Third Five-Year Review Report for the Hudson River PCBs Superfund Site

APPENDIX 3

EVALUATION OF FISH TISSUE PCB CONCENTRATIONS

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EXECUTIVE SUMMARY

Background

The purpose of this appendix is to examine polychlorinated biphenyl (PCB) concentrations in fish tissue collected annually during the 2016-2021 post-dredging (i.e., monitored natural recovery [MNR]) period of the remedial action described in the U.S. Environmental Protection Agency (EPA) 2002 Record of Decision (ROD) for the Hudson River PCBs Site (Site). Fish-tissue samples have been collected from consistent locations within River Section (RS) 1 through RS 3 and represent a range of species, communities, and trophic levels. These data provide a long-term dataset to track changes in fish tissue concentrations over time and assess whether progress is being made towards achieving the remedial action objectives (RAOs) established in the ROD. The applicable RAOs for PCBs in fish are: (1) reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish, and (2) reduce the risks to ecological receptors by reducing the concentration of PCBs in fish.

Analyses

Data collected between 2004 and 2021 (encompassing three periods: pre-dredging, 2004 to 2008; dredging, 2009 to 2015; and post-dredging, 2016 to 2021) are presented in this appendix, the focus of this appendix is on the post-dredging period and progress towards the RAOs. This appendix includes an analysis to assess whether the existing six years of post-dredging data (2016 to 2021) are sufficient to obtain meaningful trends in fish tissue concentration.

The analysis presented in this appendix include: (1) a summary of the fish tissue data from the post-dredging period (2016 to 2021); (2) an assessment of the progress toward meeting the first fish tissue target concentration as described by the ROD; (3) a comparison of the pre-dredging and post-dredging periods; (4) a presentation the species-weighted average PCB concentrations; and (5) an evaluation to assess if six years of data is adequate to establish trends in fish tissue data.

Key Results

- In general, PCB concentrations in fish tissue increased during the dredging period due to related sediment resuspension in the water column then decreased in the post-dredging period to levels at or below the pre-dredging levels.
- There are several factors that can contribute to the variability in fish tissue data: (1) variability at individual sampling stations, (2) variability between fish species, and (3)

year-to-year variability. While the sources of this variability are not fully understood, several factors include bioavailable PCB concentrations in sediment and water column, as well as species-specific variables including feeding preferences, foraging histories, lipid content, non-lipid organic matter (NLOM), weight, length, age, sex, and season.

- The 2021 species-weighted average (ROD metric for fish concentrations) for the UHR remains above the first ROD human health target of 0.4 milligrams per kilogram—wet weight (mg/kg-ww). The ROD anticipated that the first target would be achieved within five years of dredging (2020). Although the first fish target was not achieved within the expected timeframe, it appears that the species-weighted average is decreasing in the post-dredging period. Additional years of data are necessary to determine a trend in the data and if the second fish tissue target of 0.2 mg/kg-ww will be achieved within the timeframe anticipated in the ROD.
- The RAOs for protection of ecological receptors have not yet been achieved.
  - The ROD ecological targets for largemouth bass are specified on a whole-body basis and range from 0.3 to 0.03 mg/kg-ww (Section 1.2.3). There have been some changes to exposure parameters since the ROD, which have narrowed the range to 0.2 mg/kg-ww to 0.07 mg/kg-ww. The whole-body largemouth bass concentrations were estimated by multiplying fillet concentrations by a conversion factor of 2.5. In the post-dredging period, 6 percent of the estimated whole-body bass concentrations fall below the 0.3 mg/kg-ww criterion, and no results are below the 0.03 mg/kg-ww criterion. It is important to note that the ecological targets themselves are based on the dietary intake of river otters, which typically consume fish between 4 and 7 inches in size (Erlinge 1968), rather than the larger fish collected for fillet analysis. Therefore, the 6 percent estimate has some uncertainty due to the potential differences in PCB levels between smaller and larger fish, as well as the lack of site-specific fillet to whole-body conversion factor. Recognizing this data gap, the EPA plans to collect whole-body data from smaller largemouth bass in future monitoring events.
  - Ecological targets for spottail shiner (whole-body) range from 0.7 to 0.07 mg/kg-ww. Similar to bass, there have been some changes to exposure parameters since the ROD, which would narrow the range to 0.34 to 0.11 mg/kg-ww (Appendix 5). Spottail shiner was used as an indicator species to represent forage fish less than 10 cm in length in the development of the ecological risk assessment (EPA, 2000b). Since the forage fish collection in the post-dredging period include other forage fish, in addition to the spottail shiner, a comparison to the ecological targets is made for the forage fish. In the post-dredging period, approximately 20 percent of forage fish data are below the 0.7 mg/kg-ww criterion, and no results are below the 0.07 mg/kg-ww criterion. While a comparison of the forage fish data as a whole to the ecological risk criteria is appropriate, in 2021 EPA modified the fish collection program to focus solely on

spottail shiner. This will reduce uncertainty in time trends (e.g., avoids uncertainty introduced by combining different species) and a direct comparison to the ROD RAO can be made.

- The percentage of fish tissue samples with PCB compounds measured as homologue equivalents ($TPCB_{HE}$) less than the 0.4 mg/kg-ww threshold has increased across most river sections and species compared to the pre-dredging period. In the UHR, the number of samples below the 0.4 mg/kg-ww threshold increased from 21 to 37 percent. The largest gain is shown in RS 1, where the number of samples below the 0.4 mg/kg-ww threshold increased from 15 to 44 percent. The geometric mean of lipid-normalized $TPCB_{HE}$ concentrations between the pre-dredging baseline (2004 to 2008) and post-dredging (2016 to 2021) periods has also decreased across all river section-species pairs, except for largemouth in RS 3.
- The current six years of fish tissue data post-dredging are not sufficient to establish a trend in the post-dredging period. An evaluation of the pre-dredging data from RS 1 shows that at least eight or more years of data are needed to establish a trend with confidence. When using only six years of data (the current number of years of post-dredging data), time trend estimates exhibit substantial variability (as measured by deviation from the long-term time trend), with trend estimates falling well outside the 95-percent confidence limits of the long-term time trend. As such, current observations in the fish tissue data could lead to false interpretations of the data.

1 INTRODUCTION

1.1 Background and Overview

The U.S. Environmental Protection Agency (EPA) 2002 Record of Decision (ROD) for the Hudson River PCBs Superfund Site (Site) for Operable Unit (OU) 2 called for a two-part remedy: dredging (conducted between 2009 and 2015) followed by Monitored Natural Recovery (MNR). This appendix focuses on polychlorinated biphenyl (PCB) concentrations in fish tissue collected during the (ongoing) post-dredging or MNR phase of the remedy, 2016 to 2021 (referred to herein as the post-dredging period). More specifically, this appendix presents fish tissue data collected from the Upper Hudson River (UHR) and the upstream background station above the Feeder Dam. Fish samples have been collected regularly through time at multiple locations within the UHR, providing a long-term dataset to track changes in PCB concentrations and assess whether fish recoveries are on track to meet the Remedial Action Objectives (RAOs) established by the EPA in the ROD.

1.2 Purpose and Objectives of the Fish Tissue Monitoring Program

The purpose and objectives of the UHR fish collection program have varied through time, reflecting the different stages of remedial activities at OU2. Although fish have been monitored for PCBs as early as the 1970s, this appendix focuses on the post-dredging or MNR period of the remedy—specifically data collected from 2016 to 2021—but also presents data collected between 2004 and 2021 under the Superfund program. There are three major periods of data collection under the OU2 remedy: the pre-dredging baseline period, the dredging period, and the post-dredging period. The following subsections provide a brief overview of the fish sampling and PCB monitoring during each of these periods.

1.2.1 Pre-Dredging Baseline Period (2004 to 2008)

The pre-dredging baseline period (2004 to 2008) includes the Baseline Monitoring Period (BMP). The objective of the BMP for fish was to establish baseline PCB levels in resident sport fish and resident forage fish to allow for documentation of the changes in PCB concentration that result from remediation.[1]

1.2.2 Dredging Period (2009 to 2015)

The dredging period (2009 to 2015) includes the Remedial Action Monitoring Program (RAMP). During active dredging, fish tissue PCB concentrations were monitored under the procedures established in the RAMP (General Electric Company (GE) 2006, 2009, 2011, and 2012) to assess impacts to fish associated with dredging.

[1] Prior to the BMP, New York State Department of Environmental Conservation (NYSDEC) collected fish and monitored PCB levels in fish tissue in the Hudson River as early as 1975 (NYSDEC 2005).

1.2.3 Post-Dredging Period (2016 to 2021) and the RAOs

Since completion of dredging in Fall 2015, fish sampling has continued under the RAMP program through the present. In 2021, the number of fish tissue samples collected annually was optimized such that sufficient fish samples were being collected to determine if there is a minimum 5-percent annual rate of decline over 10 years.[2] Fish will continue to be monitored post-dredging to assess recovery of the river and progress towards the ROD RAOs and targets. As stated in the ROD, the directly applicable RAOs related to fish include the following:

- ***"Reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish.***

  The risk-based PRG [preliminary remediation goal] for the protection of human health is 0.05 mg/kg PCBs in fish fillet based on non-cancer hazard indices for the RME [reasonable maximum exposure] adult fish consumption rate of one half-pound meal per week (this level is protective of cancer risks as well). Other target concentrations are 0.2 mg/kg PCBs in fish fillet, which is protective at a fish consumption rate of one half-pound meal per month and 0.4 mg/kg PCBs in fish fillet, which is protective of the CT [central tendency] or average angler, who consumes one half-pound meal every two months."

- ***"Reduce the risks to ecological receptors by reducing the concentration of PCBs in fish.***

  The risk-based PRG for the ecological exposure pathway is a range from 0.3 to 0.03 mg/kg PCBs in fish (largemouth bass, whole-body), based on the LOAEL [lowest observed adverse effect level] and the NOAEL [no-observed adverse effect level] for consumption of fish by the river otter… In addition, a range from 0.7 to 0.07 mg/kg PCBs in spottail shiner (whole fish) was developed based on the NOAEL and LOAEL for the mink, which is a species known to be sensitive to PCBs."

With the issuance of the ROD in 2002, the PRGs became remedial goals (RGs) for the Site. The two human health target concentrations listed above, 0.2 mg/kg-ww and 0.4 mg/kg-ww, are hereafter referred to as the ROD human health targets.

In the technical assessment for this five-year review report (Section 5, Question B) and Appendix 11 of the Second Five-Year Review Report, there have been no significant changes to the exposure assumptions and toxicity data used at the time of the ROD that impacts the RAOs. For ecological risk, there were some changes to exposure parameters (some increasing and some decreasing) and toxicity values (i.e., the LOAEL and NOAEL). Overall, use of these updated values would result in calculated risk ranges that are narrower than presented in the ROD, with a slight reduction in the upper bounds of the risk-based concentration ranges for PCBs in fish consumed by river otter and mink. The largemouth bass PCBs concentration range would be 0.2 mg/kg-ww to 0.07

[2] The program was optimized so that a decline rate of 5 percent or higher (e.g., 6, 7, or 8 percent) could be reliably detected after 10 years of data collection.

mg/kg-ww, compared to 0.3 mg/kg-ww to 0.03 mg/kg-ww. The spottail shiner PCB concentration range would be 0.34 mg/kg-ww to 0.11 mg/kg-ww, compared with 0.7 to 0.07 mg/kg-ww. This refinement results in risk-based ranges that reduce uncertainty and focus the range of PCBs in fish expected to be protective of the ecological exposure pathway. The lower bounds of the updated ranges are not lower than the lower bounds for both ranges identified in the ROD.

1.3 Document Organization

This appendix is organized into the following sections:

- Section 1, Introduction, provides the purpose and objectives for monitoring PCBs in fish tissue.
- Section 2, Program Description, presents an overview of the fish monitoring program, sampling locations, and the analytical methods used.
- Section 3, Data Analysis Methods, describes various analysis methods for evaluating fish tissue PCB concentrations.
- Section 4, Results and Discussion, presents the results of the evaluation of PCB concentrations measured in the UHR by individual species, reach, and RS, as well as species-weighted average estimates.
- Section 5, Conclusions, summarizes appendix findings.
- Section 6, Abbreviations and Acronyms, defines the acronyms and abbreviations used in this appendix.
- Section 7, References, provides the complete references for documents cited in this appendix.

2 PROGRAM DESCRIPTION

2.1 Overview of Fish Sampling Programs

Fish tissue samples have been collected and analyzed for PCBs from the Hudson River since 1975. This appendix focuses on the post-dredging or MNR period of the remedy, specifically data collected from 2016 to 2021, but also presents data collected between 2004 and 2021.[3] The data in the appendix represents three distinct periods (see Section 1.2). GE began collecting data in 2004 under the BMP to establish baseline concentrations prior to dredging. Additional information about fish collected prior to 2004 is presented in Appendix 3 of the *Second Five-Year Review Report* (EPA 2019a).

Fish are routinely collected from River Section (RS) 1, RS 2, RS 3, and one upstream background station north of the Feeder Dam, the two former General Electric plants, and impacts from GE PCBs (Figure A3-1 and Table A3-1). Within each river section, fish are collected from four to five different areas or monitoring stations to provide representative data for that river section. Fish samples collected outside of the monitoring stations are not included in this appendix unless otherwise noted.

There are several species of fish routinely collected and analyzed for PCBs in the UHR. They represent different trophic levels and life histories. Sample collection is completed twice per year. Sport fish, including largemouth bass, smallmouth bass, brown bullhead, and yellow perch, are collected in the spring. Forage fish (including spottail shiner) and pumpkinseed are collected in the fall. Table A3-2 includes a list of fish species discussed in this five-year review.

Between 2004 and 2020, the target number of fish collected from each river section remained the same with black bass (largemouth/smallmouth bass), yellow/brown bullhead, yellow perch, yearling pumpkinseed, and forage fish (including spottail shiner) targeted.

As mentioned previously, in 2021, the number of fish collected at each station was optimized with the goal of determining a 5-percent annual rate of decline over a 10-year period on a river section and species basis. In addition to optimizing the number of samples collected, the program was designed to limit the substitution of species in a station to reduce uncertainty in the species-weighted average and determine changes of fish tissue concentrations over time. During the post-dredging period, it was observed that substitution of species introduced substantial within-year and between-year variabilities in PCB concentrations and confounded efforts to compare concentrations over time. Therefore, moving forward, the OM&M program will limit any species substitution. Similarly, supplementing the number of fish from different fish stations to achieve target number for the river section also increased year to year variability as different stations have different PCB body burdens. Table A3-3 provides a summary of the species targets from 2004 to

2020 and the updated species targets starting in 2021. Additional details outlining the rationale and evaluations supporting this updated fish program are included in Section 3.3.

River Section 3 is made up of Reaches 5 through 1. Fish from Reach 5 were collected annually as part of the BMP and RAMP programs and the collection has continued during the post-dredging period. Reaches 4 through 1 have not been consistently sampled over time. During the post-dredging period, New York State Department of Environmental Conservation (NYSDEC) sampled for pumpkinseed and other forage fish in these reaches in 2017, while GE sampled for sport fish in these reaches in 2019. In 2021, EPA reviewed these data and determined that, during the post-dredging period, these reaches should be sampled every five years for pumpkinseed (Table A3-3). The periodic data collected from these reaches will help EPA to evaluate if Reach 5 sampling stations in the UHR and the Albany/Troy sampling station in the Lower Hudson River (LHR) (not discussed here) remain representative of the intervening reaches and help inform the need for additional sampling.

2.2 Sample Preparation

Fish are processed into samples for PCB and lipid analyses in accordance with project standard operating procedures (SOPs; GE 2009, 2014) depending upon species and the size of the fish. Larger sport fish are processed into fillets (with their ribs) using NYSDEC-standard fillet methods such that only the edible (fillet) portion is analyzed for PCBs. Smaller fish are typically processed into whole-body (individual or composite) samples. Table A3-4 provides a summary of the preparation methods by species included in this appendix. For all fish samples, the portion to be analyzed is homogenized prior to extraction and analysis.

It should be noted that between 2007 and 2013, the fillet technique used for some species at several locations differed from historical and current methods. GE laboratory contractors used a non-NYSDEC-standard fillet approach by not including the rib cage material in the fillet harvested for analyses. Because this method of preparing samples differs from the NYSDEC-standard fillet method, it was important to evaluate any potential differences in PCB levels that might result from the deviation in sample preparation, so that such differences could be isolated from those due to temporal changes in environmental conditions. EPA evaluated the PCB-concentration differences between rib-in (NYSDEC-standard fillet) and rib-out (non-NYSDEC-standard fillet) samples during a special study in 2014. EPA found that, on a wet-weight basis, the differences in results between fillets prepared as rib-in *versus* rib-out are variable and can be greater than a factor of two, while for lipid-normalized data, the differences average less than 20 percent (EPA 2019a), and can be used for trend analysis on a lipid-normalized basis. However, it is important to note that with the exception of 2007 and 2008, these fish are part of the dredging years and are not used in current evaluations of fish recovery.

2.3 Laboratory Analytical Methods

The Hudson River Superfund Site fish analytical program has a robust quality assurance/quality control (QA/QC) program to confirm that PCB Aroclors are being reported consistently over time. Two important components of the program include the use of standard reference material (SRM) and the analysis of "paired" samples, which involves analyzing a small subset of fish tissues samples using both an Aroclor method and a congener method. EPA's QA/QC requirements apply strictly to the GE data, but the NYSDEC program followed a similar "paired sample" protocol.

For both the NYSDEC and GE data, fish tissue analyses were primarily conducted using Aroclor-based analytical methods to determine Total PCB concentrations (TPCB)[3], and using gravimetric techniques for percent lipids. All GE-collected fish samples are analyzed for TPCB as Aroclors using SW-846 Method 8082 (M8082). From 2004 to 2016, GE used the modified Green Bay method (mGBM) as a congener-based analytical technique on a subset of the samples to confirm the relationship between TPCB by Aroclors and TPCB by congeners. In 2017, the historical analytical lab for the project, the Pace-Schenectady Laboratory closed, and GE changed its analytical laboratory to Pace-Green Bay, Wisconsin. With the closing of the Pace-Schenectady Laboratory, the mGBM method was no longer commercially available. As a result, EPA Method 1668 (M1668) replaced mGBM as the congener method used for fish tissue analyses.

The paired analysis provides a check to confirm that the pattern of PCBs in the fish is consistent through time and that the conversion factor used to provide a consistent set of data over time (homologue equivalent data) is stable or can be adjusted (see Section 3.1 and Attachment A for details).

The use of SRM samples on a regular basis provides a means to track analytical accuracy and precision over time and across laboratories and analytical methods. This comparison is different from typical laboratory internal or calibration standard checks because it is based on an external standard reference material that provides the laboratories an independent check on accuracy and precision for the associated analytical batch of samples. Internal laboratory standards are in contact with the media for a limited period prior to analysis and may not have attained equilibrium. Specifically, the spiking solution may not be fully absorbed onto the surface of the media, thereby permitting a less rigorous extraction to still achieve a high rate of PCB mass recovery from the prepared standard sample. As a result, analysis of these internally prepared standards and laboratory check samples may not provide a true measure of the laboratory's extraction accuracy and precision. Because the project SRMs are derived from environmental media, concentrations can be assumed to be in equilibrium with their media and, therefore, provide a rigorous test of the accuracy of the entire extraction and analytical process. Additional details and evaluation of the SRM material over time is provided in Attachment A.

[3] 2017 NYSDEC-collected fish samples were analyzed using only PCB congener methods.

Additional References on Sample Collection, Processing and Analytical Methods

Additional details regarding sampling procedures, analytical methods, and validation are found in annual Data Summary Reports (DSR) prepared by GE (GE 2017, 2019a, 2019b, 2020, 2021, and 2022) as well as the Phase 2 RAMP Quality Assurance Project Plans (QAPP) (GE 2012). Further details regarding local fish monitoring stations and species are presented in the following reports:

- Baseline Modeling Report (BMR) and revisions (EPA 2000a)
- Baseline Ecological Risk Assessment (BERA) and revisions (EPA 2000c)
- Feasibility Study [FS] (EPA 2000b)
- 2002 ROD (EPA 2002)
- BMP QAPP (GE 2004)
- Phase 2 RAMP QAPP (GE 2012)

2.4 Data Used in Current Five-Year Review

A summary of the fish species collected and discussed in this appendix from 2004 and 2021 is provided in Table A3-2. Data used in the current Five-Year Review represent fish collected under the following programs:

- Between 2004 and 2009, fish were collected under the BMP.
- Between 2009 and 2015, fish were collected under the RAMP.
- Beginning in 2016 through 2021, fish have been collected following the RAMP, as the final details of the Operations, Monitoring and Maintenance program are being resolved.

3 DATA ANALYSIS METHODS

This section describes the methodologies used to evaluate the fish tissue data from the UHR in this appendix. The evaluations conducted include the following:

- Assess PCB concentrations in fish through time
- Compare fish concentrations from the pre-dredging baseline period to the post-dredging period
- Assess fish concentrations against ROD metrics for both human health and ecological risks
- Evaluate the uncertainty regarding the use of six years of data in determining recovery rates

Attachment A to this appendix reviews the QA/QC data for the fish and provides the details on the development of the conversion factor used for fish data presented in this appendix.

3.1 Data Handling

For samples analyzed using the Aroclor-based method (M8082), the calculation of the fish tissue TPCB concentration used the sum of both detected Aroclors and Aroclor concentrations flagged with a "J" qualifier (i.e., estimated). For samples analyzed using the congener-based methods, summation of individual congener results (for samples analyzed using M1668) or congener-specific peaks (for samples analyzed using the mGBM) for estimation of TPCB concentration. Congener-based calculations also included concentrations based on both detected values and values flagged with a "J" qualifier. If all the Aroclors in a M8082 sample are non-detect, then the TPCB for that sample is set to ½ of the maximum reporting limit for the individual Aroclors. Non-detect congener results are set equal to zero for purposes of summation to a TPCB concentration for the sample. There are no field duplicates samples taken for fish tissue These are the same reporting procedures as used in the ROD and prior five-year review reports.

As discussed in the *Second Five-Year Review Report*, all fish tissue data collected on the project since 1990 has been converted to and reported as Total PCB homologue equivalent ($TPCB_{HE}$ [4]) (EPA, 2019b). This conversion reconciles historical and current fish tissue sampling and analysis efforts into a single, internally consistent series of measurements that can be used to assess patterns over time. In general, fish tissue is analyzed using an Aroclor method (M8082). This data is then converted to $TPCB_{HE}$ using a conversion factor; the conversion factor for each year is presented in Table A3-5. The conversion factor is developed for different periods (reflecting different

[4] $TPCB_{HE}$ is an estimate of the TPCB concentration that would be obtained if the sample were analyzed by a homologue or congener-based methodology. A number of methods have been employed for the Hudson River PCBs Site to measure $TPCB_{HE}$ concentrations directly, including mGBM and M1668. These methods are considered more accurate since they report concentrations relative to homologue- or congener-based standards and do not approximate the PCB distribution as one or more industrial Aroclor mixtures. Over the years of study, the matched pairs of homologue- (or congener-) based analyses and analyses by M8082 have been used to develop conversion factors to convert M8082 results to their $TPCB_{HE}$ equivalents.

laboratories and possible minor differences in techniques) by utilizing a subset of paired samples that are analyzed using both the Aroclor method and a congener-based method. $TPCB_{HE}$ is calculated by multiplying the $TPCB_{Aroclor}$ concentration by the conversion factor. For any sample with an $TPCB_{congener}$ result, $TPCB_{HE}$ is equal to $TPCB_{congener}$ concentration. Details of how the conversion factor has been developed and how years of data have been grouped together are presented in Attachment A and the *Second Five-Year Review Report*.

3.2 Methods for Evaluation of PCB Concentrations

3.2.1 PCB and Lipid Concentrations through Time

Fish tissue $TPCB_{HE}$ concentrations are a function of exposure to sediment and water integrated through diet. Wet-weight concentrations provide one basis for evaluating changes in concentration through time and are the basis for estimating risk to human health and the environment as presented in the ROD. When evaluating changes in PCB in tissue, it is also important to compare changes in percent lipid over time. Wet-weight TPCB concentrations are often correlated with lipid content, therefore, declines in lipid content can confound the decline in wet-weight-based concentrations. That is, declines in wet-weight concentrations may be associated with declines in lipid, in addition to declines in exposure.

An alternative basis to determine the decline in $TPCB_{HE}$ levels is to express the $TPCB_{HE}$ concentrations on a lipid-normalized basis. Lipid-normalized concentrations ($C_{PCB\text{-}lipid}$) are calculated as PCB concentration in fish tissue ($C_{PCB\text{-}fish}$) divided by fraction lipid (f_{lipid}).

$$C_{PCB-lipid} = {C_{PCB-fish}}/{f_{lipid}} \qquad (Eq.\ 1)$$

Lipid-normalized results control for variability associated with changes in lipid content and provide an alternate basis for comparing concentrations across sampling times, locations, and species. Lipid normalization is most useful when a direct and proportional relationship can be observed between lipid content and contaminant concentrations (i.e., lipid and PCB are correlated) (Randall et al. 1991; Hebert and Keenleyside 1995; van der Heijden and Jonker 2011).

Generally, tissue contaminant burdens in two equally exposed organisms will vary proportionally to their lipid content, assuming a correlation between lipid content and contaminant concentration. However, these correlations are not always observed and fail to account for the role of protein (independent of lipid) in absorbing PCBs. At low lipid levels, the role of protein, referred to as non-lipid organic matter (NLOM), increases in importance with respect to absorption capacity relative to primary lipid, particularly in specimens with observed lipids less than 1 percent (de Bruyn and Gobas 2007; Mäenpää et al. 2015; Jahnke et al. 2015), with observed proportionality constants (to lipid) of approximately 0.035- to 0.05-inch species with observed lipids less than 1 percent. This can lead to non-linearities in observed relationships between lipid content and

contaminant concentrations. In the post-dredging period, lipid levels in fish have generally been less than 1 percent, making NLOM a more important factor for PCB absorption.

EPA uses both wet-weight and lipid-normalized approaches to evaluate PCB levels in fish. PCB concentrations in fish can show a decline in response to declines in both lipid content and environmental exposures. In addition to lipid, several factors may influence fish PCB levels in populations, including species, natural variability in fish ages and locations within a reach (exposure), different fish species life cycles, and environmental factors such as flooding, storms, flow conditions. The complementary data evaluation approaches presented here provide alternate perspectives on fish PCB levels and help address these sources of variability, along with the underlying uncertainties in sampling and measurement techniques and in lipid measurements. Concordance in results across approaches provides a more robust basis for interpreting patterns in tissue concentrations over time.

Individual fish tissue $TPCB_{HE}$ concentrations for the UHR monitoring locations were plotted against time from 2004 to 2021. Figures present the wet-weight $TPCB_{HE}$, the percent lipid, and the lipid-normalized $TPCB_{HE}$ values for select fish species collected since 2004 from each river section. Four sport fish (brown bullhead, smallmouth bass, largemouth bass, and yellow perch) and various forage fish (pumpkinseed, spottail shiner, and other forage species) were plotted for each river section. Brown bullhead are benthic feeders (similar to carp or eel). Largemouth bass and smallmouth bass represent a large, piscivorous "top predator" fish (such as bass or walleye). Yellow perch represent a mid-trophic level fish preying on invertebrates or smaller fish. Pumpkinseed (collected as yearling fish), spottail shiner (collected when they are one to three years old), and other forage fish represent rapid integration of exposure to PCBs. These contrast with the other species, which are primarily comprised of adult sport fish and often several years older than the forage fish. When the collection targets were updated in 2021, the forage fish collection was refined to focus solely on spottail shiner instead of on a range of forage fish (Table A3-3). The goal of this change is to minimize the inter-species variations, allowing for any changes in PCB concentrations to be more readily identified. The discussion of the fish tissue PCB and lipid concentrations through time is found in Section 4.1.

3.2.2 Pre- and Post-Dredging PCB Concentrations Comparison Using Analysis of Variance (ANOVA)

When comparing PCB data from different groups, it is important to understand that PCB concentrations in fish depend on several factors, including bioavailable PCB concentrations in sediment and water column, as well as species-specific variables, including feeding preferences, foraging histories, lipid content, NLOM, weight, length, age, sex, and season. While it would be ideal to have all of these variables for all samples as an aid in explaining PCB levels, in reality some cannot be readily measured (e.g., forage history) and some were not routinely recorded (e.g.,

age, sex). Lipid content was selected as a covariate for this analysis because it was recorded for every sample.

A one-way Analysis of Variance (ANOVA) with two groups was used to statistically compare the geometric mean of lipid-normalized $TPCB_{HE}$ concentrations between the pre-dredging baseline (2004 to 2008) and post-dredging (2016 to 2021) periods. Because the two periods are similar in length, grouping them together removes the impact of temporal change, and allows for a comparison of the pre-dredging and post-dredging periods. In the one-way ANOVA model, lipid-normalized wet-weight $TPCB_{HE}$ concentration was regressed against an indicator variable representing the two monitoring periods. The ANOVA analysis was performed independently for each river section-species pair. Because the fish data were strongly right-skewed and often approximated a log-normal distribution, the ANOVA model was parameterized as

$$log_{10}(C_{PCB,ww}/Lipid) = \beta_0 + \beta_1 \times Period + \epsilon \quad (Eq.\ 2)$$

Where,

$C_{PCB,ww}$ = wet-weight $TPCB_{HE}$ concentration

Period = indicator variable with two levels (0 = pre-dredging, and 1 = post-dredging)

Lipid = Lipid content

β_0 = mean log-transformed lipid-normalized concentration for the baseline pre-dredging period

β_1 = mean ratio of the log-transformed lipid-normalized concentration of post-dredging to pre-dredging period.

ϵ = random error

The ratio of lipid-normalized $TPCB_{HE}$ concentration from baseline to post-dredging, estimated as $10^{\beta 1}$, represents the degree of change in fish tissue lipid-normalized $TPCB_{HE}$ levels between these two periods. The percent change from baseline to post-dredging data is calculated as $(10^{\beta 1}-1)$. The confidence limits of the ratio were based on the 95th-confidence limits of the regression coefficients. The p-value for the coefficient β_1 was used to evaluate whether the change in geometric mean lipid-normalized $TPCB_{HE}$ concentrations from baseline period to post-dredging period was statistically significant. The ratio data with their confidence limits were converted to percent change between periods. One-way ANOVA results are discussed in Section 4.4.

3.2.3 Assessment of the Minimum Number of Years of Data Before Stable Time Trends can be Estimated

The estimation of time trends using environmental data is important because it allows for extrapolation of the data into the future to assess when certain goals are achieved. However, extrapolation of the data into the future is very sensitive to the time trend estimated from the data.

Incorrectly estimating the time trend, even by a small amount, can result in very large errors in the time needed to achieve certain goals. Therefore, before a time trend can be estimated, it is important to determine whether the dataset spans a sufficiently long period so that the time trend accurately reflects the true, long-term time trend and is not affected by short-term natural variability in the dataset. This is particularly relevant for the post-dredging datasets used in this five-year review, for which only six years of data are available. In the Second Five-Year Review Comment Response (EPA 2019b), an analysis (referred herein as the "moving window" analysis) was presented that indicated eight or more years of data would be needed to estimate a meaningful time trend in the post-dredging fish tissue data.[5] In this appendix, a similar moving window analysis was conducted using fish tissue lipid-normalized $TPCB_{HE}$ data, with the goal of determining the minimum number of years of monitoring data that are needed to reliably estimate a time trend that accurately reflects the true, long-term time trend in lipid-normalized $TPCB_{HE}$ fish tissue concentrations.

A moving window analysis requires a long-term data set to demonstrate how many years are needed to produce reliable estimates of time trends. While the post-dredging period is too short for this purpose, the continuous pre-dredging fish tissue data available from 1998 to 2008 in RS 1 can be applied for this purpose since it represents a fairly long period (11 years) and would be expected to show variability similar to that of the post-dredge period since both sampling techniques and sampling stations are similar between the two periods. The fish included in the analysis are brown bullhead, largemouth bass, yellow perch, and pumpkinseed. Data sets for RS 2, RS 3, and smallmouth bass do not contain enough continuous years of pre-dredging data to be included in this analysis, however results for RS 1 are not expected to differ substantially from RS 2 and RS 3, and smallmouth bass should be similar sufficiently to largemouth bass for this purpose.

To conduct the moving window analysis with the pre-dredging fish tissue data, the following steps were performed at each station separately:

1. Calculate the long-term time trend and 95-percent confidence limits on the trend for the full (1998 to 2008) dataset, assuming a first order rate of decline equation. Determine the percent deviation of the confidence limits from the long-term time trend using the following equation:

$$Deviation\ (\%) = \frac{(Trend_{ST} - Trend_{LT})}{Trend_{LT}} * 100\ (Eq. 3)$$

[5] The "moving window" refers to the interval of time used to estimate a rate of decline. For example, if 11 years of data are available and it was desired to assess the accuracy of a six-year data interval (i.e., "window") in predicting the actual rate of decline for the 11 years, then it would be possible to calculate a rate of decline for the following periods: years 1-6, 2-7, 3-8, 4-9, 5-10, and 6-11. This analysis would yield six different estimates of the rate of decline that could then be compared with the actual rate for the entire 11-year period.

Where $Trend_{ST}$ is a short-term trend estimated using less than 11 years of data (11 years is the number of years used to estimate the long-term trend), and $Trend_{LT}$ is the long-term trend estimate. When the deviation is calculated for the 95-percent confidence limits on the long-term trend itself, the upper or lower 95-percent confidence limit is substituted for the $Trend_{ST}$ term in this equation.

2. Identify all groups of m consecutive years between 1998 and 2008, with $3 \leq m \leq 10$. For example, for $m = 3$, the time interval is as follows: 1998 to 2000, 1999 to 2001, 2000 to 2002, 2001 to 2003, 2002 to 2004, 2003 to 2005, 2004 to 2006, 2005 to 2007, and 2006 to 2008.
3. For each grouping of m consecutive years identified in Step 2, estimate the time trend using a first order rate of decline equation. Calculate the deviation of this trend from the long-term trend estimated in Step 1.
4. Repeat Steps 1 to 3 for each value of m.
5. Plot the percent deviation as a function of m, along with the percent deviation of the confidence bounds on the long-term time trend.
6. Determine the minimum length of time series needed as the window size for which the estimate deviations are contained within the deviation of the 95-percent confidence bounds from the long-term mean trend.

The moving window method described above was performed using the pre-dredging data. The applicability of these results to post-dredging conditions was evaluated by comparing the variability in the pre- and post-dredging datasets. First, the data was log-transformed, and then mean-centered on an annual basis. This was done to account for non-normality in the dataset and to remove any variability associated with year-to-year differences in the dataset. Next, the annual standard deviation of the transformed data was calculated for the pre-dredging and post-dredging period and compared qualitatively to assess whether the variability was similar across the two periods. Second, the variance of the two periods was compared quantitatively using the Levene Test of homogeneity of variance across the two dredging periods. The Levene Test was used because it is less sensitive to small departures from normality compared with the F-Test or Bartlett's Test of homogeneity of variance. Prior to running the test, the data was pooled by dredging period to allow the variance of the two periods to be compared. The results of this analysis are presented in Section 4.6.

3.3 Species-weighted Average Calculation

The ROD utilized a "species-weighted average" to characterize concentrations associated with risk levels and to assess progress against the RGs for the site. This Section discusses how the species-weighted average is calculated. As detailed in the *Revised Human Health Risk Assessment* (EPA 2000d), fish-PCB concentrations were averaged across species and locations to characterize an

"average fish" that an "average angler" might collect and consume from a random point located within RS 1, RS 2, or RS 3. This approach was taken to characterize risk from consuming UHR fish in support of the ROD. Each year, the species-weighted average is calculated by spatially integrating species data (with uncertainty) into a single estimate. This approach represents the range of in-river habitats and across three trophic levels from any given point along the 40 miles of the UHR (EPA 2000d).

Figure A3-2 illustrates the methodology used to compute the species-weighted average first presented in Table 11-2 of the ROD, and that is further discussed in this section[6]. The UHR species-weighted average methodology involves four fish species: brown bullhead, largemouth bass, smallmouth bass, and yellow perch, representing three trophic levels. Brown bullhead are benthic feeders (similar to carp or eel). Largemouth bass and smallmouth bass represent a large, piscivorous "top predator" fish (such as bass or walleye). Yellow perch represent a mid-trophic level fish preying on invertebrates or smaller fish. These species were included in the species-weighted average based on historical monitoring conducted by NYSDEC, ROD modeling considerations, and the results of a creel survey conducted of Hudson River anglers (EPA 2002).

Based on the results of this work, it was estimated that an average fisherman's creel would be composed of approximately 44 percent brown bullhead, 47 percent black bass (smallmouth bass and largemouth bass), and 9 percent yellow perch (EPA 2000d). In building the river section species average, the data for each species are first averaged on a station basis. The species-weighted average accounts for species availability at monitoring stations by weighting species at each station equally and consistently through time. A single average is produced for each station regardless of how many species-specific samples were actually obtained from that location in a given year. For all but one station, a single black bass species (either largemouth bass or smallmouth bass) was chosen to represent each station.[7] Then, the four or five station averages (depending on river section) are simply averaged to yield the river section average for the species. This method precludes random variation in species collection across stations and within species from introducing additional uncertainty in the species-weighted average calculation. For example, in RS 2 there are four stations, all of which are sampled for brown bullhead, typically five specimens/samples per station per year. If all stations yield their quota for a given year, then an average of all samples or an average of the station averages will yield the same average for RS 2. However, if in a given year, two stations have limited success, yielding only three samples each,

[6] In 2020, the species-weighted average calculation was updated to average species at a station level before averaging together at a river section level. It also restricted the black bass species at each station to reflect the type of black bass caught at the station. This change was completed after the last five-year review was finalized and had a minimal impact on the species-weighted average calculations to date. Additional details regarding this change are presented in Attachment A.

[7] As an example, four of the five of the stations in RS 1 are represented by smallmouth bass and one station is represented by largemouth bass. In RS 2, one station has historically yielded approximately equal amounts of smallmouth and largemouth bass, so both species are collected and weighted equally to contribute to the black bass average for that station.

then a simple average of all data will place greater weight on the more successful stations. This will introduce greater variability to the annual average for the river section if the averages of the individual stations are not identical, which they typically are not. Averaging by station first maintains a consistent spatial representation across the river section, and avoids variability introduced by sample availability. The calculation of species-weighted average concentrations was performed for both wet-weight and lipid-normalized $TPCB_{HE}$.

The likelihood that a fish might be collected by an angler for consumption from a given river section was assumed to be proportional to the length of that river section. Thus, the contribution to the overall average was estimated by applying the fraction of the 40-mile Upper Hudson represented by each river section based on its length. RS 1 (Thompson Island Pool, River Mile [RM] 194.8–188.5) was weighted at 0.154. RS 2 (Fort Miller and Northumberland Pools, RM 188.5–183.4) was weighted at 0.125. RS 3 (the Stillwater, Mechanicville, Lock 2, and Waterford pools, RM 183.4–153.9) was weighted at 0.721. Note that RS 3 is weighted to reflect all of its 29.5 miles, while the RAMP fish monitoring stations representing RS 3 are all located in Reach 5, which is slightly more than half of RS 3 at 15.9 miles long. Data from Reaches 4 through 1 are not included in the species-weighted average calculation because fish from these reaches are not collected regularly. A summary of the data collected in Reaches 4 through 1 is presented in Section 4.3. The discussion of the species-weighted average results is found in Section 4.5.

4 RESULTS AND DISCUSSION

4.1 Fish Tissue Concentrations over Time

The ROD target for human health risk uses a species-weighted average approach to evaluate fish tissue data. The species-weighted average is intended to characterize an "average fish" that an "average angler" might collect and consume from a random point located within in the UHR. However, to understand how the system is recovering, it is important to also look at individual species on a more granular level. This section discusses the fish tissue data collected in the UHR by species and river section.

Data for individual species can be plotted over time to show fluctuation in PCB concentration over the three periods. Fish tissue PCB concentrations (both wet-weight and lipid-normalized) and lipid content for each species and river section are presented in Figures A3-3 through A3-9. These plots show fish tissue data from 2004 to 2021, with data from the pre-dredging baseline period (2004 to 2008) in blue, dredging period (2009 to 2015) in orange, and post-dredging period (2016 to 2021) in green. The different symbols on the plots indicate collection agency. Each figure is comprised of multiple rows, with $TPCB_{HE}$ wet-weight concentrations (top row), lipid content (middle row), and $TPCB_{HE}$ lipid-normalized concentrations (bottom row).

Results for samples collected at the Feeder Dam are shown in Figure A3-3. Figure A3-3A presents concentrations for brown bullhead, largemouth bass, and smallmouth bass. Figure A3-3B presents concentrations for yellow perch, pumpkinseed, and forage fish (including spottail shiner). Spottail shiner data are not plotted separately from other forage fish, because it has not been collected from the Feeder Dam location in the post-dredging period. Fish PCB concentrations at the Feeder Dam show little variation through time, with wet-weight $TPCB_{HE}$ concentrations typically between 0.01 mg/kg-ww and 0.1 mg/kg-ww for all species. Overall, $TPCB_{HE}$ geometric mean concentrations are less than 0.05 mg/kg-ww and 10 mg/kg-lipid for brown bullhead, smallmouth bass, largemouth bass, pumpkinseed, yellow perch, and forage fish at the upstream background station. These concentrations are more than an order of magnitude lower than the concentrations observed from within the project area, indicating that upstream conditions have a minimal influence on the observed concentrations of fish within the project area.

Figures A3-4 to A3-9 show the PCB concentration by species. There is one figure for each species. Each column represents the corresponding results for the various river sections. These plots show similar patterns in concentrations over time. In general, PCB concentrations in fish tissue show increases during dredging due to related sediment resuspension in the water column followed by a decrease in concentrations in the post-dredging period. Overall, fish concentrations are now below those observed during the pre-dredging period. In general, fish tissue concentrations have significant variability in observed PCB concentrations. Within any given year, there is typically over an order of magnitude difference in observed concentrations. As discussed above, there are

many reasons that influence this large range of observed concentrations including natural variability in fish ages and localized exposure conditions. There is also significant year-to-year variability, which is associated with environmental factors such as flooding, storms, flow conditions, and representativeness of the fish collected for sampling.

Sport fish, pumpkinseed, and forage fish (including spottail shiner) are all collected as part of the UHR monitoring program to represent different trophic levels and exposure conditions. The following paragraphs discuss observations associated with each of these fish in the post-dredging period for PCB concentration and lipid content. Because PCB concentrations covary with lipid content, declines in wet-weight concentration can result from declines in lipid content that do not reflect actual declines in exposure to PCBs. Thus, both PCB concentrations (wet-weight and lipid-normalized) are presented here. As discussed in more detail in Section 4.6, there are not sufficient data to establish the long-term trends with sufficient precision at this time, and therefore, the discussions below present current observations that are subject to change with the addition of more years of data.

For reference, the first two ROD human health targets (0.4 and 0.2 mg/kg-ww) for fish tissue PCB concentrations are shown as dashed lines for the sport fish (discussed in Section 1.2.3). Although these targets were designed for the species-weighted average, they provided good context for how individual fish are progressing. Brown bullhead are benthic feeders and spend a large fraction of their adult life in direct contact with sediment (similar to carp or eel). In the post-dredging years, the brown bullhead $TPCB_{HE}$ wet-weight concentrations decline across all three river sections (Figure A3-4). The lipid-normalized data from RS 2 and RS 3 do not show as clear of a decrease in concentrations but the lipid content in RS 2 and RS 3 has declined in the post-dredging period. This suggests that some of the decline in $TPCB_{HE}$ may be the result of the lipid decline and not a decrease in exposure. However, when lipid content is less than 1 percent as it is for many of the post-dredging samples, NLOM becomes an important factor with respect to absorption capacity (de Bruyn and Gobas 2007; Mäenpää et al. 2015; Jahnke et al. 2015). This can lead to non-linearities in the observed relationship between lipid content and contaminant concentrations, and this should be considered when evaluating changes over time.

In addition to the general trend of the data, it is also useful to note the actual distribution of the data relative to the ROD targets. Compared to the pre-dredging period, the percentage of brown bullhead that are now below the first ROD target (0.4 mg/kg-ww) has increased from 3 percent to 31 percent (Table A3-6). As discussed below (Section 4.6), additional years of data are necessary to establish a trend in the post-dredging period.

Largemouth and smallmouth bass both represent the same species group (black bass) in the UHR monitoring program. Both species are a large, piscivorous “top predator” fish. Even though largemouth and smallmouth bass represent black bass, it is important to not group these species together as they have different PCB body burdens for similar levels of exposure, with smallmouth

bass generally higher in PCB concentrations in any river section where both were sampled. In the post-dredging period, largemouth bass were obtained in limited quantities from RS 1 and RS 2, and smallmouth bass was used as a substitute species. In 2021, EPA optimized the fish collection program, part of this optimization was to identify the specific species available at a station and limit species substitution. As a result of this optimization, largemouth bass is now only collected from two of nine stations in RS 1 and RS 2 and all the stations in RS 3. This adjusted collection of largemouth and smallmouth bass in RS 1 through RS 3 is intended to reduce variance in the species-weighted average by consistently collecting the same species at each station, while still representing black bass across the UHR. While this change in the fish collection program does reduce the variation in the species-weighted average, the lack of samples does create limitations when evaluating the largemouth bass data in RS 1 and RS 2 and smallmouth bass data in RS 3. Therefore, the evaluation of black bass concentrations over time focuses on smallmouth bass for RS 1 and RS 2 and largemouth bass for RS 3 (Figures A3-5 and A3-6) in the discussion below.

The $TPCB_{HE}$ wet-weight concentrations in smallmouth bass appear to have slight decline in the concentrations in RS 2 and less change in RS 1 since 2016 (Figure A3-6). Lipid content in smallmouth bass is variable or increasing in RS 1 and shows a slight decrease in RS 2. When comparing the lipid-normalized results, the observed declines are more similar than the wet-weight concentrations.

$TPCB_{HE}$ wet-weight concentrations and lipid content in largemouth bass in RS 3 appear to have slight declines in the post-dredging years (Figure A3-5). Lipid normalization affects the year-to-year variability for both largemouth and smallmouth bass, as shown in the lipid-normalized plots. However, as noted above, at low lipid levels, the relationship between lipid and PCB becomes more complex so that simple lipid-normalization may mask the degree of change. Since the lipid content is below 1 percent for most samples, NLOM becomes an important factor with respect to absorption capacity.

In comparing the actual distribution of the pre-dredging and post-dredging data relative to the ROD targets, the percentage of largemouth bass that are now below the first ROD target has increased from 22 to 31 percent (Table A3-6) and the percentage of smallmouth bass that are now below the first ROD target has increased from 10 to 20 percent. As noted previously for brown bullhead, additional years of data are necessary to establish the long-term trends with sufficient precision to properly assess current trends in the data.

Yellow perch represent a mid-trophic level fish preying on invertebrates or smaller fish. In the post-dredging period, yellow perch $TPCB_{HE}$ wet-weight concentrations appear to have little change across all river sections for both the wet-weight and lipid-normalized data (Figure A3-7). Lipid content fluctuates in the post-dredging period but generally shows no trend. Compared to the pre-dredging period, the percentage of yellow perch that are now below the first ROD target has increased from 43 to 56 percent (Table A3-6). As noted previously, additional years of data

are necessary to establish the long-term trends with sufficient precision to properly current trends in the data.

Pumpkinseed are used as rapid integrators in the UHR monitoring program. These fish are collected as yearling fish represent a single year of exposure, unlike the other species samples, which are primarily comprised of adult sportfish several years in age—therefore, they are anticipated to reflect current conditions in the river. The short exposure period of the pumpkinseed also makes them more susceptible to annual environmental changes such as impacts associated with high flow events, which may cause unexplained variations in PCB body burdens. Consistent with this, $TPCB_{HE}$ wet-weight and $TPCB_{HE}$ lipid-normalized data in the post-dredging period show more year-to-year fluctuation than the other species (Figure A3-8). In contrast, the lipid content show much less variation than the sport fish and little change through all three period of data. Because of high year-to-year variability in PCB concentration, it is difficult to observe any changes in with the data with a short-term dataset (Figure A3-8). As noted previously, additional years of data are necessary to establish the long-term trends with sufficient precision to properly assess current trends in the data.

Similar to pumpkinseed in many respects, forage fish (including spottail shiner) are also used as rapid integrators. To align with the program's recent shift towards focusing solely on spottail shiner, two separate plots were generated (Figures A3-9A and A3-9B). Figure A3-9A presents data for all forage fish species, while Figure A3-9B focuses exclusively on spottail shiner. Figure A3-9A provides a general understanding of PCB levels within the forage fish community, but comparison of PCB concentrations across years is challenging. This difficulty comes from the fact that the species collected at each station varied over time (Figure A3-9C) and these species' $TPCB_{HE}$ concentrations can differ by a factor of five, as illustrated in Figure A3-9D. To further evaluate the difference in the average $TPCB_{HE}$ concentrations between spottail shiner and other forage fish, Lin's Concordance Correlation Coefficient (Lin's CCC) was used. This statistical metric assesses the agreement between two continuous variables by evaluating the degree to which two sets of observations fall on the 1:1 line. The Lin's CCC value is low at 0.38, which indicates a lack of agreement between the two measurements. This inconsistency in species concentrations and the variable species collected across years confound the ability to detect PCB concentration changes. To reduce such variation, the program was refined to focus on spottail shiner beginning in 2021. While this approach will increase the spottail shiner collection in the coming years, the existing spottail shiner data in the post-dredging period (2016 to 2020) is limited (Figure A3-9B). This limited data makes it difficult to observe if meaningful changes have occurred in the post-dredging period.

4.2 Progress Towards Achieving the Fish Tissue RAOs

As discussed in Section 1.2.3, there are RAOs established in the ROD for human health risk and ecological risk. The species-weighted average is the primary metric that the ROD goals and targets

are measured against. As of 2021, the species-weighted average was 0.71 and has not met the first human health target of 0.4 mg/kg-ww. As shown in Section 4.5, the species-weighted average on the wet-weight basis does appear to be decreasing in the post-dredging period (Figures A3-16A to A3-19A). However, such trend appears less apparent when concentrations are normalized to lipid (Figures A3-16B to A3-19B), illustrating that variables that affect fish tissue concentration need to be considered when determining declines in fish tissue concentrations. Because of the influence lipid normalization has on observed trends, it is important to understand the potential causes associated with the observed variability in lipid content and declines over time. EPA is continuing to evaluate this matter. Additionally, as discussed in section 3.2.1, the role of NLOM is more important at lower lipid levels and will be further evaluated. As discussed in Section 4.6, there is not yet sufficient data to establish a rate of decline during the post-dredging period. As discussed above, post-dredging individual fish-species PCB concentrations are generally approaching the ROD human health targets, but some species appear to be recovering more quickly than others. The percentage of fish with $TPCB_{HE}$ wet-weight concentrations below 0.4 mg/kg-ww has increased compared to that of the pre-dredging period (Table A3-6). This percentage has increased across most river sections and species. Overall, in the UHR, the number of samples below the 0.4 mg/kg-ww threshold increased from 21 to 37 percent. The largest gain is shown in RS 1, where the number of samples below the 0.4 mg/kg-ww threshold increased from 15 to 44 percent.

The ROD ecological targets for largemouth bass are specified on a whole-body basis and range from 0.3 mg/kg-ww to 0.03 mg/kg-ww (Section 1.2.3), as discussed in Appendix 5, there have been some changes to exposure parameters since the ROD that would narrow the range to 0.2 mg/kg-ww to 0.07 mg/kg-ww. Routine monitoring for largemouth bass is done on a fillet basis. Because ecological receptors (river otter) are expected to consume their prey on a whole-body basis, the measured fillet concentrations require an adjustment to reflect the difference between the standard fillet and the whole-body. As discussed in the BERA, a literature-based factor of 2.5 was applied to convert largemouth bass concentrations from a standard fillet to a whole-body equivalent concentration (EPA,1999). Figure A3-10 shows the resulting estimated whole-body PCB concentrations for largemouth data derived from the standard fillet samples in comparison to the ROD ecological targets of 0.3 mg/kg-ww to 0.03 mg/kg-ww. Based on the post-dredging data, largemouth bass have not yet achieved the ROD ecological targets, with 6 percent[8] of data below the 0.3 mg/kg-ww criterion and none below the 0.03 mg/kg-ww criterion. However, it is important to note that the ecological targets themselves are based on the dietary intake of river otters, which typically consume fish between 4 and 7 inches in size, rather than the larger fish collected for fillet analysis. Therefore, the estimated whole-body bass concentrations carry a significant degree of uncertainty due to the potential differences in PCB levels between smaller and larger fish, as well as the lack of site-specific fillet to whole-body conversion factor. Recognizing this data gap,

[8] This percentage is based on all post-dredging samples, including those collected from Reaches 4 to 1.

whole-body largemouth bass (that are representative in size to those that would be consumed by otter) will be collected and analyzed in the future monitoring events.

As stated in Section 1.2.3, the ROD ecological targets for spottail shiner (whole-body) range from 0.7 mg/kg-ww to 0.07 mg/kg-ww. Similar to bass, there have been some changes to exposure parameters since the ROD which would narrow the range to 0.34 mg/kg-ww to 0.11 mg/kg-ww (Appendix 5). Figure A3-9A shows the comparison of forage fish to the ROD ecological targets. In the post-dredging period, approximately 20 percent[9] of forage fish data are below the 0.7 mg/kg-ww criterion and no results are below the 0.07 mg/kg-ww criterion.

4.3 Evaluation of Reaches 4 through 1 Fish Data

RS 3 includes approximately 29.5 of the 40 miles of the UHR project length and is comprised of river Reaches 5 through 1 (Figure A3-1). Since 2004, Reach 5 (15.9 miles out of the 29.5 miles of RS 3), has been sampled annually to represent all of RS 3 (GE 2004; GE 2012). EPA made this implicit assumption in the design of the monitoring program because Reach 5 covers approximately 50 percent of the RS 3 length, Reach 5 is upstream of Reaches 4 through 1, and PCB contamination in the Hudson River generally decreases from upstream to downstream. As a result, PCB concentrations in fish tissue in Reaches 4 through 1 are expected to be the comparable to or less than that in Reach 5. As discussed in Section 2.1, NYSDEC and GE collected fish from Reaches 4 through 1 in 2017 and 2019, respectively, to examine this assumption. In 2017, NYSDEC collected pumpkinseed and forage fish (spottail shiner, golden shiner, spotfin shiner). GE sampled these same reaches for brown bullhead, yellow perch, largemouth bass, and smallmouth bass in 2019.

EPA evaluated the 2017 and 2019 fish collected from Reaches 4 through 1 and determined that the Reach 5 data are consistent with and therefore generally representative of the PCB levels in fish collected from theses lower reaches. EPA also examined data from the LHR at the Albany/Troy station (not presented here) and found that this station generally provided a lower bound to the concentrations observed in Reaches 4 through 1. To monitor the relationship between Reach 5 and Reaches 4 through 1, EPA determined that, during the post-dredging period, these reaches should be sampled every five years for pumpkinseed. In this manner, pumpkinseed will be used to evaluate if fish concentrations in Reaches 4 through 1 remain within expectations and if additional sampling is necessary.

Figures A3-11 through A3-14 present comparisons of $TPCB_{HE}$ concentrations across Reaches 5 through 1 for spottail shiner, brown bullhead, yellow perch, and pumpkinseed, respectively. Each figure contains two parts. Part A compares the results for each reach and part B plots contrasts the results of Reach 5 versus the combined results of Reaches 4 through 1. Part B compares the geometric means of the two groupings using a Tukey-Kramer test to identify statistically

[9] This percentage is based on all post-dredging samples, including those collected from Reaches 4 to 1.

significant differences between Reach 5 and Reaches 4 through 1. Generally, in a Tukey-Kramer test, if the circles overlap, the geometric means are not statistically different. For each part, A and B, there are two charts, showing $TPCB_{HE}$ results on a wet-weight (mg/kg-ww) basis on the upper panel and $TPCB_{HE}$ on a lipid-normalized (mg/kg-lipid) basis on the lower panel. The plots only contain data for years where Reaches 4 through 1 samples were collected.

The plots for spottail shiner represent 2017 data while the plots for brown bullhead, and yellow perch represent 2019 data. The pumpkinseed plots represent a comparison of both 2017 and 2021 sampling results. Largemouth bass, golden shiner, and spotfin shiner were not included in the comparison because of limited sample sizes from Reaches 4 through 1. Smallmouth bass were collected in Reaches 4 through 1 but are not collected consistently at the main stations in RS 3 (see Section 4.1), so it was not included in this analysis.

The spottail shiner data presented in Figure A3-11A show variability in $TPCB_{HE}$ concentration from Reaches 4 through 1 but the concentrations are generally at or below those of Reach 5. In Figure A3-11B, the Tukey-Kramer analysis shows that the geometric mean PCB concentration for Reaches 4 through 1 is statistically lower from that of Reach 5 on both a wet-weight and a lipid-normalized basis.

Sport fish spatial variability appears less pronounced than spottail shiner for Reaches 4 through 1 (Figures A3-12A and A3-13A). In Figures A3-12A and A3-13A, $TPCB_{HE}$ concentrations for each species on a wet-weight basis in Reaches 4 through 1 are similar to, and generally fall within the ranges of concentrations observed at the upstream Reach 5 station. On a lipid-normalized basis, a few samples for both brown bullhead and yellow perch in Reaches 2 and 1 exceed the maximum value observed at the Reach 5 stations. This result is not unexpected because of the high variability in fish data. It is more appropriate to compare the data with metrics like the geometric mean. The Reach 5 geometric mean is greater than or equal to the geometric mean for Reaches 4 through 1 in nearly all cases. The one exception is yellow perch lipid-normalized plot in Figure A3-13B, where the geometric mean for Reaches 4 through 1 is greater than Reach 5. However, the Reach 5 yellow perch wet-weight geometric mean is still greater than the Reaches 4 through 1 species data.

Figure A3-14A shows pumpkinseed that were collected in 2017 by NYSDEC and in 2021 by GE. In 2017, $TPCB_{HE}$ concentrations are highest in Reach 5 and gradually decrease downstream, with some minor variation in the concentrations across stations. In 2021, the samples collected by GE show less variation across all the reaches except for Reach 2. The geometric mean in Reach 2 during 2021 was higher than all other reaches in RS 3. A detailed review of the data indicated that the pumpkinseed specimens were collected from a small section of the reach and were not representative the previous sampling locations or the reach as a whole. Given this concern, additional sampling was conducted in 2022 to further evaluate concentrations in Reach 2. These results are not yet available.

In Figure A3-14B, the Tukey-Kramer analysis shows the geometric means for the two groups (Reach 5 vs. Reaches 4 through 1) either agree within error or the geometric mean for the Reach 4 through 1 dataset is lower than Reach 5 alone, indicating that Reach 5 can serve as an upper bound for the concentrations of the lower reaches—even with the inclusion of the Reach 2 data. EPA will continue to monitor in Reaches 4 to 1 by sampling for pumpkinseed every five years to confirm concentrations are within expectations.

4.4 Pre- and Post-Dredging Data Comparison

As described in Section 3.2.2, one-way ANOVA with two groups was used to assess the change in geometric mean of the lipid-normalized wet-weight fish tissue $TPCB_{HE}$ concentrations between the pre-dredging baseline (2004 to 2008) and post-dredging (2016 to 2021) periods. Figure A3-15 shows the percent changes in fish tissue the lipid-normalized $TPCB_{HE}$ wet-weight concentrations during the post-dredging period relative to the pre-dredging baseline period. A positive value indicates an increase in lipid-normalized concentration and a negative value indicates a decrease in lipid-normalized concentration. On this figure, an asterisk (*) was used to denote that the change in lipid-normalized concentration was significant at a 95-percent confidence level as indicated by the p-value of the regression coefficient. These results indicate that within the UHR (RS 1 through RS 3), the geometric mean of the fish tissue lipid-normalized $TPCB_{HE}$ concentrations declined consistently across all species for nearly all river sections relative to baseline conditions. The reduction was statistically significant for all species in all river sections with the exception of largemouth bass in RS 3. Statistically significant reductions by species and river section ranged from 22 to 68 percent.

For brown bullhead, yellow perch and pumpkinseed, the magnitude of the reduction in tissue PCB concentrations was statistically greater in RS 1 than in RS 2 or RS 3. This parallels the decline in surface sediment concentration in that RS 1 also exhibited the greatest percent decline from the pre-dredging to post-dredging period. In RS 1, brown bullhead and pumpkinseed showed the largest decrease, about 68 percent, with all species showing at least a 40 percent decline. In RS 2, spottail shiner had the largest decrease at 65 percent, while smallmouth bass showed a decrease of about 22 percent. Again, all declines were statistically significant in this river section. In RS 3, brown bullhead shows the largest decrease at 48 percent, while largemouth bass appears to have experienced no change. As discussed in Section 4.1, the evaluation of black bass concentrations over time focuses on smallmouth bass for RS 1 and RS 2 and largemouth bass for RS 3.

In summary, a one-way ANOVA analysis was able to identify changes in $TPCB_{HE}$ between the pre-dredging and post-dredging periods independent of lipid variations. This analysis identified substantial (22 to 68 percent), statistically significant reductions across all river section-species pairs, except for largemouth bass at RS 3, compared to the pre-dredging baseline period.

4.5 Species-Weighted Average Results

As discussed in Section 3.3, the species-weighted average is used to characterize an "average fish" that an "average angler" might collect and consume for the purpose of characterizing exposures from fish consumption. It is calculated from the $TPCB_{HE}$ concentrations in sport fish fillet samples collected by GE in RS 1, RS 2, and Reach 5 (part of RS 3) from 2004 to 2021. Figures A3-16A to A3-18A (wet-weight) and A3-16B to A3-18B (lipid-normalized) show the species-weighted average concentrations for RS 1, RS 2, and RS 3, respectively. Figure A3-19A (wet-weight) and A3-19B (lipid-normalized) show the species-weighted average concentrations for the entire UHR. The species-weighted average values for the BMP (2004 to 2008) are shown in blue; the dredging period (2009 to 2015) is shown in orange; and the post-dredging period (2016 to 2021) is shown in green. The first two ROD human health targets (0.4 and 0.2 mg/kg-ww) for fish PCB concentrations are shown as dashed lines on the wet-weight concentration figures.

Table A3-7 shows the wet-weight species-weighted average $TPCB_{HE}$ concentrations by river section for 2004 to 2021. Figures A3-16A to A3-19A show declining wet-weight species-weighted average $TPCB_{HE}$ concentrations within each river section since the end of the dredging period. From 2016 to 2021, the species-weighted average in RS 1 decreased from 1.3 mg/kg-ww to 0.71 mg/kg-ww. In RS 2, the species-weighted average decreased from 1.9 mg/kg-ww to 0.76 mg/kg-ww and in RS 3, the average decreased from 0.99 mg/kg-ww to 0.69 mg/kg-ww. The species-weighted average for the UHR has decreased from 1.1 mg/kg-ww in 2016 to 0.71 mg/kg-ww in 2021. Like the results obtained by the ANOVA analysis described previously, RS 1 and RS 2 show the largest declines since dredging.

Figures A3-16B to A3-19B show that declines in wet-weight $TPCB_{HE}$ are less apparent when normalized to lipid content, suggesting that variability in lipid is important in determining concentration changes over time.

The ROD had anticipated the first target of 0.4 mg/kg-ww would be achieved within five years of dredging. Five years after dredging, in 2020, the species-weighted average was 0.63 mg/kg-ww. Although the first target was not achieved in the time frame anticipated in the ROD, concentrations have continued to decline. Additional data are needed for the post-dredging period to determine a reliable trend in the data that can be used to evaluate if the remedy is on track to meet the second ROD target of 0.2 mg/kg-ww in about 16 years after dredging. EPA is further assessing factors that can be considered when evaluating rates of decline, such as lipids. However, as noted in the response to comments for the second Five-Year Review Report, actual conditions during dredging did not (and were not expected to) match up in every way with conditions as understood when the ROD modeling was conducted. Therefore, direct comparisons of observed fish tissue concentrations to the ROD forecasts need to be carefully considered (EPA 2019b).

4.6 Data Requirements for Estimating Reliable Time Trends in Fish Tissue Data

As discussed in Section 3.2.3, the data from the pre-dredging period was used to examine the ability to accurately estimate long-term rates of change when relatively limited periods of data (six years or less) are available. Figure A3-20 presents the results of the moving window analysis described in Section 3.2.3. For brown bullhead, largemouth bass, yellow perch, and pumpkinseed in RS 1, for a given consecutive six-year grouping of pre-dredging data (six years is the current number of years of post-dredging data), the estimated time trend can vary approximately ± 50 percent of the long-term time trend (based on the years 1998 to 2008).

- For brown bullhead, only two of 11 potential short-term time trends calculated using either six or seven years of consecutive data fell within the 95-percent confidence limits of the average long-term time trend. When short-term time trends calculated using 8 to 10 consecutive years of data, five of nine potential time trends fell within the 95-percent confidence limits of the average long-term time trend.
- For largemouth bass, only two of 11 potential short-term time trends calculated using either six or seven years of consecutive data fell within the 95-percent confidence limits of the average long-term time trend. When short-term time trends calculated using eight to 10 years of data, six of nine potential time trends fell within the 95-percent confidence limits of the average long-term time trend.
- For yellow perch, none of short-term time trends calculated using either six or seven years of consecutive data fell within the 95-percent confidence limits of the long-term time trend. When short-term time trends calculated using eight to 10 years data, only two of nine potential time trends fell within the 95-percent confidence limits of the average long-term time trend.
- For pumpkinseed, only three of 11 potential short-term time trends calculated using either six or seven years of consecutive data fell within the 95-percent confidence limits of the average long-term time trend. When short-term time trends calculated using eight to10 years of data, only two of nine potential time trends fell within the 95-percent confidence limits of the average long-term time trend.

To evaluate if the moving window analysis conducted on the pre-dredging data is applicable to the post-dredging data, a comparison of the variability exhibited in each data set was conducted. Table A3-8 presents the annual standard deviation of the of the lipid-normalized $TPCB_{HE}$ concentrations for the four species listed above for RS 1. For brown bullhead and yellow perch, the similarity in the standard deviation for the pre- and post-dredging years is evident and supports the conclusion that indicates the variability in the data collected within the two dredging periods is similar. The Levene Test for homogeneity of variances between groups indicate that the variances between the pre- and post-dredging datasets for two of the four species evaluated were not significantly different (for brown bullhead, F-value = 0.073, p-value = 0.787; for yellow perch, F-value = 2.76,

p-value = 0.097). For largemouth bass and pumpkinseed, the results of the Levene test indicated that the variances between the pre- and post-dredging datasets were significantly different (for largemouth bass, F-value = 7.78 p-value = 0.006; for pumpkinseed, F-value = 12.6, p-value = 0.0004). Both largemouth bass and pumpkinseed have a higher variability in post-dredging period than the pre-dredging period. The higher variability plus the results of the Levene test indicate that more years of data are needed to accurately estimate trend post-dredging that than predicted by the pre-dredging moving window analysis. The variability in largemouth bass in RS 1 in the post-dredging period is due to the limited collection of that species in the river section (Section 4.1). For largemouth bass, the results of the moving window analysis can serve conservative estimate of the minimum number of years of data needed to calculate a meaningful trend. The results of the moving window analysis and the Levene test presented here support the conclusion that at least eight or more years of fish tissue data are needed before meaningful time trends can be calculated.

While the ROD goal for human health is applicable to the species-weighted average, the species-weighted average cannot but used in the moving window analysis above because species need to be evaluated individually. Given the inter-annual variation in concentration data, which results from variability in covariates like lipid and NLOM, long-term datasets are required to reliably estimate time trends. Insufficient or short-term datasets can result in unreliable and unstable estimates and may result in premature conclusions on recovery and future concentrations. Furthermore, because a first order rate of decline equation is used to estimate time trends, time trends based on a small number of years are sensitive to the starting and ending concentrations. This explains why the greatest variability is observed for shorter periods and the variability exponentially decreases as the window size increases and more data is available for estimating the trend. Using data from the Great Lakes region, Gewurtz et al. (2011) analyzed datasets from different contaminant monitoring programs and demonstrated that more than 10 years of data appear optimal for use in estimating time trends and were less sensitive to the starting and ending concentrations. In contrast, the authors found that shorter term datasets could exhibit decreasing, increasing, or no significant trends, depending on the starting and ending concentrations. Statistical analysis indicates the current six years of fish tissue data are insufficient to establish the long-term trends with sufficient precision to properly assess the success of the remedy.

5 CONCLUSIONS

Major Conclusions of this appendix are as follows:

- In general, PCB concentrations in fish tissue increased during dredging due to related sediment resuspension in the water column, then decreased in the post-dredging period to levels at or below the pre-dredging levels.
- In the post-dredging period, there is high variability in PCB concentrations among fish species. Some fish such as the brown bullhead appear to show a consistent decline in wet-weight while in other species the change in concentration is not as apparent. In addition to the inter-species variability, there is also year-to-year variability in the relationship between lipid and PCB concentration. While the sources of this variability are not specifically known, the relationship between lipid and PCB is generally complex and becomes more so when lipid content is less than 1 percent, as it is in several fish species in the UHR. At these levels, NLOM becomes an important factor with respect to PCB absorption capacity. This can lead to non-linearities in the observed relationship between lipid content and contaminant concentrations.
- While the 2021 species-weighted average for the UHR remains above the first ROD human health target of 0.4 mg/kg-ww, at the species level, the percentage of sport fish with $TPCB_{HE}$ wet-weight concentrations below 0.4 mg/kg-ww has increased compared to that of the pre-dredging period. The percentage of fish tissue samples with $TPCB_{HE}$ less than the 0.4 mg/kg-ww threshold has increased across most river sections and species. In the UHR, the number of samples below the 0.4 mg/kg-ww threshold increased from 21 to 37 percent. The largest gain is shown in RS 1, where the number of samples below the 0.4 mg/kg-ww threshold increased from 15 to 44 percent.
- A one-way ANOVA with two groups was used to statistically compare the geometric mean of lipid-normalized $TPCB_{HE}$ concentrations between the pre-dredging baseline (2004 to 2008) and post-dredging (2016 to 2021) periods. This analysis identified substantial (22 to 68 percent), statistically significant reductions across all river section-species pairs, except for largemouth in RS 3, compared to the pre-dredging baseline period.
- The species-weighted average characterizes an “average fish” consumed by an “average angler” for risk characterization. The ROD had anticipated the first species-weighted average target of 0.4 mg/kg-ww would be achieved within five years of dredging. Five years after dredging, in 2020, the species-weighted average was 0.63 mg/kg-ww. Although the first target was not achieved in the time frame anticipated by the ROD, concentrations have continued to decline. Additional data are needed for the post-dredging period to determine a trend in the data that can be used to determine if the second ROD target of 0.2 mg/kg-ww will be achieved within the expectations of the ROD.

- Statistical analysis indicates the current six years of fish tissue data are insufficient to establish the long-term trends in the data. Using 11 consecutive years of pre-dredging data from RS 1 it was determined that reliable estimates of the long-term trends in PCB concentration can be obtained when at least eight or more years of data are available. When using only six years of data (the current number of years of post-dredging data), time trend estimates exhibit substantial variability (as measured by deviation from the long-term time trend), with trend estimates falling well outside the 95-percent confidence limits of the long-term time trend. This analysis indicates that to determine a meaningful time trend in fish tissue PCB concentrations, at least eight or more years of fish tissue data are needed. The results of this analysis are consistent with results from the Second Five-Year Review Comment Response (EPA 2019b) using pre-dredging fish tissue data.
- The preliminary fish data from 2022 have been included in Figures A3-21 through A3-24. This data does not change the conclusions of this report and indicates a continued decline in fish concentrations. The 2022 fish data will be finalized as part of the project data treatment approach (Attachment A), once the 2023 congener matched pairs are evaluated and incorporated.
- EPA examined the Reaches 4 through 1 data from 2017, 2019, and 2021 to confirm that Reach 5 data is representative or conservative of Reaches 4 through 1. The data show that the Reach 5 PCB wet-weight data are consistently greater than or equal to concentrations found in samples collected in Reaches 4 through 1 for the species sampled. This included brown bullhead, yellow perch, and pumpkinseed. Pumpkinseed will continue to be sampled once every five years to confirm that Reaches 4 through 1 concentrations are within expectations and determine if any additional sampling is necessary.

6 ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
BCA	Bias-Corrected and Accelerated
BERA	Baseline Ecological Risk Assessment
BMP	Baseline Monitoring Program (pre-dredging baseline period, 2004-2008)
BMR	Baseline Modeling Report
CT	Central Tendency
DSR	Data Summary Report
EPA	United States Environmental Protection Agency
FS	Feasibility Study
GE	General Electric Company
	HRGC/HRMS high-resolution gas chromatography/high-resolution mass spectrometry
LHR	Lower Hudson River
LOAEL	Lowest observed adverse effect level
MNR	Monitored Natural Recovery
M1668	EPA high-resolution gas chromatography / mass spectrometry congener-based PCB analysis method; version 1668c of the method has been used primarily since 2016. Referenced to congener standards.
M8082	EPA gas chromatography Aroclor-based PCB analysis method. Referenced to Aroclor standards.
mGBM	modified Green Bay Method; gas chromatography / electron capture detector quasi-congener-based PCB analysis method adapted by GE for the Hudson River from one originally developed for the Great Lakes. Referenced to Aroclor standards.
mg/kg	milligram per kilogram
mg/kg-ww	milligram per kilogram wet-weight
mg/kg-lipid	milligram per kilogram lipid-normalized
NIST	National Institute of Standards and Technology
NLOM	Non-lipid organic matter

NOAEL	No-observed adverse effect level
NYSDEC	New York State Department of Environmental Conservation
OU	Operable Unit
PCBs	Polychlorinated Biphenyls
PE	Performance Evaluation
PRG	Preliminary Remediation Goal
QA/QC	Quality Assurance/ Quality Control
QAPP	Quality Assurance Project Plan
RAMP	Remedial Action Monitoring Program
RAO	Remedial Action Objective
RG	Remedial Goals
RM	River mile
RME	Reasonable Maximum Exposure
ROD	Record of Decision
RS	River Section
Site	Hudson River PCBs Superfund Site
SOP	Standard Operating Procedure
SRM	Standard Reference Material
TPCB	Total PCB
$TPCB_{Aroclor}$	Total PCB Aroclors
$TPCB_{congener}$	Total PCB congeners
$TPCB_{HE}$	Total PCB homologue equivalents
UHR	Upper Hudson River
ww	Wet-weight

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Appendix 3
Tables and Figures

Tables

Table A3-1
Fish Monitoring Locations in the Upper Hudson

River Section	River Reach	River Mile (RM) Range	Monitoring Stations	RS for Figures	Number of Species Examined
Upstream Background		Approximately 201	Feeder Dam (FD)	Feeder Dam	5
RS 1	8	194.8 to 188.5	Thompson Island Pool (TD1 - TD5)	RS 1	6
RS 2	7 and 6	188.5 to 183.4	Northumberland Pool (ND1 - ND5)	RS 2	6
RS 3[1]	5	183.4 to 153.9	Stillwater Pool (SW1 - SW5)	RS 3	6
	4 through 1		RH4 - RH1		5

Note:
1. As described in the BMP QAPP (GE 2004) and RAMP QAPP (GE 2009, GE 2012), RS 3 is represented by Reach 5 (Stillwater Pool, RM 183.4 through RM 167.5). Samples are collected from Reaches 4 through 1 for additional monitoring, but they are not sampled regularly.

Table A3-2
Hudson River Species Discussed in this Five-Year Review

Species	River Section	Period of Data	
Largemouth Bass	Feeder Dam	2004	2021
	RS 1	2004	2021
	RS 2	2004	2021
	RS 3	2004	2021
Smallmouth Bass	Feeder Dam	2004	2021
	RS 1	2004	2021
	RS 2	2004	2021
	RS 3	2004	2020
Brown Bullhead	Feeder Dam	2004	2021
	RS 1	2004	2021
	RS 2	2004	2021
	RS 3	2004	2021
Yellow Perch	Feeder Dam	2004	2021
	RS 1	2004	2021
	RS 2	2004	2021
	RS 3	2004	2021
Pumpkinseed	Feeder Dam	2004	2021
	RS 1	2004	2021
	RS 2	2004	2021
	RS 3	2004	2021
Spottail Shiner	RS 1	2005	2020
	RS 2	2004	2019
	RS 3	2004	2020
Other Forage Fish	Feeder Dam	2004	2020
	RS 1	2004	2020
	RS 2	2004	2020
	RS 3	2004	2020

Note:
1. The above table includes both Aroclor and congener data.
2. The majority of the data in this report is GE Data, however there are some samples from NYSDEC in 2004, 2005, 2007 and 2017.

Table A3-3
Fish Monitoring Program Summary

Fish Sampling Targets 2004-2020[1]						
Location	**Frequency**	**Black Bass[2]**	**Bullhead[3]**	**Yellow Perch**	**Pumpkinseed**	**Forage Fish[4]**
Feeder Dam	**Annual**	20	20	20	20	10
RS 1 Reach 8	**Annual**	30	30	30	30	10
RS 2 Reach 7 and 6	**Annual**	25	25	25	25	10
RS 3 Reach 5	**Annual**	30	30	30	30	10
RS 3 Reaches 4 to 1	**Periodic (2019 only)[5]**	50	50	50	50	

Fish Sampling Targets 2021 to Present							
Location	**Frequency**	**Black Bass**		**Brown Bullhead**	**Yellow Perch**	**Pumpkinseed**	**Spottail Shiner**
		Largemouth Bass	**Smallmouth Bass**				
Feeder Dam	**Every 3 years**	10	10	20	20	20	10
RS 1 Reach 8	**Annual (except spottail shiner)**	8	32	20	20	30	15
RS 2 Reach 7 and 6	**Annual (except spottail shiner)**	3	21	20	12	16	28
RS 3 Reach 5	**Annual (except spottail shiner)**	20		20	20	15	15
RS 3 Reaches 4 to 1	**Every 5 Years**					80	

Note:
1. Based on GE 2004 Quality Assurance Project Plan for the Hudson River PCBs Site (GE 2004)
2. Black bass include either largemouth bass or smallmouth bass
3. Bulhead include either brown bullhead or yellow bullhead
4. Forage fish collected as composite samples in accordance with the Phase 1 and Phase 2 RAMP QAPPs.
5. Fish were collected in Reaches 4 through 1 in 2019 only, as described in the GE 2019 Water and Fish Data Summary Report
7. Sampling Frequency:

Annual
Every 3 Years
Every 5 Years

Table A3-4
Fish Preparation Methods By Species

Species	Preparation Methods
Brown Bullhead[1]	- NYSDEC Standard fillet with rib cage - Left fillet with rib cage - Fillet without rib cage -Whole-body minus head and viscera (in the event that a single fillet does not yield enough mass for sample analyses)
Yellow Perch	
Largemouth Bass	- NYSDEC Standard fillet with rib cage - Left fillet with rib cage - Right Fillet with rib cage - Fillet without rib cage - Whole-body minus head and viscera(in the event that a single fillet does not yield enough mass for sample analyses)
Smallmouth bass	
Pumpkinseed	- Individual whole-body samples
Spottail Shiner	-Whole-body composites (typically multiple individual specimens combined to make a single blended sample)

Note:
1. Brown bullhead are skinned before filleting.

Table A3-5
Upper Hudson River PCB Superfund Site Fish Tissue Regression and Conversion Factor Equations

Data Source	Period of Available Data	Applicable Laboratory Codes	Equation Used to Estimate the TPCB Homologue Equivalent Concentration ($TPCB_{HE}$)	Equation Source	Period of Application
NYSDEC	1999-2000	MSC	1.174 * $TPCB_{Aroclor}$	Geometric mean of measured $TPCB_{congener}$ / $TPCB_{Aroclor}$ matched pairs. 1999-2000 NYSDEC. See Figure A5-15 of the Second Five Year Review.	1999-2015[2]
GE	2004-2008	NEA	0.849 * $TPCB_{Aroclor}$	Geometric mean of measured $TPCB_{congener}$ / $TPCB_{Aroclor}$ matched pairs. 2004-2008 GE data. See Figure A5-19 of the Second Five Year Review.	2004-2008
	2009, 2010, 2011, 2013	NEA/ Pace-SC	0.782 * $TPCB_{Aroclor}$	Geometric mean of measured $TPCB_{congener}$ / $TPCB_{Aroclor}$ matched pairs. 2009-2013 GE data. See Figure A5-23 of the Second Five Year Review.	2009-2015
	2016	Pace-SC	0.772 * $TPCB_{Aroclor}$	Geometric mean of measured $TPCB_{congener}$ / $TPCB_{Aroclor}$ matched pairs. 2016 GE data.	2016
	2018, 2020, 2021	Pace-GB	0.766 * $TPCB_{Aroclor}$	Geometric mean of measured $TPCB_{congener}$ / $TPCB_{Aroclor}$ matched pairs. 2018, 2020, and 2021 GE data.	2017-2021

Notes:
1. Conversion factors in the table above are based on Upper Hudson River data only
2. NYSDEC Data from 1999-2001 is not discussed in this five-year review but additional details can be found in the *Second Five-Year Review Report* (EPA 2019).
3. $TPCB_{Aroclor}$ refers to the sum of detected Aroclor concentrations in the sample.
4. Lab codes used in this table:
   - MSC: Mississippi St. Chem. Laboratories
   - NEA: Northeast Analytical Laboratories
   - Pace-SC: Pace Schenectady
   - Pace-GB: Pace Green Bay

Table A3-6
Percent of Samples Less than 0.4 mg/kg-ww Target

Species	River Section 1		River Section 2		River Section 3		UHR	
	Pre-Dredging	**Post-Dredging**	**Pre-Dredging**	**Post-Dredging**	**Pre-Dredging**	**Post-Dredging**	**Pre-Dredging**	**Post-Dredging**
Brown Bullhead	2%	40%	2%	16%	5%	34%	3%	31%
Largemouth Bass	14%	42%	10%	39%	33%	25%	22%	31%
Smallmouth Bass	8%	21%	6%	16%	18%	30%	10%	20%
Yellow Perch	30%	64%	38%	30%	60%	68%	43%	56%
All Sport Fish	**15%**	**44%**	**17%**	**22%**	**31%**	**42%**	**21%**	**37%**

Table A3-7
2004-2021 Total PCB_{HE} Species-Weighted Averages by River Section

Monitoring Period	Year	Upper River Average		River Section 1		River Section 2		River Section 3	
		River Section 1-3 Mean	Confidence Interval	River Section 1 Mean	Confidence Interval	River Section 2 Mean	Confidence Interval	River Section 3 Mean	Confidence Interval
Baseline(Pre-Dredge) Monitoring Period (BMP)	2004	2.3	2.0 - 2.6	4.9	3.5 - 6.4	3.7	3.2 - 4.3	1.5	1.2 - 1.8
	2005	2.1	1.9 - 2.3	2.3	1.8 - 2.9	3.0	2.3 - 3.7	1.9	1.7 - 2.1
	2006	3.1	2.8 - 3.4	2.3	1.9 - 2.8	2.4	2.2 - 2.7	3.4	3.0 - 3.8
	2007	2.0	1.8 - 2.2	2.7	2.3 - 3.1	2.5	2.0 - 3.0	1.8	1.5 - 2.1
	2008	1.2	0.99 - 1.4	1.5	1.2 - 1.9	2.5	1.7 - 3.5	0.85	0.69 - 1.0
Dredging (2009, 2011-2015) Remedial Action Monitoring Program (RAMP)	2009	1.2	1.0 - 1.4	1.7	1.3 - 2.2	2.0	1.5 - 2.6	0.98	0.77 - 1.2
	2010	1.4	1.2 - 1.8	2.9	2.4 - 3.5	1.7	1.3 - 2.2	1.1	0.84 - 1.5
	2011	1.4	1.2 - 1.6	1.9	1.6 - 2.1	1.9	1.6 - 2.5	1.1	0.94 - 1.4
	2012	1.9	1.7 - 2.2	3.5	2.8 - 4.2	3.3	2.8 - 4.0	1.3	1.1 - 1.6
	2013	1.7	1.6 - 1.9	2.3	2.1 - 2.6	2.7	2.3 - 3.2	1.4	1.2 - 1.6
	2014	2.2	1.9 - 2.5	2.3	1.9 - 2.9	3.3	2.8 - 3.9	2.0	1.6 - 2.4
	2015	1.1	0.97 - 1.3	1.6	1.3 - 1.9	1.7	1.4 - 2.0	0.93	0.72 - 1.2
OM&M Monitoring (on-going)	2016	1.1	1.0 - 1.3	1.3	0.98 - 1.7	1.9	1.6 - 2.2	0.99	0.84 - 1.2
	2017	0.88	0.80 - 0.97	0.95	0.79 - 1.1	1.4	1.2 - 1.8	0.77	0.67 - 0.88
	2018	0.71	0.64 - 0.79	0.73	0.61 - 0.87	0.90	0.71 - 1.1	0.68	0.58 - 0.78
	2019	0.70	0.59 - 0.82	0.77	0.60 - 0.96	0.97	0.75 - 1.3	0.65	0.50 - 0.80
	2020	0.63	0.56 - 0.70	0.86	0.63 - 1.1	0.95	0.74 - 1.2	0.52	0.45 - 0.60
	2021	0.71	0.59 - 0.86	0.71	0.58 - 0.9	0.76	0.66 - 0.89	0.69	0.54 - 0.90

Notes:
1.Individual species are averaged by collection station and then averaged together by River Section.
2.Reach and River Section fish tissue PCB concentrations are weighted by species. Black bass = 47%, bullhead = 44%, yellow perch = 9%.
3.Upper Hudson River average is weighted by both species and river reach length. Reach 8: = 6.3 miles (15.4%); Reach 7 = 2.2 miles (5.4%); Reach 6 = 2.9 miles (7.1%); and Reach 5 = 29.5 miles (72.1%). Fish sampling stations in Reaches 4-1 are not currently included in the calculation set. Fish samples from monitoring stations in Reach 5, which is 14 miles long, are used to represent all 29.5 miles of River Section 3. Fish data were not available for Reach 7 in 2008.
4.Dredging was not performed in 2010 so that a planned peer-review of the project could be convened for the purpose of refining the selected remedy.
5.The samples from 2007-2013 are rib-out fillets, all other data are from NYSDEC standard fillet samples.
6. 95% confidence limits on the mean are calculated using a bias-corrected and accelerated (BCA) bootstrap method.

Table A3-8
Annual Variability in Lipid-Normalized Fish Tissue $TPCB_{HE}$ Data Collected Between 1998 to 2008 and 2016 to 2021 in River Section

	Brown Bullhead		
Year	Dataset Time Period	Number Samples Included in Analysis	Standard Deviation
1998	Pre-Dredging Period	20	0.49
1999		28	0.60
2000		21	0.52
2001		8	0.59
2002		16	0.50
2003		15	0.58
2004		25	1.0
2005		24	1.0
2006		28	0.94
2007		26	0.59
2008		20	0.81
2016	Post-Dredging Period	30	0.82
2017		25	0.73
2018		27	0.71
2019		29	0.78
2020		25	0.61
2021		20	0.71

	Largemouth Bass		
Year	Dataset Time Period	Number Samples Included in Analysis	Standard Deviation
1998	Pre-Dredging Period	23	0.89
1999		24	0.77
2000		21	0.63
2001		20	0.65
2002		21	1.1
2003		12	0.61
2004		10	0.54
2005		12	0.70
2006		13	1.3
2007		11	0.67
2008		19	1.0
2016	Post-Dredging Period	16	1.4
2017		9	1.2
2018		11	0.88
2019		11	1.5
2020		9	1.0
2021		8	0.62

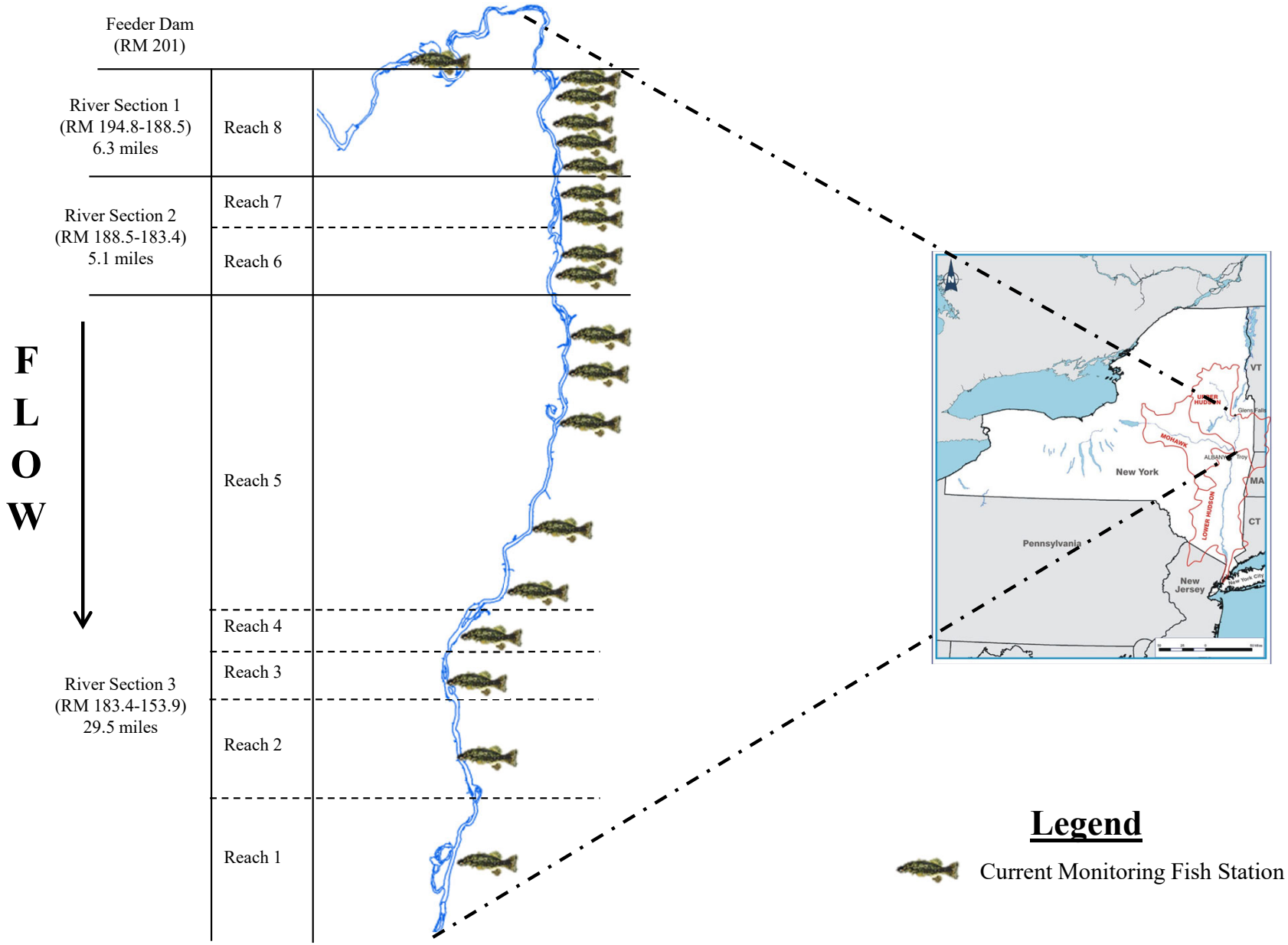
	Yellow Perch		
Year	Dataset Time Period	Number Samples Included in Analysis	Standard Deviation
1998	Pre-Dredging Period	33	0.53
1999		30	0.65
2000		21	0.60
2001		20	0.60
2002		20	0.39
2003		31	0.36
2004		30	0.85
2005		30	0.75
2006		30	0.76
2007		33	1.0
2008		30	0.68
2016	Post-Dredging Period	30	0.68
2017		30	0.89
2018		32	0.74
2019		31	0.81
2020		30	0.75
2021		20	0.75

	Pumpkinseed		
Year	Dataset Time Period	Number Samples Included in Analysis	Standard Deviation
1998	Pre-Dredging Period	19	0.36
1999		12	0.20
2000		17	0.69
2001		10	0.26
2002		10	0.21
2003		21	0.28
2004		35	1.0
2005		31	0.92
2006		30	0.68
2007		32	0.79
2008		30	0.62
2016	Post-Dredging Period	30	0.54
2017		50	1.1
2018		30	0.84
2019		30	0.89
2020		30	0.73
2021		30	1.3

Note:
1. Standard deviation is calculated using data that is first log-transformed, then mean centered on an annual basis. This is the same data handling procedure used for the Levene Test.

Figures

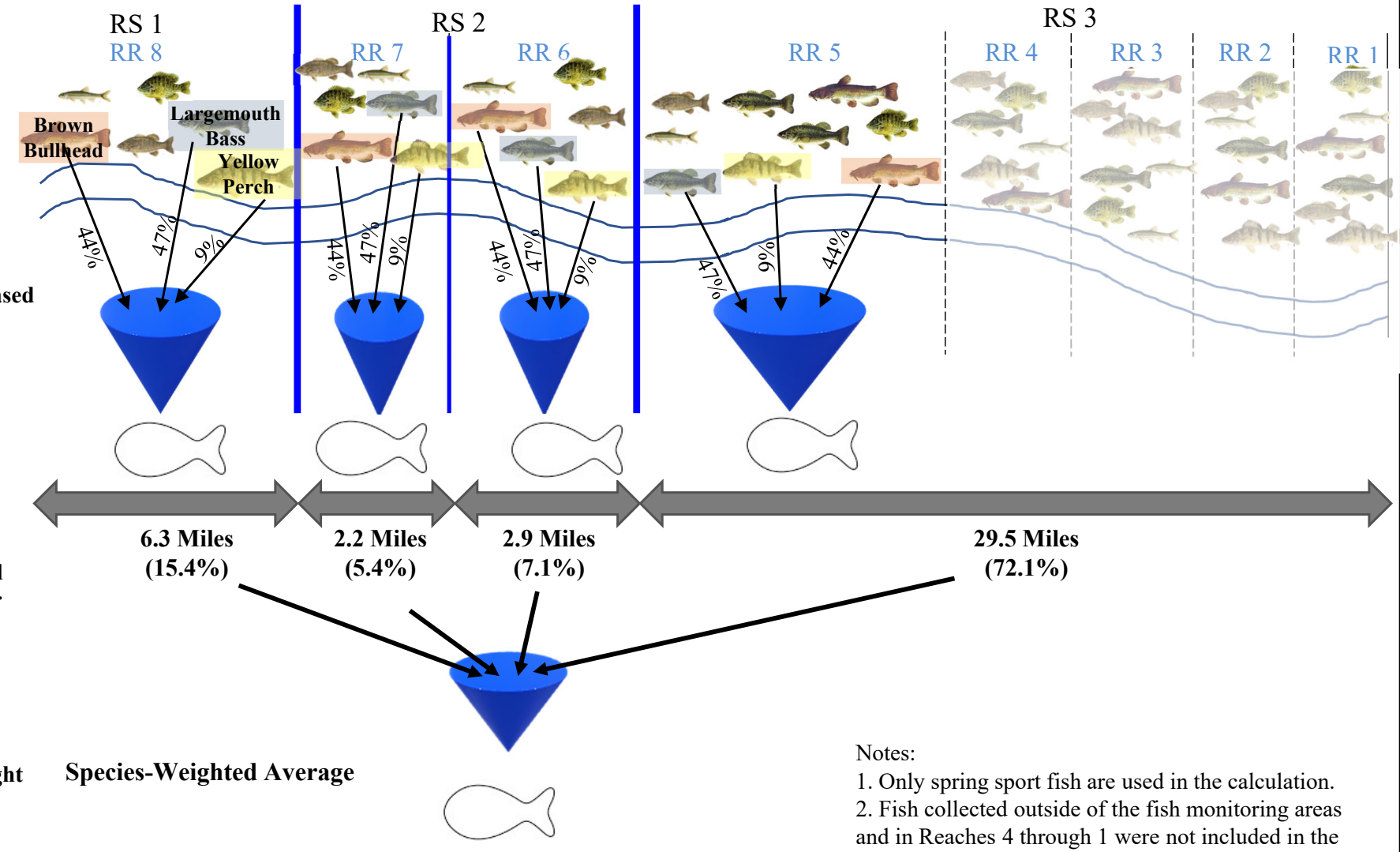
Draft



Fish Monitoring Location Map with Reaches and River Sections

Figure A3-1

July 2024

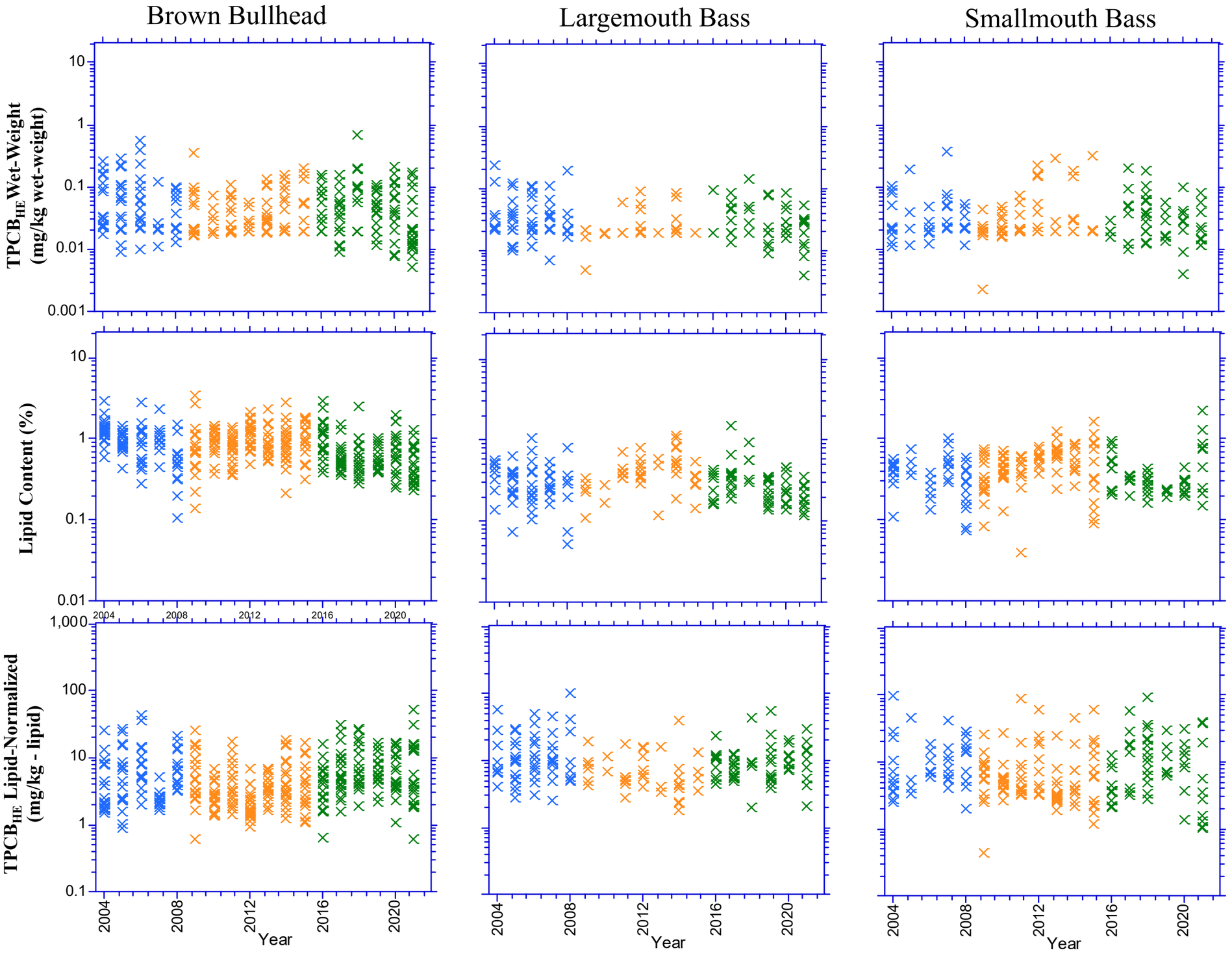


Notes:
1. Only spring sport fish are used in the calculation.
2. Fish collected outside of the fish monitoring areas and in Reaches 4 through 1 were not included in the calculation.
3. The same proportions for each of the three species are used in each river section (*i.e.,* 44% brown bullhead, 47% largemouth bass and 9% yellow perch).

Species-Weighted Average Calculation "Original ROD Methodology"

Figure A3-2

July 2024



Feeder Dam

Legend

Agency	+	NYSDEC
	×	GE
Sampling Period	■	Pre-Dredging Period (2004-2008)
	■	Dredging Period (2009-2015)
	■	Post-Dredging Period (2016-2021)

Notes:

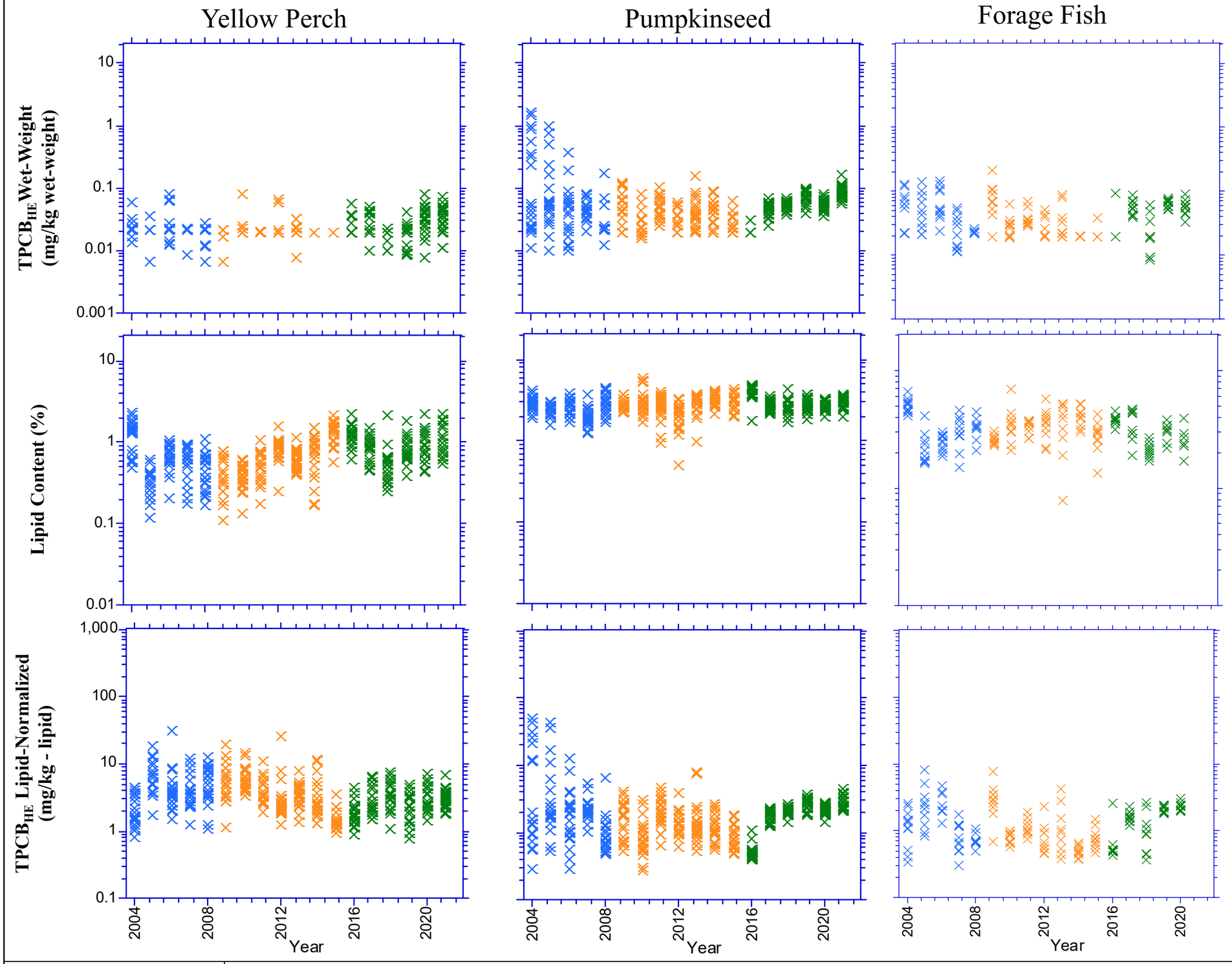
1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2. There are no post-dredging data for spottail shiner at the Feeder Dam.
3. The samples from 2007-2013 are rib-out fillets; all other data except pumpkinseed are NYSDEC standard fillet samples.
4. Pumpkinseed are whole-body samples.

Hudson River PCBs Superfund Site

TPCB$_{HE}$, Lipid and Lipid-Normalized TPCB$_{HE}$ at the Feeder Dam

Figure A3-3A

July 2024



Feeder Dam

Legend

Agency	+	NYSDEC
	×	GE
Sampling Period	■	Pre-Dredging Period (2004-2008)
	■	Dredging Period (2009-2015)
	■	Post-Dredging Period (2016-2021)

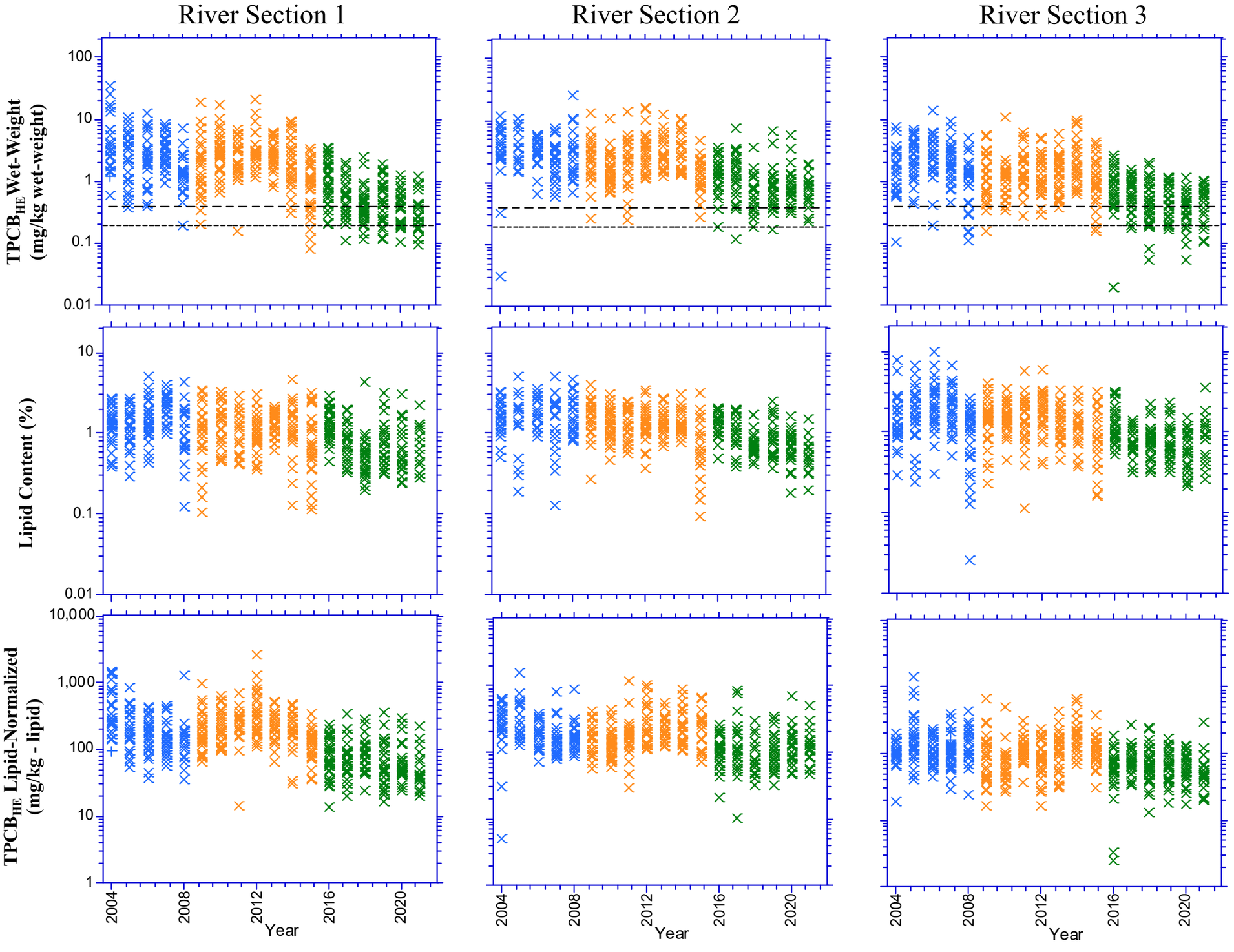
Notes:

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2. There are no post-dredging data for spottail shiner at the Feeder Dam.
3. The samples from 2007-2013 are rib-out fillets; all other data except pumpkinseed are NYSDEC standard fillet samples.
4. Pumpkinseed are whole-body samples.

TPCB$_{HE}$, Lipid and Lipid-Normalized TPCB$_{HE}$ at the Feeder Dam

Figure A3-3B

July 2024



Brown Bullhead

Legend

Agency	+	NYSDEC
	×	GE
Sampling Period	■	Pre-Dredging Period (2004-2008)
	■	Dredging Period (2009-2015)
	■	Post-Dredging Period (2016-2021)
Human Health ROD Target PCB Concentrations	------	0.4 mg/kg-ww
	--------	0.2 mg/kg-ww

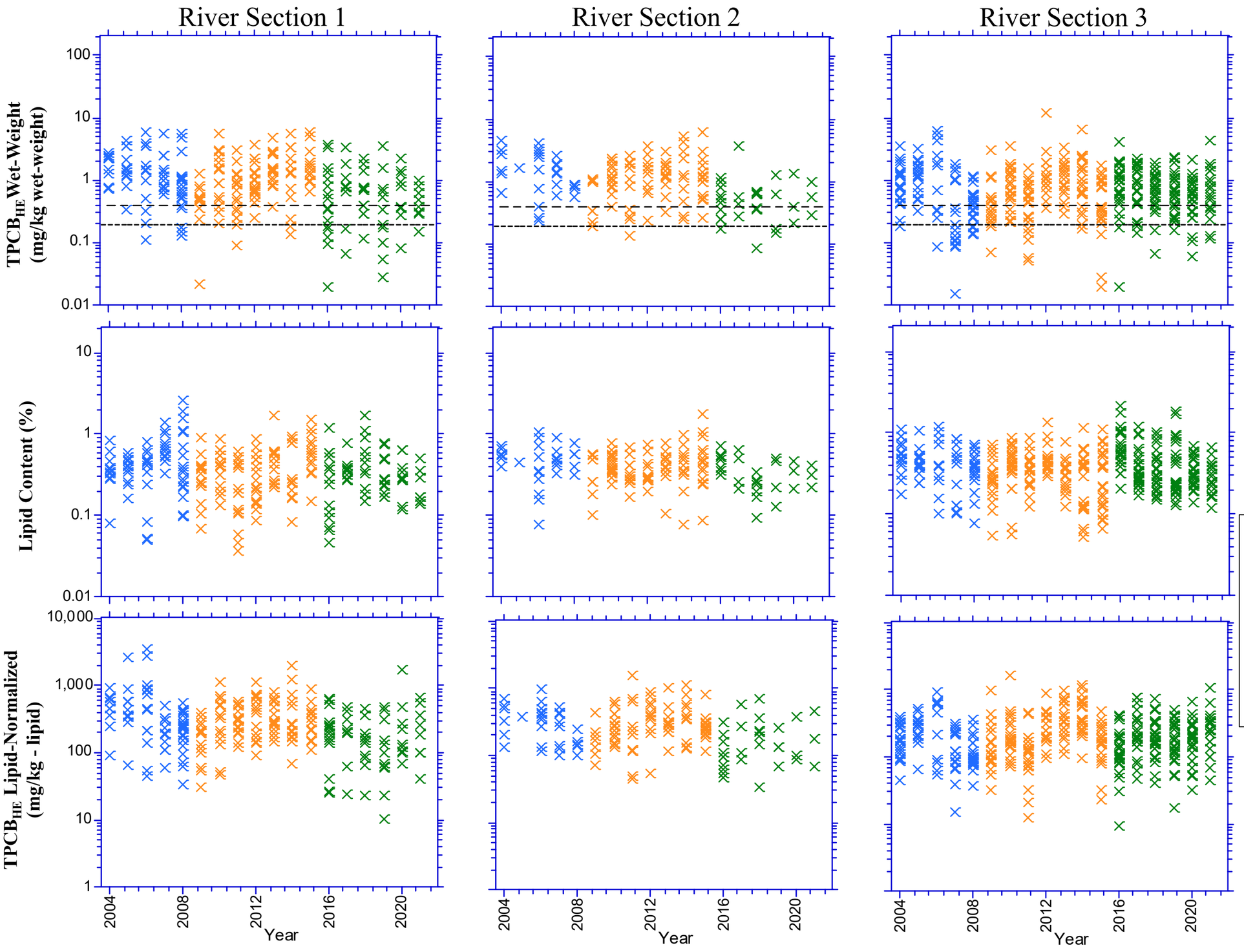
Notes:

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2. The samples from 2007-2013 are rib-out fillets; all other data are NYSDEC standard fillet samples.

TPCB$_{HE}$, Lipid and Lipid-Normalized TPCB$_{HE}$ in Brown Bullhead Fish Tissue Samples

Figure A3-4

July 2024



Largemouth Bass

Legend

Agency
- + NYSDEC
- × GE

Sampling Period
- Pre-Dredging Period (2004-2008)
- Dredging Period (2009-2015)
- Post-Dredging Period (2016-2021)

Human Health ROD Target PCB Concentrations
- ------ 0.4 mg/kg-ww
- -------- 0.2 mg/kg-ww

Notes:

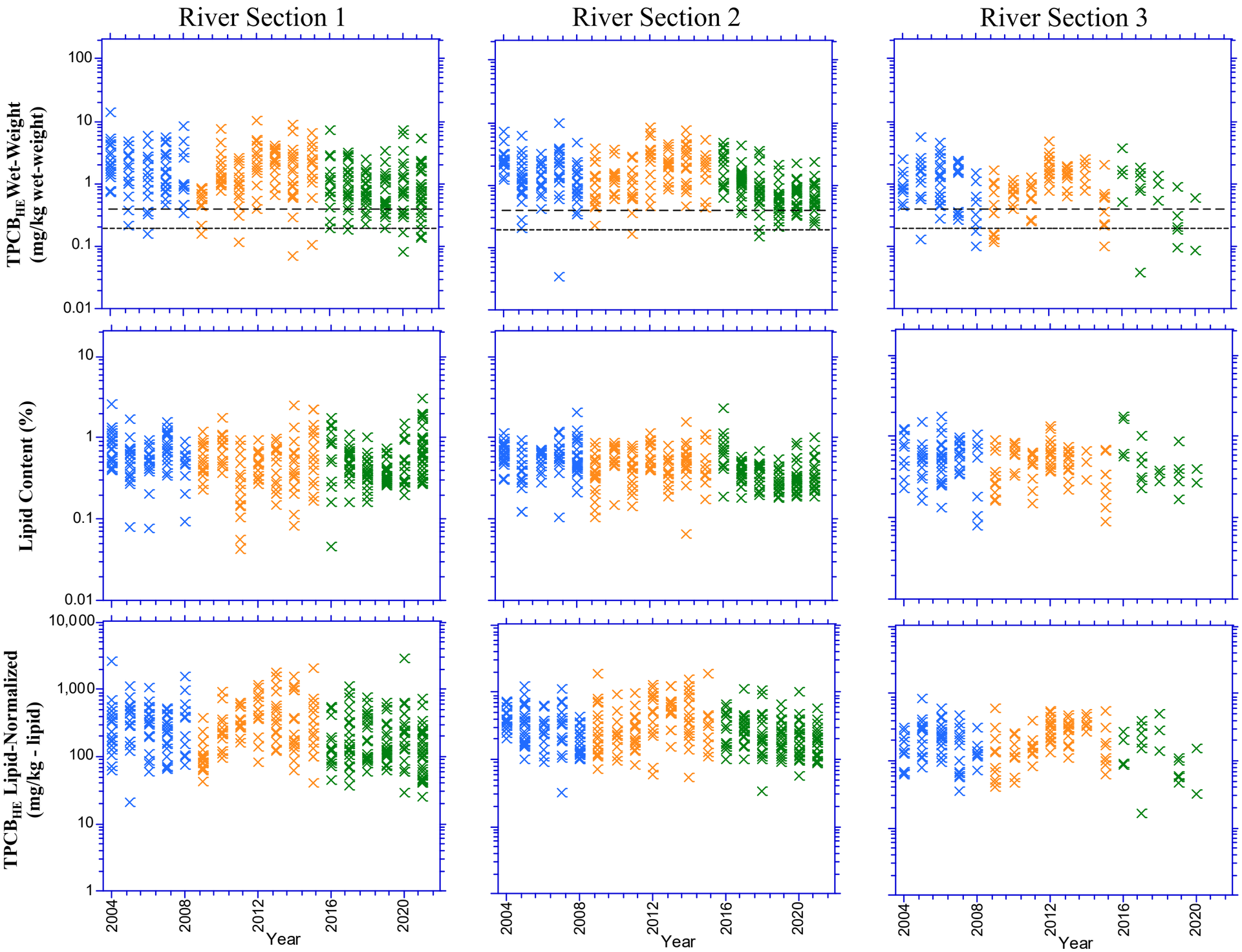
1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2. The samples from 2007-2013 are rib-out fillets; all other data are NYSDEC standard fillet samples.
3. Due to limited in-river availability, largemouth bass are collected in limited quantities in RS 1 and RS 2. As a result, there may be limitations on data usability for this species.

Hudson River PCBs Superfund Site

TPCB$_{HE}$, Lipid and Lipid-Normalized TPCB$_{HE}$ in Largemouth Bass Fish Tissue Samples

Figure A3-5

July 2024



Smallmouth Bass

Legend

Agency
- + NYSDEC
- × GE

Sampling Period
- Pre-Dredging Period (2004-2008)
- Dredging Period (2009-2015)
- Post-Dredging Period (2016-2021)

Human Health ROD Target PCB Concentrations
- ------ 0.4 mg/kg-ww
- -------- 0.2 mg/kg-ww

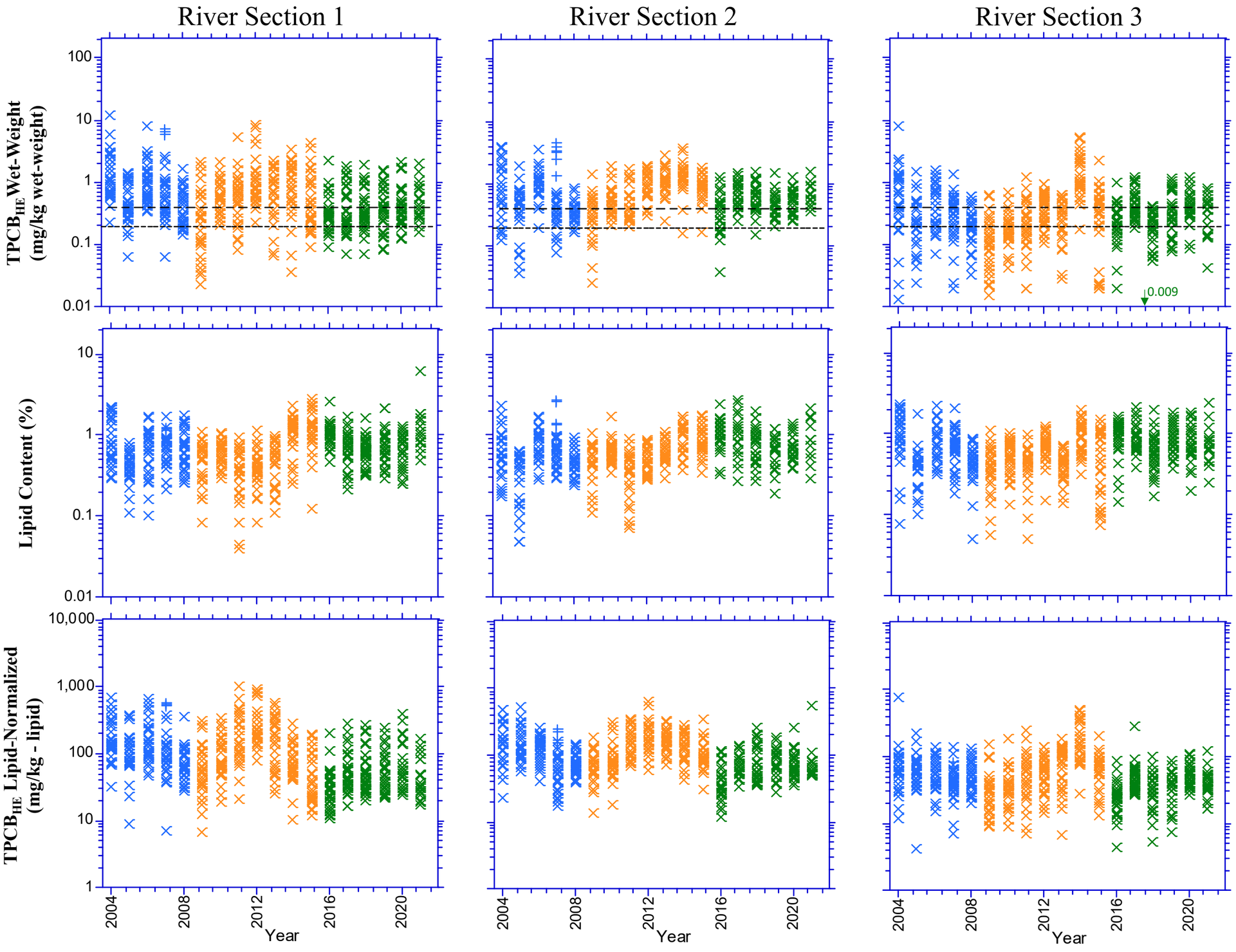
Notes:

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2. The samples from 2007-2013 are rib-out fillets; all other data are NYSDEC standard fillet samples.
3. Due to limited in-river availability, smallmouth bass are not regularly collected in RS 3. As a result, there may be limitations on data usability for this species.

TPCB$_{HE}$, Lipid and Lipid-Normalized TPCB$_{HE}$ in Smallmouth Bass Fish Tissue Samples

Figure A3-6

July 2024



Yellow Perch

Legend

Agency
- \+ NYSDEC
- × GE

Sampling Period
- Pre-Dredging Period (2004-2008)
- Dredging Period (2009-2015)
- Post-Dredging Period (2016-2021)

Human Health ROD Target PCB Concentrations
- ------ 0.4 mg/kg-ww
- -------- 0.2 mg/kg-ww

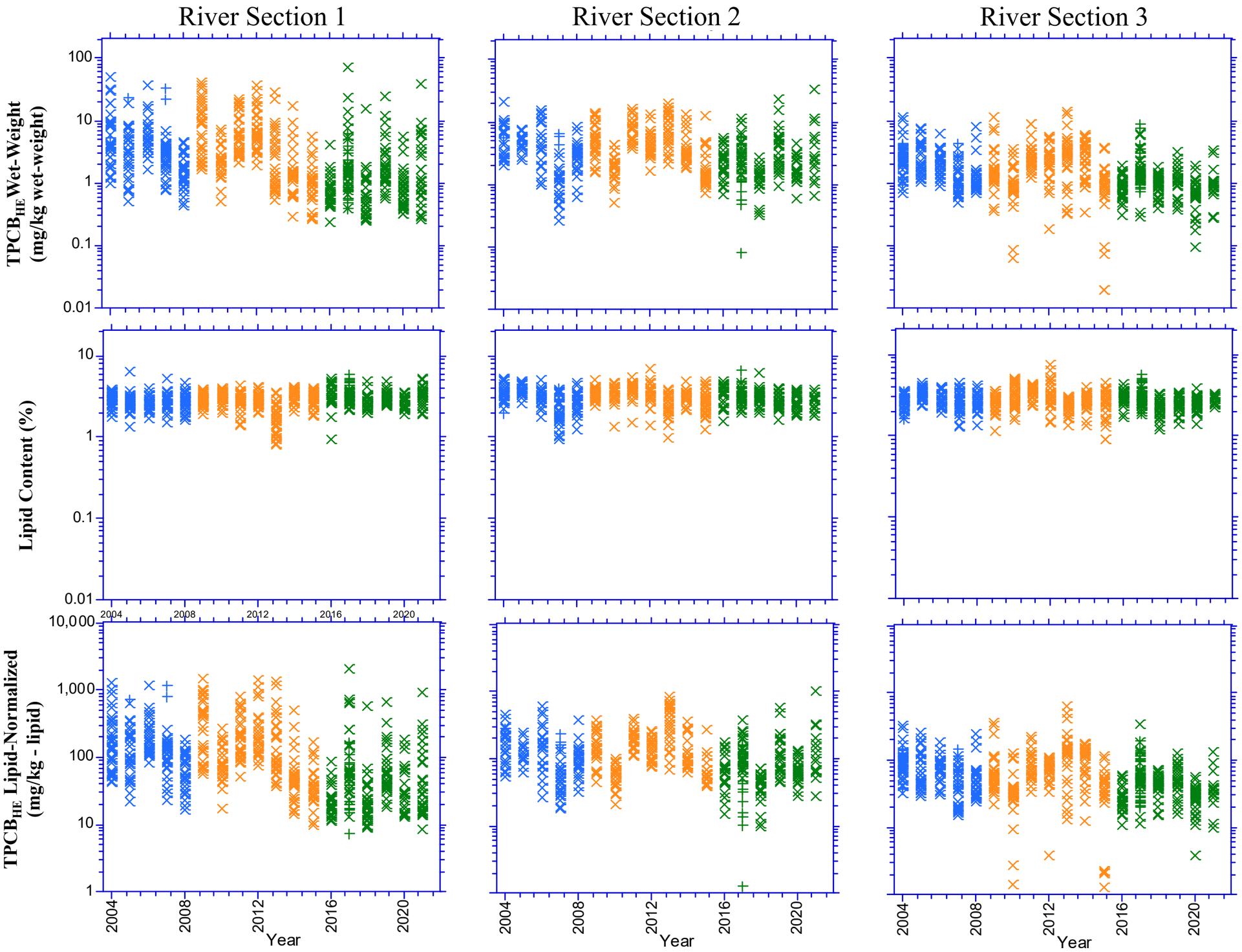
Notes:

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2.The samples from 2007-2013 are rib-out fillets; all other data are NYSDEC standard fillet samples.

TPCB$_{HE}$, Lipid and Lipid-Normalized TPCB$_{HE}$ in Yellow Perch Fish Tissue Samples

Figure A3-7

July 2024



Pumpkinseed

Legend

Agency	+	NYSDEC
	×	GE
Sampling Period	■	Pre-Dredging Period (2004-2008)
	■	Dredging Period (2009-2015)
	■	Post-Dredging Period (2016-2021)

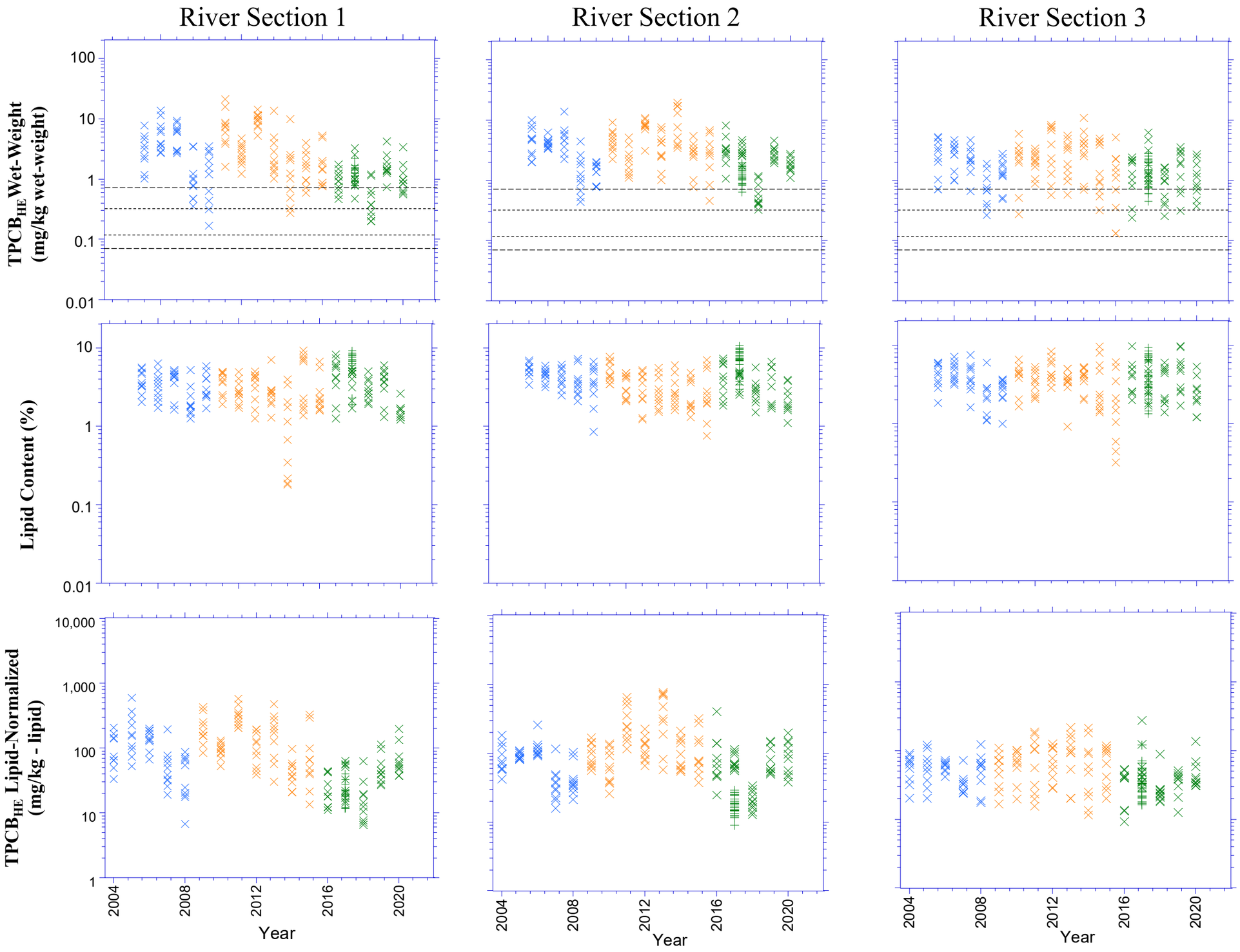
Notes:

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2. Pumpkinseed are whole-body samples.

TPCB$_{HE}$, Lipid and Lipid-Normalized TPCB$_{HE}$ in Pumpkinseed Fish Tissue Samples

Figure A3-8

July 2024



Forage Fish

Legend

Agency + NYSDEC
× GE

Sampling Period
- Pre-Dredging Period (2004-2008)
- Dredging Period (2009-2015)
- Post-Dredging Period (2016-2021)

ROD Ecological Risk Target PCB Concentrations
- 0.7 mg/kg-ww
- 0.07 mg/kg-ww

Refined Ecological Risk Target PCB Concentrations
- 0.34 mg/kg-ww
- 0.11 mg/kg-ww

Notes:

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2. Forage fish are whole-body composites samples and consists the following species: Banded Killifish, Bluntnose Minnow, Common Shiner, Emerald Shiner, Fall Fish, Golden Shiner, Mimic Shiner, Minnow Species, Rosyface Shiner, Spotfin Shiner and Spottail Shiner.

TPCB$_{HE}$, Lipid and Lipid-Normalized TPCB$_{HE}$ in Forage Fish Tissue Samples

Figure A3-9A

July 2024

River Section 1 | River Section 2 | River Section 3

$TPCB_{HE}$ Wet-Weight (mg/kg wet-weight)

Lipid Content (%)

$TPCB_{HE}$ Lipid-Normalized (mg/kg - lipid)

Year

Spottail Shiner

Legend

Agency: + NYSDEC; × GE

Sampling Period: Pre-Dredging Period (2004-2008); Dredging Period (2009-2015); Post-Dredging Period (2016-2021)

ROD Ecological Risk Target PCB Concentrations: 0.7 mg/kg-ww; 0.07 mg/kg-ww

Refined Ecological Risk Target PCB Concentrations: 0.34 mg/kg-ww; 0.11 mg/kg-ww

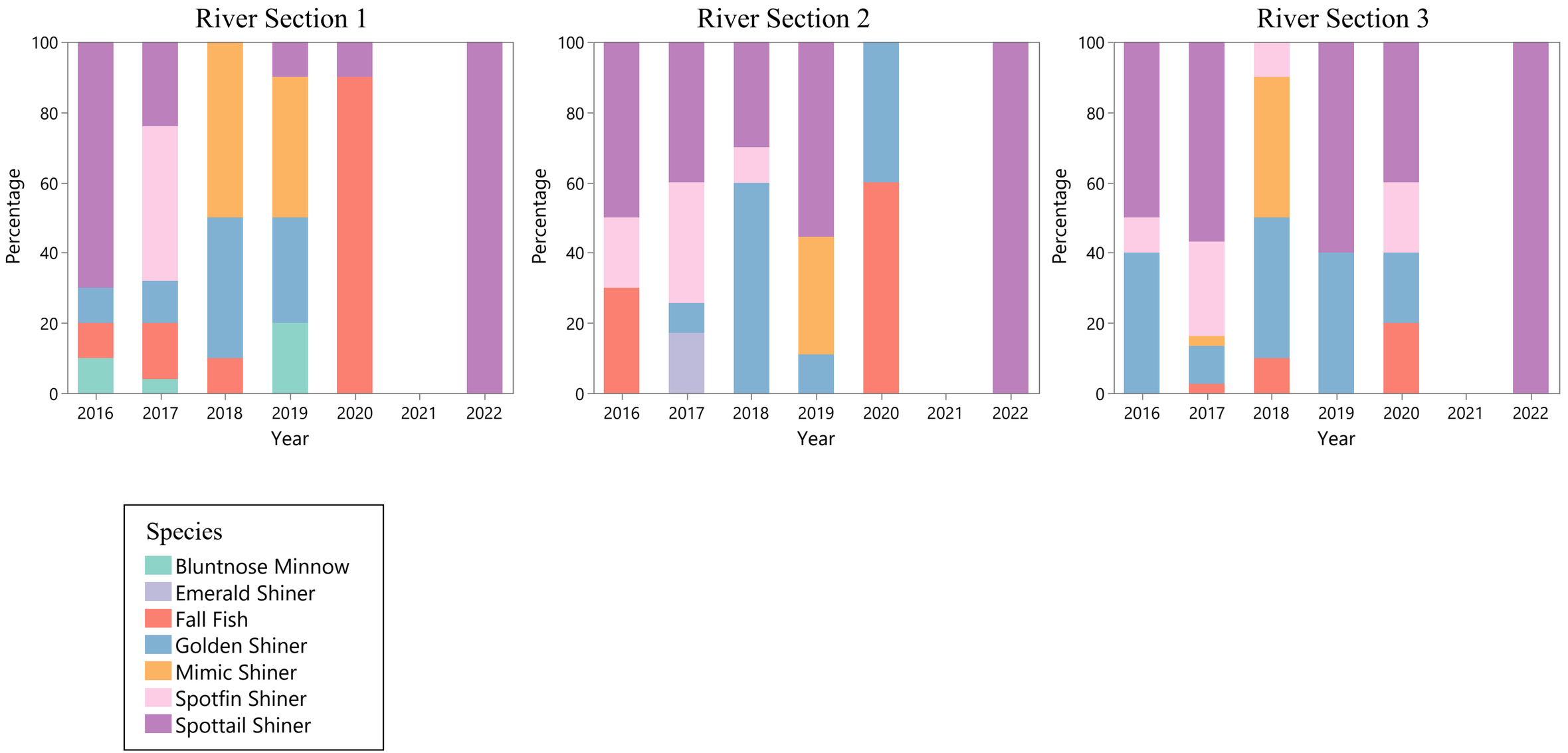
Notes:

1. PCB concentrations are expressed as Total PCB homologue equivalent values ($TPCB_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2. Spottail shiner are whole-body composites samples.

$TPCB_{HE}$, Lipid and Lipid-Normalized $TPCB_{HE}$ in Spottail Shiner Fish Tissue Samples

Figure A3-9B

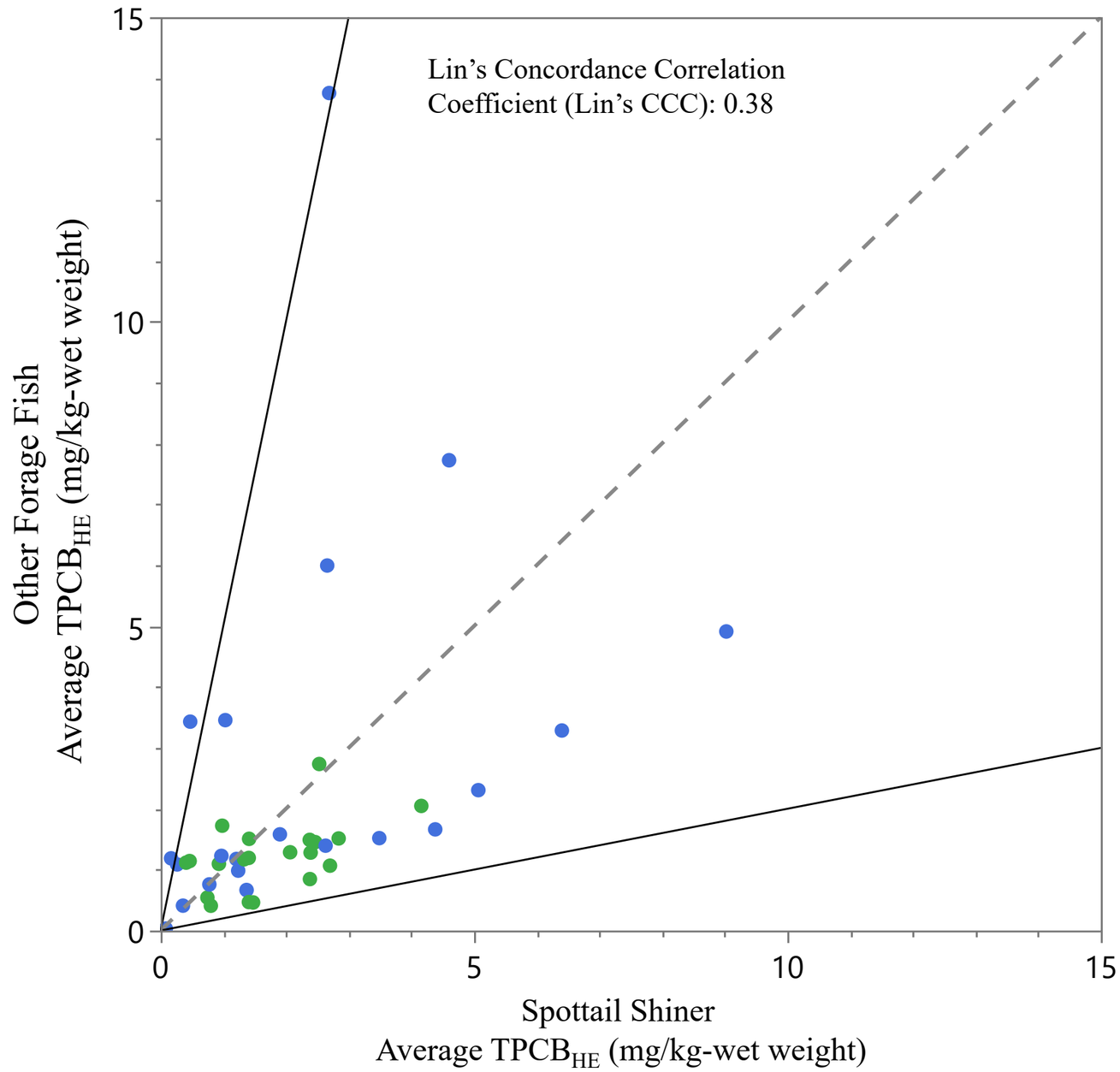
July 2024



Variation of Forage Fish Species Collected Over Time By River Section

Figure A3-9C

July 2024



Legend

- Pre-Dredging Period (2004-2008)
- Post Dredging Period (2016-2020)
- 1:1 Line
- 5x Line

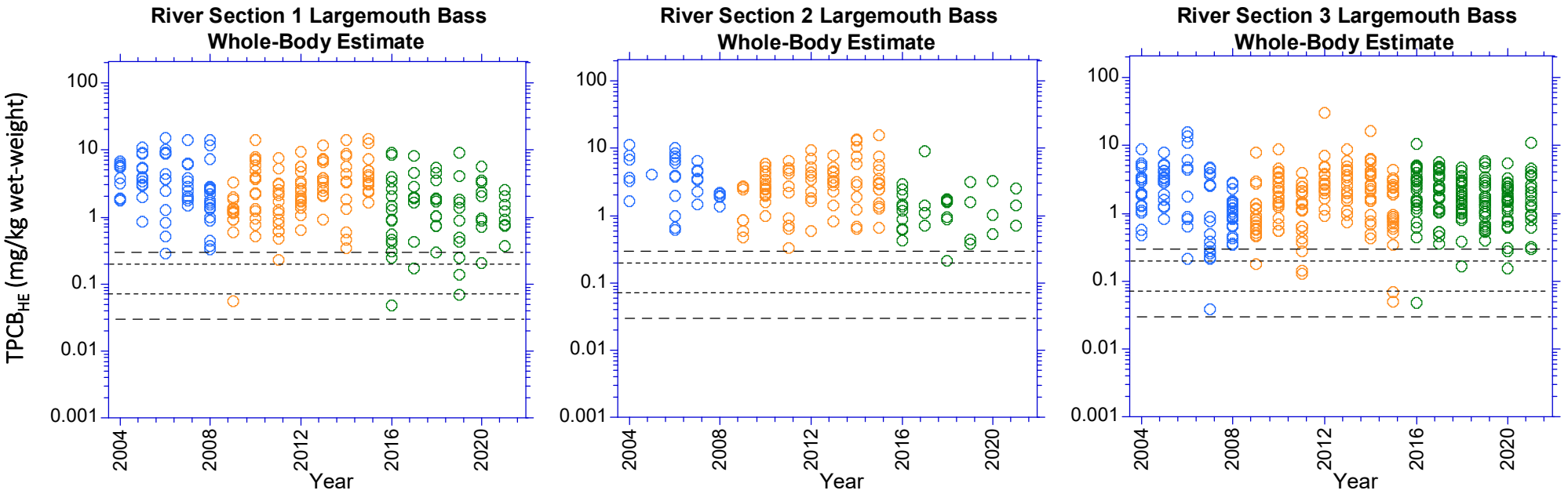
Notes:

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results. See Section 3 of the text for an explanation of the conversion process.
2. Each circle on the graph represents the average concentration for each station and year combination.

Comparison of Average TPCB$_{HE}$ Concentrations between Spottail Shiner and Other Forage Fish

Figure A3-9D

July 2024



Legend

Sampling Period
- Pre-Dredging Period (2004-2008)
- Dredging Period (2009-2015)
- Post-Dredging Period (2016-2021)

ROD Eco Risk Target PCB Concentrations
- 0.3 mg/kg-ww
- 0.03 mg/kg-ww

Refined Eco Risk Target PCB Concentration
- 0.2 mg/kg-ww
- 0.07 mg/kg-ww

Notes:

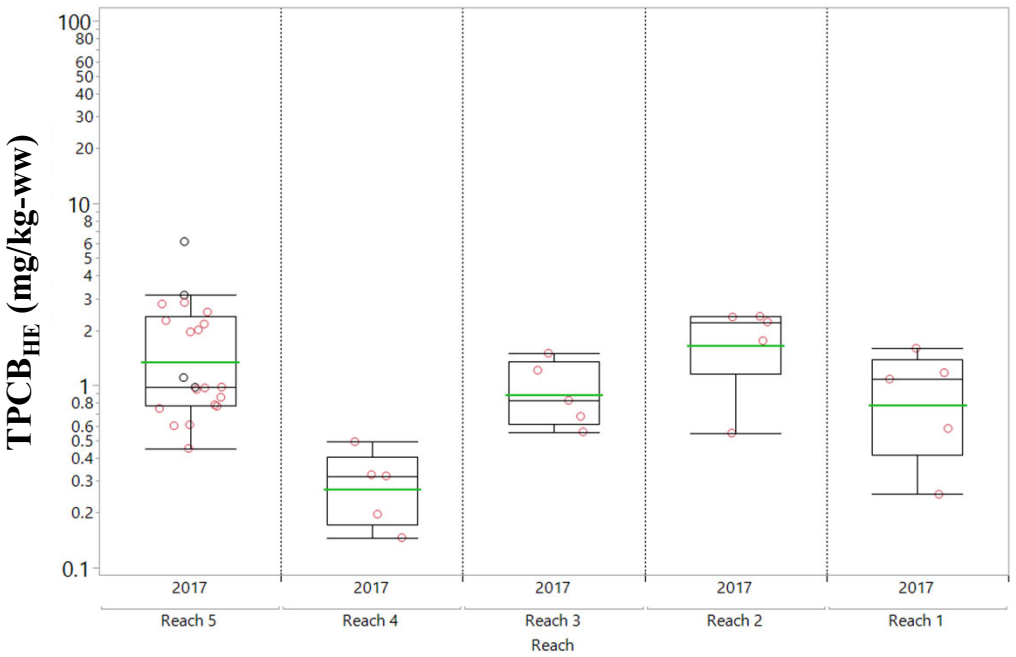
1.Largemouth bass samples are analyzed on a fillet basis. To obtain an estimate of the whole-body concentration, the fillet results are multiped by a factor of 2.5 (EPA 1997c).

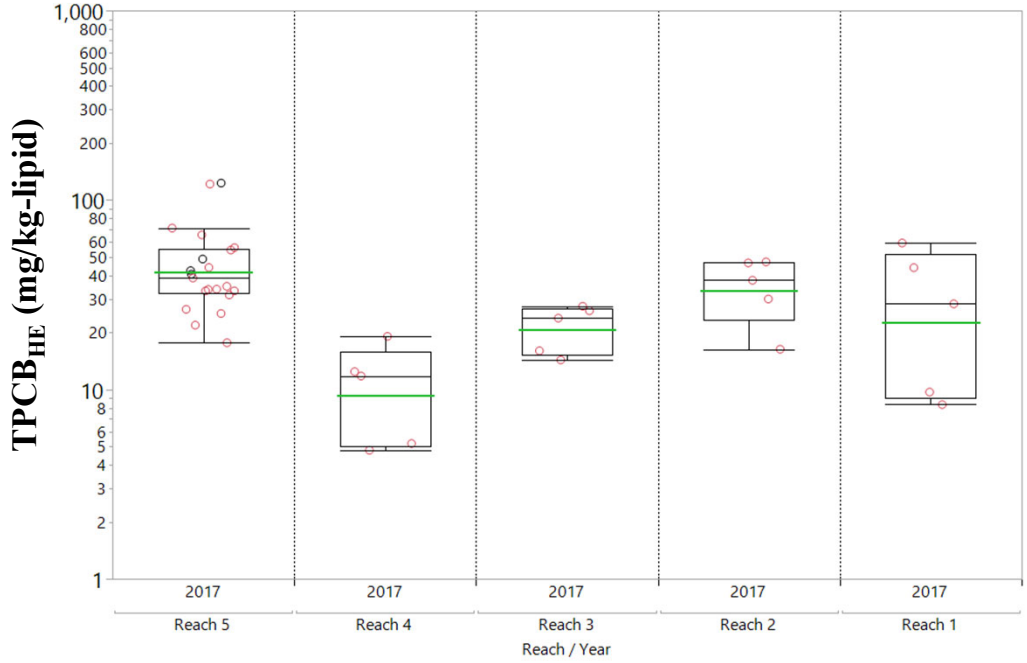
2. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results.

Whole-Body PCB Concentrations and Ecological Risk Targets for Largemouth Bass

Figure A3-10

July 2024

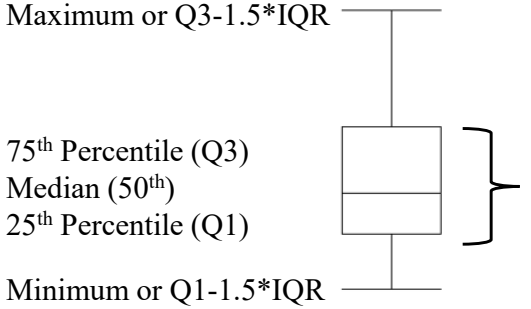




2017 Samples

Legend

- GE
- NYSDEC
- Geometric mean



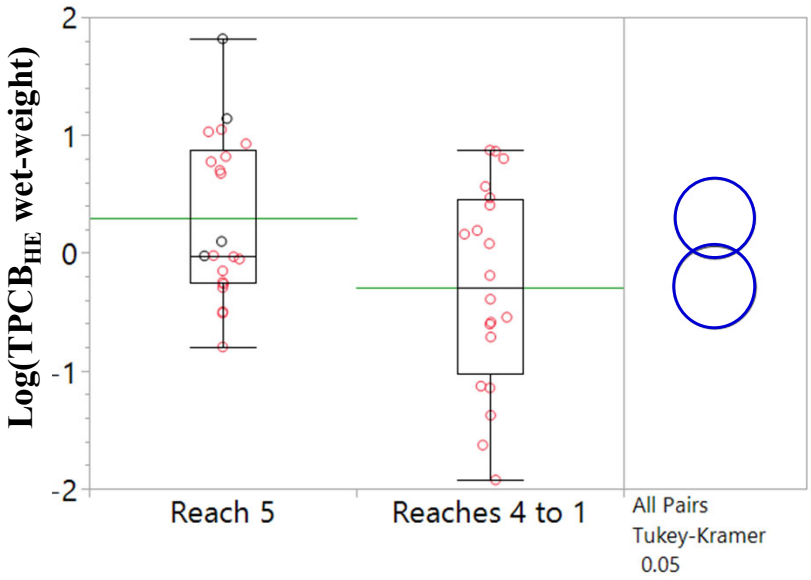
Notes

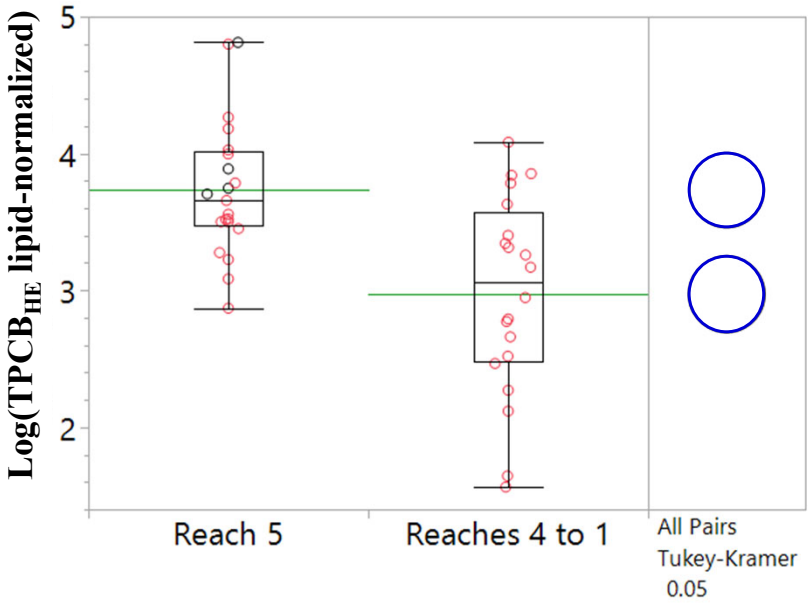
1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results.

Spatial Variation of TPCB$_{HE}$ Concentrations in Spottail Shiner, Reach 5 through Reach 1– Wet-Weight and Lipid-Normalized Bases

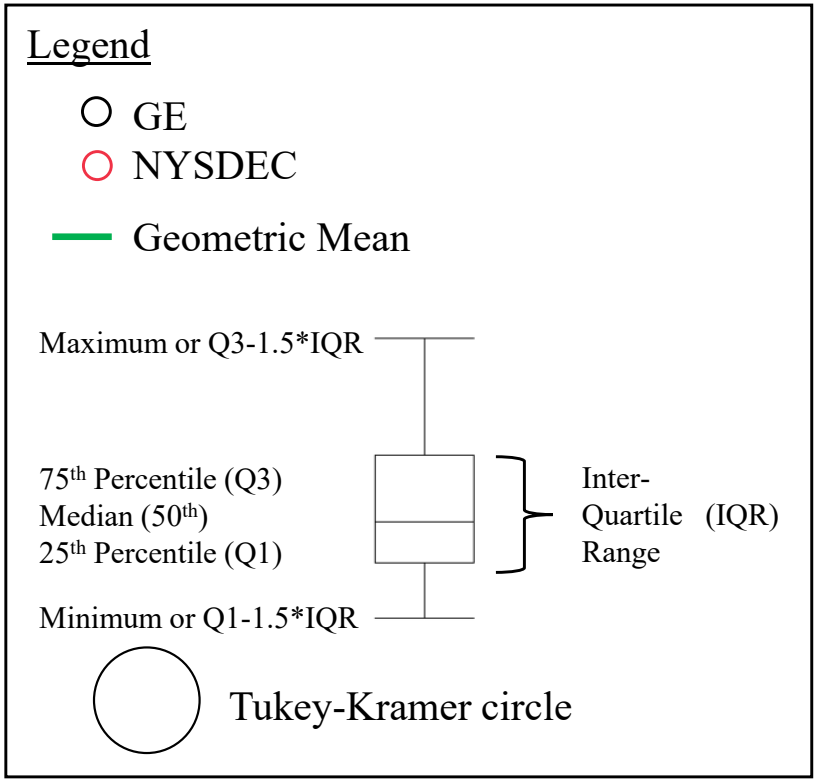
Figure A3-11A

July 2024





2017 Samples



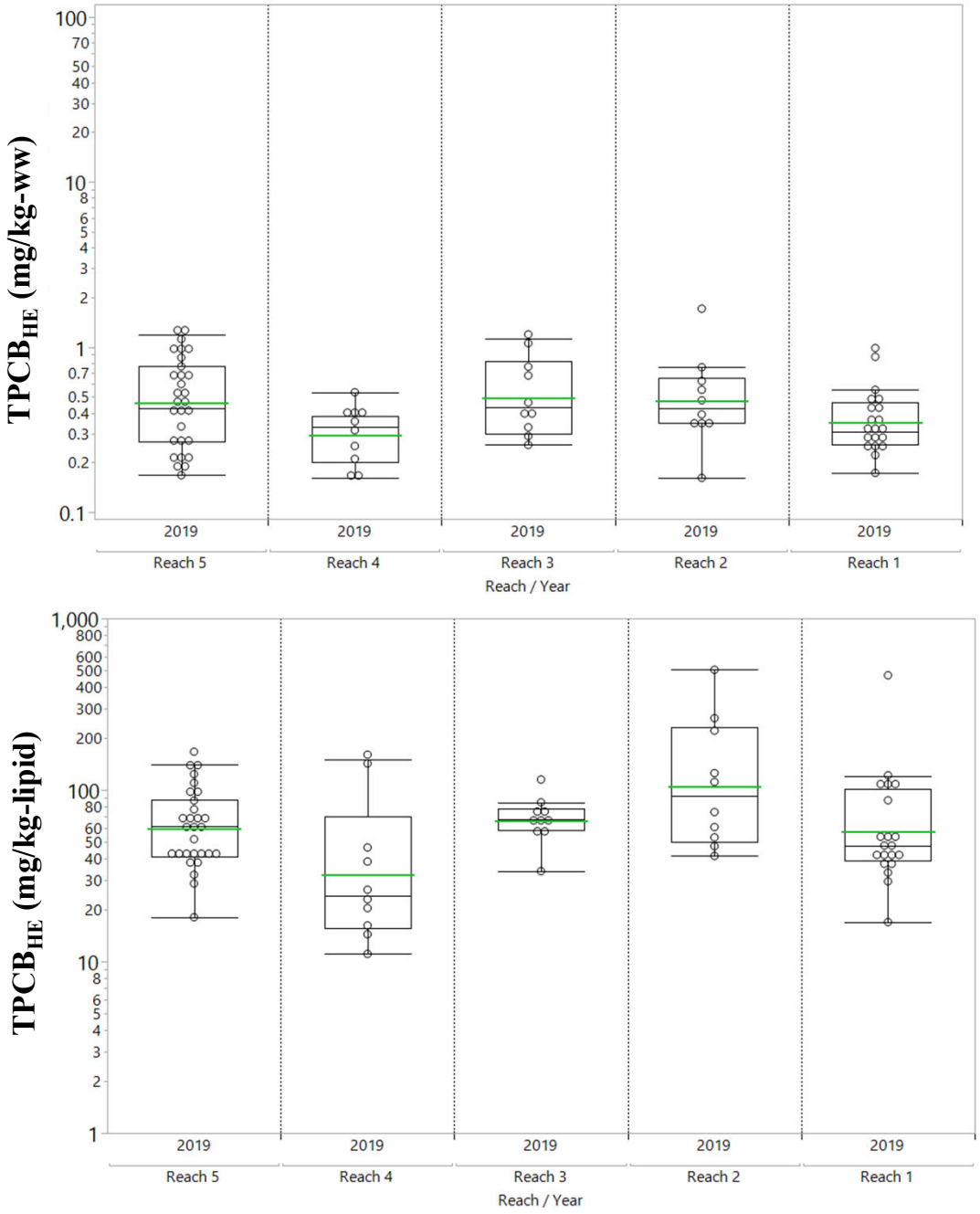
Notes

1. PCB concentrations are expressed as Total PCB homologue equivalent values ($TPCB_{HE}$), based on conversion from reported Aroclor results.
2. Tukey-Kramer circles represent the geometric mean (center of the circle) and its uncertainty (circle radius) for each of the sample groups examined. Tukey-Kramer circles that do not touch or intersect slightly are indicative of sample groups that are statistically different from each other. Statistically different groups are shown with blue Tukey-Kramer circles.

Spatial Variation of $TPCB_{HE}$ Concentrations in Spottail Shiner, Reach 5 through Reach 1– Wet-Weight and Lipid-Normalized Bases

Figure A3-11B

July 2024



2019 Samples

Legend

- GE
- NYSDEC
- Geometric mean

Maximum or Q3-1.5*IQR

75th Percentile (Q3)
Median (50th)
25th Percentile (Q1)

Inter-Quartile Range (IQR)

Minimum or Q1-1.5*IQR

Notes

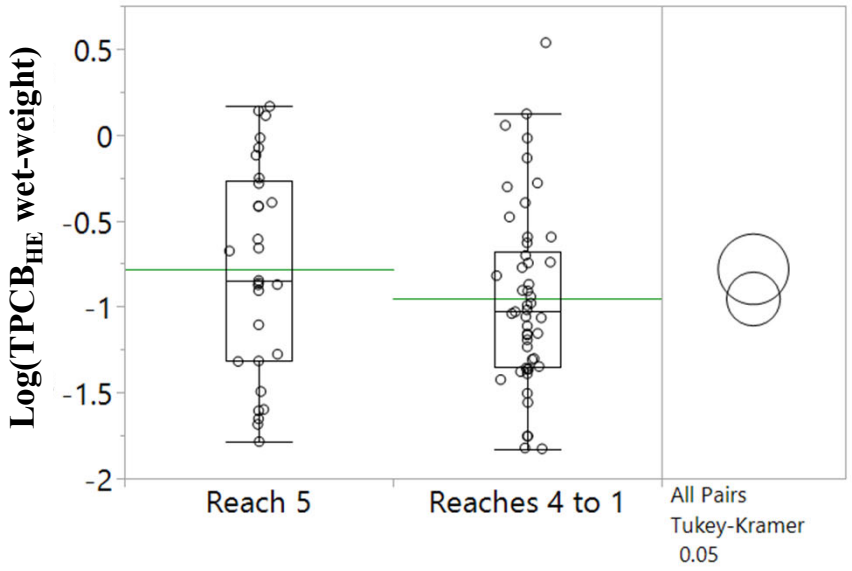
1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results.

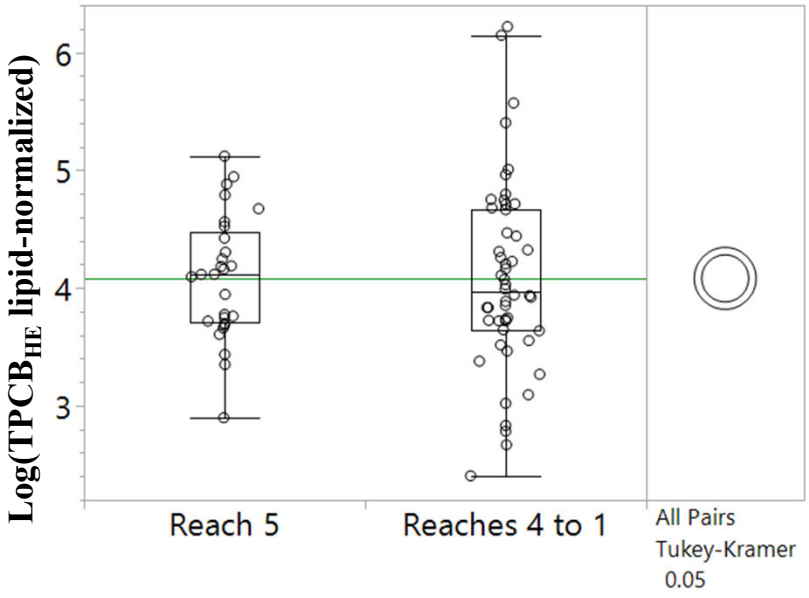
Spatial Variation of TPCB$_{HE}$ Concentrations in Brown Bullhead, Reach 5 through Reach 1 – Wet-Weight and Lipid-Normalized Bases

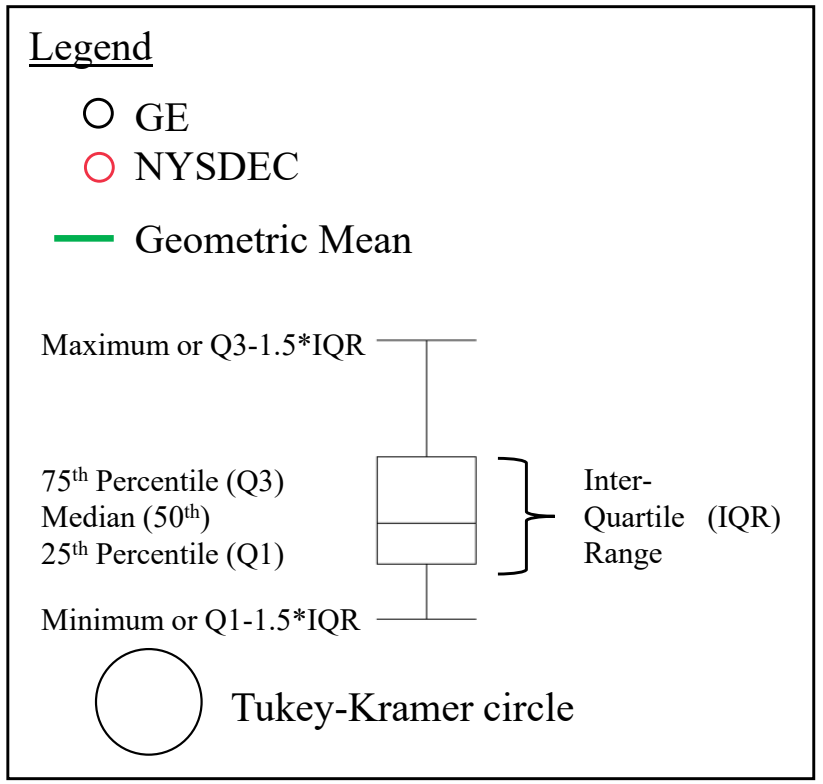
Figure A3-12A

July 2024

2019 Samples







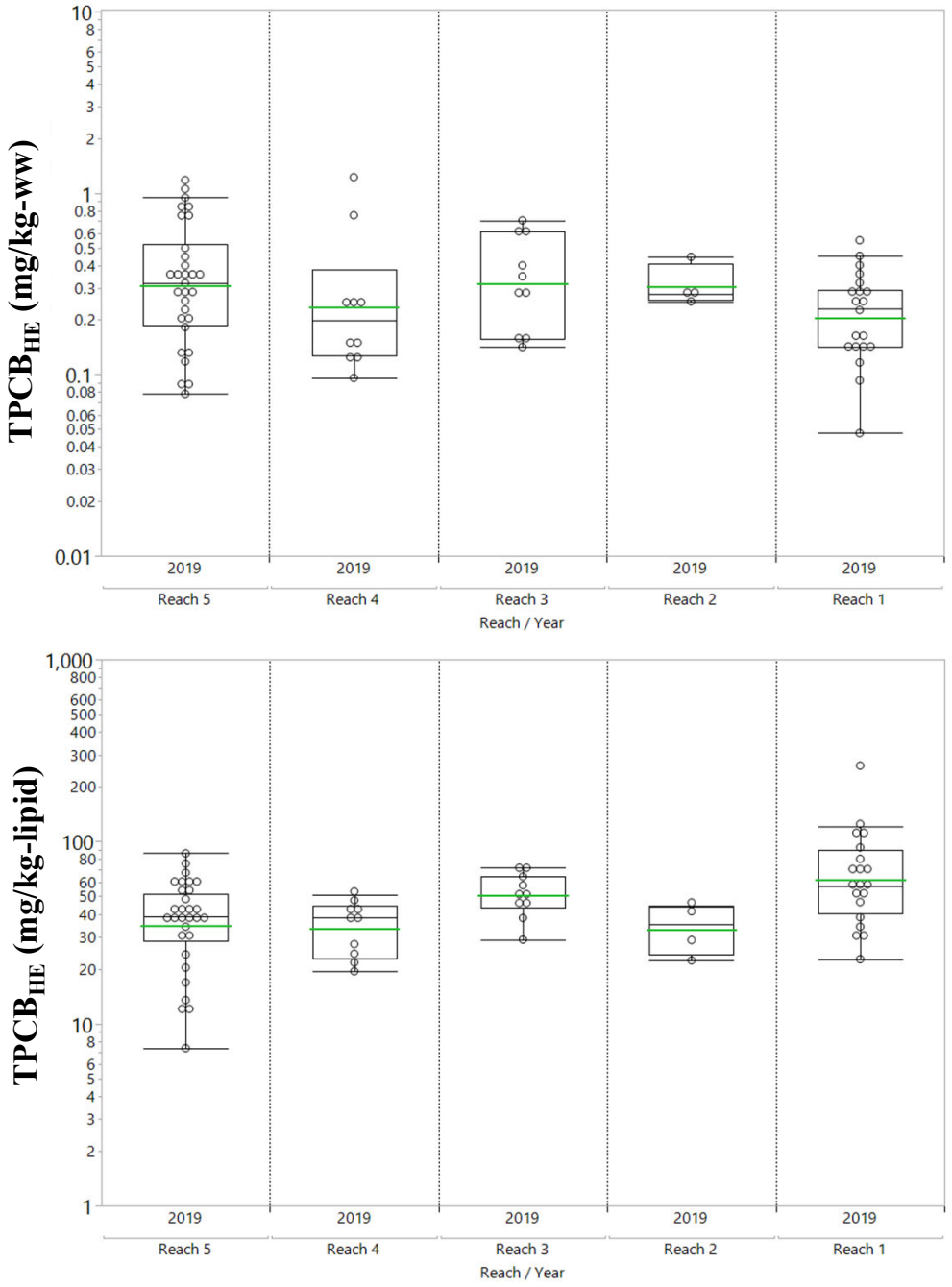
Notes

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results.
2. Tukey-Kramer circles represent the geometric mean (center of the circle) and its uncertainty (circle radius) for each of the sample groups examined. Tukey-Kramer circles that do not touch or intersect slightly are indicative of sample groups that are statistically different from each other. Statistically different groups are shown with blue Tukey-Kramer circles.

Spatial Variation of TPCB$_{HE}$ Concentrations in Brown Bullhead, Reach 5 through Reach 1 – Wet-Weight and Lipid-Normalized Bases

Figure A3-12B

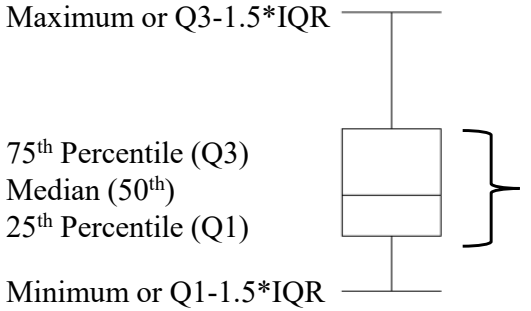
July 2024



2019 Samples

Legend

- GE
- NYSDEC
- Geometric mean



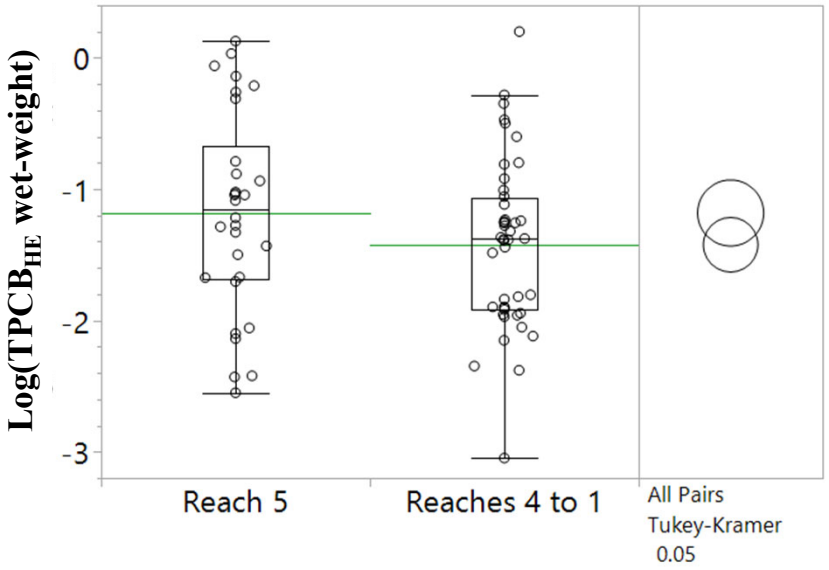
Notes

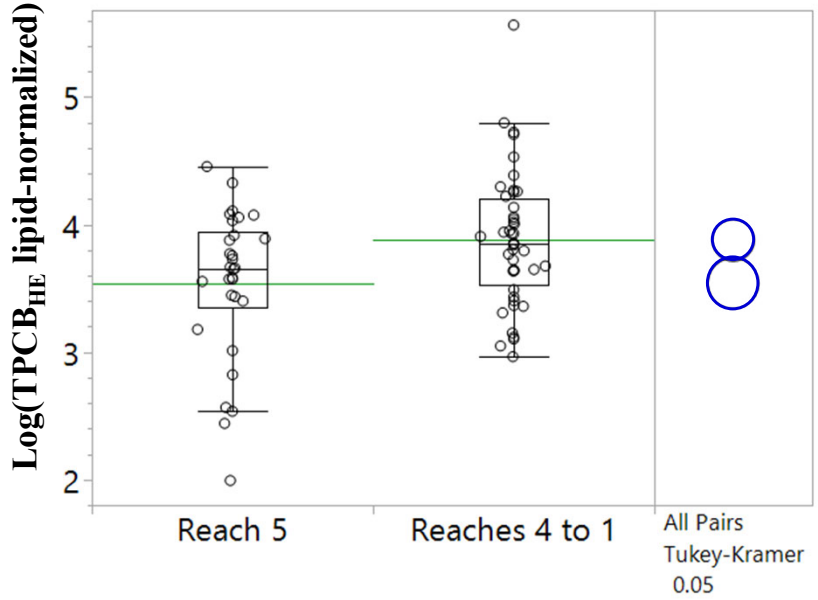
1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results.

Spatial Variation of TPCB$_{HE}$ Concentrations in Yellow Perch, Reach 5 through Reach 1– Wet-Weight and Lipid-Normalized Bases

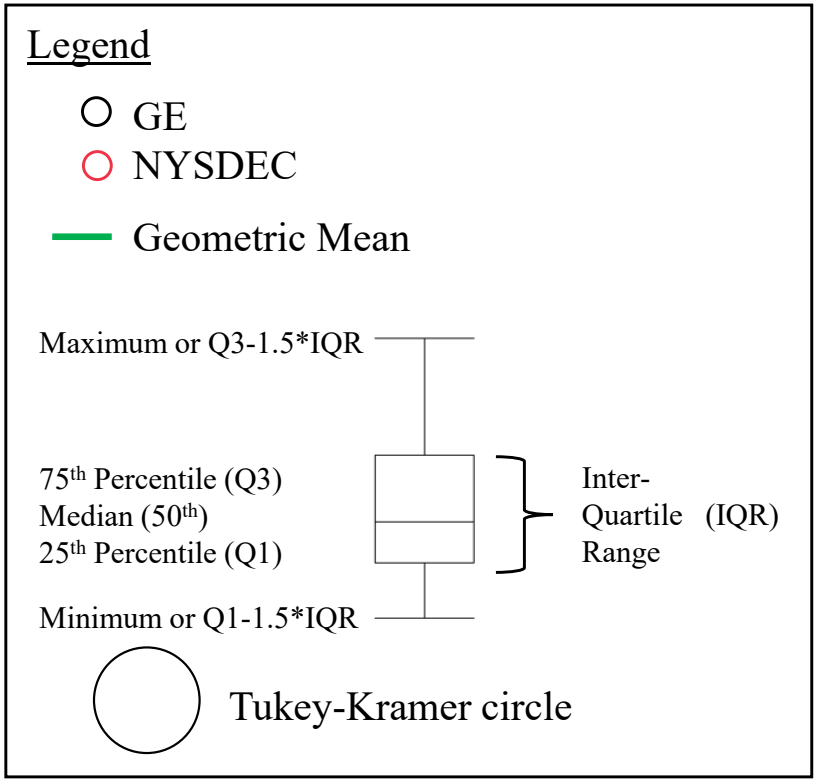
Figure A3-13A

July 2024





2019 Samples



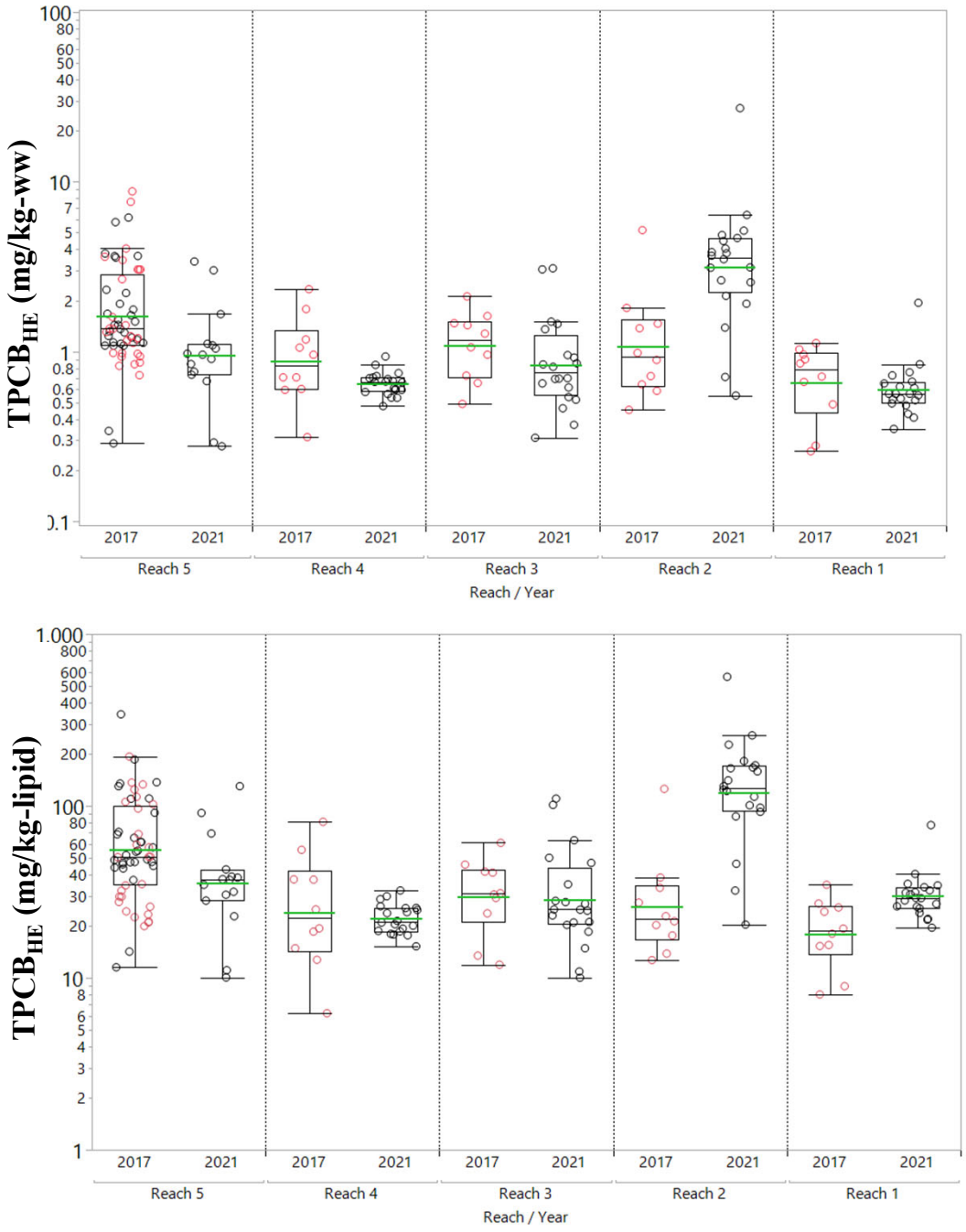
Notes

1. PCB concentrations are expressed as Total PCB homologue equivalent values ($TPCB_{HE}$), based on conversion from reported Aroclor results.
2. Tukey-Kramer circles represent the geometric mean (center of the circle) and its uncertainty (circle radius) for each of the sample groups examined. Tukey-Kramer circles that do not touch or intersect slightly are indicative of sample groups that are statistically different from each other. Statistically different groups are shown with blue Tukey-Kramer circles.

Spatial Variation of $TPCB_{HE}$ Concentrations in Yellow Perch, Reach 5 through Reach 1– Wet-Weight and Lipid-Normalized Bases

Figure A3-13B

July 2024



2017 and 2021 Samples

Legend

- GE
- NYSDEC
- Geometric mean

Maximum or Q3-1.5*IQR

75th Percentile (Q3)
Median (50th)
25th Percentile (Q1)

Minimum or Q1-1.5*IQR

Inter-Quartile Range (IQR)

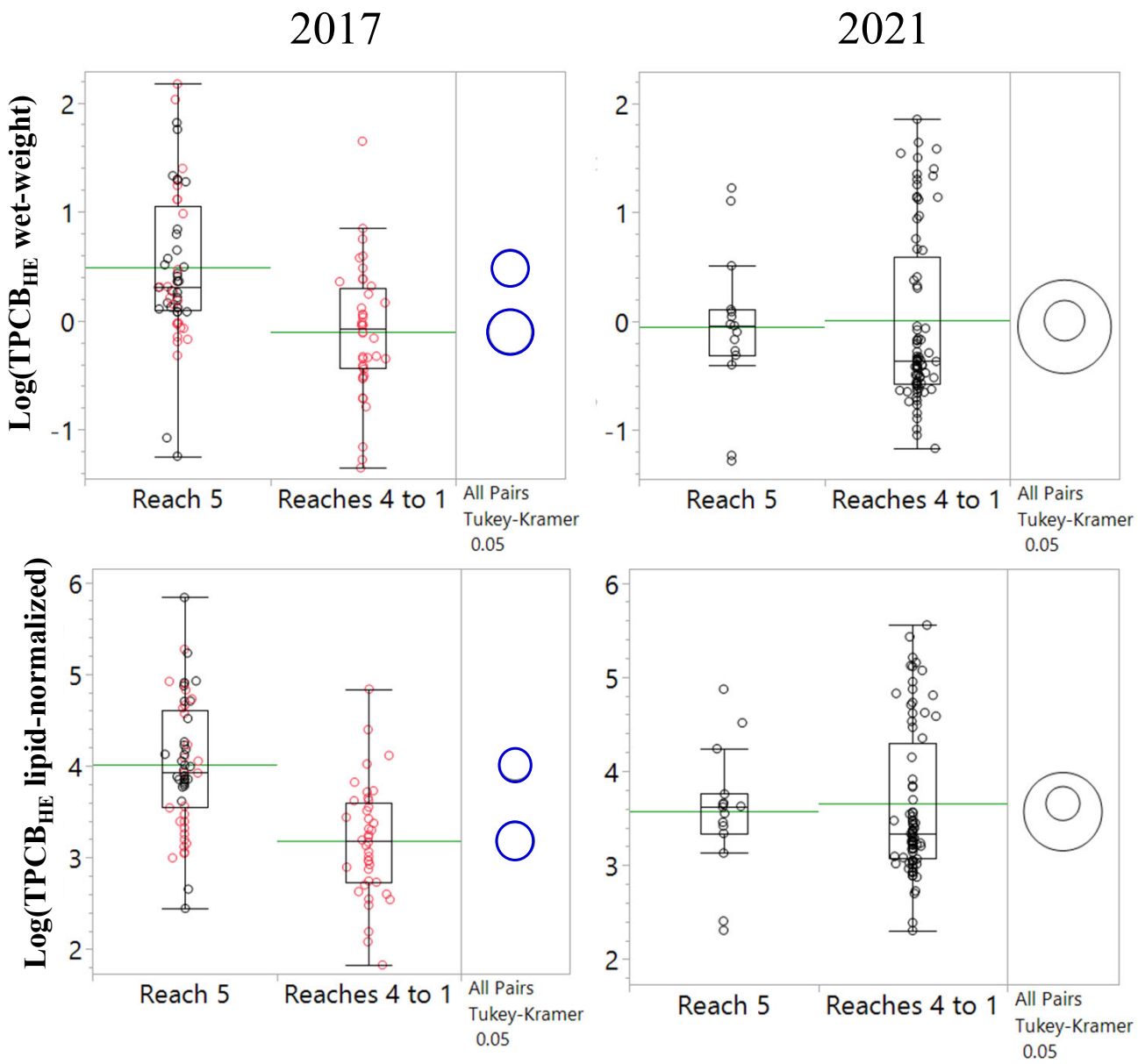
Notes

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results.

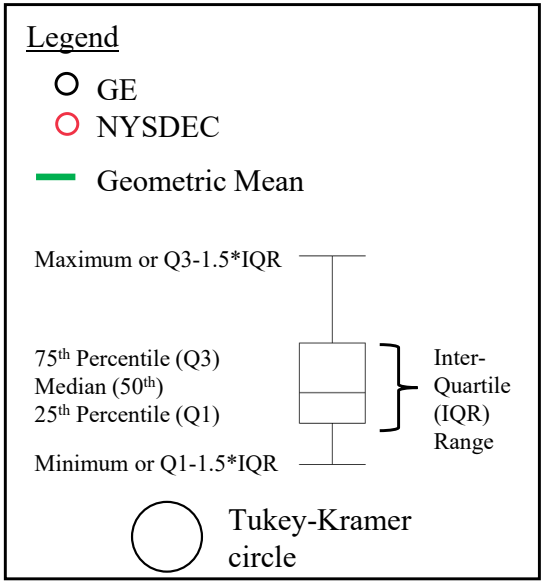
Spatial Variation of TPCB$_{HE}$ Concentrations in Pumpkinseed, Reach 5 through Reach 1– Wet-Weight and Lipid-Normalized Bases

Figure A3-14A

July 2024



2017 and 2021 Samples



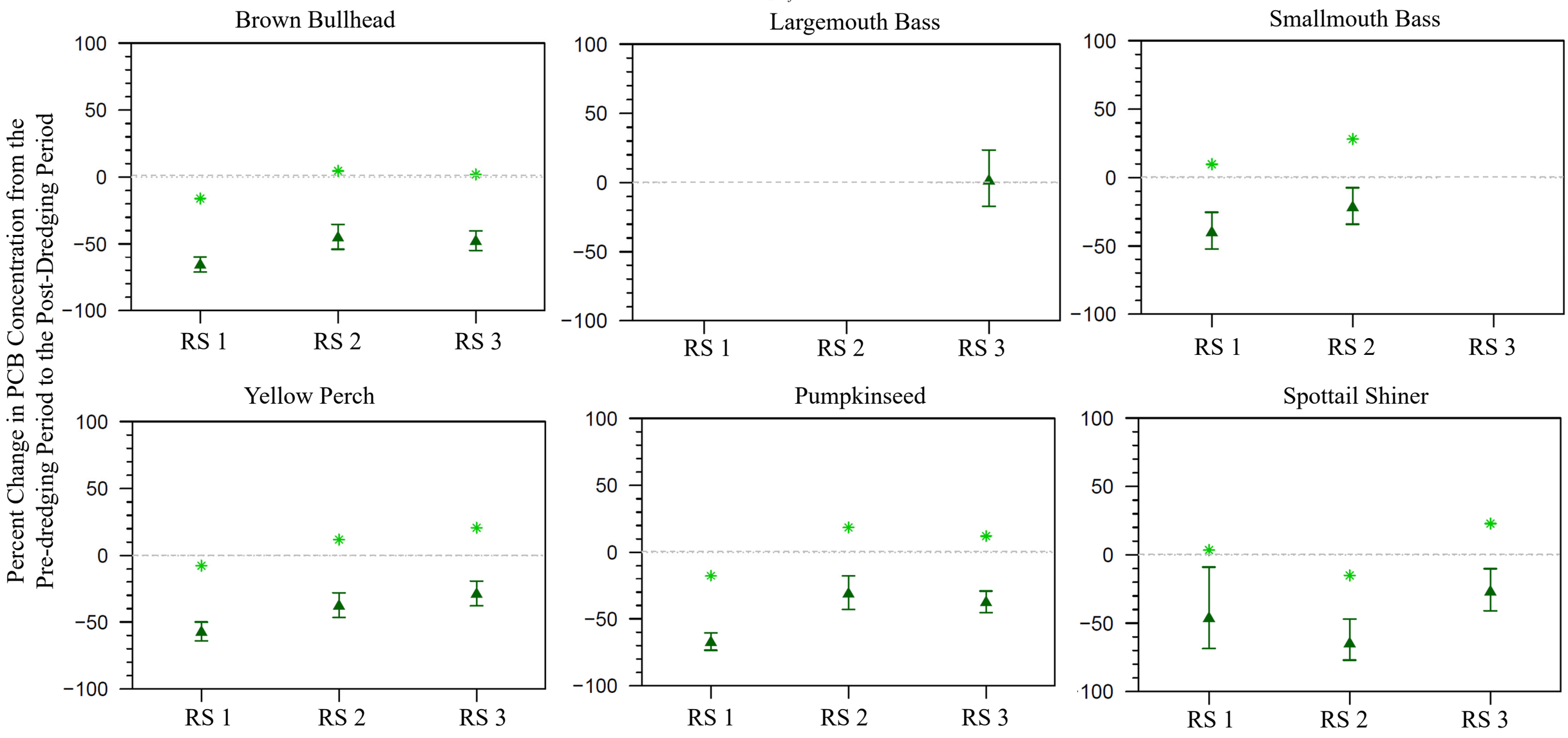
Notes

1. PCB concentrations are expressed as Total PCB homologue equivalent values (TPCB$_{HE}$), based on conversion from reported Aroclor results.
2. Tukey-Kramer circles represent the geometric mean (center of the circle) and its uncertainty (circle radius) for each of the sample groups examined. Tukey-Kramer circles that do not touch or intersect slightly are indicative of sample groups that are statistically different from each other. Statistically different groups are shown with blue Tukey-Kramer circles.

Spatial Variation of TPCB$_{HE}$ Concentrations in Pumpkinseed, Reach 5 through Reach 1– Wet-Weight and Lipid-Normalized Bases

Figure A3-14B

July 2024



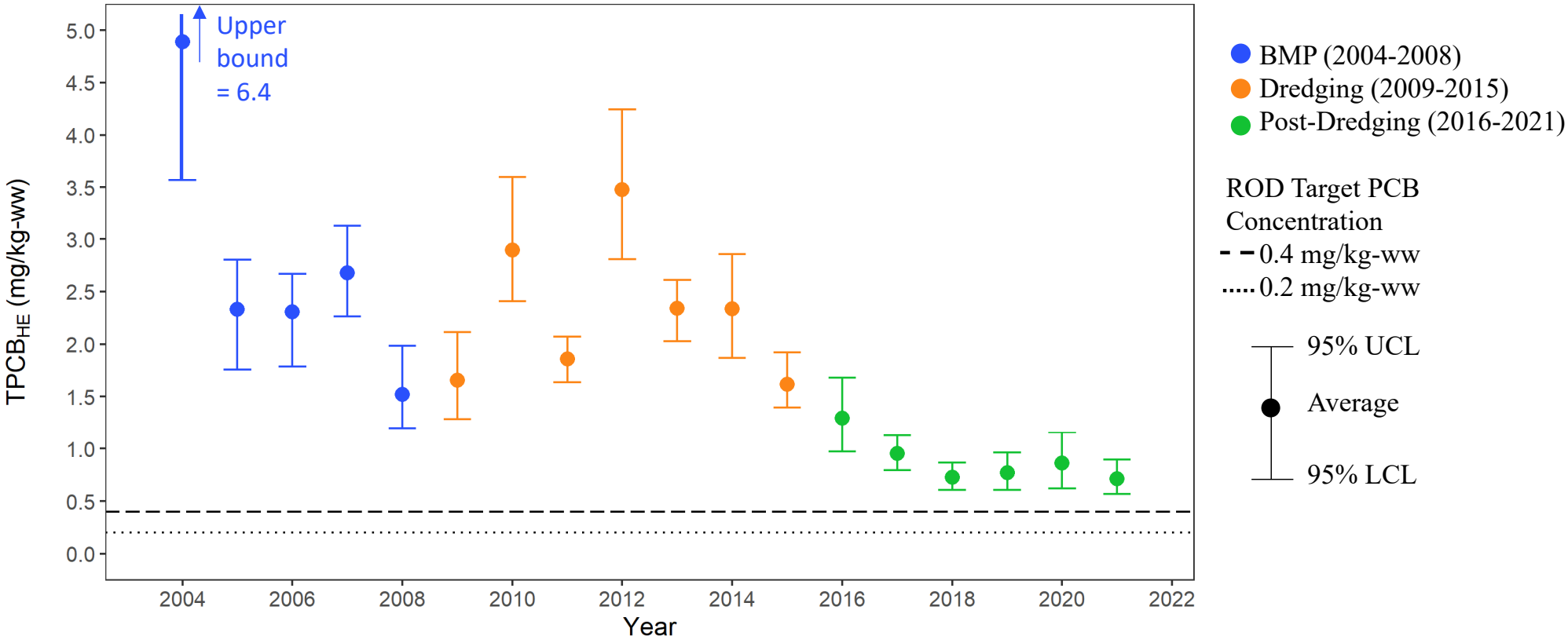
Notes:

1. The percent changes were based on the coefficients from the ANOVA model They represent the change in the geometric mean, from the pre-dredging baseline period (2004-2008) to post-dredging period (2016-2021), after accounting the variance caused by lipid. In general, statistically significant changes will not include 0% change (the grey dashed line) in the confidence interval. (See text for discussion.)
2. An asterisk "*" indicates the change is significant at the 95 percent confidence level as indicated by the p-value of the regression coefficient (p-value < 0.05).
3. The samples from 2007-2008 are rib-out fillets, all other data are NYSDEC standard fillet samples.
4. Data from river Reaches 4 through 1 are not included since they were not collected regularly during the comparison periods.

Percent change in $TPCB_{HE}$ Concentrations from the BMP to Post-Dredging

Figure A3-15

July 2024



Notes

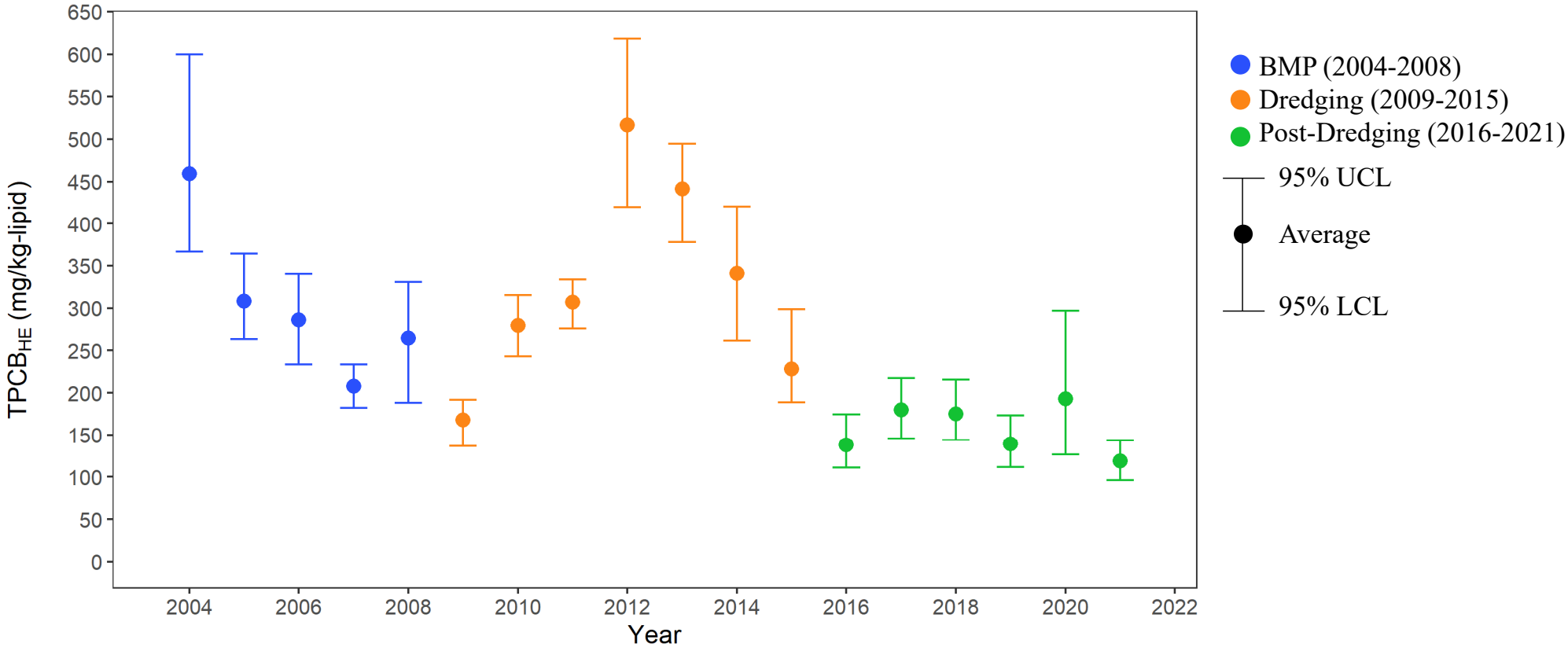
1. To create the River Section average, individual species are first averaged by collection station. The results for each species at each station are then equally weighted to create an average for the species for the River Section. The individual species averages are then combined in a species-weighted average for the River Section. Largemouth bass and smallmouth bass results are combined and treated as a single species in the calculation. (See text for discussion.)
2. River Section fish tissue PCB concentrations are weighted by species as follows: Largemouth and smallmouth bass = 47%, brown bullhead = 44%, yellow perch = 9%.
3. 95% lower confidence limit (LCL) and upper confidence limit (UCL) on the average are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
4. The samples from 2007-2013 are rib-out fillets, all other data is NYSDEC standard fillet samples. (See text for discussion.)

Wet-Weight Species-Weighted Average in River Section 1

Figure A3-16A

July 2024

Draft



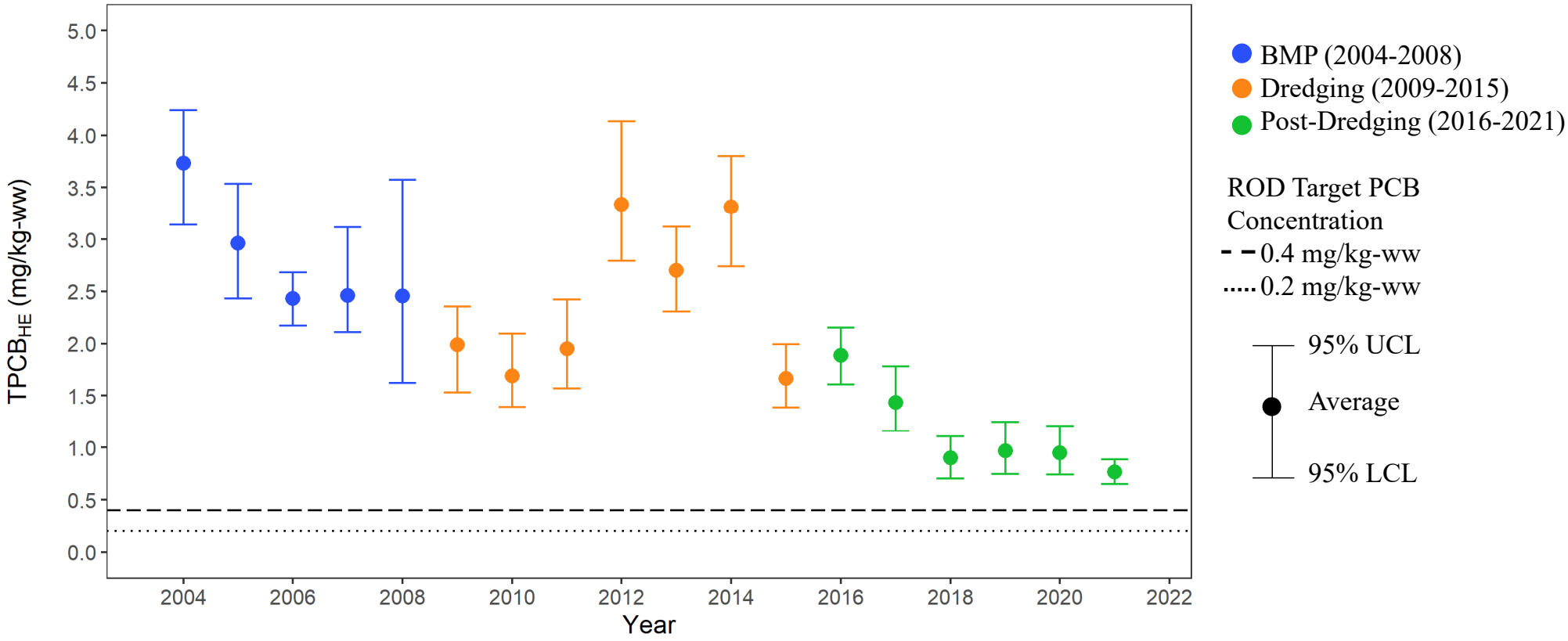
Notes

1. To create the River Section average, individual species are first averaged by collection station. The results for each species at each station are then equally weighted to create an average for the species for the River Section. The individual species averages are then combined in a species-weighted average for the River Section. Largemouth bass and smallmouth bass results are combined and treated as a single species in the calculation. (See text for discussion.)
2. River Section fish tissue PCB concentrations are weighted by species as follows: Largemouth and smallmouth bass = 47%, brown bullhead = 44%, yellow perch = 9%.
3. 95% lower confidence limit (LCL) and upper confidence limit (UCL) on the average are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
4. The samples from 2007-2013 are rib-out fillets, all other data is NYSDEC standard fillet samples. (See text for discussion.)

Lipid-Normalized Species-Weighted Average in River Section 1

Figure A3-16B

July 2024



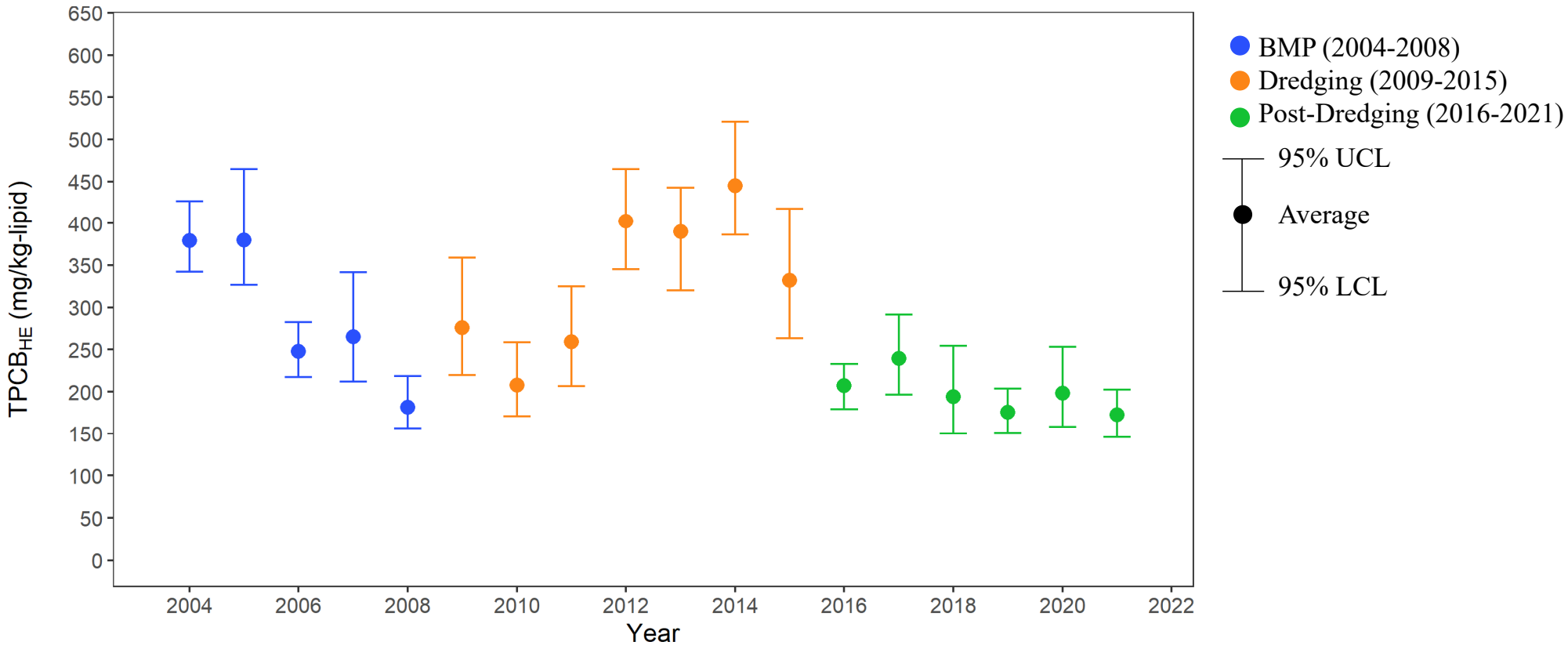
Notes

1. To create the River Section average, individual species are first averaged by collection station. The results for each species at each station are then equally weighted to create an average for the species for the River Section. The individual species averages are then combined in a species-weighted average for the River Section. Largemouth bass and smallmouth bass results are combined and treated as a single species in the calculation. (See text for discussion.)
2. River Section fish tissue PCB concentrations are weighted by species as follows: Largemouth and smallmouth bass = 47%, brown bullhead = 44%, yellow perch = 9%.
3. 95% lower confidence limit (LCL) and upper confidence limit (UCL) on the average are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
4. The samples from 2007-2013 are rib-out fillets, all other data is NYSDEC standard fillet samples. (See text for discussion.)

Wet-Weight Species-Weighted Average in River Section 2

Figure A3-17A

July 2024



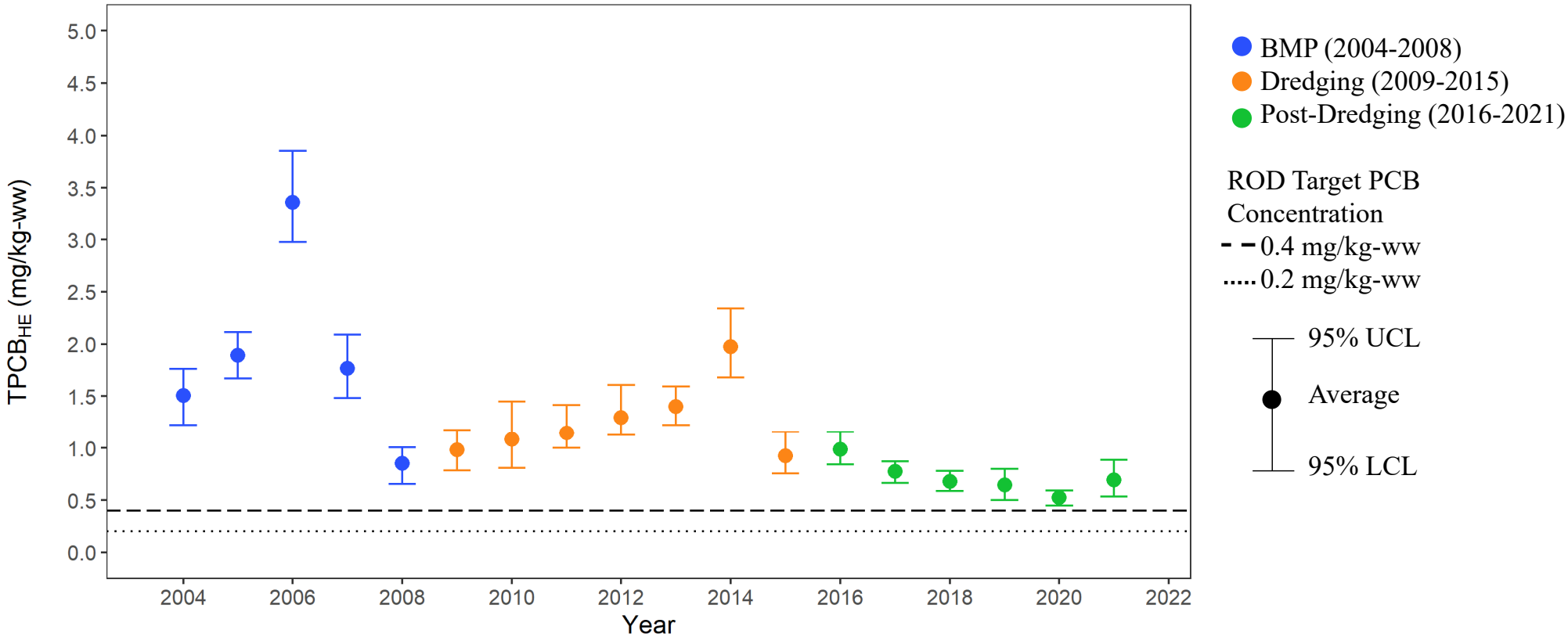
Notes

1. To create the River Section average, individual species are first averaged by collection station. The results for each species at each station are then equally weighted to create an average for the species for the River Section. The individual species averages are then combined in a species-weighted average for the River Section. Largemouth bass and smallmouth bass results are combined and treated as a single species in the calculation. (See text for discussion.)
2. River Section fish tissue PCB concentrations are weighted by species as follows: Largemouth and smallmouth bass = 47%, brown bullhead = 44%, yellow perch = 9%.
3. 95% lower confidence limit (LCL) and upper confidence limit (UCL) on the average are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
4.The samples from 2007-2013 are rib-out fillets, all other data is NYSDEC standard fillet samples. (See text for discussion.)

Lipid-Normalized Species-Weighted Average in River Section 2

Figure A3-17B

July 2024



Notes

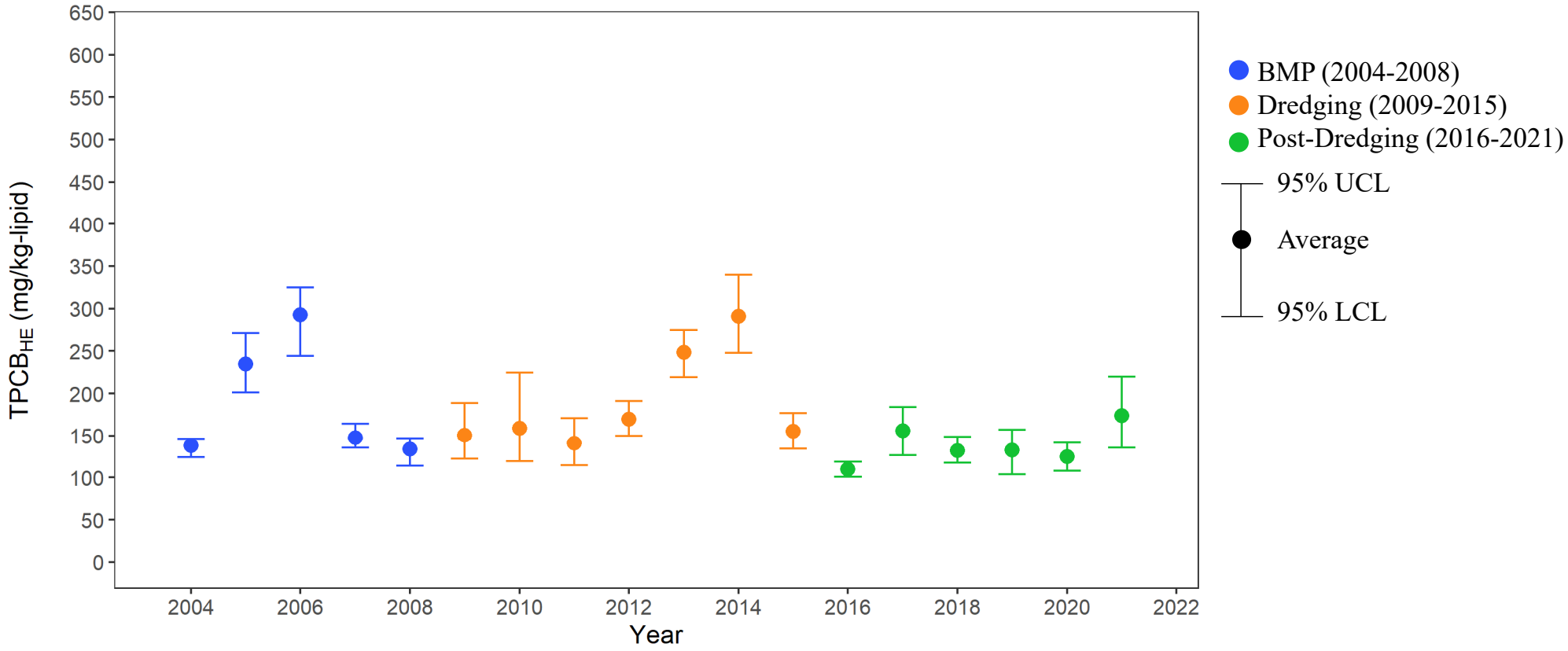
1. To create the River Section average, individual species are first averaged by collection station. The results for each species at each station are then equally weighted to create an average for the species for the River Section. The individual species averages are then combined in a species-weighted average for the River Section. Largemouth bass and smallmouth bass results are combined and treated as a single species in the calculation. (See text for discussion.)
2. River Section fish tissue PCB concentrations are weighted by species as follows: Largemouth and smallmouth bass = 47%, brown bullhead = 44%, yellow perch = 9%.
3. 95% lower confidence limit (LCL) and upper confidence limit (UCL) on the average are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
4. The samples from 2007-2013 are rib-out fillets, all other data is NYSDEC standard fillet samples. (See text for discussion.)

Wet-Weight Species-Weighted Average in River Section 3

Figure A3-18A

July 2024

Draft



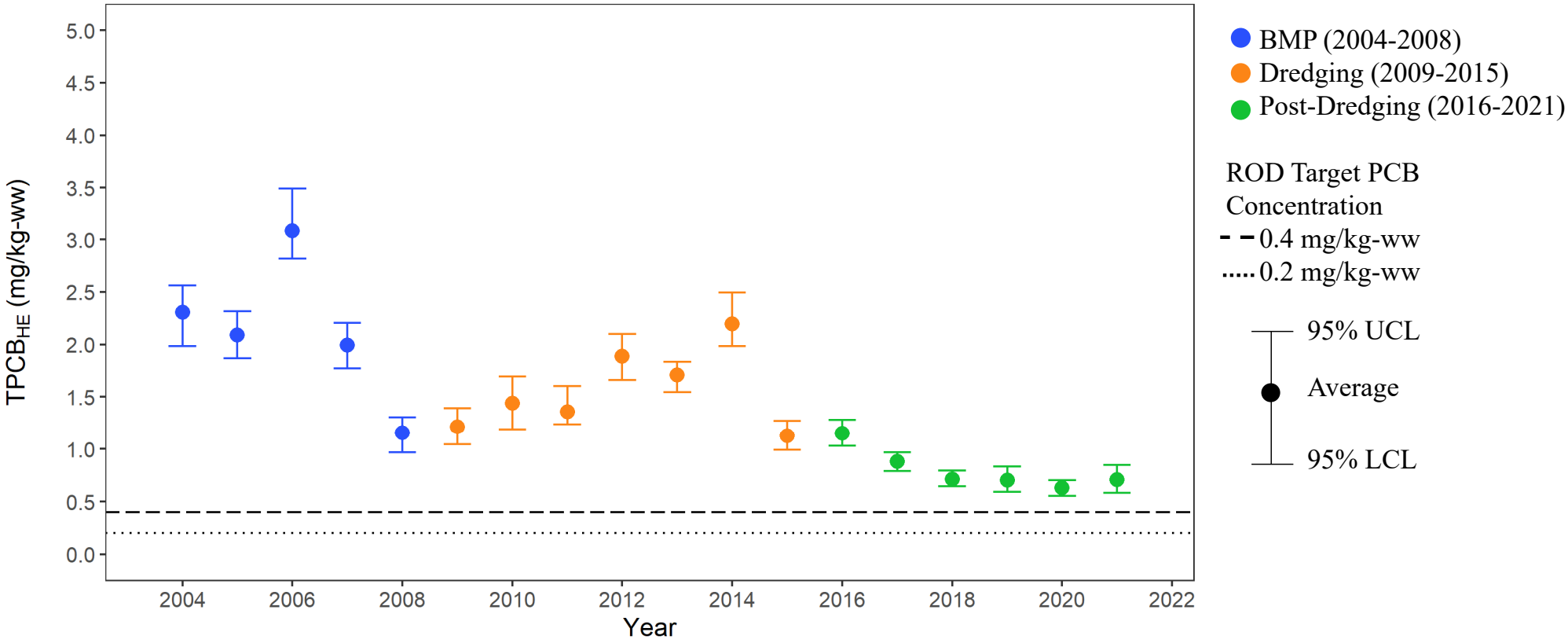
Notes

1. To create the River Section average, individual species are first averaged by collection station. The results for each species at each station are then equally weighted to create an average for the species for the River Section. The individual species averages are then combined in a species-weighted average for the River Section. Largemouth bass and smallmouth bass results are combined and treated as a single species in the calculation. (See text for discussion.)
2. River Section fish tissue PCB concentrations are weighted by species as follows: Largemouth and smallmouth bass = 47%, brown bullhead = 44%, yellow perch = 9%.
3. 95% lower confidence limit (LCL) and upper confidence limit (UCL) on the average are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
4. The samples from 2007-2013 are rib-out fillets, all other data is NYSDEC standard fillet samples. (See text for discussion.)

Lipid-Normalized Species-Weighted Average in River Section 3

Figure A3-18B

July 2024



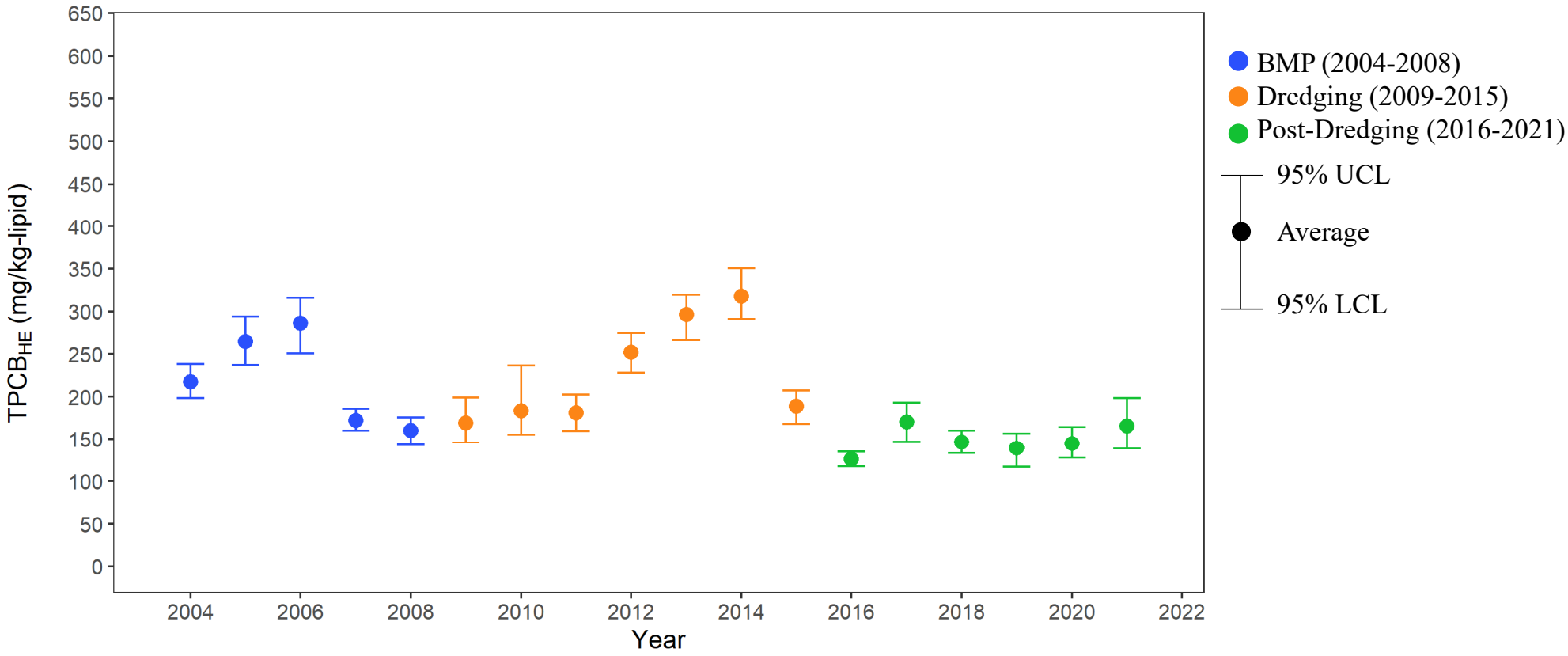
Notes

1. The Upper Hudson River average is weighted by both species and river section length. First, a species-weighted average is created for each River section, weighting the species as follows: Largemouth and smallmouth bass = 47%, brown bullhead = 44%, yellow perch = 9%. Then the results for the three River Sections are combined based on their relative lengths: River Section 1 = 6.3 miles (15.4%); River Section 2= 5.1 miles (12.5%); and River Section 3= 29.5 miles (72.1%). Data from river Reaches 4 through 1 are not included in this calculation since they were not collected regularly. Data from Reach 5 in River Section 3 are weighted to reflect all 29.5 miles of River Section 3, while the fish monitoring stations representing River Section 3 are all located in Reach 5, which is 14 miles long.
2. 95% lower confidence limit (LCL) and upper confidence limit (UCL) on the average are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
3. The samples from 2007-2013 are rib-out fillets, all other data is NYSDEC standard fillet samples. (See text for discussion.)

Wet-Weight Species-Weighted Average in the Upper Hudson River (RS 1 to RS 3)

Figure A3-19A

July 2024



Notes

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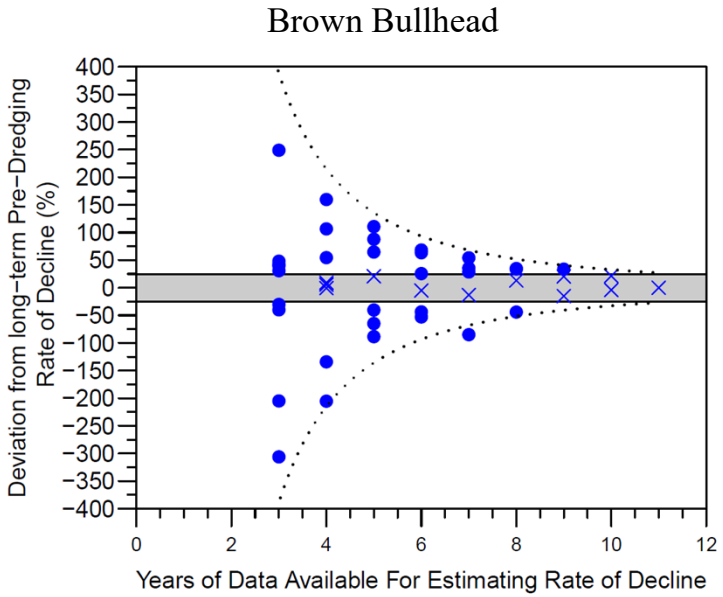
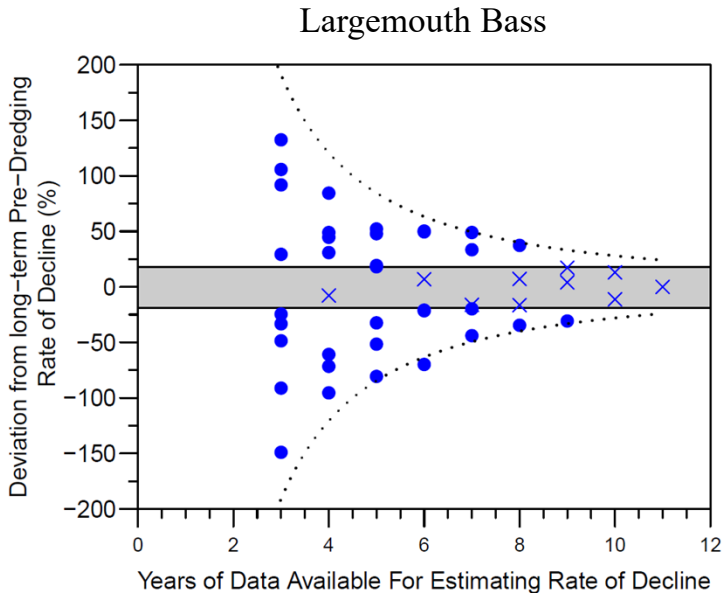
2. 95% lower confidence limit (LCL) and upper confidence limit (UCL) on the average are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
3. The samples from 2007-2013 are rib-out fillets, all other data is NYSDEC standard fillet samples. (See text for discussion.)

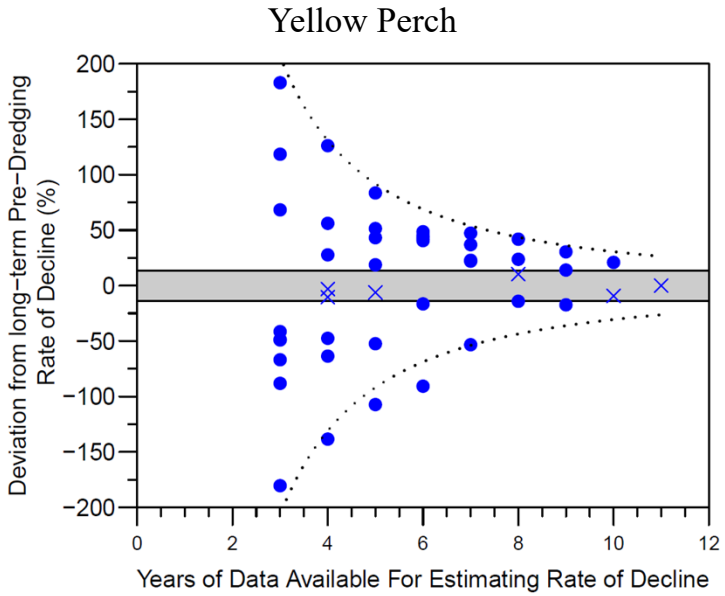
Lipid-Normalized Species-Weighted Average in the Upper Hudson River (RS 1 to RS 3)

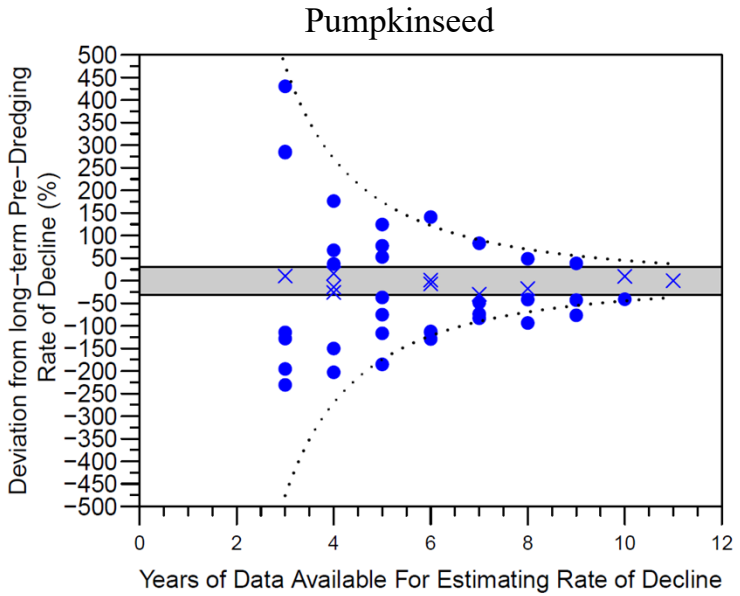
Figure A3-19B

July 2024









× Deviation within 95% CI of long-term rate of decline
● Deviation outside 95% CI of long-term rate of decline

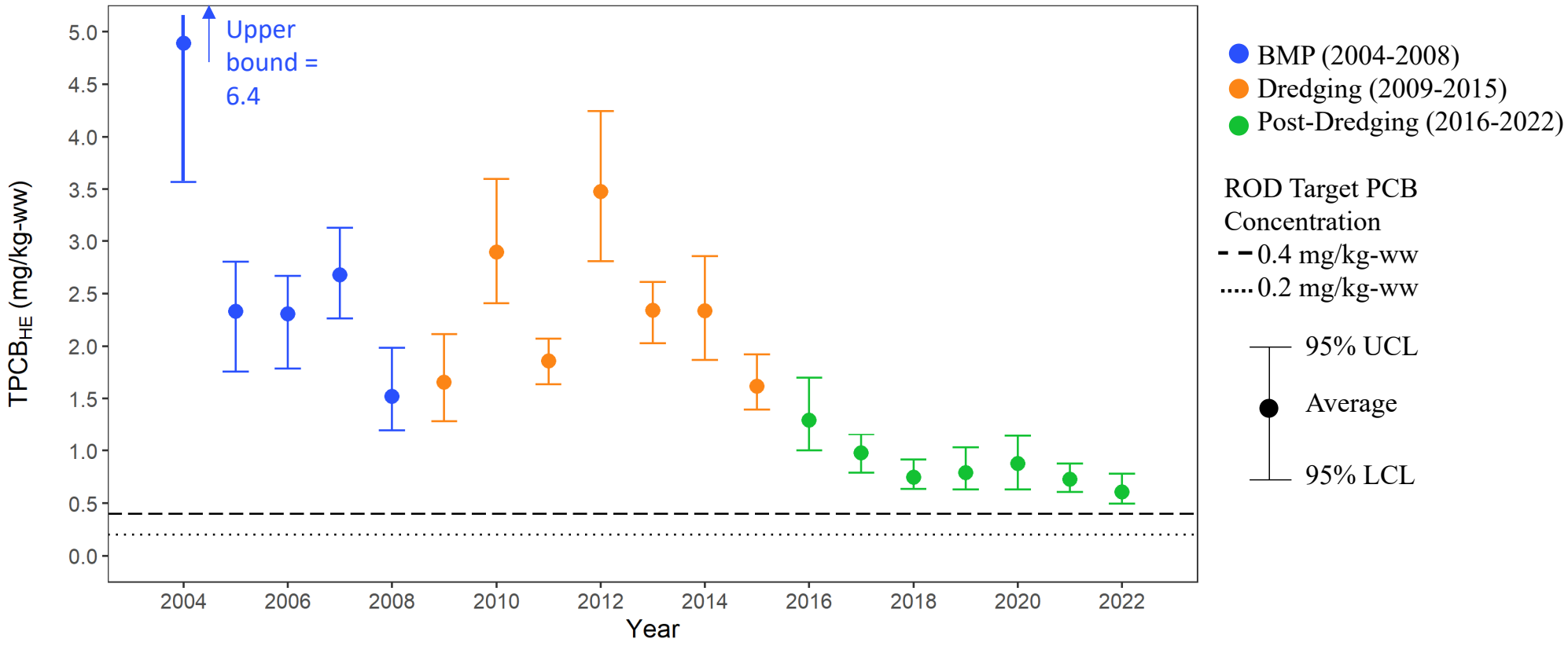
Notes:

- Deviation from long-term pre-dredging rate of decline was calculated as the relative change of the short-term average rate of decline to the 11-year rate of decline.
- As an example, the symbols at the six-year interval on the X- axis represent the rates calculated for the following intervals: 1998 to 2003, 1999 to 2004, 2000 to 2005, 2001 to 2006, 2002 to 2007 and 2003 to 2008, resulting in six separate estimates of the rate of decline, represented by the seven points on the graph at 6 years.
- Shaded region represented 95% confidence bands on the 11-year rate of decline.
- Dotted lines are empirical lines to show the approximate decline in variance with increasing number of years for averaging.
- Note that a positive deviation of 100% is equal to a decay rate that is twice as fast as the 11-year rate, whereas a negative deviation of 100% is equal to a decay rate of 0%/year (a flat line trend).
- The data used in this figure represents the 11-year period 1998 to 2008.

Variation in PCB Decline Rate Estimates vs Period of Available Data: Pre-Dredging Decline Example for the Period 1998 to 2008

Figure A3-20

July 2024



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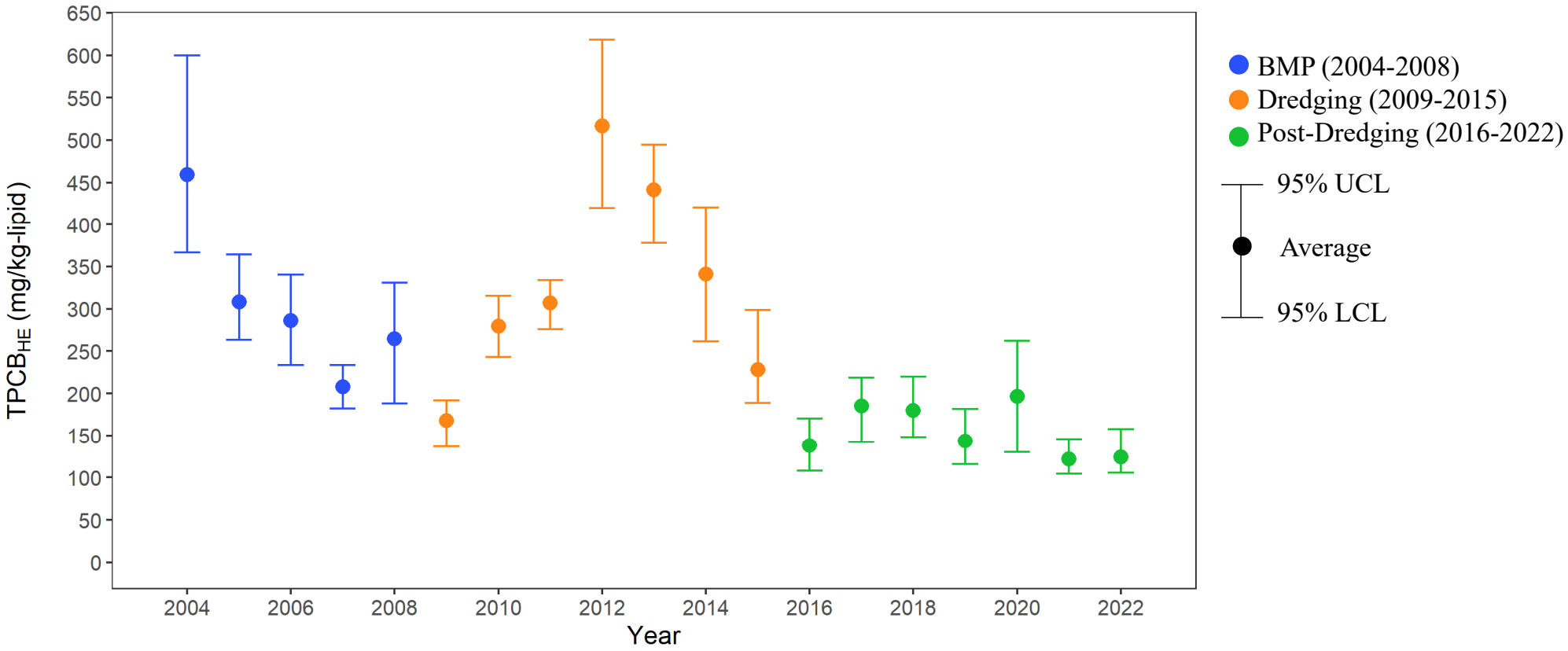
2. To create the River Section average, individual species are first averaged by collection station. The results for each species at each station are then equally weighted to create an average for the species for the River Section. The individual species averages are then combined in a species-weighted average for the River Section. Largemouth bass and smallmouth bass results are combined and treated as a single species in the calculation. (See text for discussion.)
3. River Section fish tissue PCB concentrations are weighted by species as follows: black bass (largemouth or smallmouth) = 47%, brown bullhead = 44%, yellow perch = 9%.
4. 95% lower confidence limit (LCL) and upper confidence limit (UCL) on the average are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
5. The GE samples from 2007-2013 are rib-out fillets, all other fillet data were processed using the NYSDEC standard fillet procedure. (See text for discussion.)

Wet-Weight Species-Weighted Average in River Section 1 with 2022 Data

Figure A3-21A

July 2024

Draft



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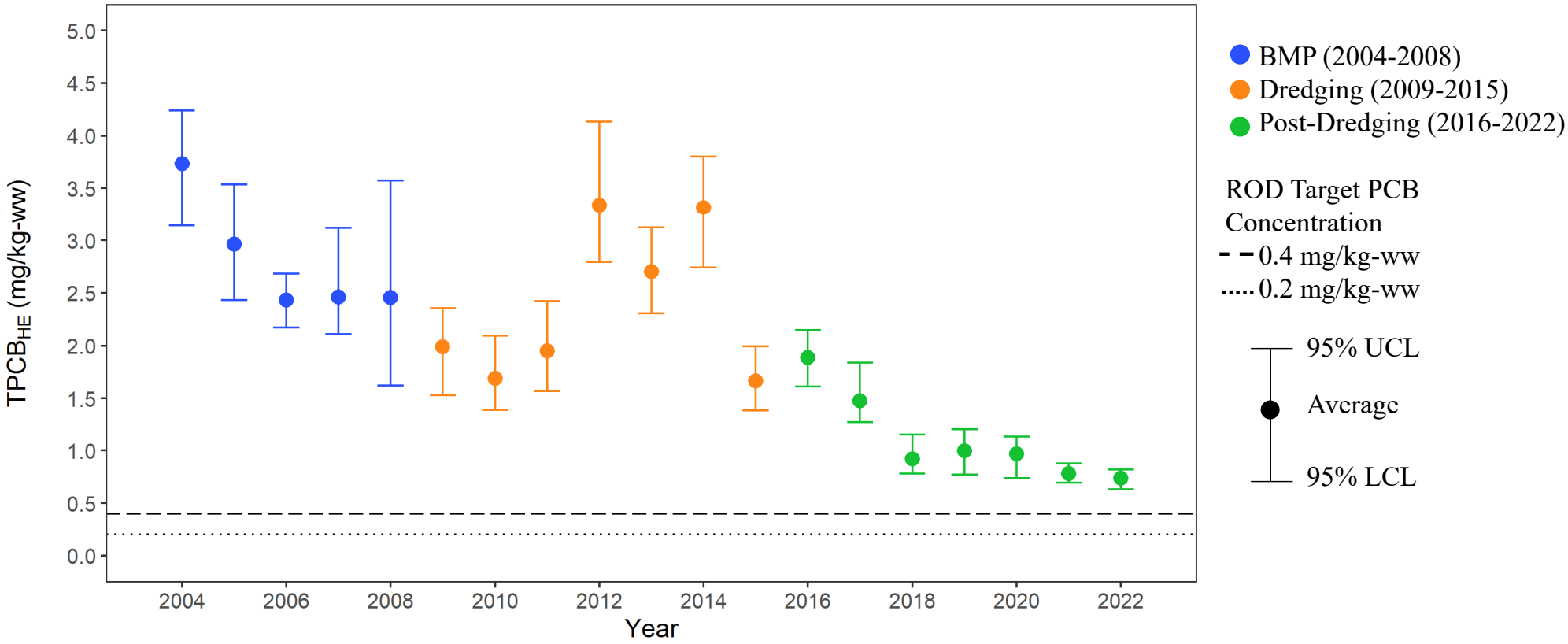
Lipid-Normalized Species-Weighted Average in River Section 1 with 2022 Data

Figure A3-21B

July 2024

Draft



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Wet-Weight Species-Weighted Average in River Section 2 with 2022 Data

Figure A3-22A

July 2024

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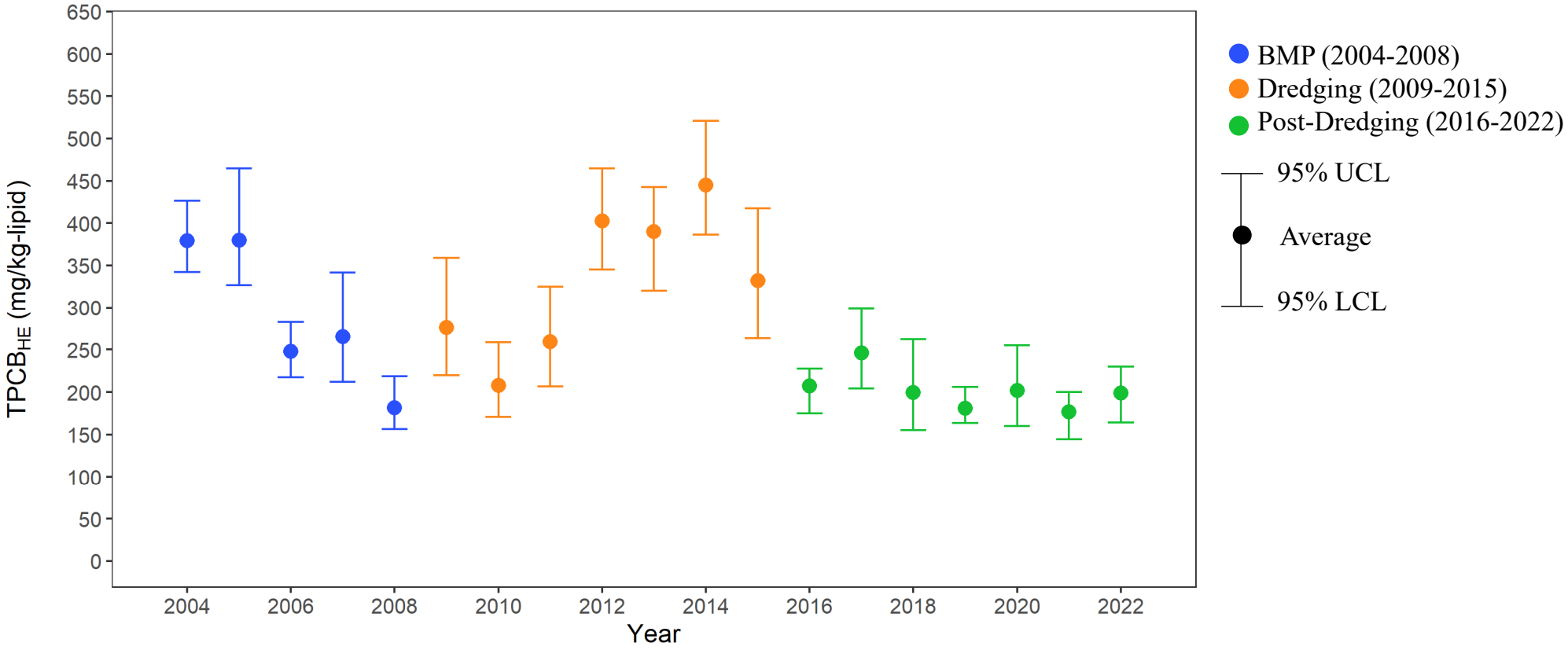

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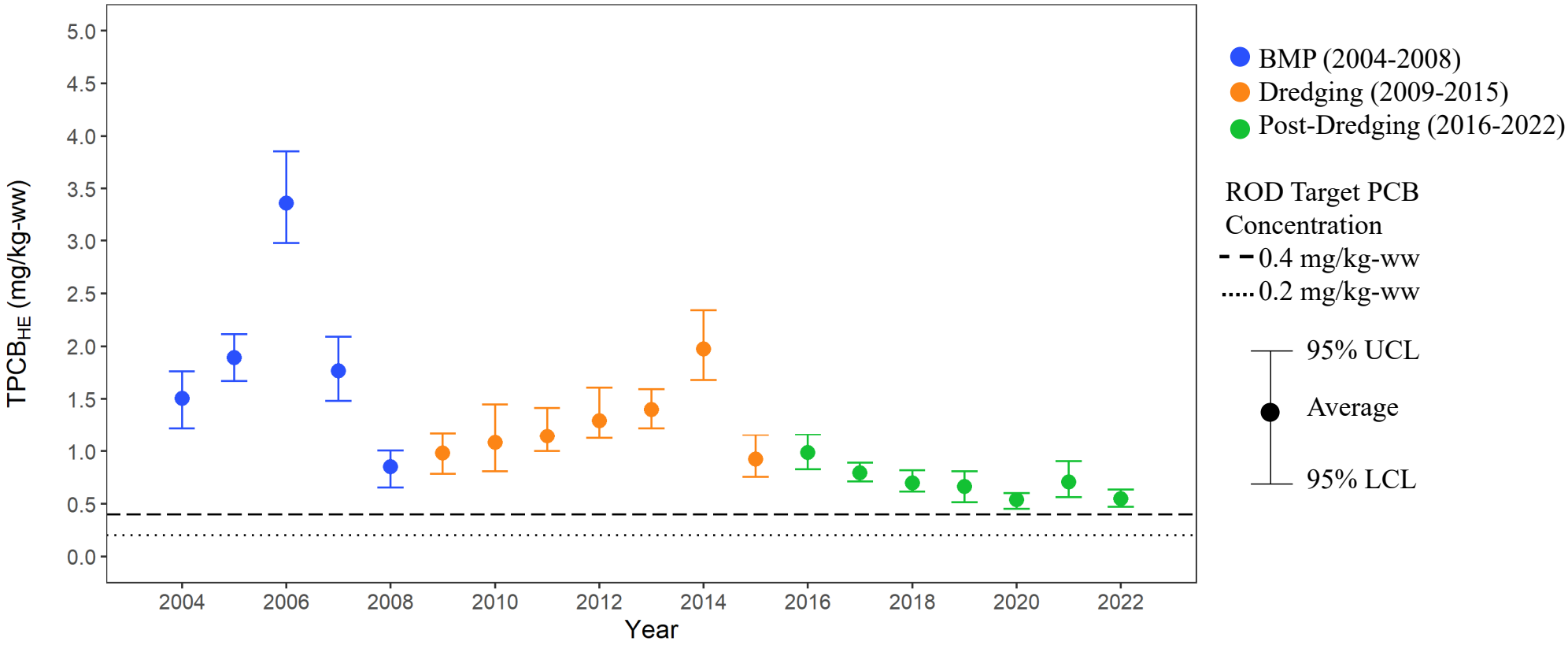
Lipid-Normalized Species-Weighted Average in River Section 2 with 2022 Data

Figure A3-22B

July 2024

Draft



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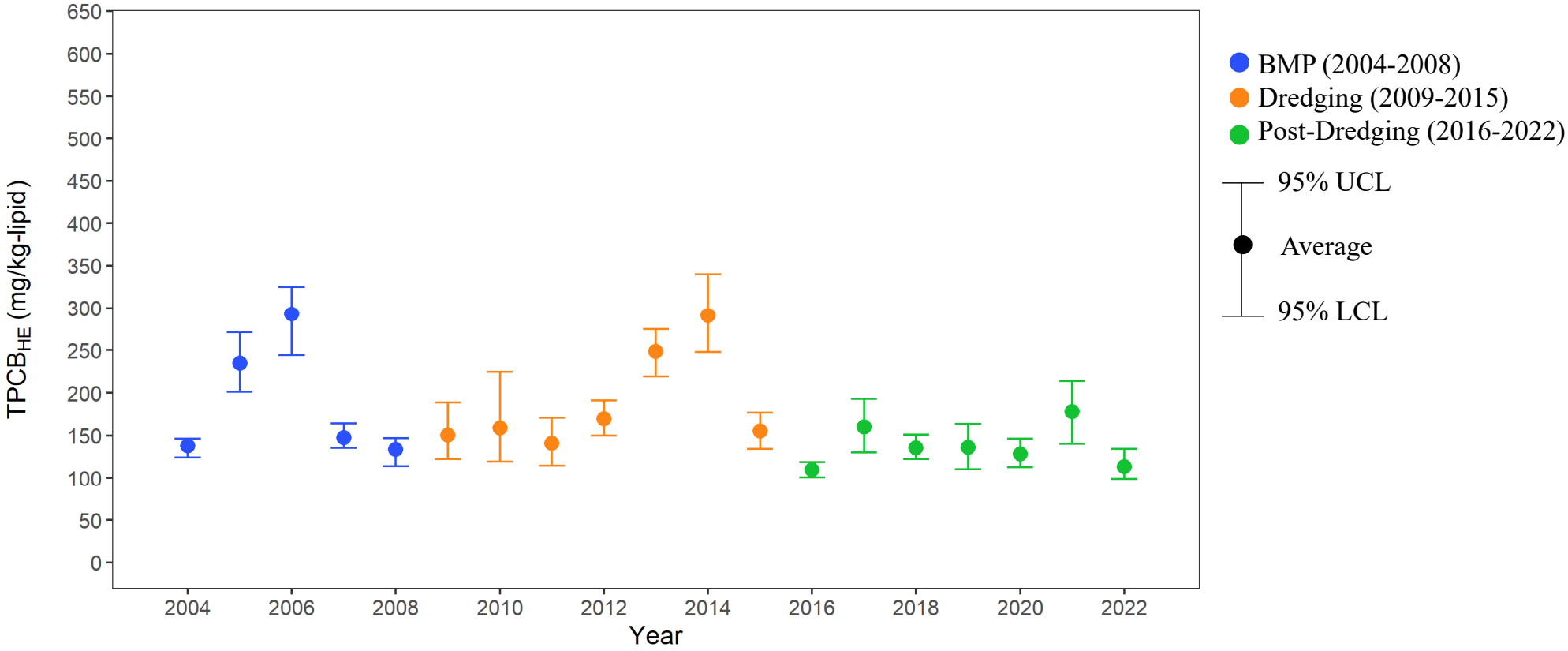
Wet-Weight Species-Weighted Average in River Section 3 with 2022 Data

Figure A3-23A

July 2024

Draft



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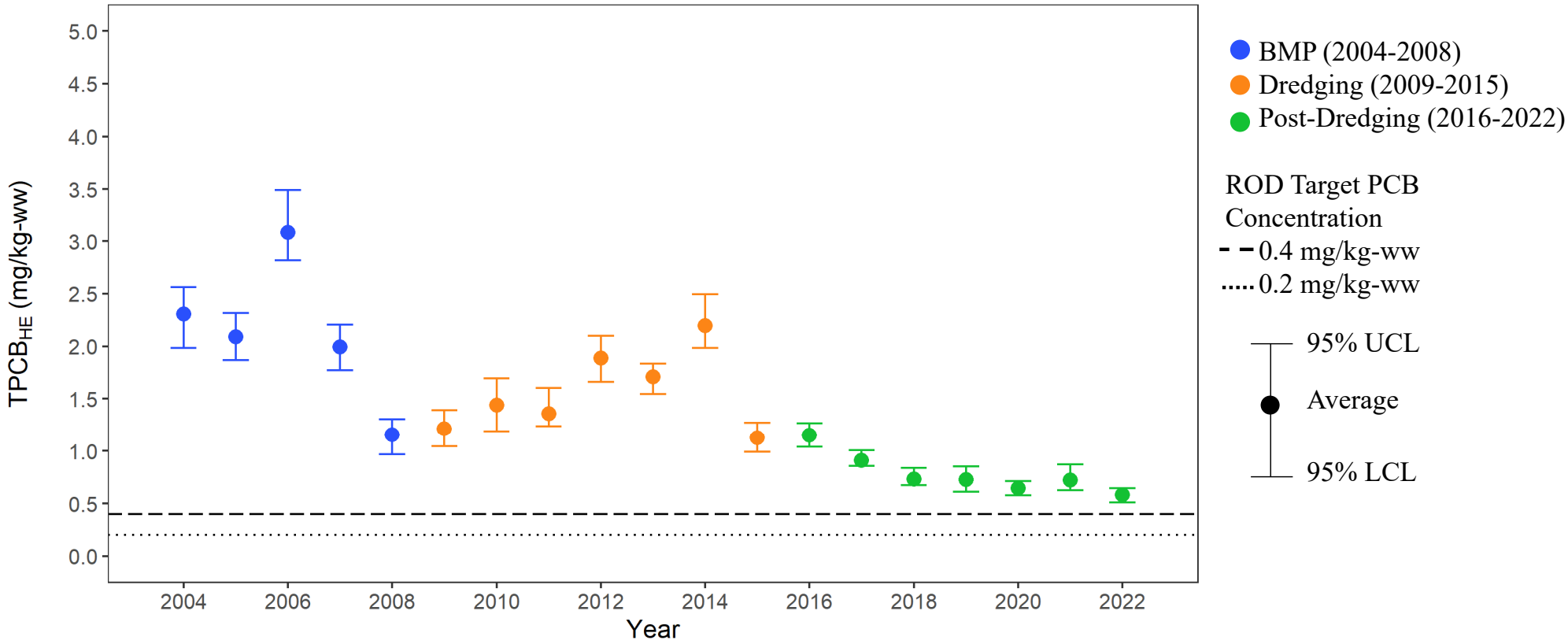
5. The GE samples from 2007-2013 are rib-out fillets, all other fillet data were processed using the NYSDEC standard fillet procedure. (See text for discussion.)

Lipid-Normalized Species-Weighted Average in River Section 3 with 2022 Data

Figure A3-23B

July 2024



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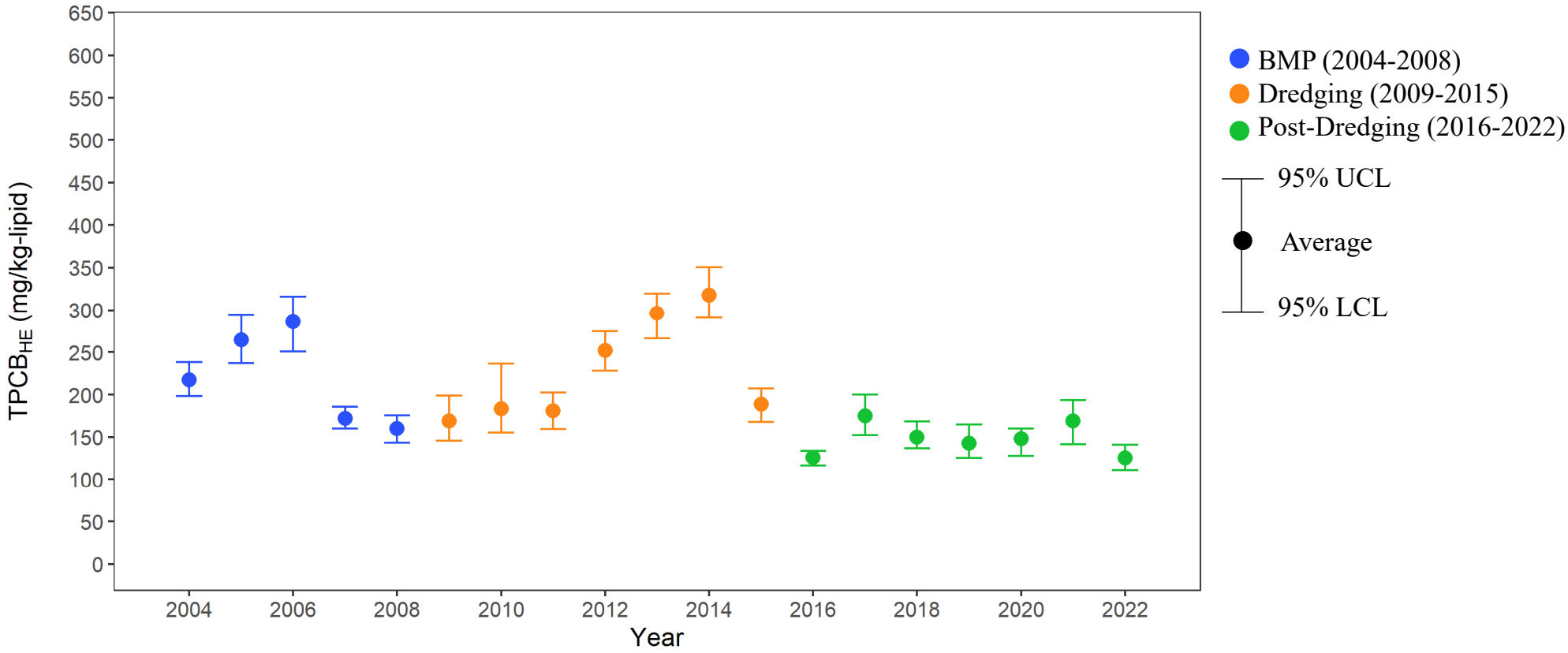
Wet-Weight Species-Weighted Average in the Upper Hudson River (RS 1 to RS 3) with 2022 Data

Figure A3-24A

July 2024

Draft



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Lipid-Normalized Species-Weighted Average in the Upper Hudson River (RS 1 to RS 3) with 2022 Data

Figure A3-24B

July 2024

ATTACHMENT A

Third Five-Year Review Report for the Hudson River PCBs Superfund Site

APPENDIX 3

ATTACHMENT A

FISH TISSUE PCB DATA TREATMENT

Prepared by:
WSP USA Solutions Inc.

July 2024

THIRD FIVE-YEAR REVIEW REPORT FOR THE HUDSON RIVER PCBs SUPERFUND SITE

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1 INTRODUCTION

This attachment discusses various analyses used to assess the intra- and inter-laboratory precision and accuracy in order to be able to compare data through time across different laboratories. The following analyses are discussed in this attachment:

- Assessment of the National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) performance evaluation (PE) samples
- Changes in relative Aroclor proportions through time
- Matched pair data used to generate the Homologue Equivalent TPCB (Total PCB_{HE})
- Adaptation of the species-weighted average calculation based on species availability

2 NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY STANDARD REFERENCE MATERIAL STANDARD REFERENCE MATERIAL RESULTS

2.1 Methodology

In 2019, the use of SRM as a PE sample was added to the Upper Hudson River (UHR) fish laboratory quality assurance/quality control (QA/QC) program. The use of SRM samples on a regular basis provides a means to track analytical accuracy and precision over time and across laboratories and analytical methods. Two SRMs were selected for use in 2019, NIST SRM 1946 (Lake Superior Fish Tissue) and NIST SRM 1947 (Lake Michigan Fish Tissue). These SRMs are environmental samples derived from fish collected from the Great Lakes in the late 1990s (NIST, 2017a, 2017b).

The use of SRM materials to document analytical consistency through time will facilitate the quantification of real changes in fish tissue concentrations over time. Further, using SRM samples on a regular basis provides a means to track analytical accuracy and precision over time and across laboratories and analytical methods. This comparison is different from typical laboratory internal or calibration standard checks because it is based on an external standard reference material that provides the laboratories with an independent check on accuracy and precision for the associated analytical batch of samples. Internal laboratory standards are in contact with the media for a limited period prior to analysis and may not have attained equilibrium. Specifically, the spiking solution may not be fully absorbed onto the surface of the media, thereby permitting a less rigorous extraction to still achieve a high rate of PCB mass recovery from the prepared standard sample. As a result, analysis of these internally prepared standards and laboratory check samples may not provide a true measure of the laboratory's extraction accuracy and precision. Because the project SRMs are derived from environmental media, concentrations can be assumed to be in equilibrium

with their media and therefore provide a rigorous test of the accuracy of the entire extraction and analytical process.

For the Hudson River PCBs Site Operations, Monitoring, and Maintenance (OM&M) program PE fish tissue samples are needed for both the congener-based method 1668 (M1668) and Aroclor-based method 8082 (M8082). NIST SRM 1946 and 1947 are not certified for individual Aroclors or sum of Aroclor concentrations by M8082 ($TPCB_{Aroclor}$). Prior to using the NIST SRMs as part of the QA/QC program, General Electric Company (GE) analyzed seven samples of both NIST SRMs to determine total Aroclors and TPCB concentrations using the project methods and laboratory. The SRMs were also analyzed for lipid content using the project methods [SOP S-GB-O-067-Rev.01] (GE, 2019a, 2019b). These seven samples of both NIST SRMs serve as a baseline dataset against which subsequent groups of samples are being compared. For congener analysis, the NIST SRMs provide a number of certified and reference values[1] (42 of the congeners in NIST SRM 1946 and 45 of the congeners in NIST SRM 1947) derived as part of the SRM certification process. Because only a subset of the 209 PCB congeners within each NIST SRM have certified or reference values, NIST SRMs are not generally used as a "standard" for comparison with respect to the Total PCB (TPCB) concentration or the sum of congeners ($TPCB_{congener}$). Rather, they are used to verify the accuracy of the quantitation of the certified and reference value congeners. When a laboratory is able to reproduce these certified and reference values to within acceptable tolerance levels, it is inferred that the other analytical results, and their sums, like $TPCB_{congener}$, will be of similar (high) quality.

2.2 Assessment of NIST SRM Aroclor Results

NIST SRMs were analyzed to establish a baseline level in May 2019. Subsequently, NIST SRMs have been analyzed as PE samples, along with fish samples, between 2018 and 2021. Figure 2-1 presents the results of NIST SRMs samples analyzed as PCB Aroclor since 2019. On these figures, the baseline mean $TPCB_{Aroclor}$ values for NIST 1946 and NIST 1947, 1.8 milligrams per kilogram (mg/kg) and 2.4 mg/kg, respectively, are presented along with results over time. The standard errors for the NIST 1946 and NIST 1947 baseline datasets are 0.07 and 0.02 mg/kg, respectively. Results from the baseline samples and subsequent PE samples indicate that the $TPCB_{Aroclor}$ values for NIST 1946 exhibit more variability than those reported for NIST 1947.

To assess laboratory performance during the post-dredging period, the PE samples $TPCB_{Aroclor}$ results were compared to the baseline mean ± 2 times the standard error (the GE-established data quality index for fish monitoring [GE, 2019a]) and ± 20 percent of the baseline mean (based on the calibration for acceptance criteria for M8082 [EPA 2007]). As shown on Figure 2-1, individual

[1] NIST certified values are values for which NIST has the highest confidence in their accuracy in that all known or suspected sources of bias have been investigated or taken into account. NIST reference values are noncertified values that represent the best estimate of the true values based on available data; however, the values do not meet the NIST criteria for certification (NIST 2017a).

PE results for 2019 to 2021 fall within ± 20 percent of the baseline mean, except for two points of the NIST 1947 from the May to August 2019 results. The results of these analyses do not indicate systematic long-term drift. This suggests good laboratory performance over time and across sample-batches.

2.3 Assessment of NIST SRM Congener Results

An assessment of M1668 laboratory accuracy on the individual single-elute PCB congener certified and reference values for NIST 1946 and NIST 1947 is presented in Figure 2-2. As discussed earlier, NIST established certified or reference values for several congeners in each SRM, so baseline analyses for comparison were not needed. This figure shows the percentage difference between each single-elute[2] congener result from the laboratory and the certified or reference value. Figure 2-2 indicates that the majority of the M1668 results fall within ± 25 percent of the certified and reference values (the 25-percent threshold is based on the quality control acceptance criteria for M1668 [EPA, 2010]). GE laboratory results for NIST 1947 PE congener-based analysis are generally less variable than those for NIST 1946, but both sets of results indicate reasonable precision through time. For NIST 1946, both Aroclor and congener results show more variability than NIST 1947, suggesting that the SRM may be more variable. For the single-elute congeners, 85, 88, and 81 percent of the sample results fall within ± 25 percent of the certified or reference values for the 2018, 2020, and 2021 NIST 1947 SRM analyses, respectively. In comparison, for NIST 1946 SRMs, 63, 79, and 71 percent of the sample results fall within ± 25 percent of the certified or reference values for the 2018, 2020, and 2021 analyses, respectively.

Table 2-1 compares the sums of measured PCB congeners that have certified or reference values to the sums of NIST-certified or -reference congener values of each SRM. The sum of NIST-certified or -reference congener values are 0.88 mg/kg (883 ng/g) for NIST 1946 and 1.7 mg/kg (1,686 ng/g) for NIST 1947. When the sum of the measured PCB congeners that have certified or reference values is compared to the sum of the NIST-certified or NIST-reference congener values, the percent difference is between -15 percent and 8 percent. This shows good agreement between the sums of laboratory-measured SRM for which certified and reference values have been derived, and the sum of the independently measured SRM certified and reference values.

Table 2-2 shows the $TPCB_{congener}$ to $TPCB_{Aroclor}$ ratio for both NIST 1946 and 1947 SRM analyzed as PE samples. Since both the NIST Aroclor and NIST congener analyses show good performance over time, the NIST ratio should be stable over time. If drift was observed in one of the analyses, it would be reflected here by a decrease or increase in the ratio over time. The NIST $TPCB_{Aroclor}$ concentration shown on the table represents the average of PE samples analyzed during the period indicated on the table (e.g., samples analyzed in May to August 2019), while the $TPCB_{congener}$ shows a single PE sample (except for NIST 1947 congener sample from September 17, 2019,

[2] A single-elute congener is a congener that is quantified by M1668 based on a single chromatographic peak.

which appears twice because it is applied to two sets of Aroclor samples). The $TPCB_{congener}$ to $TPCB_{Aroclor}$ ratio for NIST 1946 ranges from 0.59 to 0.71 and the $TPCB_{congener}$ to $TPCB_{Aroclor}$ ratio for NIST 1947 ranges from 0.78 to 0.95. The ratio of $TPCB_{congener}$ to $TPCB_{Aroclor}$ for the NIST samples is stable over time.

The initial results for the SRM analyses have already demonstrated their value in tracking analytical precision through time. In particular, the $TPCB_{Aroclor}$ results for NIST 1947 SRM have shown minimal variability over time, indicating that the laboratory has been able to maintain good precision (by demonstrating the ability to consistently reproduce the baseline $TPCB_{Aroclor}$ result over time) across the analytical program. The NIST 1946 $TPCB_{Aroclor}$ data show more variability over time, although a temporal trend in the mean is not apparent.

2.4 Assessment of NIST SRM Lipid Results

Figure 2-3 shows the results of the SRM samples analyzed for lipid content (as extractable fat) by Pace-Green Bay as part of the M8082 program. Although certified/reference values are available for the NIST SRMs, they may be based on different analytical and extraction methods that make them not directly comparable. Therefore, the NIST SRM results are compared to the baseline dataset developed in 2019, which allows for consistency between the two data sets. NIST 1946 lipid results consistently fall above the baseline mean, but within the 20 percent of the baseline. Additionally, there is very little year-to-year variation in the reported values showing consistency over time. Ninety-seven percent of the results fall within 20 percent of the baseline mean and 77 percent of them fall within ± 2 times standard errors of the baseline mean. The average GE baseline (analyzed in 2019) result for NIST 1946 lipid content was 8.9 percent and the standard error was 0.26 percent. The average of NIST 1946 lipid content for PE samples associated with the 2018, 2019, 2020, and 2021 fish tissue samples was 9.6 percent.

The NIST 1947 lipid content results fell consistently around their baseline mean of 9.3 percent throughout the analytical program, but also consistently reported below the reference range of NIST 1947 (10.4 ± 0.5 percent, as extractable fat). Ninety-seven percent of the results fall within 20 percent of the baseline mean and 66 percent of the points fall within two standard errors of the baseline mean. The average of PE samples associated with the 2018, 2019, 2020, and 2021 fish tissue samples was 9.3 percent, which is within ± 2 times the standard error on the baseline mean.

The lipid content data have shown good consistency with respect to the baseline values for each SRM over time.

3 PROPORTION OF AROCLORS IN PCB DATA

TPCB analysis by Aroclors, typically M8082, can be subjective in its reliance upon the discretion of the analyst as to the selection of Aroclors to be reported and quantitated in a sample. As a result, the mixture of Aroclors reported, as well as the sum of Aroclors, can vary among analysts and

from laboratory to laboratory for equivalent samples. The United States Environmental Protection Agency (EPA) closely oversees the analytical program to account for these circumstances. As part of the fish data review, the Aroclor mixture reported by the lab is reviewed. This mixture is expected to be relatively consistent over time unless the pattern of PCBs has changed. Modifications to the environment, like resuspension of PCBs during dredging, can impact the mixture of Aroclors reported. The consistency in PCB pattern is an important consideration in the designation of different periods for the application of the homologue equivalent conversion factor (further discussed in Section 4). Additionally, a subset of samples is analyzed using both an Aroclor-based method and a congener-based method to evaluate differences.

Project data indicate that, since 2004, the proportions of different Aroclors reported in $TPCB_{Aroclor}$ results have varied over time. Figure 3-1 shows the average Aroclor composition detected in fish samples collected by GE from 2004 to 2021. Prior to 2009, Aroclors 1248 and 1254 were reported as the dominant fractions, with minor amounts of Aroclors 1242 and 1260. Aroclor 1221 is essentially absent during this period. However, beginning in 2009, and continuing during dredging, the Aroclor 1221 fraction reported begins increasing and peaks in 2012. After 2012, Aroclor 1221 decreases and then begins to increase again from 2017 to 2021. During each of these periods of Aroclor 1221 fluctuation (2009–2016 and 2017–2021), consistent laboratories were used to analyze fish tissues for Aroclors and congeners (Pace-Schenectady, and Pace-Green Bay/Vista, respectively, Figure 3-1). As a result, the differences in the Aroclor distributions in fish tissues observed during the dredging and post-dredging periods are presumably not due to a change in analytical procedures or an analyst's judgment.

During dredging, fluctuation may have been expected and likely reflects the increased exposure of fish to congeners associated with Aroclor 1221 (more specifically, due to the presence of congener BZ#4, Peak 5 based on GE's modified Green Bay Method [mGBM]) released into the water column when remedial dredging operations started in the Hudson River in 2009. An increase in the proportion of lighter congeners in the water column was extensively observed and documented in the various dredging reports issued by EPA and GE.

As seen in Figure 3-1, the increase in the fraction of Aroclor 1221 being reported in the post-dredging period is due to an increase in the frequency that Aroclor 1221 is reported in fish. Figure 3-2 shows that from 2017 to 2021, when Aroclor 1221 is detected, it consistently makes up approximately 15 percent of the PCB in the sample. Even though the detection frequency is increasing (Panel A), the proportion of Aroclor 1221 in the fish is not increasing (Panel B). Therefore, the observed increase in Aroclor 1221 is due to an increase in the number of samples reported with Aroclor 1221, and not a change in the PCB makeup of the fish. The cause for the increased detections of Aroclor 1221 is not clear and EPA will continue to monitor this trend in the data.

4 MATCHED PAIR ANALYSIS AND DEVELOPMENT OF HOMOLOGUE EQUIVALENT BASIS

The analytical methods used to measure PCB concentrations in fish on the Hudson River have changed over time in response to advances in analytical method technology, laboratory availability, and lessons learned by EPA in studying the fish data collected in the Hudson River. Because variations in analytical methods can confound evaluations of fish-tissue concentrations over time, EPA has developed a method to standardize the reported values of PCBs. This section focuses on the evaluation of the post-dredging fish dataset and the methods used to standardize these results to a homologue equivalent value ($TPCB_{HE}$). The procedure follows the calculation process first described in the Hudson River PCBs Site remedial investigation reports and in Butcher, et al. 1998, and uses $TPCB_{Aroclor}$ and $TPCB_{congener}$ to calculate the $TPCB_{HE}$. Details around the methods used to standardize fish collected during the pre-dredge and dredging period were discussed in the *Second Five-Year Review Report* (EPA, 2019a).

EPA gas chromatography (GC) Aroclor-based PCB analysis Method 8082 (M8082) is one of the most common ways to measure PCBs and is based on detection of industrial Aroclor mixtures. Aroclors are specific mixtures (recipes) of the 209 individual PCB congeners. When M8082 is employed to determine whether a sample includes an Aroclor PCB mixture, the analytical chemist looks for a distinctive gas chromatographic pattern that indicates of one or more Aroclors. There are nine common PCB Aroclor mixtures: 1016, 1221, 1232, 1242, 1248, 1254, 1260, 1262, and 1268. Each exhibits a distinctive gas chromatographic pattern.

Measuring PCBs as Aroclors relies on a consistently fixed (over time) composition of congeners in the mixture. M8082 uses a pattern recognition technique to qualitatively determine whether a given Aroclor mixture is present, after which that portion of the spectrum is quantified using a standard which includes that particular Aroclor. This process references certain well-identified PCB peaks and compares them to the Aroclor standards to quantify Aroclor concentrations in the sample. Provided the sample has not been subjected to conditions that might degrade or change the configuration of congeners in it, quantitation of PCB Aroclors using M8082 indicates the concentrations of Aroclor mixtures and the sum of detected Aroclors in the sample (as opposed to the identity or concentrations of the PCB congeners present). However, if an environmental sample has been subject to degradation, weathering or dichlorination—as is the case with Hudson River fish samples (indeed, all environmental samples)—Aroclor-based analysis may over or underestimate the actual Aroclor-related PCB concentrations. This is because the Aroclor mixture apparent in the environmental sample may no longer reflect the same suite of congeners or internal Aroclor standard to which it is being compared.

In such cases, even if the PCB congeners that comprise the original Aroclor mixture are present in the environmental sample, the specific PCB Aroclor concentration may be reported inaccurately due to a lack of pattern recognition or the mixture may inadvertently be quantified as a different

Aroclor (e.g., when environmental degradation or weathering has occurred). This is especially true when more than one Aroclor is determined to be present. As the multiple Aroclors in a mixture may contain some of the same PCB congeners, there is a possibility that "double counting" of these congeners (and thus the Aroclors they make up) could also occur. Both EPA's *Data Evaluation and Interpretation Report* (EPA, 1997) and Frame et al. (1996) document the presence of overlapping Aroclor spectra. However, since Aroclor-based analyses do not quantitate all PCB-related peaks in the sample chromatogram, it is also possible that Aroclor-based analysis can under-report PCB concentrations. Thus, analytical results between Aroclor standards and environmental samples may not be directly comparable due to potential differences between the congeners in the Aroclor standard and the congeners in the environmental sample.

A robust QA/QC program has been developed to confirm that PCB levels in Hudson River fish tissues based on Aroclor analytical results are consistently reported. One component of the Project QA/QC program involves analyzing the same fish-tissue sample using both the Aroclor method 8082 and a congener specific method and tracking the ratio of the results over time. This paired analysis approach provides confirmation that the pattern of PCBs in the fish is consistent through time and that the approach being used to convert $TPCB_{Aroclor}$ data to a homologue equivalent basis is stable (or requires adjustment).

For fish samples from 2004 to 2016, GE used the mGBM as a congener-based analytical technique. From 2017 to 2021, GE used M1668. Additional details about mGBM can be found in Appendix 5 of the *Second Five-Year Review Report* (EPA, 2019a). M1668 determines the concentrations of individual congeners by a sophisticated analytical method using high-resolution gas chromatography/high-resolution mass spectrometry (HRGC/HRMS) combined with isotope dilution techniques. M1668 identifies the presence and concentration of each of the 209 PCB congeners in a sample. Because M1668 does not involve the same level of laboratory or analyst interpretation of chromatograph peaks, the method is more comparable over time and between laboratories.

As discussed above, the subset of samples analyzed for congeners and Aroclors as matched pairs provides EPA with a way to convert the Aroclor results reported for all fish samples to a consistent basis ($TPCB_{HE}$[3]). In addition, this subset of data provides an additional level of analytical program quality control and affords EPA a consistent basis for observing changes in PCB patterns over time. Table 4-1 indicates the number of fish tissue samples analyzed for the Project since dredging

[3] $TPCB_{HE}$ is an estimate of the total PCB concentration that would be obtained if the sample were analyzed by a homologue or congener-based methodology. A number of methods have been employed for the Hudson River PCBs Site to measure $TPCB_{HE}$ concentrations directly, including mGBM and M1668. These methods are considered more accurate since they report concentrations relative to homologue- or congener-based standards and do not approximate the PCB distribution as one or more industrial Aroclor mixtures. Over the years of study, the matched pairs of homologue- (or congener-) based analyses and analyses by M8082 have been used to develop conversion factors to convert M8082 results to their $TPCB_{HE}$ equivalents.

was completed (2016 to 2021) using Aroclor-based and congener-based methods, and the laboratories that conducted the analyses. A detailed discussion of the chromatographic resolution limits of PCB Aroclor results as well as the application of PCB Aroclor and PCB congener analytical approaches to Hudson River fish samples are provided in Section 1.2 of Appendix 5 of the *Second Five-Year Review Report* (EPA, 2019a).

To provide continuity in the assessment of changes in PCB concentrations over time, contemporary Project data need to be comparable to these historical $TPCB_{HE}$ data. The geometric mean of the ratios of measured $TPCB_{congener}$ to measured $TPCB_{Aroclor}$ values (i.e., $TPCB_{congener}/TPCB_{Aroclor}$) from matched sample pairs has historically been shown to be a reliable factor for converting $TPCB_{Aroclor}$ results to $TPCB_{HE}$ data because of its simplicity and insensitivity to outlier values as compared to a simple linear regression. $TPCB_{HE}$ is calculated by multiplying the $TPCB_{Aroclor}$ concentration by the conversion factor. For any sample with an $TPCB_{congener}$ result, $TPCB_{HE}$ is equal to $TPCB_{congener}$ concentration. Table A3-5, in Appendix 3 provides the equations used to convert UHR $TPCB_{Aroclor}$ fish tissue sample results to $TPCB_{HE}$ equivalents. Additional details on $TPCB_{Aroclor}$ to $TPCB_{HE}$ conversion can be found in Appendix 5 of the *Second Five-Year Review Report* (EPA, 2019a).

4.1 Conversion Factor Analysis in the Upper Hudson River

The *Second Five-Year Review Report* relied on all project data (UHR and Lower Hudson River [LHR]) in developing the conversion factors to convert $TPCB_{Aroclor}$ to $TPCB_{HE}$ (EPA, 2019a). Since the last five-year review, the LHR has been designated a separate Operable Unit (OU) 5. As a result, additional sampling and analysis are being completed in the LHR. Data to date suggest that the PCB patterns in LHR fish may differ from those observed in the UHR, although the available data is limited at this time. The additional data collection in the LHR will make it possible to develop a unique conversion factor. There were limited sets of $TPCB_{Aroclor}/TPCB_{congener}$ matched pairs for the LHR and a unique conversion factor would not have been possible. Therefore, the conversion factors applied in this five-year review use exclusively UHR data, and the results in this appendix may vary slightly from those presented in the *Second Five-Year Review Report* (EPA, 2019a).

Figure 4-1 compares the geometric means of the $TPCB_{congener}$ to $TPCB_{Aroclor}$ ratio with and without the LHR samples. The 95-percent confidence limits on the geometric mean are calculated using a bias-corrected and accelerated (BCA) bootstrap method. Geometric means based on combined UHR and LHR data are shown in blue, and geometric means based on UHR data only are shown in green. The total number of samples for each geometric mean are included at the top of the plot.

Comparing the confidence limits on the geometric means shows that all the confidence limits overlap, indicating that they are not statistically distinguishable. Even though the 2016 geometric mean ratios shown on the figure are not statistically different from one another, 2016 shows the

largest change in the ratio. For 2016, the geometric mean ratios shown on the figure are not statistically different from one another. These two geometric means are based on the 2016 data but previously the conversion factor for 2004-2008 was applied to the 2016 dataset because no significant difference was observed between the 2004-2008 and 2016 datasets. The removal of the eight LHR samples from the 2016 dataset shifts the geometric mean down, indicating that the removed LHR samples had a higher $TPCB_{congener}$ to $TPCB_{Aroclor}$ ratio. For the current Five-Year Review, a 2016-based conversion factor was applied to the 2016 data, rather than the 2004 to 2008 conversion factor.

Because the geometric means all agree within predefined error bounds, the updated conversion factors based only on UHR data were applied across the dataset. The minor differences in the conversion factors suggest that there may be slight differences in the PCB patterns between the UHR and the LHR. However, the limited number of samples from the LHR makes it difficult to draw any firm conclusions about the PCB patterns.

4.2 Conversion Factor Analysis in Post-Dredging data

This section presents the procedure used to calculate the $TPCB_{HE}$ concentrations in the post-dredging period. It is anticipated that the conversion factor in the post-dredging period will be stable with additional data, unless there is a change in either the analytical methods or laboratories, or if there is a shift in the PCB patterns observed in the fish.

As discussed in the previous section, an updated conversion factor has been developed for 2016 post-dredging data for this five-year review. There was a change in GE's contracted congener method laboratory from Pace Schenectady Laboratory to Vista Analytical Laboratory and a change in method from mGBM to M1668 from 2016 to 2017. Because of this, 2016 matched pair results cannot be combined with other matched pairs data to generate a single conversion factor for the post-dredging period. Post-dredging $TPCB_{Aroclor}$ data, from 2017 to 2021, have been converted to $TPCB_{HE}$ based on geometric mean ratios derived from matched-pair samples of fish collected in 2018, 2020, and 2021. All analyses presented in Appendix 3 combined the three years of matched-pair data to generate a single conversion factor for the data. When the matched pairs are compared across the three years, it appears the geometric mean ratio may be declining. However, as will be discussed further in this section, this observation is due to annual variability and not a true downward trend as there has not been a notable shift observed in PCB patterns, labs, or methods. Note that with additional years of data the conversion factor will need to be adjusted.

The initial step in developing the post-dredging conversion factor is to evaluate each year of matched pairs data separately and then determine whether the data is comparable and should be combined into a single dataset. Twenty-five 2018-collected fish samples were analyzed using M8082 and M1668. These matched pairs represent seven different species collected from Upper Hudson River Section (RS) 1, RS 2, and RS 3. For 2020 samples, 33 matched pairs were analyzed

using M8082 and M1668. The 2020 samples represent eight different species also collected from RS 1, RS 2, and RS 3. For 2021 samples, 35 matched pairs were analyzed using M8082 and M1668. The 2021 samples represent five different species collected from the same general areas as the 2020 samples.

To develop a conversion factor using matched pair data, it is important that the paired data is representative of the dataset as a whole. As discussed above, the paired data was selected from all three river sections and across multiple species. It is also important that the paired data represent the full range of concentrations observed in the dataset. Figure 4-2 presents the range of $TPCB_{Aroclor}$ concentrations for the matched pairs samples obtained in 2018, 2020, and 2021. In each panel of Figure 4-2, samples selected for M1668 analysis (matched pairs) are noted by the red markers, whereas the samples with $TPCB_{Aroclor}$ results are shown by the small black dots. Note that because of great numbers of $TPCB_{Aroclor}$ results, the black dots symbols appear to form a nearly continuous line.

The data show that the matched pair results range from 0.19 mg/kg-ww to 17 mg/kg-ww $TPCB_{Aroclor}$ in 2018 (the upper 80 percent), 0.19 to 13 mg/kg-ww $TPCB_{Aroclor}$ in 2020 (the upper 80 percent), and 0.13 to 40 mg/kg-ww $TPCB_{Aroclor}$ in 2021 (the upper 85 percent). Based on these distributions, the range of concentrations is considered appropriate for developing a conversion factor from $TPCB_{Aroclor}$ to $TPCB_{HE}$.

Figure 4-3 presents scatter plots of $TPCB_{congener}$ concentrations as a function of $TPCB_{Aroclor}$ concentrations based on matched pairs from the 2018 (Panel A), 2020 (Panel B), and 2021 (Panel C) samples.

Panel A of Figure 4-3 indicates that in 2018, $TPCB_{congener}$ concentrations were strongly correlated with $TPCB_{Aroclor}$ results (log-transformed correlation coefficient is 0.91 with a p-value < 0.0001). For the 2018 data, the sample ratios of the 25 matched pairs varied from 0.57 to 2.93 with a geometric mean of 0.92. The 95-percent confidence limits on the geometric mean ratio for 2018 matched pairs are 0.80 to 1.1 based on a 10,000-replicate bootstrap analysis of the matched pairs. Panel B indicates that $TPCB_{congener}$ and $TPCB_{Aroclor}$ concentrations also exhibit a strong correlation for the 2020 samples. The correlation coefficient on log-transformed concentration data is 0.88 (p-value < 0.0001) for the 2020 data. For the 2020 data, the sample ratios of the 33 matched pairs range from 0.21 to 3.90 with a geometric mean of 0.75. The 95-percent confidence limits on the geometric mean ratio are 0.64 to 0.91, based on a 10,000-replicate bootstrap analysis of the matched pairs. Panel C of Figure 4-3 shows that 2021 $TPCB_{congener}$ and $TPCB_{Aroclor}$ concentrations show a weaker correlation compared to the others. The correlation coefficient on log-transformed concentration data is 0.86 (p-value < 0.0001) for the 2021 samples. For the 2021 data, the sample ratios of the 35 matched pairs range from 0.19 to 3.50 with a geometric mean of 0.68. The 95-percent confidence limits on the geometric mean ratio are 0.56 to 0.86, based on a 10,000-

replicate bootstrap analysis of the matched pairs. The ratio-based regression line and its confidence limits are plotted on Figure 4-3.

From 2018 to 2021, the geometric mean ratio appears to be declining. However, historical data show that the geometric mean fluctuates year by year and there are times when the ratio appeared to be declining in a relatively brief time period. Figure 4-4 shows the changes in the geometric mean ratio from 2004 to 2021. As shown in the figure, the geometric mean ratio fluctuates over time with periods of increases and decreases. Figure 4-5 shows that when the three years of matched pair data (2018, 2020, and 2021) are treated as separate groups (boxplots in left panel), they are not statistically different from one another. Figure 4-5 also shows the results of comparing these data using a Tukey Kramer means comparison (circles in right panel). Generally, in a Tukey Kramer test, if the circles overlap, the means are not statistically different. Note that since the data were log-transformed, the means compared by Tukey Kramer test are equivalent to the geometric means. As discussed in Section 1, the Aroclor NIST data show the Aroclor technique is consistent through time, supporting grouping the data together for use as a single conversion factor.

There is no apparent reason for the observed differences in the geometric mean ratios in the 2018, 2020, and 2021 data. There were no changes in laboratories contracted or analytical methods from 2017 to 2021 that could drive such a change. In addition, because the $TPCB_{Aroclor}$ to $TPCB_{congener}$ conversion factor has declined based on the three years of matched-pair data (from 0.92 to 0.75, and then to 0.68), applying different conversion factors effectively introduces an apparent 10 percent annualized rate of decline in $TPCB_{HE}$ concentrations across years if actual concentrations are unchanged. Additional years of data will be necessary to confirm that there is no real decline in the conversion factor, at this point one conversion factor will be used for 2017 to 2021.

When the results from 2018, 2020, and 2021 are combined, the geometric mean ratio is 0.77 with a 95-percent confidence limits from 0.69 to 0.86. Equation 1 presents the formula for converting $TPCB_{Aroclor}$ to $TPCB_{HE}$ from the combined 2018, 2020, and 2021 matched pair results.

$$\text{Combined 2018, 2020, and 2021 data: } TPCB_{HE} = 0.77 \times TPCB_{Aroclor} \quad \text{(Eq.1)}$$

5 OPTIMIZING THE CALCULATION OF THE SPECIES-WEIGHTED AVERAGE

5.1 Original ROD Method

This section discusses the evolution of the species-weighted average approach and how it was adapted based on species availability and with the goal of reducing variance. The species-weighted average approach described in the Record of Decision (ROD), (used in the *Second Five-Year Review Report*) represented a simple numerical composite of fish tissue analyses used to represent the response of the river to the remedial action over time (EPA, 2002; EPA, 2019a). The species-weighted average calculation design was originally based on three fish species (largemouth bass,

brown bullhead, and yellow perch). These species were included in the average based on historical monitoring conducted by NYSDEC, ROD modeling considerations, and the results of a creel survey of Hudson River anglers. This method involved first computing a mean concentration by species across all samples within a RS. These individual species mean concentrations were then weighted by the species factors to yield "RS species-weighted averages" and then by RS length to generate an "UHR species and length-weighted average." The species-weighted average using the original ROD methodology was calculated for 2016 and was reported in the *Second Five-Year Review Report* for 2016 (see Approach 1 in Section 5.4) (EPA, 2019a).

Due to changes in the river since dredging, the populations of largemouth bass appear to be in flux across UHR habitats. While all the original species (largemouth bass, brown bullhead, and yellow perch) can be found in each RS, they may not forage or be found at each station within each reach. For example, largemouth bass is not typically observed in Reach 7. In addition, there are not enough largemouth bass collected at the stations within RS 1 and RS 2 to be representative of each river section. Because of this, the original ROD methodology is no longer used.

5.2 Adapting to Changes in Species Availability

The species collected from 2004 to 2020 included varying numbers of smallmouth bass and yellow bullhead, which were collected interchangeably for largemouth bass and brown bullhead, respectively. Due to differences in species availability within reaches and river sections, smallmouth and largemouth bass concentration data were combined as "black bass," and yellow and brown bullhead concentrations were combined as bullhead (or ictalurids) in the calculation of the UHR species-weighted average. There were no species substitutions for yellow perch in the UHR. From 2017 to 2020, the species-weighted average was calculated using black bass, ictalurids and yellow perch. The results of the calculation were presented in Community Advisory Group meetings (see Approach 2 in Section 5.4).

Switching between species and among stations would be of little consequence to the species-weighted average calculation if the species involved were equivalent or the exposure at all stations was equal. Even though largemouth and smallmouth bass represent black bass, it is important to not group these species together as they have different PCB body burdens for similar levels of exposure—with smallmouth bass generally higher in PCB concentrations in any river section where both were sampled. A similar difference may exist for the bullhead species, but there is insufficient data to make this comparison.

The degree of variation among species across fish collections over time is illustrated in Figures 5-1 to 5-6. Figures 5-1 to 5-3 show the proportion of largemouth and smallmouth bass collected from each station and river section from 2004 to 2020. Figure 5-1 shows that in RS 1, smallmouth bass has been the dominant species collected at TD1 to TD4, but largemouth bass has been the dominant species collected at TD5. In RS 2 (Figure 5-2), smallmouth bass dominates all stations except for

ND5, where a mix of largemouth and smallmouth bass has been collected. The RS 3 (Figure 5-3) ratio of largemouth to smallmouth collected at most stations has changed since the dredging period, but overall RS 3 collection has been dominated by largemouth bass. In addition, there have been fewer smallmouth bass caught at RS 3 stations since 2016.

Figures 5-4 to 5-6 show the proportion of brown and yellow bullhead collected from each station and river section. Brown bullhead is the dominant species collected across all stations from 2004 to 2020. However, collection of yellow bullhead appears to occur randomly, and can represent the entire catch at some stations for a given year (see ND2 in 2020 for RS 2, for example). Like smallmouth bass, yellow bullhead was not considered in the original species-weighted average calculation design. But unlike smallmouth bass, yellow bullhead has not been collected frequently or consistently enough at any given station to warrant inclusion in the species-weighted average estimate. In general, annual collections of brown bullhead have resulted in sufficient numbers to provide consistency with the original ROD methodology.

Post-dredging sediment investigations have demonstrated variations in surface concentrations within each reach, these variations would be expected to yield different body burdens across different stations. Yellow perch were specified in the original species-weighted average design and have been consistently collected since 2004. However, post-dredging results for yellow perch show significant variability from station to station within a river section, suggesting localized exposures. Examining these data by station across RS 1 shows that the five stations are not equivalent.

A statistical comparison of means based on Tukey Kramer is presented in Figure 5-7. This figure illustrates that yellow perch geometric mean concentrations differ statistically across the RS 1 stations in from 2016 to 2020. On this figure, TD3 has the highest geometric mean concentration as indicated by the highest circle on the right panel of the figure. TD5 has the lowest geometric mean concentration and is indicated by the lowest circle (generally, if the circles overlap, the means are not statistically different). Consistent sampling of stations minimizes the variability across stations. Variability between stations within a species and variability between similar species represent two sources of uncertainty in the species-weighted average that are better controlled with improved sampling design and calculation procedures, as described below.

5.3 Adjusting the Species-Weighted Average to Reduce Variance

To avoid the potential impacts of variable species collection within a RS, or unequally weighted station sample sizes on the species-weighted average estimates, the species collection targets and the calculation were adjusted in 2021 (Appendix 3, Table A3-3). Although the adjustments in sampling collection targets will help reduce variability in the future, it is important that the species-weighted average calculation reflects these known sources of variability. To account for these

known sources of variability, the species-weighted average for this five-year review has been calculated using the following methodology:

- Averaging on a Station Basis: The data for each station is averaged by species to yield an arithmetic mean for each species-station pair. A single arithmetic average is produced for each species-station pair, regardless of how many samples of the species were obtained at that station.
- Averaging on a River Section Basis: The species-station arithmetic means are further averaged together to yield an arithmetic mean for each species for each river section.
  - For yellow perch and brown bullhead, species-river section arithmetic means are generated by averaging the species-station means for each species.
  - For all but one station, a single black bass species (either largemouth bass or smallmouth bass) was chosen to represent each station. As an example, stations TD1 through TD4 are represented by smallmouth bass and TD5 is represented by largemouth bass. ND5 (in RS 2) has historically yielded approximately equal amounts of smallmouth and largemouth bass, so both species are collected and weighted equally to contribute to the black bass average for that station. Table 5-1 presents the weighting factors for each species to yield the station-scale equal weighting approach that leverages existing data collection and adjusts results to account for imbalances in sample size across stations. Smallmouth bass and/or largemouth bass (depending on the station) concentrations from each station are combined with an arithmetic mean to generate a river section mean for black bass.
- Weighting by Species: Each species-river section mean is weighted by species, 44 percent brown bullhead, 47 percent black bass, and 9 percent yellow perch. The species weights are derived from ROD modeling considerations and the results of a creel survey conducted on Hudson River anglers (EPA, 2000). Each species of fish has a characteristic PCB concentration, and the average concentration an angler consumes will, in part, be based on the relative percentages of the different fish species consumed. The weighted groups are combined to generate a species-weighted average estimate for each river section.
- Weighting by River Section: To determine the river wide species weighted average, each river section estimate is weighted by river section length. RS 1 (Thompson Island Pool, River Mile [RM] 194.8–188.5) was weighted at 15.4 percent, RS 2 (Fort Miller and Northumberland Pools, RM 188.5–183.4) was weighted at 12.5 percent and RS 3 (the Stillwater, Mechanicville, Lock 2, and Waterford pools, RM 183.4–153.9) was weighted at 72.1 percent.

5.4 Comparison of Species-Weighted Average Methodologies

The approach to calculating the UHR species-weighted average has been modified since the *Second Five-Year Review Report* (EPA, 2019a). These refinements were necessary as the original three species that were the focus of the ROD could no longer be collected at enough stations to represent the entire river section (EPA, 2002). These modifications are designed to help reduce the introduction of variance in the calculation and to be able to detect trends in fish-tissue PCB levels over time. Three iterations were compared to evaluate how these changes affected species-weighted average values.

Approach 1

- Original methodology described in the ROD and calculated for the Second Five-Year Review.
- Species: largemouth bass, brown bullhead and yellow perch.
- Method: The data for each species is first averaged on a river section basis and then combined to generate an average for the UHR.

Approach 2

- Modified ROD method presented during Community Advisory Group meetings.
- Species: black bass (largemouth bass and smallmouth bass), Ictalurid (brown bullhead and yellow bullhead), and yellow perch.
- Method: The data for each species group is first averaged on a river section basis and then combined to generate an average for the UHR.

Approach 3 (Results of which are reported in Appendix 3)

- Stratified method.
- Species: largemouth bass, smallmouth bass, brown bullhead, and yellow perch.
- Method: The data for each species is first averaged on a station basis, then on a river section basis and then combined to generate an average for the UHR.

Figure 5-8 shows the yearly species-weighted average results for 2016 through 2021 for the three iterations discussed above. The 95-percent confidence limits on the mean for each year overlap, indicating that the two methods do not yield statistically different results.

The species-weighted mean values obtained by the three approaches always agrees within the error, indicating that the approach does not change the interpretation. Additionally, Approach 3 recognizes and addresses the "hidden" sources of variance arising from variable sample counts by species and station. In developing Approach 3, the EPA has assembled a procedure that minimizes

the impacts of past sample collection variations and will minimize those that may arise in the future.

6 REFERENCES

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Tables

Figures

Tables

Table 2-1
Comparison of the Sums of NIST Congener Certified

Date of Congener NIST Analysis	SRM	Sum of PCB Congeners Certified Values (ng/g)	Sum of Measured PCB Congeners that have Certified Values (ng/g)	Percent Difference
NIST 1946				
6/4/2019	NIST 1946	883	750	-15%
1/28/2021	NIST 1946	883	953	8%
1/24/2022	NIST 1946	883	878	-1%
NIST 1947				
9/17/2019	NIST 1947	1,686	1,624	-4%
11/30/2020	NIST 1947	1,686	1,815	8%
2/4/2022	NIST 1947	1,686	1,618	-4%

Note

1. Certified values are available for a subset of congeners, these values can be summed to generate the sum of PCB congener certified values and then compared against the corresponding sum of the PCB congeners measured by the laboratory.

Table 2-2
$TPCB^{congener}$ to $TPCB^{Aroclor}$ Ratio with NIST samples

Date Range of Aroclor NIST Analysis	Date of Congener NIST Analysis	SRM	TPCB 209 Congeners (mg/kg)	TPCB Aroclor Average per Period (mg/kg)	Ratio of TPCB Congener to TPCB Aroclor
NIST 1946					
May to August 2019	6/4/2019	NIST 1946	0.95	1.6	0.59
July, August, November 2020	1/28/2021	NIST 1946	1.2	1.7	0.71
August to October 2021	1/24/2022	NIST 1946	1.1	1.8	0.62
NIST 1947					
May to August 2019	9/17/2019	NIST 1947	2.0	2.3	0.89
Nov 2019 to Jan 2020	9/17/2019	NIST 1947	2.0	2.4	0.83
July, August, November 2020	11/30/2020	NIST 1947	2.2	2.4	0.95
July to November 2021	2/4/2022	NIST 1947	2.0	2.6	0.78

Notes:

1. The NIST 1947 congener sample from 9/17/2019 appears on the table twice because it is applied to two sets of Aroclor samples, May to August 2019 and Nov 2019 to Jan 2020.
2. TPCB 209 congeners was calculated using sum of all detected congeners.
3. TPCB Aroclor was calculated using sum of all detected Aroclors.

Table 4-1
Hudson River PCB Superfund Site Post-Dredging Data by Laboratory Analytical Method and Year Since 2016

PCB Data Type:	Fish Congener Results				Fish Aroclor Results		
Data Source:	GE[1]		NYSDEC	Total Number of Fish Congener Results	GE		Total Number of Fish Aroclor Results
Analytical Method:	mGBM	USEPA Method 1668C	USEPA Method 1668C		SW846 Method 8082A		
Laboratory: / Year	Pace-SC	Vista	Pace-GB		Pace-SC	Pace-GB	
2016	26			26	460		460
2017			232	232		460	460
2018		25		25		463	463
2019				0		604	604
2020		33		33		460	460
2021		35		35		417	417
Total Number of Samples	**26**	**93**	**232**	**351**	**460**	**2,404**	**2,864**

Notes:
1. Congener data from GE also has a matching Aroclor result.
2. Lab codes used in this table:

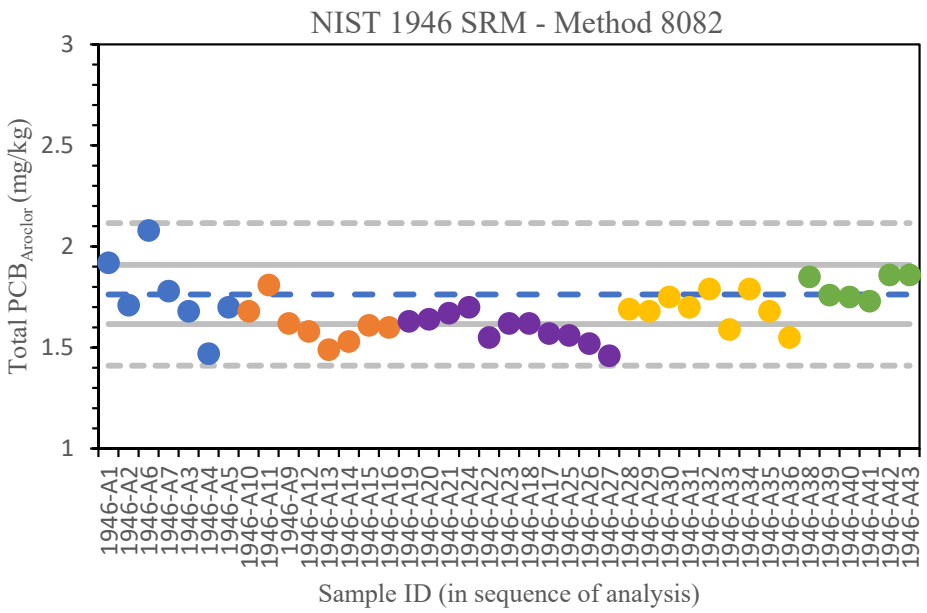
Pace-SC: Pace Schenectady
Pace-GB: Pace Green Bay
Vista: Vista Analytical Laboratory
mGBM: modified Green Bay Method
USEPA Method 1668C: Congener based analytical method
SW846 Method 8082A: Aroclor based analytical method

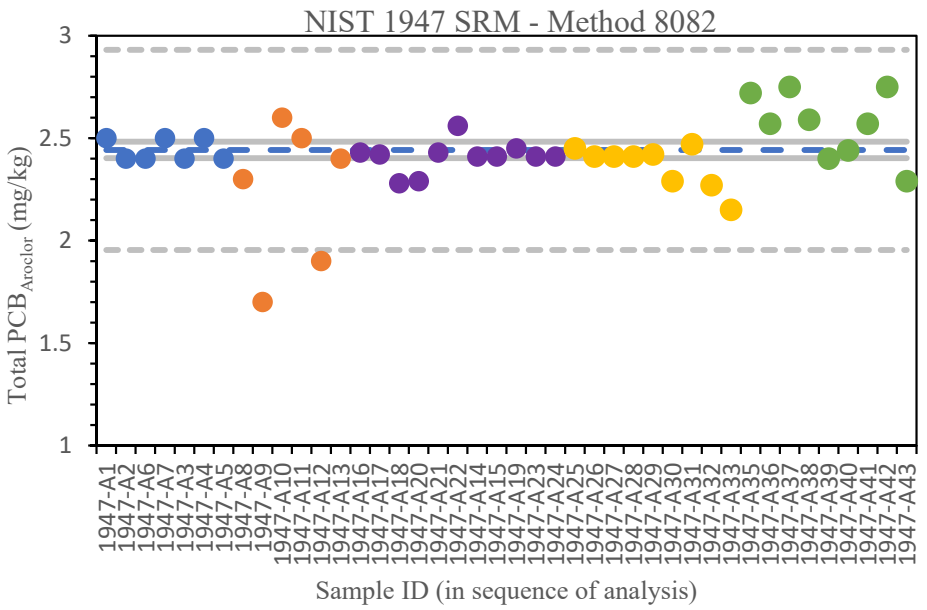
Table 5-1
Equal Station Weighting Factors for Species-Weighted Average

River Section	Station	Black Bass		Brown Bullhead Station Weight	Yellow Perch Station Weight
		Largemouth Bass Station Weight	Smallmouth Bass Station Weight		
RS 1	TD1	0	1	1	1
	TD2	0	1	1	1
	TD3	0	1	1	1
	TD4	0	1	1	1
	TD5	1	0	1	1
RS 2	ND1	0	1	1	1
	ND2	0	1	1	1
	ND3	0	1	1	1
	ND5	0.5	0.5	1	1
RS 3	SW1	1	0	1	1
	SW2	1	0	1	1
	SW3	1	0	1	1
	SW4	1	0	1	1
	SW5	1	0	1	1

Notes:
1. Station weights for largemouth bass and smallmouth bass are based on a review of historical fish collection data.
2. River Section 1 (Thompson Island Dam Pool, TD) fish monitoring station IDs and approximate river mile ranges: TD1: RM 193.7-194.7, TD2: RM 192.7-193.2, TD3: RM 191.6-192.1, TD4: RM 190.5-191, TD5: RM 189.5-190.5.
3. River Section 2 (Northumberland Dam Pool, ND) fish monitoring station IDs and approximate river mile (RM) ranges: ND1: RM 187-188, ND2: RM 186.3-186.8, ND3: RM 185.3-186.1, ND5: RM 183.7-183.9.
4. River Section 3 (Stillwater Pool, SW) fish monitoring station IDs and approximate river mile (RM) ranges: SW1: RM 181.5-182.5, SW2: RM 178-178.6, SW3: RM 177.7-178, SW4: RM 172-173, SW5: RM 168.3-169.6

Figures





Legend

May '19 (Baseline) | May-Aug '19 (2018 fish) | Nov '19-Jan '20 (2019 fish) | Jul-Nov'20 (2020 fish) | Aug-Nov'21 (2021 fish)

NIST 1946 SRM Application	$TPCB_{Aroclor}$ Average (mg/kg)	Standard Error $TPCB_{Aroclor}$
$TPCB_{Aroclor}$ Baseline Mean	1.8	0.07
2018 Fish PE Samples	1.6	0.03
2019 Fish PE Samples	1.6	0.02
2020 Fish PE Samples	1.7	0.03
2021 Fish PE Samples	1.8	0.02

Baseline Mean
± 2*Standard Error on the Baseline Mean
± 20% on the Baseline Mean

Notes:

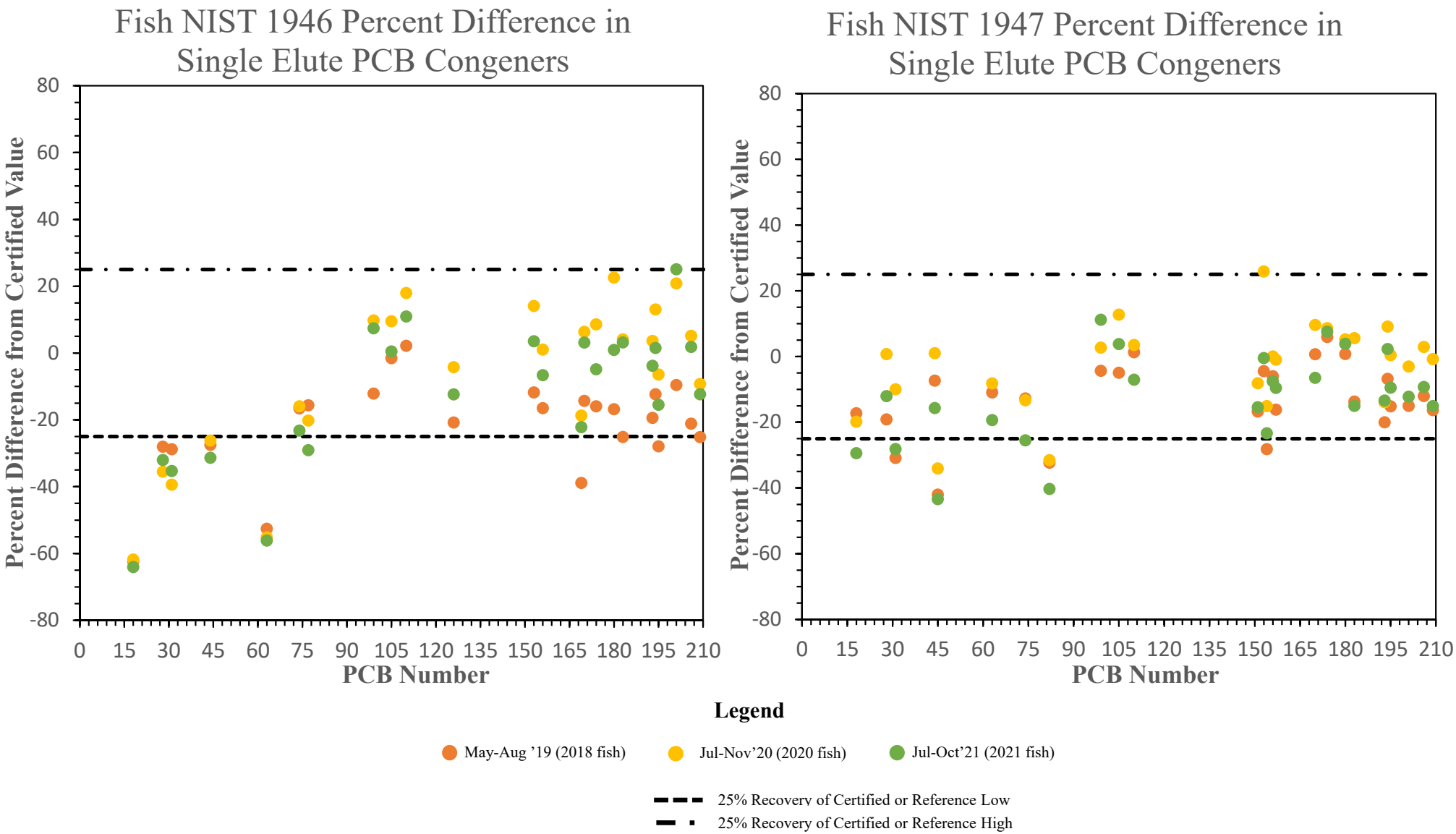
1. Only Aroclors 1254 and 1260 were reported as detected in NIST SRMs analyzed by GE via M8082.
2. $TPCB_{Aroclor}$ does not have a NIST certified value.

NIST 1947 SRM Application	$TPCB_{Aroclor}$ Average (mg/kg)	Standard Error $TPCB_{Aroclor}$
$TPCB_{Aroclor}$ Baseline Mean	2.4	0.02
2018 Fish PE Samples	2.2	0.15
2019 Fish PE Samples	2.4	0.02
2020 Fish PE Samples	2.4	0.04
2021 Fish PE Samples	2.6	0.05

NIST SRM Performance Evaluation Sample Results: $TPCB_{Aroclor}$ (mg/kg)

Figure 2-1

July 2024



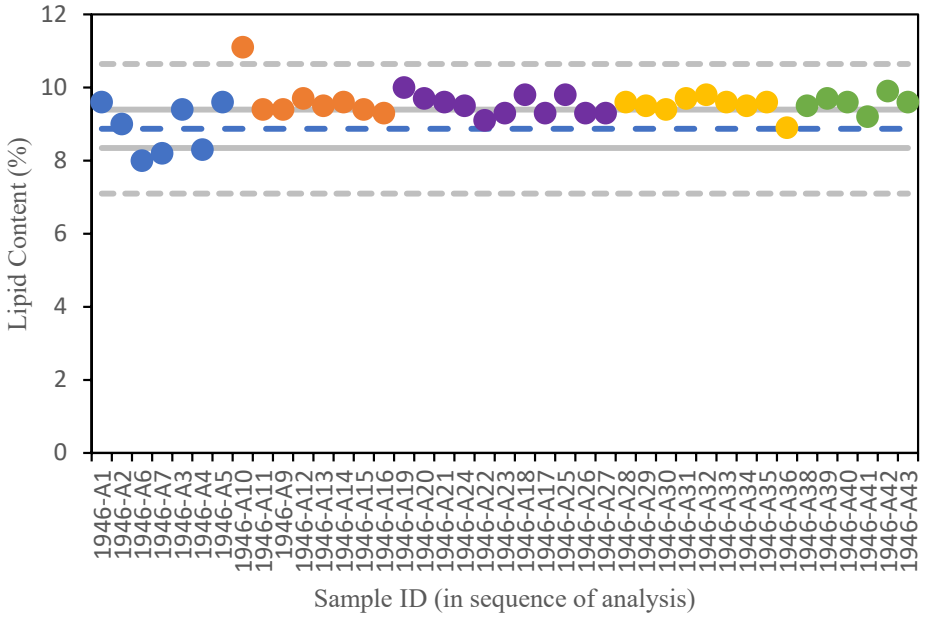
Note:
1. This plot does not include any coeluted congeners
2. Baseline samples are not needed for the NIST Congener samples because there are certified or reference values for a subset of congeners.

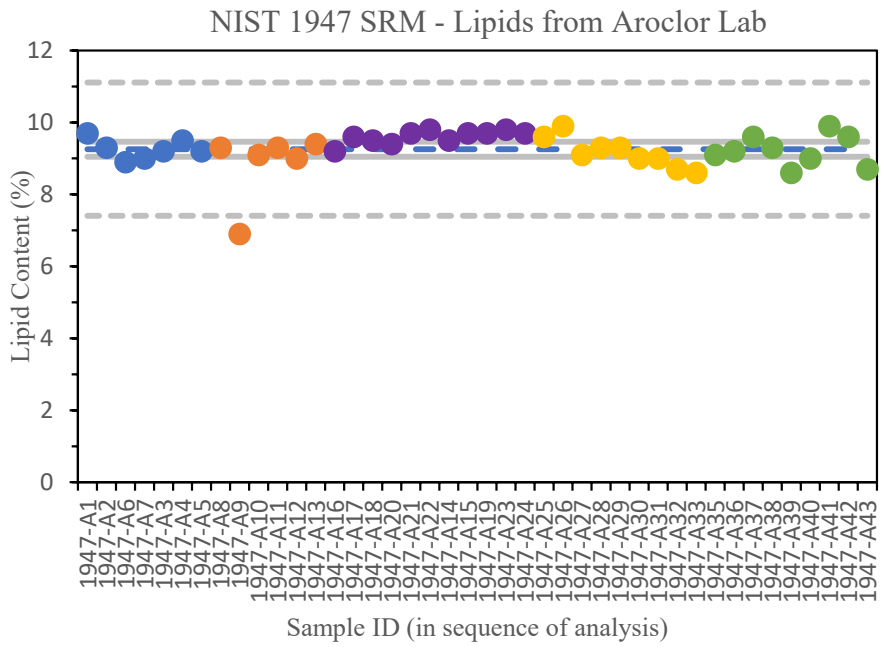
NIST SRM Performance Evaluation Sample Results: Single Elute PCB Congeners Percent Difference

Figure 2-2

July 2024

Draft





Legend

May '19 (Baseline) · May-Aug '19 (2018 fish) · Nov '19-Jan '20 (2019 fish) · Jul-Nov'20 (2020 fish) · Jul-Oct'21 (2021 fish)

Baseline Mean

± 2*Standard Error on the Baseline Mean

± 20% on the Baseline Mean

NIST 1946 SRM Application	Percent Lipid Average	Standard Error Percent Lipid
Percent Lipid Baseline Mean	8.9	0.26
2018 Fish PE Samples	9.7	0.21
2019 Fish PE Samples	9.5	0.09
2020 Fish PE Samples	9.5	0.09
2021 Fish PE Samples	9.6	0.09

Note:

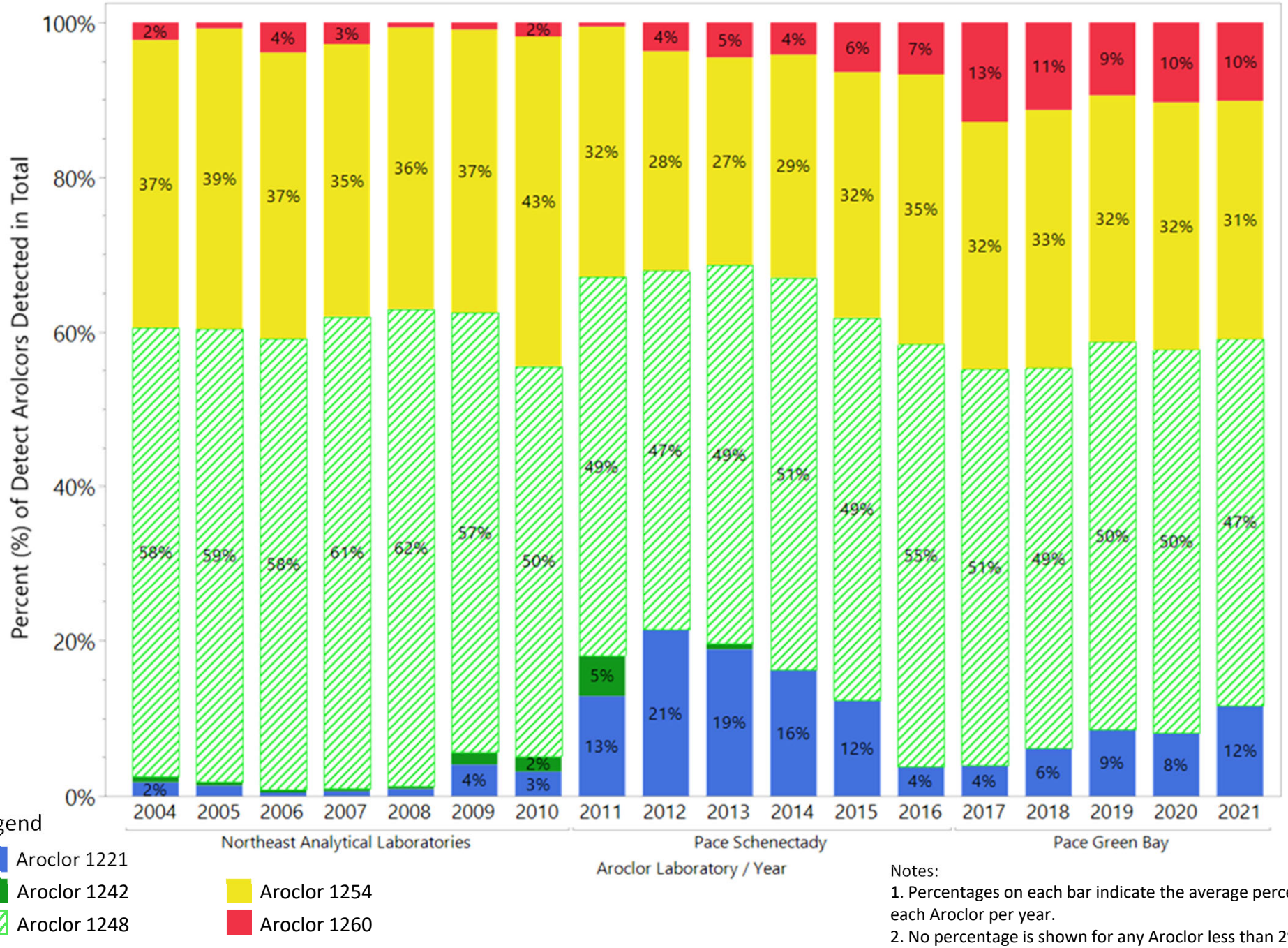
- The Extractable Fat Certified Value Range for the NIST 1946 SRM is 10.17 +/- 0.48
- The Extractable Fat Certified Value Range for the NIST 1947 SRM is 10.4 +/- 0.5

NIST 1947 SRM Application	Percent Lipid Average	Standard Error Percent Lipid
Percent Lipid Baseline Mean	9.3	0.10
2018 Fish PE Samples	8.8	0.39
2019 Fish PE Samples	9.6	0.06
2020 Fish PE Samples	9.2	0.14
2021 Fish PE Samples	9.2	0.14

NIST SRM Performance Evaluation Sample Results: Percent Lipid

Figure 2-3

July 2024

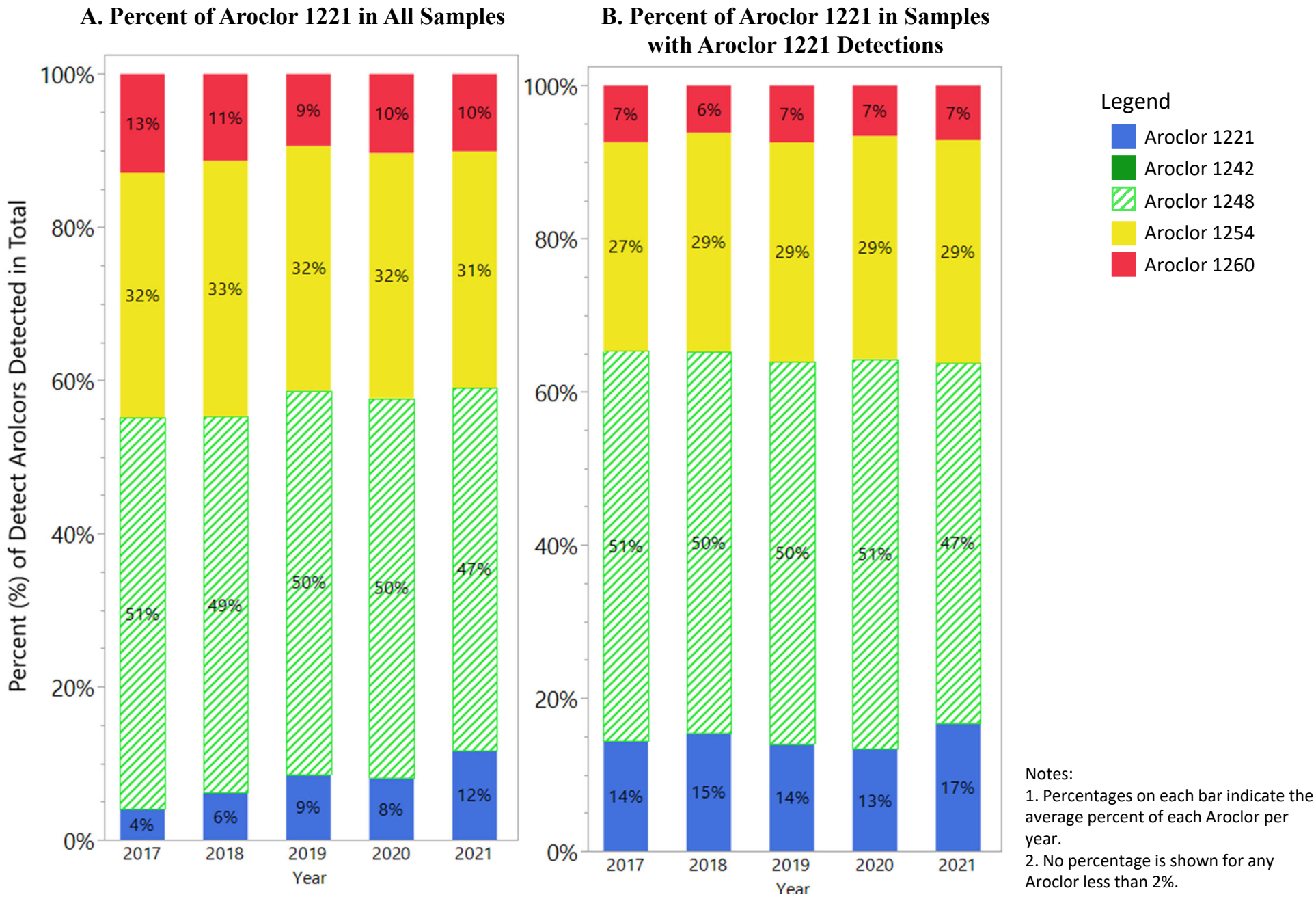


Notes:
1. Percentages on each bar indicate the average percent of each Aroclor per year.
2. No percentage is shown for any Aroclor less than 2%.

Average Aroclor Composition in Fish by GE Laboratories, 2004 to 2021

Figure 3-1

July 2024

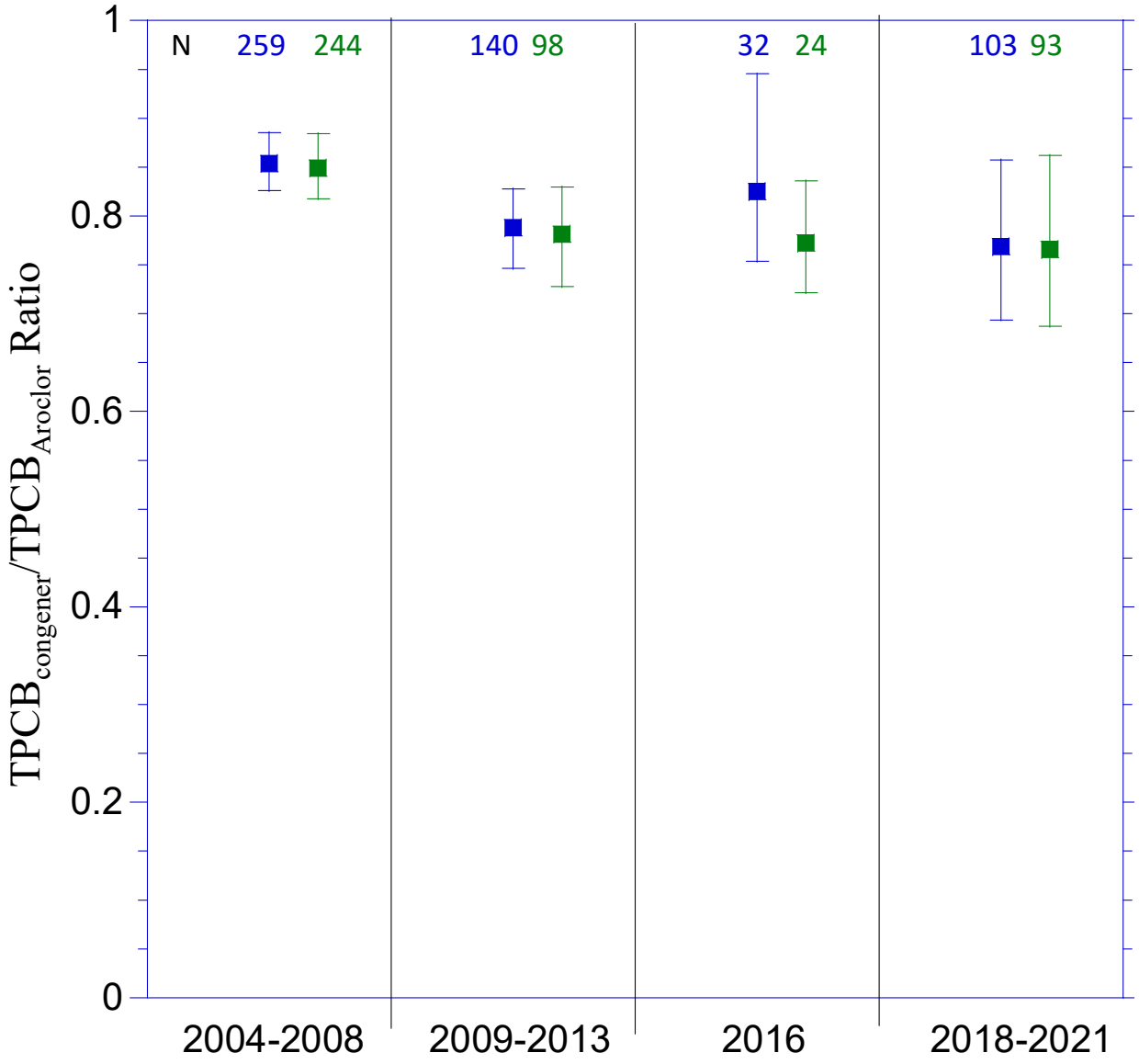


Notes:
1. Percentages on each bar indicate the average percent of each Aroclor per year.
2. No percentage is shown for any Aroclor less than 2%.

Changes in Aroclor 1221 in the Post-Dredging Period

Figure 3-2

July 2024



Notes

1. 95% confidence limits on the geometric mean are calculated using a bias-corrected and accelerated (BCA) bootstrap method.
2. In the Second Five-Year Review the conversion factors applied to the data to generate the $TPCB_{HE}$ were based on UHR and LHR data.
3. In this five-year review the conversion factors applied to the data to generate the $TPCB_{HE}$ is based on UHR data only.
4. The original conversion factor for the 2016 data was derived from the period 2004-2008 because the 2016 data was not statistically different from the conversion factor for 2004-2008 data.

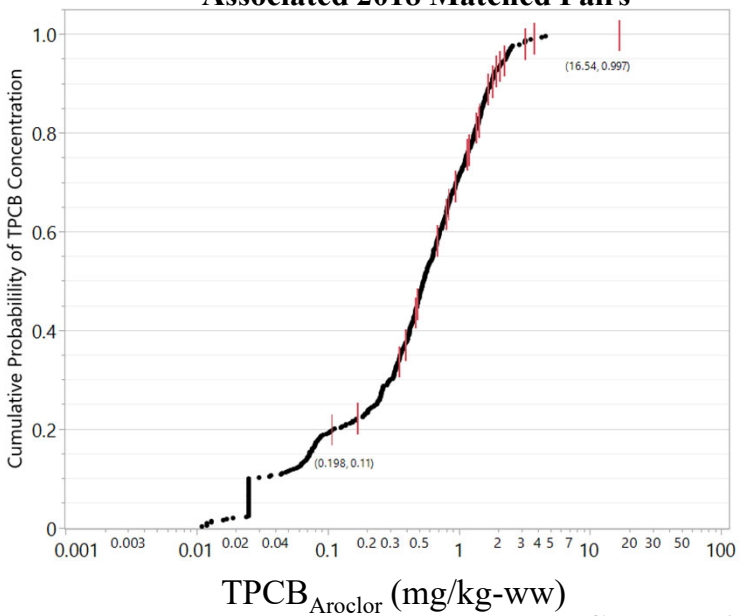
Comparison of the $TPCB_{congener}$ to $TPCB_{Aroclor}$ Geometric Mean Ratio

Figure 4-1

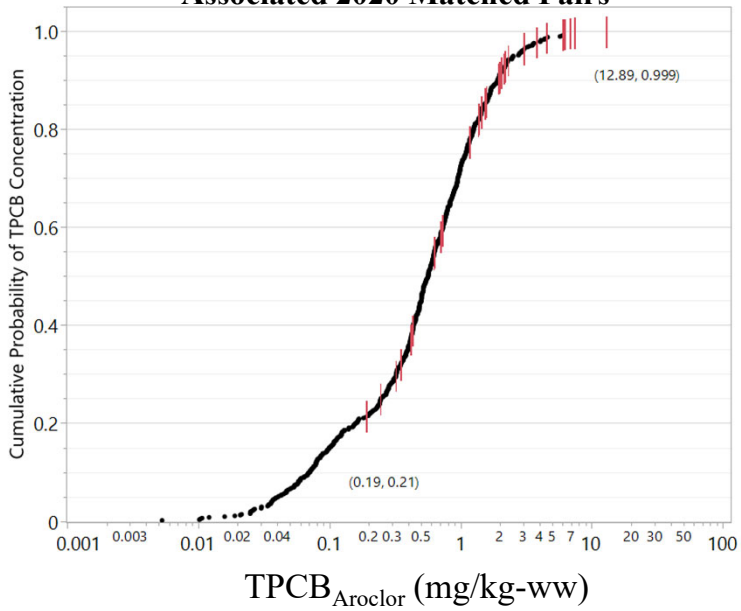
July 2024

Draft

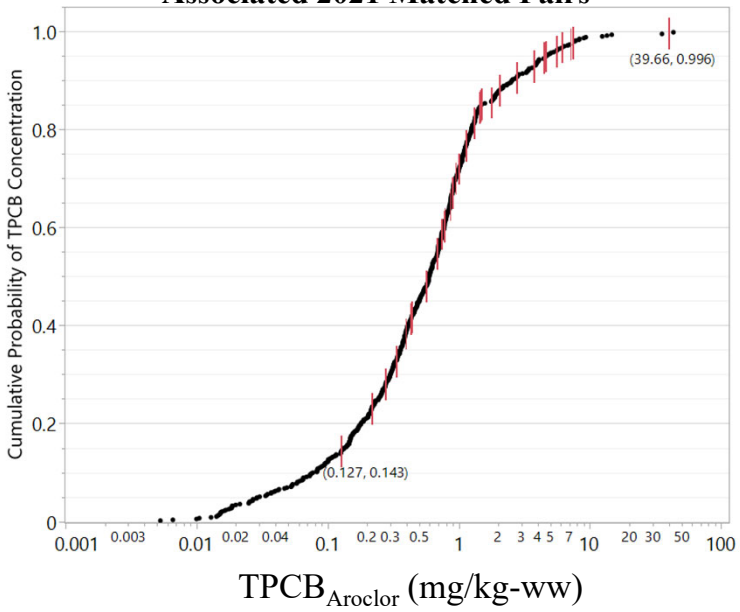
A. Probability Distribution of 2018 Fish Results and Associated 2018 Matched Pairs



B. Probability Distribution of 2020 Fish Results and Associated 2020 Matched Pairs



C. Probability Distribution of 2021 Fish Results and Associated 2021 Matched Pairs



Legend:

- ● Sample with $TPCB_{Aroclor}$ only
- ▌ Matched Pair Sample (sample selected for congener-based analysis)

(a, b) a = lowest or highest $TPCB_{Aroclor}$ in the matched pair dataset
b = percentile value of the matched pair $TPCB_{Aroclor}$ result in the entire dataset of $TPCB_{Aroclor}$ results

Notes:

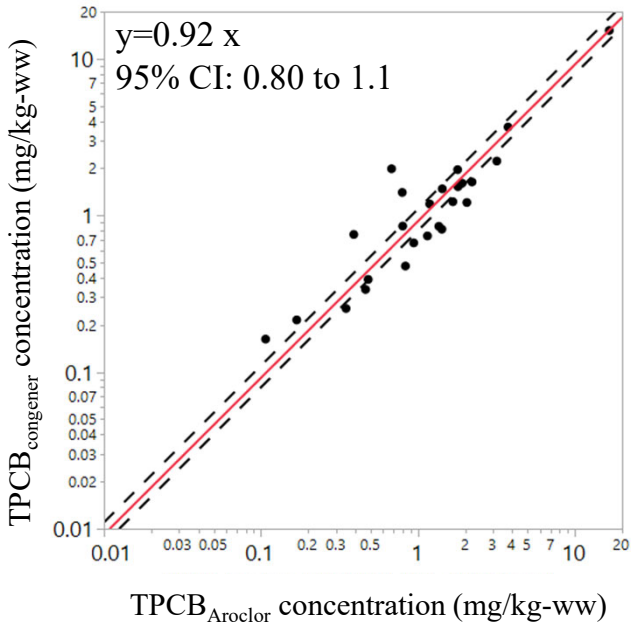
1. The two labeled points on each plot are the matched pairs that have the lowest and the highest $TPCB_{Aroclor}$ concentrations determined by M8082.
2. Non-detect $TPCB_{Aroclor}$ results were reported at half of the reporting limits. These non-detect results are clustered at concentrations around 0.025 mg/kg-ww.

Comparison of the Cumulative Probability of $TPCB_{Aroclor}$ for All Fish Samples and for Matched Pair Fish Samples Collected by GE in 2017 to 2019, 2020, and 2021

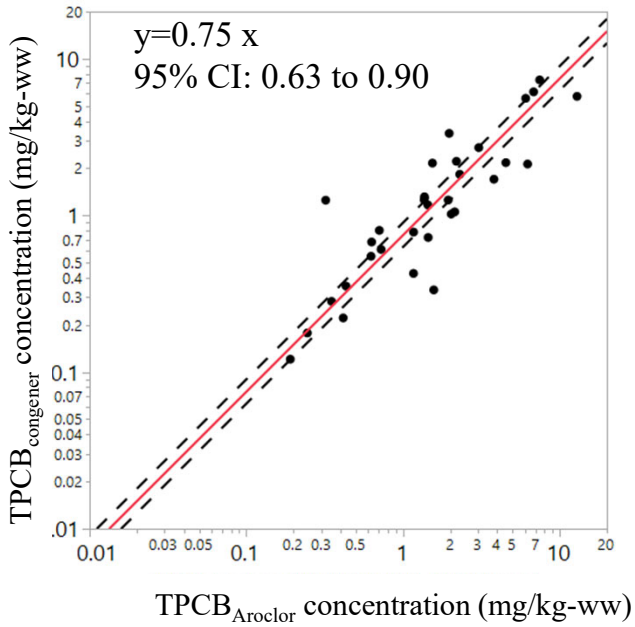
Figure 4-2

July 2024

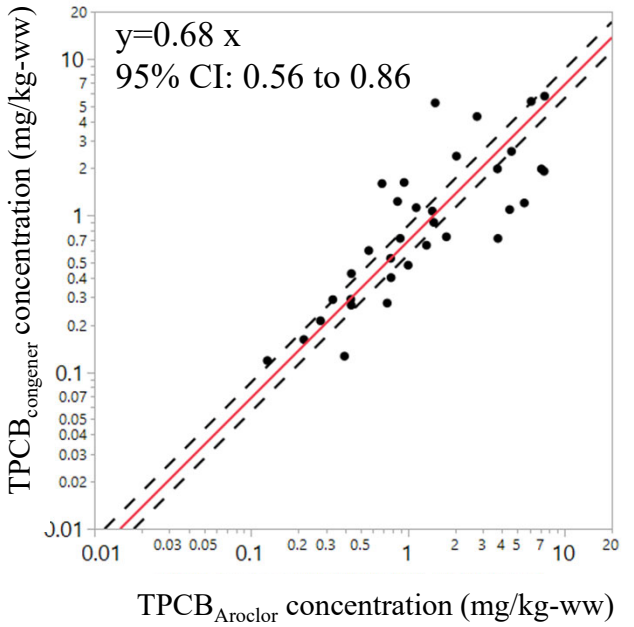
A. GE 2018 Fish Matched Pairs



B. GE 2020 Fish Matched Pairs



C. GE 2021 Fish Matched Pairs



Legend:

- Geometric mean Ratio
- 95% CI of the Ratio

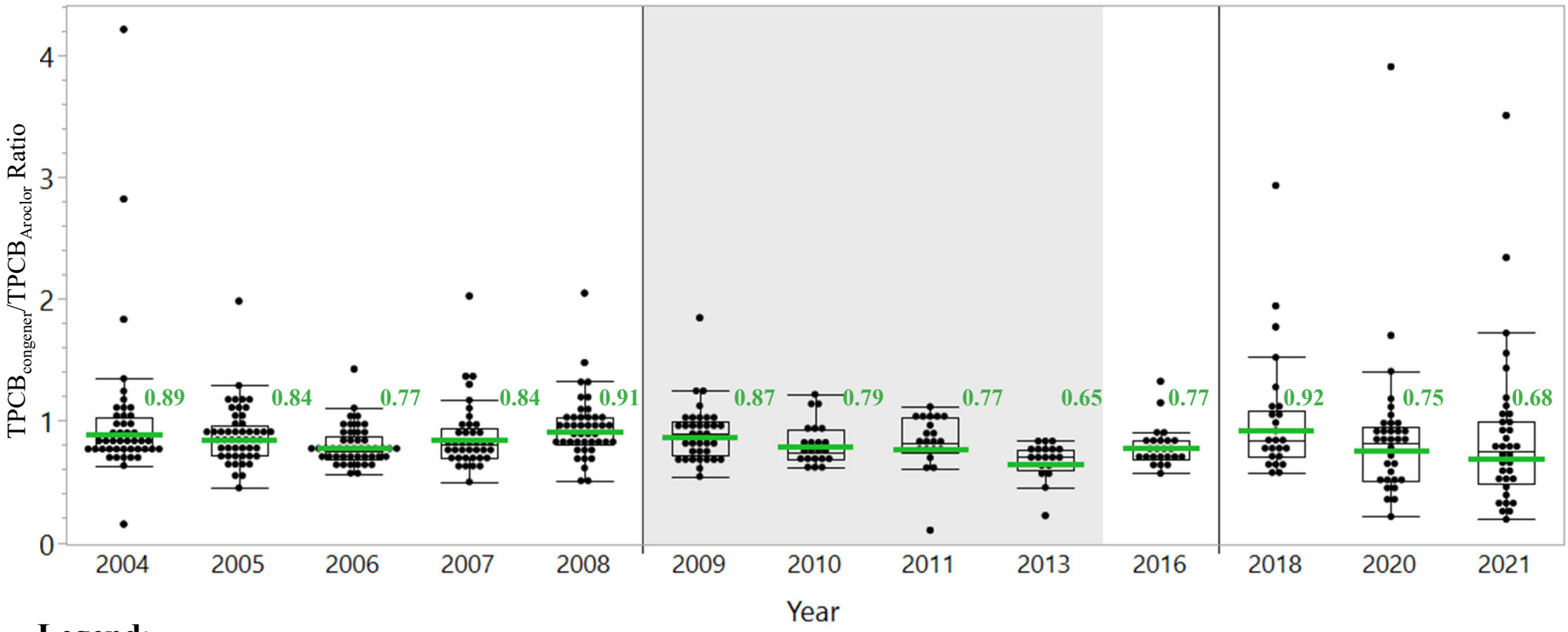
Note:

1. 95% confidence limits on the slope is based on bias-corrected and accelerated (BCa) bootstrap evaluation.

Ratio-based Regression Results for $TPCB_{congener}$ as a Function of $TPCB_{Aroclor}$: 2018, 2020, and 2021 GE Matched Pair Fish Data

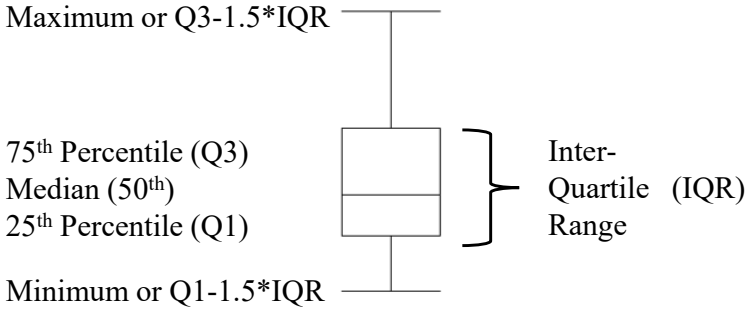
Figure 4-3

July 2024



Legend:

- Data point
- 0.68 Geometric Mean
- Change in Analytical Laboratory
- Dredging Period

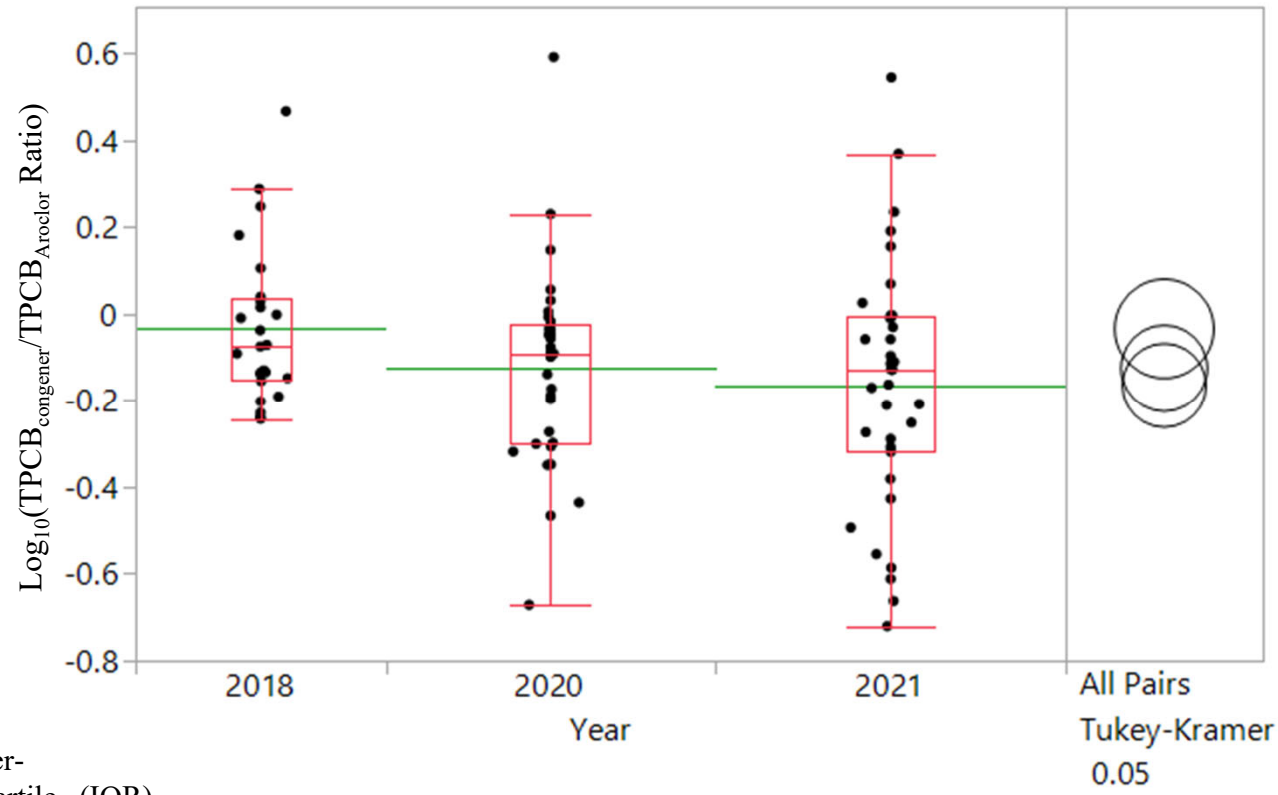


Changes in PCB $TPCB_{congener}$ to $TPCB_{Aroclor}$ Ratio Over Time

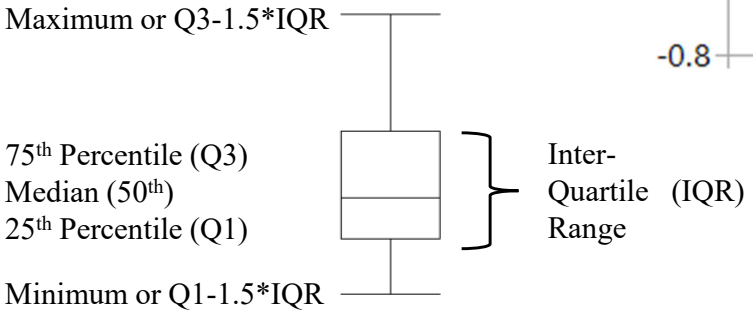
Figure 4-4

July 2024

Draft



Legend:



Station mean

Data point

Tukey-Kramer circle

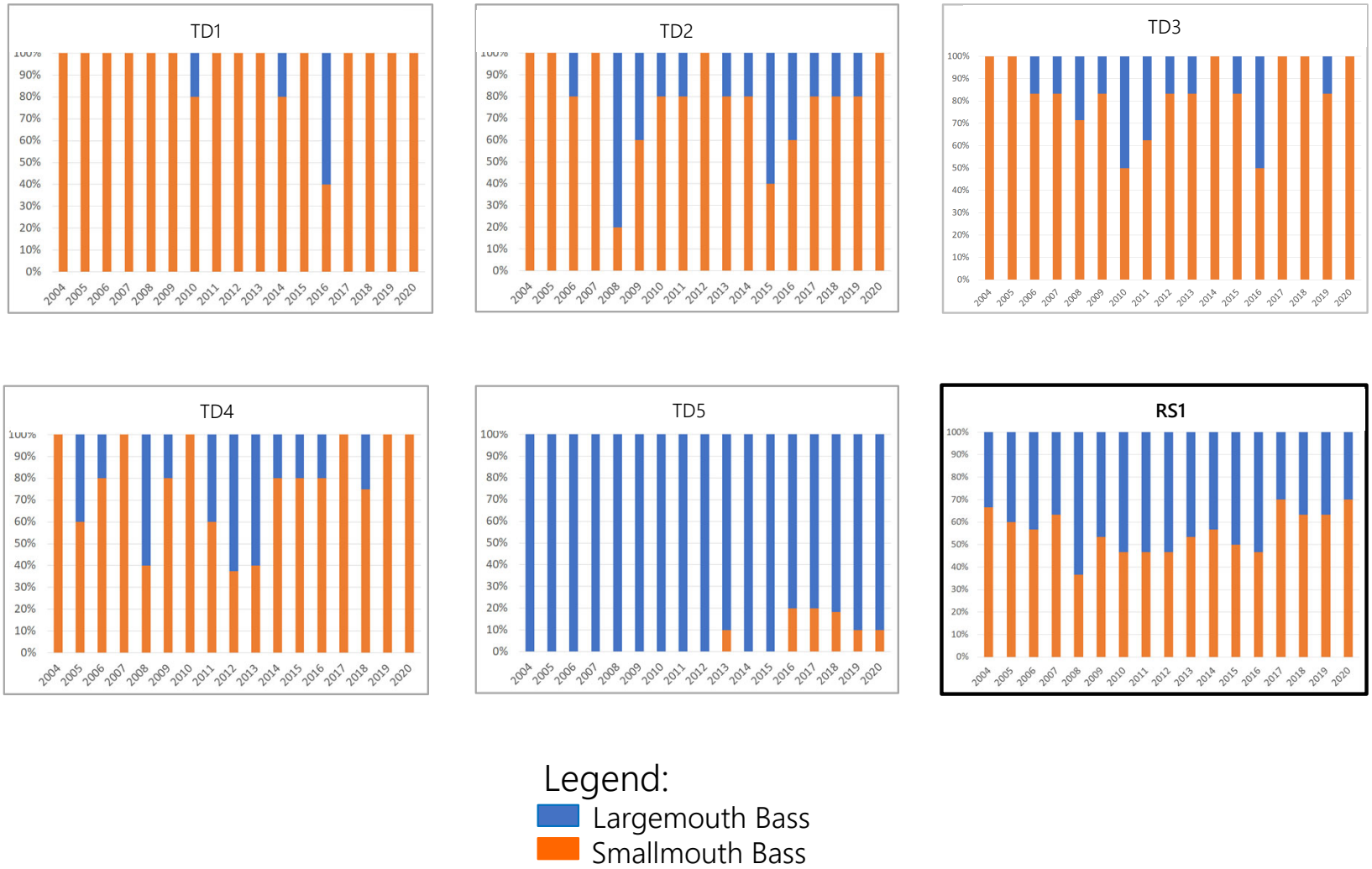
Notes:

1. Tukey-Kramer circles represent the geometric mean (center of the circle) and its uncertainty (circle radius) for each of the sample groups examined. Tukey-Kramer circles that do not touch or intersect slightly are indicative of sample groups that are statistically different from each other.

Comparison of the 2018, 2020, and 2021 Conversion Factors as Individual Groups

Figure 4-5

July 2024

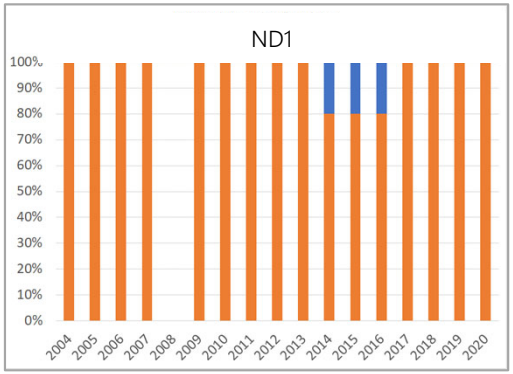


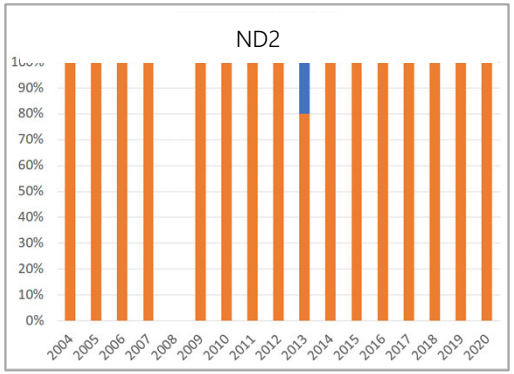
Proportion of Largemouth and Smallmouth Bass Collected from River Section 1, 2004 - 2020

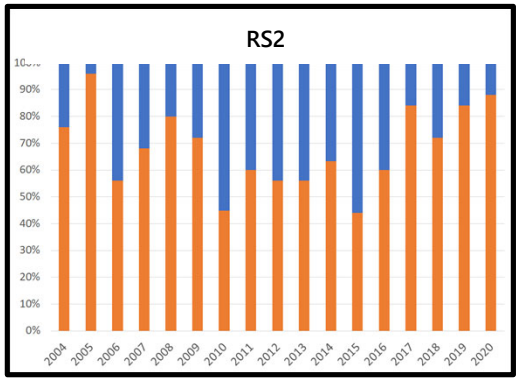
Figure 5-1

July 2024

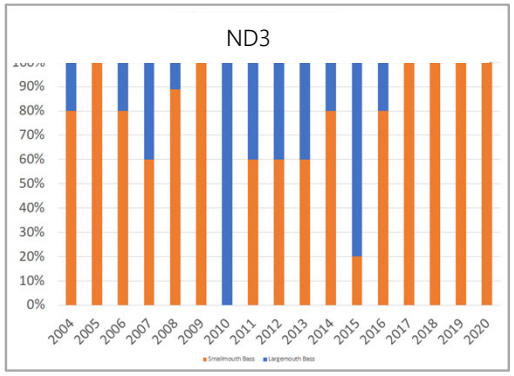
Reach 7

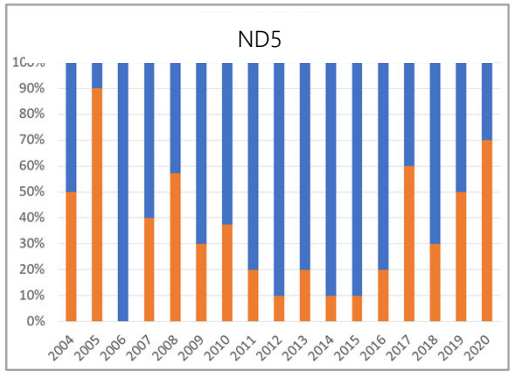






Reach 6



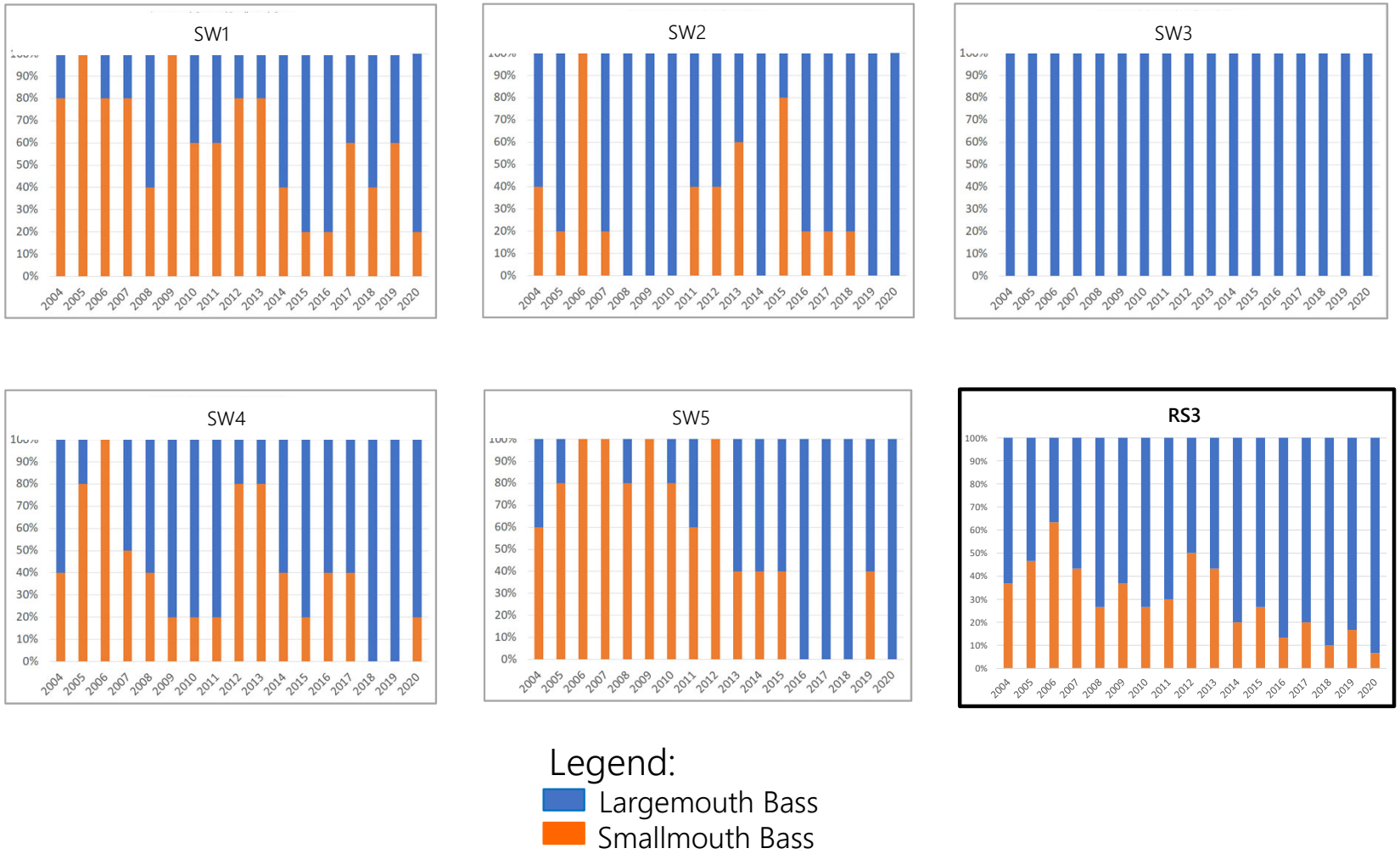


Legend:
- Largemouth Bass
- Smallmouth Bass

Proportion of Largemouth and Smallmouth Bass Collected from River Section 2, 2004 - 2020

Figure 5-2

July 2024



Proportion of Largemouth and Smallmouth Bass Collected from River Section 3, 2004 - 2020

Figure 5-3

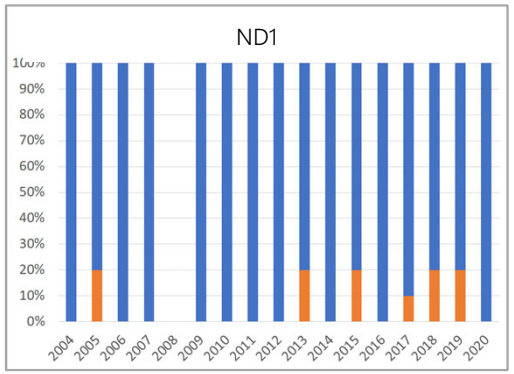
July 2024

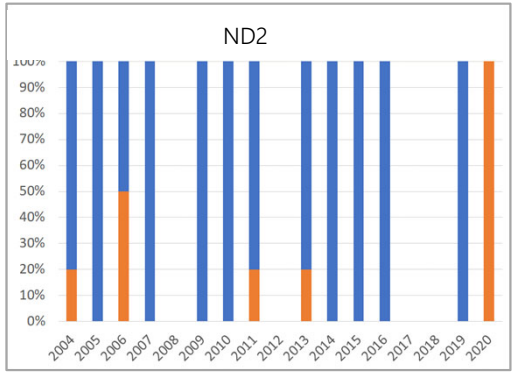
Proportion of Brown Bullhead and Yellow Bullhead Collected from River Section 1, 2004 - 2020

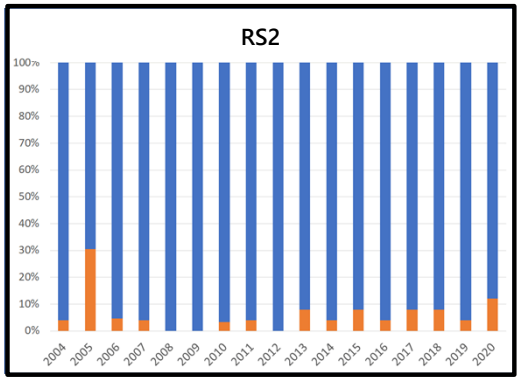
Figure 5-4

July 2024

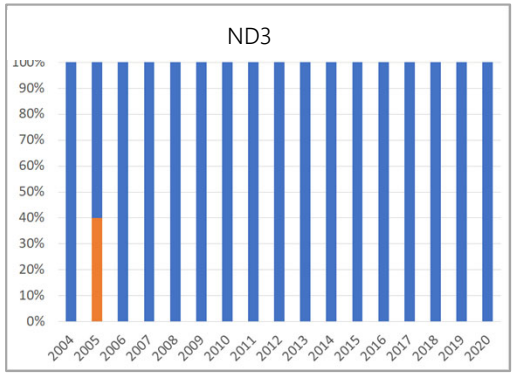
Reach 7

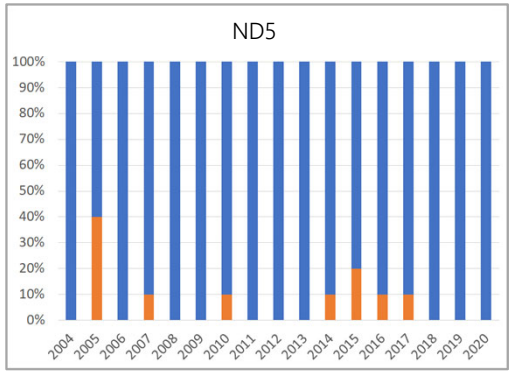






Reach 6



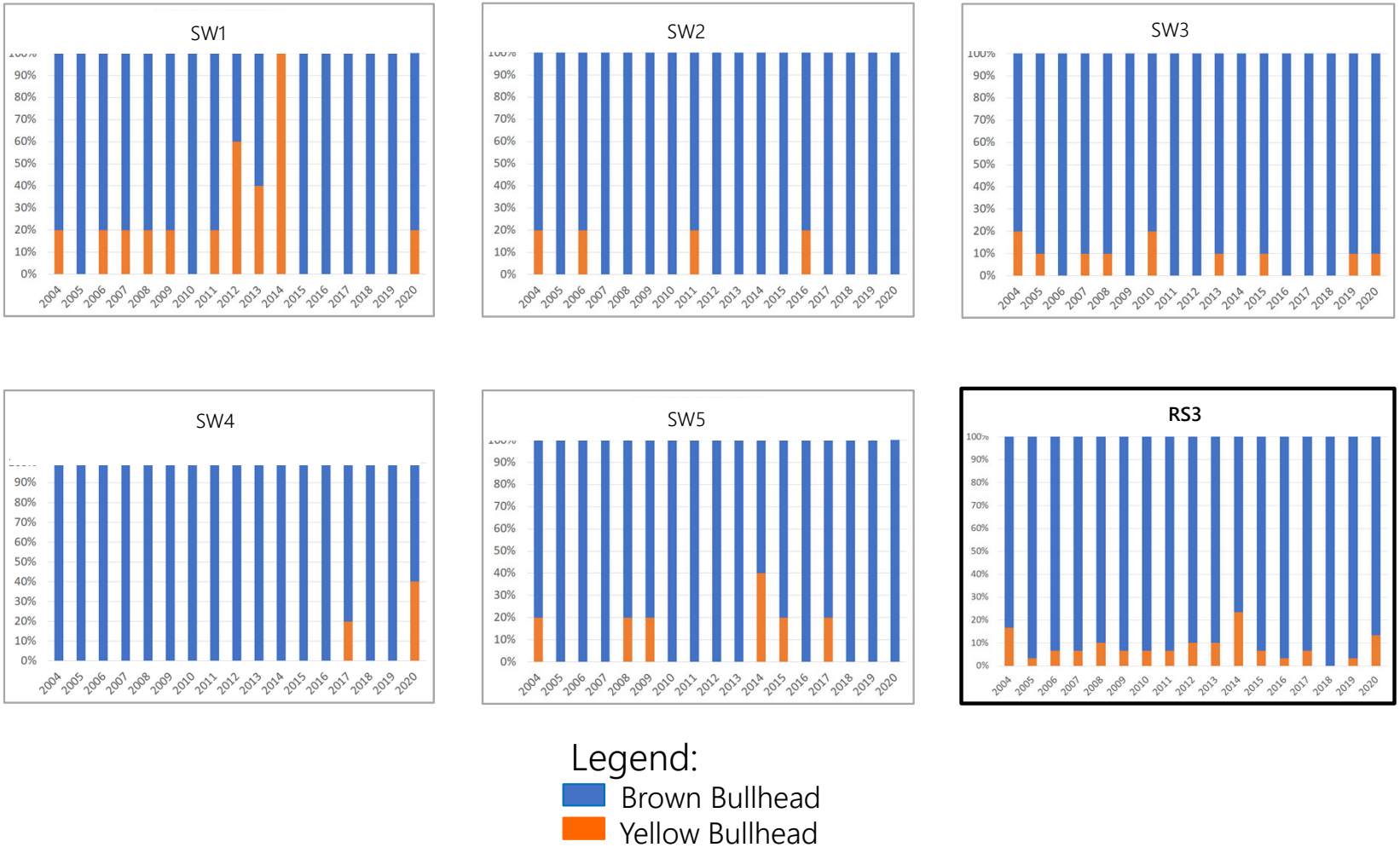


Legend:
- Brown Bullhead
- Yellow Bullhead

Proportion of Brown Bullhead and Yellow Bullhead Collected from River Section 2, 2004 - 2020

Figure 5-5

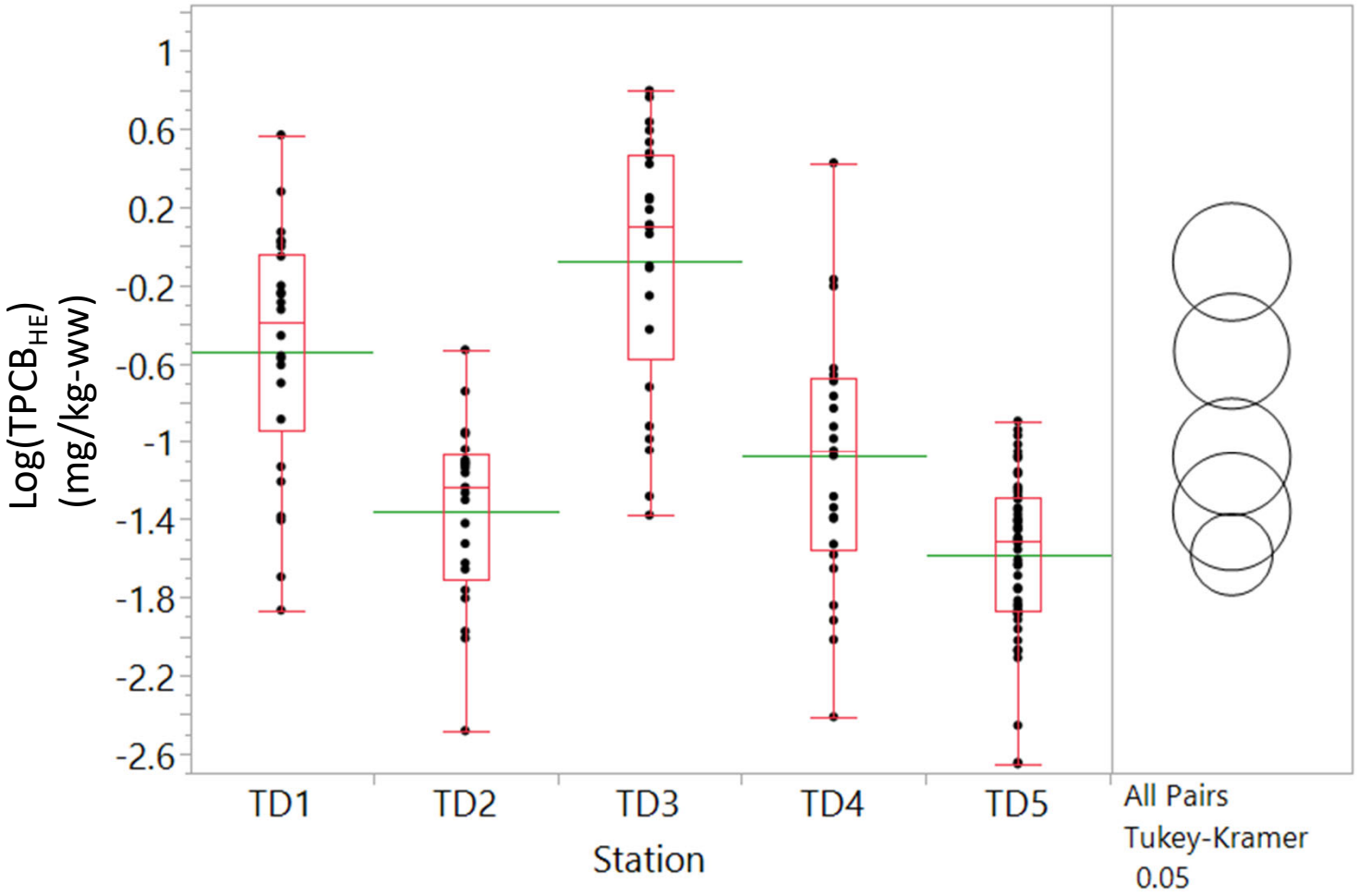
July 2024



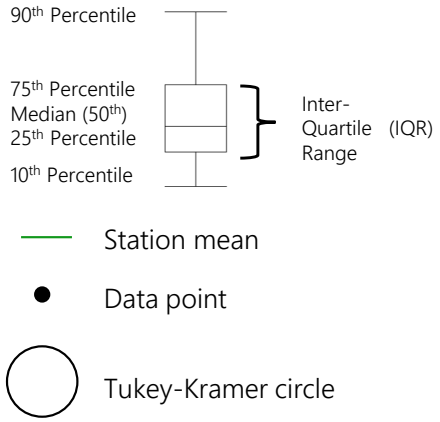
Proportion of Brown Bullhead and Yellow Bullhead Collected from River Section 3, 2004 - 2020

Figure 5-6

July 2024



Legend:



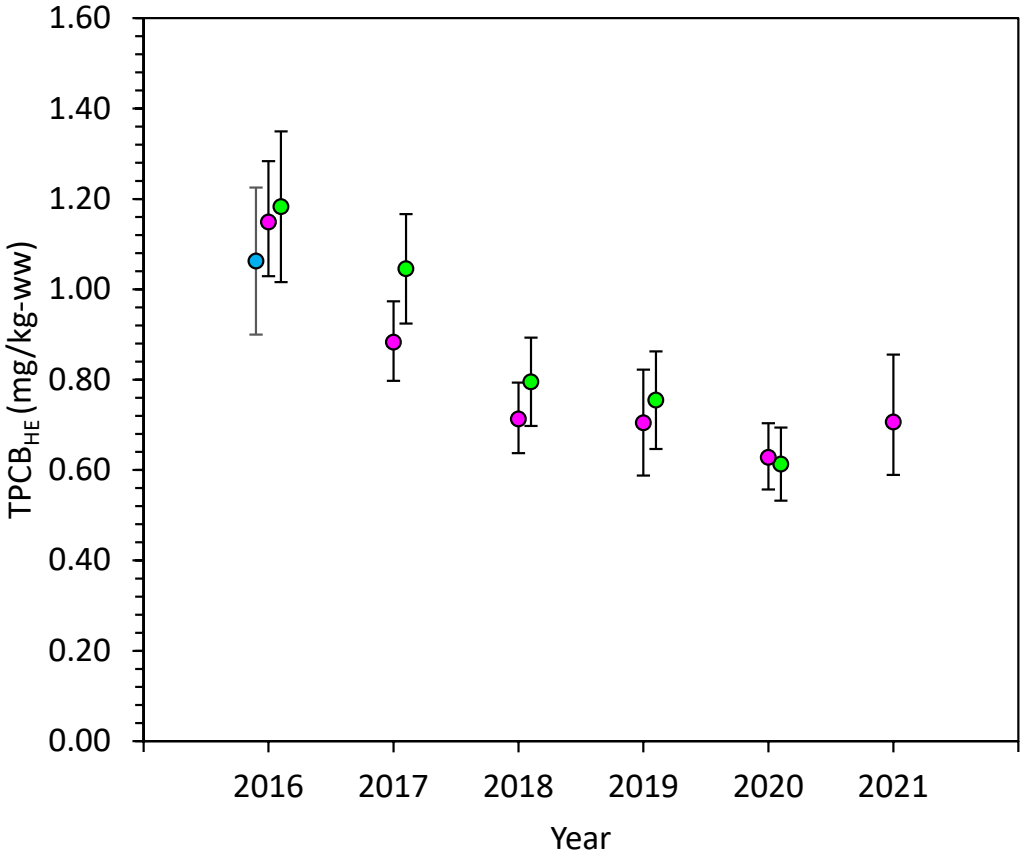
Notes:

1. Tukey-Kramer circles represent the geometric mean (center of the circle) and its uncertainty (circle radius) for each of the sample groups examined. Tukey-Kramer circles that do not touch or intersect slightly are indicative of sample groups that are statistically different from each other.
2. The plots above include data from 2016-2020 grouped by collection station

Yellow Perch TPCB$_{HE}$ Concentration Across All Stations in River Section 1

Figure 5-7

July 2024



Approach 1

- Original methodology described in the ROD and calculated for the Second Five-Year Review
- Species: largemouth bass, brown bullhead and yellow perch
- Method: The data for each species is first averaged on a river section basis and then combined to generate an average for the UHR.

Approach 2

- Modified ROD method presented during CAG meetings
- Species: black bass (largemouth bass and smallmouth bass), Ictalurid (brown bullhead and yellow bullhead) and yellow perch
- Method: The data for each species group is first averaged on a river section basis and then combined to generate an average for the UHR.

Approach 3

- Stratified method, results of which are reported in Appendix 3 of this five-year review
- Species: largemouth bass, smallmouth bass, brown bullhead and yellow perch
- Method: The data for each species is first averaged on a station basis, then on a river section basis and then combined to generate an average for the UHR.

Comparison of Upper Hudson River Species-Weighted Average Methods

Figure 5-8

July 2024