



**Environmental
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Aquatic Life Criteria for Per- and Polyfluoroalkyl Substances (PFAS): Results from the Large River Survey

Summary

In 2023 and 2024, Ohio's large rivers across the state were sampled for PFAS compounds (per- and polyfluoroalkyl substances) at 149 sites through a study funded by the H2Ohio Rivers program. Water column, fish body and fillet tissue, and macroinvertebrate tissue samples were collected and analyzed using U.S. Environmental Protection Agency's (U.S. EPA) Method 1633, which provides results for 40 PFAS compounds. The study gives Ohio a baseline measurement of the existence of PFAS in its rivers compared to U.S. EPA's aquatic life criteria.

Ohio EPA found that most samples in all three categories are well below the U.S. EPA's criteria. Nine of the 40 PFAS compounds measured were detected at 80 percent of the sampling locations but at low-level concentrations. Ohio's statewide survey results are similar to those of neighboring states.

Aquatic Life Criteria

The U.S. EPA has established [aquatic life criteria](#) and benchmarks for ten PFAS. These substances have been widely employed by industry, numbering in the thousands, and are used in many common products. They are extremely difficult to break down through natural processes and consequently are ever-present in the environment, typically in vanishingly small concentrations. However, some PFAS compounds are more common than others, especially Perfluorooctanesulfonic acid (PFOS), an agent used in certain firefighting foams, and Perfluorooctanoic acid (PFOA), an agent used in non-stick coatings.

The aquatic life criteria were established in response to growing evidence that linked PFAS to adverse environmental outcomes. These criteria are intended to protect the diversity and abundance of aquatic life in freshwater lakes, rivers, and streams. Extensive toxicological testing of the effects of PFOA and PFOS on various organisms has identified acute and chronic criteria, which are listed in Table 1.

Table 1. U.S. Environmental Protection Agency aquatic life criteria for PFOA and PFOS

Criteria Component	Acute Water Column (CMC)* (mg/L)	Chronic Water Column (CCC) [†] (mg/L)	Invertebrate Whole-Body (mg/kg ww [‡])	Fish Whole-Body (mg/kg ww [‡])	Fish Muscle (mg/kg ww [‡])
PFOA Magnitude	3.1	0.10	1.18	6.49	0.133
PFOS Magnitude	0.071	0.00025	0.028	0.201	0.087
Duration	1-hour average	4-day average	Instantaneous	Instantaneous	Instantaneous
Frequency	Not to be exceeded more than once in three years, on average	Not to be exceeded more than once in three years, on average	Not to be exceeded	Not to be exceeded	Not to be exceeded

* Criterion Maximum Concentration

[†] Criterion Continuous Concentration

[‡] Wet Weight

Acute water column benchmarks have also been established for eight additional compounds¹. These compounds and their corresponding benchmarks are listed in Table 2.

Table 2. U.S. Environmental Protection Agency acute water quality benchmarks for eight additional PFAS

Compound	Water Column (mg/L)
Perfluorobutanoic acid (PFBA)	5.30
Perfluorohexanoic acid (PFHxA)	4.80
Perfluorononanoic acid (PFNA)	0.65
Perfluorodecanoic acid (PFDA)	0.50
Perfluorobutanesulfonic acid (PFBS)	5.00
Perfluorohexanesulfonic acid (PFHxS)	0.21
Hexadecafluoro-2-decenoic acid (8:2 FTUCA)*	0.037
Pentadecafluorodecanoic acid (7:3 FTCA)	0.012

* 8:2FTUCA is not included in Method 1633

Unlike hydrophobic contaminants such as polychlorinated biphenyls (PCBs), PFAS have comparatively short half-lives in the tissues of aquatic organisms (Martin et al. 2003; Jørgensen et al. 2006). What this suggests is that if a source of PFAS contamination is detected and remediated, the response by aquatic organisms, either in terms of recovery from exposure or reductions in body burdens of the compound, will be relatively fast.

¹ Determining chronic endpoints takes more extensive testing, as thresholds for sublethal effects need to be identified.

Baseline Determination of PFAS Concentrations in Ohio's Large Rivers

To understand the potential to which our principal rivers in the state are affected by PFAS contamination, a study was commissioned to systematically sample large rivers throughout the state. Large rivers in this context are defined as those with drainage areas 500 mi² or greater. Details of sampling locations and collection methodologies are found in the companion report prepared by EnviroScience². The following media were collected at each sampling location and analyzed for PFAS: the water column, a composite of benthic macroinvertebrates, and, in any combination or aggregate, whole bodies of bluegill sunfish, spotfin shiner, and fillets of channel catfish. [Method 1633](#) was the laboratory analytical method used to quantify the concentrations of 40 PFAS compounds in sampled media.

The results from the study provide a snapshot of present conditions across the state and establish a baseline for future comparisons. Evaluating the results against the aquatic life criteria helps quantify the potential risk these contaminants may pose to Ohio's rivers. Lastly, the results from the study can be compared to findings reported from adjacent states for the context of understanding where Ohio's results fall within the range of those other studies.

Comparison to Aquatic Life Criteria: Water Column Samples

None of the concentrations measured in water column samples for PFOS or PFOA surpassed the chronic or acute criteria for aquatic life, as shown in Figure 1. The highest reported value for PFOS was 100 ng/L, compared to the chronic criterion of 250 ng/L. The highest reported value for PFOA was 13 ng/L, compared to the chronic criterion of 100,000 ng/L. Five samples for both PFOS and PFOA were reported at less than analytical reporting limits. Modeled distributions that accounted for these censored values (values reported at less than the analytical reporting limits) were fitted by maximum likelihood for each compound using the [fitdistrplus package](#) in [R](#). The respective modeled distributions³ based on modeled parameters are included in Figure 1. The model distributions are similar to the empirical distributions because most of the data are above analytical reporting limits, as expected.

² Large River Emerging Contaminants Sampling and Analysis Project, 2023 and 2024

³ The modeled distributions are based on 1,000 random deviates.

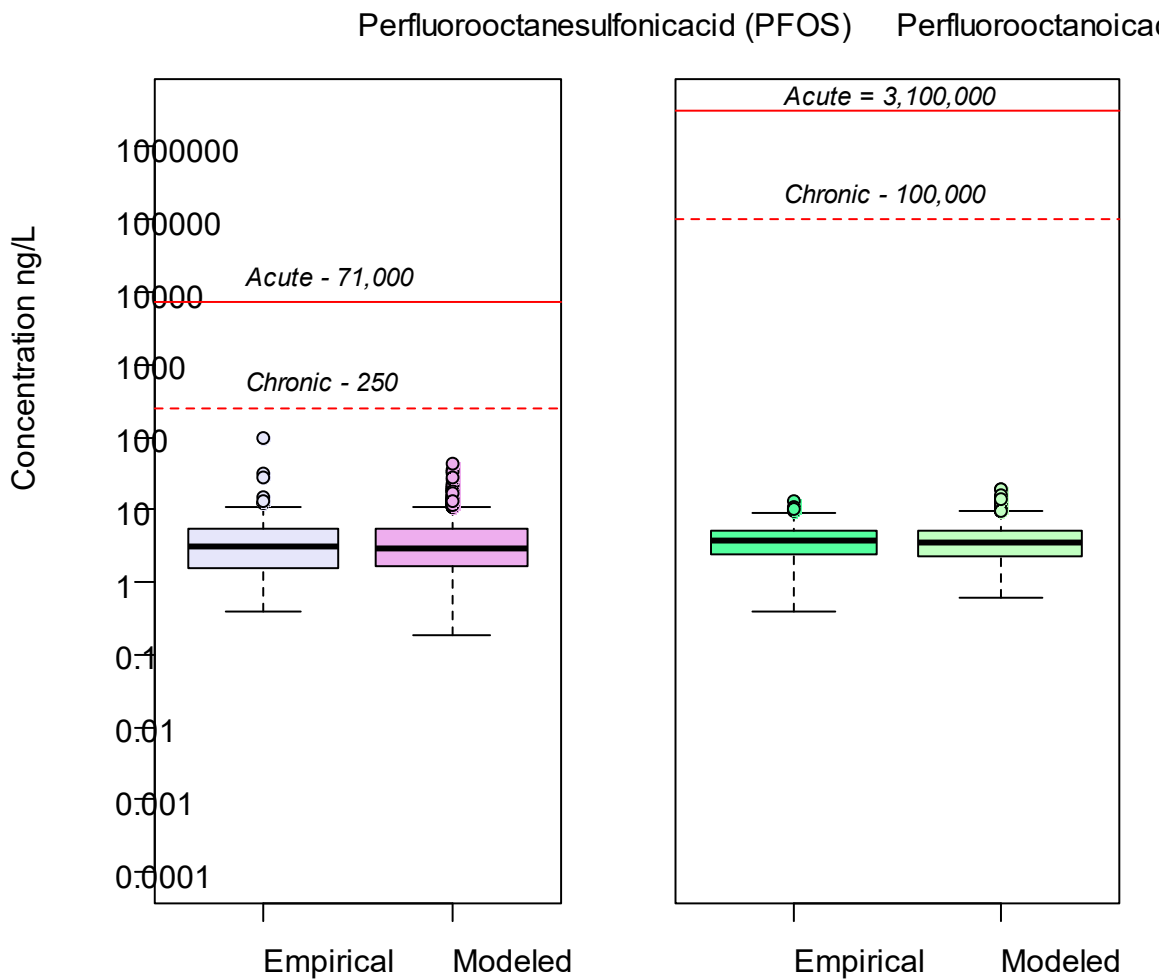


Figure 1. Empirical and modeled distributions of PFOS and PFOA in relation to chronic and acute aquatic life criteria.

For the seven compounds included in Method 1633 where acute benchmarks have been derived, none were above their respective benchmark, and the maximum reported values were all 2 to 5 orders of magnitude less than those benchmarks, as shown in Figure 2.

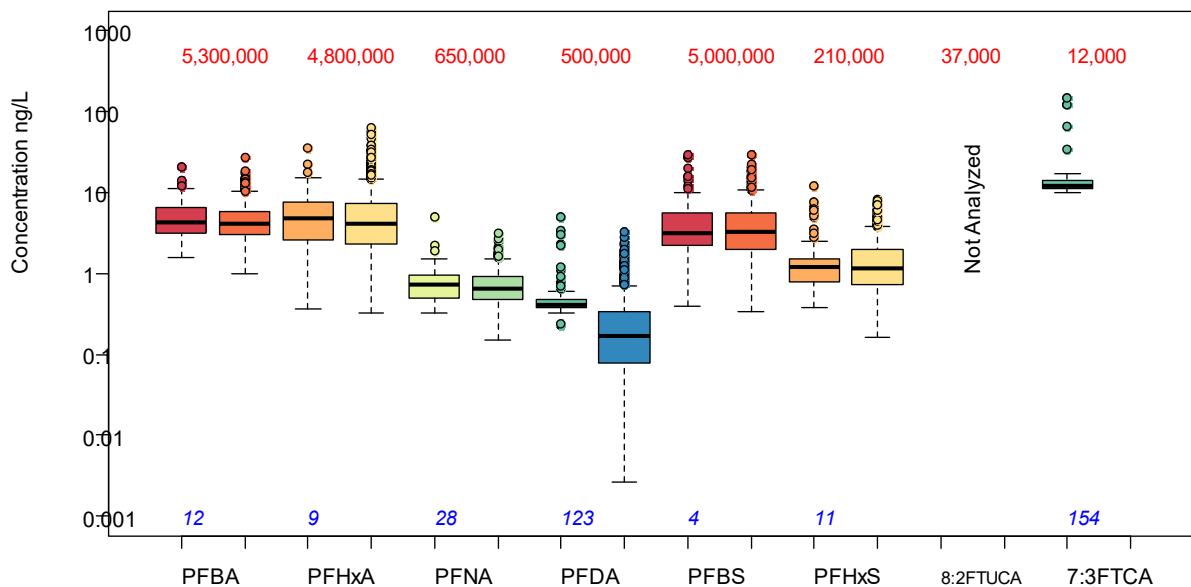


Figure 2. Concentrations of PFAS compounds where acute aquatic life benchmarks have been established. The respective benchmark values are arrayed along the top margin and appear in red font. The blue numbers along the bottom margin show the number of results that were below analytical detection limits (i.e., censored values). Empirical distributions for each parameter are shown above the label on the x-axis, and modeled distributions are shown to the immediate right. For the heavily censored PFDA, the modeled distribution provides a likely more realistic portrayal of actual concentrations in the environment. All the values for 7:3FTCA were below the analytical reporting limits and are reported here at those limits. Because no 7:3FTCA values were above the reporting limits, a realistic modeled distribution could not be constructed, but the concentrations are expected to be vanishingly low.

Comparison to Aquatic Life Criteria: Tissue Samples

None of the tissues sampled for PFOA exceeded the aquatic life criteria, and where detections occurred, those were typically two to three orders of magnitude less than corresponding criteria (Figure 2). Over half of the sample results in all four tissue types were either at non-detectable levels or below the quantification ability⁴ of the analytical method; hence, Figure 3 includes both the empirical and modeled distributions for PFOA by tissue type. For heavily censored results, the modeled distributions provide an estimate for what is likely extant in the environment.

⁴ The analytical method may either not detect a compound, or detect that a compound is present but at a level too small to be reliably converted into a concentration. These cases are both treated as censored values when modeling the distributions.

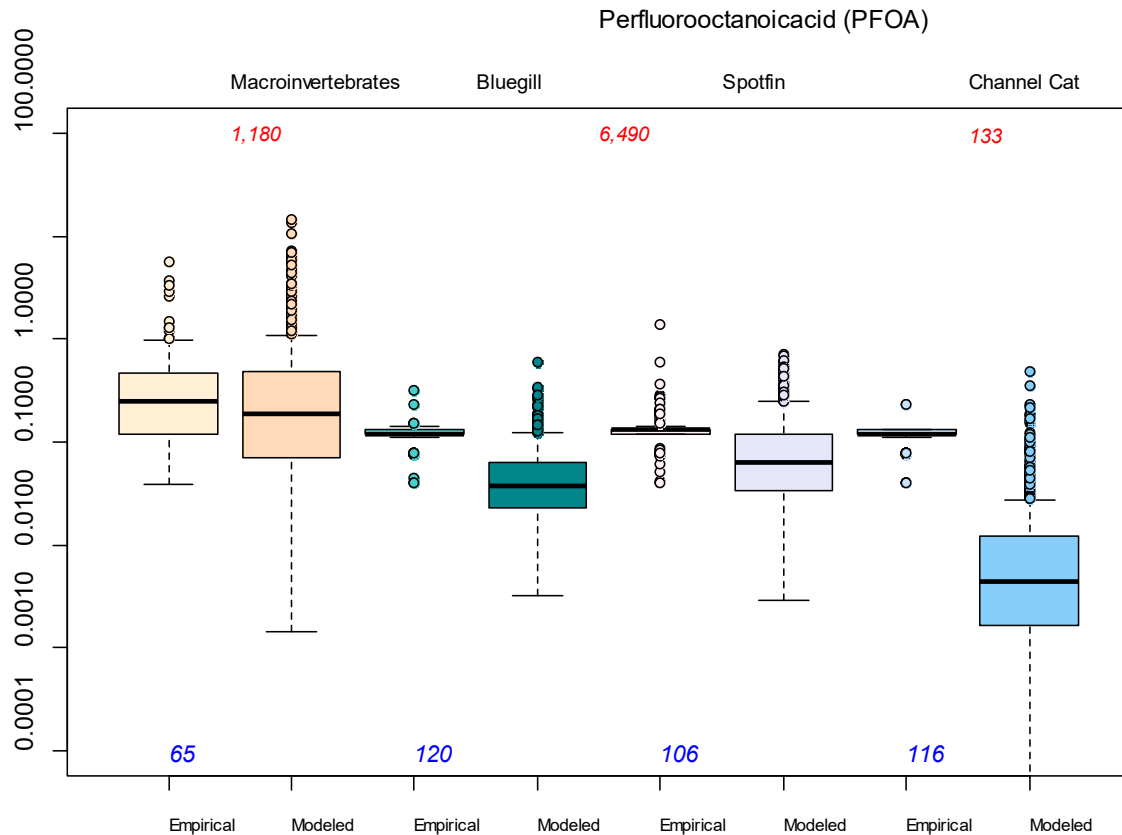


Figure 2. Tissue results for PFOA from composite benthic macroinvertebrate samples, whole body bluegill sunfish, whole body spotfin shiner, and fillets from channel catfish. The red numbers along the top margin are the respective aquatic life criteria values in ng/g (macroinvertebrate, whole body fish, fillet). The blue numbers along the bottom show the number of results reported at less than analytical quantification limits. Y-axis units are ng/g.

One bluegill tissue sample exceeded the aquatic life criteria for PFOS. Otherwise, concentrations were typically one to two orders of magnitude less than the respective criteria, as shown in Figure 3. Most results were reported above quantification limits. The one bluegill sample that exceeded the criterion for whole body fish was re-analyzed to confirm the first result (the two results were 450 and 220 ng/L).

Perfluorooctanesulfonicacid (PFOS)

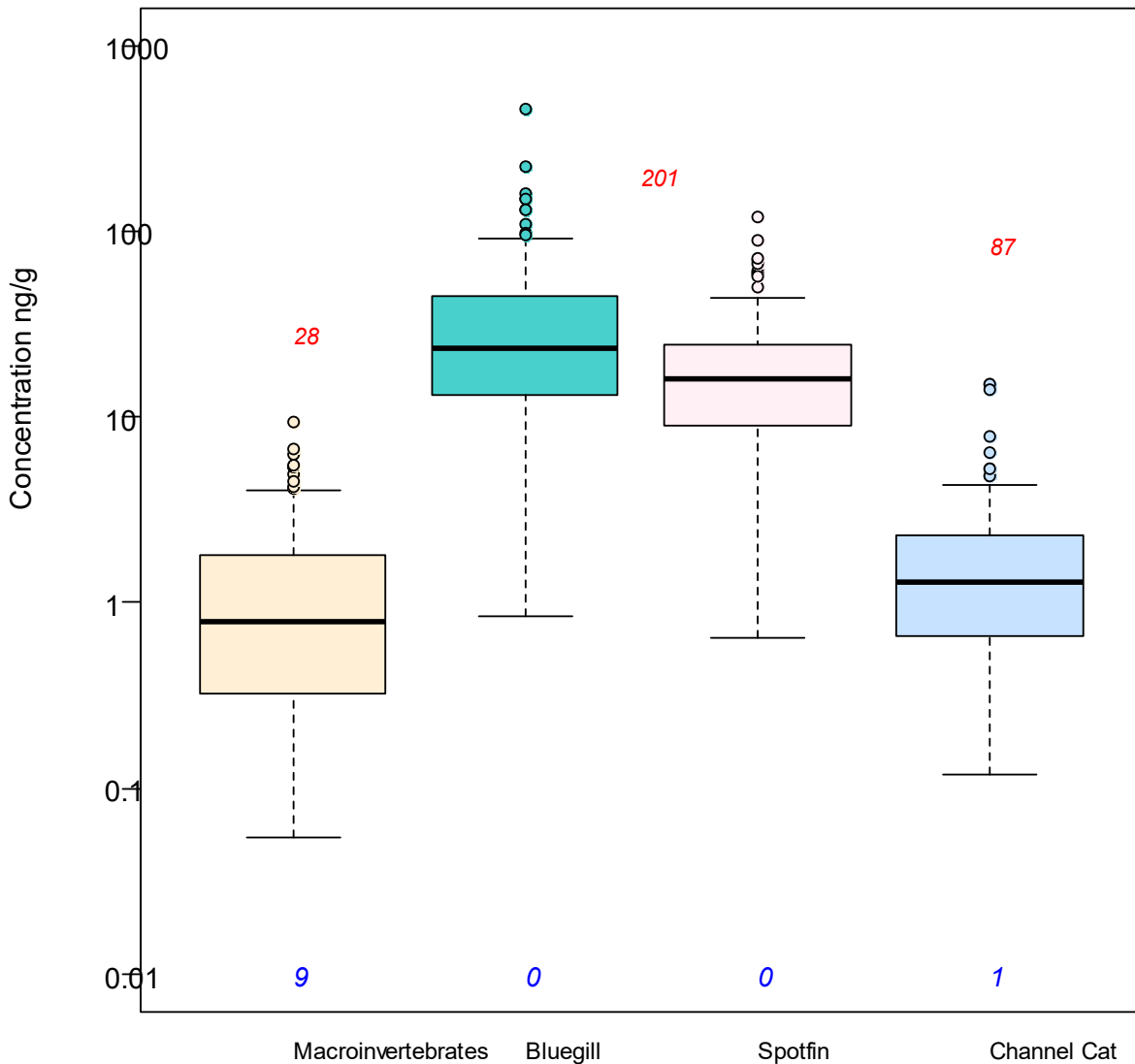


Figure 3. Tissue concentrations of PFOS for composite macroinvertebrate samples, whole body bluegill sunfish and spotfin shiner, and channel catfish fillets. The red numbers correspond to the respective aquatic life criteria (ng/g). The blue numbers show the number of results reported at less than quantification limits. The two points that exceed the 201 ng/g criterion for whole body fish are from the same bluegill sample.

PFOS was the only compound where a relatively strong relationship between water column concentrations and tissue concentrations was consistently detected across tissue types. Figure 4 shows scatter plots of PFOS tissue concentrations on water column concentrations for each of the sampled media. A weak association was also observed with the compound PFDA across tissue types (Figure 5). The only association of note was between spotfin shiner and the compound PFHxS ($r = 0.318$).

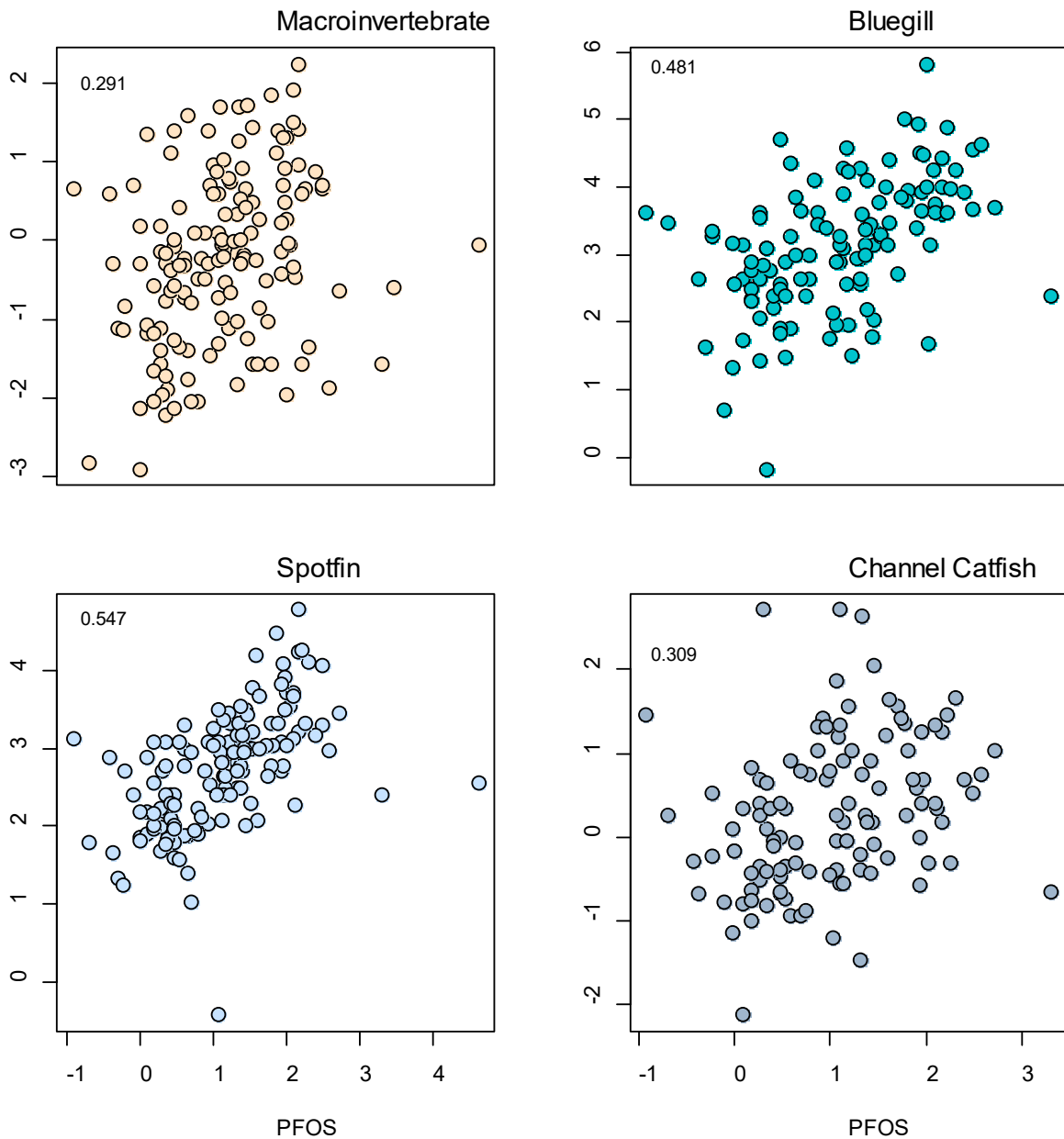


Figure 4. Scatter plots of tissue concentrations (y-axes) and water column concentration (x-axes). Units are natural log (ng/g for the y-axis; ng/L for the x-axis). The numbers in the upper left corner of each plot are the respective correlation coefficients.

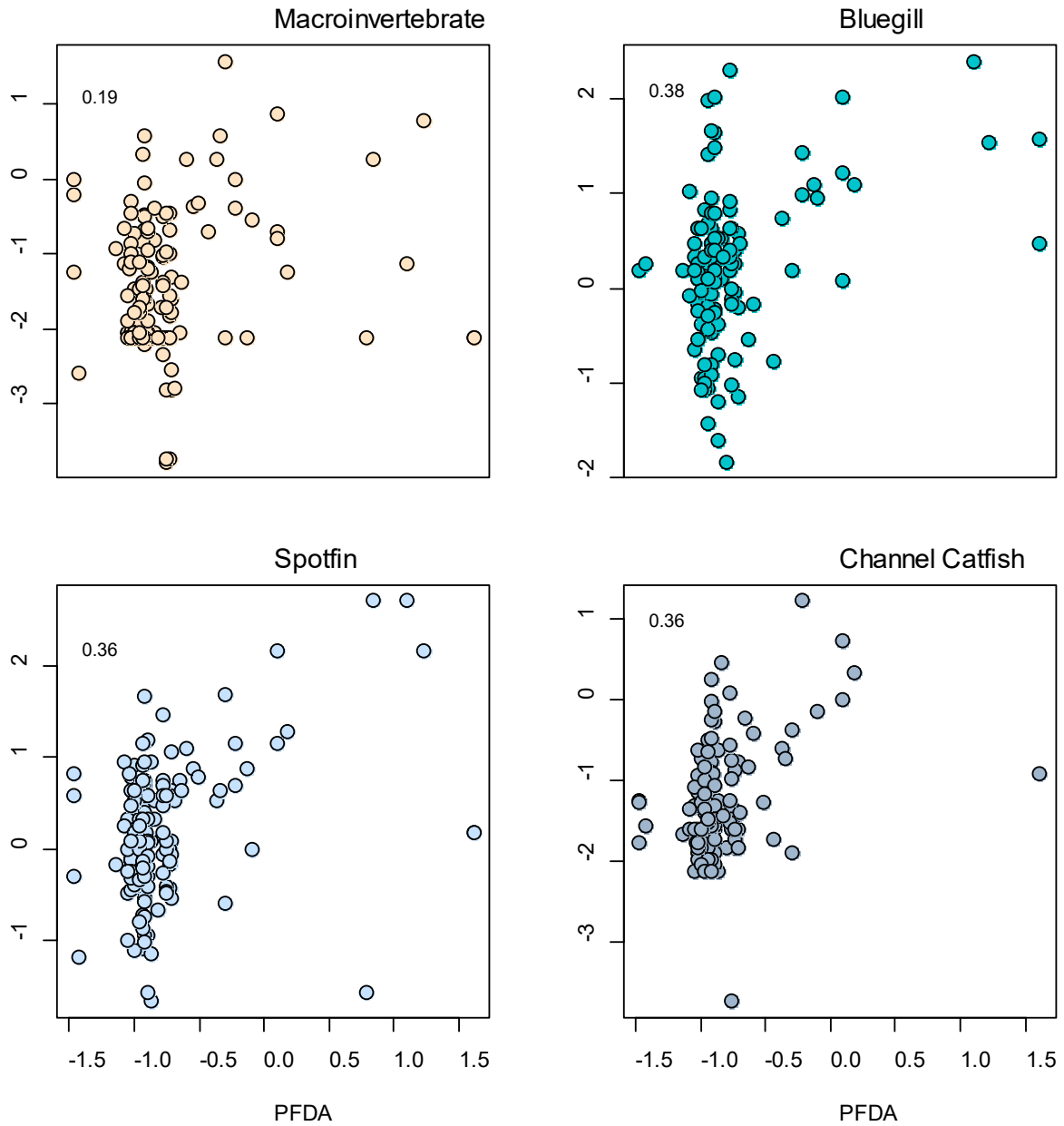


Figure 5. Scatter plots of tissue concentrations (y-axes) and water column concentration (x-axes). Units are natural log (ng/g for the y-axis; ng/L for the x-axis). The numbers in the upper left corner of each plot are the respective correlation coefficients.

Table 3. Correlations (Pearson) between water column and tissue concentrations of 40 PFAS compounds covered under Method 1633. Compounds are listed by their shorthand names. For a list of shorthand names and corresponding analytical names, see Appendix Table 1.

PFAS Compound	Macroinvertebrate	Bluegill	Spotfin	Channel Catfish
11Cl-PF3OUdS	-0.036	-0.104	-0.049	-0.111
3:3FTCA	0.196	0.134	0.225	0.287
4:2FTS	0.159	0.076	0.164	0.195
5:3FTCA	0	0.029	0.044	0.039
6:2FTS	0.231	-0.061	0.006	-0.006
7:3FTCA	-0.114	-0.101	-0.118	-0.148
8:2FTS	0.284	0.007	0.081	0.08
9Cl-PF3ONS	0.12	0.059	0.136	0.159
ADONA	0.318	0.24	0.363	0.434
HFPO-DA	0.019	-0.031	0.017	-0.012
NEtFOSA	0.019	0.175	0.107	0.286
NEtFOSAA	-0.05	0.303	0.382	-0.317
NEtFOSE	0.201	0.141	0.262	0.307
NFDHA	-0.032	0.006	-0.027	-0.087
NMeFOSA	-0.163	-0.246	-0.031	-0.368
NMeFOSAA	-0.282	-0.042	-0.048	-0.379
NMeFOSE	0.196	0.023	0.037	0.171
PFBA	0.214	0.258	0.25	0.27
PFBS	0.002	0.183	0.019	-0.038
PFDA	0.19	0.376	0.359	0.36
PFDoA	-0.095	0.048	0.06	-0.122
PFDoS	0.074	0.015	0.073	0.1
PFDS	0.078	-0.009	0.028	0.062
PFEESA	0.107	0.082	0.123	0.124
PFHpA	0.133	0.089	-0.044	0.024
PFHpS	0.123	0.114	0.038	0.159
PFHxA	0.066	0.102	0.042	0.036
PFHxS	-0.044	0.16	0.318	-0.367
PFMBA	0.293	0.207	0.326	0.4
PFMPA	0.322	0.233	0.359	0.435
PFNA	0.058	0.277	0.234	0.298
PFNS	0.082	0.193	0.094	0.095
PFOA	0.048	0.315	0.285	0.212
PFOS	0.291	0.481	0.547	0.309
PFOSA	0.047	0.264	0.101	0.136
PFPeA	-0.066	0.074	0.04	0.033
PFPeS	-0.127	-0.199	-0.145	-0.265
PFTeA	-0.056	-0.043	0.092	0.026
PFTriA	-0.104	-0.02	0.051	-0.055
PFUnA	-0.16	0.018	0.093	0.089

General Findings – Water Column

Of the 40 PFAS compounds included in Method 1633, nine were detected at 80% of the sampling locations (Figure 6), but typically at concentrations near laboratory detection limits. The distributions show a bimodal pattern of two peaks, one centered on ~ 1 ng/L, and another on ~5 ng/L, with a small fraction of observations exceeding ~ 20 ng/L. The commonality in distributions likely reflects the presence of residual background contamination of these compounds in the environment. The relatively small fraction of comparatively high concentrations potentially reflect contamination from localized, recent or existing sources.

Comparisons to results published by neighboring states or jurisdictions (Figure 7) shows that the concentrations for PFOA from Ohio are statistically indistinguishable from those reported by Ohio River Valley Water Sanitation Commission (ORSANCO)⁵ or Pennsylvania (Breitmeyer et al. 2024). The PFOA concentrations from Michigan averaged lower compared to the other three jurisdictions, but Michigan reported higher maximum values. Note that the Michigan and Pennsylvania data sets include targeted and background samples.

⁵ Data for ORSANCO, Michigan EGLE, and Indiana IDEM are available on the respective agency websites.

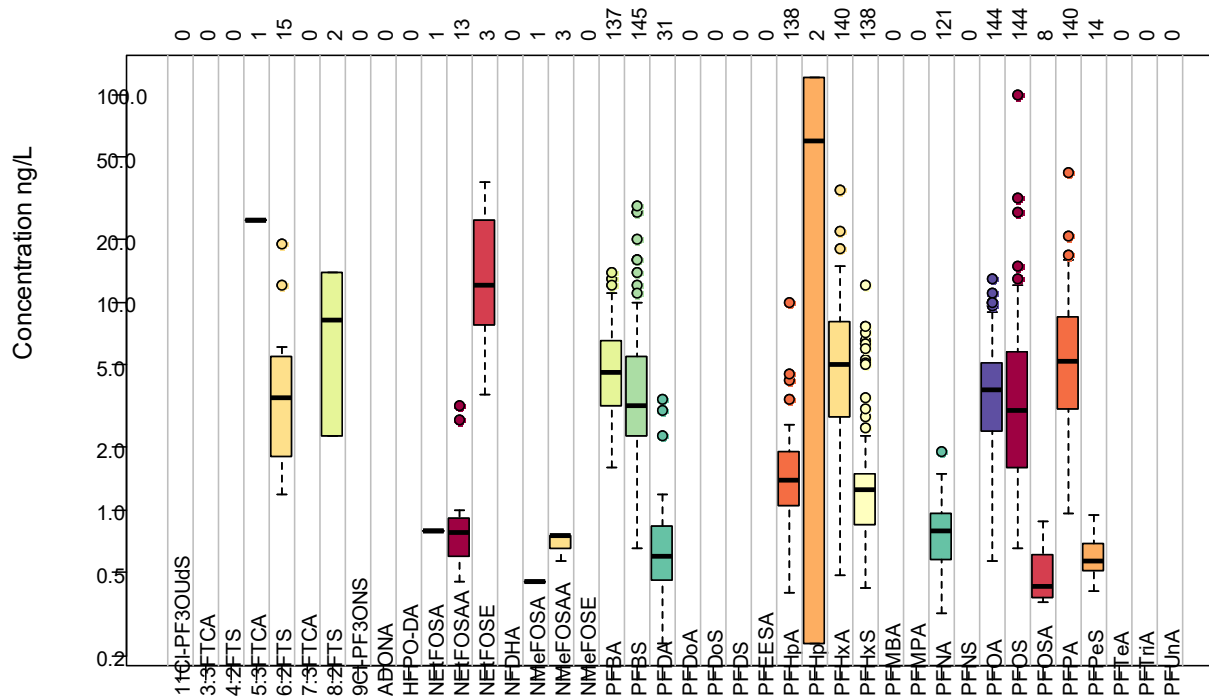


Figure 6. Distributions of PFAS compounds detected in water column samples. Only values reported above quantification limits are included in the distributions. The numbers arrayed along the top margin show the respective number of detections.

The average concentrations of PFOS are similar across jurisdictions. Again, the tendency to observe higher concentrations in the Michigan, and to a lesser extent the Pennsylvania, data sets, likely reflects targeted sampling in those cases. For PFHpS concentrations, Ohio averaged lower than the other jurisdictions. The overall similarity of distributions across the four domains reinforces the suggestion that observed concentrations largely reflect low-level background contamination.

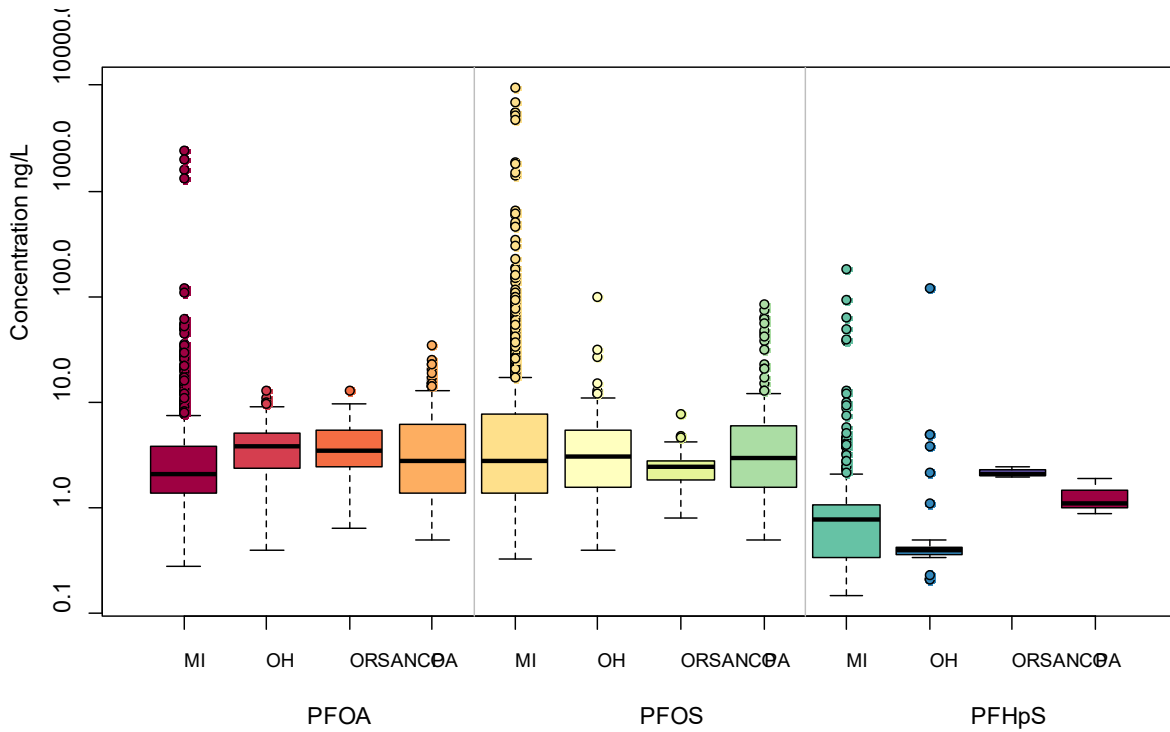


Figure 7. Distributions of concentrations of water PFOA, PFOS and PFHpS for Michigan, Ohio, ORSANCO, and Pennsylvania. The distributions include values reported below quantification limits (note that few results for PFOA or PFOS are below quantification limits in all cases).

That said, the variation in concentrations of PFAS compounds tends to decrease with increasing drainage area (Figure 8). This suggests that contamination is not uniform across the landscape and that smaller streams are more influenced by proximal sources. While the first point is self-evident, the second implies that sampling in streams smaller than those included in the target population of this survey may occasionally yield results exceeding the chronic aquatic life criteria for PFOS.

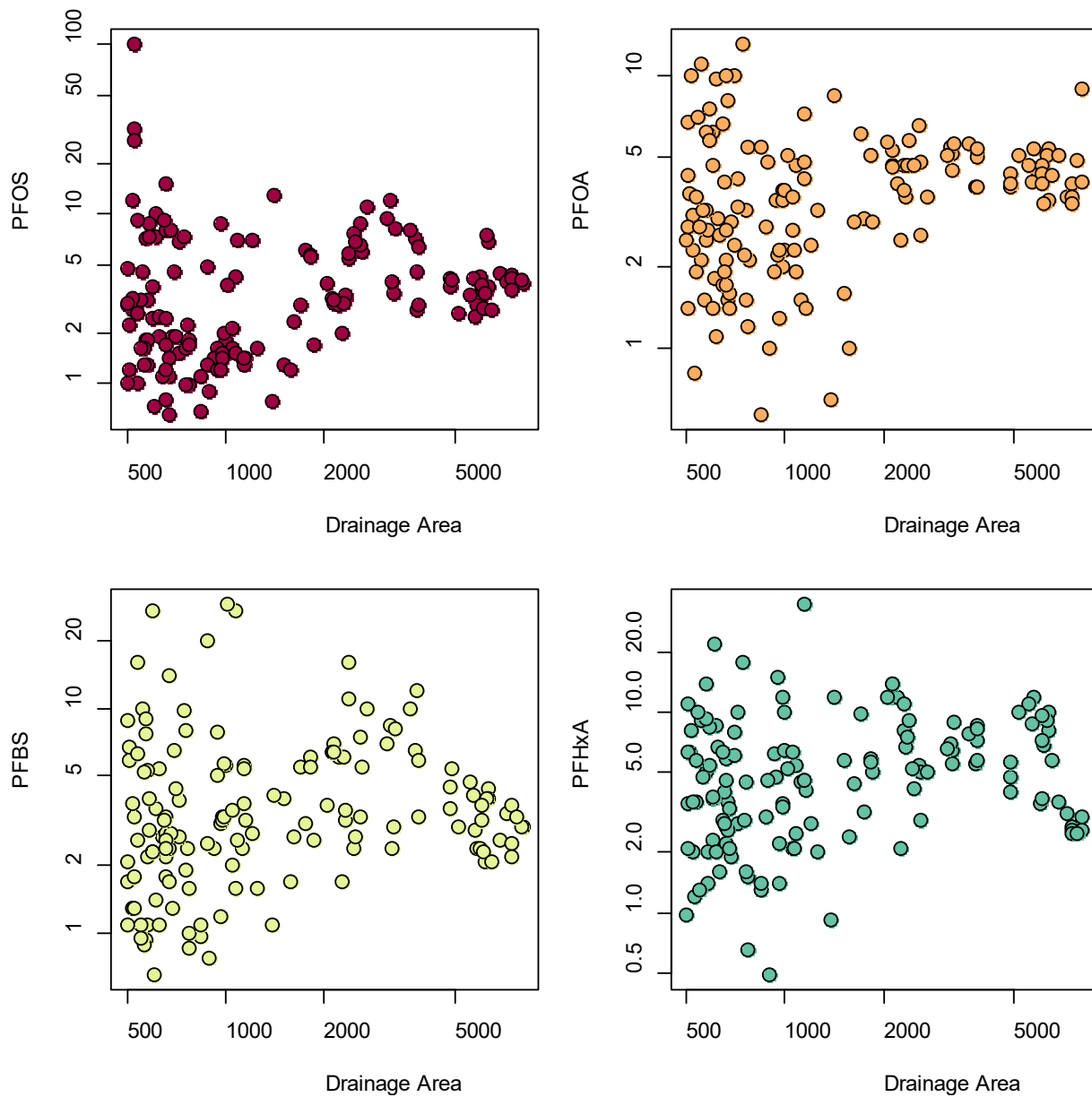


Figure 8. Concentrations of selected PFAS compounds in water samples plotted against drainage area.

General Findings – Tissue

Figures 10-13 show distributions of PFAS concentrations reported above quantification limits in tissue samples collected during the Large River survey. The pattern across fish tissue appears superficially similar, with PFOS, PFDA, and PFUnA tending to have the highest concentrations and most detections across media. This pattern was similarly reported for New Jersey by Goodrow et al. (2020). These three PFAS compounds are all considered long-chain forms, which tend to have the longest half-lives in tissue (Martin et al. 2003). PFOS and PFDA were the only compounds that had relatively strong associations between water column and tissue concentrations in fish; however, PFUnA was not detected above quantification limits in water

samples. This latter observation demonstrates a practical aspect of monitoring tissues. Apart from PFOS, concentrations tended to be relatively low, and generally within the same magnitude (i.e., 75% of the detections above quantification limits were between 0.1 to 1 ng/g).

Macroinvertebrate tissue had a tendency toward higher concentrations of precursor compounds (Figure 12) relative to fish, especially for 5:3 fluorotelomer carboxylic acid (5:3 FTCA). 5:3 FTCA is a precursor of PFHxA and PFBA and is often a dominant constituent of PFAS found in landfills, being a coating used on carpets⁶. Apart from the precursor compounds, the distributions of other compounds followed a similar pattern as that observed in fish tissue. Macroinvertebrates have been identified as an important vector in moving PFAA precursors up the food chain (Hopkins et al. 2023).

Relative to findings available from adjacent states (Michigan and Indiana), the distribution of concentrations of PFOS in channel catfish fillet samples from Ohio are statistically indistinguishable from those from Indiana (Figure 13), and lower than those from Michigan. The Michigan results, however, include more targeted samples than those from Ohio or Indiana. These results reflect the low-level but pervasive contamination of PFAS compounds in the environment.

⁶ <https://pfas-1.itrcweb.org/2-6-pfas-releases-to-the-environment/>

Bluegill Sunfish

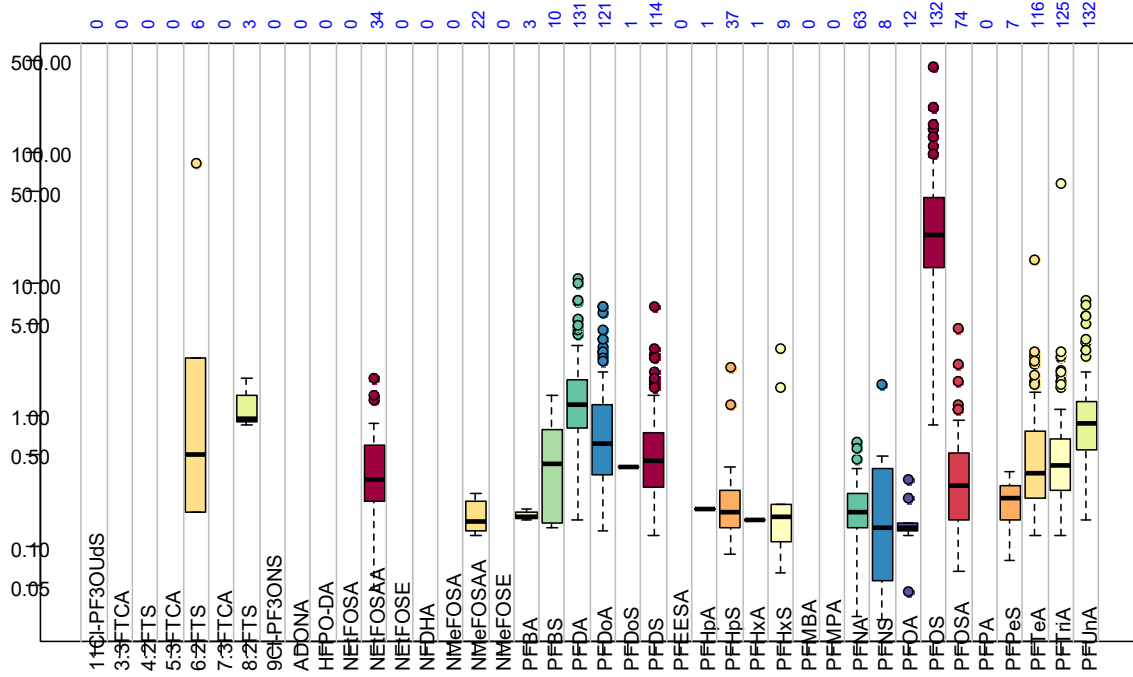


Figure 9. Distributions of PFAS compounds detected above quantification limits in whole-body bluegill sunfish samples. The blue numbers arrayed along the top margin show the number of detections. Note that the y-axis range varies between Figures 10-13. Y-axis units are ng/g.

Spotfin Shiner

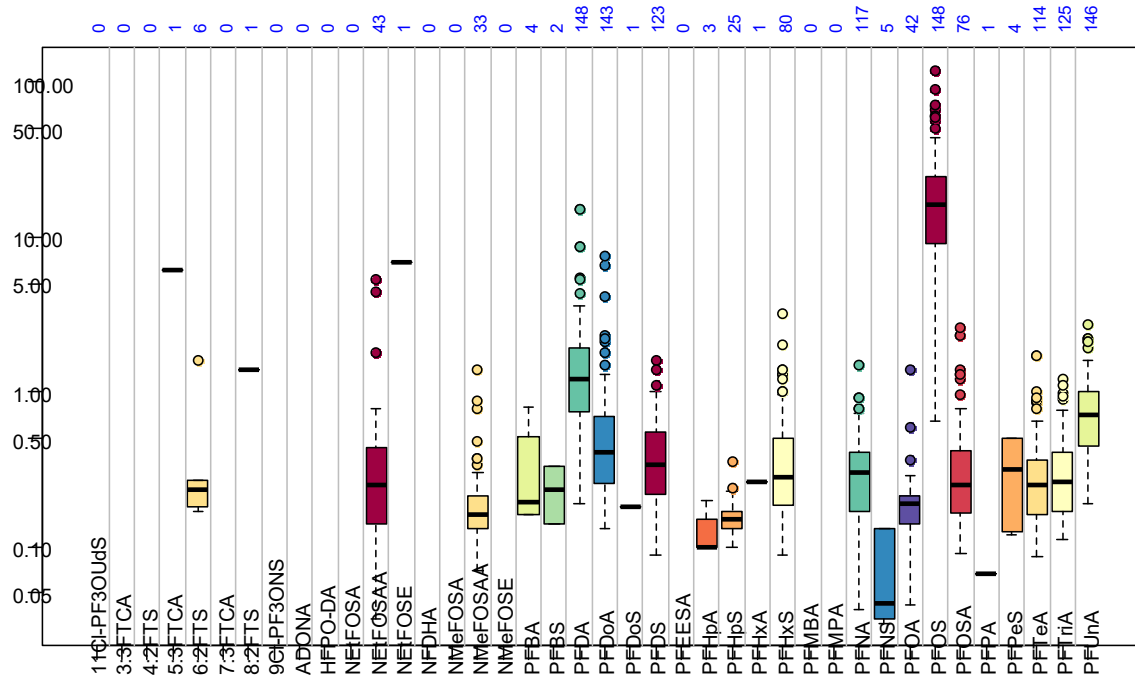


Figure 10. Distributions of PFAS compounds detected above quantification limits in whole-body spotfin shiner samples. The blue numbers arrayed along the top margin show the number of detections. Y-axis units are ng/g.

Channel Catfish Fillet

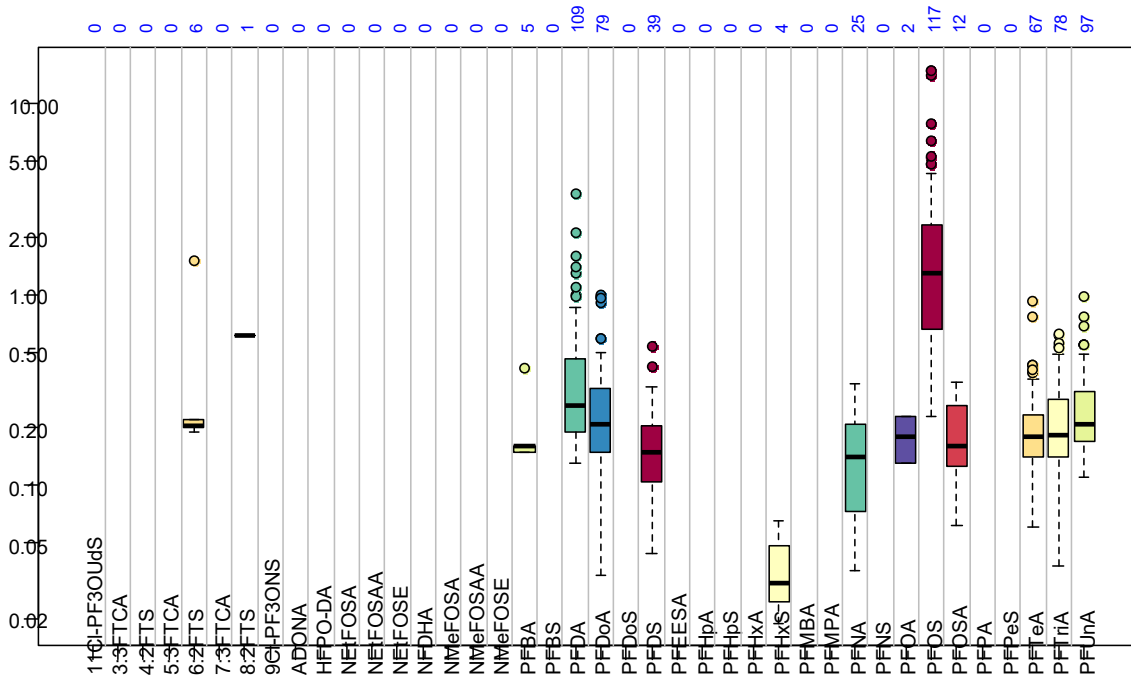


Figure 11. Distributions of PFAS compounds detected above quantification limits in channel catfish fillet samples. The blue numbers arrayed along the top margin show the number of detections. Y-axis units are ng/g.

Macroinvertebrates

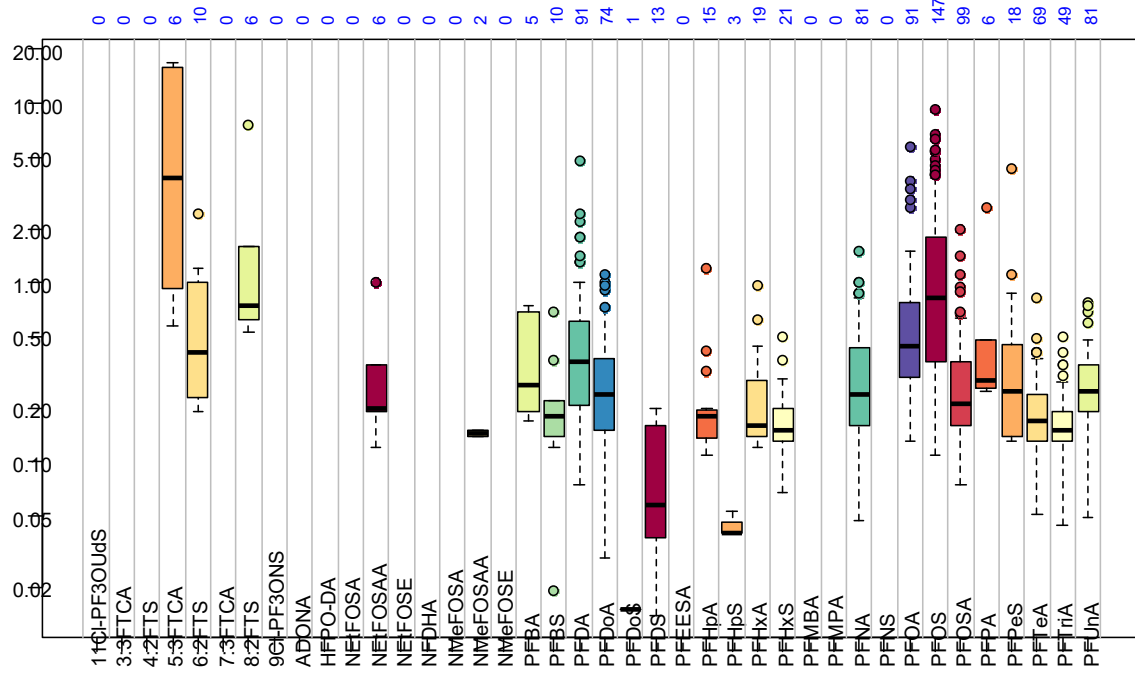


Figure 12. Distributions of PFAS compounds detected above quantification limits in composite macroinvertebrate samples. The blue numbers arrayed along the top margin show the number of detections. Compounds that start with numbers (e.g., 5:3 FTCA) are precursors to other compounds (e.g., 5:3 FTCA → PFHxA & PFBA). Y-axis units are ng/g.

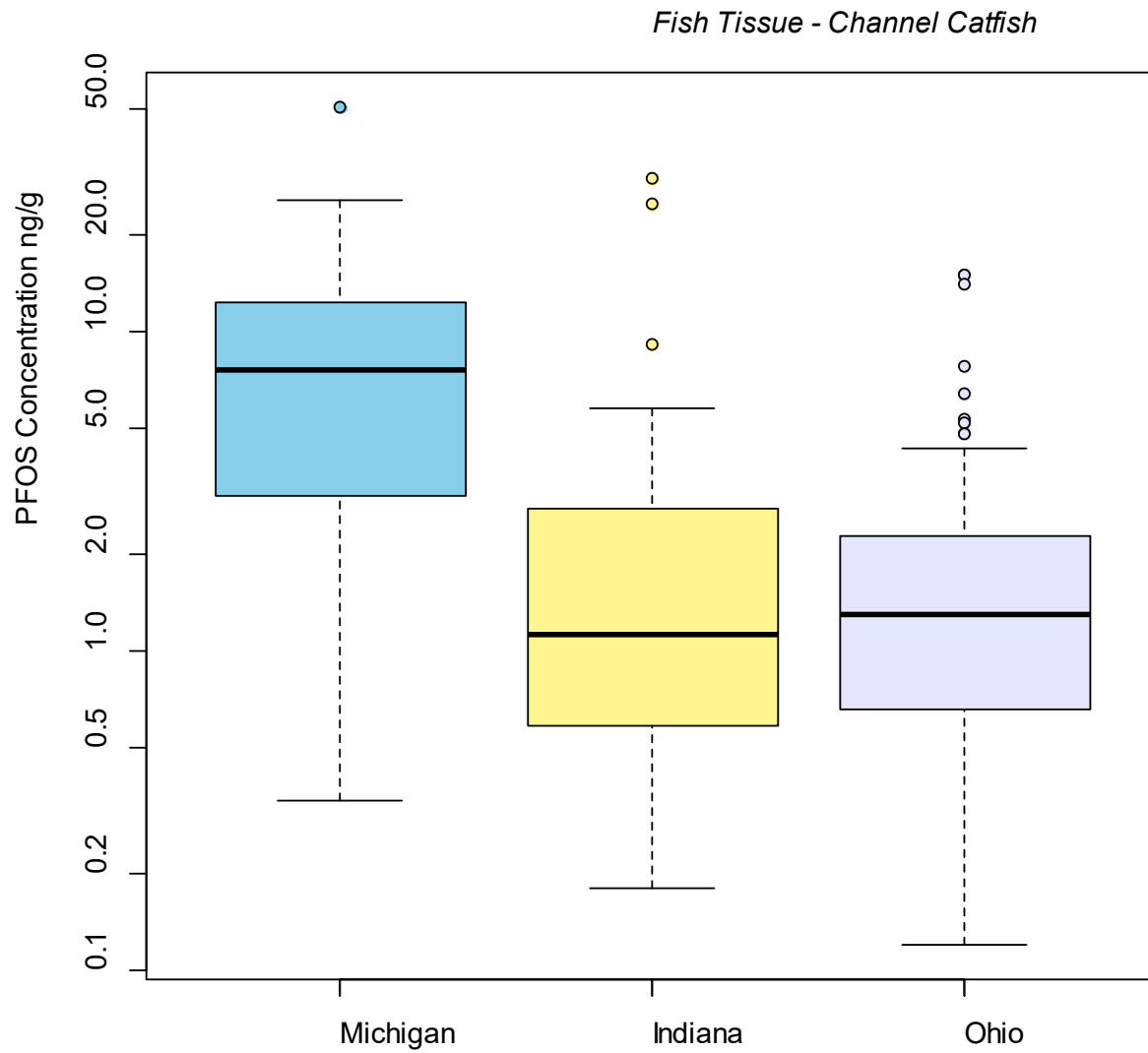


Figure 13. Distributions of PFOS concentrations in channel catfish fillet samples reported by Michigan, Indiana, and Ohio.

References

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Appendix 1. A list of PFAS compounds included in Method 1633

Analyte	Shorthand	CAS Number
Perfluorooctanesulfonic acid	PFOS	1763-23-1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS	763051-92-9
3-Perfluoropropylpropanoic acid	3:3FTCA	356-02-5
1H,1H,2H,2H-Perfluorohexanesulfonic acid	4:2FTS	757124-72-4
3-Perfluoropentylpropanoic acid	5:3FTCA	914637-49-3
1H,1H,2H,2H-Perfluorooctanesulfonic acid	6:2FTS	27619-97-2
3-Perfluoroheptylpropanoic acid	7:3FTCA	812-70-4
1H,1H,2H,2H-Perfluorodecanesulfonic acid	8:2FTS	39108-34-4
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS	756426-58-1
4,8-Dioxa-3H-perfluorononanoic acid	ADONA	919005-14-4
Hexafluoropropylene oxide dimer acid	HFPO-DA	13252-13-6
N-ethylperfluorooctanesulfonamide	NEtFOSA	4151-50-2
N-ethylperfluorooctanesulfonamidoacetic acid	NEtFOSAA	2991-50-6
N-ethylperfluorooctanesulfonamidoethanol	NEtFOSE	1691-99-2
Nonafluoro-3,6-dioxaheptanoic acid	NFDHA	151772-58-6
N-methylperfluorooctanesulfonamide	NMeFOSA	31506-32-8
N-methylperfluorooctanesulfonamidoacetic acid	NMeFOSAA	2355-31-9
N-methylperfluorooctanesulfonamidoethanol	NMeFOSE	24448-09-7
Perfluorobutanoic acid	PFBA	375-22-4
Perfluorobutanesulfonic acid	PFBS	375-73-5
Perfluorodecanoic acid	PFDA	335-76-2
Perfluorododecanoic acid	PFDoA	307-55-1
Perfluorododecanesulfonic acid	PFDoS	79780-39-5
Perfluorodecanesulfonic acid	PFDS	335-77-3
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	113507-82-7
Perfluoroheptanoic acid	PFHpA	375-85-9
Perfluoroheptanesulfonic acid	PFHpS	375-92-8
Perfluorohexanoic acid	PFHxA	307-24-4
Perfluorohexanesulfonic acid	PFHxS	355-46-4
Perfluoro-4-methoxybutanoic acid	PFMBA	863090-89-5
Perfluoro-3-methoxypropanoic acid	PFMPA	377-73-1
Perfluorononanoic acid	PFNA	375-95-1
Perfluoro-1-nonanesulfonate	PFNS	68259-12-1
Perfluorooctanoic acid	PFOA	335-67-1
Perfluorooctanesulfonamide	PFOSA	754-91-6
Perfluoropentanoic acid	PFPeA	2706-90-3
Perfluoropentanesulfonic acid	PFPeS	2706-91-4
Perfluorotetradecanoic acid	PFTeA	376-06-7
Perfluorotridecanoic acid	PFTriA	72629-94-8
Perfluoroundecanoic acid	PFUnA	2058-94-8