total DDT	Dieldrin	Heptachlor Epoxide
	LB1MCM20S01	8/10/20	63	9	26.49	1.87	396	0.0404	34.6	6.14	3.49	2.08
					Mean	1.77	313	0.0310	32.2	6.49	3.85	2.26
					Stdev	0.379	66	0.0087	16.1	1.64	1.13	0.67
LB1.5BK20	LB1.5BKF20J1	7/31/20		3	20.13	1.5	253	0.0219	42.5	5.81	4.31	2.8
	LB1.5BKF20L1	7/31/20	70	7	23.44	1.31	233	0.0209	30.7	3.9	3.99	2.25
	LB1.5BKF20L2	7/31/20	77	5	21.32	1.67	221	0.0197	52.6	4.96	6.1	3.87
	LB1.5BKM20L1	7/31/20	68	7	19.83	1.7	414	0.0443	74.3	13	10.2	6.4
	LB1.5BKM20L2	9/22/20	70.5	6	20.55	1.29	351	0.0596	35.1	6.35	3.64	1.79
	LB1.5BKM20L3	9/23/20	77	6	20.21	2.21	491	0.0626	74.1	10.7	11.3	6.4
					Mean	1.61	327	0.0382	51.6	7.44	6.59	3.92
					Stdev	0.34	110	0.0202	19.0	3.56	3.35	2.04
LB2BK18	LB2BKL01	10/18/18	68	9	25.14	3.19	897	0.0173	160.8	11.2	34.2	15.6
	LB2BKL02	10/18/18	70	9	24.52	2.57	920	0.0222	129.8	6.68	29.2	12.4
	LB2BKL03	10/18/18	70	9	26.98	3.23	918	0.0176	138.3	7.83	23.1	15.7
	LB2BKL04	10/18/18	79	7	24.31	2.03	712	0.0199	94.3	4.78	23.6	9.5
	LB2BKS01	10/18/18	60	16	26.31	3.38	1120	0.0236	205.6	11.3	26.1	18.9
					Mean	2.88	913	0.0201	146	8.37	27.2	14.4
					Stdev	0.57	145	0.0029	41	2.86	4.6	3.6
LB2BK20	LB2BKF20J01	7/31/20	89	3	22.6	2.03	772	0.0171	111	5.52	10.6	4.63
	LB2BKF20J02	10/4/20	94.5	2	21.44	4.49	890	0.0322	197	11.6	32.8	17.2
	LB2BKF20S01	10/3/20	55	10	19.2	3.67	577	0.0201	134	7.77	21.4	13.1
	LB2BKM20L01	7/31/20	82	4	23.53	1.87	1210	0.0430	221	9.94	12	8.7
	LB2BKM20S01	10/3/20	53	11	20.34	4.31	719	0.0262	210	13.6	31.5	12.4
					Mean	3.27	834	0.0277	174	9.69	21.7	11.2
					Stdev	1.25	239	0.0105	49	3.17	10.4	4.8
LB2MC18	LB2MCL01	10/18/18	68	7	27.51	3.18	887	0.0208	99	5.85	29.9	16.8
	LB2MCL02	10/18/18	71.5	6	25.66	2.72	574	0.0179	90.6	7.8	24.9	13.7

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordane	Total DDT	Dieldrin	Heptachlor Epoxide
	LB2MCL03	10/18/18	70	7	28.66	2.68	780	0.0192	86.5	6.5	19.2	13.8
	LB2MCL04	10/18/18	69	7	27.3	3.31	780	0.0217	111.9	14.5	23.5	16.4
	LB2MCS01	10/18/18	58.5	10	20.46	3.53	596	0.0181	98.7	6.81	33.2	18.2
					Mean	3.08	723	0.0196	97.3	8.29	26.1	15.8
					Stdev	0.37	134	0.0019	9.8	3.53	5.5	2.0
LB2MC20	LB2MCF20L01	10/3/20	68	5	19.7	4.87	701	0.0221	258	10.9	37	14
	LB2MCF20S01	10/3/20	60.5	8	23.16	3.9	716	0.0312	133	7.01	24.3	10.3
	LB2MCF20S02	10/3/20	57	9	21.45	4.13	636	0.0225	139	10	25.3	11.2
	LB2MCM20S01	10/3/20	56	9	20.27	3.69	539	0.0184	145	9.54	23.5	12
	LB2MCM20S02	10/3/20	63.5	6	19.53	4.64	665	0.0217	173	8.59	27.6	13.8
	LB2MCM20S03	10/4/20	59.5	8	20.69	4.11	643	0.0239	346	10.5	27.1	15.5
					Mean	4.22	650	0.0233	199	9.41	27.5	12.8
					Stdev	0.45	63	0.0043	86	1.42	4.9	2.0
NEBK18	NEBKJ01	10/18/18	88	5	30.49	4.12	86.7	0.0135	198	17.5	100	21.3
	NEBKJ02	10/18/18	87	5	28.81	2.68	74.0	0.0149	130	13.5	37.2	18.5
	NEBKJ03	10/18/18	90	4	26.45	2.59	68.7	0.0127	152	12.3	46.3	26.8
					Mean	3.13	76.5	0.0137	160	14.4	61.2	22.2
					Stdev	0.86	9.3	0.0012	35	2.7	33.9	4.2
NEMC18	NEMCL01	10/18/18	77	5	30.75	2.61	52.8	0.0106	80.4	9.7	48	16.1
	NEMCL02	10/18/18	77	5	31.37	2.54	42.9	0.0085	124	8.3	55.9	24.5
					Mean	2.58	47.9	0.0095	102	9.00	52.0	20.3
					Stdev	0.05	7.0	0.0015	31	0.93	5.6	5.9
NWBK18	NWBKL01	9/18/18	79	7	26.49	2.46	48.6	0.0075	127	23.2	35.6	18.8
	NWBKS01	9/18/18	55	15	19.83	2.78	55.1	0.0069	155	22	30.6	23
	NWBKS02	9/18/18	55	17	21.83	2.57	58.9	0.0050	156	22	30.9	18.9
	NWBKS03	9/18/18	56	17	23.59	3.38	53.2	0.0068	220	21.9	35.5	17.1

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordanes	Total DDT	Dieldrin	Heptachlor Epoxide
					Mean	2.80	54.0	0.0066	165	22.3	33.2	19.5
					Stdev	0.41	4.3	0.0011	39	0.6	2.8	2.5
DMBK20	DMBKF20J01	6/30/20	85.5	4	23.11	1.36	40.7	0.0097	9.11	5.81	0.84	0.25
	DMBKM20S01	6/30/20	62	13	26.89	1.71	98.9	0.0243	18.9	19.1	1.31	0.44
	DMBKF20L01	6/30/20	70	7	25.19	1.26	60.9	0.0126	11.7	12.1	1.24	0.49
	DMBKF20L02	6/30/20	81	5	26	1.36	74.2	0.0155	14.6	12.3	1.27	0.67
	DMBKM20J01	6/30/20	87	5	30.6	1.25	147	0.0372	25.7	23.5	1.43	0.4
	DMBKM20L01	6/30/20	71	6	20.06	1.36	151	0.0332	26	24.1	1.34	0.4
					Mean	1.38	95.5	0.0221	17.7	16.1	1.24	0.44
					Stdev	0.17	45.6	0.0114	7.1	7.3	0.21	0.14
P3BK19	P319BKL01	8/8/19	71.5	4	14.32	1.89	89.5	0.0243	28.7	17.9	1.18	0.49
P3BK20	P3BKF20L02	10/23/20	75	5	19.16	3.31	236	0.0657	19.6	16	2.19	0.77
P3BK20	P3BKF20L03	10/23/20	67	8	21.35	3.64	55.2	0.0128	19.3	11.6	2.34	0.66
P3BK20	P3BKF20S01	10/23/20	63	9	20.88	4.51	135	0.0199	26.3	23.7	3.07	1.13
P3BK20	P3BKM20L01	10/23/20	73	5	18.76	3.46	254	0.0619	21	18.3	2.57	0.91
P3BK20	P3BKM20L02	10/23/20	66	7	20.14	3.57	688	0.1704	20	17.7	2.19	0.83
P3BK20	P3BKM20S01	10/23/20	64	9	19.49	3.95	60.2	0.0131	19.8	13.5	2.04	1.05
					Mean	3.74	238	0.0573	21.0	16.8	2.40	0.89
					Stdev	0.43	236	0.0606	2.6	4.2	0.37	0.18
KBBK19	K19BKL01	8/6/19	67	6	20.17	1.65	36.8	0.0100	19.3	12.9	1.69	0.52
	K19BKL02	8/6/19	72	4	14.5	1.63	32.7	0.0085	11.9	8.27	2.32	0.67
	K19BKS01	8/6/19	60	10	21.42	2.48	39.1	0.0112	26.8	14.2	4.03	1.26
	K19BKS02	8/6/19	60.5	10	20.9	2.76	40.1	0.0091	30.9	13.2	5.03	1.36
	K19BKS03	8/6/19	59	10	20.07	2.81	98.7	0.0253	24.5	15.8	3.33	1.05
	K19BKS04	8/6/19	56	12	20.43	3.01	37.1	0.0100	29.9	12.2	5.24	1.52

(Table 3 continued)												
Collection Code	Sample	Date	Length (mm)	No. fish	sample wt (g)	% Lipid	Total PCBs	PCB TEQ	Total chlordanes	Total DDT	Dieldrin	Heptachlor Epoxide
	K19BKS05	8/6/19	57	12	22.58	3.02	66.0	0.0144	26.4	14.8	4.96	1.23
	K19BKS06	8/6/19	58	13	24.96	2.8	39.5	0.0092	22.8	12.4	6.50	1.53
					Mean	2.52	48.8	0.0123	24.1	13.0	4.14	1.14
					Stdev	0.57	22.6	0.0056	6.1	2.3	1.61	0.37
KBBK20	KBBKF20L01	10/23/20	73	6	20.7	4.2	276	0.0611	77.9	45	14.9	3.55
	KBBKF20L02	10/23/20	69	7	21.53	4.48	122	0.0170	96.2	55.9	19.1	4.49
	KBBKF20S01	10/23/20	60	9	20.56	3.87	153	0.0206	89.6	47.1	17.9	4.01
	KBBKM20L01	10/23/20	69.5	6	18.76	4.39	135	0.0183	103	64.2	21	4.28
	KBBKM20S01	10/23/20	62.5	8	19.61	3.86	151	0.0218	92.2	56.6	18.8	3.79
					Mean	4.16	167	0.0278	91.8	53.8	18.3	4.02
					Stdev	0.29	62	0.0190	9.3	7.8	2.2	0.37
P4BK19	P419BKL01	8/8/19	76	3	14.94	1.88	13.5	0.0034	13.7	11.2	1.55	0.57
	P419BKS01	8/8/19	61	10	22.8	2.84	45.6	0.0085	42.1	28	2.25	2.64
	P419BKS02	8/8/19	57	10	21.15	3.16	28.9	0.0001	37.4	28.1	3.12	1.2
					Mean	2.63	29.3	0.0060	31.1	22.4	2.31	1.47
					Stdev	0.67	16.1	0.0036	15.2	9.7	0.79	1.06
P4BK20	P4BKF20L01	10/23/20	75	5	21.03	2.98	42.8	0.0084	21.4	11.3	1.87	0.75
	P4BKF20L02	10/23/20	69	5	16.08	3.75	43.9	0.0093	29.2	19.9	2.58	1.05
	P4BKF20S01	10/23/20	53	12	18.68	4.33	38.4	0.0068	23	11.8	2.84	1.31
	P4BKM20L01	10/23/20	70	6	20.89	3.74	43.9	0.0095	25.2	14	2.95	1.41
					Mean	3.70	42.3	0.0085	24.7	14.3	2.56	1.13
					Stdev	0.55	2.6	0.0012	3.4	3.9	0.49	0.29

^a Mean results for composite sample of 6 fish split in the lab after homogenization into 11ABK19A and 11ABK19B; results for A and B samples in Appendix A.

^b Mean results for composite sample of 6 fish split in the lab after homogenization into A2BKF20L03A and A2BKF20L03B; results for A and B samples in Appendix A.

^c Watts Branch (WB) samples are designated as WC in all lab samples

Table 4. Risk apportionment (percent) for PCBs, total chlordane, total DDT, dieldrin, and heptachlor epoxide for MC and BK collections using mean data. Cumulative risk calculated according to DNREC/DHSS (2017, J. Cargill, DNREC, personal communication).

Collection	Total PCB TEQ	Total Non-dioxin PCBs	Total PCBs	Total chlordane	Total DDT	Dieldrin	Heptachlor epoxide	Sum of 4 OC pesticides
A1BK18	87.0	7.7	94.7	0.7	0.2	3.4	1.0	5.3
11ABK19	87.8	7.9	95.7	0.6	0.3	2.9	0.6	4.4
11ABK20	91.6	6.2	97.8	0.4	0.2	1.5	0.2	2.3
A2BK18	85.5	9.0	95.5	0.6	0.3	3.6	0.9	5.4
A2BK20	90.0	6.8	96.8	0.5	0.2	2.1	0.5	3.3
A2MC18	89.1	6.5	95.6	0.4	0.3	2.8	0.9	4.4
A2MC20	91.5	5.5	97.0	0.3	0.2	2.0	0.6	3.1
PCBK19	89.1	7.9	97.0	0.3	0.1	2.0	0.5	2.9
PCBK20	90.6	7.7	98.3	0.3	0.1	1.1	0.2	1.7
PCMC18	91.7	6.7	98.4	0.2	0.1	1.1	0.4	1.8
PCMC19	89.3	7.7	97.0	0.3	0.1	2.1	0.6	3.1
PCMC20	92.1	6.6	98.7	0.1	0.1	0.9	0.2	1.3
DCMC20	91.6	4.6	96.2	0.3	0.1	2.6	0.7	3.7
BLBK18	79.2	6.9	86.1	1.1	0.3	9.8	2.7	13.9
BLBK20	87.6	4.5	92.1	0.8	0.2	5.2	1.7	7.9
BLMC18	78.1	4.9	83.0	0.8	0.2	12.2	3.8	17.0
BLMC20	88.6	3.5	92.1	0.6	0.2	5.7	1.5	8.0
KLBK18	86.8	9.0	95.8	0.5	0.3	2.6	0.9	4.3
KLMC18	89.4	7.4	96.8	0.3	0.2	2.1	0.6	3.2
KHBK20	89.1	7.9	97.0	0.3	0.2	1.9	0.5	2.9
KHMC20	90.5	7.0	97.5	0.3	0.2	1.7	0.4	2.6
KGBK20	89.4	7.2	96.6	0.4	0.2	2.3	0.7	3.6
KGMC20	89.3	7.3	96.6	0.4	0.1	2.3	0.6	3.4
HRMC18	81.3	7.5	88.8	0.7	0.4	8.2	1.9	11.2
WBBK18 ^a	57.1	17.3	74.4	1.2	0.5	19.9	4.0	25.6
WBMC18 ^a	61.3	15.9	77.2	0.8	0.5	16.75	4.6	22.7
NRBK20	82.3	11.5	93.8	0.5	0.2	4.0	1.6	6.3
NRMC20	85.0	9.6	94.6	0.4	0.2	3.3	1.5	5.4
LB1BK18	81.9	15.1	97.0	0.3	0.1	2.1	0.7	3.2
LB1BK20	86.2	12.5	98.7	0.2	0.1	0.8	0.3	1.4
LB1MC18	79.0	17.3	96.3	0.2	0.1	2.5	0.8	3.6
LB1MC20	87.3	10.9	98.2	0.2	0.04	1.2	0.4	1.8
LB1.5BK20	88.3	9.3	97.6	0.3	0.04	1.6	0.5	2.4
LB2BK18	54.4	33.5	87.9	1.0	0.1	8.5	2.6	12.2
LB2BK20	65.5	25.9	91.4	1.0	0.1	5.8	1.7	8.6
LB2MC18	57.7	29.4	87.1	0.7	0.1	9.0	3.1	12.9
LB2MC20	64.4	23.4	87.8	1.3	0.1	8.5	2.3	12.2
NEBK18	60.5	4.1	64.6	1.6	0.1	27.9	5.8	35.4

Table 4 (continued)								
NEMC20	56.4	3.4	59.8	1.4	0.1	31.7	7.0	40.2
NWBK18	53.3	5.4	58.7	3.1	0.4	28.4	9.5	41.4
DMBK20	94.1	4.9	99.0	0.2	0.2	0.6	0.1	1.1
P3BK19	94.7	4.3	99.0	0.3	0.2	0.5	0.1	1.1
P3BK20	94.6	4.7	99.3	0.1	0.1	0.4	0.1	0.7
KBBK19	91.3	4.4	95.7	0.4	0.2	3.2	0.5	4.3
KBBK20	86.0	6.3	92.3	0.7	0.4	5.9	0.7	7.7
P4BK19	88.3	5.2	93.5	1.0	0.7	3.5	1.3	6.5
P4BK20	90.0	5.5	95.5	0.6	0.3	2.9	0.7	4.5
Mean	82.5	9.4	91.9	0.6	0.2	5.8	1.5	8.1
Standard dev.	12.3	6.7	9.8	0.5	0.1	7.4	1.9	9.8
Minimum	53.3	3.4	58.7	0.1	0.04	0.4	0.1	0.7
Maximum	94.7	33.5	99.3	3.1	0.7	31.7	9.5	41.4

^a Watts Branch (WB) samples are designated as WC in all lab sample reports

Table 5. Rationale for proposed forage fish thresholds and categories.

Threshold (ppb)	Color	Estimated game fish (ppb fillet)	MDE meal thresholds (ppb)	General population advisory
≤50	Green	≤40	21.25 to 42.49	≥4 meals/month
>50 ≤ 200	Yellow	>40≤160	>42.49 to 169.9	2-4 meals/month
>200 ≤ 400	Orange	>160≤320	169.99 to 339.99	1 meal/month
>400	Red	>320	>339.99	Do not consume

The estimated game fish fillet concentration is based on a food chain multiplier of 2 and a whole body/fillet ratio of 2.5 (M. Bokare, UMBC, personal communication)

Table 6. Samples identified as outliers for PCBs and total chlordane through Rosner's test. There were no mummichog PCB outliers. Concentrations are lipid-adjusted means.

Total PCBs				
Location	Sample ID	Conc. (ppb)	obs.res	stu.res
LB2	LB2BKM20L01	1210	413	5.17
LB2	LB2BKF20S01	577	-267	-2.98
P3	P3BKM20L02	688	454	5.41
Total Chlordane: BK				
LB2	LB2BKM20L01	221	83.1	6.10
Total Chlordane: MC				
LB2	LB2MCF20S01	133	-59.3	-2.65
LB2	LB2MCF20S02	139	-58.1	-2.58
LB2	LB2MCM20S03	346	149	10.2

Table 7. Separate and combined species model results for total PCBs. Analyses for banded killifish and for combined species performed without and with removal of three banded killifish outliers (see Table 6).

source	sum of squares	df	mean square	F-stat	p-value
Banded killifish					
Including three outliers (Slope estimate: 26.3)					
Collection ^a	8534346	27	316086	29.1	<0.0001
Lipid	22699	1	22699	2.10	0.15
Residuals	1096273	101	10854	NA	
Total	9653317	129	NA	NA	
After three outliers removed (Slope estimate: 53.6)					
Collection ^a	7885326	27	292049	49.6	<0.0001
Lipid	87119	1	87119	14.8	0.0002
Residuals	576619	98	5883	NA	
Total	8549065	126	NA	NA	
Mummichog					
Collection ^a	4026610	18	223700.55	57.4	<0.0001
Lipid	30352	1	30352.34	7.8	0.0069
Residuals	257374	66	3899.61	NA	
Total	4314337	85	NA	NA	
Slope estimate: 45.9					
Combined Species					
Including three banded killifish outliers (Slope estimate: 21.9)					
Species	1952	1	1952	0.21	0.65
Location/year ^b	12236355	30	407879	43.9	<0.0001
Lipid	29379	1	29379	3.16	0.08
Residuals	1701919	183	9300	NA	
Total	13969606	215	NA	NA	
After three banded killifish outliers removed (Slope estimate: 39.2)					
Species	18039	1	18039	3.02	0.084
Location/year ^b	11594405	30	386480	59.3	<0.0001
Lipid	87732	1	87732	13.4	0.0003
Residuals	1181264	180	6563	NA	
Total	12881440	212	NA	NA	

^a Collection= all samples of one species collected in one year.

^b Location/year= both BK and MC collections from one location in the same year.

Table 8. Comparison of model based lipid-adjusted mean concentrations of total PCBs (ppb wet weight) for **banded killifish** using Holm multiple comparison test with experiment-wise error rate of $p=0.05$. Adj: adjusted, SD: Standard Deviation; SE: standard error, LB: lower bound and UB: upper bound 95th percentile confidence intervals for the mean. See Table 1 for location/collection abbreviations.

Collection^a	N	Mean $\pm$SD	Adj. Mean	Adj mean SE	LB Est.	UB Est.	Group^b
LB1BK18	3	1110 $\pm$ 131	1102	60	982	1222	A
LB2BK18	5	913 $\pm$ 145	908	47	815	1000	A
LB2BK20	5	834 $\pm$ 239	817	48	722	912	AB
LB1BK20	6	588 $\pm$ 133	623	49	526	720	B
PCBK20	7	476 $\pm$ 123	480	40	402	559	BC
A1BK18	2	458 $\pm$ 21	436	75	287	585	BCD
LB1.5BK20	6	327 $\pm$ 110	355	47	262	447	C
KLBK18	1	376	341	107	129	553	BCD
NRBK20	2	354 $\pm$ 32	329	76	178	479	BCD
PCBK19	4	313 $\pm$ 155	309	52	206	413	CD
A2BK18	4	320 $\pm$ 66	296	55	188	404	CD
KHBK20	2	295 $\pm$ 76	268	76	118	419	BCD
WBBK18 ^c	2	272 $\pm$ 38	263	74	117	410	CD
A2BK20	4	224 $\pm$ 93	229	43	144	313	CD
KGBK20	4	224 $\pm$ 45	224	52	121	327	CD
11ABK20	6	196 $\pm$ 92	218	45	129	308	CD
P3BK20	6	238 $\pm$ 236	210	47	117	303	CD
11ABK19	13	193 $\pm$ 40	201	30	143	260	CD
DMBK20	6	95.5 $\pm$ 45.6	129	48	33	225	CD
KBBK20	5	167 $\pm$ 62	128	54	21	235	CD
BLBK18	6	119 $\pm$ 50	126	43	41	210	CD
P3BK19	1	89.5	110	105	-98.8	318	CD
BLBK20	6	103 $\pm$ 40	103	43	19	188	D
NEBK18	3	76.1 $\pm$ 9.5	64.1	60.8	-56.4	185	CD
KBBK19	8	48.8 $\pm$ 22.6	52.4	36.9	-20.8	126	D
NWBK18	4	54.0 $\pm$ 4.3	50.3	52.2	-53.1	154	D
P4BK19	3	29.3 $\pm$ 16.1	30.2	60.2	-89.1	150	D
P4BK20	4	42.3 $\pm$ 2.6	14.8	55.4	-95.1	125	D

^a Collection= all samples of one species collected in one year.

^b Groups with different letters are significantly different at $p<0.05$.

^c Watts Branch (WB) samples are designated as WC in all lab sample reports

Table 9. Comparison of model based lipid-adjusted mean concentrations of total PCBs (ppb wet weight) for **mummichogs** using Holm multiple comparison test with experiment-wise error rate of $p=0.05$. LB (Lower Bound) Estimate and UB (Upper Bound) Estimate: 95th percentile confidence intervals for the mean. See Table 1 for location/collection abbreviations.

Collection^a	N	Mean ±SD	Adj. Mean	Adj mean SE	LB Est.	UB Est.	Group^b
LB1MC18	5	726±79	732	28	676	788	A
LB2MC18	5	723±134	711	28	655	768	A
LB2MC20	6	650±63	585	34	517	654	AB
PCMC18	4	468±106	481	32	418	544	B
LB1MC20	6	313±66	361	31	300	422	BC
PCMC20	4	296±88	327	33	261	393	BC
PCMC19	3	252±67	281	38	207	356	C
NRMC20	6	308±83	279	27	224	334	C
WBMCI8 ^c	3	314±79	271	39	193	349	CD
KLMI8	3	233±34	246	36	174	319	CD
KGMI20	6	192±47	212	26	159	264	CD
KHMI20	6	181±41	191	26	139	242	CD
A2MI8	4	206±30	180	33	115	245	CD
A2MI20	2	109±62	142	46	51	233	CD
DCMI20	8	98.9±17.0	125	24	77	173	D
BLMI20	4	29.3±13.2	82.4	36.6	9.4	155	D
HRMI8	5	127±34	61.2	36.6	-11.9	134	D
NEMI8	2	47.9±7.0	59.0	44.3	-29.5	148	D
BLMI8	4	77.2±18.6	44.9	33.3	-21.6	111	D

^a Collection= all samples of one species collected in one year.

^b Groups with different letters are significantly different at $p<0.05$.

^c Watts Branch (WB) samples are designated as WC in all lab sample reports

Table 10. Comparison of model based mean concentrations of total PCBs (ppb wet weight) for **combined species**. Holm multiple comparison test with experiment-wise error rate of $p=0.05$. Number of samples per species; BK: banded killifish; MC: mummichog. See Table 1 for location/collection abbreviations.

Location/year ^a	BK n=	MC n=	Adjusted Mean	Group ^b
LB1/18	3	0	885	A
LB2/18	5	0	813	A
LB2/20	5	6	716	AB
PC/18	0	4	539	B
LB1/20	6	6	477	B
PC/20	7	4	401	BC
A1/18	2	0	375	BC
NR/20	2	6	336	BC
KL/18	1	3	299	BC
WB/18 ^c	2	3	295	BC
LB1.5/20	6	0	286	C
PC/19	4	3	282	C
A2/18	4	4	247	CD
KH/20	2	6	240	CD
KG/20	4	6	223	CD
DC/20	0	8	176	CD
A2/20	4	2	170	CD
HR/18	0	5	160	CD
11A/20	6	0	150	CD
P3/20	6	0	150	CD
11A/19	13	0	136	CD
BL/18	6	4	86.6	CD
BL/20	6	4	71.0	D
KB/20	5	0	70.3	CD
DM/20	6	0	59.0	D
NE/18	3	2	48.1	D
P3/19	1	0	42.0	CD
KB/19	8	0	-12.5	D
NW/18	4	0	-13.4	D
P4/19	3	0	-34.3	D
P4/20	4	0	-44.9	D

^a Location/year = both BK and MC collections from one location in the same year.

^b Groups with different letters are significantly different at $p<0.05$.

^c Watts Branch (WB) samples are designated as WC in all lab sample reports

Table 11. Provisional color categories^a for forage fish based on lipid-adjusted data with categories reflecting the combined species adjusted mean total PCB concentrations (ppb wet weight).

Location/year^b	BK adjusted mean	MC adjusted mean	Combined species adjusted mean/Color
LB1/18	1102/RED	732/RED	885/RED
LB2/18	908/RED	711/RED	813/RED
LB2/20	817/RED	585/RED	716/RED
PC/18	NO FISH	481/RED	539/RED
LB1/20	623/RED	361/ORANGE	477/RED
PC/20	480/RED	327/ORANGE	401/RED
A1/18	436/RED	NO FISH	375/ORANGE
NR/20	329/ORANGE	279/ORANGE	336/ORANGE
KL/18	341/ORANGE /	247/ORANGE	299/ORANGE
WB/18 ^c	263/ORANGE	271/ORANGE	295/ORANGE
LB1.5/20	355/ORANGE	NO FISH	286/ORANGE
PC/19	309/ORANGE /	281/ORANGE	282/ORANGE
A2/18	296/ORANGE	180/YELLOW	247/ORANGE
KH/20	268/ORANGE	191/YELLOW	240/ORANGE
KG/20	224/ORANGE	212/ORANGE	223/ORANGE
DC/20	NO FISH	125/YELLOW	176/YELLOW
A2/20	228/ORANGE	142/YELLOW	170/YELLOW
HR/18	NO FISH	61.2/YELLOW	160/YELLOW
11A/20	218/ORANGE	NO FISH	150/YELLOW
P3/20	210/ORANGE	NO FISH	150/YELLOW
11A/19	201/ORANGE	NO FISH	136/YELLOW
BL/18	126/YELLOW	44.9/ GREEN	86.6/YELLOW
BL/20	103/YELLOW	82.4/ YELLOW	71.0/YELLOW
KB/20	128/YELLOW	NO FISH	70.3/YELLOW
DM/20	129 YELLOW	NO FISH	59.0/YELLOW
NE/18	64.1/YELLOW	59.0/YELLOW	48.1/GREEN
P3/19	110/YELLOW	NO FISH	42.0/GREEN
KB/19	52.4/YELLOW	NO FISH	-12.5/GREEN
NW/18	50.3/YELLOW	NO FISH	-13.4/GREEN
P4/19	30.2/GREEN	NO FISH	-34.3/GREEN
P4/20	14.8/GREEN	NO FISH	-44.9/GREEN

^a Green: ≤ 50 ppb, Yellow: > 50 ppb and ≤ 200 ppb; Orange: > 200 ppb and ≤ 400 ppb, Red: > 400 ppb

^b Location/year = both BK and MC collections from one location in the same year.

^c Watts Branch (WB) samples are designated as WC in all lab sample reports

Table 12. Separate and combined species model results for total chlordane. Analyses for banded killifish, mummichogs and for combined species performed without and with removal of one banded killifish and three mummichog outliers (see Table 6).

source	sum of squares	df	mean square	F-stat	p-value
Banded killifish					
With outlier (Slope estimate: 26.2)					
Collection ^a	274530	27	10168	29.9	<0.0001
Lipid	22446	1	22446	65.9	<0.0001
Residuals	34395	101	340.5	NA	
Total	331371	129	NA	NA	
With outlier removed (Slope estimate: 31.0)					
Collection ^a	257187	27	9525	38.0	<0.0001
Lipid	29091	1	29091	116.1	<0.0001
Residuals	25059	100	250.6	NA	
Total	311337	128	NA	NA	
Mummichog					
With outliers (Slope estimate: 20.8)					
Collection ^a	151491	18	8416	12.7	<0.0001
Lipid	6231	1	6231	9.41	0.0031
Residuals	43698	66	662	NA	
Total	201420	85	NA	NA	
With outliers removed (Slope estimate: 20.7)					
Collection ^a	88928	18	4940	22.0	<0.0001
Lipid	6053	1	6052	27.0	<0.0001
Residuals	14164	63	225	NA	
Total	109145	82	NA	NA	
Combined Species					
With outliers (Slope estimate: 24.1)					
Species	13595	1	13595	27.0	<0.0001
Location/year ^b	404926	30	13498	26.8	<0.0001
Lipid	35613	1	35613	70.6	<0.0001
Residuals	92252	183	504	NA	
Total	546387	215	NA	NA	
With outliers removed (Slope estimate: 26.0)					
Species	20718	1	20718	68.0	<0.0001
Location/year ^b	327449	30	10915	35.8	<0.0001
Lipid	38518	1	38518	126.5	<0.0001
Residuals	54516	179	304.6	NA	
Total	441200	211	NA	NA	

^a Collection= all samples of one species collected in one year.

^b Location/year= both BK and MC collections from one location in the same year.

Table 13. Comparison of model based mean concentrations of total chlordane (ppb wet weight) for **banded killifish** using Holm multiple comparison test with experiment-wise error rate of $p=0.05$. Adj: adjusted, SE: standard error, LB: lower bound and UB: upper bound 95th c percentile confidence intervals for the mean. See Table 1 for location/collection abbreviations.

Collection ^a	N	Mean $\pm$ SD	Adjusted Mean	Adj mean SE	LB Est.	UB Est.	Group ^b
A1BK18	2	218 $\pm$ 12	197	13	170	223	A
NWBK18	4	165 $\pm$ 39	161	9	143	179	A
LB2BK20	6	174 $\pm$ 49	159	8	142	175	A
NEKB18	3	160 $\pm$ 35	148	11	126	169	AB
LB2BK18	5	146 $\pm$ 41	140	8	124	157	AB
BLBK18	6	99.4 $\pm$ 29.7	105	8	90.4	120	B
LB1BK18	3	105 $\pm$ 21	96.2	10.7	75.0	117	BC
A2BK18	4	120 $\pm$ 25	96.2	9.7	77.0	115	BC
A2BK20	6	89.1 $\pm$ 37.5	93.8	7.6	78.8	109	BC
WBBK18 ^c	2	102 $\pm$ 22	93.1	13.1	67.1	119	BC
BLBK20	6	91.5 $\pm$ 13.2	91.6	7.5	76.6	106	BC
PCBK20	7	84.0 $\pm$ 27.0	88.8	7.0	74.9	103	BC
11ABK20	6	64.4 $\pm$ 20.8	86.0	8.0	70.1	102	BC
11ABK19	13	73.3 $\pm$ 14.4	81.9	5.2	71.5	92.2	BC
KLBK18	1	116	81.5	18.9	43.9	119	BC
LB1BK20	6	44.8 $\pm$ 20.1	79.7	8.7	62.5	96.9	BC
LB1.5BK20	6	51.6 $\pm$ 19.0	78.9	8.2	62.6	95.3	BC
PCBK19	4	69.6 $\pm$ 22.6	66.1	9.2	47.7	84.4	BC
KGBK20	4	64.4 $\pm$ 17.0	64.3	9.2	46.0	82.6	BC
KBBK20	5	91.8 $\pm$ 9.3	52.5	9.6	33.6	71.5	C
DMBK20	6	17.7 $\pm$ 7.1	51.1	8.6	34.0	68.1	CD
NRBK20	2	75.6 $\pm$ 15.6	50.7	13.4	24.1	77.3	BCD
P3BK19	1	28.7	48.8	18.6	11.9	85.8	BCD
KHBK20	2	67.6 $\pm$ 27.3	41.6	13.4	14.9	68.2	CD
P4BK19	3	31.1 $\pm$ 15.2	31.9	10.6	10.8	53.1	CD
KBBK19	8	24.1 $\pm$ 6.1	27.7	6.5	14.8	40.7	CD
P4BK20	4	24.7 $\pm$ 3.4	-2.5	9.8	-22.0	17.0	D
P3BK20	6	21.0 $\pm$ 2.6	-7.3	8.3	-23.7	9.2	D

^a Collection= all samples of one species collected in one year.

^b Groups with different letters are statistically different at $p<0.05$.

^c Watts Branch (WB) samples are designated as WC in all lab sample reports

Table 14. Comparison of model based mean concentrations of total chlordane (ppb wet weight) for **mummichogs** using Holm multiple comparison test with experiment-wise error rate of $p=0.05$. Adj: adjusted, SE: standard error, LB: lower bound and UB: upper bound 95th c percentile confidence intervals for the mean. See Table 1 for location abbreviations.

Collection^a	N	Mean $\pm$SD	Adjusted Mean	Adj mean SE	LB Est.	UB Est.	Group^b
LB2MC20	5	1995 $\pm$ 85	170	14	141	198	A
NEMC18	2	102 $\pm$ 31	107	18	71	144	AB
LB2MC18	5	97.3 $\pm$ 9.8	91.8	11.6	68.6	115	B
WBMCMC18 ^c	3	85.9 $\pm$ 9.4	66.3	16.2	34.1	98.6	B
PCMC18	4	59.0 $\pm$ 13.7	64.8	13.0	38.8	90.7	B
KGMC20	6	53.9 $\pm$ 18.4	62.9	10.9	41.1	84.6	B
KLMC18	3	53.7 $\pm$ 12.0	59.8	15.0	29.9	89.8	B
PCMC19	3	45.4 $\pm$ 5.9	58.6	15.5	27.8	89.5	B
LB1MC18	5	54.1 $\pm$ 20.6	57.1	11.6	34.0	80.1	B
NRMC20	6	68.1 $\pm$ 23.7	55.3	11.3	32.7	77.8	B
LB1MC20	6	32.2 $\pm$ 16.1	54.0	12.7	28.7	79.3	B
BLMC18	4	66.0 $\pm$ 23.0	51.4	13.7	24.0	78.7	B
BLMC20	4	25.9 $\pm$ 4.1	49.9	15.1	19.8	80.0	B
A2MC18	4	60.8 $\pm$ 7.8	49.4	13.4	22.6	76.1	B
A2MC20	2	33.6 $\pm$ 14.2	48.5	18.8	10.9	86.1	B
PCMC20	4	31.5 $\pm$ 9.0	45.5	13.6	18.2	72.7	B
DCMC20	8	32.8 $\pm$ 8.6	44.6	9.9	24.9	64.4	B
KHMC20	6	38.9 $\pm$ 6.9	43.4	10.6	22.2	64.6	B
HRMC18	5	62.7 $\pm$ 9.0	32.7	15.1	2.6	62.9	B

^a Collection= all samples of one species collected in one year.

^b Groups with different letters are statistically different at $p<0.05$.

^c Watts Branch (WB) samples are designated as WC in all lab sample reports

Table 15. Comparison of model based mean concentrations of total chlordane (ppb wet weight) for **combined species**; Holm multiple comparison test with experiment-wise error rate of $p=0.05$. Number of samples per species; BK: banded killifish; MC: mummichog.

Location/year ^a	BK n=	MC n=	Adjusted Mean	Group ^b
A1/18	2	0	185	A
LB2/20	5	6	164	A
NW/18	4	0	148	AB
NE/18	3	2	130	AB
LB2/18	5	0	116	B
BL/18	6	4	79.9	BC
PC/18	0	4	79.2	BC
WB/18 ^c	2	3	78.2	BC
A2/20	4	2	76.0	BC
LB1/18	3	0	75.7	BC
BL/20	6	4	73.7	C
KL/18	1	3	73.4	BC
A2/18	4	4	72.8	C
11A/20	6	0	70.7	BC
PC/20	7	4	69.9	C
11A/19	13	0	67.6	C
LB1/20	6	6	67.2	C
KG/20	4	6	67.0	C
LB1.5/20	6	0	63.2	C
PC/19	4	3	62.0	C
DC/20	0	8	60.0	C
NR/20	2	6	59.9	C
KH/20	2	6	50.7	CD
KB/20	5	0	42.1	CD
HR/18	0	5	41.6	CD
DM/20	6	0	34.8	CD
P3/19	1	0	33.7	BCD
P4/19	3	0	18.3	CD
KB/19	8	0	13.9	D
P4/20	4	0	-13.9	D
P3/20	6	0	-18.6	D

^a Location/year = both BK and MC collections from one location in the same year.

^b Groups with different letters are significantly different at $p<0.05$.

^c Watts Branch (WB) samples are designated as WC in all lab sample reports

Table 16. PCB concentration data and calculated percentages of cumulative cancer risk assigned to PCBs, dioxins and furans, and total chlordane in 2014 – 2016 whole fish and fillet data for the Anacostia River Sediment Project Remedial Investigation (Tetra Tech 2019a, Appendix K). Cumulative risk based on DNREC/DHSS 2017, J. Cargill, DNREC, personal communication).

	Total PCBs (ppb)	Risk contribution (percent)		
Sample ID		PCBs	Dioxins/Furans	Chlordane
Fillets 2016 (n=18)				
P2-IC-008-GTA	33.9	97.0	1.5	1.5
P2-IC-009-GT1A+GT2A ^a	20.5	76.3	17.7	6.0
P2-IC-010-GT2A+GT3A ^a	46.5	86.7	10.5	2.8
P2-NEB-007-GTA	41.1	97.4	2.0	0.6
P2-NEB-011-GTA	43.3	93.4	2.3	4.3
P2-NEB-012-GTA	46.0	96.2	1.6	2.2
P2-NWB-001-	28.4	88.1	4.0	7.9
P2-NWB-002-	19.0	87.5	8.5	4.0
P2-NWB-003-GTA	41.2	88.2	8.4	3.4
P2-NWB-004-GT2A	18.0	87.9	6.7	5.5
P2-NWB-013-	23.4	84.3	9.0	6.8
P2-NWB-014-GTA	9.5	76.0	12.6	11.4
P2-NWB-015-GTA	16.9	92.3	1.7	6.0
P2-NWB-016-GTA	30.2	83.2	13.0	3.7
P2-NWB-017-GTA	18.4	75.5	17.5	7.0
P2-NWB-018-GT1A	17.7	68.5	20.1	11.4
P2-PB-005-GT1A+GT2A ^a	29.3	82.7	12.4	4.9
P2-PB-006-GTA	53.5	91.3	8.7	0.0
Mean		86.3	8.8	5.0
Standard Deviation		8.1	5.9	3.2
Minimum		68.5	1.5	0.0
Maximum		97.4	20.1	11.4
Whole Body 2014&15 (n=122)				
RI-KL-FT-16-GF	290	97.1	1.3	1.5
RI-KL-FT-18-GF	334	97.6	1.0	1.4
RI-KL-FT-21-GF	294	96.7	1.9	1.4
RI-KL-FT-21-GM	259	98.1	1.0	0.9
RI-KL-FT-25-GF	341	97.0	1.6	1.4
RI-R3-FT-12-GF	207	95.4	2.6	2.1
RI-R3-FT-14-GF	334	97.5	1.5	1.0
RI-R4-FT-15-GF	323	96.3	2.5	1.2
RI-R4-FT-15-GM	417	97.7	1.8	0.5
RI-R4-FT-17-GF	321	96.6	2.1	1.3
RI-R5-FT-19-GF	321	94.8	3.0	2.2
RI-R6-FT-28-GF	284	93.7	5.1	1.1
RI-R6-FT-30-GF	438	96.7	2.2	1.2
RI-R6-FT-31-GF	502	96.4	2.0	1.6

Table 16 (continued)				
	Total PCBs (ppb)	Risk contribution (percent)		
		PCBs	Dioxins/Furans	Chlordane
RI-R7-FT-32-GF	404	95.8	2.9	1.3
RI-R7-FT-33-GF	225	95.3	2.4	2.3
RI-R7-FT-34-GF	174	96.9	1.5	1.6
RI-R7-FT-35-GF	125	96.5	1.6	1.9
RI-R7-FT-36-GF	132	95.1	2.4	2.5
RI-R7-FT-37-GF	157	95.8	1.6	2.6
RI-R7-FT-38-GF	216	96.7	1.2	2.1
RI-R7-FT-40-GF	91.7	97.7	0.7	1.6
RI-R7-FT-41-GF	92.1	94.7	1.8	3.5
RI-R7-FT-42-GF	147	96.3	1.5	2.2
RI-R7-FT-43-GF	122	95.6	1.9	2.5
RI-R7-FT-44-GF	96.5	95.6	2.0	2.4
RI-R7-FT-45-GF	130	97.0	1.4	1.6
RI-R7-FT-46-GF	72.8	97.3	1.4	1.3
RI-R7-FT-46-GT	71.3	87.2	5.8	7.0
RI-KL-FT-16-GM	368	96.7	2.8	0.5
RI-KL-FT-16-GT	454	98.8	0.9	0.4
RI-KL-FT-18-GM	365	98.6	1.0	0.4
RI-KL-FT-18-GT	432	98.0	1.2	0.8
RI-KL-FT-20-GF	300	98.4	1.0	0.6
RI-KL-FT-20-GM	304	97.6	2.0	0.4
RI-KL-FT-20-GT	462	95.0	4.5	0.5
RI-KL-FT-21-GT	656	95.9	3.3	0.8
RI-KL-FT-23-GF	308	95.5	3.4	1.1
RI-KL-FT-23-GM	199	97.0	2.5	0.5
RI-KL-FT-24-GF	354	99.1	0.7	0.2
RI-KL-FT-24-GM	261	97.3	1.6	1.0
RI-KL-FT-24-GT	399	96.7	2.1	1.1
RI-KL-FT-26-GF	395	91.9	6.6	1.6
RI-KL-FT-27-GF	396	89.8	8.9	1.3
RI-KL-FT-27-GM	276	94.4	4.9	0.7
RI-KL-FT-27-GT	615	95.3	4.2	0.5
RI-R1-FT-07-GF	174	96.9	2.2	0.9
RI-R1-FT-07-GM	274	98.6	0.9	0.5
RI-R1-FT-07-GT	420	94.1	5.6	0.3
RI-R1-FT-08-GF	178	97.2	1.8	1.0
RI-R1-FT-08-GM	415	95.7	3.7	0.6
RI-R1-FT-08-GT	141	98.3	1.3	0.3
RI-R1-FT-09-GF	260	97.2	1.4	1.3
RI-R1-FT-09-GM	551	94.8	4.1	1.1
RI-R1-FT-09-GT	457	95.7	2.7	1.5

Table 16 (continued)				
	Total PCBs (ppb)	Risk contribution (percent)		
		PCBs	Dioxins/Furans	Chlordanee
RI-R1-FT-10-GF	329	95.1	3.3	1.6
RI-R1-FT-10-GM	339	94.0	4.8	1.2
RI-R1-FT-10-GT	552	93.8	5.9	0.3
RI-R3-FT-11-GF	238	96.9	1.7	1.4
RI-R3-FT-11-GM-A +GM-	403	95.3	3.6	1.1
RI-R3-FT-11-GT	1858	96.0	3.5	0.5
RI-R3-FT-12-GM	490	97.4	1.6	1.1
RI-R3-FT-12-GT	1369	96.3	3.2	0.5
RI-R3-FT-13-GF	363	96.8	1.6	1.7
RI-R3-FT-13-GM	313	98.0	1.5	0.5
RI-R3-FT-13-GT	1483	97.2	2.5	0.3
RI-R3-FT-14-GM	302	97.7	1.5	0.8
RI-R3-FT-14-GT	898	98.5	1.2	0.3
RI-R4-FT-15-GT	748	94.8	4.7	0.6
RI-R4-FT-17-GM	435	95.2	4.1	0.8
RI-R4-FT-17-GT	1738	92.7	6.4	0.9
RI-R5-FT-19-GM	300	96.4	2.7	0.9
RI-R5-FT-19-GT	406	95.9	3.5	0.6
RI-R5-FT-22-GF	362	95.0	3.9	1.2
RI-R5-FT-22-GM	385	98.5	1.1	0.4
RI-R5-FT-22-GT	581	98.6	0.9	0.5
RI-R6-FT-28-GM	390	98.8	0.4	0.8
RI-R6-FT-28-GT	865	96.6	2.9	0.5
RI-R6-FT-29-GF	263	99.4	0.3	0.3
RI-R6-FT-29-GM	233	98.1	1.4	0.5
RI-R6-FT-29-GT	496	99.0	0.6	0.4
RI-R6-FT-30-GM	487	97.5	1.3	1.2
RI-R6-FT-31-GM	375	97.1	2.1	0.8
RI-R6-FT-31-GT	134	94.9	3.8	1.3
RI-R7-FT-32-GM	288	94.9	4.1	1.0
RI-R7-FT-32-GT	523	97.5	2.1	0.4
RI-R7-FT-33-GM	190	97.6	1.4	0.9
RI-R7-FT-33-GT	134	92.6	6.0	1.3
RI-R7-FT-34-GM	542	98.5	1.0	0.5
RI-R7-FT-34-GT	966	97.4	1.8	0.7
RI-R7-FT-35-GM	241	97.7	2.3	0.0
RI-R7-FT-35-GT	447	98.1	1.2	0.8
RI-R7-FT-36-GM	162	97.6	1.8	0.6
RI-R7-FT-36-GT	312	95.2	4.2	0.6
RI-R7-FT-37-GM	129	98.0	1.2	0.8
RI-R7-FT-37-GT	180	94.5	2.9	2.6

Table 16 (continued)				
	Total PCBs (ppb)	Risk contribution (percent)		
		PCBs	Dioxins/Furans	Chlordane
RI-R7-FT-38-GM	166	96.8	2.1	1.1
RI-R7-FT-38-GT	476	97.2	2.0	0.7
RI-R7-FT-39-GF	105	95.6	2.4	2.0
RI-R7-FT-39-GM	106	97.3	1.4	1.3
RI-R7-FT-39-GT	333	97.3	1.5	1.2
RI-R7-FT-40-GM	103	98.7	0.6	0.7
RI-R7-FT-41-GM	135	98.4	1.0	0.6
RI-R7-FT-41-GT	320	97.5	1.8	0.7
RI-R7-FT-42-GM	163	99.0	0.004	1.0
RI-R7-FT-42-GT	184	97.6	1.1	1.2
RI-R7-FT-43-GM	163	92.8	5.8	1.4
RI-R7-FT-44-GM	205	97.8	1.6	0.6
RI-R7-FT-44-GT	264	95.4	2.9	1.7
RI-R7-FT-45-GM	121	97.6	1.1	1.3
RI-R7-FT-45-GT	354	92.2	6.6	1.2
RI-R7-FT-46-GM	159	97.8	1.3	0.8
RI-WC-FT-01-GM	202	96.9	2.3	0.7
RI-WC-FT-01-GT	597	95.9	4.1	0.0
RI-WC-FT-02-GM	414	97.2	2.8	0.0
RI-WC-FT-02-GT	1386	98.8	1.0	0.2
RI-WC-FT-04-GF	105	92.8	4.2	3.0
RI-WC-FT-04-GM	294	96.9	2.5	0.6
RI-WC-FT-04-GT	360	97.7	1.5	0.8
RI-WC-FT-05-GF	139	96.2	1.4	2.3
RI-WC-FT-05-GM	254	98.8	0.7	0.5
RI-WC-FT-05-GT	1085	98.2	1.6	0.2
Mean (2014/2015, n=122)		96.5	2.4	1.1
Standard Deviation		1.9	1.6	0.9
Minimum		87.2	0.004	0.0
Maximum		99.4	8.9	7.0
Whole Body 2016 (n=38)				
P2-IC-005-GM	233	89.3	7.9	2.8
P2-IC-006-GM	77.2	86.9	4.7	8.4
P2-IC-017-GM	105	91.7	4.7	3.6
P2-IC-018-GM	76.7	94.5	3.2	2.3
P2-IC-019-GM	112	81.4	12.2	6.4
P2-IC-020-GM	208	91.2	6.6	2.3
P2-LPB-001-GM	89.5	81.8	9.6	8.6
P2-LPB-002-GM	100	84.4	9.3	6.4
P2-LPB-011-GM	108	86.1	6.7	7.2
P2-LPB-012-GM	82.4	84.3	9.6	6.1

Table 16 (continued)				
	Total PCBs (ppb)	Risk contribution (percent)		
		PCBs	Dioxins/Furans	Chlordane
P2-NEB-015-GM	134	89.2	7.4	3.4
P2-NEB-016-GM	143	89.0	6.8	4.3
P2-NWB-007-GM	61.7	84.2	7.7	8.1
P2-NWB-008-GM	79.8	82.4	7.3	10.3
P2-NWB-009-GM	33.3	72.3	17.8	9.8
P2-NWB-010-GM	83.6	88.2	5.4	6.4
P2-PB-003-GM	265	87.3	8.5	4.2
P2-PB-004-GM	165	93.7	3.1	3.2
P2-PB-013-GM	184	91.9	5.6	2.5
P2-PB-014-GM	107	92.7	3.9	3.4
P2-IC-008-GT	150	87.5	9.9	2.5
P2-IC-009-GT1+GT2	126	84.7	10.1	5.2
P2-IC-010-GT2+GT3	174	80.5	15.4	4.1
P2-NEB-007-GT	239	86.9	10.1	3.0
P2-NEB-011-GT	245	91.0	6.8	2.2
P2-NEB-012-GT	236	91.7	6.4	1.9
P2-NWB-001-GT1+GT2	149	79.6	12.0	8.4
P2-NWB-002-	161	81.4	11.3	7.2
P2-NWB-003-GT	561	88.1	8.8	3.2
P2-NWB-004-GT2	85.7	76.4	15.0	8.6
P2-NWB-013-	87.8	80.0	10.3	9.7
P2-NWB-014-GT	87.1	82.4	12.3	5.3
P2-NWB-015-GT	73.2	78.9	12.1	9.0
P2-NWB-016-GT	148	83.5	10.0	6.5
P2-NWB-017-GT	125	83.7	9.7	6.6
P2-NWB-018-GT1	82.9	64.6	24.8	10.6
P2-PB-005-GT1+GT2	140	75.9	16.2	7.9
P2-PB-006-GT	271	81.7	14.0	4.4
Mean (2016, n=38)		84.8	9.6	5.7
Standard Deviation		6.2	4.4	2.7
Minimum		64.6	3.1	1.9
Maximum		94.5	24.8	10.6
Whole body data (2014-2016, n=160)				
Mean		93.7	4.1	2.2
Standard Deviation		6.1	4.0	2.5
Minimum		64.6	0.004	0.0
Maximum		99.4	24.8	10.6

Table 17. Pre-remedial lipid-adjusted total PCB (ppb wet weight) and standardized lipid concentration data. Data from collections at the same location are pooled across years. Results of the power analysis computer simulation are provided for locations in bold that span a range of concentrations in Tables 18 and 19 (see Appendix D for results for all locations).

Mummichogs				
Location	prePCB	sdPCB	preLipid	sdLipid
A2	174	62	0.13	0.71
DC ACROSS FROM DUELING CRK	98.9	17.1	-0.57	0.59
BLADENSBURG (Main Ana)	53.8	30.0	-0.23	1.05
HICKEY RUN	137	32	1.44	0.8
KING UP TO E CAP	234	34	-0.3	0.14
KINGMAN GOLF	192	47	-0.43	0.48
KINGMAN HERIT	181	41	-0.22	0.3
LOW BEAVERDAM 1	502	228	-0.64	0.61
LOW BEAVERDAM2	685	104	0.89	0.71
NASH RUN	307	83	0.62	0.31
NORTHEAST BRANCH	48.4	7.0	-0.24	0.05
PEPCO COVE (Main Ana)	348	128	-0.52	0.4
WATTS BRANCH	316	79	0.94	0.95
Banded killifish				
11A (Main Ana)	194	58	-0.48	0.35
A1 (Poplar Point Main Ana)	460	22	0.83	0.23
A2 (Main Ana)	262	94	0.25	0.87
BLADENSBURG (Main Ana)	112	44	-0.12	0.66
DYKE MARSH (Pot)	95.4	45.6	-1.28	0.17
FLETCHERS (Potomac)	36.6	11.6	0.58	0.79
KEY BRIDGE (Potomac)	94.4	72.0	0.49	0.95
KING UP TO E CAP	378	75	1.32	0.45
KINGMAN GOLF	224	45	0.01	0.65
KINGMAN HERIT	294	76	1	0.45
LOW BEAVERDAM 1	763	290	-0.78	0.91
LOW BEAVERDAM 1.5	327	110	-1.05	0.34
LOW BEAVERDAM 2	875	190	0.42	0.94
NASH RUN	353	31	0.95	0.38
NORTHEAST BRANCH	77.1	9.5	0.47	0.86
NORTHWEST BRANCH	54.3	4.4	0.14	0.41
PEPCO COVE (Main Ana)	416	152	-0.07	0.67
THEO ROOSE IS (Pot)	217	223	0.82	0.8
WATTS BRANCH	273	38	0.33	0.7

Table 18. Power analysis for decreases in lipid-adjusted total PCBs based on computer simulation for **mummichogs** at selected locations. Data from collections at the same location are pooled across years. Power ≥ 0.8 shown in bold. For each location, the lowest effect size that can be detected with power ≥ 0.8 and $\alpha=0.05$ are shown in bold italics.

Location	Pre-remediation lipid-adjusted tPCBs mean $\pm$ SD (ppb) Coefficient of Variation in parentheses	Effect Size ^a	Post-remed. tPCBs Mean ppb	Power $\alpha=0.05$	Power $\alpha=0.10$	Power $\alpha=0.05$	Power $\alpha=0.10$	Power $\alpha=0.05$	Power $\alpha=0.10$
				Sample size=5		Sample size=10		Sample size=15	
DC	98.9 $\pm$ 17.1 (17%)	0.25	74.2	0	0	0	0	0	0
		0.5	49.4	0	0	0	0	0	0
		0.75	24.7	0	0	0.05	0.42	0.37	0.84
BLAD	53.8 $\pm$ 30.0 (56%)	0.25	40.4	0	0	0	0	0	0
		0.5	26.9	0	0	0	0	0	0
		0.75	13.4	0	0	0	0	0	0
KG	192 $\pm$ 47 (24%)	0.25	144	0	0	0	0	0	0
		0.5	96	0.01	0.05	0.1	0.3	0.22	0.51
		0.75	48	0.49	0.76	0.96	0.99	1	1
LB1	502 $\pm$ 228 (45%)	0.25	376	0.52	0.57	0.69	0.73	0.78	0.82
		0.5	251	0.89	0.91	0.99	0.99	1	1
		0.75	126	0.99	0.99	1	1	1	1
LB2	685 $\pm$ 104 (15%)	0.25	514	0.31	0.42	0.63	0.74	0.8	0.88
		0.5	342	1	1	1	1	1	1
		0.75	171	1	1	1	1	1	1
PC	348 $\pm$ 128 (37%)	0.25	261	0.23	0.3	0.42	0.5	0.55	0.65
		0.5	174	0.81	0.86	0.97	0.99	1	1
		0.75	87	0.99	1	1	1	1	1

^a Effect sizes of 0.25, 0.5, and 0.75 are equivalent to decreases of 25, 50, and 75 percent.

Table 19. Power analysis for decreases in lipid-adjusted total PCBs based on computer simulation for **banded killifish** at selected locations. Data from collections at the same location are pooled across years. Power ≥ 0.8 shown in bold. For each location, the lowest effect size that can be detected with power ≥ 0.8 and $\alpha=0.05$ are shown in bold italics.

Location	Pre-remediation lipid-adjusted tPCBs mean $\pm$ SD (ppb); Coefficient of Variation in parentheses	Effect Size ^a	Post-remed. tPCBs Mean ppb	Power $\alpha=0.05$	Power $\alpha=0.10$	Power $\alpha=0.05$	Power $\alpha=0.10$	Power $\alpha=0.05$	Power $\alpha=0.10$
				Sample size=5		Sample size=10		Sample size=15	
11A	194 $\pm$ 58 (30%)	0.25	146	0	0	0	0	0	0
		0.5	97	480	0.02	0.12	0.23	0.31	0.52
		0.75	48	0.29	0.48	0.89	0.96	0.99	1
DM	95.4 $\pm$ 45.6 (48%)	0.25	72	0	0	0	0	0	0
		0.5	48	0	0	0	0	0	0
		0.75	24	0	0	0	0	0	0.01
LB1	763 $\pm$ 290 (38%)	0.25	572	0.55	0.6	0.71	0.75	0.79	0.82
		0.5	382	0.94	0.96	1	1	1	1
		0.75	191	1	1	1	1	1	1
LB1.5	327 $\pm$ 110 (34%)	0.25	245	0.03	0.04	0.03	0.06	0.02	0.05
		0.5	164	0.3	0.42	0.63	0.76	0.8	0.9
		0.75	82	0.88	0.93	1	1	1	1
LB2	875 $\pm$ 190 (22%)	0.25	656	0.56	0.6	0.76	0.82	0.89	0.93
		0.5	438	1	1	1	1	1	1
		0.75	219	1	1	1	1	1	1
PC	416 $\pm$ 152 (37%)	0.25	312	0.1	0.14	0.15	0.2	0.22	0.3
		0.5	208	0.61	0.69	0.89	0.92	0.97	0.98
		0.75	104	0.97	0.99	1	1	1	1

^a Effect sizes of 0.25, 0.5, and 0.75 are equivalent to decreases of 25, 50, and 75 percent.

Table S1. Comparison of PCB homolog distributions (percent) in forage fish, caged *Elliptio complanata* mussels, and surface water and pore water passive samplers.^a

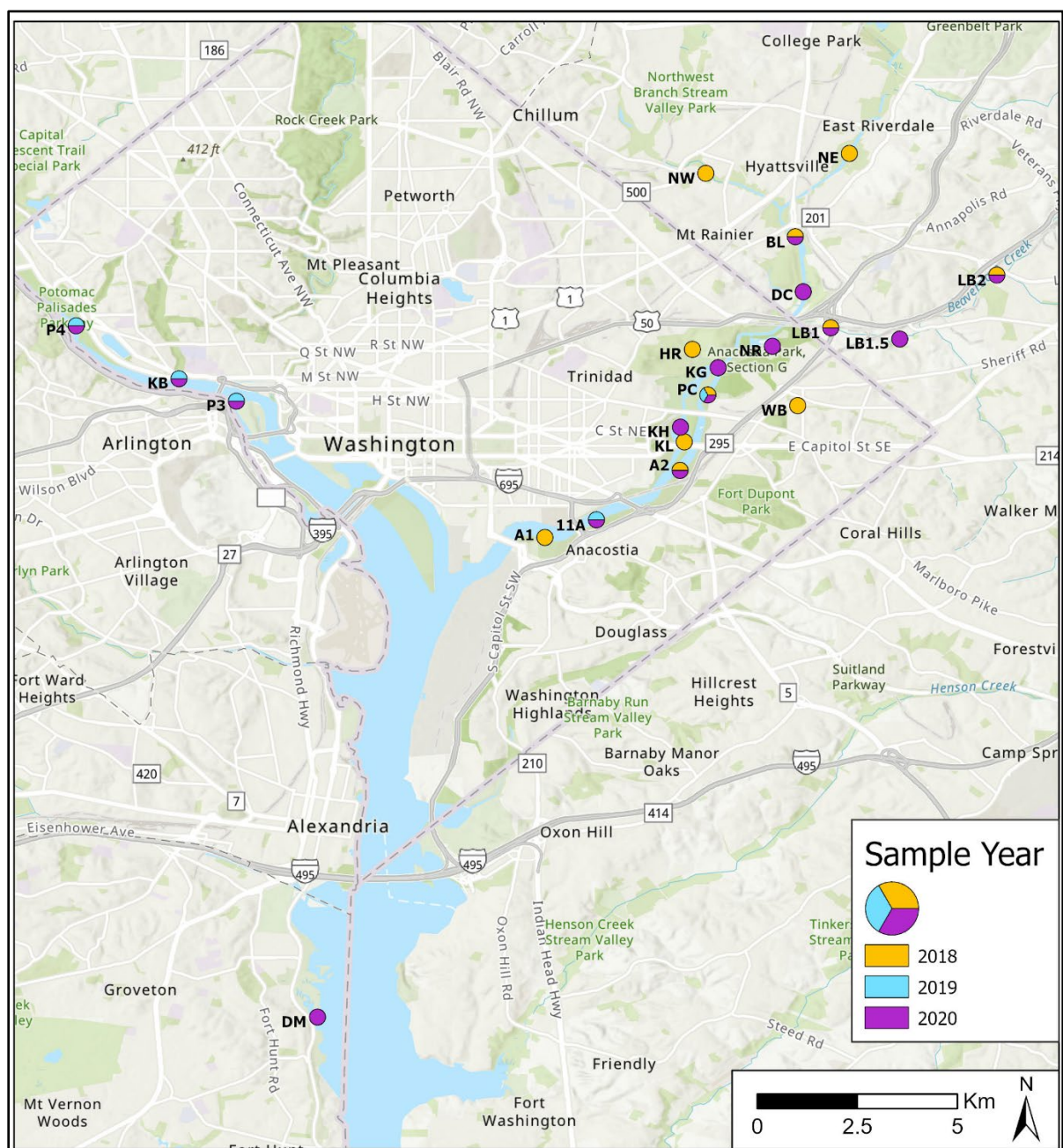
	Forage Fish								
	di	tri	tetra	penta	hexa	hepta	octa	sum: di—tetra	sum: penta—octa
LB1BK18	3.0	18.9	28.7	20.1	19.7	7.9	1.5	50.7	49.3
LB1BK20	1.3	15.3	28.1	25.6	20.7	7.4	1.6	44.7	55.3
LB1MC18	4.4	25.3	29.4	17.3	15.4	6.7	1.5	59.1	40.9
LB1MC20	1.1	14.1	29.6	24.6	19.8	8.7	2.1	44.8	55.2
LB1.5BK20	1.6	9.5	28.3	25.5	22.0	11.0	2.1	39.5	60.5
LB2BK18	3.8	16.5	47.6	24.2	5.9	1.8	0.3	67.9	32.1
LB2BK20	4.4	20.0	43.5	23.1	6.3	2.2	0.5	67.9	32.1
LB2MC18	4.7	20.1	45.4	21.2	5.9	2.2	0.4	70.2	29.8
LB2MC20	4.5	22.8	42.0	21.2	6.5	2.5	0.5	69.3	30.7
NEBK18	0.7	3.5	6.1	20.1	44.5	20.9	4.1	10.3	89.7
NEMC18	0.5	3.4	6.0	17.9	43.4	24.2	4.7	9.9	90.1
NWBK18	0.0	3.3	13.8	32.0	35.6	12.5	2.7	17.2	82.8
HRMC18	0.0	3.2	13.9	23.0	35.7	20.0	4.1	17.1	82.9
WBBK18	0.1	2.4	12.3	44.6	34.2	5.6	0.8	14.8	85.2
WBMC18	0.1	1.6	9.6	43.4	37.5	6.7	1.0	11.3	88.7
	Caged <i>Elliptio complanata</i> mussels								
LB1	0.1	8.9	29.7	27.5	17.5	14.3	1.8	38.7	61.1
LB1.5	0.0	5.6	30.1	35.9	18.0	8.2	2.0	35.7	64.1
LB2	2.5	16.3	44.2	29.0	5.5	1.9	0.5	63.0	36.9
NE	0.0	0.3	6.0	57.0	21.3	11.6	3.5	6.3	93.4
NW	0.1	0.3	7.3	70.2	14.7	5.3	1.5	7.7	91.7
HR	0.0	0.1	6.6	44.2	28.0	15.9	4.6	6.7	92.7
WB	0.0	1.6	19.5	50.5	21.9	5.4	0.8	21.1	78.6
	Passive samplers: Surface water								
LB1	12.1	40.7	38.8	7.2	0.9	0.3	0.0	91.6	8.4
LB1.5	14.4	35.4	39.9	9.2	0.9	0.1	0.0	89.7	10.2
LB2	40.4	36.1	20.8	2.6	0.1	0.0	0.0	97.3	2.7
NE	0.0	5.4	34.0	49.2	9.5	1.7	0.2	39.4	60.6
NW	0.5	8.1	33.9	51.8	5.0	0.6	0.1	42.5	57.5
HR	1.8	2.8	33.7	46.9	11.8	2.8	0.4	38.3	61.9
WB	0.2	14.8	45.1	34.3	5.0	0.5	0.1	60.1	39.9
	Passive samplers: Pore water								
LB1	32.8	40.8	20.8	3.7	0.5	0.1	0.0	94.4	4.3
LB1.5	25.3	38.5	29.8	5.8	0.6	0.1	0.0	93.6	6.5
LB2	37.5	36.4	22.5	3.3	0.2	0.0	0.0	96.4	3.5
NE	0.0	4.8	33.9	53.5	6.7	1.0	0.1	38.7	61.3
NW	1.8	10.9	37.6	45.6	3.8	0.3	0.0	50.3	49.7
HR	3.5	19.5	33.4	36.2	6.5	0.8	0.2	56.4	43.7
WB	1.4	20.6	40.7	33.1	3.8	0.4	0.0	62.7	37.3

^a Forage fish from current study, mussels and passive samplers from Ghosh et al. 2020 at the same locations. The location numbers from that report described LB1.5 as LB2 and LB2 as LB3. Mussel and passive sampler data are from averages of data from 2016 and 2017 deployments. See Table 1 for abbreviations and location descriptions.

FIGURES



Figure 1. Photos of mummichogs (top left: female left, male right) and banded killifish (top right: males left, females right); beach seining (bottom left); deploying a minnow trap (bottom right).



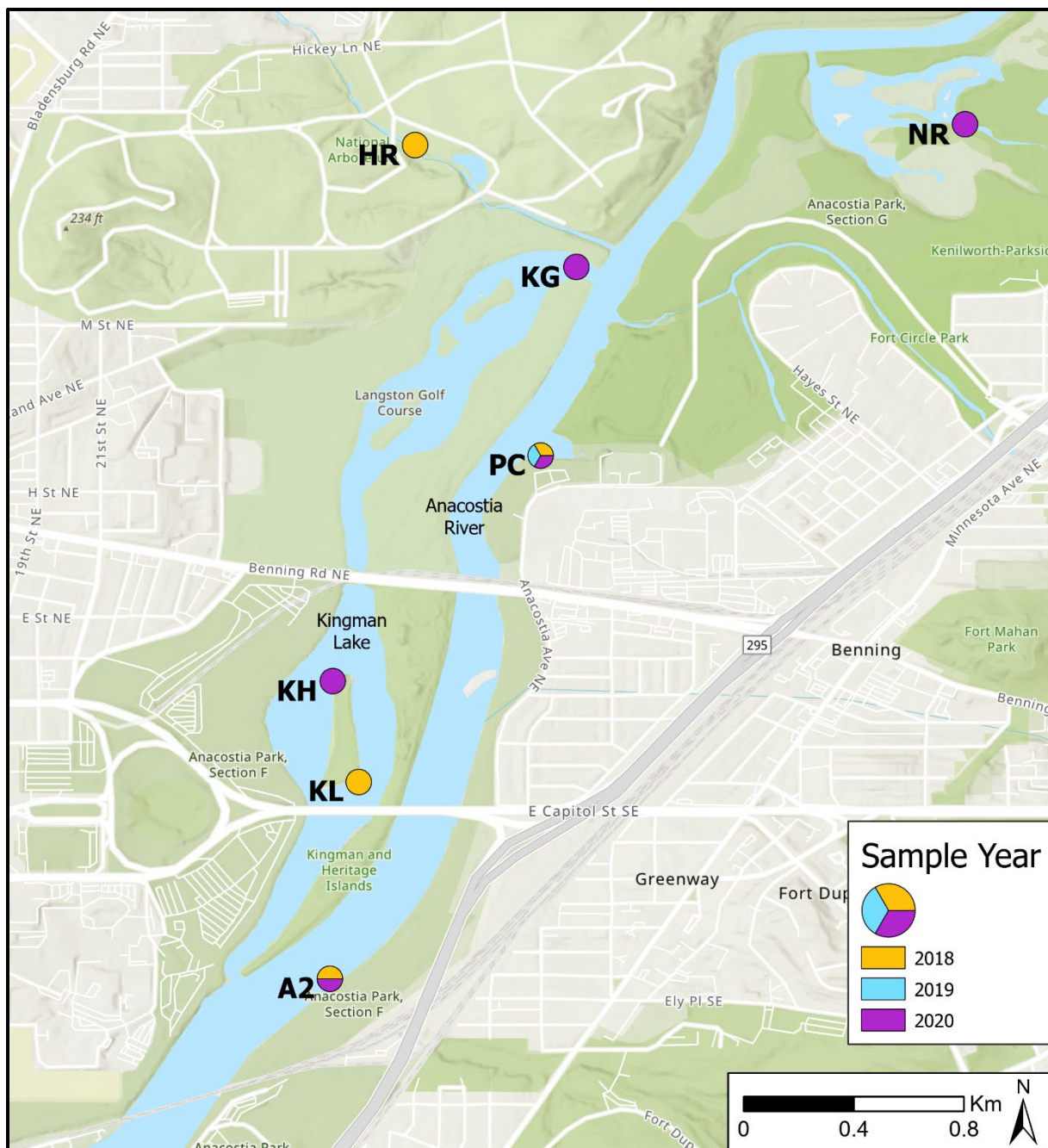


Figure 2b. Mummichog and banded killifish sampling locations in Kingman Lake and nearby areas: 2018 through 2020. See Table 1 for location descriptions and abbreviations.

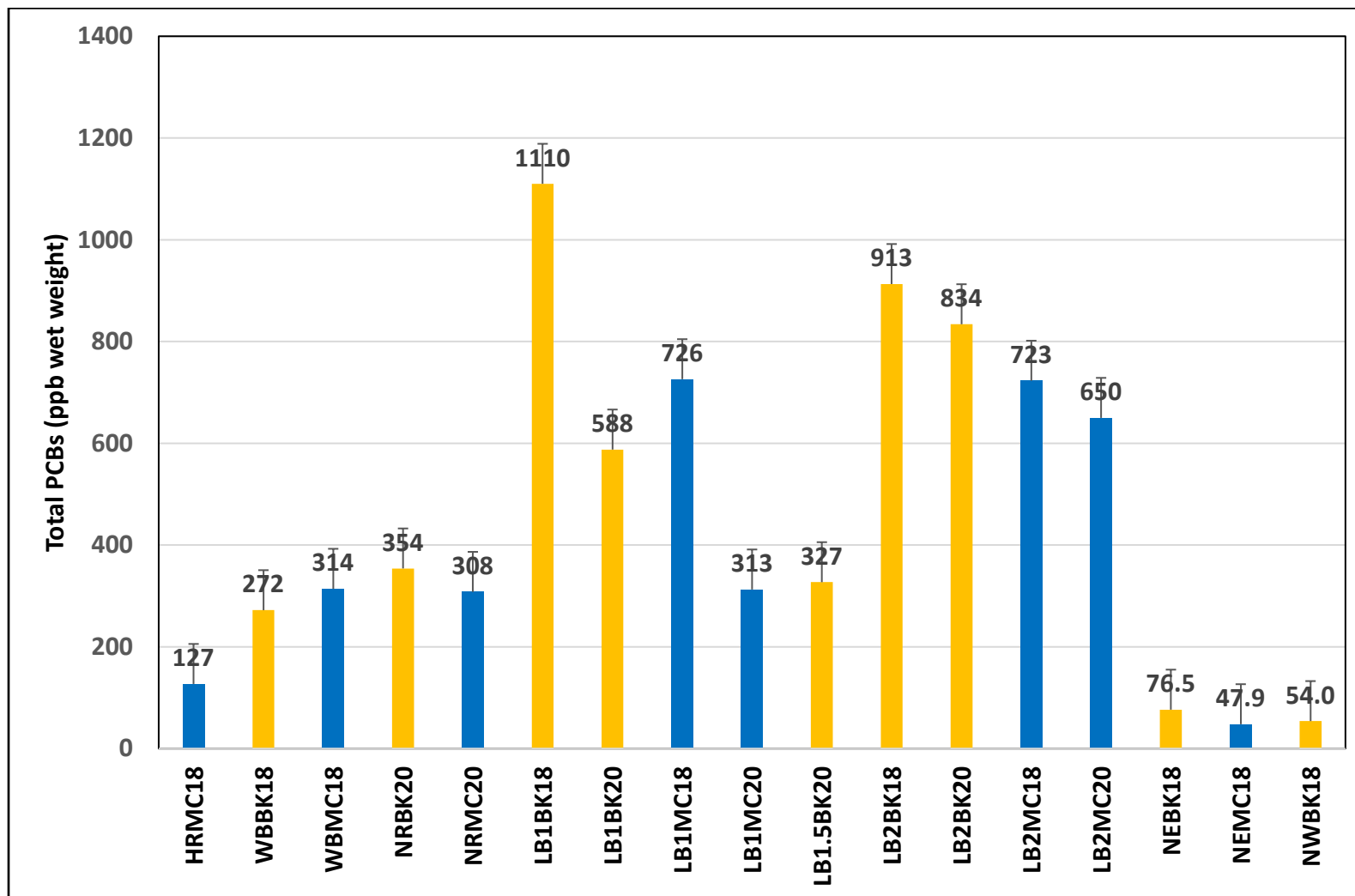


Figure 3 Total PCBs (ppb wet wt., mean + standard deviation) in mummichogs (MC) and banded killifish (BK) from Anacostia Tributaries. See Table 1 for location/collection abbreviations.

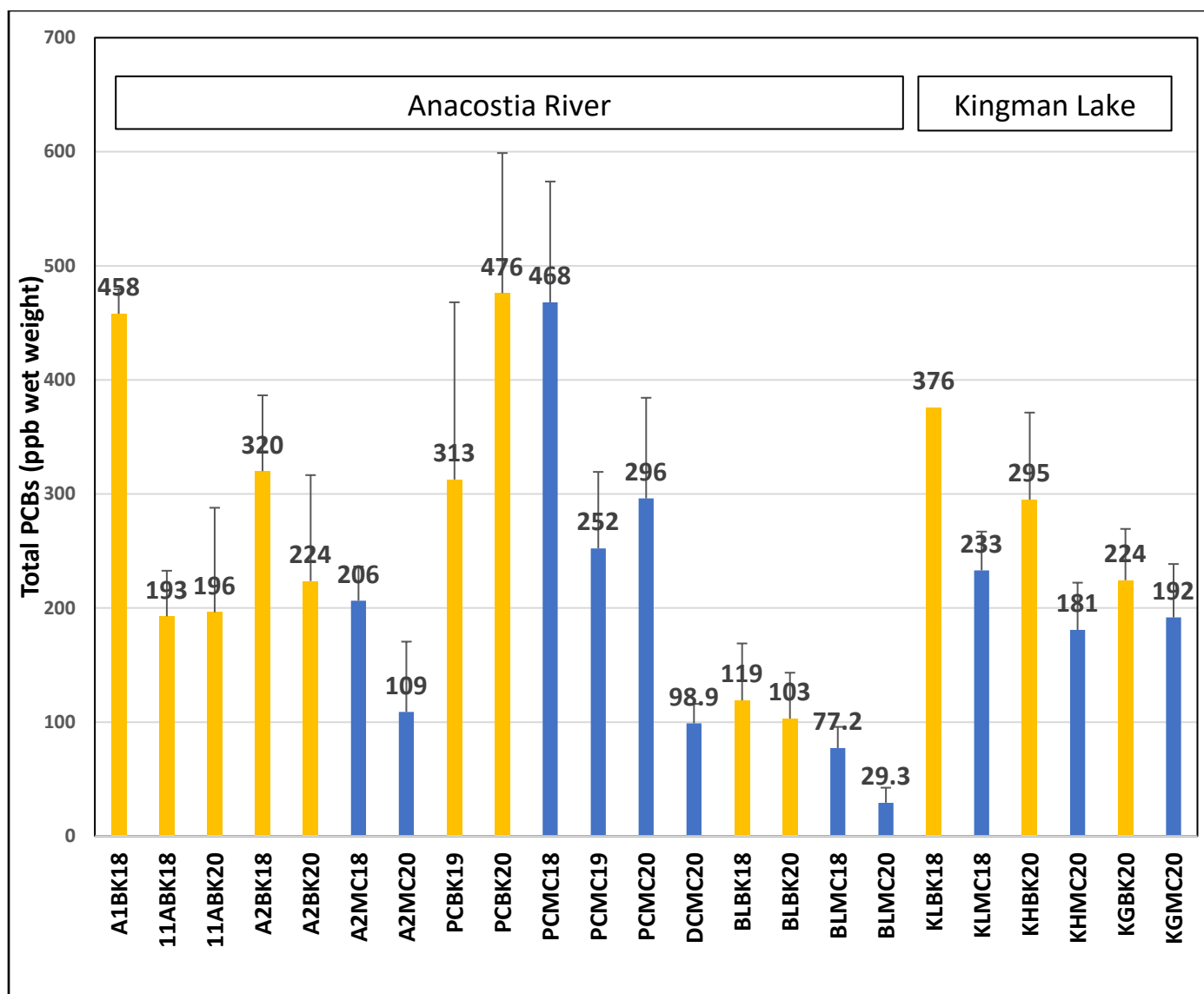


Figure 4. Total PCBs (ppb wet wt., mean + standard deviation) in mummichogs (MC) and banded killifish (BK) from the Anacostia River and Kingman Lake. See Table 1 for location/collection abbreviations.

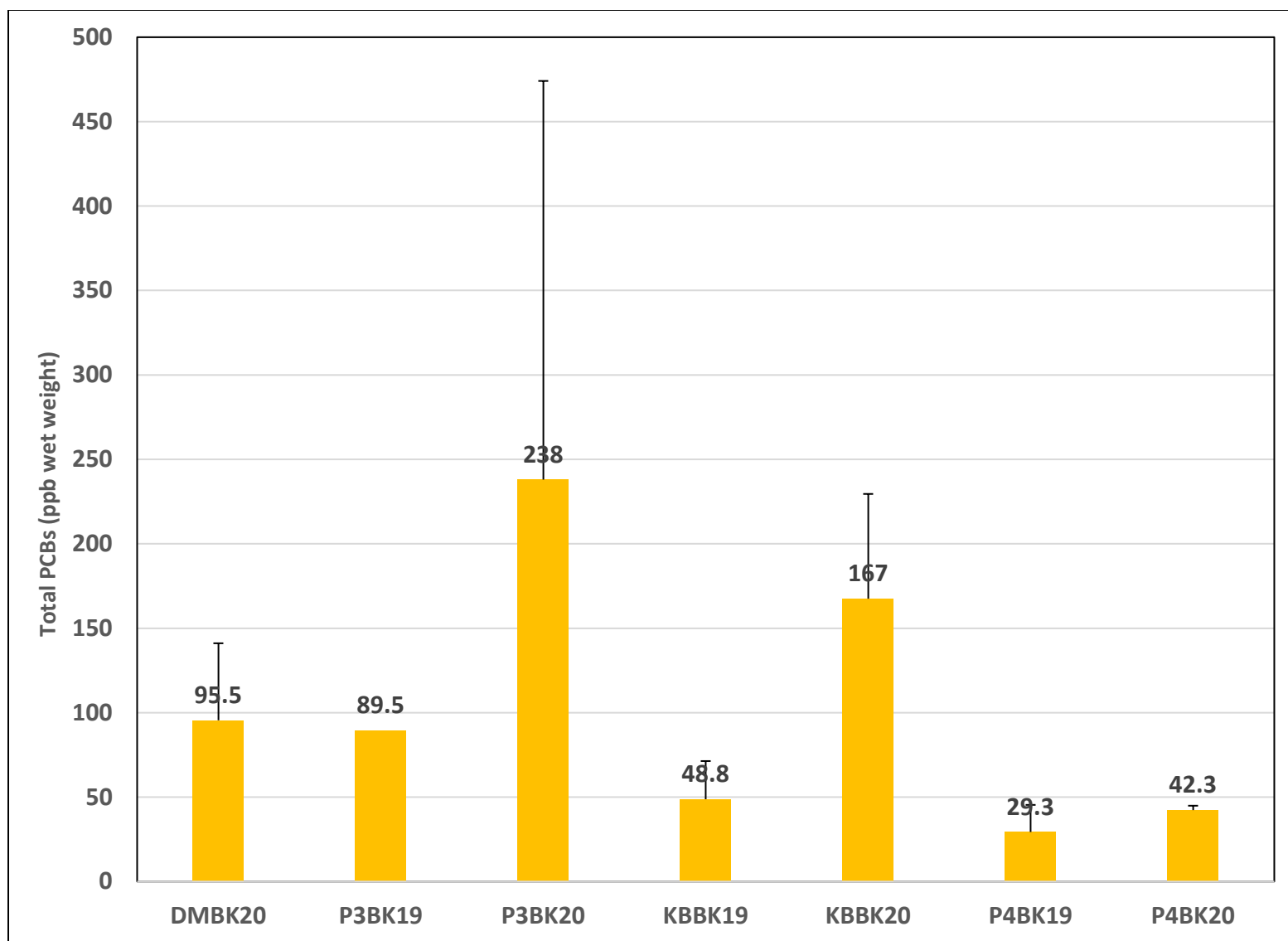


Figure 5. Total PCBs (ppb wet wt. mean + standard deviation) in mummichogs (MC) and banded killifish (BK) from the Potomac River. See Table 1 for location/collection abbreviations.

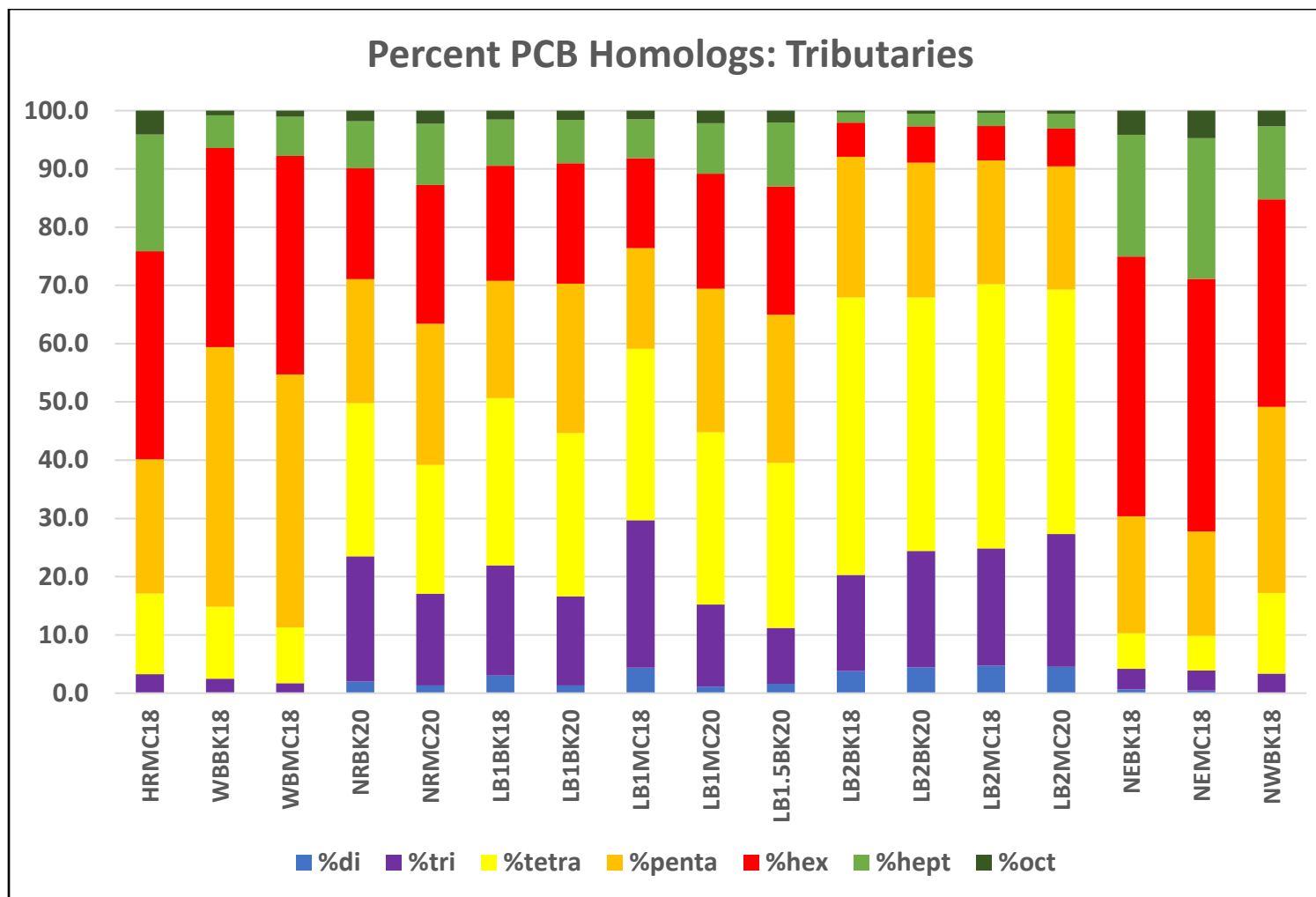


Figure 6. Mean PCB homolog distribution (% of total) in banded killifish (BK) and mummichogs (MC) from Anacostia River tributaries. Mono-, nano-, and deca- were minimal. See Table 1 for location/collection abbreviations.

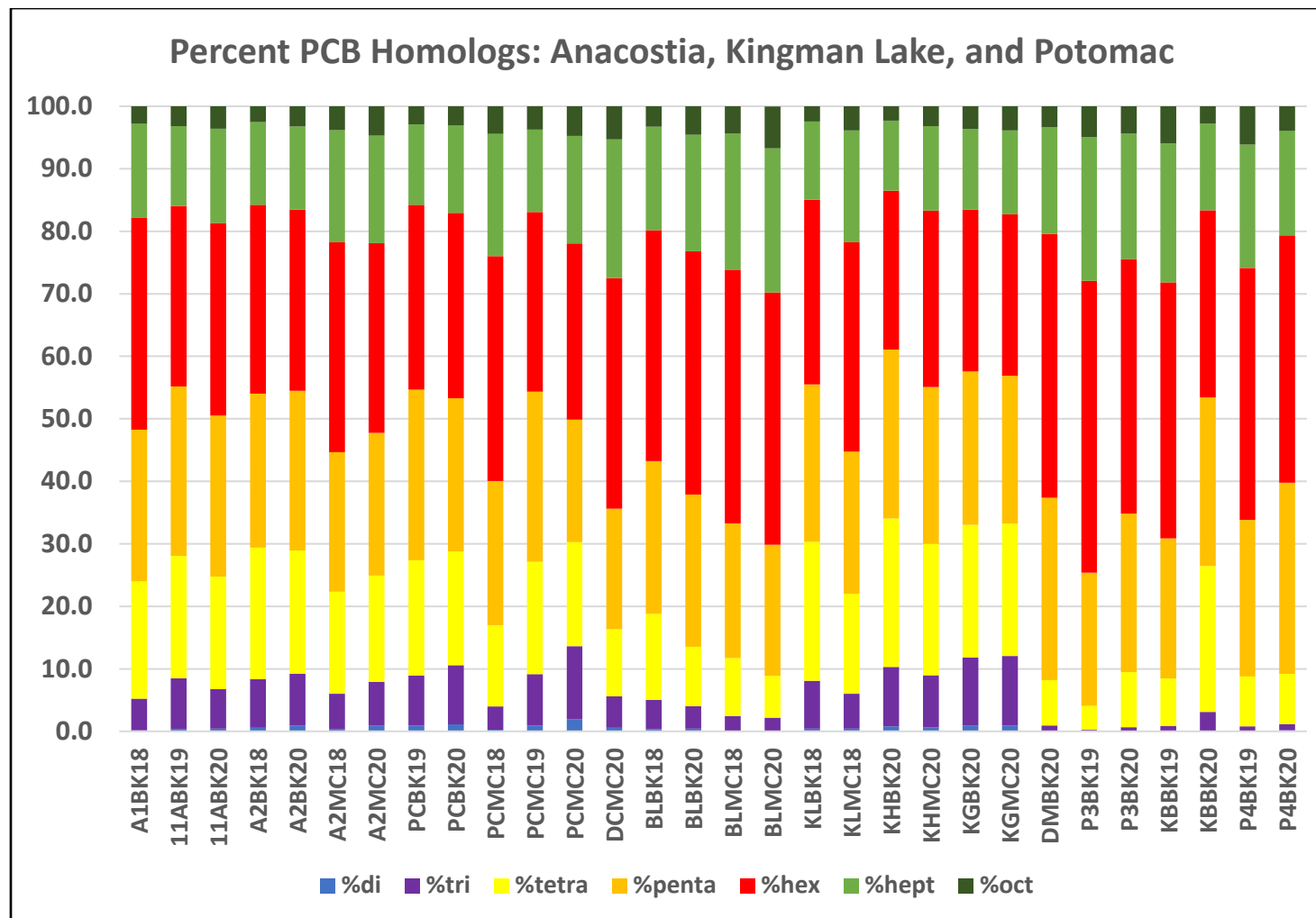


Figure 7. Mean PCB homolog distribution (% of total) in banded killifish (BK) and mummichogs (MC) from the mainstem Anacostia River, Kingman Lake, and the Potomac River. Mono-, nano-, and deca- were minimal. See Table 1 for location/collection abbreviations.

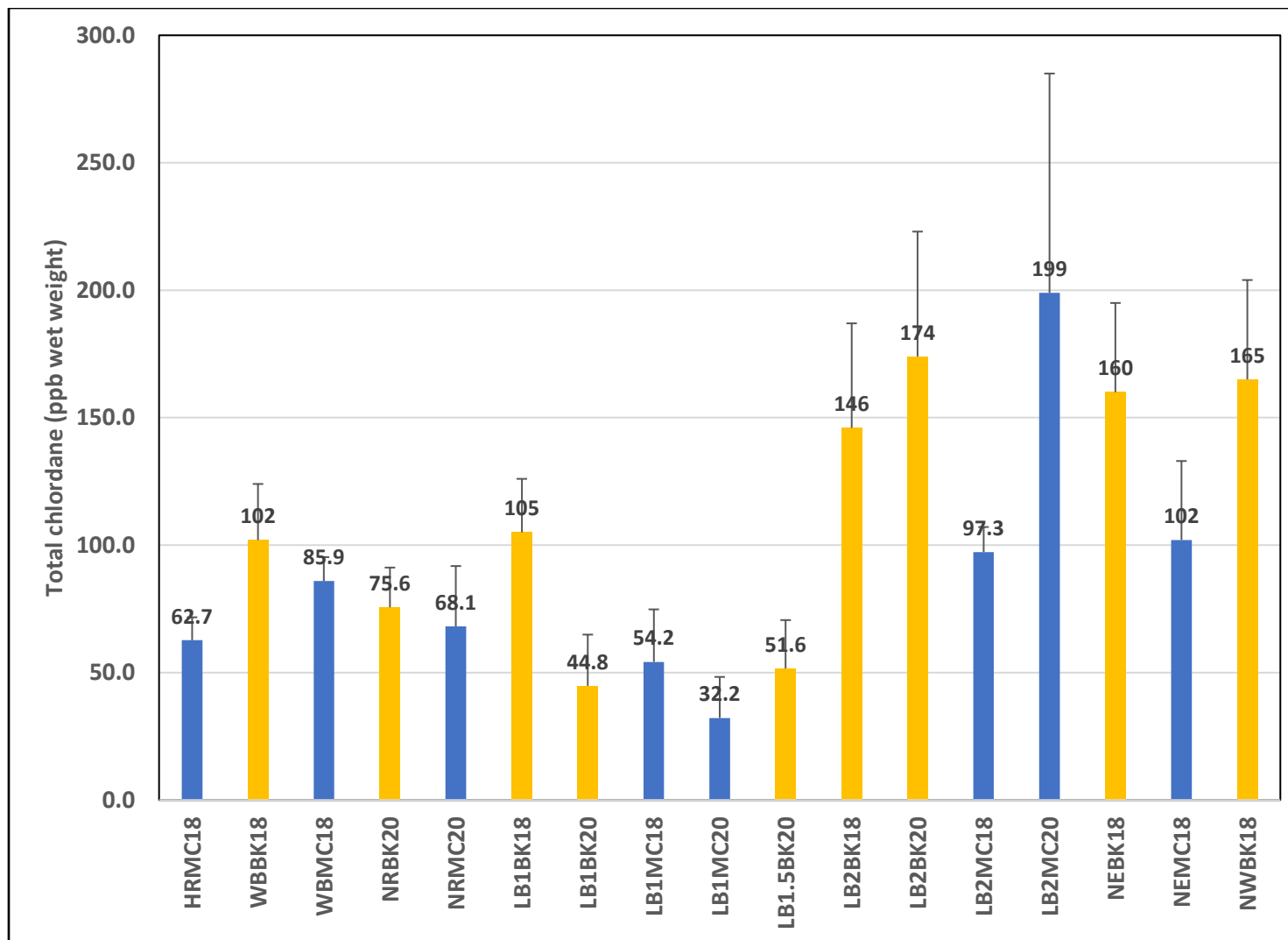


Figure 8. Total chlordane concentrations (ppb wet wt., mean + standard deviation) in mummichogs (MC) and banded killifish (BK) from the Anacostia tributaries. See Table 1 for location/collection abbreviations.

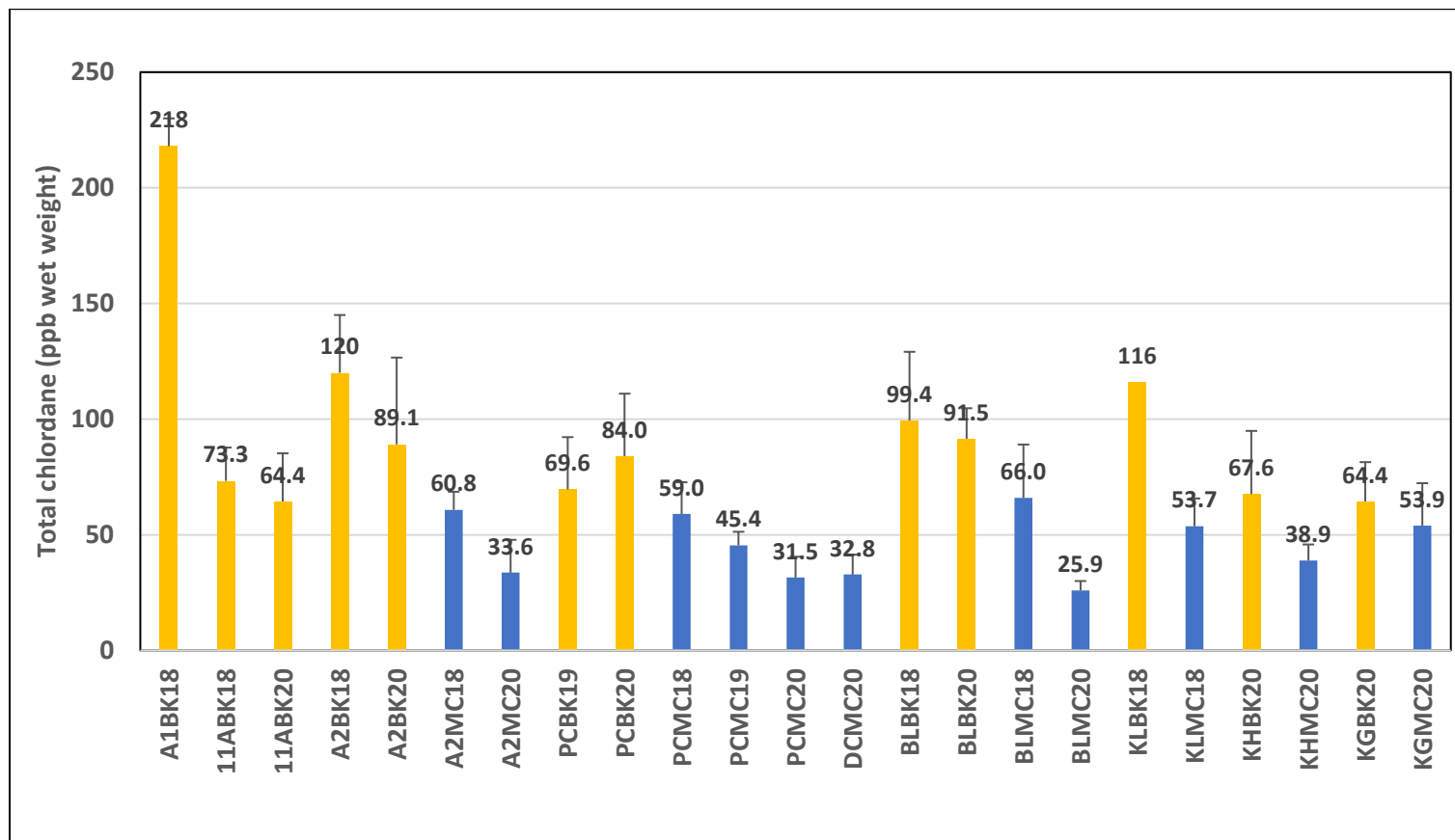


Figure 9. Total chlordane concentrations (ppb wet wt., mean + standard deviation) in mummichogs (MC) and banded killifish (BK) from the mainstem Anacostia River and Kingman Lake. See Table 1 for location/collection abbreviations.

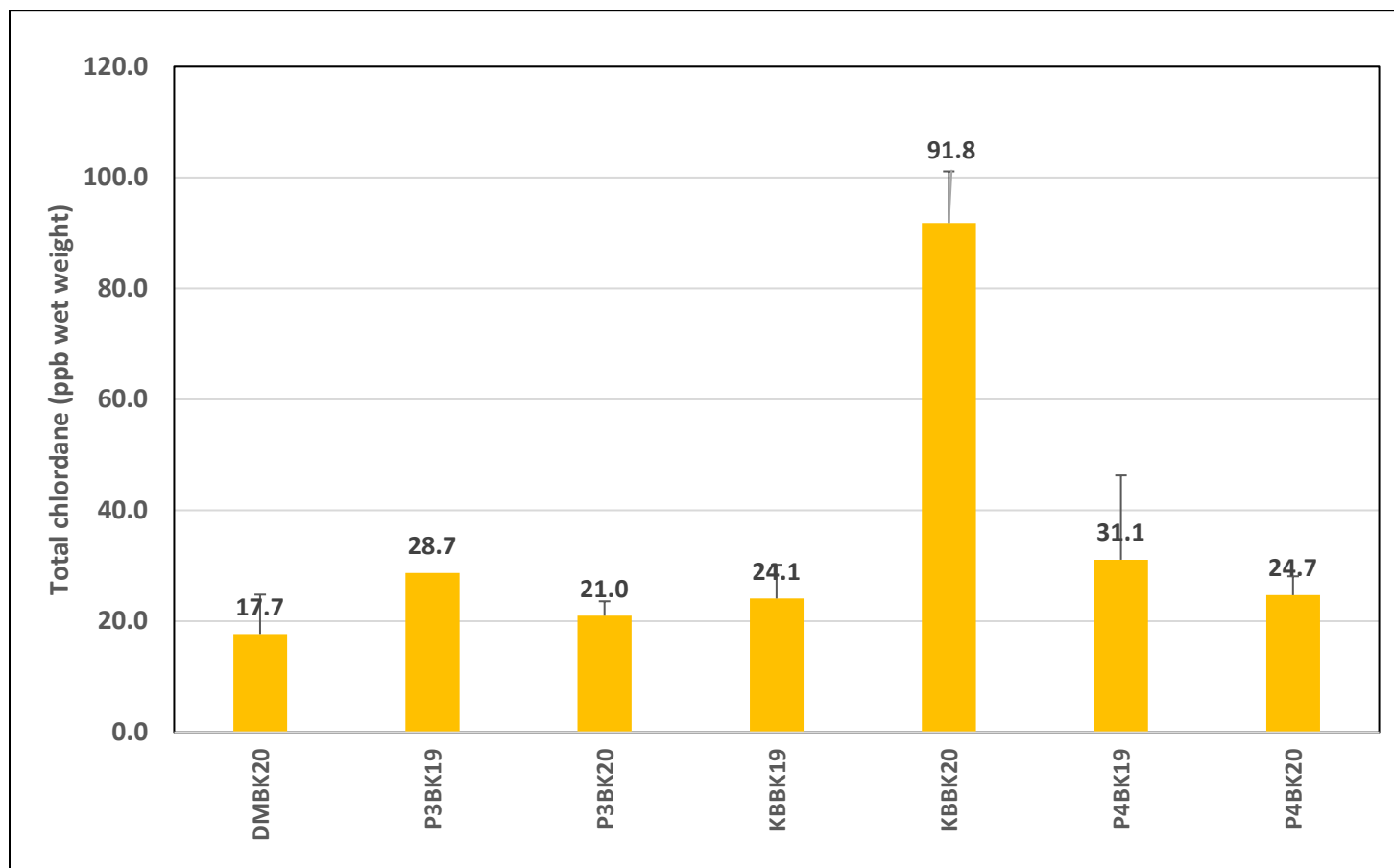


Figure 10. Total chlordane concentrations (ppb wet weight; mean + standard deviation) in mummichogs (MC) and banded killifish (BK) from the Potomac River. See Table 1 for location/collection abbreviations.