ADDENDUM 01

# Characterization of Potential Adverse Health Effects Associated with Consuming Fish from Lake Worth

Tarrant County, Texas

2021

## INTRODUCTION

This addendum report summarizes per- and polyfluoroalkyl substances (PFAS) found in fish collected in December 2020 from Lake Worth, Texas. The addendum report addresses public health implications of consuming contaminated fish with PFAS from Lake Worth, individually and cumulatively, and suggests actions to protect humans from possible adverse health effects of consuming contaminated fish from this water body.

## BACKGROUND

### *History of Lake Worth Fish Consumption Advisory*

In August 1990, the United States Environmental Protection Agency (USEPA) placed Air Force Plant No. 4 (AFP4) on the USEPA National Priorities List as a Superfund site. The site was listed primarily because of contamination of groundwater (ATSDR 1998a). In 1999, the United States Geological Survey (USGS) surveyed fish from Lake Worth and found widespread polychlorinated biphenyls (PCB) contamination in fish (USGS 1999). In 2000, the Texas Department of Health (now the Texas Department of State Health Services, DSHS) issued Fish and Shellfish Consumption Advisory 18 (ADV-18) to protect people from consuming PCB-contaminated fish from Lake Worth (DSHS 2000).

In 2008, the DSHS expanded the 2000 fish survey to include additional sampling locations and contaminants. The 2000 results confirmed PCB contamination in catfish and smallmouth buffalo and identified aldrin, dieldrin, polychlorinated dibenzo-para-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs) in channel catfish. Based on these results, DSHS rescinded ADV-18 and issued ADV-45. ADV-45 advised people not to consume blue catfish, channel catfish, and smallmouth buffalo from Lake Worth (DSHS 2010).

In 2016, DSHS conducted a follow-up survey to investigate any potential changes in fish tissue contamination in Lake Worth. Results of the 2016 survey indicated that the combination of PCBs and PCDDs/PCDFs in specific fish species, including blue catfish, common carp, flathead catfish, freshwater drum, smallmouth buffalo, striped bass, and white bass, exceeded DSHS guidelines for protection of human health (DSHS 2016). Based on these results, DSHS rescinded ADV-45 and issued ADV-60 (DSHS 2018). ADV-60 recommends all people not eat smallmouth buffalo, women of childbearing age and children less than 12 years not eat flathead catfish and all people limit their consumption of blue catfish, common carp, flathead catfish, freshwater drum, striped bass, and white bass from Lake Worth.

*Per- and Polyfluoroalkyl Substances*

Per- and polyfluoroalkyl substances (PFAS) are a group of environmental persistent and ubiquitous chemicals. Because their chemical structure produces an ability to repel both oil and water, these compounds have been widely used for several decades in many consumer products, including non-stick cookware, clothing and cosmetics, and to produce various materials, including aqueous film forming foam (Barzne-Hanson 2017, Lindstrom 2011).

Evidence from both animal and human studies demonstrate associations between PFAS exposure and a variety of adverse health effects, including high cholesterol, adverse reproductive and developmental effects, altered liver enzymes, thyroid disorders, and pregnancy hypertension (USEPA 2021). Some PFAS chemicals have also been identified as possible human carcinogens (ATSDR 2020).

People are primarily exposed to PFAS through their diet, and fish and other seafood often contain high concentrations. Several studies have confirmed that fish intake is associated with elevated levels of multiple PFAS compounds in the US population (Holzer 2020, Fujii 2015). Although PFAS contamination in water bodies is pervasive and comes from a wide range of sources, water bodies located near military locations where aqueous film forming foam was frequently used are especially at risk for contamination. Previous studies have observed higher levels of PFAS in fish tissue collected adjacent to military sites with PFAS-contaminated soil and groundwater, compared with other locations without PFAS contamination (Goodrow 2020).

In Texas, aqueous film forming foam was used at several former and active military bases throughout the state and has resulted in PFAS contamination in soil and groundwater (ATSDR 2020b). Some of these military facilities are located adjacent to water bodies. It is possible that historic use of aqueous film forming foam has also led to PFAS contamination in nearby surface water and may have contaminated fish in these water bodies.

*Lake Worth, Texas*

Lake Worth is a 3,489-acre impoundment of the West Fork Trinity River located within the city limits of Fort Worth, Texas in northwest Tarrant County. It was constructed in 1914 by the City of Fort Worth to provide a municipal water supply. The reservoir is bordered by the Fort Worth Nature Center and Refuge at the upstream end of the lake and residential and commercial properties surround most of the other parts of the lake. Two large industrial facilities are located adjacent to the south side of the reservoir: United States Air Station Joint Reserve Base–Fort Worth (NASFW) and AFP4. Past operations from these facilities have resulted in documented environmental contamination to Lake Worth. Additionally, the NASFW has identified PFAS in groundwater from former facility operations using aqueous film forming foam.

PURPOSE

The purpose of the 2020 fish survey was to 1) determine the presence of PFAS in fish from Lake Worth; 2) determine the public health implications of consuming PFAS-contaminated fish, individually and cumulatively, and 3) suggest actions to protect humans from possible adverse health effects of consuming contaminated fish from this water body.

METHODS

*Fish Sampling and Preparation*

DSHS targeted a sample size of at least 60 fish samples based on power calculations using estimates from the New Jersey Department of Environmental Protection for safe amounts of specific PFAS compounds in fish for unlimited human consumption. DSHS determined 60 samples to be of adequate power (almost 100%) to detect differences between safe levels of PFAS and levels needing consumption advisories for each species of fish, should these differences truly exist (NJDEPP 2019).

DSHS aimed to collect 5 different fish species at each sampling location to represent distinct ecological groups, capture a wide geographical distribution, include fish that are of local recreational fishing value, and include fish that are commonly consumed. Among these fish species, catfish and bass are the most popular among anglers at from Lake Worth (TWPWD 2021).

DSHS collected fish samples from 10 sample sites across Lake Worth to provide spatial coverage of the study area (Figure 1). These were the same sampling locations from the 2016 DSHS fish survey at Lake Worth (DSHS 2016). The locations included Lake Worth Dam (site 1), near the NASFW (site 2), near Carswell Field Runway (site 3), near Meandering Creek Road (site 4), Woods Inlet (site 5), Live Oak Creek (site 6), near Woods Island (site 7), near Mosque Point (site 8), State Highway 199 Bridge (site 9) and West Fork Trinity River (site 10).

Figure 1. Fish sampling locations, Lake Worth, December 2020

DSHS stored fish on wet ice and processed fish at the Texas Parks and Wildlife inland fisheries (Fort Worth, Texas) immediately after catching the fish. DSHS following standard operating procedures from the DSHS Seafood and Aquatic Life Unit survey team standard operating procedures and EPA quality control/assurance manual (DSHS 2020, USEPA 2000a). All fish were weighed and measured, and two fish skin-off fillets were prepared. DSHS properly packaged and froze fish, and then hand-delivered the samples to the Geochemical and Environmental Research Group (GERG) Laboratory, Texas A&M University, College Station, Texas, for chemical analysis.

DSHS also removed sagittal otoliths from fish for age estimation following otolith extraction procedures recommended by the Gulf States Marine Fisheries Commission and Texas Parks and Wildlife Department (GSMFC 2009, TPWD 2009).

*PFAS*

Twenty-eight analytes of PFAS compounds from the following seven groups of PFAS were evaluated:

- Perfluoroalkylcarboxilic acids (PFCAs)
- Perfluoroalkylsulfonates (PFASs)
- Perfluorooctanesulfonamides (PFOSAs)
- Telomer sulfonates
- Fluorotelomer carboxylic acids (FTCAs)
- Perfluorooctanesulfonamidoacetic acids
- Perfluoroether carboxylic acids (Gen X)

These seven categories of PFAS include 28 specific and common variations of PFAS analytes (Table 3). Among these compounds, perfluorohexanoic acid (PFHxA), a type of PFCA, and perfluorooctanesulfonic acid (PFOS), a type of PFAS, are both associated with aqueous film forming foam substances (Houtz 2013). Additionally, PFOS, PFHxA, perfluoro-n-nonanoic acid (PFNA), and perfluoro-n-octanoic acid (PFOA) have all been detected in other fish studies (NJDEPP 2018).

PFAS can be categorized by not only the terminal functional group, but by the chain length as well. Short-chain PFAS include those carboxylates with less than seven fluorinated carbon atoms (less than eight total carbons; PFHpA and shorter), and those sulfonates with less than six carbons (PFBS). The long-chain compounds tend to bioaccumulate and be toxic, while solubility in water is inversely proportional to the length of the carbon chain (Conder 2008, Lau 2012, Prevedouros 2006). Both short- and long-chain types of PFAS were evaluated in fish collected from Lake Worth.

*PFAS Analysis in Fish Samples*

The GERG laboratory evaluated fish samples for PFAS analysis using established methods (van Leeuwen 2009, Powley 2008). Briefly, the samples were stored frozen until homogenized, then frozen again until extraction. The samples and quality control samples were subsampled, weighed, spiked with surrogate standards and extracted through dispersive solid phase extraction. The extracts were injected with injection standards then analyzed using liquid chromatography tandem mass spectrometry. There were five batches of samples: one set of surface water samples and four sets of fish tissue samples. DSHS conducted QA/QC on data following standard operating procedures and determined that data met QC/QC criteria as outlined in DSHS Seafood and Aquatic Life Unit survey team standard operating procedures and EPA quality control/assurance manual (DSHS 2020, USEPA 2000a).

*Health-Based Assessment Comparison (HAC) Values*

If diverse species of fish are available, DSHS assumed that people eat a variety of species from a water body. Further, DSHS assumed that most fish species are mobile. In this analysis, DSHS combine data from different fish species and/or sample sites within Lake Worth to evaluate mean contaminant concentrations of PFAS in all samples. This approach intuitively reflects consumers' likely exposure over time to contaminants in fish from any water body but may not reflect the reality of exposure at a specific location within a water body or a single point in time.

DSHS evaluated PFAS in fish by comparing the mean concentration of a contaminant to its health-based assessment comparison (HAC) value for non-cancer endpoints. HAC values are levels below which no adverse health effects are expected to occur following long-term and regular exposure. Chemical concentrations above HAC values do not necessarily mean there is a health concern, but rather suggests that further public health evaluation based on site-specific exposure conditions is needed. DSHS derived HAC values using reference doses (RfD) derived by the Texas Commission on Environmental Quality (TCEQ 2016) or other available health guidelines (Table 1). Health guidelines were not available for some PFAS compounds, including perfluoroundaconoic acid (PFUdA), perfluorononanesulfonic acid (PFNS), perfluoropentanesulfonic acid (PFPeS), perfluoroheptanoic acid (PFHpS) fluorotelomer carboxylic acids (FTCAs), perfluorooctancesulfonamidoacetic acids, and perfluoro ether carboxylic acids (such as Gen X). If detected, compounds without health guidelines were evaluated cumulatively as part of total PFAS.

| Table 1. Per- and polyfluoroalkyl substances (PFAS) analytes (abbreviations) analyzed and available reference doses (RfD) | |
|---|---|
| Perfluoroalkylcarboxilic Acids (PFCAs) | RfD (mg/kg/day) |
| Perfluorotetradecanoic acid (PFTeDA) | 1.2E-05 |
| Perfluorotridecanoic acid (PFTrDA) | 1.2E-05 |
| Perfluorododecanoic acid (PFDoA) | 1.2E-05 |
| Perfluoroundaconoic acid (PFUdA) | NA |
| Perfluorodecanoic acid (PFDA) | 1.5E-05 |
| Perfluorononanoic acid (PFNA) | 1.2E-05 |
| Perfluorooctanoic acid (PFOA) | 1.2E-05 |
| Perfluoroheptanoic acid (PFHpA) | 2.3E-05 |
| Perfluorohexanoic acid (PFHxA) | 3.8E-06 |
| Perfluoropentanoic acid (PFPeA) | 3.8E-06 |
| Perfluorobutanoic acid (PFBA) | 2.9E-03 |
| Perfluoroalkylsulfonates (PFASs) | |
| Perfluorodecansulfonic acid (PFDS) | 1.2E-05 |
| Perfluorononanesulfonic acid (PFNS) | NA |
| Perfluorooctanesulfonic acid (PFOS) | 2.3E-05 |
| Perfluoroheptanesulfonic acid (PFHpS) | NA |
| Perfluorohexanesulfonic acid (PFHxS) | 3.8E-06 |
| Perfluoropentanesulfonic acid (PFPeS) | NA |
| Perfluorobutanesulfonic acid (PFBS) | 1.4E-03 |
| Perfluorooctanesulfonamides (PFOSAs) | |
| Perfluoro-1-octanesulfonamide (FOSA-1) | 1.2E-05 |
| Telomer Sulfonates | |
| Sodium 1H,1H,2H,2H-perfluorodecane sulfonate (8:2 FTS) | NA |
| Sodium 1H,1H,2H,2H-perfluorooctane sulfonate (6:2 FTS) | NA |
| Sodium 1H,1H,2H,2H-perfluorohexane sulfonate (4:2 FTS) | NA |

| | |
|---|---|
| Fluorotelomer carboxylic acids (FTCAs) | |
| 2-Perfluorodecyl ethanoic acid (10:2 FTCA) FDEA | NA |
| 2-Perfluorooctyl ethanoic acid (8:2 FTCA) FOEA | NA |
| 2-Perfluorohexyl ethanoic acid (6:2 FTCA) FHEA | NA |
| Perfluorooctancesulfonamidoacetic Acids | |
| N-ethylperfluoro-1-octanesulfonamidoacetic acid (N-EtFOSAA) | NA |
| N-methylperfluoro-1-octanesulfonamidoacetic acid (N-MeFOSAA) | NA |
| Perfluoro ether carboxylic acids | |
| Hexafluoropropylene oxide dimer acid (GenX) | NA |

Abbreviations: NA=not available; RfDs are from TCEQ (TCEQ 2016).

The HAC values were determined as follows:

$$HAC = \frac{RfD \times BW \ x \, RSC}{IR}$$

Where:

- HAC = Health advisory concentration (ng/kg-day)
- RfD = Reference dose (ng/kg-day)
- BW = Body weight (kg)
- IR = Intake rate (kg/day)
- RSC = Relative source contribution (unitless)

DSHS used a relative source contribution of 1 for all HAC calculations assuming the majority of PFAS exposure is from fish consumption.

DSHS used standard exposure parameters for healthy adults, children (under 6 years) and subsistence fishers (Table 2) (USEPA 2000a). DSHS assumed an adult weight of 70 kilograms (kg) and consumes 30 grams (g) of fish per day and a child weighs 15 kg and consumes 15 g per day. DSHS assumed a meal size of 227 g (about 8 ounces) and 113 g (about 4 ounces) for an adult and child, respectively. Taken together, these assumptions equal about one meal of fish per week (or 4 meals per month) for both adults and children. This is a health protective exposure estimate which is consistent with a full and unrestricted use of the fish resource. Instead of estimating health risks for women of childbearing age, the health risks for children were applied to women of childbearing age. Subsistence fishers are those that rely on fishing to provide for basic needs. This group might be at greater risk of exposure to contaminants in fish due to higher consumption rates. DSHS used a consumption rate of 142 g per day and meal size of 227 grams per meal for subsistence fishers (USEPA 2000a). Using these exposure parameters, DSHS estimated that a subsistence fisher would eat about 4.6 meals per week (or about 19 meals per month).

Table 2. Exposure parameters for target populations

| Target Population | Body Weight (kg) | Intake Rate (g/day) | Meal Size (g/meal) |
|---|---|---|---|
| Adults | 70 | 30 | 227 |
| Children (less than 6 years) | 15 | 15 | 113 |
| Subsistence Fishers | 70 | 142 | 227 |

Abbreviations: kg=kilogram; g/day=grams per day; g/meal=grams per meal

*Hazard Quotients and Hazard Indices*

To calculate non-cancer health risks, DSHS calculated the hazard quotient (HQ). The HQ is the ratio of the estimated exposure to a chemical over the level at which no adverse effect is expected. The HQ is derived by dividing the contaminant concentration detected in fish by the HAC. An HQ less than 1 means no adverse health effects are expected and an HQ greater than 1 means adverse health effects are possible.

The HQ was determined as follows:

$$HQ = \frac{C}{HAC}$$

Where:
- HQ = Hazard quotient (unitless)
- C = Mean concentration in fish (ng/kg wet)
- HAC = Health advisory concentration (ng/kg)

DSHS calculated the hazard index (HI) to assess additive mixture toxicity. The HI is the sum of HQs for a group of chemicals that share a similar mode of action and target organ.

The HI was determined as follows:

$$HI = \sum HQ$$

Where:

- HI = Hazard index (unitless)
- HQ = Hazard quotient (unitless)

Because PFAS compounds have similar and overlapping mode of actions and target organs and to consider PFAS without health guidelines, HIs were determined for all PFAS substances detected (ATSDR 2021). DSHS also calculated HIs combining the mean concentrations of PFAS with contaminants, PCBs and PCDDs/PCDFs, detected in the 2016 Lake Worth fish survey (DSHS 2016). For this evaluation, DSHS assumed the mode of actions and target organs of PCBs and PCDDs/PCDFs were similar to PFAS (ATSDR 1998b, ATSDR 2000).

The HI was determined as follows:

$$HI = \sum HQ$$

Where:

- HI = Hazard index (unitless)
- HQ = Hazard quotient (unitless)

*Fish Consumption Advisory*

Fish consumption advisories are not regulatory standards, but are recommendations intended to provide additional information of interest to high-risk groups. DSHS develops risk-based fish consumption advisories following EPA guidance (USEPA 2020) and uses species-specific data on concentrations of individual contaminants to determine how often it is safe to eat a species of fish. A consumption advisory may be triggered when the HI is above 1 or if the calculated meals per week is below 1 meal per week (or 4 meals per month). DSHC calculated the maximum number of recommended meals of fish per month (MpM) using standard exposure parameters (Table 2), health guidelines (such as TCEQ's RfDs) and the measured mean concentration of contaminant using the equation below:

$$MpM = \frac{RfD * BW * ED}{MS * C}$$

Where:

- MpM = Meals per month (meals/month)
- RfD = Reference dose (mg/kg-day)
- BW = Body weight (kg)
- ED = Exposure duration (30.44 days/month)
- MS = Meal size (kg/meal)
- C = Mean concentration in fish (ng/kg wet)

DSHS also determined meals per month from ingestion of fish contaminated with multiple substances (MpMmixture) using the equation below:

$$MpM(mixture) = \sum_{i=1} \left(\frac{RfD_i}{C_i}\right) * \frac{BW * ED}{MS}$$

Where:

- MpM = Meals per month (meals/month)
- $RfD_i$ = Reference dose for chemical i (mg/kg-day)
- $C_i$ = Mean concentration in fish for chemical i (ng/kg wet)
- BW = Body weight (kg)
- ED = Exposure duration (30.44 days/month)
- MS = Meal size (kg/meal)

*Statistics*

DSHS used a non-parametric analysis, Kendall's Tau, to determine significant correlations between average PFOS concentrations for each fish species and fish length, weight, and age where $p > 0.05$ (Figure A2).

RESULTS AND DISCUSSION

DSHS collected a total of 60 fish of 5 different species (blue catfish, smallmouth buffalo, channel catfish, freshwater drum and largemouth bass) from 10 different locations from Lake Worth (Table 3). These included six blue catfish, 16 smallmouth buffalo, 10 channel catfish, 18 freshwater drum, and 10 largemouth bass.

Fish were collected from the same sampling locations as the 2016 DSHS fish survey event (DSHS 2016). The number of fish collected from each location were similar with 6 to 9 (10% to 15%) of the samples coming for sites 1, 2, 3, 4, 6 and 9. However, smaller numbers of fish (5% to 7%) were collected from sites 5, 7, 8 and 10.

The length and age for largemouth bass, channel catfish and blue catfish appear to be positively correlated (Figure A1). Statistically significant correlations were not observed between total PFAS or PFOS concentrations and fish length, weight, or age (Table 3; Figure A2).

| Table 3. Location, type and number of fish collected from Lake Worth, Texas, December 2020 | |
|---|---|
| Species | Fillets* (n=60) |
| Blue Catfish | 6 (10) |
| Channel Catfish | 16 (27) |
| Freshwater Drum | 10 (17) |
| Largemouth Bass | 18 (30) |
| Smallmouth buffalo | 10 (17) |
| Location | |
| Lake Worth Dam (site 1) | 9 (15) |
| Naval Air Station (site 2) | 7 (12) |
| Carswell Runway (site 3) | 8 (13) |
| Meandering Creek (site 4) | 9 (15) |
| Woods Inlet (site 5) | 3 (5) |
| Live Oak Creek (site 6) | 6 (10) |
| Woods Island (site 7) | 4 (7) |
| Mosque Point (site 8) | 4 (7) |
| State Highway Bridge 199 (site 9) | 6 (10) |
| West Fork Trinity River (site 10) | 4 (7) |
| Length (mm) | |
| Blue Catfish | 640.3 (125.1) |
| Smallmouth Buffalo | 673.6 (51.5) |
| Channel Catfish | 504.8 (58.9) |
| Freshwater Drum | 495.5 (53.1) |
| Largemouth Bass | 435.1 (39.7) |
| Weight (g) | |
| Blue Catfish | 3181.7 (1926.7) |
| Smallmouth Buffalo | 6359.5 (1474.3) |
| Channel Catfish | 1165.9 (501.3) |

| Table 3. Location, type and number of fish collected from Lake Worth, Texas, December 2020 | |
|---|---|
| Species | Fillets* (n=60) |
| Freshwater Drum | 1771.1 (701.3) |
| Largemouth Bass | 1320.5 (488.9) |
| Age (year) | |
| Blue Catfish | 11.7 (2.9) |
| Smallmouth Buffalo | N/A |
| Channel Catfish | 6.3 (2.1) |
| Freshwater Drum | N/A |
| Largemouth Bass | 4.3 (1.1) |

Notes: *Categorical variables are reported as n (percent) and continuous variables are reported as mean (standard deviation). Abbreviations: mm = millimeter; g = grams

*PFAS Levels in Fish*

The overall summary of PFAS levels per fish species and location is provided in Table A1. PFAS was detected in all fish species and at all locations. Of the 28 PFAS analytes included in the survey, 19 were detected in at least one fish fillet (PFTeDA, PFTrDA, PFDoA, PFUdA, PFDA, PFNA, PFOA, PFPeA, PFBA, PFDS, PFNS, PFOS, PFHpS, PFHxS, PFHxA, PFPeS, PFBS, FOSA-1, and 6:2FTS) and 9 were not detected (PFHpA, 8:2FTS, 4:2FTS, FHEA, FOEA, FDEA, N-EtFOSAA, N-MeFOSAA, and GenX) in any fish samples.

PFOS was spatially heterogeneous (Table A1). Highest concentrations were measured in smallmouth buffalo (15,842.3 ng/kg), largemouth bass (14,025.9 ng/kg) at NASFW site (site 2). The lowest levels of PFOS were detected in channel catfish (406.9 ng/kg and 557.7 ng/kg) at Woods Island and State Highway Bridge 199 (site 9) and in blue catfish (881.1 ng/kg) at West Fork Trinity River (site 10) (Table A1). PFOS levels varied among species. Regardless of sample location, smallmouth buffalo, largemouth bass, and freshwater drum generally contained higher levels than channel catfish and blue catfish.

While PFOS was measured in the highest concentrations in all samples, there was variation in the mixture of other (non-PFOS) PFAS analytes present by sample location and species (Table A1). Shorter chain PFAS (less than 6 carbons) were found in all locations and fish species at levels ranging from

15 ng/kg to 147 ng/kg. Highest levels were detected in channel catfish at State Highway Bridge 199 (site 9) and Live Oak Creek (site 6).

The longest chain PFAS compounds (greater than 10 carbons) were found in all fish species. Highest levels were measured in largemouth bass and freshwater drum at Lake Worth Dam (site 1) and Carswell Runway (site 3).

*PFAS in Water Samples*

DSHS also collected two water samples. One sample was collected at Meandering Creek (site 4) and another at State Highway Bridge 199 Bridge (site 9). Water samples were analyzed for PFAS concentrations (Table 4). Two water samples were taken from Lake Worth. One sample was collected at Meandering Creek (site 4) and another at SH 199 Bridge (site 9). Both samples were analyzed for PFAS concentrations (Table 4). Ten PFAS compounds were detected in at least one of the water samples (PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFBS PFPeS PFHxS, and PFOS) and 18 were not detected (PFDA, PFUdA, PFDoA, PFTrDA, PFTeDA, PFHpS, PFNS, PFDS, FOSA-1, 4:2FTS, 6:2FTS, 8:2FTS, FHEA, FOEA, FDEA, N-MeFOSAA, N-EtFOSAA, and GenX). Detected concentrations were low and ranged between 0.51 ng/L and 7.44 ng/L. These levels are also below U.S. Environmental Protection Agency's health advisory level (70 ng/L) for lifetime exposure to PFOA and PFOS from drinking water.

Table 4. Detected PFAS (ng/L) in surface water, Lake Worth.

| Site Location | PFBA | PFPeA | PFHxA | PFHpA | PFOA | PFNA | PFBS | PFPeS | PFHxS | PFOS |
|---|---|---|---|---|---|---|---|---|---|---|
| Meandering Creek (site 4) | 7.4 | 5.3 | 3.0 | 1.3 | 2.7 | 0.5 | 3.5 | 1.5 | 6.4 | 2.6 |
| SH 199 (site 9) | 7.4 | 3.5 | 1.5 | 0.9 | 1.5 | 0.5 | 1.8 | ND | 0.9 | 0.9 |

Abbreviations: ng/L=nanogram per liter; ND= not detected; PFAS= per- and polyfluoroalkyl substances; PFBA= perfluorobutanoic acid; PFPeA= perfluoropentanoic acid; PFHxA= perfluorohexanoic acid; PFOA= perfluorooctanoic acid; PFNA= perfluorononanoic acid; PFBS= perfluorobutanesulfonic acid; PFPeS= perfluoropentanesulfonic acid; PFHxS= perfluoropentanesulfonic acid; PFOS= perfluorooctanesulfonic acid; PFHpS=perfluoroheptanesulfonic acid

*Fish Consumption/Risk Assessment*

DSHS evaluated the contribution of fish consumption on human exposure to PFAS by comparing the mean level of a contaminant to its HAC value for non-cancer endpoints. None of the species of fish evaluated contained any PFAS at concentrations at or above HAC values derived for subsistence fishers, adults, and pregnant women and children. Table 5 shows the comparison to HAC values for PFOS, which was detected at highest levels in fish.

| Table 5. PFOS in fish and health assessment comparison (HAC) values and hazard quotients (HQ) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Subsistence Fisher | | Adult | | Children/Pregnant Women* | |
| PFAS Type | Species | HAC (ng/kg) | HQ | HAC (ng/kg) | HQ | HAC (ng/kg) | HQ |
| PFOS | Blue catfish | 11,338 | 0.10 | 53,667 | 0.02 | 23,000 | 0.05 |
| | Channel catfish | 11,338 | 0.12 | 53,667 | 0.02 | 23,000 | 0.06 |
| | Freshwater drum | 11,338 | 0.47 | 53,667 | 0.10 | 23,000 | 0.24 |
| | Largemouth bass | 11,338 | 0.70 | 53,667 | 0.15 | 23,000 | 0.35 |
| | Smallmouth buffalo | 11,338 | 0.53 | 53,667 | 0.11 | 23,000 | 0.26 |

Notes: *Women of childbearing age and children less than 6 years.
Abbreviations: HAC=health assessment comparison; HQ=hazard quotient; ng/kg=nanogram per kilogram; PFAS= per- and polyfluoroalkyl substances; PFOS= perfluorooctanesulfonic acid.

DSHS calculated the number of 8-ounce meals of fish healthy adults, subsistence fishers, pregnant women, and children could consume without significant risk of PFAS-related adverse effects (Table 6). DSHS estimated that adults could consume 7 to 42 meals per week (28 to 168 meals per month) of various fish contaminated with PFOS and not experience any adverse health effects. Similarly, women of childbearing age and children less than 6 years could safely consume 3 to 18 meals per week (12 to 72 meals per month) of various fish contaminated with PFOS. The estimated meals per week and month are also higher than what a subsistence fisher would expect to eat (19 meals per month).

| Table 6. Estimated number of meals (per week and per month) for PFOS | | | |
|---|---|---|---|
| | | Adult/Subsistence Fishers | Children/Pregnant Women* |

| PFAS Type | Fish Species | Meals/ Month | Meals/W eek | Meals/ Month | Meals/W eek |
|---|---|---|---|---|---|
| PFOS | Blue catfish | 184 | 42 | 79 | 18 |
| | Channel catfish | 163 | 37 | 70 | 16 |
| | Freshwater drum | 39 | 9 | 17 | 4 |
| | Largemouth bass | 27 | 6 | 12 | 3 |
| | Smallmouth buffalo | 36 | 8 | 16 | 4 |

Notes: *Women of childbearing age and children less than 6 years.
Abbreviation: PFOS= perfluorooctanesulfonic acid.

*PFAS Mixture*

DSHS evaluated how a potential additive mixture would affect the consumption results. DSHS assumed all detected PFAS have the same mode of action and target organ. The results show the HIs are below 1 and adults the number of meals per month vary from 22 to 76 for adults and 9 to 33 for women of childbearing age and children less than 6 years (Table 7). The number of meals per month are protective for subsistence fishers. Therefore, consuming fish with PFAS, either individually or cumulatively, is not likely to cause adverse health effects.

| Table 7. Potential additive mixture for all PFAS, HI and meals per month | | | | | |
|---|---|---|---|---|---|
| | Subsistence Fishers | Adult | Children/ Pregnant Women* | Meals/Month Mixture | |
| Species | Hazard Index | Hazard Index | Hazard Index | Adult/Subsistence Fisher | Children/Pregnant Women* |
| Blue catfish | 0.23 | 0.05 | 0.11 | 82 | 35 |
| Channel catfish | 0.24 | 0.05 | 0.12 | 80 | 35 |
| Freshwater drum | 0.74 | 0.16 | 0.37 | 26 | 11 |
| Largemouth bass | 0.90 | 0.19 | 0.44 | 21 | 9 |
| Smallmouth buffalo | 0.69 | 0.15 | 0.34 | 28 | 12 |

| Table 7. Potential additive mixture for all PFAS, HI and meals per month | | | | | |
|---|---|---|---|---|---|
| | Subsistence Fishers | Adult | Children/ Pregnant Women* | Meals/Month Mixture | |
| Species | Hazard Index | Hazard Index | Hazard Index | Adult/Subsistence Fisher | Children/Pregnant Women* |

Notes: *Women of childbearing age and children less than 6 years. Abbreviation: PFOS= perfluorooctanesulfonic acid. Abbreviations: PFAS= per- and polyfluoroalkyl substances; HI=hazard index.

The results from the 2016 fish survey from Lake Worth determined that consumption of multiple contaminants, PCBs and PCDDs/PCDFs, in fish (blue catfish, common carp, flathead catfish, freshwater drum, smallmouth buffalo, striped bass and white bass) increases the likelihood of non-cancer health risks. Even though fish consumption advisories were not triggered for PFAS, either cumulatively or individually, in the current evaluation, there is potential that it may affect consumption advisories when treated as a mixture with other chemicals. Therefore, DSHS calculated HIs and meals per week (and meals per month) and assumed that PFOS have a similar mode of action as PCBs and PCDDs/PCDFs that would produce an additive mixture toxic effect.

Table 8 shows that the cumulative effect of PFOS, PCBs and PCDDs/PCDFs contamination does not change the existing estimated meals per week for blue catfish, freshwater drum and smallmouth buffalo from what was determined in 2016 for adults. While the meals per week for channel catfish and largemouth bass decreased slightly from 1.1 to 0.9 meals per week, the decrease is not enough to trigger a fish consumption advisory for these fish.

| Table 8. Hazard quotient and meals per week for adult consumption of fish with combined contaminants | | | | |
|---|---|---|---|---|
| | PCB and PCDD/PCDFs* | | PCB and PCDD/PCDFs added with PFOS | |
| Contaminant/Species | Hazard Quotient | Meals per Week (adult) | Hazard Quotient | Meals per Week (adult) |
| Blue catfish | | | | |
| PCBs | 0.41 | 2.3 | 0.41 | 2.3 |
| PCDDs/PCDFs | **1.10** | **0.8** | **1.10** | **0.8** |

| Table 8. Hazard quotient and meals per week for adult consumption of fish with combined contaminants | | | | |
|---|---|---|---|---|
| | PCB and PCDD/PCDFs* | | PCB and PCDD/PCDFs added with PFOS | |
| Contaminant/Species | Hazard Quotient | Meals per Week (adult) | Hazard Quotient | Meals per Week (adult) |
| PFOS | | | 0.02 | 42.2 |
| Hazard Index (meals per week) | **1.51** | **0.6** | **1.53** | **0.6** |
| Channel catfish | | | | |
| PCBs | 0.43 | 2.2 | 0.43 | 2.2 |
| PCDDs/PCDFs | 0.44 | 2.1 | 0.44 | 2.1 |
| PFOS | | | 0.02 | 37.4 |
| Hazard Index (meals per week) | 0.87 | 1.1 | 0.89 | 1.0 |
| Freshwater drum | | | | |
| PCBs | 0.26 | 3.6 | 0.26 | 3.6 |
| PCDDs/PCDFs | 1.00 | **0.9** | 1.00 | **0.9** |
| PFOS | | | 0.10 | 9.3 |
| Hazard Index (meals per week) | **1.26** | **0.7** | **1.36** | **0.7** |
| Largemouth bass | | | | |
| PCBs | 0.19 | 4.8 | 0.19 | 4.8 |
| PCDDs/PCDFs | 0.69 | 1.4 | 0.69 | 1.4 |
| PFOS | | | 0.15 | 6.3 |
| Hazard Index (meals per week) | 0.88 | 1.1 | **1.03** | **0.9** |
| Smallmouth buffalo | | | | |
| PCBs | **2.27** | **0.4** | **2.27** | **0.4** |
| PCDDs/PCDFs | **3.39** | **0.3** | **3.39** | **0.3** |
| PFOS | | | 0.11 | 8.3 |

| Table 8. Hazard quotient and meals per week for adult consumption of fish with combined contaminants | | | | |
|---|---|---|---|---|
| | PCB and PCDD/PCDFs* | | PCB and PCDD/PCDFs added with PFOS | |
| Contaminant/Species | Hazard Quotient | Meals per Week (adult) | Hazard Quotient | Meals per Week (adult) |
| Hazard Index (meals per week) | **5.66** | **0.2** | **5.77** | **0.2** |

Notes: *The results from the 2016 fish survey from Lake Worth determined that consumption of multiple contaminants (DSHS 2016a). Bold values show HQ> 1 or meals per week < 1. PCB= polychlorinated biphenyls; PCDD/PCDF= polychlorinated dibenzo-para-dioxins and polychlorinated dibenzofurans; PFOS= perfluorooctanesulfonic acid.

Table 9 shows that the cumulative effect of PFOS, PCBs and PCDDs/PCDFs contamination does not change the existing estimated meals per week for blue catfish, freshwater drum and smallmouth buffalo from what was determined in 2016 for women of childbearing age and children less than 6 years. While the meals per week for channel catfish and largemouth bass decreased slightly from 0.5 to 0.4 meals per week, respectively. However, the decrease is not enough to change the existing recommendations.

| Table 9. Hazard quotient and meals per week women of childbearing age and children less than 6 years consumption of fish with combined contaminants | | | | |
|---|---|---|---|---|
| | PCB and PCDD/PCDFs* | | PCB and PCDD/PCDFs added with PFOS and | |
| Contaminant/Species | Hazard Quotient | Meals per Week (child) | Hazard Quotient | Meals per Week (child) |
| Blue catfish | | | | |
| PCBs | 0.95 | **1.0** | 0.95 | **1** |
| PCDDs/PCDFs | **2.57** | **0.4** | **2.57** | **0.4** |
| PFOS | | | 0.05 | 18 |
| Hazard Index (meals per week) | **3.52** | **0.3** | **3.57** | **0.3** |
| Channel catfish | | | | |
| PCBs | 1.00 | **0.9** | 1.00 | **0.9** |

| Table 9. Hazard quotient and meals per week women of childbearing age and children less than 6 years consumption of fish with combined contaminants | | | | |
|---|---|---|---|---|
| | PCB and PCDD/PCDFs* | | PCB and PCDD/PCDFs added with PFOS and | |
| Contaminant/Species | Hazard Quotient | Meals per Week (child) | Hazard Quotient | Meals per Week (child) |
| PCDDs/PCDFs | **1.02** | **0.9** | **1.02** | **0.9** |
| PFOS | | | 0.06 | 16 |
| Hazard Index (meals per week) | **2.02** | **0.5** | **2.08** | **0.4** |
| Freshwater drum | | | | |
| PCBs | 0.26 | 3.6 | 0.60 | 1.5 |
| PCDDs/PCDFs | 1.00 | **0.9** | **1.00** | **0.9** |
| PFOS | | | 0.24 | 4 |
| Hazard Index (meals per week) | **2.93** | **0.3** | **3.17** | **0.3** |
| Largemouth bass | | | | |
| PCBs | 0.45 | 2.3 | 0.45 | 1.0 |
| PCDDs/PCDFs | **1.60** | **0.6** | **1.60** | **0.3** |
| PFOS | | | 0.34 | 3 |
| Hazard Index (meals per week) | **2.05** | **0.5** | **2.39** | **0.4** |
| Smallmouth buffalo | | | | |
| PCBs | **5.30** | **0.2** | **5.30** | **0.2** |
| PCDDs/PCDFs | **7.90** | **0.1** | **7.90** | **0.1** |
| PFOS | | | 0.26 | 3.6 |
| Hazard Index (meals per week) | **13.20** | **0.07** | **13.46** | **0.07** |

Notes: Bold values show HQ> 1 or meals per week < 1. PCB= polychlorinated biphenyls; PCDD/PCDF= polychlorinated dibenzo-para-dioxins and polychlorinated dibenzofurans; PFOS= perfluorooctanesulfonic acid

CONCLUSIONS

This fish survey addresses the public health implications of consuming fish contaminated with PFAS, individually and cumulatively, from Lake Worth, Texas. Confidence in the conclusions from several species of fish is limited by the small sample size and one-time sampling event.

PFAS levels detected in fish, including blue catfish, channel catfish, freshwater drum, largemouth bass, and smallmouth buffalo, do not exceed DSHS guidelines for protection of human health. Therefore, consumption of these species of fish containing only PFAS poses no apparent non-cancer risk to human health.

The results of the 2016 risk characterization from Lake Worth showed that regular and long-term consumption of blue catfish, freshwater drum, smallmouth buffalo, striped bass and white bass contaminated with PCBs and PCDDs/PCDFs may result in adverse non-cancer health effects. In the current risk characterization, the addition of PFOS to the existing contamination does not change this non-cancer health risk conclusion. However, striped bass and white bass were not analyzed in the current evaluation.

Based on 2016 results, DSHS made the following recommendations:

- All people should not consume smallmouth buffalo from Lake Worth.
- Women of childbearing age and children less than 6 years should not consume flathead catfish.
- Women of childbearing age and children less than 6 years may consume up to one four-ounce meal per month of blue catfish, common carp, freshwater drum, striped bass or white bass.
- Adults and non-pregnant women may consume up to one eight-ounce meal per month of flathead catfish.
- Adults and non-pregnant women may consume up to two eight-ounce meals per month of blue catfish, common carp, striped bass or white bass.
- Adults and non-pregnant women may consume up to three eight-ounce meals per month of freshwater drum.

The results of the current evaluation do not change these recommendations. Please note that common carp, striped bass, white bass, and flathead catfish were not evaluated in the current evaluation.

## RECOMMENDATIONS

1. DSHS continue the consumption advisory (ADV-60) presently in place for fish from Lake Worth until contaminants, such as PCBs and

PCDDs/PCDFs, are shown to have decreased to levels that are unlikely to pose a risk to human health.

2. DSHS continue to regularly monitor fish from Lake Worth for the presence and concentrations of PCBs, PCDDs/PCDFs, and PFAS.
3. DSHS include this addendum to the 2016 Risk Characterization for Lake Worth.

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APPENDICES

**Table A1. Mean concentrations of PFAS in fish fillets from Lake Worth, Texas 2021.**

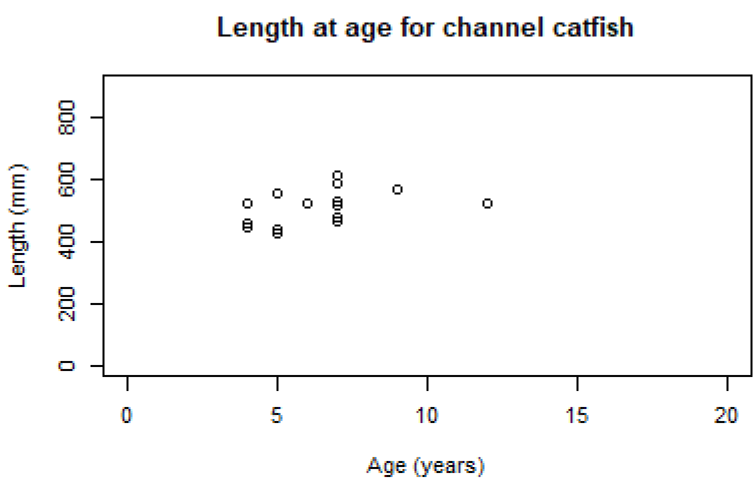
| Location | Fish Species (number detected) | PFAS* type (ng/kg wet) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PFBA | PFPeA | PFHxA | PFOA | PFNA | PFDA | PFUdA | PFDoA | PFTrDA | PFTeDA | PFBS | PFPeS | PFHxS | PFHpS | PFOS | PFNS | PFDS | FOSA-I | 62FTS |
| Lake Worth Dam (Site 1) | Channel catfish (2) | 36.5 | ND | ND | 25.4 | 35.1 | 402.1 | 267.5 | 205.5 | 91.1 | 92.3 | ND | ND | 32.5 | ND | 1436.6 | ND | 95.4 | ND | ND |
| | Freshwater drum (1) | 47.6 | ND | ND | 63.9 | 35.4 | 899.4 | 942.4 | 941.4 | 308.9 | 247.7 | ND | ND | ND | ND | 7701.2 | 27.5 | 399.3 | ND | ND |
| | Largemouth bass (5) | 43.8 | ND | ND | 41.6 | 28.9 | 754.4 | 519.3 | 403.6 | 123.3 | 104.0 | ND | ND | 25.8 | ND | 7313.0 | ND | 230.9 | ND | ND |
| | Smallmouth buffalo (1) | 32.2 | ND | ND | 27.4 | 44.9 | 427.2 | 420.8 | 314.6 | 107.5 | 86.4 | ND | ND | 31.3 | ND | 4422.8 | ND | 32.2 | ND | ND |
| Naval Air Station (NAS) (Site 2) | Blue catfish (2) | 50.6 | ND | ND | 15.8 | ND | 467.6 | 392.5 | 268.2 | 80.9 | 86.6 | ND | ND | ND | ND | 1857.5 | ND | 70.0 | ND | ND |
| | Channel catfish (4) | 56.5 | 25.7 | ND | 23.1 | 67.5 | 327.5 | 202.9 | 153.0 | 55.6 | 49.7 | ND | ND | 20.7 | ND | 1112.3 | ND | 35.3 | ND | ND |
| | Largemouth bass (1) | 54.7 | ND | ND | 19.4 | ND | 746.6 | 443.8 | 296.2 | 96.0 | 71.5 | ND | ND | ND | ND | 14025.9 | 69.0 | 351.8 | ND | ND |
| | Smallmouth buffalo (1) | 51.7 | ND | ND | 27.9 | 29.2 | 288.4 | 347.4 | 256.6 | 89.3 | 94.4 | ND | ND | 72.5 | 20.1 | 13406.4 | 51.2 | 290.7 | ND | ND |
| Carswell Field Runway (Site 3) | Channel catfish (2) | 48.6 | 23.9 | ND | 22.9 | 32.3 | 194.6 | 129.5 | 110.0 | 45.7 | 35.7 | ND | ND | 201.9 | 17.9 | 3986.3 | ND | 42.5 | 329.1 | ND |
| | Freshwater drum (4) | 60.5 | 18.0 | 17.0 | 23.9 | 97.8 | 759.6 | 636.6 | 606.3 | 225.7 | 213.4 | ND | ND | 35.0 | ND | 7352.9 | 17.4 | 123.2 | ND | ND |
| | Largemouth bass (1) | 51.0 | ND | 15.8 | 23.6 | 30.8 | 351.4 | 176.8 | 167.0 | 65.0 | 52.4 | ND | ND | 22.7 | ND | 6654.8 | ND | 77.1 | ND | ND |
| | Smallmouth buffalo (2) | 58.4 | ND | ND | 31.7 | 68.3 | 395.1 | 470.7 | 467.5 | 235.8 | 273.8 | ND | ND | 95.8 | ND | 11702.3 | 43.6 | 231.6 | ND | ND |
| Mean-dering Creek Road (Site 4) | Freshwater drum (1) | 37.4 | ND | ND | ND | 35.3 | 298.1 | 166.7 | 125.7 | 81.2 | 58.8 | ND | ND | ND | ND | 1416.1 | ND | 54.2 | ND | 361.8 |
| | Largemouth bass (6) | 47.8 | ND | ND | ND | ND | ND | 480.6 | 191.8 | 49.4 | 36.6 | ND | ND | ND | ND | 6976.0 | 17.1 | 139.2 | ND | ND |
| | Smallmouth buffalo (2) | 44.6 | ND | ND | 16.5 | 59.1 | 314.8 | 235.1 | 206.7 | 58.8 | 56.0 | ND | 60.4 | 31.4 | ND | 2402.7 | ND | 72.5 | ND | ND |
| Woods Inlet (Site 5) | Channel catfish (1) | 66.4 | ND | ND | 21.4 | 36.2 | 182.0 | 123.4 | 97.8 | 64.4 | 47.4 | ND | ND | 22.3 | ND | 984.7 | ND | 31.0 | ND | ND |
| | Freshwater drum (1) | 54.5 | ND | ND | <LOQ | 64.5 | 436.9 | 426.0 | 711.2 | 266.2 | 332.2 | ND | ND | ND | ND | 2054.8 | ND | 47.8 | ND | ND |
| | Smallmouth buffalo (1) | 55.4 | ND | ND | 29.6 | 87.7 | 609.7 | 477.4 | 299.9 | 87.1 | 78.1 | ND | ND | 26.8 | ND | 7367.1 | 18.7 | 144.3 | ND | ND |

**Table A1. Mean concentrations of PFAS in fish fillets from Lake Worth, Texas 2021.**

| Location | Fish Species (number detected) | PFAS* type (ng/kg wet) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PFBA | PFPeA | PFHxA | PFOA | PFNA | PFDA | PFUdA | PFDoA | PFTrDA | PFTeDA | PFBS | PFPeS | PFHxS | PFHpS | PFOS | PFNS | PFDS | FOSA-I | 62FTS |
| Live Oak Creek (Site 6) | Blue catfish (1) | 47.0 | ND | ND | ND | ND | 212.0 | 211.2 | 137.9 | 48.9 | 47.7 | ND | ND | ND | ND | 885.5 | ND | 59.9 | ND | ND |
| | Channel catfish (2) | 68.7 | 49.8 | ND | ND | 36.1 | 275.5 | 179.7 | 98.4 | 50.6 | 43.4 | ND | ND | ND | ND | 837.3 | ND | 47.8 | ND | ND |
| | Freshwater drum (1) | 64.3 | ND | ND | 31.4 | ND | 688.5 | 362.6 | 185.8 | 60.8 | 43.8 | ND | ND | ND | ND | 5924.5 | ND | 116.5 | ND | ND |
| | Largemouth bass (1) | 34.5 | ND | ND | ND | 25.8 | 600.5 | 345.2 | 362.7 | 105.8 | 135.6 | ND | ND | ND | ND | 4140.0 | ND | 93.6 | ND | ND |
| | Smallmouth buffalo (1) | 63.7 | 39.9 | ND | 26.2 | ND | 114.0 | 140.3 | 80.1 | 25.0 | 26.3 | ND | ND | ND | ND | 1081.1 | ND | 36.9 | ND | ND |
| Woods Island (Site 7 | Blue catfish (1) | 72.1 | ND | ND | ND | ND | 430.5 | 510.3 | 295.0 | 101.6 | 70.4 | ND | ND | ND | ND | 1185.6 | ND | 80.8 | ND | ND |
| | Channel catfish (2) | 60.8 | ND | ND | ND | 19.8 | 253.2 | 182.7 | 100.1 | 41.3 | 27.1 | ND | ND | ND | ND | 482.3 | ND | 32.6 | ND | ND |
| | Smallmouth buffalo (1) | 70.2 | ND | ND | 26.5 | 19.8 | 208.3 | 228.4 | 138.0 | 44.6 | 42.1 | ND | ND | ND | ND | 2290.4 | ND | 88.7 | ND | ND |
| Mosque Point (Site 8) | Channel catfish (1) | 60.8 | ND | ND | ND | 19.8 | 253.2 | 182.7 | 100.1 | 41.3 | 27.1 | ND | ND | ND | ND | 482.3 | ND | ND | ND | ND |
| | Freshwater drum (1) | 59.5 | ND | ND | ND | 70.5 | 541.2 | 402.8 | 318.8 | 116.9 | 105.6 | ND | ND | ND | ND | 2359.2 | ND | 58.4 | ND | ND |
| | Largemouth bass (2) | 71.4 | ND | ND | ND | ND | ND | 255.9 | 150.7 | 43.6 | 43.1 | ND | ND | ND | ND | 5605.1 | ND | 105.2 | ND | ND |
| State Highway Bridge 199 (Site 9) | Channel catfish (3) | 92.0 | ND | ND | 22.9 | 42.6 | 240.3 | 139.1 | 133.5 | 55.0 | 75.5 | 25.8 | ND | ND | ND | 624.4 | ND | 52.1 | ND | ND |
| | Largemouth bass (2) | 86.1 | ND | ND | 18.5 | 20.2 | 467.0 | 381.5 | 281.7 | 72.6 | 84.0 | ND | ND | 112.5 | 34.5 | 6782.8 | ND | 165.3 | ND | ND |
| | Smallmouth buffalo (1) | 82.3 | ND | ND | ND | ND | 96.1 | 128.7 | 181.1 | 76.7 | 149.9 | ND | ND | ND | ND | 1005.5 | ND | 67.2 | ND | 344.9 |
| West Fork Trinity River (Site 10) | Blue catfish (3) | 54.3 | ND | ND | ND | 24.4 | 374.5 | 325.7 | 209.1 | 94.8 | 63.9 | ND | ND | ND | ND | 1044.1 | ND | 72.6 | ND | ND |
| | Freshwater drum (1) | 60.8 | ND | ND | ND | 26.8 | 562.0 | 450.2 | 309.8 | 143.7 | 97.9 | ND | ND | ND | ND | 4273.4 | ND | 144.7 | ND | ND |

Notes: ND=not detected * PFHpA, FOSA1, 8:2FTS, FHEA, FOEA, FDEA, NEtFOSAA, NMEFOSAA, and GenX were analyzed but not detected. Data not shown.

Figure A1. Length at age for largemouth bass (n = 16), channel catfish (n = 16), and blue catfish (n = 6).

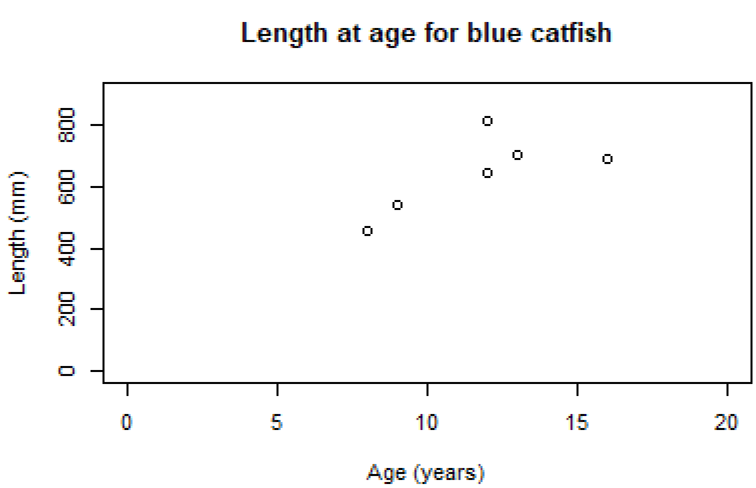
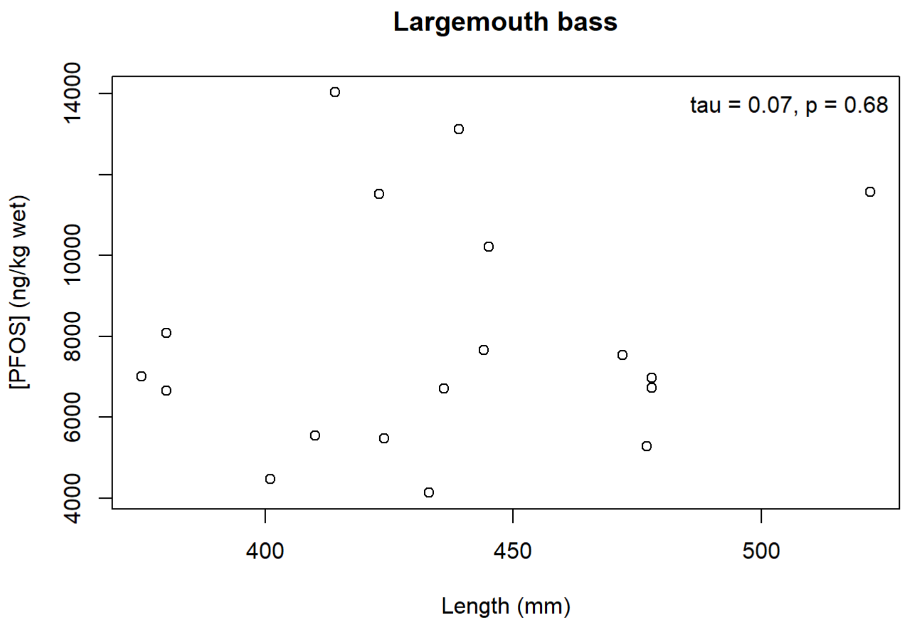
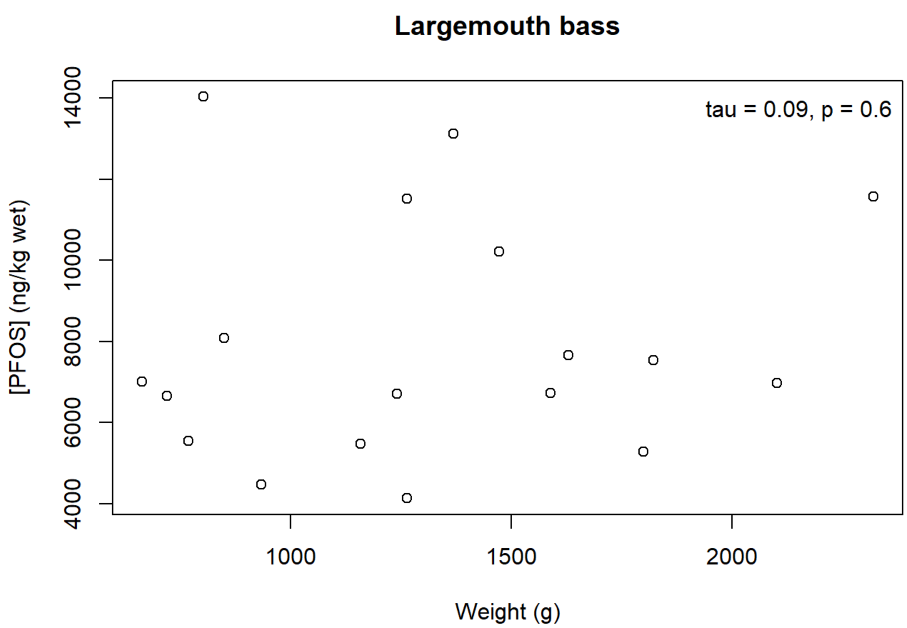
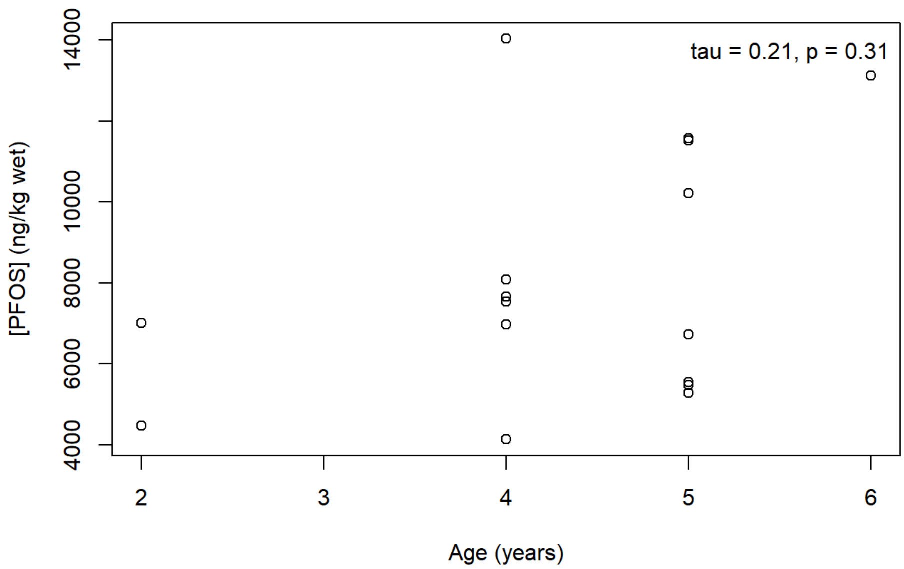



Figure A2. Correlation plots comparing PFOS concentrations (ng/kg wet) with length (mm), weight (g), and age (years) for each fish species. Age was not included for smallmouth buffalo or freshwater drum. Correlations were analyzed using Kendall's Tau, where 0 is not correlated and -1 and 1 are most correlated.

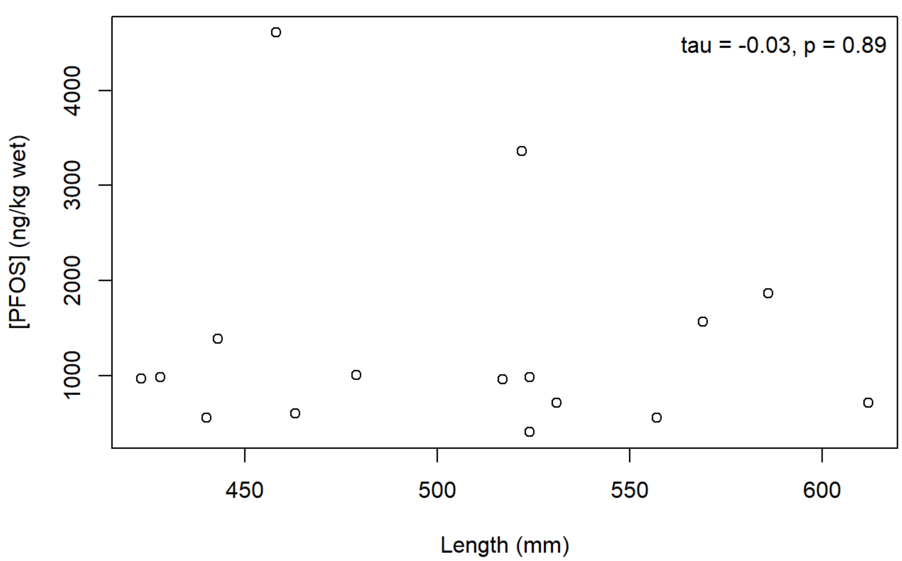


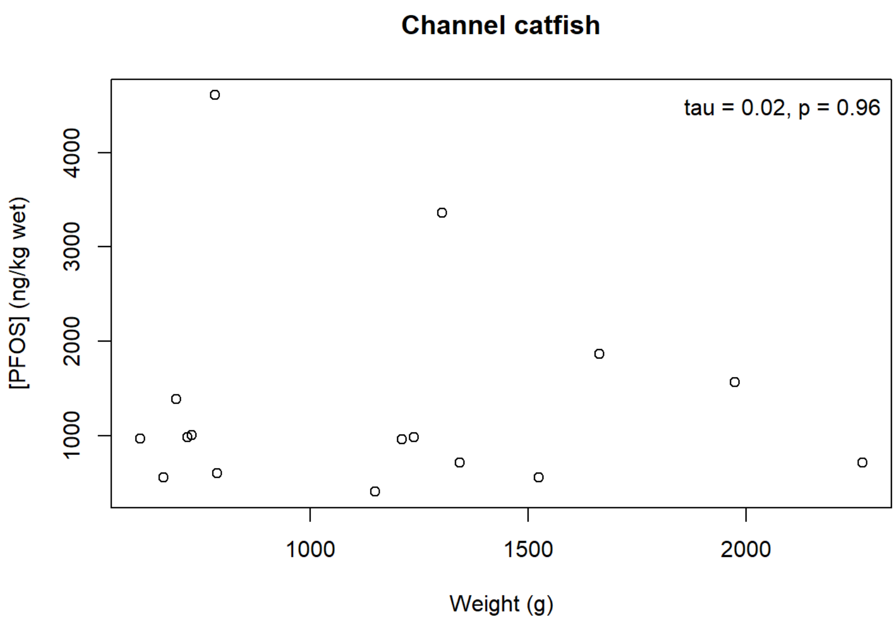



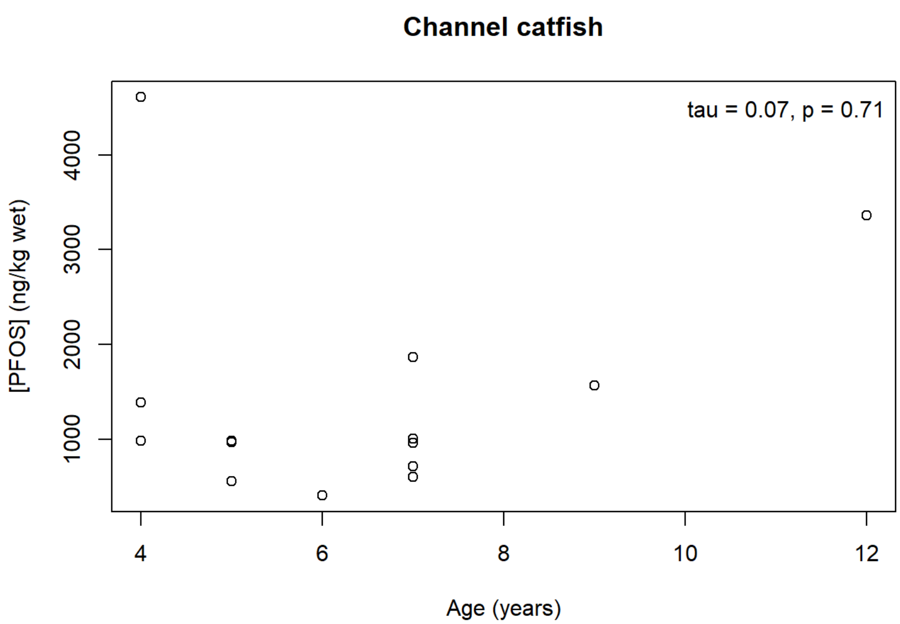
## Largemouth bass

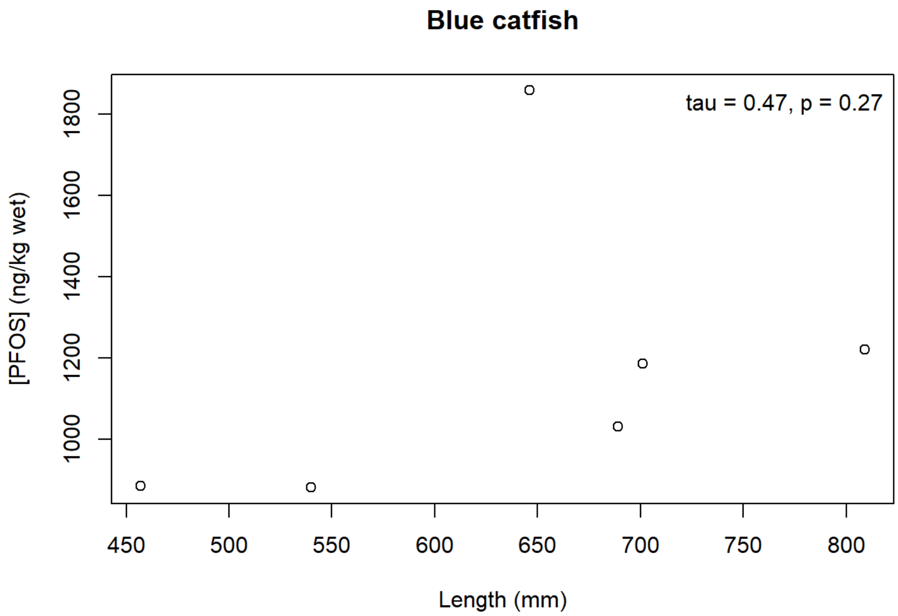



## Channel catfish

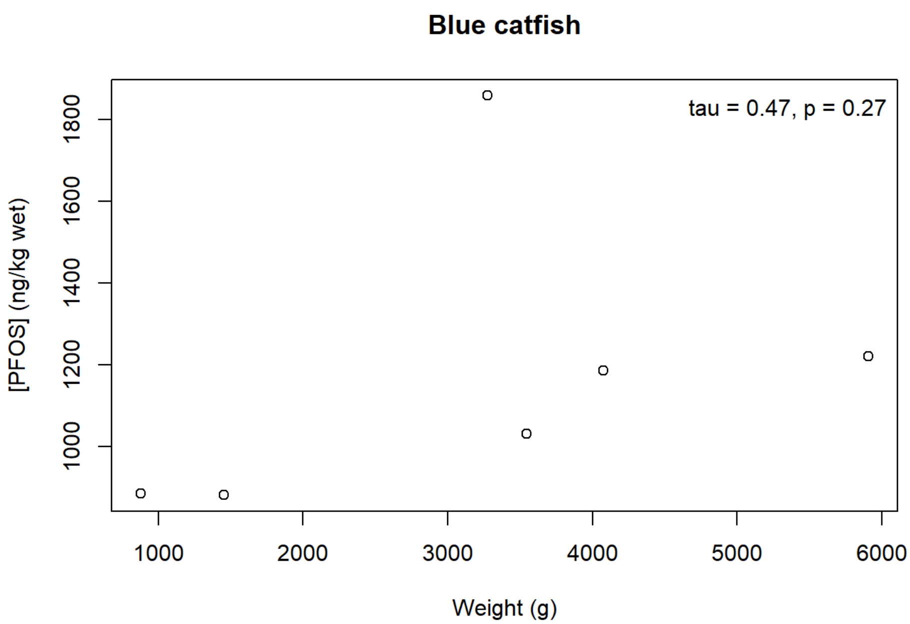



Channel catfish
tau = 0.02, p = 0.96
[PFOS] (ng/kg wet)
1000
2000
3000
4000
1000
1500
2000
Weight (g)

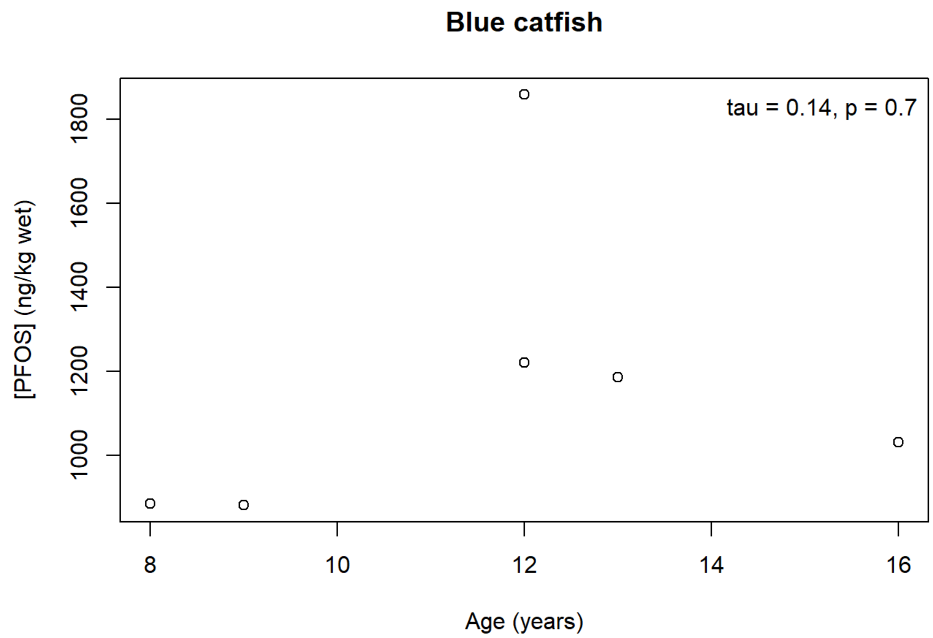

Channel catfish
tau = 0.07, p = 0.71
[PFOS] (ng/kg wet)
1000
2000
3000
4000
4
6
8
10
12
Age (years)

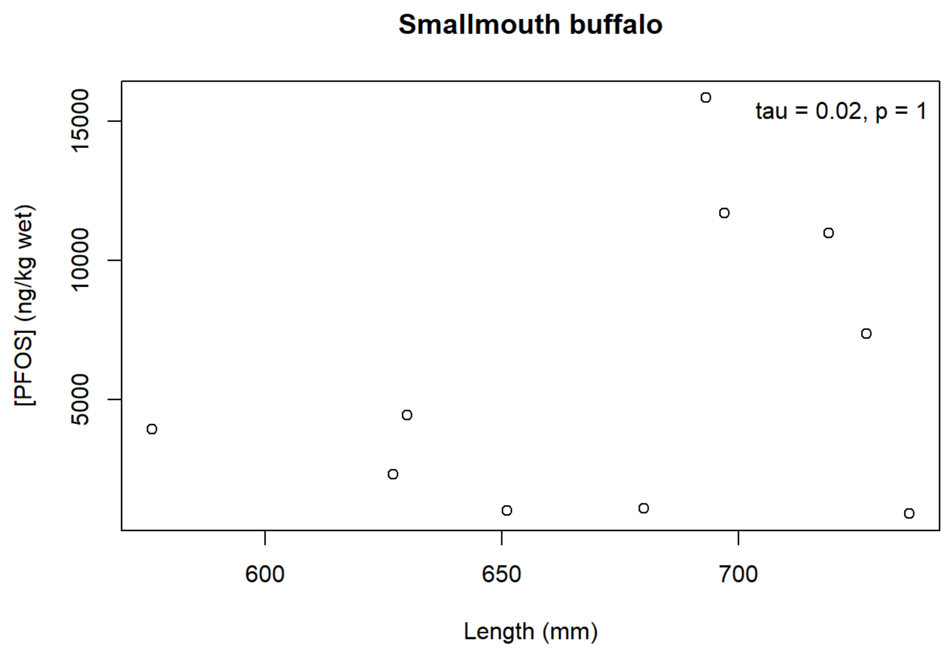


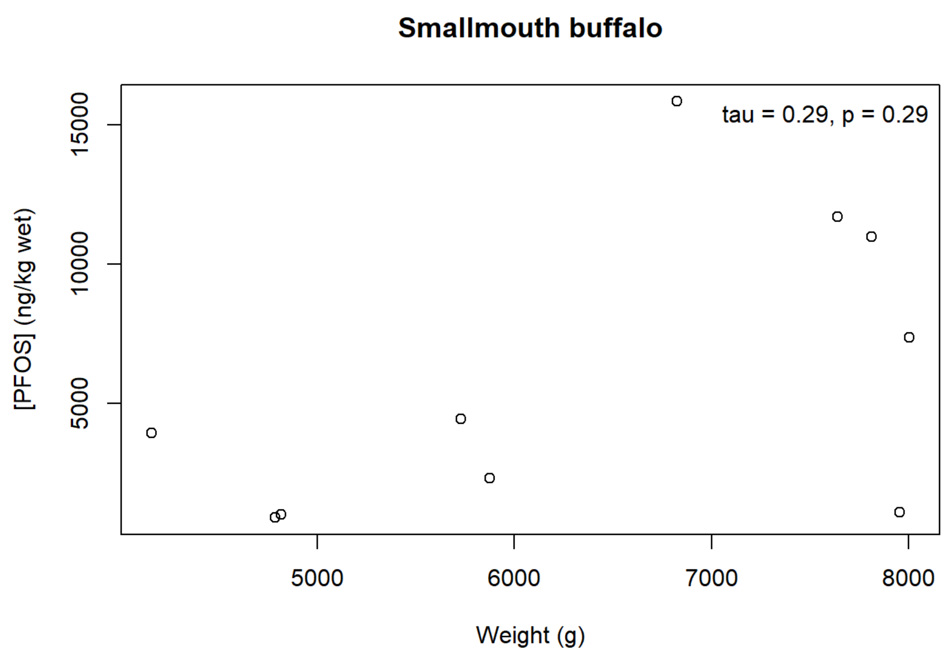
Blue catfish
tau = 0.47, p = 0.27
[PFOS] (ng/kg wet)
1000
1200
1400
1600
1800
450
500
550
600
650
700
750
800
Length (mm)

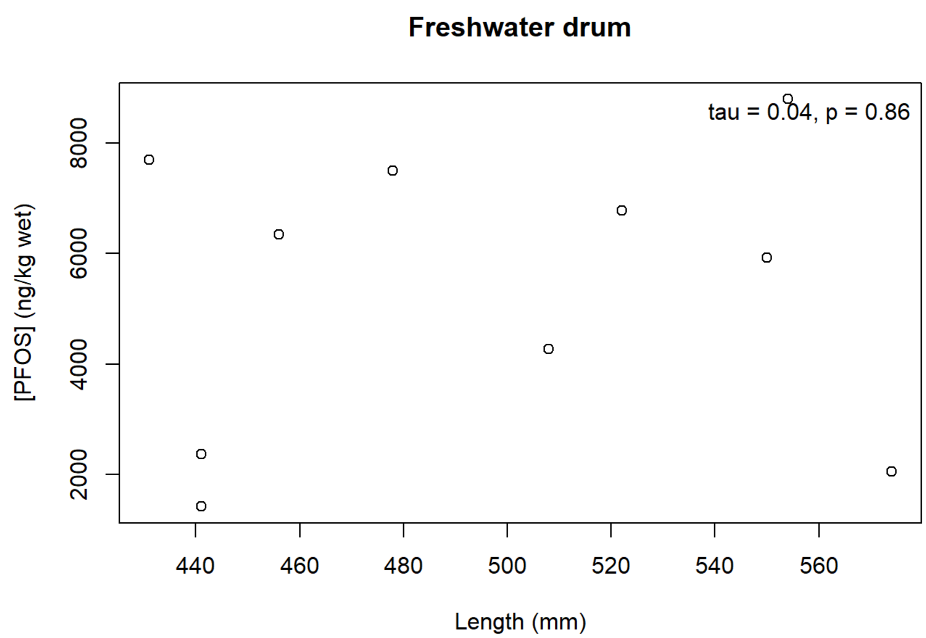



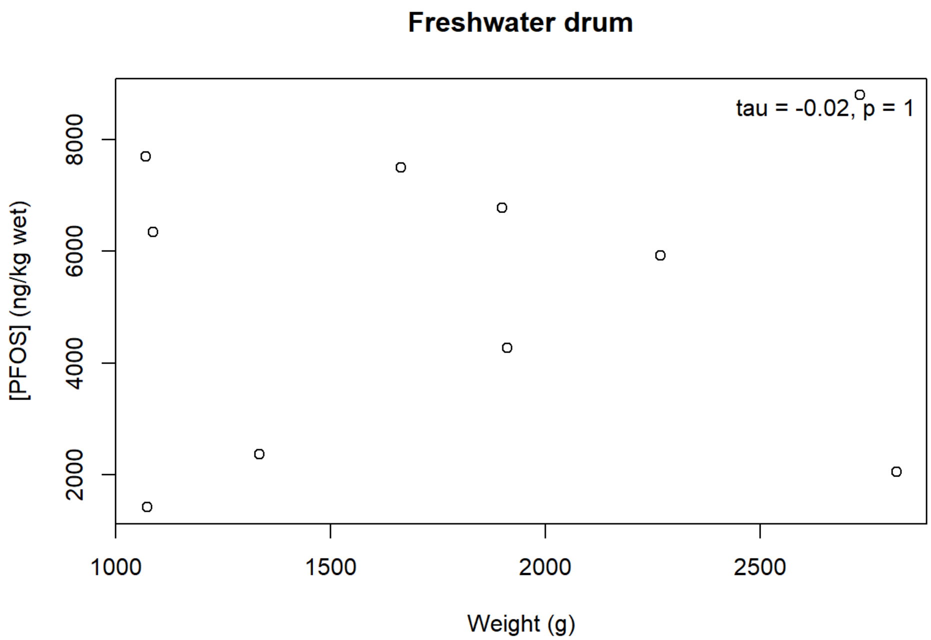
Blue catfish
tau = 0.47, p = 0.27
[PFOS] (ng/kg wet)
1000
1200
1400
1600
1800
1000
2000
3000
4000
5000
6000
Weight (g)


Blue catfish
tau = 0.14, p = 0.7
[PFOS] (ng/kg wet)
1000
1200
1400
1600
1800
8
10
12
14
16
Age (years)


Smallmouth buffalo
tau = 0.02, p = 1
[PFOS] (ng/kg wet)
5000
10000
15000
600
650
700
Length (mm)


Smallmouth buffalo
tau = 0.29, p = 0.29
[PFOS] (ng/kg wet)
5000
10000
15000
5000
6000
7000
8000
Weight (g)


Freshwater drum
tau = 0.04, p = 0.86
[PFOS] (ng/kg wet)
2000
4000
6000
8000
440
460
480
500
520
540
560
Length (mm)


Freshwater drum
tau = -0.02, p = 1
[PFOS] (ng/kg wet)
2000
4000
6000
8000
1000
1500
2000
2500
Weight (g)