ABSTRACT

Title of Dissertation:	ADVANCING UNDERSTANDING OF TERRESTRIAL RECEPTOR EXPOSURE TO MIXTURES OF PER- AND POLYFLUOROALKYL SUBSTANCES
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Per- and polyfluoroalkyl substances (PFAS) are synthetic molecules that are generally defined by their carbon-fluorine bond(s). PFAS are used in a wide array of commercial and household products and have been in production and use around the earth for decades. Their desirable features: stability and surfactant properties, are also key drivers in their emergence as globally widespread environmental toxicants. As such, they present complex issues in estimating exposure and effects in ecological risk assessments at individual sites or screening assessments across many sites. Further, PFAS commonly occur in products and environmental media in complex mixtures that increase uncertainty in assessments. This dissertation aims to improve the understanding of PFAS mixture exposure in terrestrial ecological receptors to inform ecological risk assessment.

The first question addressed is “what is the mixture of PFAS that is representative of PFAS mixtures in surface soil?” The underlying hypothesis explored is simply the hypothesis that there is such a mixture that represents surface soil PFAS concentrations from aqueous film-

forming foam (AFFF) use sites. To address this question, we defined a representative mixture as made of highly sampled PFAS, from high concentration sites, and contributing to more than 90% of the sum PFAS concentration. These metrics were generated at several scales given the nested structure of the data, but the final interpretation is based on the 95th percentile samples on a site-specific basis. This arrangement captures the most potential for risk at the smallest spatial extent. The analysis demonstrated that mixtures of PFAS in surface soil on sites within military installations are of a predictable complexity. Only three PFAS are needed to represent over 90% of sum PFAS concentration at AFFF use sites. Further, perfluorooctane sulfonic acid (PFOS) was consistently the most prevalent PFAS with the highest proportional contribution to sum PFAS. The most prevalent second and third ranked PFAS were perfluorohexane sulfonic acid (PFHxS) and perfluorooctanoic acid (PFOA), respectfully. Across all sites, the median PFHxS:PFOS ratio was 0.10 and PFOA:PFOS was 0.03. These observations indicate that PFAS mixtures in surface soil on military installations can be represented by a relatively simple mixture of PFAS largely dominated by a single PFAS. The resultant conclusion is that risk assessments at sites can exclude minority PFAS and that toxicological studies to inform risk assessments can be simplified.

The second questions addressed are “what are mammalian tissue concentrations when exposed to PFAS mixtures?” and “does the mixture matter when predicting tissue concentrations?” The specific PFAS mixtures of interest are those identified as representative of surface water and surface soil on military installations. The hypothesis was that exposure and potential effects observations would indicate additive relationships, but the main objective was to quantify tissue concentrations as a function of dose while considering or ignoring the mixture. To explore the hypothesis and quantify tissue concentrations, an outbred mouse was exposed to single PFAS and mixtures of PFAS. A true whole body extraction concentration was measured and in a second study, serum, liver, kidney, and brain concentrations were measured. One of the mixtures was representative of surface water and contained PFOS, PFHxS, perfluorohexanoic acid (PFHxA), and PFOA while the second mixture was representative of surface soil and contained PFOS, 6:2 fluorotelomer sulfonate (FTS), and 8:2 FTS. Mixture treatments were at varying concentrations, but a constant proportion of sum profile. The sum of the highest mixture treatment approximately overlapped the corresponding single PFAS exposure treatments' concentrations. Interpreted in a hierarchical modeling framework, the results of this study indicate that prediction of tissue concentrations does not require knowledge of the mixture as interactive relationships between PFAS are less impactful than variation across individual mice. This simplifies models required to predict tissue concentrations given dose information, but is also indicative of dose additivity and relative tissue affinity. Further, we identified relative liver weight increases and increases in serum alanine aminotransferase (ALT). These responses can be effectively predicted by a relative potency factor (RPF) approach. Each PFAS's RPF is relative to PFOS. The success of the RPF approach is a further signal of dose additivity in effects in addition to additivity in exposure. Our conclusions are largely highlighting the potential increased efficiency of exposure and effect prediction using additive models that do not require knowledge of the mixture. This is a key addition to risk assessments on sites where mixtures of PFAS will be observed, but regulations will generally be focused on single PFAS. The demonstration of relative affinity and potency also allows for relative ranking of PFAS in their potential for exposure and effects. So, while the list of PFAS addressed here is from a narrow applicability context, there is concurrence between our observations and the literature that legacy PFAS likely have similar potential for exposure and effects. Those PFAS with reduced potential for exposure and effects are generally smaller PFAS or those PFAS that appear to have excretion pathways.

The third questions addressed is “how do mixture profiles change with increasing trophic levels?” and “can toxicokinetic data inform estimates of potential for trophic transfer?” The underlying hypothesis is that the two food chains studied—soil to worms to toads and soil to plants to rabbits—would have differing PFAS profiles in the diet, but knowledge of the internal kinetics would be required to explain the PFAS profile in the upper trophic level consumers. To explore these questions, two studies were performed. In the first study, adult, terrestrial lifestage toads were fed a diet of worms that had been grown in PFAS-spiked soil and their liver and pooled remaining tissue PFAS concentrations were quantified. In the second study, adult rabbits were fed a diet of plants that had been spiked to match concentrations in plants grown in PFAS-spiked soil. Rabbit livers, kidneys, and muscle tissue PFAS concentrations were quantified. Toxicokinetic models were fit on a tissue- and PFAS-specific basis for both organisms. In the toads, a differential equation system was also developed to evaluate the utility of physiological realism. The uptake and elimination rates from the definitive per-PFAS models of the estimated whole animal concentrations were used to generate trophic transfer coefficients (TTCs). Interpretation of the TTCs along with the toxicokinetic data suggests that some PFAS (i.e. PFOS) are consistently likely to be trophic magnifiers regardless of food chain, while others (i.e. perfluoroheptane sulfonic acid (PFHpS), 8:2 FTS) vary from trophic magnifiers to trophic diluters depending on food chain. The downstream conclusions, in context to field data in literature and the above observations of additivity, are that food chain specific trophic transfer data may be needed to predict upper trophic level exposure levels, but that, for PFOS specifically, uniform potential for trophic magnification is likely. A further observation is that kinetic data is informative towards relative estimates of potential for trophic magnification and explanatory towards general mechanisms. As an example, we note that elimination rate variation likely drives the difference in potential for trophic magnification in toads, while in rabbits, both uptake and elimination rates appear to be equivalent drivers of potential for trophic magnification.

Overall, this dissertation identifies priority PFAS (Chapter 2), clarifies additivity of PFAS mixtures (Chapter 3), and advances the understanding of potential for trophic transfer in terrestrial food webs (Chapters 4 and 5). As a whole, these conclusions can simplify the data and approaches needed to perform an ecological risk assessment, support the desire to generalize across common PFAS, and provide laboratory confirmation of some field observations. Areas of improvement or continued research broadly fall under refining or increasing resolution. The representativeness of the soil and mouse mixtures are spatiotemporally static and are assumed to be consistently postprocessing of fate and transport dynamics. If this assumption were to be replaced by an understanding of spatiotemporally dynamics, site-specific risk assessments and exposure assessments could be of increased spatiotemporal resolution and increase their accuracy in regards to the where and when PFAS were released on the site and where and when receptors are present on the site. This refinement could influence the entire suite of study methods in this dissertation. Additionally, an increased number of PFAS analyzed is a desire of all PFAS studies. In this case, increased quantification of 'ultra-short' PFAS such as trifluoroacetic acid (TFA), volatile PFAS (i.e. alcohol head groups), and known degradation pathway member PFAS could increase the capacity to extend these observations to a greater range of PFAS, but also address concerns about missed biotransformations. In conclusion, this dissertation suggests that exposure to mixtures is not as complicated as feared.

ADVANCING THE UNDERSTANDING OF TERRESTRIAL RECEPTOR EXPOSURE TO MIXTURES OF PER- AND POLYFLUOROALKYL SUBSTANCES

by

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Preface

This dissertation is a product of teamwork. To more sufficiently give credit to the contributing co-authors and acknowledge the data sources please see and cite the below works. All material chapters are in various stages of publication in peer-reviewed works and differences may emerge upon publication.

Chapter 2: Surface soil PFAS mixtures dominated by PFOS: Prioritization for ecotoxicity testing and ecological risk assessment at current and former U.S. military installations." is included as published in:

East AG, RH Anderson, CM Duncan, CJ Salice. 2025. Surface soil PFAS mixtures dominated by PFOS: Prioritization for ecotoxicity testing and ecological risk assessment at current and former U.S. Air Force Bases. *Environmental Toxicology and Chemistry*, Volume 44, Issue 3, March 2025, Pages 856–865, https://doi.org/10.1093/etojnl/vgaf001

Chapter 3: Evidence of additivity observed in mice exposed to a risk-relevant PFAS mixture. is based upon:

https://serdp-estcp.mil/projects/details/1bb64556-9d51-48fb-88b3-8ee0d8a38dd2

East, AG, AM Narizzano, S Thomas, B Chandramouli, LA Holden. Evidence of additivity observed in mice exposed to a risk-relevant PFAS mixture. ACS Environmental Au. *In review (vg-2025-002416).*

Chapter 4: Dietary kinetics of a PFAS mixture in the American toad (*Anaxyrus americanus*): laboratory insights into trophic transfer of PFAS is based upon:

AG East, M Simini, EE Stricklin, GR Lotufo, JL Guelfo, Z Yang, T Gallo, MJ Quinn, RG Kuperman. Dietary kinetics of a PFAS mixture in the American toad (*Anaxyrus americanus*); laboratory insights into trophic transfer of PFAS. *Environmental Toxicology and Chemistry*, Volume 44, Issue 10, October 2025, Pages 3051–3066, https://doi.org/10.1093/etojnl/vgaf180

and Chapter 5: Trophic transfer and dietary kinetics of a PFAS mixture in rabbits (*Oryctolagus cuniculus*) is based upon:

Kuperman RG, M Simini, LK Wright, R Moretz, EE Stricklin, GR Lotufo, R Boyd, AG East, MJ Quinn, J Guelfo, Z Yang. 2025. Determination of Biomagnification Potentials for Per- and Polyfluoroalkyl Substances in Terrestrial Food Webs: Final Report. DEVCOM CBC-TR-1919. https://serdp-estcp.mil/projects/details/2782ce3e-bc3f-4669-9c76-eba0a2803610/er19-1041-project-overview

Dedication

This work is dedicated to the memory of mom’s contribution to my academic pursuits. She doesn’t get to share in this, and I can’t think of anything more unfair.

Acknowledgements

I would like to acknowledge the work that my committee put towards these documents, improving my capacity as a scientist, and generally facilitating this exercise. You've all been wonderful to work with. "Working with" is the key statement. I think the tone of my relationship with my committee members was established early on by Dr. Lance Yonkos. It is rare, in my experience, to identify people sufficiently skilled for the "What are your goals? Ok, let's do that then." approach to be successful. Dr. Natalie Karouna-Renier and Dr. Mike Quinn are to blame for suggesting that we try to pull this off, but my career has been made by networking so it's only fitting. Thank you for being collaborators ready to execute. Dr. Candice Duncan's injections of chemistry knowledge are critical and welcome for an effort that is (accidentally) mostly about chemistry. Dr. Travis Gallo opened some new doors for me computationally that sealed the fate of two entire chapters. It's a good reminder to acknowledge the ecological forces of serendipity and path-dependence.

I would like to acknowledge funding by the Strategic Environmental Research and Development Program (SERDP) through projects ER-2627 (Salice), ER19-1041 (Kuperman, Lotufo, Quinn), and ER22-3388 (East, Karouna-Renier). I would also like to acknowledge the data sharing, technical support, and very long leashes of the SERDP study teams. Dr. Roman Kuperman and Dr. Christopher Salice need especially clear acknowledgement as they supported half of the data in this work.

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Lastly, I would like to acknowledge the direct and indirect support of friends and family. Many ears and shoulders and hands make it happen. Above all, thanks to Kelly for your patience.

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Chapter 1: Introduction.

Per- and polyfluoroalkyl substances in the environment

Per- and polyfluoroalkyl substances (PFAS) are synthetic molecules used in many industrial, household, and medical applications for their durability and concurrent oil and water repellency characteristics. The desirable characteristics emerge from a generic molecular form of a hydrocarbon with some (poly-) or all (per-) hydrophobic tail hydrogens replaced with fluorine (C-H to C-F). These replacements create carbon-fluorine (C-F) polar covalent bonds that are extremely durable and relatively small. Notably, the definition of PFAS in applied fields and trades varies by source. See Buck et al. (2021) and Evich et al. (2022) for contrasting exclusive and inclusive views, respectively. The Buck et al. (2011) definition "[…] the highly fluorinated aliphatic substances that contain 1 or more C atoms on which all the H substituents […] have been replaced by F atoms, […] contain the perfluoroalkyl moiety C_nF_{2n+1}—" remains the molecular level basis for most descriptions of the variety of PFAS. Wang et al. (2017) presented a concise "tree" of PFAS that describes how the acids relate by changes in functional groups (e.g. carboxylic or sulfonic), the legacy PFAS "precursors" (e.g. fluorotelomers), and fluoropolymers generally considered of low concern on their own (e.g. "Teflon" polytetrafluoroethylene (PTFE)). Further, at the time of publication (2017), the number of peer-reviewed articles since 2002 showed clear patterns of substantial focus on "legacy" long chain "terminal" PFAS such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) (Wang et al. 2017). This pattern persists to date but is clearly changing based on commentary such as Lohmann et al. (2020) that indicate the regulatory environment is not capturing the complete life-cycle sense of how PFAS can enter environmental matrices. Several works have attempted to contextualize the issue of defining and grouping PFAS to ensure efficient and encompassing regulation. Cousins et al. (2019) and Glüge et al. (2020) generally consider the persistence and expansive number of uses of PFAS as grounds for wide-scale prospective/protective/precautionary regulations to reduce release across the whole span of potential molecules that could meet a definition of PFAS. Buck et al. (2021) present a contrasting view that regulations are intended to control commercial uses and that there are actually substantially fewer PFAS of commercial relevance than suggested by definitions and searches by Glüge et al. (2020). The implications of these diverging precautionary and pragmatic perspectives is that there are, at the least, several choices for regulators to choose from (Cousins et al. 2020). Actual strategies to regulate PFAS exposure and risk of effects that have emerged in the United States are specific to a single PFAS molecule or address a small mixture of PFAS molecules in drinking water (see https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas). The overarching basis of the U.S. EPA's approach is that it is specific (both in expanse but also in detection feasibility) and tied to those PFAS that have robust toxicological data profiles.

This work is substantially motivated by the release of PFAS to the environment through the use of aqueous film-forming foam (AFFF) products. AFFF products used to fight liquid fuel fires (e.g. Class B, nonpolar solvents, Jet A, etc.) at public and private airports and other firefighting facilities have contained PFAS since their development in the 1960s (U.S. Government Accountability Office 2017; U.S. Government Accountability Office 2018; Leeson et al. 2021). Accordingly, PFAS have been intentionally and accidentally released to the environment during training and emergency responses using PFAS-containing AFFF products. In general, AFFF products are up to 5% PFAS by weight (see products on Qualified Products List QPL-24385, governed by mil-spec MIL-PRF-24385 "Fire Extinguishing Agent, Aqueous

Film-Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water") so the potential mass release is immense when the scale of AFFF use is considered. However, PFAS observed in the environment can be attributed to many sources. As summarized in Evich et al. (2022), PFAS synthesis is a many-branched process that is based on procuring fluorine and building carbon-fluorine (C-F) bonds in sufficient numbers, chains, structures, etc. based on the desired characteristics of the final molecules. A useful example is PTFE ("Teflon"), which meets definitions of a PFAS, but is a final target product that is a polymer of low concern (Wang et al. 2017; Buck et al. 2021). Teflon is produced through intermediary PFAS molecules—historically PFOA (8 carbon chain, 7 fluorinated, carboxylic acid) and more recently alternatives such as GenX (HFPO-DA) (Expanded PTFE Applications Handbook 2017). Accordingly, imperfect manufacturing and waste streams of polymers of low concern (PTFE) manufacture can all produce environmental releases of PFAS. Further, other polymerized CF-based molecules can lead to degradation of polymer branches which release non-polymerized PFAS (Evich et al. 2022).

Importantly, regardless of the definition of PFAS, management strategy, or source, PFAS are widely detected in the global environment (Cousins et al. 2022). In effect, Cousins et al. (2022) imply that rainwater may not meet U.S. EPA drinking water requirements. While this has obvious implications for human health interests, it also stages a complex ecological exposure and effect problem. Giesy and Kannan (2001) were effectively the first to identify the global nature of PFOS contamination in animals and that concentrations in animals were higher than their diets, indicative of bioaccumulative properties. Since then, a substantial body of work exploring PFAS in environmental matrices and receptors has emerged. Aquatic systems have the most data (Evich et al. 2022; Gkika et al. 2023), sufficient to perform site-specific risk assessments (Salice et al. 2018), food web exposure models covering broad systems (Munoz et al. 2022; Ren et al. 2022), and refinement of models used in ecological risk assessments (Sun et al. 2022; Kelly et al. 2024). The availability of aquatic data has recently facilitated new approaches that capture the riparian or aquatic to terrestrial transitions (Larson et al. 2018; Koch et al. 2020). While data from terrestrial organisms ("air-breathing" (ECHA 2022; Sample et al. 2024)) is available, there is less (Vendl et al. 2024), and important to ecological risk assessment methods, few of the data are associated with complete food web quantification. As highlighted by Vendl et al. (2024), PFAS concentrations in polar bear are reported second most often (6% of studies) but the understanding of PFAS in circumpolar food webs is still described in a stepwise, biomagnification/bioaccumulation focused fashion (Lohmann et al. 2024) rather than in a complete food chain-wise trophic magnification fashion as in Müller et al. (2011).

Food web studies that support the understanding of chemical movement from environmental media (e.g. soil, groundwater) to primary producers and consumers to higher trophic level organisms are generally defined by determining chemical concentrations in two or more trophic level transitions (Gkika et al. 2023). Four studies are described below that are likely the sole terrestrial food web studies available to date. One of the core goals of this work (among others) is to explore multiple PFAS and attempt to inform the food web transport of PFAS with inter-PFAS relationships to efficiently address the potentially complicated mixtures observed at sites. In contrast, for instance, the work of D'Hollander et al. (2014) captures the movement of PFOS alone from soil to plants to small mammals. They describe stepwise transfer factors that, in concert with food ingestion factors and other exposure model parameters (Sample et al. 2024), could be used to predict small mammal exposure based on a soil concentration. While this is exactly the desired information and application for terrestrial risk assessors (Larson et al. 2018;

Zodrow et al. 2021), it clearly indicates that sites with more than one PFAS will require more time, costs, and data to perform risk assessments. At DoD sites, many PFAS are observed in soil. An alternative interpretation of East et al. (2025b) is that up to 23 PFAS are identified in at least 11 sites. Efficiency of exposure estimation of multiple PFAS from minimal supporting media samples is critical to addressing the need for assessments (Leeson et al. 2021).

Exploring available studies on multiple PFAS and multiple trophic levels in the field lead to four main citations. They inconsistently describe the PFAS-to-PFAS relationships, but their presentations of data can be evaluated as such. Fremlin et al. (2023) is a recent analysis based on field data in an urban system of avian consumers and predators. They identified that many PFAS do magnify through increasing trophic levels using Gobas et al. (2016) definition of trophic magnification factor (TMF) "increase in accumulative rate per increase in trophic level." They highlight use of a chemical activity approach and point out specifically that binding to albumin protein fraction is an important component in predicting PFAS trophic magnification (Fremlin et al. 2023). Müller et al. (2011), Huang et al. (2022), Ecke et al. (2024), and Heimstad et al. (2024) use the definition of TMF that emerged through work on lipophilic compounds—an increase in tissue concentrations with increase in trophic level (Burkhard et al. 2012; Gobas et al. 2023). These terrestrial studies of PFAS concentrations in wildlife tissues were field derived and had at least 3 defined trophic levels (made continuous by nitrogen stable isotopes ($\delta^{15}N$) in some cases) and identified differing patterns. The nonlinear relationship between carbon chain length and TMF in Müller et al. (2011) is based on the early hypotheses that carbon chain length and parameters such as octanol:water partitioning coefficient (K_{OW}) would be linearly predictive as was the case for lipophilic molecules. Nonetheless, given what is known about the stability of terminal/legacy C8 PFAS (e.g. PFOS and PFOA) it is not unexpected that their TMF's would be local maxima as many other precursor or fluoropolymer degradants effectively contribute to PFOS/PFOA in tissues and media observations (Evich et al. 2022). Additionally, with a multivariate additive model of the various affinities of PFAS to the macromolecular makeup of organisms (chemical activity approach), there is no basis to assume a response and the predictor relationship will appear linear in one (or some or all) predictive factor(s) (Gobas et al. 2018; Fremlin et al. 2023; Kelly et al. 2024). In short, PFOS/PFOA may also be local maxima due to their combined macromolecule affinities/solubilities and the trophic arrangement of those macromolecules in the food web (Kelly et al. 2024).

In contrast, Huang et al. (2022) did not see meaningful relationships between PFAS (i.e. carbon chain) and TMF. The uniformity of the TMFs for a variety of PFAS including short chain PFAS (e.g. PFBS, PFBA) was hypothesized to be related to partitioning coefficients (Kelly et al. 2007) that are nonlinear across PFAS or that precursors not captured in analytical work were transforming into terminal PFCAs or PFSAs (Huang et al. 2022). Heimstad et al. (2024) also saw limited relationship between TMF and PFAS. Their observations are confounded by a 'short' food web in that the expected two levels of avian eggs had substantial $\delta^{15}N$ overlap. The PFAS with statistically significantly different than zero slopes had TMFs that ranged from 1.6 to 2.5 with only PFHxS appearing as a trophic diluter (TMF=0.5) (Heimstad et al. 2024). Ecke et al. (2024) demonstrate that long chain PFAS (>8 fluorinated carbons), lacking a pattern, may have variable potential for food chain transfer. They do not provide TMFs (while they did sample enough trophic levels) but do report biomagnification factors (BMFs) for vole liver to avian eggs and blood that range from 1 to 6. These works demonstrate that more data are needed to explain trophic transfer of PFAS from a physico-chemical basis (i.e. the approach of Fremlin et al. (2023) and Kelly et al. (2024) appear supported) but that the detection of PFAS throughout food webs is indicative that trophic transfer does occur and expanded quantification is the main data gap.

In order to inform the understanding of PFAS movement in terrestrial food webs from a causal perspective, laboratory data are likely informative and quicker to generate in comparison to field studies. In the laboratory, studies of PFAS mixture trophic transfer in terrestrial systems are limited to soil, plant, and invertebrate systems. McDermett et al. (2022) grew alfalfa in sand irrigated with PFAS mixture spiked water and then fed the alfalfa to crickets (*Acheta domesticus*). Notably, they did not report a trophic magnification factor, but their bioconcentration factors for matrix to plant and plant to cricket are based on the observed trophic transfer of PFAS and can be averaged to represent the anticipated trophic transfer through the food web (Burkhard et al. 2012). Using PFOS as an example, the BCF was 2 for soil:plants and 0.11 for plant:cricket (using units as reported in McDermett et al. (2022)). Accordingly, without consideration of elimination rates or full understanding of kinetics and tissue partitioning of PFOS, the implication is that PFOS may transfer (something other than magnify or dilute) through trophic levels in this system as the average of these two stepwise rates rounds to 1 (mean of 2 and 0.11 = 1.06). The reduction of BCF from plants to crickets was consistent across all PFAS studied (McDermett et al. 2022) and is likely the most impactful observation in that PFAS may magnify into plants but dilute into higher organisms. The disruption in ‘flow’ of PFAS adds uncertainty in food web transfer models as an assumed average of ~1 would generate estimates with more uncertainty (error) vs specific values 2 and 0.11. Judy et al. (2022) exposed tomato plants to PFAS mixture spiked water in a hydroponic system and then fed the tomato plants to tobacco hornworms (*Solanum lycopersicum*). They did not evaluate partitioning factors for the plants, but did describe the movement of PFAS from plants into the caterpillars as biomagnification factors (exposed via diet). Similar to McDermett et al. (2022), they observed plant to invertebrate BMFs of less than 1 (PFOS ≈ 0.15) for all PFAS studied, indicating again that excluding other normalizing factors, PFAS may dilute moving from plants to invertebrates.

Exposure estimates in wildlife

Another area of meaningful uncertainty in exposure estimates of PFAS mixtures in wildlife is the actual method by which exposure estimates occur. Ecological receptors—ecological entities that are the topic of an ecological risk assessment—that inhabit terrestrial systems present challenging foci for chemical exposure estimation as they are not inherently surrounded by a contaminated matrix. Aquatic/sediment dwelling organisms that are surrounded by a matrix that can be analytically measured for chemical stressors present an inherently (relatively) simpler exposure estimation scenario (assuming bioavailability). Terrestrial organisms may largely exist in a media that presents exposure near zero (e.g. uncontaminated air above contaminated soil) and their diet items are the only major route of exposure. Accordingly, their intake may be, at best, inconsistent. Gobas et al. (2016) summarize this issue from an analytical standpoint (as compared to my behavioral ecology example above) by stating that exposure model parameters like bioconcentration and bioaccumulation are "descriptors of chemical distribution between biota and water. Their application […] in terrestrial organisms has been questioned […]." The premise is that using a model (as compared to empirical measurements) of chemical distribution in a terrestrial ecosystem should not assume that exposure via surrounding media is equivalent to dietary/dermal/air-breathing exposure.

Relevant to this work, similar to the widespread detection of PFAS in abiotic environmental media, PFAS are detected in wildlife globally. Giesy and Kannan (2001) were first to demonstrate PFOS detection in both terrestrial and aquatic organisms around the globe, and since then, there have been sufficient PFAS-specific biomonitoring studies to generate multiple summary reviews (Ankley et al. 2021; De Silva et al. 2021; Bangma et al. 2022). Notably, to capture the observations from biomonitoring in exposure models relevant to risk assessment, several key adjustments need to be made when comparing PFAS to other persistent organic chemicals (i.e. PCBs). For instance, as summarized in De Silva et al. (2021), K_{OW} is regularly used to explain partitioning of neutral organics from aqueous environments to lipid tissues within organisms. With PFAS (organic neutral or anionic surfactants), membrane-water partitioning ratios have been predictive of internal concentrations (Narizzano et al. 2021) alongside protein binding affinities (Bangma et al. 2022) depending on the specific PFAS, tissue of interest, or transition (abiotic to biotic, tissue to tissue, etc.). De Silva et al. (2021) consider parameters for air-breathing animals to be a key gap as there remain limited field or lab data specifically addressing their quantification.

Chemical activity approaches that effectively account for the solubility of chemicals in organisms' macromolecules are hypothesized to be the most useful method to estimate PFAS movement in food webs (Gobas et al. 2018; Fremlin et al. 2023; Kelly et al. 2024). These models are analogous to fugacity approaches in that a chemical and the macromolecular makeup of an organism lead to a unitless rate or affinity (activity) that describes the potential for a chemical to move into an organism made of said macromolecular contents. The utility in a food web basis is that macromolecular contents change in the movement through a food web (the classic lipophilic example would be an increase in lipid/adipose tissue in higher order organisms) and the increase in accumulation rate (determined by the chemical activity of the chemical-tissue pair) can be mapped against the increase in trophic level (Fremlin et al. 2023). A challenge to using this approach is that it remains unlikely in an ecological risk assessment context that the macromolecular content of ecological receptors and solubility in said macromolecules will be known for a sufficient sweep of organisms.

Exposure models commonly used in ecological risk assessments for terrestrial organisms largely follow the US EPA Exposure Factors Handbook (EPA 1993), which provides guidance and estimates to generalize ingestion-focused exposures (Sample et al. 2024). The overarching premise is to compare the exposure estimate against a laboratory toxicity reference value (Sample et al. 2024) in the media of interest and available in the toxicology literature (dermal to dermal, dietary to dietary, etc.). These types of models and ecological risk assessment scenarios have been utilized (Larson et al. 2018; Conder et al. 2021; Zodrow et al. 2021) to speak to PFAS mixtures in riparian and terrestrial environments based on empirical observations. In general, the parameterization of these models is quite simple: matrix concentration multiplied by an uptake factor multiplied by some sort of exposure factor, e.g. soil concentration times bioaccumulation factor would be a predictor of worm concentration. Worm concentration times trophic transfer coefficient times proportion of diet as worms would be a predictor of a worm predator's ingestion, etc. Accordingly, to predict PFAS mixture exposure in any sort of expansive/inclusive empirical manner requires a substantial amount of data. Collection of data in the field where multiple trophic levels are evaluated is rare, especially in terrestrial environments (D'Hollander et al. 2014; Fremlin et al. 2023). In contrast, for some taxa, the magnitude of field and laboratory data is substantial (Burkhard and Votava 2023). Earthworms have the interesting properties of being an intermediate carrier of soil-derived contamination to upper trophic levels while also being a taxa reasonable to culture in a laboratory—hence the amount of data available. Regardless, even when mixtures are of interest, the mixtures are effectively ignored. Larson et al. (2018), estimated PFAS-specific concentrations through a sediment to avian predator food web.

The avian exposure (as a dose) for ΣPFAS was then compared against the avian toxicity reference value (TRV) for PFOS. The assumption being that avian receptors are the most sensitive to PFOS and there are no mixture interactions (dose additivity with equivalent potency is assumed). This approach is considered protective, but it is not explicitly accurate nor is it precise (Larson et al. 2018).

This dissertation aims to address the broad topic of improving understanding of terrestrial organism exposure to mixtures of PFAS (Figure 1): The target audience is largely ecological risk assessors that have a need to address exposure estimates in wildlife that may be exposed to mixtures of PFAS. The second chapter identifies and prioritizes representative surface soil PFAS mixtures on DoD installations. The third chapter provides evidence of dose additivity in exposure and effects in mice exposed to DoD-site-relevant PFAS. The fourth chapter quantifies the toxicokinetics and potential for trophic transfer of a food-web driven mixture of PFAS in terrestrial life stage amphibians exposed via diet. The last chapter similarly quantifies the toxicokinetics and potential for trophic transfer of a food-web driven mixture of PFAS, but in a terrestrial mammal. In sum, with a focus on empirical observations and efficiency, certain PFAS (such as PFOS) are clearly worthy of their focus in ecological risk assessment, but other PFAS (such as fluorotelomer sulfonates) and taxa (amphibian vs mammal) remain in need of data. In the meantime, approachable estimates are likely sufficient to advance the broader effort to determine priority PFAS and remediation sites.

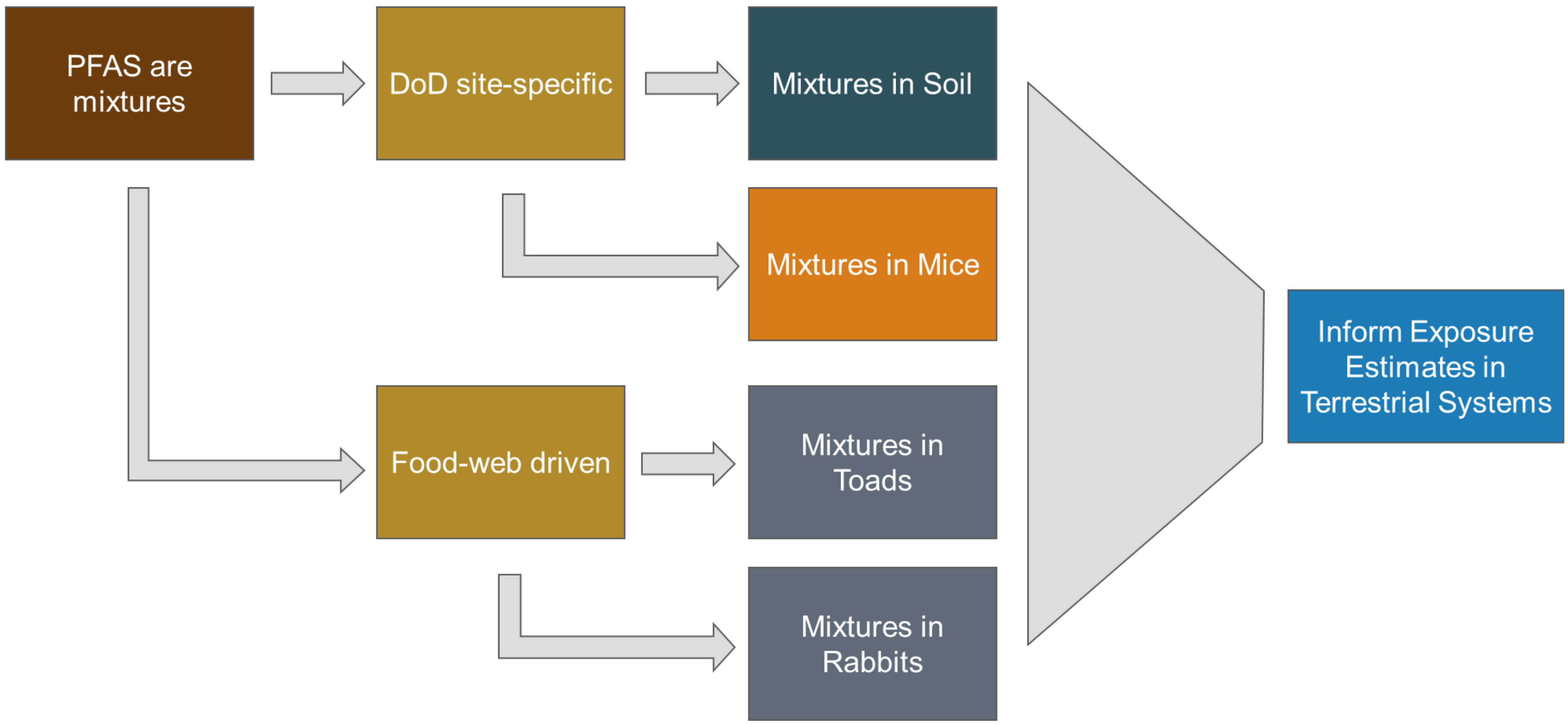


Figure 1. Graphical abstract of this dissertation. Broadly, this work is to inform PFAS exposure estimates in terrestrial systems. All chapters are basally motivated by observations of PFAS in the environment as mixtures. Two broad types of mixtures are foci here—one based on observations from DoD sites and another that is emergent from (laboratory) food-web processes.

Chapter 2: Surface soil PFAS mixtures dominated by PFOS: Prioritization for ecotoxicity testing and ecological risk assessment at current and former U.S. military installations.

Abstract

Per- and polyfluoroalkyl substances (PFAS) detection at military installations where current and historical aqueous film-forming foam (AFFF) use has occurred drive a need for empirical derivation of environmentally relevant PFAS mixtures to facilitate toxicity testing and risk assessment efforts. We applied a formalized prioritization method to a large dataset of PFAS concentrations in surface soil at AFFF-impacted sites on active and former US Air Force installations. Our approach revealed several observations about PFAS at these sites. First, perfluorooctane sulfonate (PFOS) occurred most commonly and often at the highest concentration across the PFAS measured. Second, two to three PFAS contributed 86 to 91%, respectively, of the sum PFAS in any given site-specific mixture. Third, after PFOS, the most common and high concentration PFAS among target analytes were perfluorohexane sulfonate (PFHxS), perfluorooctanoic acid (PFOA), perfluorooctanesulfonamide (PFOSA), and/or perfluorohexanoic acid (PFHxA), in that order. Site specific PFAS mixtures are approximately 5 to 12% PFHxs, PFOA, PFOSA, and PFHxA behind approximately 82% PFOS. Another observation relevant to future sampling is the high concentration but inconsistent prevalence of the 6:2 and 8:2 fluorotelomer sulfonates (FTSs). An uncertainty that could also be addressed through future sampling is the detection of less abundant or yet unmeasured PFAS that have unknown or poorly characterized toxicological potency. These results support the continued importance of efforts to understand effects and exposure of PFOS but highlight the need to

consider other PFAS such as PFHxS and fluorotelomers in exposure and effect estimations to support ecological risk assessments and ecotoxicological testing of PFAS mixtures.

Introduction

Per- and polyfluoroalkyl substances (PFAS) are synthetic fluorinated chemicals used in a variety of industrial and household goods and processes. One specific application of PFAS has been as key constituents of aqueous film-forming foams (AFFFs), which are a substantial source of environmental and occupational releases and subsequent exposures to PFAS. AFFF have been used on public and private airports for decades in Class B fuel-fire emergency response and training activities (U.S. Government Accountability Office 2017; U.S. Government Accountability Office 2018). The demand for PFAS-based AFFF was driven by the need to meet specifications for fire suppression; military specification (Mil-spec) qualified AFFF products were those that contained PFAS. Importantly, the PFAS used in Mil-spec qualified AFFF products have changed over time in response to manufacturer choices and performance criteria (Leeson et al. 2021). Concerns related to persistence, bioaccumulation, or toxicity of specific PFAS constituents has also driven change in PFAS used in AFFF products (Leeson et al. 2021). These changes have resulted in a complex mixture of PFAS that could occur in the environment associated with any given AFFF use site.

Importantly, as fate and transport processes act upon this complex PFAS mixture, changes in the PFAS mixture profile may be difficult to characterize. Some overarching patterns can be anticipated. The transition to short-chain PFAS and fluorotelomer sulfonate PFAS in AFFF products (after the voluntary phase out of PFOS and PFOA production by 3M) to reduce the persistence and likelihood of bioaccumulation, led to release of precursors and byproducts that have the potential to become "terminal" PFAS (e.g., PFOS) (Field and Seow 2017; Ruyle, Pickard, et al. 2021; Zhang et al. 2021; Evich et al. 2022). Accordingly, high concentrations of PFOS in soil, sediment or surface water (or other "terminal" PFAS) may indicate use of historical AFFF products and/or contributions from new AFFF products plus biodegradation processes. Further, there are empirical observations and modeling approaches that suggest PFAS of concern such as PFOS are retained by the vadose zone under common soil and weather conditions (Zeng and Guo 2023), PFAS, in general, are observed in highest relative concentrations in surface/vadose zones compared to deep samples (Brusseau et al. 2020), and that, globally, soil concentrations are higher than many other environmental media (Johnson et al. 2022).

Additionally, contamination of soil by PFAS remains an important potential source of PFAS to both ground and surface waters (and, by extension, drinking water) (Johnson et al. 2022; Zeng and Guo 2023). The general conceptual model for AFFF-associated PFAS environmental impact is that AFFF was used on land in an emergency or training event which likely resulted in PFAS contamination of soil and nearby surface waters. Subsequently, based on anion disassociation, binding characteristics, and water solubility, PFAS can be transported from surface soil to groundwater and/or surface water (e.g. Zeng and Guo (2023)). This conceptual model has been described in risk assessment contexts previously (Salice et al. 2018; Conder et al. 2021; Leeson et al. 2021; Ruyle, Pickard, et al. 2021) and sets the stage for problem formulation and scenario characterization for site-specific risk assessments focused on estimating risk from PFAS-mixtures with AFFF sources (Johnson et al. 2022) and potentially current PFAS regulatory efforts (e.g. Drinking Water proposed rule (EPA 2023)). Previously, we identified priority PFAS and PFAS mixtures in surface water samples collected near AFFF use sites to help guide ecotoxicological studies and problem formulation in support of ecological risk assessments

(East et al. 2021) and these priority PFAS have been cited in toxicokinetic model development in humans (Sweeney 2022), toxicity testing in tadpoles (Hoskins et al. 2023) and aquatic invertebrates (Kadlec et al. 2024).

In the effort to prioritize PFAS in surface waters near AFFF use sites, the focus was based on which PFAS and PFAS mixtures were likely to result in exposure to ecological (and human) receptors. An alternative approach might rely on relative toxicity as a guide for prioritization but this becomes problematic given that toxicity data is, at present, limited to relatively few PFAS. It should also be noted that exposure is a prerequisite for toxicity, so focusing on potential exposure is effective. Few terrestrial and/or soil-dwelling organism toxicity data exists (see Ankley et al. (2021) or Zodrow et al. (2021) for summaries), but even fewer data based on PFAS mixtures that may be present on AFFF use sites exist. Studies conducted by Dennis, Subbiah et al., Dennis, Hossain et al., Dennis et al., (2021; 2021; 2022) and Bursian et al. (2021) exposed quail to binary mixtures of PFOS and PFHxS, PFOS and PFHxA, and PFOS, PFOA plus a legacy 3M brand AFFF product, respectively, and are specifically AFFF-relevant terrestrial toxicity datasets. In surface water, four-PFAS mixtures make up over 80% of the sum PFAS in any given sample from AFFF-impacted DoD sites (East et al. 2021). The question remains as to whether 'classic' binary mixtures of legacy PFAS (i.e. PFOS and PFOA) or those mimicking un-weathered AFFF products or a sufficiently representative mixture are effectively supporting terrestrial ecological receptor exposure and effect estimations. Nonetheless, efforts to prioritize PFAS in soils based on likelihood and magnitude of exposure is more tractable than a focus on toxicity given the data available.

The dataset analyzed here is based on environmental matrix sampling and PFAS quantification at US Department of Defense installations (largely U.S. Air Force). Samples were collected from surface soil, sediment, groundwater, and surface water. The PFAS data from these samples have been interpreted as a whole (Anderson et al. 2016), based upon specific matrices (surface water; East et al. (2021)), specific locations (Anderson et al. 2019), in specific risk assessment scenarios (food web exposure; Larson et al. (2018)), or specific risk assessment data needs (background concentrations; Anderson and Modiri (2024)). Each of these analyses have identified specific PFAS or specific concentrations as more likely to be important to ecological risk assessors. For instance, Anderson et al. (2016) identified PFOS as an important PFAS in AFFF-sourced contamination based on the relatively high measured concentrations and very frequent detections in samples. East et al. (2021) identified PFOS, PFHxS, PFOA, and PFHxA as key PFAS in site-representative mixtures for surface water based on sampling magnitude, frequency of occurrence, and concentration.

Given the widespread nature of PFAS impacts to terrestrial environments and subsequent exposures to humans and wildlife, it would be helpful for ecotoxicologists and ecological risk assessors to have an *a-priori* sense of which PFAS and PFAS mixtures are likely to occur in surface soils at U.S. DoD installations with current and/or historical AFFF use. Our main goal here is to identify the most prevalent PFAS and PFAS mixtures detected in surface soil with high confidence (Objective 1) and to then identify a representative mixture by exploring the PFAS-specific proportional contribution to sum PFAS (Objective 2). Collectively, the results of this soil PFAS prioritization can inform risk assessment and toxicity testing efforts to fill data gaps associated with PFAS mixtures. We present the results of these objectives using the formalized prioritization process developed for surface water samples (East et al. 2021). The importance of these insights are discussed to provide to the ecological risk assessment community additional context for understanding terrestrial fate and transport of PFAS and what is known about toxicity of the representative compound mixtures to terrestrial ecological receptors.

Methods

The methods for the current effort largely follow the approach of East et al. (2021). In short, East et al. (2021) utilized a surface water data of multiple PFAS analytes at multiple sites across multiple U.S. military installations over several years to similarly identify priority PFAS and PFAS mixtures. Here, priority refers to those PFAS that, based on the available data, representative of the PFAS in any given soil sample with potential to result in exposures to receptors. In East et al. (2021), there were three considerations in identifying priority PFAS or PFAS mixtures. The first was concentration of individual PFAS as risk assessors would likely begin to conceive conceptual models around those PFAS likely to lead to high exposure of receptors. The second was mixture profile, which, based on stakeholder input, was described by the dominant proportions of sum PFAS. The result of East et al. (2021) was that the priority mixture profile was the most prevalent PFAS mixture that captured more than 80% of the sum PFAS at a site. The third consideration in East et al. (2021) was data quality. Critically, the confidence in any prioritization approach must consider data quality. Several metrics were used to describe data quality—including number of samples, proportion of analysis across sites (completeness), and number of samples above method reporting limits among other statistical descriptors.

As described in East et al. (2021), PFAS and PFAS mixtures in surface water were considered higher priority based on high concentration, high representativeness, and high data quality ("Group 1" here and in East et al. (2021)), but PFAS or PFAS mixtures in surface water that had varying concentrations, different degrees of representativeness, and low data quality were considered a secondary priority ("Group 2" or "Group 3" here and in East et al. (2021)). It is anticipated that increased sampling effort could resolve data quality concerns and increase confidence in both the concentration and representativeness of a Group 2 PFAS.

Similar to East et al. (2021), stakeholders were involved iteratively throughout analysis and communication stages as PFAS characterization and prioritization were developed and refined. The dataset used here has many of the uneven characteristics of Anderson et al. (2016) and East et al. (2021) so confidence in occurrence and magnitude remains a key component in establishing higher priority PFAS. Hence, key factors contributing to priority PFAS included (1) PFAS that are observed consistently in samples and (2) at relatively high measured concentrations. It is important to acknowledge that this approach is applied to the dataset of PFAS measurements from DoD AFFF use sites and, therefore, likely has limited utility for sites with different PFAS sources or even different AFFF product use (e.g. AFFF not meeting Mil-spec). While the outcomes presented here are our chosen "best representative priority PFAS in soils from AFFF sites," given the path dependent nature of stakeholder involvement in analysis and communication, we acknowledge that different outcomes are possible as a result of different interests, choices, or endpoints analyzed. That said, we also believe the method used here is robust and would likely lead to very similar priority PFAS and PFAS mixtures for AFFF sites. While our primary goal, motivated by terrestrial-sourced PFAS impacts to aquatic systems (Salice et al. 2018; Conder et al. 2021; Leeson et al. 2021; Johnson et al. 2022), is to identify soil-specific PFAS and PFAS mixtures for testing and risk assessment, a secondary goal is to demonstrate the efficacy of this method and its outcome for this specific dataset given the heterogeneity of the dataset (e.g., not all PFAS measured from all samples). All graphics and summary approaches were performed using the R statistical language (version 4.0.5, (R Core Team 2024)).

Dataset

The major characteristic of the dataset available is that sampling was focused on current and historical AFFF use in both training and emergency responses at military installations, generally in Class B fire suppression. Not all sample sites were directly contaminated (e.g. training sites with direct/near-direct application to surface soil), but all sample sites were within installations where AFFF usage has occurred. Therefore, PFAS occurrence and detection at a specific site was a product of either direct application or environmental mobility and associated environmental fate and transport processes.

Surface soil PFAS concentrations, reported as µg/kg, were obtained from 941 sample sites across 149 installations, and varied by 7 orders of magnitude ($1x10^{-3}$ to $1x10^{4}$ ppb). There was uneven sampling across time, location, and PFAS analyte; this unevenness, however, was captured by sampling confidence metrics (completeness, number of samples, etc.) developed in East et al. (2021). We did not explicitly account for year as there are minimal influences of time on limit of detection or reporting in concentration metadata (Table SI2.1 and Figure SI2.1). Similar to East et al. (2021), we generally excluded non-detects as it is unlikely that they would be relevant for exposures to ecological receptors (Brusseau et al. 2020) and that low-level (i.e. background) PFOS concentrations in this dataset are unlikely to impacted by any particular non-detect management strategy (Anderson and Modiri 2024).

Data Processing

Data were summarized dependent on the scale of the analysis. For dataset-wide summary metrics, PFAS data were summarized by individual PFAS compound. For determination of the contribution of each PFAS relative to a site sum total, PFAS were summarized by site (within installation) and PFAS. Lastly, PFAS data were summarized by specific mixture ('3-PFAS' mixtures) across all sites across installations to identify final representative, high confidence mixtures.

Confidence and Summary Metrics

Summary metrics for each PFAS at each site were: number and proportion below minimum detection level (<MDL, below the ability for an instrument to differentiate signal from noise), below reporting level (<RL, above the MDL but below some protocol-specific quality criteria for reporting), above reporting level (>RL, a concentration that meets all quality criteria for reporting), total count of samples, mean, median, 95th percentile, and standard deviation (sd) of $\log_{10}$ adjusted concentrations, and completeness. Completeness, represents how frequently each PFAS was included as an analyte and is calculated by the number of samples taken where that specific PFAS was included as an analyte divided by the total number of samples collected. In essence, the completeness metric provides a measure of confidence in PFAS-specific inferences. As an example, a given PFAS that was included as an analyte in only 50% of the samples would have a completeness score of 0.5. Generally, the higher the completeness score, the more confidence there would be in concentration distributions and frequency of occurrence. Those values below reporting level but above minimum detection were presented in summary statistics as unadjusted values (not adjusted as in 0.5*RL, etc.) to specifically focus on higher concentration PFAS which are likely to lead to high exposures to receptors and, hence, a focus of risk assessments. When replicate data were summarized by site and PFAS, the PFAS-specific 95th percentile was used as the site-wise representative value. Including this as a high-end estimate is conservative and such values are often used in screening assessments that initially focus on high concentration sites or PFAS. Confidence increases with high sample size, high completeness scores, frequent occurrence and high proportion of samples above reporting limits. Confidence metrics were largely used to guide the best representative PFAS or mixture within this specific dataset, not a universal sense of PFAS sampling effort in all environments.

Prioritization Workflow

As in East et al. (2021), data were first 'tidied' following Wickham and Grolemund (2016)—checked for obvious omissions, typographical errors, etc. Given the size of the dataset: >140,000 individual measures across 31 PFAS at 941 sites within 149 installations, and the multivariate prioritization scheme, the 'tidyverse' package in R was extremely useful (see code example in SI) (Wickham et al. 2019). Once tidy, the dataset can move to the analysis stage, which, in this case, consisted of summarization steps to produce the needed descriptive statistics for figures.

Throughout and as in East et al. (2021), visualization was a critical element of this approach. The first series of graphics were produced to provide a sense of the confidence in sampling of each PFAS. Specifically, the number of samples that fell into each detection class by PFAS across all sites. Stakeholder input here was based on clearly identifying the variation in sampling effort and relation to detection class frequency. The second graphic involved a heatmap and clustering dendrogram to identify potential clusters of PFAS both in summary concentration statistics and confidence metrics. This analysis was conducted across the entire dataset and is not spatially explicit to installation (or site within installation). The heatmap color scheme was fitted by a z-score calculated by column to visualize the deviation of each cell against its column 'neighbors.' The dendrogram was fitted by the complete match method agglomerative hierarchical clustering in the R function {hclust} (R Core Team 2024). Stakeholder input here was to identify statistical trends by PFAS, irrespective of site, and retaining a sense of sampling effort and subsequent confidence. The third graphic focuses on identifying the number of PFAS that contribute to relevant mixtures on a site-specific basis. We sought to identify the minimum number of PFAS from a given site that comprised 90% or more of the total sum PFAS for that specific site. Stakeholder indicated a desire to identify the majority bulk contribution of specific PFAS to any given sample to determine if a 'simple' or 'complex' mixture was needed to represent any given sample. The final series of graphics were generated to identify the proportional contribution of individual PFAS (i.e., PFOS) to total PFAS concentration in the most prevalent 3-PFAS mixtures. We represent the most common 3-PFAS mixtures as proportional contribution to sum PFAS and secondarily, represent the second and third most common PFAS in relative ratios to PFOS which was universally the first most common PFAS. The ultimate objective, informed by stakeholder interests, was to identify the most representative, simplest, and most confident high concentration PFAS mixture(s). These PFAS and PFAS mixtures would likely be of initial highest concern from an exposure perspective. Secondary objectives were to then identify PFAS or PFAS mixtures that may have more variable representativeness, confidence, or concentrations and would be considered high priority for future sampling effort. The output of this interpretative 'roadmap' can inform eco/toxicity testing designs and provide some insight for risk assessments by, for example, informing *a priori* problem formulation for terrestrial ecological receptors.

Results

Ranking individual PFAS by sampling and analysis effort yielded the following seven PFAS as the highest and most commonly measured: PFOS, PFHxS, PFOA, PFHxA, PFBA, PFNA, PFHpA (Figure 2.1). Because these seven PFAS had the largest number of samples in which they were measured, this translates to high confidence in subsequent numerical and representativeness interpretation with respect to these seven (considered "Group 1" hereafter, see Figure 2.2 and below). The vast majority of samples with PFOS detections were above the RL, which indicates that concentrations were likely higher or PFOS measurement techniques were the most developed (along with the other highly studied PFCAs and PFSAs). The PFAS not included in Group 1 exhibited some variation in sampling effort but generally have lower proportional detection frequency than PFOS. Sampling effort and detection frequency could be attributed to availability of analytical techniques over time (e.g., fluorotelomers and new alternatives such as ADONA have fewer opportunities for detection).

The heatmap and dendrogram (Figure 2.2) identified the PFAS within three dominant clusters across all sites and measurements of each PFAS. Interestingly, PFAS in Group 1 had measurable concentrations that spanned relatively low (PFHpA) to high values with PFOS being the highest. Group 2 PFAS and Group 3 PFAS consistently decrease in completeness and proportion > RL, but have varying measured concentrations (upper and lower portion of Figure 2.2). An important note about Group 1 PFAS is that PFOS was clustered by itself, split at the same level as the rest of the PFAS in Group 1 (see dendrogram in Figure 2.2). This clearly indicates that if we 'zoom in' one level to reassess groupings, PFOS would be alone and represent a separate distinct group. This is suggestive of the dominance of PFOS alone in soil and not just as a dominant member of a representative mixture.

To identify the complexity of PFAS mixtures that would be representative of sites' samples, we identified the number of PFAS chemicals that, generally, represent the majority of the sum PFAS for a given site. To do this, we plotted the individual *i*th PFAS proportional contribution to site-specific sum PFAS against the *i*th rank of contribution (Figure 2.3). The median proportion of sum PFAS accounted for by the two highest contribution PFAS was 0.86 and adding a third PFAS raises this median to 0.91 of the sum PFAS. Accordingly, across all samples and sites, a three-PFAS mixture accounts for more than 90% of the total sum of all PFAS for that sample and site. On a site-specific scale, two or three PFAS represent the vast majority of sum PFAS by concentration.

By ranking the count of observations in the four most prevalent 3-PFAS mixtures, we were able to determine that PFOS, PFHxS, PFOSA, PFOA, and PFHxA occur most frequently at sites and were representative of spatially explicit surface soil PFAS mixtures at AFFF impacted sites (Figure 2.4). It is clear from Figure 2.4 (see also Figure SI2.2 and Figure SI2.3) that PFOS was the most prevalent and highest contributor to sum PFAS in the representative mixtures. Mix 1 we would consider the most common representative PFAS mixture and it was comprised of PFOS, PFHxS, and PFOA as the first, second, and third highest contributors to sum total (Figure 2.4). The remaining three mixtures include PFOS>PFHxS>PFHxA; PFOS alone (not a mixture); and PFOS>PFOSA>PFHxS in descending order (Figure 2.4, also Figure SI2.2, Figure SI2.3).

An additional, experimentally relevant route to label mixtures was by ratio against PFOS (the most prevalent majority contribution to sum PFAS) or as total contribution to the sum PFAS. Table 2.1 and Figure 2.5 shows that median ratio to PFOS for PFHxS, PFHxA, PFOA, and PFOSA were 10%, 3%, 3%, and 3% (rounded to single digit), respectively. The overall distributions indicate that these target secondary PFAS were unlikely to occur in ratios above

0.25 or 0.5 (i.e., ratio = target PFAS concentration / PFOS concentration) for PFHxA, PFOA, and PFOSA, or PFHxS, respectively, at approximately 10th percentiles (Figure 2.5). These extreme scenarios were notably similar to the ratios of PFHxS to PFOS in the surface water analysis of East et al. (2021). Overall, regardless of PFAS, the primary PFAS in a mixture study representing AFFF-impacted military installation soil should represent approximately 81%, the second contributor 12%, and the third 5% of the sum PFAS (Figure 2.4, dashed lines). Thereby capturing 98% of the sum PFAS (Figure 2.4 and Table 2.1). When weighted to a complete mixture (e.g. 81/(98/100) for the dominant), these values round to 83%, 12%, and 5%.

It is important to note that the prioritization of PFAS is not strictly based on occurrence at high concentration. The frequency of occurrence and sampling effort was also important. Figure SI2.4 and Figure SI2.5 (along with Table 2.1) show that other PFAS are sampled at high concentrations (e.g. 8:2 FTS), but given the low rate for which they were sampled-for or detected and quantified, we have reduced confidence in prioritizing these or classifying them as "representative" due to this important uncertainty. They are, however, prioritized as requiring increased sampling effort to further understand their magnitude in surface soil samples.

Table 2.1. Priority ranked per- and polyfluoroalkyl substances (PFAS) and PFAS mixtures with summary data and short description of priority justification based on aqueous film-forming foam (AFFF) impacted surface soil. Summary statistics are µg/kg and proportional ratios use site-specific 95th percentile concentrations.

	Mean (SD) µg/kg	75th	95th	Justification
PFOS	**1058** (10143)	136	2000	"Group 1"
PFHxS	**105** (782)	18	235	
PFHxA	**33** (267)	5	47	
PFOA	**61** (1180)	6	86	
FOSA	**134** (1041)	16	273	

	25th, **Median**, 75th (95ths) : **PFOS**	
PFHxS : **PFOS**	0.04, **0.09**, 0.23 **: 1**	*i*th most dominant binary mixture
PFHxA : **PFOS**	0.01, **0.03**, 0.09 **: 1**	
PFOA : **PFOS**	0.01, **0.03**, 0.11 **: 1**	
FOSA : **PFOS**	0.01, **0.02**, 0.08 **: 1**	

	Median Prop. of Sum PFAS (95ths)	Total[a]	
PFOS : PFHxS : PFOA	0.79 : 0.08 : 0.04	0.91	*i*th most common 3-PFAS mixture
PFOS : PFHxS : PFHxA	0.74 : 0.13 : 0.04	0.91	
PFOS : NA : NA	1.00 : NA : NA	1.00	
PFOS : FOSA : PFHxS	0.76 : 0.10 : 0.05	0.91	

[a]The proportion of the total sum PFAS accounted for by the specific 3-chemical mixture.
SD = standard deviation; prop. = proportion; 75th, etc. = 75th percentile, etc.; NA = not applicable; PFOS = perfluorooctane sulfonate; PFHxS = perfluorohexane sulfonate; PFOA = perfluorooctanoic acid; PFHxA = perfluorohexanoic acid; FOSA = perfluorooctane sulfonamide.

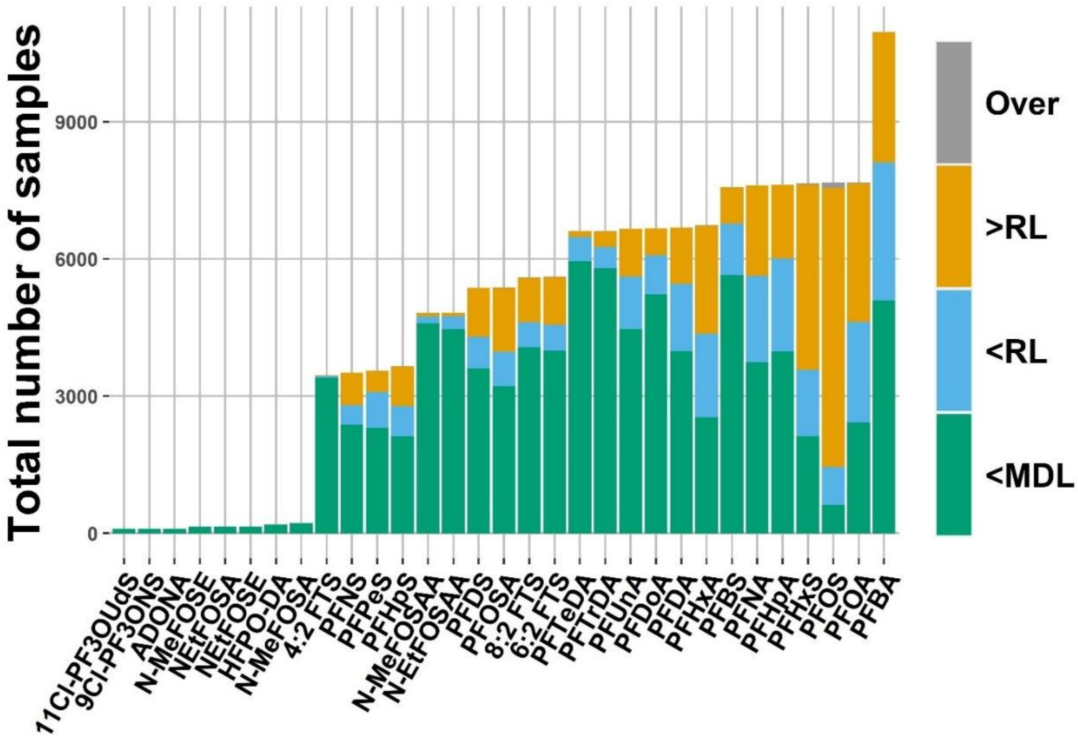


Figure 2.1 Total number of samples collected for each PFAS divided into detection categories. <MDL (green) is below minimum detection limit, <RL (blue) is below reporting limit, >RL (orange) is above reporting limit, and Over (gray) indicates sample measurement was reported but above range of standard curve in analytical techniques. Importantly, samples of >RL (orange) are considered highest confidence. The actual concentrations for MDL, RL, and Over vary by the PFAS, the laboratory performing the analysis, and the time of sampling and analysis (see the SI). PFBS = perfluorobutanesulfonic acid, PFPeS=Perfluoropentanesulfonic acid, PFHxS = perfluorohexanesulfonic acid, PFHpS = perfluoroheptane sulfonic acid, PFOS = perfluorooctanesulfonic acid, PFNS=Perfluorononanesulfonic acid, PFDS = perfluorodecane sulfonic acid, ADONA=Ammonium 4,8-dioxa-3H-perfluorononanoate, 11Cl-PF3OUdS=11-Chloroperfluoro-3-oxaundecanesulfonic acid, HFPO-DA=Perfluoro-2-methyl-3-oxahexanoic acid, 9Cl-PF3ONS=Perfluoro(2-((6-chlorohexyl)oxy)ethanesulfonic acid), NetFOSA = N-ethylperfluorooctane sulfonamide, NEtFOSE = N-ethylperfluorooctane sulfonamidoethanol, NMeFOSA = N-methylperfluorooctane sulfonamide, NMeFOSE = N-methylperfluorooctane sulfonamidoethanol, NetFOSAA = N-ethylperfluorooctane sulfonamide acetic acid, NMeFOSAA = N-methylfluorooctane sulfonamide acetic acid, PFOSA = perfluorooctane sulfonamide, 4:2, 6:2, 8:2 FTS = 4:2, 6:2, 8:2 fluorotelomer sulfonate, PFBA = perfluorobutanoic acid, PFHxA = perflurohexanoic acid, PFHpA perfluoroheptanoic acid, PFOA = perfluorooctanoic acid, PFNA = perfluorononanoic acid, PFDA = perfluorodecanoic acid, PFUnA = perfluoroundecanoic acid, PFDoA = perfluorododecanoic acid, PFTrDA = perfluorotridecanoic acid, PFTA = perfluorotetradecanoic acid.

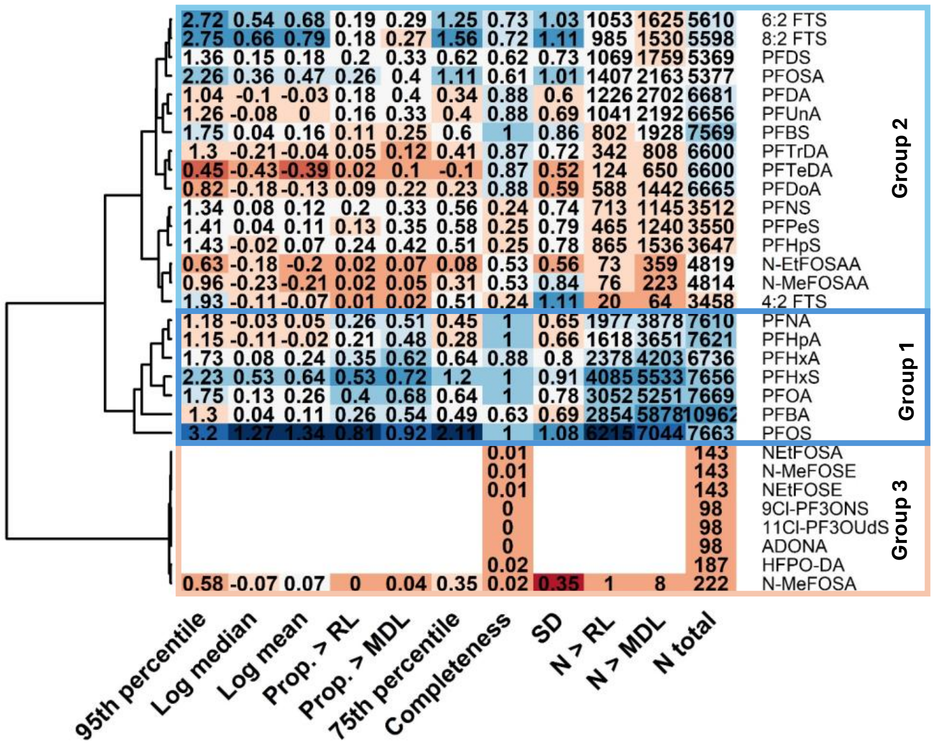


Figure 2.2 Heatmap and dendrogram of each per- and polyfluoroalkyl substance (PFAS) and summary metrics across all data. Completeness is at the site within installation level (number of sites sampled out of total number of sites possible [N = 941]). Median, mean, standard deviation (SD), and 75th and 95th percentiles are log, base 10, values. N total is total number of sampling efforts regardless of detection level. RL is reporting limit and MDL is minimum detection limit as reported by each analytical laboratory for each sample analysis. Prop. is proportion. Red, orange, white, light blue, and dark blue represent the scale from low to high based on column-specific z-scores for the distribution of data in cells. PFBS = perfluorobutanesulfonic acid, PFPeS=Perfluoropentanesulfonic acid, PFHxS = perfluorohexanesulfonic acid, PFHpS = perfluoroheptane sulfonic acid, PFOS = perfluorooctanesulfonic acid, PFNS=Perfluorononanesulfonic acid, PFDS = perfluorodecane sulfonic acid, ADONA=Ammonium 4,8-dioxa-3H-perfluorononanoate, 11Cl-PF3OUdS=11-Chloroperfluoro-3-oxaundecanesulfonic acid, HFPO-DA=Perfluoro-2-methyl-3-oxahexanoic acid, 9Cl-PF3ONS=Perfluoro(2-((6-chlorohexyl)oxy)ethanesulfonic acid), NetFOSA = N-ethylperfluorooctane sulfonamide, NEtFOSE = N-ethylperfluorooctane sulfonamidoethanol, NMeFOSA = N-methylperfluorooctane sulfonamide, NMeFOSE = N-methylperfluorooctane sulfonamidoethanol, NetFOSAA = N-ethylperfluorooctane sulfonamide acetic acid, NMeFOSAA = N-methylfluorooctane sulfonamide acetic acid, PFOSA = perfluorooctane sulfonamide, 4:2, 6:2, 8:2 FTS = 4:2, 6:2, 8:2 fluorotelomer sulfonate, PFBA = perfluorobutanoic acid, PFHxA = perflurohexanoic acid, PFHpA perfluoroheptanoic acid, PFOA = perfluorooctanoic acid, PFNA = perfluorononanoic acid, PFDA = perfluorodecanoic acid, PFUnA = perfluoroundecanoic acid, PFDoA = perfluorododecanoic acid, PFTrDA = perfluorotridecanoic acid, PFTA = perfluorotetradecanoic acid.

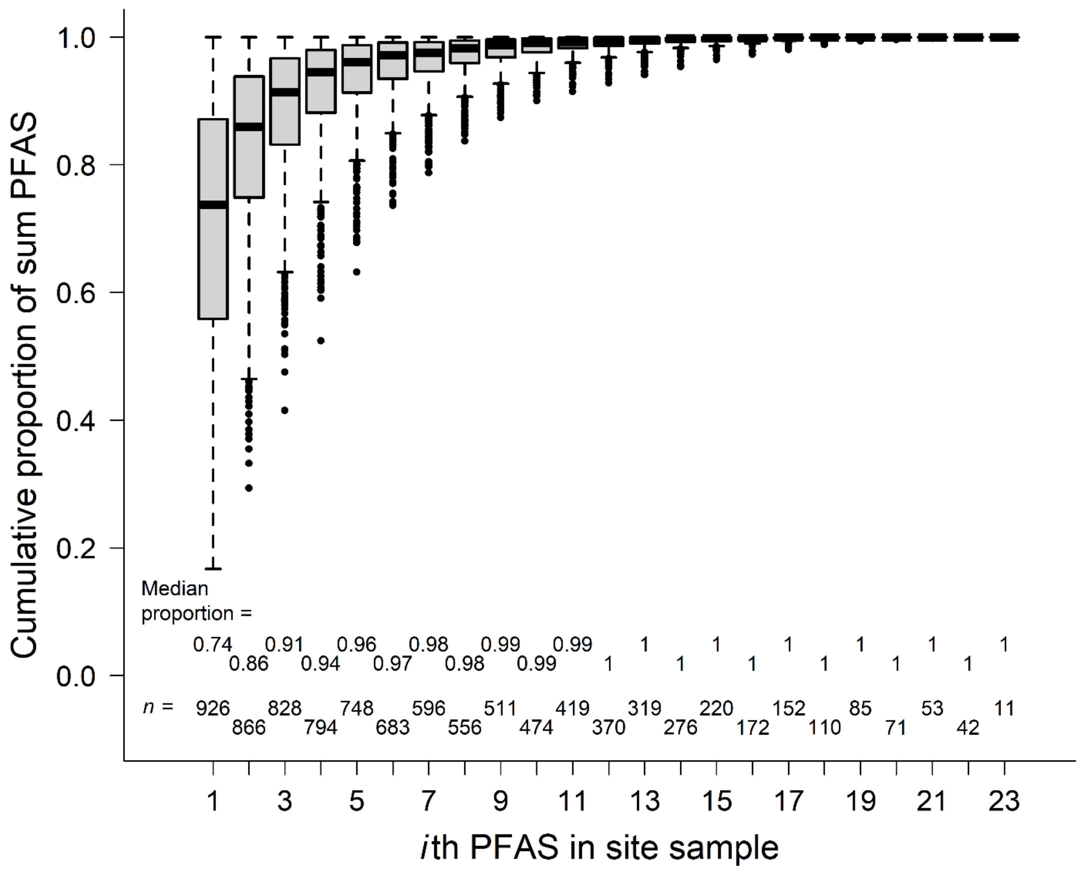


Figure 2.3 Cumulative proportion of sum per- and polyfluoroalkyl substances (PFAS) concentration from a sample (Xi/sum[Xn]) against the ranked ith of n PFAS in that sample. Three chemical mixtures of PFAS were the simplest mixture that described >90% of the sum PFAS, on average (see bottom of figure).

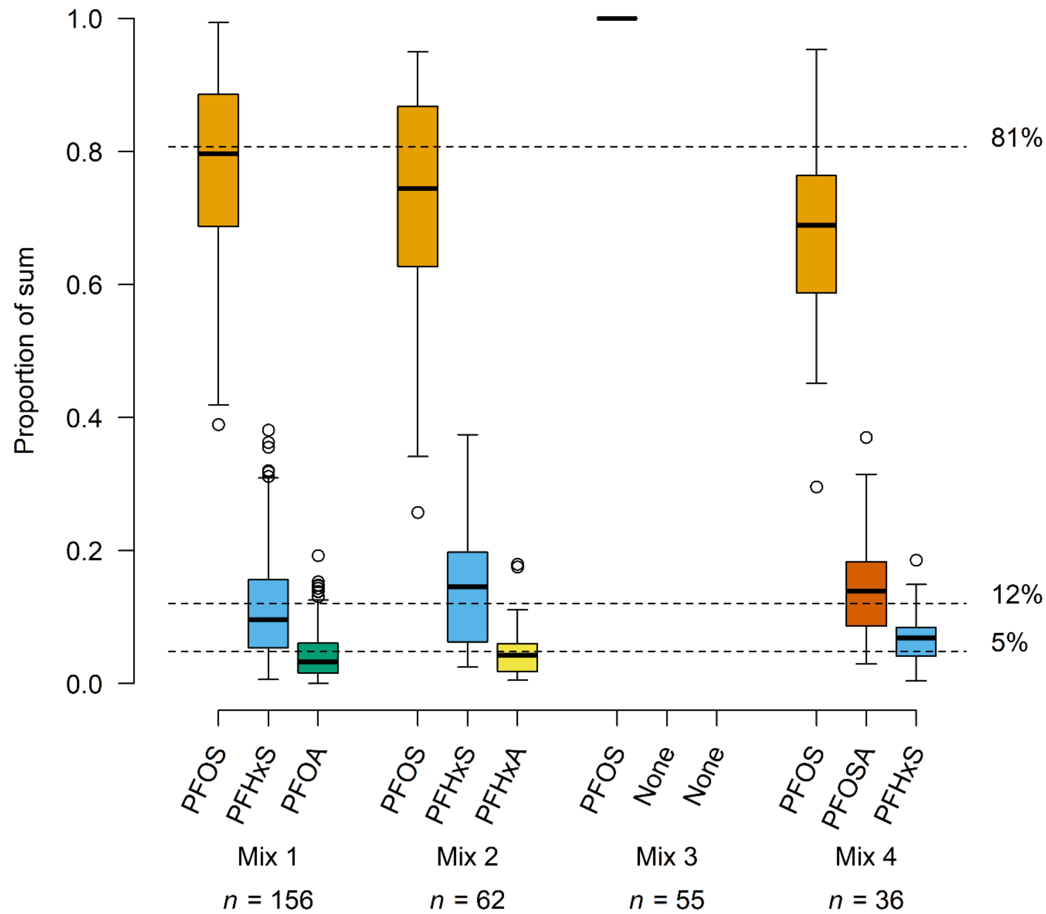


Figure 2.4 Relative composition of the 3-per- and polyfluoroalkyl substances (PFAS) mixtures that represent the majority of the 3-PFAS mixtures that then account for approximately 90% of the total sum site-specific PFAS. In essence, this represents the simplest, most representative PFAS mixture profile for the surface soil data set. Mix 1, Mix 2, etc. represent the top four 3-PFAS mixtures by occurrence (n). Note Mix 3 is a "mixture" only containing perfluorooctanesulfonic acid (PFOS) and no other detected PFAS, so not actually a mixture. PFHxS = perfluorohexanesulfonic acid, PFOS = perfluorooctanesulfonic acid, PFHxA = perflurohexanoic acid, PFOSA = perfluorooctane sulfonamide.

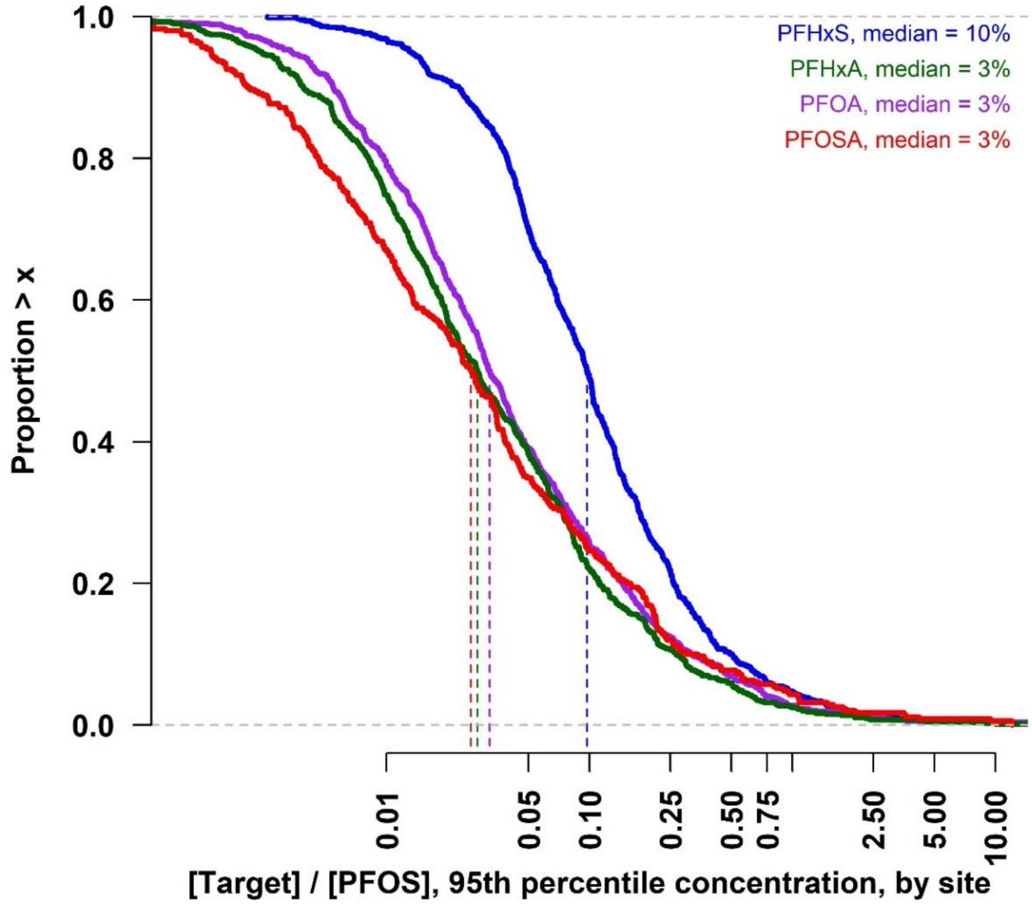


Figure 2.5 Proportion of binary mixture dataset larger than observed ratio to PFOS concentrations (w:w, µg) for PFHxS, PFHxA, PFOA, and PFOSA in surface soil. Thick lines are cumulative distribution functions fitted to observed values (smooth appearance is due to large sample sizes). Median estimates are listed in top right and demarked by vertical lines on plot. X-axis is log-scaled. PFHxS = perfluorohexanesulfonic acid, PFOS = perfluorooctanesulfonic acid, PFHxA = perflurohexanoic acid, PFOSA = perfluorooctane sulfonamide.

Discussion

Overall, these results show that PFOS is a dominant PFAS in surface soil samples at current and historical AFFF use sites on Air Force installations. Indeed, PFOS alone was identified as the third most common observed ‘mixture’ among 941 sites. Further, dominant PFAS mixtures that are representative of these sites are relatively simple—two or three PFAS capture the vast majority (>90%) of sum PFAS. The focus of this analysis was identifying a representative mixture while limiting confounding effects potentially introduced by relying on concentration alone (Figure SI2.4 and Figure SI2.5). While PFAS concentration would likely drive ecological risk assessment site selection, confidence based on sampling effort (among other metrics) and identification of a representative mixture inform problem formulation efforts and allow risk assessors to contextualize sites with similar AFFF use profiles.

The similarity of PFAS mixtures in surface water (also PFOS and PFHxS dominated) supports the hypothesis that observed surface water PFAS mixtures proximal to AFFF use sites (East et al. 2021; Ruyle, Pickard, et al. 2021) are similar to surface soil, however we note the overall relative reduction in complexity in surface soil mixtures compared to surface water mixtures. In the characterization of surface water PFAS mixtures, the data showed that mixtures comprised of four different PFAS equaled or exceeded 80% of sum PFAS; in surface soils, however, three PFAS mixtures exceeded 90% of sum PFAS. Further, among the four most common 3-PFAS mixtures in soils, the PFOS alone was >80% of the mixture’s sum PFAS. With ecotoxicological studies in mind, the binary mixtures used by Bursian et al. (2021), Dennis, Subbiah et al. (2021), and McCarthy et al. (2021) are clearly very relevant—PFOS and PFHxS capture an approximate range of 85-90% of sum PFAS in representative soil mixtures. Further, these mixtures are best described as 90:10 PFOS:PFHxS and the resultant observed toxicity in a study, with such an exposure scheme, would largely be a function of PFOS unless PFHxS was identified as 10-fold more toxic than PFOS.

Although the results point strongly to PFOS as a dominant constituent of surface soils contaminated by AFFF on U.S. DoD installations, it is worth noting the high concentration of fluorotelomer sulfonates (6:2 FTS and 8:2 FTS here) that occur in some samples. Collectively, the FTS chemicals were components of the ninth most common PFAS mixture (Figure SI2.3, Figure SI2.4, and Figure SI2.5). These PFAS may be of interest for ecotoxicological studies because of their inclusion in recent qualified product list AFFF products (see "Buckeye" product, (Gharehveran et al. 2022; Jones et al. 2022; East, et al. 2023) and supplementary material in Ruyle, Thackray et al. (2021)). The toxicity of the FTS products alone is of interest, but it is also important to consider that fluorotelomer sulfonates are precursors to other more stable PFCA (as summarized in Evich et al. (2022)) and, hence, there is the potential for toxicity 'downstream' in space and time resulting from transformation of FTS to related PFCA. It is not unreasonable, given consideration of fate and transport processes and age of these sites, that observations of high abundance of 'terminal' perfluorocarboxylates such as PFOA or PFHxA may originate directly from fluorotelomer formulations of historically applied AFFF products (Ruyle, Pickard, et al. 2021). Similarly, PFOS and PFOSA observations may be terminal or intermediates, respectively, in the degradation of NEtFOSE (Zhang et al. 2021) which (among the other related precursors (as summarized in Evich et al. (2022)) was observed rarely or at low concentrations (Figure 2.1, Figure 2.2, Figure SI2.4). These results suggest that both PFOS and PFOS precursors in surface soil contribute to a similar signal which is high terminal PFAS such as PFOS. This concurs with other observations, albeit in surface water (Ruyle, Pickard, et al. 2021). Given the indication that many precursors that are related to 6:2 FTS may be identified in contemporary AFFF products (Ruyle, Thackray, et al. (2021); and see 6:2 FTS in Buckeye (Gharehveran et al. 2022)) and that transformation processes are diverse (Evich et al. 2022, among others) there is evidence that the reduction in precursors and increase in 'terminal' PFAS may be a signal of some transformation of AFFF-sourced PFAS (Ruyle, Pickard, et al. 2021) and that current samples of surface soil represent the integration of decades of physicochemical activity.

The importance of soil as a test system relevant to ecotoxicology and ecological risk assessments is largely based on surface soil in AFFF use sites as a source of PFAS exposure. Multiple researchers (Salice et al. 2018; Conder et al. 2021; Leeson et al. 2021; Ruyle, Pickard, et al. 2021; Johnson et al. 2022; Zeng and Guo 2023) have described the movement of PFAS from terrestrial environments through groundwater to surface water. This implies that organisms in multiple habitats proximal to AFFF use sites could be potentially exposed, but also that exposure to PFAS could occur away from AFFF use sites by off-site transport of PFAS via surface water. A conceptual model of site-specific PFAS and or AFFF contamination by Leeson et al. (2021) indicated the clear acceptance of this hypothesis of PFAS movement within and beyond AFFF use sites on military installations within the large-scale U.S. Department of Defense effort to study AFFF use sites. Anderson et al. (2021) provided a similar summary of research on fate and transport properties of PFAS on AFFF impacted sites supported by the U.S. Department of Defense. Data gaps and areas of development highlighted include phase partitioning and leachability. This clearly highlights that to perform a high-quality risk assessment of either a site or chemical/chemical class and the required exposure estimates, and understanding of the movement of PFAS from source zones to receptors is critical. Phase partitioning is particularly problematic for PFAS as the surface-active properties of PFAS are critical to their usefulness but complicate anticipating where to find PFAS in a given abiotic environment or across variable abiotic environments (Zeng and Guo 2023). The obvious extension of this concept is related to leachability and the larger scale understanding of how fate and transport processes as a whole can be applied to estimates of on- and off-site exposure (Brusseau et al. 2020; Zeng and Guo 2023; Anderson and Modiri 2024).

Koch et al. (2020) indicated an interesting amendment to the hypothesis described above where surface soil sources of PFAS eventually lead to groundwater transport and surface water. They observed isotopically labeled PFAS moving from surface water to riparian systems via emergent aquatic insects and their trophic transfer to riparian/terrestrial predators (Koch et al. 2020). The implication of this observation is that the movement of PFAS may even be classified as multi-directional and requiring not just sophisticated physicochemical models to predict fate and transport (Zeng and Guo 2023), but dynamic models of large-scale systems that link biotic and abiotic processes. Falk et al. (2019) explored the influence of time on movement of PFAAs throughout a terrestrial system and suggested that, in general, PFAS concentrations tend to decrease through time which, would imply slowing of transport from source zones or reduced source zone concentrations. They did, however, note that PFBA appeared to be increasing over time (Falk et al. 2019). Potentially, this may be due to cyclical patterns of PFAS movement through systems, but incomplete characterization of source zones and uncertainty around fate and transport properties of individual and mixtures of PFAS remain problematic to resolving this discussion.

Regarding toxicity of PFAS mixtures to terrestrial ecological receptors, there are few data. Even fewer toxicity data are in context of the potential variability in exposure pathways from soil to receptor. Accordingly, concerns about additive, synergistic, antagonistic, or other mixture toxicity properties may remain uncertainties for ecological risk assessments regardless of available toxicity data. The goal of this paper was to identify PFAS soil mixtures relevant to

AFFF-contaminated soils to help inform ecological risk assessments but also ecotoxicological studies. Zodrow et al. (2021) summarize risk-based soil screening levels (RBSLs) for a variety of PFAS and wildlife receptors. Importantly, while this summary is a critical addition to the data availability, it does not explicitly account for mixture effects beyond additivity. Regardless, some context of relative potency across PFAS while accounting for exposure can be applied to this work. In Zodrow et al. (2021), the lowest NOAEL-based RBSL (most protective of all taxa and PFAS evaluated) was for PFOS. The PFOS value is 44-fold lower than the PFOA value, two orders of magnitude lower than PFNA, three orders of magnitude lower than PFBA, and four orders of magnitude lower than the PFHxA NOAEL-based RBSLs across all taxa evaluated (Zodrow et al. 2021). While the lack of perfluorosulfonates (i.e. no PFHxS) is a limitation of this comparison, none of the sites in our analysis have PFOA 44-fold higher than PFOS (Figure 2.5) and the interpretation is that risk from PFAS other than PFOS in soil may be low due to comparatively low exposure and toxicity.

Relative potency as well as mixture effects of PFAS are critical issues with respect to understanding and estimating risk to ecological receptors. Understanding effects of PFAS mixtures is an active area of study; varied approaches for PFAS mixture effects have been described. Goodrum et al. (2021) and Bil et al. (2021) describe PFAS mixture toxicity in mammals as not additive (Goodrum et al. 2021) and additive (Bil et al. 2021) largely based on divergent interpretations of the degree to which dose response functions are parallel. An example of several studies that explored mixture effects in terrestrial wildlife species included exposures to PFOS, PFHxS, PFHxA, and binary mixtures of each combination (Dennis, Subbiah, et al. 2021; Dennis, Hossain, et al. 2021; Dennis et al. 2022). They ultimately found that that PFHxS and PFOS were more bioaccumulative, but that PFHxA was more toxic than PFOS or

PFOS:PFHxS mixtures in quail (Dennis, Subbiah, et al. 2021; Dennis et al. 2022). This observation confounds the attractive and simplifying assumption that sum PFAS would be directly related to protective toxicity thresholds from single PFAS (e.g. Larson et al. (2018) used PFOS avian toxicity reference values (TRVs) to estimate risk of sumPFAS exposure). In contrast, in Bursian et al. (2021), quail exposed to PFOS only were more sensitive than quail exposed to a PFOS:PFHxS:PFBS:PFOA containing AFFF. This suggests that the slight reduction in toxicity of AFFF may not be due to mixture interactions or differing mechanisms of toxicity between constituent PFAS, but simply a reduction in exposure to PFOS. Of note, Bursian et al. (2021) suggested PFOS TRVs in alignment with the Newsted et al. (2005) TRV, an oft cited terrestrial toxicity study, while others (e.g. Dennis et al. (2022)) suggest much lower TRVs for PFOS and PFOS containing mixtures, although these studies did incorporate different exposure pathways.

Gray et al. (2024) re-analyzed the data of Bursian et al. (2021) to specifically ask whether dose addition or response addition (independent action) approaches could more successfully predict the lethal response of quail chicks exposed to PFOS and PFOA mixtures via diet. Gray et al. (2024) identify that PFOA is approximately half as potent as PFOS in day 8 lethality measures and that dose addition is the best predictor (i.e. PFOS:PFOA mixtures can be appropriately described via relative potency approaches). Accordingly, movement of PFOA from soil to diet must be twice that of PFOS at a site with equivalent PFOA and PFOS concentrations in order to generate equivalent toxicity of PFOA. A protective estimate from Figure 5 suggests only 5% of the sites in the dataset used here may have equivalent PFOS and PFOA soil concentrations. Using the summarized soil to plant (quail are granivorous) bioaccumulation factors from Zodrow et al. (2021), the movement of PFOA from soil to plants is 1/5th that of

PFOS. Accordingly, a relevant site would have to contain 20-fold higher soil PFOA than PFOS to generate equivalent plant concentrations. There are no sites in our dataset with this soil concentration relationship between PFOS and PFOA and it is subsequently low likelihood (under the constraints of this scenario) that an avian diet with 20-fold higher PFOA (compared to PFOS) concentration would be identified.

In regards to perfluorosulfonates, data in wild mammals (*Peromyscus* spp., “deer mice”) exposed to PFOS or PFHxS individually is available. Narizzano et al. (2022; 2023) identify LOAELs for a variety of endpoints relevant to population-level effects such as litter loss and stillbirths at 1.0 mg/kg-d PFOS and 14 mg/kg-d PFHxS. If an additivity approach (as identified in humans (i.e. mammals) in Bil et al. (2021)) is assumed, then a mouse would require a diet 14-fold higher in PFHxS compared to PFOS to expect equivalent toxicity. Goodrum et al. (2021) would suggest that the dietary toxicity thresholds of PFOS and PFHxS are additive and this proportional interpretation is reasonable. However, considering internal dosimetry (serum concentrations), Goodrum et al. (2021) do not identify parallel dose responses for PFOS and PFHxS and this proportional approach may not be reasonable.

In conclusion, we demonstrate that sites proximal to current and historic AFFF use on U.S. Airforce installations can be reasonably represented by simple 3-PFAS mixtures dominated by PFOS. Other priority PFAS include PFHxS, PFOA, PFHxA, and PFOSA based on high confidence sampling and high prevalence in mixtures across sites. Concentrations vary, but PFAS precursors (fluorotelomers) may be of increased priority with increased sampling effort. In contrast to surface water samples at these same sites (4 chemicals to meet 80% sum PFAS; (East et al. 2021)), on average, 91% of the sum PFAS in surface soils at any given site will be just 3 PFAS. The implications of this observation may reduce uncertainty around priority PFAS for ecological risk assessments but critical data needs for toxicity testing in terrestrial ecological receptors remain. The results reported here, call specifically for studies involving mixtures dominated by PFOS but including combinations of PFHxS, PFOA, PFHxA, and PFOSA.

Chapter 3: Evidence of additivity observed in mice exposed to a risk-relevant PFAS mixture.

Abstract

Per- and polyfluoroalkyl substances (PFAS) are widespread environmental contaminants that are largely observed as mixtures. PFAS-focused ecological risk assessments largely assess individual PFAS but understanding PFAS mixture exposure and potential ecological and biological effects is critical to characterize real world risk. To address this, we exposed CD-1® mice to individual PFAS and mixtures of PFAS that are relevant to surveyed environmental media and aqueous film-forming foams (AFFF) used on Department of Defense (DoD) sites. Our study was performed in two parts: (1) Assess the whole-body concentration of PFAS and (2) Assess tissue compartment concentrations of PFAS (*i.e.*, serum, liver, kidney, and brain). Organ weights and clinical chemistry were collected in the tissue compartment study to measure potential toxicological effects of individual and mixtures of PFAS. Mixed effect models were used to evaluate how well relationships between dose and body compartments predicted exposure with and without the influence of mixtures. A relative potency factor approach was evaluated for the potential to predict select effects from dose and tissue concentrations. We apply the laboratory-based finding to a desktop ecological risk assessment scenario and find that while changes in PFAS dietary concentrations may alter exposure and effect estimates, differentiating reference vs impacted sites is difficult. Our results indicate that dose addition methods are successful predictors of PFAS exposure and liver effects and, importantly, provide efficient predictive screening tools for ecological risk assessors evaluating sites' PFAS risks.

Introduction

Per- and polyfluoroalkyl substances (PFAS) are commonly observed in the environment as mixtures, some of which are highly complex (Brusseau et al. 2020). In the case of aqueous film-forming foam (AFFF) use on military installations, the bulk of PFAS mass in environmental media may be comprised of only a few PFAS (Anderson et al. 2016; East et al. 2021; East et al. 2025b). To support ecological risk assessments at locations where there is known or suspected PFAS contamination due to historical AFFF use, simplified approaches such as indicator PFAS or relative potency factors may be a reasonable approach to reduce the complexity of PFAS hazard and exposure assessment data requirements. One of the challenges of assessing sites with detectable PFAS mixtures in environmental media is accurately quantifying the uncertainty associated with chemical-to-chemical exposure or toxicity interactions. This requires knowledge of well-studied studied PFAS and PFAS that lack robust exposure and toxicity data. Further, site-specific field sample data often adds uncertainty due to the inherent variability associated with receptor behavior, natural history, lifespan, or other biological characteristics (Custer 2021), which may be misattributed to the identity and physicochemical characteristics of the PFAS at a specific site.

Data to support ecological risk assessments (exposure and effect data) in aquatic systems is available for many PFAS (Evich et al. 2022), but terrestrial systems have substantially fewer data to support ecological risk assessment-relevant analyses (Gkika et al. 2023). For example, Zodrow et al. (2021) found sufficient data to develop risk-based screening levels for 2 of 6 highly relevant PFAS in birds and 6 of 6 highly relevant PFAS in terrestrial mammals; Grippo et al. (2024) identified toxicity data for mammals exposed to perfluorooctanoic acid (PFOA) in 19 sources, perfluorooctanesulfonic acid (PFOS) in 17 sources, and “Other PFAS” in 13 sources;

and Reinikainen et al. (2022) suggest that PFOS is the primary driver of risk, but the lack of availability of terrestrial exposure and effect studies across the large PFAS chemical family may unintentionally result in the conclusion that the PFAS that are driving risk are simply the most well studied (Cousins et al. 2020). The stark difference availability of in terrestrial data between PFOA or PFOS and all other PFAS presents a major challenge to risk assessments on sites with PFAS mixtures.

To provide relevant and appropriate site-specific ecological risk assessments, there is a need to define specific terrestrial food web exposure parameters. As an example, predators of small mammals often consume the entire animal and an optimal food-web model would rely on whole animal concentrations (Grippo et al. 2024). Estimating whole animal body burden concentrations through dynamic/kinetic models (Sun et al. 2022; Mikkonen et al. 2023) or solubility/activity models (Fremlin et al. 2023; Kelly et al. 2024) from field data is plausible, but laboratory-based empirical observations have the fewest causal factors, and subsequently, the least uncertainty. In short, the observations are directly tied to the PFAS-organism system only. Similarly, there is need to define dose-response relationships concurrent to exposure measures in order to assess the hypothesis of additive toxicity of mixtures of PFAS (Bil et al. 2021; Ruyle, Thackray, et al. 2021; Conley et al. 2022; Conley et al. 2023). Translating laboratory study findings to apical organismal effect estimates can support efficient risk assessment decision-making. As such, this study was designed to assess exposure and effects of individual and mixtures of PFAS within the controlled laboratory space using field-relevant PFAS mixtures representing soil or water substrates at toxicologically relevant concentrations.

The three main objectives of this study were to (1) quantify individual and mixtures of PFAS in multiple tissue compartments of a small mammal (CD-1® mice) exposed for 28 days;

(2) evaluate additivity or non-additivity of PFAS concentrations and effects across tissue compartments using hierarchical models; and (3) provide PFAS-specific predictive models for ΣPFAS exposure and effects. These objectives address hypothesized additivity of PFAS in exposure and effects with the goal of supporting ecological risk assessments for terrestrial small mammals by providing a useful, accurate, and accessible approach to predicting PFAS mixtures exposure and effects across similar terrestrial systems. To demonstrate the applicability of this approach and some specific insights into these types of systems, we provide a worked example of a desktop screening ecological risk assessment.

Methods

PFAS and dosing solutions

PFAS selected for study were based on mixtures representative of AFFF-impacted surface waters (East et al. 2021) or mixtures representative of AFFF-impacted surface soils (Salice et al. 2021; East et al. 2025b). Individual PFAS exposures to perfluorooctanesulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexanoic acid (PFHxA), perfluorohexanesulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluorobutanesulfonic acid (PFBS), 6:2 fluorotelomer sulfonate (FTS), or 8:2 FTS represent baseline single PFAS data analogous to prior work (Narizzano et al. 2021) and were all at 2.5 mg/kg-d to avoid mortality observed at the next highest dose administered with PFOS, 20 mg/kg-d (Narizzano et al. 2022; Bohannon et al. 2023; Narizzano et al. 2023; Narizzano et al. 2024). PFAS mixtures were delivered at 3 concentrations, all relative to PFOS, and containing concentrations of PFOS and ΣPFAS that were approximately, nominally equal to 2.5 mg/kg-d (Table SI3.1). The surface water C6-8 mixture contained PFOS, PFHxS, PFHxA, and PFOA by nominal ratio

1:0.62:0.25:0.17 (Table SI3.1) based on previous characterization of PFAS-impacted surface water at military sites (East et al. 2021). The surface soil FTS mixture contained PFOS, 6:2 FTS, and 8:2 FTS by nominal ratio 1:0.1:0.05 (Table SI3.1) based on previous characterization of PFAS-impacted soil at military sites (Salice et al. 2021; East et al. 2025b). PFAS were purchased from a variety of suppliers, based upon availability, with the goal of obtaining the potassium salt (K^+) or anionic form (see details in Table SI3.2). All chemicals were stored at room temperature and in the dark, as suggested by the manufacturer.

Dosing solutions were prepared by weighing neat PFAS as purchased (either as acid or as salt) using a calibrated and verified scale and dissolving in a known volume of deionized water in HDPE bottles. Weights of salts were not adjusted to account for cations based on the small influence of cations on target concentration (e.g., 39.1 g/mol out of 538.22 g/mol for PFOS K+ salt is a smaller relative influence on error than the 70-130% error expected in analytical methods). Disassociated anion concentrations from analytical measures were used in all cases, whereas nominal concentrations were guides for dosing and study design.

Two batches of dosing solutions were prepared 72 hours prior to study start and were maintained on orbital shaker plates constantly running throughout the study at 60-100 rpm, per sampling and storage validation exercises (Rewerts et al. 2021). Batches were alternated daily for daily dosing aliquots, sampled for analytical verification on study days 0 and 28, and pooled in equal volumes from each batch by a calibrated and verified pipette. Control dosing solutions (deionized water) were bottled, shaken, and sampled as PFAS dosing solutions.

Mice husbandry, dosing, and sampling

CD-1® mice (Crl:CD1(ICR)) arrived from Charles River Laboratories at 42 days old in two batches (whole body study and serum study) of 300 mice (10 per sex per treatment; 15 treatments: 1 control, 8 individual analytes, 6 mixtures). The animal facility at Defense Centers for Public Health-Aberdeen (DCPH-A) Toxicology is AAALAC accredited, supported by a GLP-trained Quality Assurance team, and this animal use was approved in animal use protocol #26-22-02-01 by DCPH-A IACUC and conducted according to the Guide for Care and Use of Laboratory Animals and all applicable federal and DoD regulations (National Research Council (U.S.) et al. 2011).

Male mice were individually-housed due to consistent observation of fighting that precluded confidence in animal health (East et al. 2023); female mice were group-housed at 5 per cage. Animals were housed in temperature-, relative humidity-, and light-controlled rooms with automated data recording and 24 hour monitored out-of-range alarm systems. Target conditions in the room were 20-22 °C, 30-70% humidity, and 12:12 hour light:dark cycle. A certified pesticide-free rodent chow (Envigo Teklad® 2020X Certified Rodent Diet) and filtered tap water were available ad libitum. Feeding, bedding, and enrichment materials were plastic-free (e.g., steel, paper, wood) to minimize uncontrolled PFAS-contamination. Mice were dosed daily (every 22-26 hours) by trained staff via oral gavage at 10 mL/kg using a 1 mL disposable syringe and 16-gauge 1.5 inch stainless steel ball end oral gavage needle. Animals were weighed weekly.

On the 29th day (~24 hours after receiving 28 consecutive daily doses), mice in the whole body study were euthanized by inhalation of CO_2 and cervical dislocation. Entire skin was removed and bodies were placed in a clean, labeled Whirl-Pak. Whirl-Paks were placed in a -80 °C freezer in small batches throughout sample collection and stored at -80 °C until shipping for analysis. On the 29th day (~24 hours after receiving 28 consecutive daily doses), mice in the serum study were rendered insensate by inhalation of CO_2 and euthanized by decapitation and exsanguination. Whole trunk blood was collected into a clean, labeled 1.5 mL polypropylene disposable microcentrifuge tube, allowed to clot, centrifuged, and serum was decanted into clean, labeled 0.8 mL microcentrifuge tube and transferred to -80 °C for storage until shipping for analysis. Serum was also aliquoted for clinical chemistry analysis from specific treatments (see below). The liver, kidneys (paired), brain, and ~1 cm^2 skin were collected by trained necropsy staff (including a board-certified veterinary pathologist to ensure notation of gross lesions or other observations that may influence kinetics), weighed, and transferred into clean labeled cryovials (1.5 mL and 5 mL) and stored at -80 °C until shipping for analysis.

PFAS quantification in tissues and dosing solutions

Dosing solution, whole body, and serum samples from all treatments and animals were shipped on dry ice with chain of custody to SGS Axys (Sidney, BC, Canada). Liver, kidneys, and brain samples from select treatments and animals (logistically constrained to 13 treatments—excluded PFNA and PFBS, as not in either mixture—and 7 animals per sex) were shipped on dry ice with chain of custody to SGS Axys (Sidney, BC, Canada). All tissue samples were homogenized and tissue, serum, and dosing solution samples were prepared, extracted, and analyzed for 40 PFAS via ultra-high performance liquid chromatography with tandem mass spectrometry (UHPLC-MS/MS) following the procedures of draft method (4th) EPA 1633 ("Method 1633 Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolids, and Tissue Samples by LC-MS/MS"). Briefly, a portion of each sample was accurately weighed into a tube spiked with isotopically labeled quantification standards (surrogate compounds) and was extracted with 50% formic acid. The resulting extract was cleaned by solid phase extraction (SPE) using a disposable cartridge containing a weak anion exchange sorbent. The SPE cartridge was eluted by basic methanol. The extract for each sample was spiked with labeled recovery (internal) standards and analyzed by UHPLC-MS/MS. UHPLC-MS/MS is a reversed phase C18 column using a solvent gradient. The column was coupled to a triple quadrupole mass spectrometer run at unit mass resolution in the multiple reaction monitoring (MRM) mode, using negative electrospray ionization. The instrument was calibrated after every 10 samples or every 12 hours, whichever came first and at the end of every run. Summarized reporting limits (determined per batch) are included in the SI (Table SI3.3 through Table SI3.8). Data flagged as 'beyond the standard curve' were included as quantitative measures based on pilot studies that indicated dilution and undiluted runs were within 10% of each other. Data flagged as below reporting but above detection (J-flag, 'trace') were included as quantitative measures due to consistent overlap of measures in batches where given samples were above reporting vs below reporting (see Figure SI3.1). In the brain tissues, J-flagged data were excluded as substantially less than 50% of sample sizes were above detection limits and the overlap between J-flag data and quantitative data could not be confirmed (see Figure SI3.1). This approach is based on a tradeoff between censoring methods (Helsel et al. 2012; Hites 2019) and including maximal individual data. Note that summarization techniques for 'trace environmental samples' lose individual-level resolution and our laboratory studies with many individuals and high concentrations are intended to express variation as a combination of individuals and instrumental analysis.

Clinical chemistry quantification

Standard serum chemistry parameters were evaluated on select thawed serum samples using the DiaSys response 910 Vet Analyzer (DiaSys Diagnostic Systems, MI, USA) within calibration and verification. The nine parameters analyzed were: albumin (ALB), alanine aminotransferase (ALT), aspartate aminotransferase (AST), blood urea nitrogen (BUN), cholesterol (CHOL), glucose (GLUC), total protein (TP), creatinine (CREA), and triglycerides (TRIG). The three calculated parameters were: Globulin (GLOB), the ALB/GLOB ratio, and the BUN/CREA ratio. Samples were selected randomly from mice exposed to the C6-8 mixture (low, medium, and high), PFOS, PFOA, PFHxS, PFHxA, and control treatments. Samples from other treatments (e.g. FTS mixture) were excluded due to cost constraints.

Statistical modeling of exposure and effects

All model development, evaluation, and figure generation utilized R (version 4.4.0) (R Core Team 2024). A selection of relevant code is provided in the Supplementary Information for a reproducible example. The overarching approach is based on the hypothesis: If PFAS exposure or effects data from mixture treatment groups are predictive of single PFAS treatment groups, then mixtures will behave additively (see Figure SI3.2). PFAS concentration data (individual PFAS and ΣPFAS) that were used to address exposure include the dose, whole body, serum, liver, kidney, and brain. PFAS effect data that were used to explore effects were relative liver weight and alanine aminotransferase (ALT) concentration as they had consistent dose-response relationships. Other PFAS effect data that did not have a consistent dose-response relationship included bodyweight, brain and kidney weights, and the remaining clinical chemistry parameters (see Table SI3.18 through Table SI3.21). Some differences were identified in per-contrast to control ANOVAs, but they were in singleton PFAS treatments and less directly contributory to the observed liver toxicity pattern. For instance, ALB, AST, CREA, TP, GLU, and CHOL differences were detected, but not in the mixture treatments (with increasing concentrations) and all with either weaker biological ties to liver impacts (i.e. TP) or weaker levels of response to liver impacts (i.e. AST).

Modeling additivity in exposure

To explore the additivity hypothesis, a mixed effects model (i.e., 'hierarchical model' (Gelman and Hill 2019)) was fit for a variety of dose:sample or sample:sample combinations for each individual PFAS where dose or sample and sex were the independent variables (fixed effects in Model 1). Random effects in Model 1 were PFAS-specific varying both y-intercept and slope (see Figure SI3.2), which provided a measure of the variance of interactive effects in relation to individual-to-individual variability. Model 1 was fit to compare the variance of the random effects against overall residuals to determine whether to reject the hypothesis of additivity. Specifically, if the variance associated with the random effects is greater than the residuals, then any one animal's concentrations require accounting for a non-additive mixture relationship. If the variance associated with the random effects is less than the residuals, then any one animal's concentrations do not require accounting for a non-additive mixture relationship and an additive mixture relationship is inferred (see Figure SI3.2). If this additive mixture relationship was observed, mixed effect models with varying intercept only were fit to the same predictor and estimate pair (Model 2). These mixed effects models (Model 1 and Model 2) also accounted for sex to more completely describe the relationship between dose and tissue or sample and tissue.

Model 1. Linear mixed effect model predicting a $\log_e$-transformed tissue concentration (normally distributed) from a $\log_e$-transformed dose concentration (or other tissue concentration) and sex of mice (male = 1). The intercept (alpha) and slope (beta) are normally distributed around a mean with PFAS-specific variance and co-variance. This is described as a varying-intercept and varying-slope mixed effects model—in this case, the intercept and slope vary by PFAS and provide a measure of whether a dose and tissue relationship varies when exposure is a mixture vs singleton.

$$\ln(\text{Tissue, ng/g})_i \sim N(\mu, \sigma^2),$$
$$\mu = \alpha_{j[i]} + \beta_{1j[i]}(\ln(\text{Dose, mg/kg-d})) + \beta_2(\text{Sex}_{Male}),$$
$$\begin{pmatrix}\alpha_j \\ \beta_{1j}\end{pmatrix} \sim N\left(\begin{pmatrix}\mu_{\alpha j} \\ \mu_{\beta 1j}\end{pmatrix}, \begin{pmatrix}\sigma^2_{\alpha j} & \rho_{\alpha j\beta 1j} \\ \rho_{\beta 1j\alpha j} & \sigma^2_{\beta 1j}\end{pmatrix}\right), for \text{ PFAS } j = 1 \ldots j$$

Model 2. Linear mixed effect model predicting a $\log_e$-transformed tissue concentration (normally distributed) from a $\log_e$-transformed dose concentration (or other tissue concentration) and sex of mice (male = 1). The intercept (alpha) is normally distributed around a mean with PFAS-specific variance. This is described as a varying-intercept mixed effects model—in this case, the intercept varies by PFAS and provides a measure analogous to PFAS-specific tissue affinity as the dose to tissue relationship is constant here regardless of mixture or singleton exposure.

$$\ln(\text{Tissue, ng/g})_i \sim N(\mu, \sigma^2),$$
$$\mu = \alpha_{j[i]} + \beta_1(\ln(\text{Dose, mg/kg-d})) + \beta_2(\text{Sex}_{Male}),$$
$$(\alpha_j) \sim N(\mu_{\alpha j}, \sigma^2_{\alpha j}), for \text{ PFAS } j = 1 \ldots j$$

Modeling additivity in effects

A dose addition relative potency factor (RPF) approach is expected to perform well for these data (Bil et al. 2021; Gray et al. 2024). Data from single-PFAS exposures were utilized as relative potency factors (RPF) specific to each individual PFAS. These RPFs were then used to weight the individual PFAS dose in mixture treatments to calculate a ΣPFAS that predicted the effect. Effects require a common normalization factor for this approach—here, as PFOS is the most relevant PFAS at the sites of interest, mean relative liver weight of the PFOS alone treatment (by sex) was used to generate a proportional relative liver weight value for each animal (relative to the PFOS treatment mean). The interpretation is then that the proportional relative liver weight change ($\log_{10}$ transformed to ensure equivalent up/down comparison) is a function of ΣPFAS dose. The mixture treatments proportional to PFOS treatment relative liver weights were used to estimate the overall slope (beta in Model 3). The single PFAS treatments proportional to PFOS treatment relative liver weights were used to estimate the relative potency (RPF_i) of each PFAS. To evaluate the model performance, if a regression fit to the RPF-adjusted proportion PFOS treatment relative liver weights were inside the confidence intervals of the original, unadjusted, proportion PFOS treatment relative liver weights linear regression, then additivity should not be rejected.

Model 3. Linear regression predicting relative liver weight as a proportion of PFOS-specific relative liver weight by dose (untransformed) (or serum or liver) and relative potency factor (RPFi). Intercept, slope, and variance are determined by linear regression of relative weight as a proportion of PFOS-specific relative liver weight across all **mixture**-exposed mice. RPFi is the mean relative weight as a proportion of PFOS-specific relative liver weight for ith PFAS **singleton**-exposed mice.

$$\ln\left(Rel.Liver/\overline{Rel.Liver_{PFOS}}\right) \sim N(\mu, \sigma^2),$$
$$\mu = a + \sum \beta(RPF)_i(\text{Dose, mg/kg-d})_i\,, for\ i = \text{PFAS}_1 \ldots \text{PFAS}_n$$

As ALT showed a dose-response effect and is often utilized as a measure of hepatocyte damage, a linear regression was fit to $\log_{10}$ relative liver weight proportion change and $\log_{10}$ ALT proportional change to generate a slope (unit change per unit change in relative effects with equal up/down directionality). Modeling the ALT endpoint provides an example of translation from organ weight effect (determined via lethal sample collection) to apical organismal health effect (determined via nonlethal sample collection).

Results

PFAS concentrations

The studies were run in two cohorts, and between the two cohorts, the dosing solutions were comparable (Table SI3.9). As such, only measured data are incorporated into statistical models. There are consistent impurities that appear to be associated with the commercially available PFAS salts/anions used in this study. Specifically, perfluoropentanesulfonic acid (PFPeS), perfluoroheptanesulfonic acid (PFHpS), and perfluorononanesulfonic acid (PFNS) were detected in all treatments that contain PFOS (Table SI3.9). PFAS concentrations in mouse tissues (Figure 3.1 and Figure 3.2) indicate that relative PFAS concentrations across tissues were consistent (see complete summarized dataset in SI). In PFOS-, PFOA-, and PFHxS-singly exposed animals, common relative concentration is consistently observed across the tissues analyzed with [liver] > [serum] > [whole body], [kidney] > [brain] (Figure 3.1 and Figure 3.2). PFNA samples were not available for analysis, but it is expected that the same relative concentration across tissues would be observed in the PFNA-singly exposed animals. Note that PFHxS-singly exposed animals had serum concentrations that were approximately equivalent to liver concentrations (Figure 3.1), and that in the C6-8 mixture-exposed animals, PFHxS appears to be the dominant PFAS in serum, but not in other compartments, despite PFOS being the dominant analyte in the dosing solution (Figure 3.2 and Table SI3.9). PFHxA, PFBS, and 6:2 FTS have wider distributions within and across compartments and lower concentrations than the other PFAS, likely due to known elimination kinetics (Narizzano et al. 2021; East et al. 2024). 8:2 FTS-singly exposed animals generally followed the pattern of relative tissue compartment concentrations observed with animals exposed to PFOS, PFOA, and PFHxS. Further summary figures and tables addressing impurities and PFAS detected in control tissues are provided in the SI. Tables of reporting limits (averaged across analysis batches) are also included in SI.

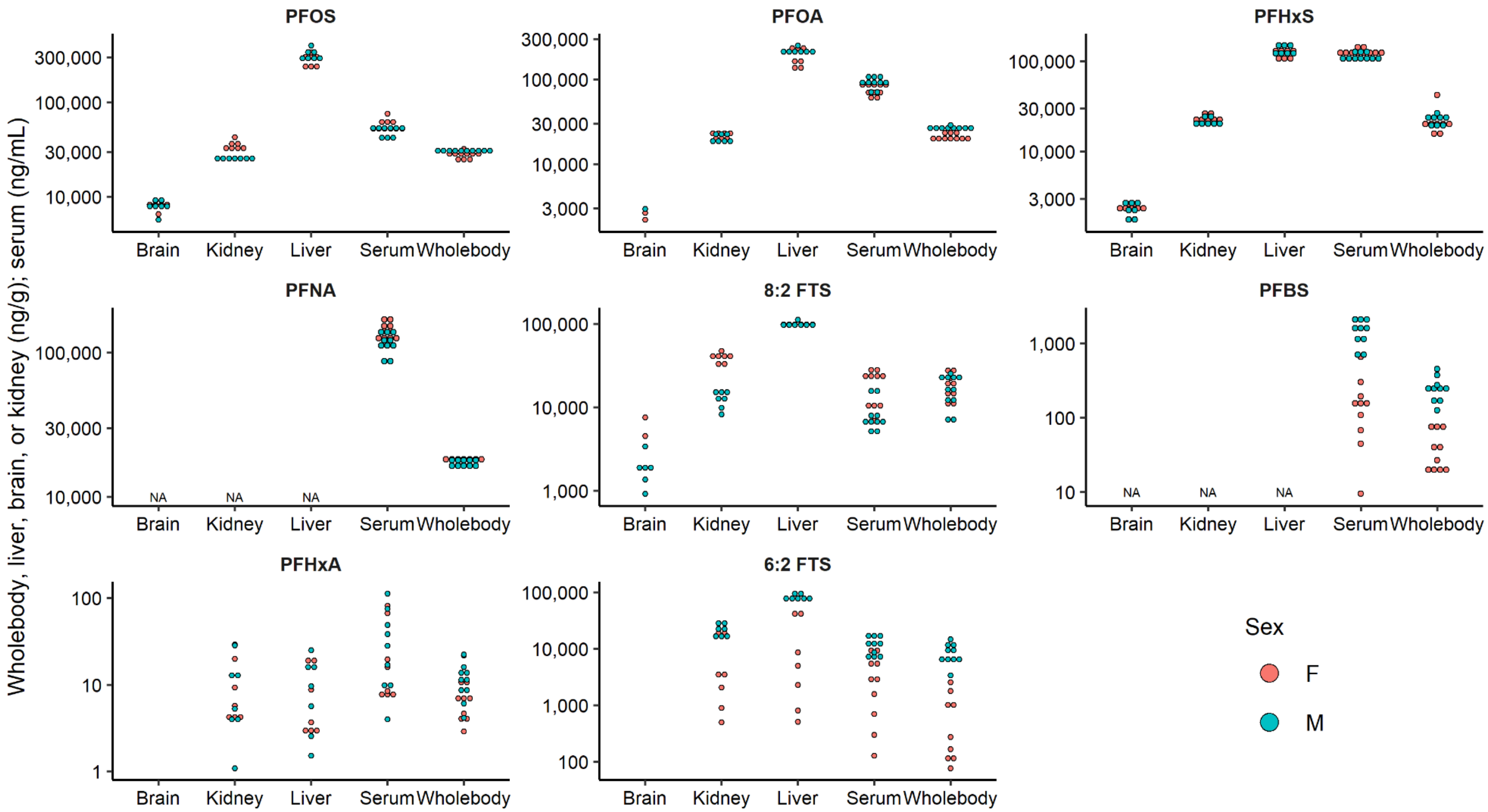


Figure 3.1. PFAS concentrations (ng/g or ng/mL) across tissues by sexes grouped by singleton PFAS. Dots are binned by 1/30th the range of the data and are from individual mice with samples meeting inclusion criteria. Overlaps may obscure some points. Note that wholebody samples are not paired with brain, kidney, liver, or serum (which are paired). Note also that ng/g is only approximately equivalent to ng/mL. Blanks (i.e., lack of dots) indicate no samples above detection limit and NA indicates no sample analyzed.

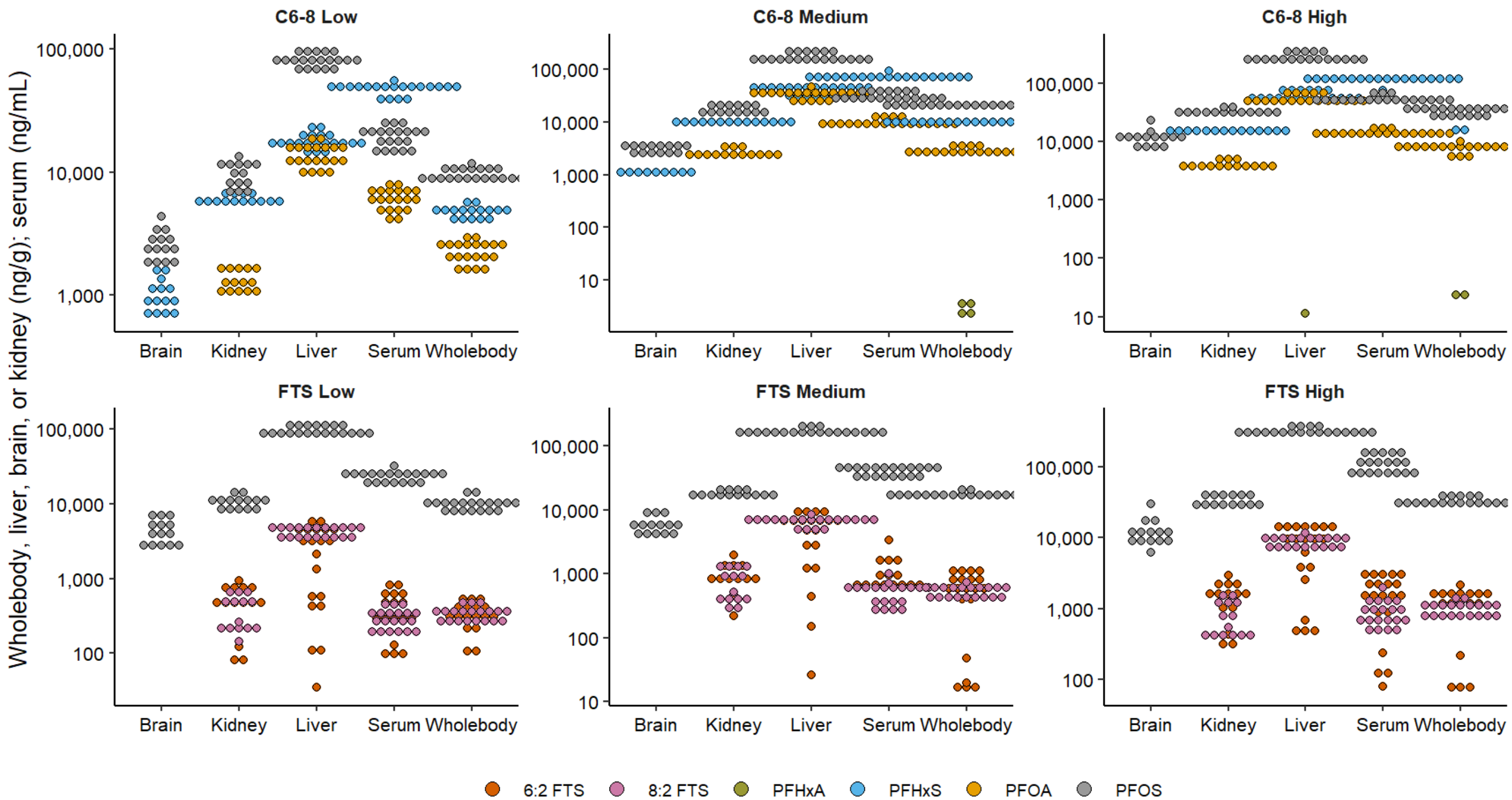


Figure 3.2. PFAS concentrations (ng/g or ng/mL) across tissues grouped by mixture treatments. Sexes are not differentiated. Dots are binned by 1/30th the range of the data and are from individual mice with samples meeting inclusion criteria. Overlaps and figure extent may obscure some points. Note that wholebody samples are not paired with brain, kidney, liver, or serum (which are paired). Note also that ng/g is only approximately equivalent to ng/mL. Blanks (i.e., lack of dots) indicate no samples above detection limit.

Effects summary

Effects data are summarized in detail in the SI (Table SI3.18 through Table SI3.21), and we note that concentrations selected were intended to avoid inducing overt effects and toxicodynamic confounders. Bodyweight trajectories of the mice were only impacted by exposure to PFNA across all groups (Table SI3.20), and this impact was not weight loss, but less weight gained. Organ weights were sometimes impacted by PFAS exposure, and liver weights from PFAS-exposed mice were often greater than those of controls (Table SI3.21). Specifically, relative liver weights (liver weight (g) / (terminal body weight (g) – liver weight (g))) , as a measure of potency, differed across PFAS by 1.03 to 2.80 vs control treatment relative liver weight (Table #) Our individual PFAS doses were quantified at 1.39 to 2.46 mg/kg-d, which is comparable to the commonly reported LOAELS near 1 mg/kg-d in literature, (Narizzano et al. 2022; Narizzano et al. 2023b; Narizzano et al. 2024) and concurs with our observed increases in relative liver weights.

Several clinical chemistry parameters were impacted by individual and mixtures of PFAS, but the ALT data showed consistent dose-response and are appropriate to consider total liver health based on the observed increases in relative liver weight (Table SI3.18 and Table SI3.19). Specifically, ALT values (Units/L) increased by as much as 2- to 6-fold in the highest ΣPFAS treatment (C6-8 High) and 4- to 5-fold in the PFOA alone treatment (SI).

Evidence of additivity in exposure measures

The $\log_e$-linear relationship between dose and tissue concentrations are qualitatively similar across PFAS, regardless of whether animals were exposed to singletons or in mixtures (Figure 3.3, Figure SI3.3, Figure SI3.4). When evaluated quantitatively using a median dose and median y-intercept, the tissue- and sex-specific slopes produce mean predicted tissue concentrations that fall entirely within the maximal confidence intervals estimated by the regression residuals (Figure SI3.5). In short, the difference in slopes is equal to or smaller than the difference in individuals. If the PFAS-specific linear models were less parallel, it would indicate that there was a different relationship between dose and tissue concentration for PFAS singletons (higher doses, rightwards on the x-axis) and PFAS mixtures (lower doses, leftwards on the x-axis) (Figure 3.3, Figure SI3.3, Figure SI3.4). Some PFAS were impurities and were not part of the intended dosing schemes (for example, PFPeS (Figure SI3.3)) but appear regularly and along similar linear trajectories.

A further demonstration of additivity in exposure measures is that the linear model fit to the dose (mg/kg-d) and whole body (ng/g) data from mixture treatments and impurities (lower doses, leftward on the X-axis) captures the mean observed singleton treatment data (higher doses, rightward on the X-axis) or has confidence intervals that contain a linear model fit to most available data (including singleton treatments) (Figure 3.4, other dose and tissue combinations Figure SI3.9 through Figure SI3.13). This successful prediction is suggesting that accumulation of specific PFAS is not impacted by co-exposure to other PFAS and an additive model can be assumed. Whole body PFOA dosed as a singleton appears to be lower than expected in the all-data model than the mixture- and impurity-data model, implying that PFOA may not fit a strict additive model or uptake/deposition is concentration-dependent, but we note the extensive range of data, subsequent narrow confidence intervals, and qualitatively minor overprediction.

Using a mixed effect (hierarchical) model (Model 1) that includes analyte-specific correlated varying slopes and intercepts, the variation around the model that is associated with individual animals and general “noise” (residuals, Table 3.1, σ_{ij}) is in all cases larger than the variation associated with a potential mixture effect (e.g. variable slope by PFAS) (non-additivity effect variation, Table 3.1, $\sigma_{\beta i}$). The interpretation is that a mixture-driven interaction is unlikely as the non-additive effect would be unlikely to be detected given the variability in individual data. In mixed effect modeling parlance, the mixture interaction parameter is not informative and should be trimmed from the model. Subsequent interpretation is then that the less complicated model (Model 2), with analyte-specific intercepts only, sufficiently represents the system. To evaluate this assertion, a comparison between Model 1 (Figure SI3.14) and Model 2 (Figure SI3.15) suggests that the simplification of the model from accounting for a mixture effect (Model 1) to strictly additive (Model 2) only minorly reduces the precision or accuracy. Comparing the Residuals columns (σ_{ij}) in Table 3.1, simplifying the model increases dose-to-tissue predictions' residuals by < 0.01 $\log_e$ units in 3 of 5 cases. All other Model 1 vs Model 2 σ_{ij} comparisons have residual increases of < 0.1 $\log_e$ units. On an untransformed scale, this translates to approximately a 10% increase in variation that would then be attributed to individuals and not (mis-)attributed to a non-additive mixture relationship. Further, as individual-driven tissue concentration variability is larger than the difference between slopes in Model 1, if an interactive non-additive mixture effect existed (e.g. synergism, potentiating, etc.), it would be challenging to detect in a field setting.

Accordingly, Model 2, the additive and simpler model, is the better method to predict tissue concentrations. PFAS-specific models predicting whole body concentrations by PFAS-specific dose are reported in Table 3.2 with other predictors and estimates in the SI (Table SI3.11 through Table SI3.13). The sum of PFAS-specific measures is equal to ΣPFAS and unknown PFAS can be estimated by the central parameters in Table 3.1 (within the limitations of the target PFAS in Method 1633). We do not assert that this model will perform well for "all" PFAS or measures of "Total Organic Fluorine," but the premise of this modeling approach (i.e. PFAS-specific variation around the mean y-intercept) does suggest that unobserved PFAS (in this study) could be distributed around the mean trend. Individual concentrations are normally distributed about these estimates by the standard deviation in Table 3.2 (and Table SI3.11 through Table SI3.13). In summary, given the propensity of evidence for additivity (11 of 11 Model 1 σ_{ij} vs $\sigma_{\beta i}$ comparisons in Table 3.1), it is unlikely that the substantially more complicated model is needed, nor does a more complicated model detect an impactful mixture effect that is more influential than individual variation alone (Table 3.1, Figure SI3.14 and Figure SI3.15).

Evidence of additivity in effects

Relative liver weights from singleton PFAS exposures, proportional to PFOS, were used as relative potency factors (RPFs) (Figure SI3.16, Table SI3.14) because PFOS is expected to be representative of PFAS in surface soil and surface water on contaminated military sites (East et al. 2021; East et al. 2025b). RPFs weight the PFAS-specific contribution to the dose response function. Model 3 describes the ΣPFAS predictor of relative liver weight (proportional to PFOS) to a per-PFAS dose-additive predictor of relative liver weight (Model 3, Figure 3.5, Table SI3.15). Because the proportional increase in relative liver weight predicted by the additive model is inside the confidence intervals of the original dose response model and the RPF-adjusted means move closer to the dose response models (Figure 3.5), the weighted dose-additive response does not influence the expected dose response function and any given PFAS-specific prediction is sufficiently normalized to a ΣPFAS prediction. PFOA appears to be the only PFAS that may have an unique mechanism that influences liver weight based on the RPF-adjusted toxicity estimate falling outside the mixture model confidence intervals. See SI for other combinations of predictor and liver effects and model performance plots (Figure SI3.16 through Figure SI3.25) and parameter estimates (Table SI3.14 through Table SI3.16). Overall, the prediction of PFAS-mixture toxicity using a PFOS-relative potency factor are adequate for these environmentally relevant PFAS and this risk-relevant endpoint.

Because ALT is often utilized as a measure of hepatocyte damage, ALT measures were also relativized to the PFOS treatment and a linear model was then fit with the relative liver weight (proportional to PFOS treatment mean relative liver weight) as predictor and ALT value proportional to PFOS treatment mean ALT value (Table SI3.16, Figure SI3.26). The resulting slope of these linear models binned by sex show that females have approximately 25% more ALT proportional increase than males (females' slope = 2.11, males' slope = 1.52) (Table SI3.16). Because these slopes are greater than 1, serum ALT is likely a more sensitive measure of health effects than liver weight alone.

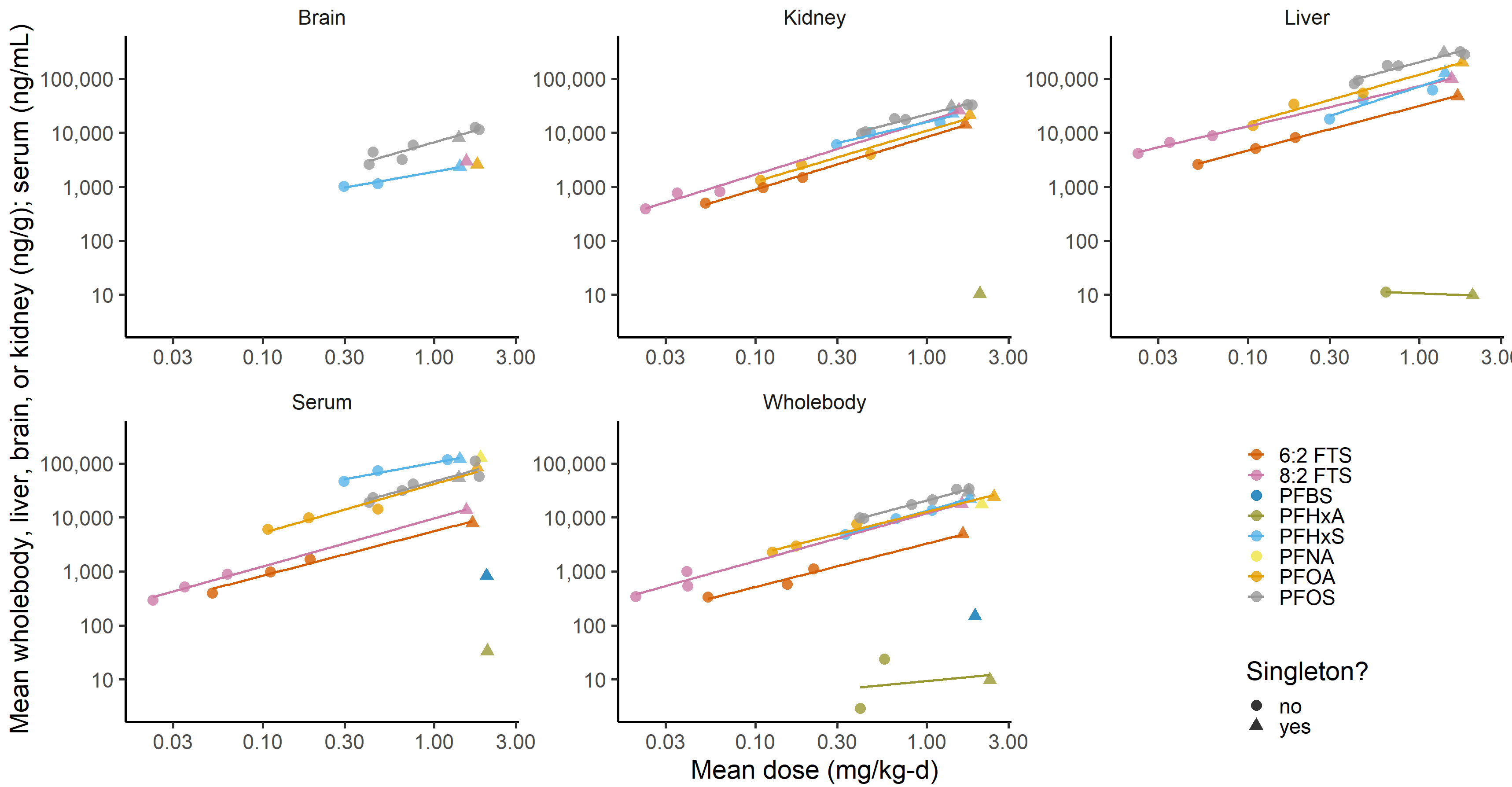


Figure 3.3. Relationship between mean dose (mg/kg-d) and mean compartment concentration (wholebody, liver, brain or kidney, ng/g or serum ng/mL) by PFAS (color) and if the exposure was a singleton treatment (triangle) or not a singleton treatment (dot). Data used in this figure are trimmed to those that are "in mixture," which means excluding impurities (e.g., low concentration PFOS detected in the PFOA singleton treatment). See Supplementary Information for an analogous figure including all PFAS detected whether "in mixture" or an impurity. Some data (e.g., PFHxA, PFPeS) are considered 'trace' data (above detection, below reporting limit) and may introduce variability on the extremes. Points without lines indicate that PFAS was not present in multiple doses.

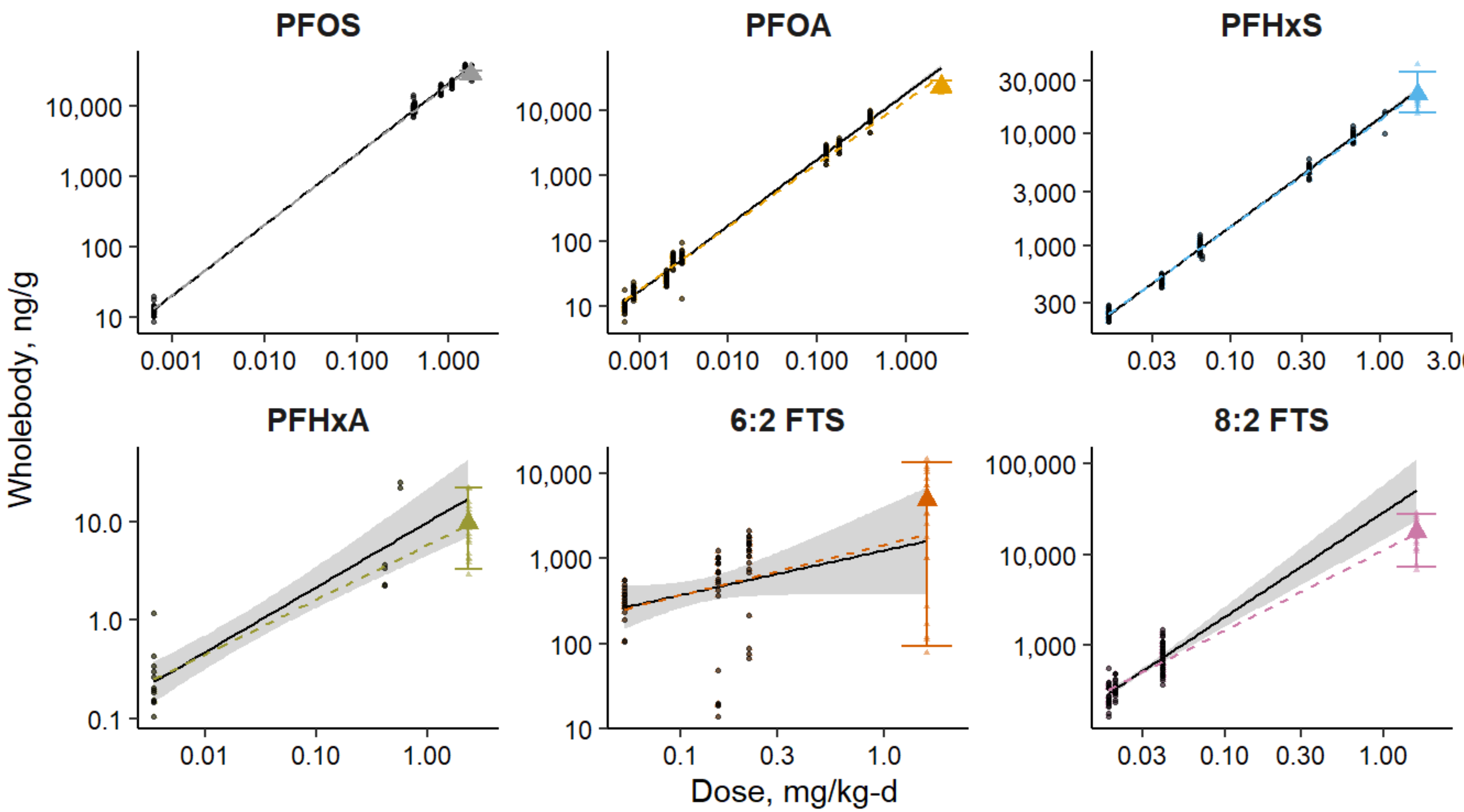


Figure 3.4. Extrapolated relationship between dose (mg/kg-d) and whole body (ng/g) when predicted from mixture treatments or impure mixtures (black points, black line, gray confidence intervals) are consistent with models that utilize all data (dashed color-matched line). Only PFOA's extrapolated prediction is outside the observed 95% confidence intervals for the singleton exposure (yellow error bars) or mean observed (yellow triangle) outside the extrapolated confidence intervals. See Supplementary Information for extended evaluation.

Table 3.1. Evidence of additivity is based on the small relative contribution of PFAS-specific slope ($\boldsymbol{\sigma_{\beta i}}$), in relation to individual-specific deviation ($\boldsymbol{\sigma_{ij}}$) using a mixed effects model (Model 1) that allows a correlated PFAS-specific slope and intercept around an overall linear model between ln-transformed dose and tissue or tissue:tissue or a mixed effects model (Model 2) that allows only a PFAS-specific intercept. Bold indicates the larger source of variation between individuals and a non-additivity effect (only relevant for Model 1).

			Random effects		**Residuals**	**Fixed effects**		
			Non-additivity effect	**PFAS-effect**	**Individual-effect**	**Overall relationship**		**Sex-effect**
Model	**Predictor**	**Estimate**	**Slope $\sigma_{\beta i}$**	**Intercept $\sigma_{\alpha i}$**	**σ_{ij}**	**Slope β**	**Intercept α**	**β_{Sex}**
1	Dose	Whole body	0.20	2.83	**0.48**	0.83	7.68	0.32
	Dose	Serum	0.16	2.73	**0.50**	0.84	8.92	0.03
	Dose	Liver	0.29	3.55	**0.90**	0.82	9.86	0.40
	Dose	Kidney	0.16	2.59	**0.74**	0.82	8.33	-0.26
	Dose	Brain	0.12	0.63	**0.35**	0.73	7.87	-0.06
	Serum	Liver	0.27	1.79	**0.48**	0.94	0.76	0.44
	Serum	Kidney	0.28	1.56	**0.57**	0.77	0.64	-0.06
	Serum	Brain	0.12	1.02	**0.56**	0.62	1.55	0.14
	Liver	Kidney	0.10	0.62	**0.50**	0.75	0.25	-0.40
	Liver	Brain	0.11	1.03	**0.58**	0.67	0.09	-0.06
	Kidney	Brain	0.16	0.97	**0.51**	0.77	0.02	0.22
2	Dose	Whole body	-	2.56	0.55	0.91	7.72	0.33
	Dose	Serum	-	2.80	0.51	0.92	8.96	0.03
	Dose	Liver	-	3.41	0.92	0.95	9.98	0.40
	Dose	Kidney	-	2.58	0.74	0.88	8.38	-0.26
	Dose	Brain	-	0.63	0.36	0.75	7.86	-0.06
	Serum	Liver	-	1.68	0.53	0.91	0.82	0.44
	Serum	Kidney	-	0.96	0.66	0.75	0.96	-0.11
	Serum	Brain	-	0.98	0.61	0.67	1.09	0.22
	Liver	Kidney	-	0.61	0.52	0.80	0.02	-0.41
	Liver	Brain	-	0.19	0.65	0.76	-0.66	0.01
	Kidney	Brain	-	0.32	0.59	0.90	-0.86	0.32

Table 3.2. Predicting tissues (ng/g or ng/mL) based on daily dose (mg/kg-d) for 28 days via oral gavage in CD-1 mice. $\boldsymbol{Sex}_{\mathrm{M}}=1$ for male mice and $\boldsymbol{Sex_M = 0}$ for female mice. $\boldsymbol{N(\mu_i, 0.55)}$ is a normal distribution with mean $\boldsymbol{\mu_i}$ and standard deviation 0.55 as an example. See other combinations of predictors and estimates in the SI.

Predictor	Estimate	μ Function	Prediction
Dose (mg/kg-d)	Whole Body (ng/g)	$\mu_i = \begin{bmatrix} 6:2\,FTS & 7.55 \\ 8:2\,FTS & 9.22 \\ PFBS & 3.94 \\ PFHpS & 9.30 \\ PFHxA & 2.11 \\ PFHxS & 9.25 \\ PFNA & 9.14 \\ PFNS & 9.31 \\ PFOA & 9.17 \\ PFOS & 9.68 \\ PFPeS & 6.22 \end{bmatrix} + 0.91\,ln(Dose_i) + 0.33 Sex_M$	$\ln(\widehat{Whole\,Body_i}) \sim N(\mu_i, 0.55)$
Dose (mg/kg-d)	Serum (ng/mL)	$\mu_i = \begin{bmatrix} 6:2\,FTS & 8.41 \\ 8:2\,FTS & 9.15 \\ PFBS & 5.34 \\ PFHpS & 11.01 \\ PFHxA & 2.40 \\ PFHxS & 11.74 \\ PFNA & 10.75 \\ PFNS & 9.83 \\ PFOA & 10.57 \\ PFOS & 10.73 \\ PFPeS & 8.68 \end{bmatrix} + 0.91\,ln(Dose_i) + 0.03 Sex_M$	$\ln(\widehat{Serum_i}) \sim N(\mu_i, 0.51)$
Dose (mg/kg-d)	Liver (ng/g)	$\mu_i = \begin{bmatrix} 6:2\,FTS & 8.69 \\ 8:2\,FTS & 11.56 \\ PFHpS & 11.84 \\ PFHxA & 1.17 \\ PFHxS & 10.75 \\ PFNA & 11.96 \\ PFNS & 12.23 \\ PFOA & 11.41 \\ PFOS & 12.03 \\ PFPeS & 8.11 \end{bmatrix} + 0.95\,ln(Dose_i) + 0.40 Sex_M$	$\ln(\widehat{Liver_i}) \sim N(\mu_i, 0.92)$
Dose (mg/kg-d)	Kidney (ng/g)	$\mu_i = \begin{bmatrix} 6:2\,FTS & 8.07 \\ 8:2\,FTS & 9.40 \\ PFHpS & 9.42 \\ PFHxA & 1.51 \\ PFHxS & 9.77 \\ PFNA & 9.13 \\ PFNS & 9.86 \\ PFOA & 9.41 \\ PFOS & 10.11 \\ PFPeS & 7.14 \end{bmatrix} + 0.88\,ln(Dose_i) + -0.26 Sex_M$	$\ln(\widehat{Kidney_i}) \sim N(\mu_i, 0.74)$
Dose (mg/kg-d)	Brain (ng/g)	$\mu_i = \begin{bmatrix} 8:2\,FTS & 7.51 \\ PFHxS & 7.69 \\ PFOA & 7.48 \\ PFOS & 8.77 \end{bmatrix} + 0.75\,ln(Dose_i) \pm 0.05 Sex_M$	$\ln(\widehat{Brain_i}) \sim N(\mu_i, 0.36)$

Table 3.3. Relative liver weights expressed as proportion of specific treatment means. PFOS-relative effects, in single PFAS treatments, are the RPF_i used in Model 3 and, in mixtures, are indicators of additive effects. Control-relative effects are indicators of overall ΣPFAS effect as single PFAS and mixtures. Bold highlights the expected common relative effects of PFOS and C6-8 Medium FTS High mixture treatments with similar ΣPFAS exposure.

Treatment	Sex	PFOS-relative effects Mean, (97.5^{th}, 2.5^{th})	Control-relative effects Mean, (97.5^{th}, 2.5^{th})
Control	Female	0.60, (0.68, 0.52)	1.00, (1.13, 0.86)
	Male	0.62, (0.67, 0.58)	1.00, (1.07, 0.93)
PFOS	Female	**1.00, (1.10, 0.84)**	**1.67, (1.83, 1.40)**
	Male	**1.00, (1.11, 0.88)**	**1.61, (1.78, 1.42)**
PFOA	Female	1.45, (1.68, 1.21)	2.41, (2.80, 2.02)
	Male	1.74, (1.88, 1.63)	2.80, (3.02, 2.62)
PFHxS	Female	0.95, (1.02, 0.85)	1.58, (1.70, 1.42)
	Male	0.97, (1.05, 0.87)	1.55, (1.68, 1.40)
PFHxA	Female	0.65, (0.71, 0.57)	1.08, (1.18, 0.94)
	Male	0.64, (0.70, 0.55)	1.03, (1.12, 0.88)
6:2 FTS	Female	0.63, (0.70, 0.54)	1.05, (1.17, 0.90)
	Male	0.83, (0.90, 0.76)	1.33, (1.45, 1.22)
8:2 FTS	Female	0.76, (0.88, 0.69)	1.27, (1.47, 1.14)
	Male	0.75, (0.84, 0.67)	1.20, (1.35, 1.08)
C6-8 Low	Female	0.78, (0.84, 0.71)	1.31, (1.40, 1.19)
	Male	0.87, (0.99, 0.73)	1.40, (1.59, 1.17)
C6-8 Medium	Female	**1.01, (1.09, 0.89)**	**1.69, (1.82, 1.48)**
	Male	**1.06, (1.20, 0.96)**	**1.70, (1.93, 1.54)**
C6-8 High	Female	1.34, (1.48, 1.23)	2.22, (2.47, 2.05)
	Male	1.32, (1.41, 1.23)	2.11, (2.26, 1.98)
FTS Low	Female	0.71, (0.79, 0.59)	1.18, (1.32, 0.99)
	Male	0.74, (0.86, 0.63)	1.18, (1.38, 1.02)
FTS Medium	Female	0.84, (0.97, 0.66)	1.40, (1.61, 1.11)
	Male	0.87, (0.92, 0.81)	1.40, (1.47, 1.30)
FTS High	Female	**0.99, (1.12, 0.90)**	**1.65, (1.86, 1.50)**
	Male	**1.08, (1.20, 0.95)**	**1.73, (1.92, 1.53)**

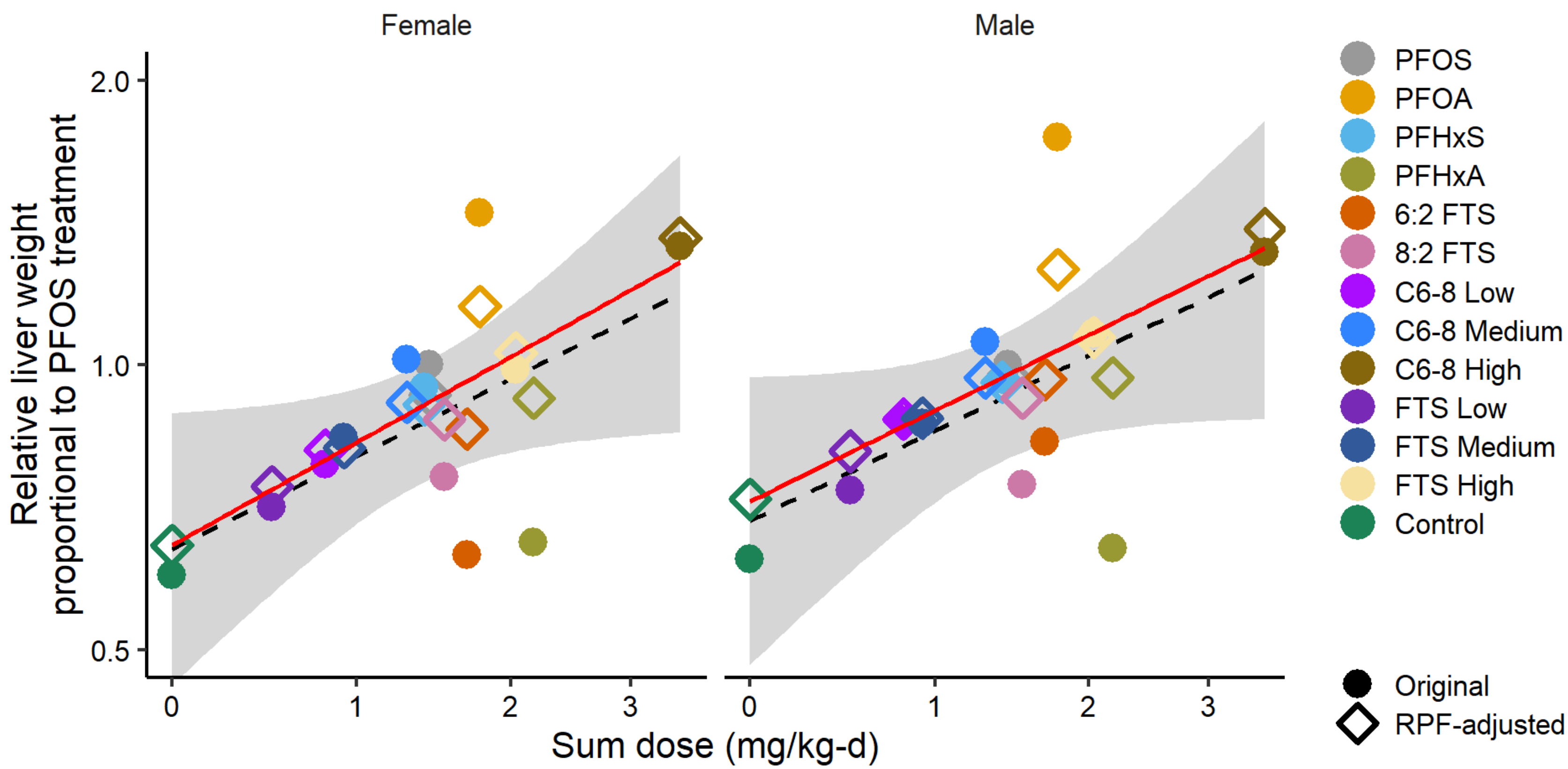


Figure 3.5. Adjusted mean relative liver weight dose response (red line, solid points) in C6-8 and FTS mixtures are not outside the confidence intervals for unadjusted mixtures (dashed line, gray confidence intervals, diamonds)—supporting the additive hypothesis. Points are means. Y-axis is $\log_{10}$-scaled (fold-change interpretation) and x-axis is $\log_e$-scaled.

Discussion

CD-1® mice were exposed via oral gavage to individual and mixtures of PFAS that are relevant to environmental media concentrations at sites where PFAS-containing AFFF products have been used. Whole body, serum, liver, kidney, and brain concentrations were determined using EPA Method 1633 for 40 PFAS analytes. Body weights, organ weights and clinical chemistry were collected to evaluate effects. Evidence of additivity in exposure measures and select effect measures are demonstrated by exploring the prior hypothesis that single-PFAS data would be predicted by PFAS mixture relationships. We found that a hierarchical model approach using exposure data does not require an interaction term, and a PFOS-relative potency factor (RPF) sufficiently predicts relative liver weights. Taken together, results suggest that a dose-additive interpretation should not be rejected for these PFAS and that a non-additive interpretation (e.g. interactive) is less likely to capture the underlying process.

In this study, we have shown that assessment of environmentally relevant PFAS mixtures can be reasonably simplified by the assumption of exposure additivity and demonstrated the application of relative exposure and potency approaches for specific endpoints. This means that ΣPFAS is predictive of tissue concentrations and liver effects for most mixtures and that individual PFAS observations are not influenced by being in a mixture. So even if exposure or effects details about individual PFAS (i.e. less studied or less observed PFAS) are not known, a central estimate can be attained for ΣPFAS through average parameters. This work is broadly motivated by the desire to understand risk at military sites where potential impacts to mammals are of interest (Grippo et al. 2024) and a specific suite of prevalent PFAS are expected (Anderson et al. 2016; Brusseau et al. 2020; East et al. 2021; East et al. 2025b). Further, as this study is based on 28-days of exposure and “grab samples” and ignore kinetics or toxicodynamics, it is most aligned with scenario-relevant short term toxicological studies (Narizzano et al. 2021; East et al. 2023) and short, but ecologically relevant time spans of animals' time on potentially impacted sites. Nonetheless, in an ecological assessment, the length of exposure on a site may not be constant and a timeline of one month may be reasonable. Further, in a screening assessment, protective approaches may be taken, and a risk assessor may be interested in calculating the highest potential concentrations or highest potential impacts. While some PFAS (e.g., PFOS) have slow elimination resulting in nearly continuous uptake (Tarazona et al. 2016), some PFAS have high elimination rates and trajectories of tissue concentrations may have high early peaks and low steady state concentrations (Narizzano et al. 2021; East et al. 2024). As an example, in CD-1 mice exposed to a 6:2 FTS containing AFFF for 28 days vs 42 (male) to ~63 (female) days, liver weight effects were not observed in the long term exposures (East et al. 2023; East et al. 2025c) and the hypothesis is that this was due to a reduction in serum concentrations (Narizzano et al. 2021; East et al. 2024). While we don't have time course data to verify this hypothesis, the left-skewed female 6:2 FTS serum distributions in the present study do provide some indication that concentrations may be dropping near 28 days exposure in CD-1 mice.

Our successful dose-additive prediction of mixture exposure and effects suggest dose-response functions are likely parallel in the dose ranges tested and with relative liver weight as an endpoint. Notably, dose-additive exposure and effects are expected across mammalian and avian taxa reproductive and survival endpoints (Bil et al. 2021; Conley et al. 2022; Conley et al. 2023; Gray et al. 2024). In this study, only 6:2 FTS (females only) and PFHxA-exposed animals had non-significant liver effects; all other individual and mixtures of PFAS tested resulting in increased relative liver weights in exposed animals. We note that animals exposed to 6:2 FTS (females only) and PFHxA have some of the lowest, per dose, internal concentrations, and 6:2 FTS is not expected to impact liver weights in longer exposures (Bohannon et al. 2023; East et al. 2025c). In decreasing order of fold-change relative liver weights vs control treatment, PFOA > PFOS > PFHxS > 8:2 FTS ≥ 6:2 FTS (depends on comparator sex) ≥ PFHxA (depends on comparator sex) at approximate mean relative potencies of 2.6, 1.6, 1.6, 1.2, 1.2, 1.1 (Table 3). While a LOAEL approach indicates many of these PFAS have common effect thresholds, it is reasonable to consider that they are not at common effect magnitudes—including that some may not be adverse if relative liver weights are not observed after serum concentrations decrease (i.e., 6:2 FTS (Narizzano et al. 2021; Bohannon et al. 2023; East et al. 2024; East et al. 2025c)).

Importantly, based on our ALT observations, detection of liver effects may be better served, both practically (i.e., survival sampling) and protectively (i.e., sensitivity), by this clinical chemistry measure, as the $\log_{10}$ unit change in ALT vs $\log_{10}$ unit change in relative liver weight is 1.5 in males and 2.1 in females (Table SI3.16, Figure SI3.26). To demonstrate utility of serum ALT as a practical and sensitive measure of effects, consider a hypothetical reference vs impacted site desktop ecological risk assessment. As shown in Figure 3.6, a 10-fold increase in ΣC6-8PFAS in dose (i.e., dietary concentration) may lead to overlapping individual PFAS measures in body burden and internal concentration (Figure 3.6, top). Naturally, a 10-fold increase in exposure will result in an increase in relative liver weight (~20%), but this health effect may be challenging to confidently detect given individual variability and substantial reference vs impacted confidence interval overlap (Figure 3.6, bottom left). ALT measures, however, appear more sensitive and a 10-fold increase in diet ΣC6-8PFAS may yield a 20-30% increase in ALT measures (Figure 3.6, bottom right). The downstream interpretation of the 10-fold change in diet concentration example is that effect differences may be challenging to detect with statistical techniques even if exposures are quite different (Figure 3.6), which may complicate refinement of remediation plans and pre- and post-remediation monitoring of terrestrial systems.

To provide a PFAS-to-PFAS potential to magnify comparative basis, these dose-to-tissue concentration relationships can also be interpreted as analogous to biomagnification factors (BMFs) using the definition of $BMF = \frac{C_{Consumer}}{C_{Diet}}$ at a steady state like OECD TG#305 (OECD 2012), Gobas et al. (2023), and an European Chemicals Agency discussion paper (ECHA 2022). These type of transfer factors are generally applied in food webs (Larson et al. 2018; Zodrow et al. 2021) where prey or diet to receptor transfer is desired with a high level of simplicity and assumptions of steady state are held. This approach is also based in the common utilization of the OECD TG# 305 method, which addresses the movement of chemicals from water and/or diet into fish and should result in a steady state $C_{Consumer}$. It is generally considered a reasonable expectation that the kinetics observed in a TG#305 test may be predictive of movement of chemicals into terrestrial mammals from diet (ECHA 2022; Gobas et al. 2023). However, an unadjusted transfer factor approach contrasts with toxicokinetic approaches where time is accounted for (East et al. 2025a) or fugacity/chemical activity approaches where physicochemical details are accounted for (Fremlin et al. 2023; Kelly et al. 2024). In our case, simplifying the experimental design to a single timepoint was a required feasibility factor given the focus on mixtures and desired tie back to 28-day toxicity studies (Narizzano et al. 2021; East et al. 2023). We provide below a translation of our 28-day predictive functions to a simplistic transfer factor, but we note that the appearance of concentration dependence is more analogous to accounting for dilution into a whole animal/dietary efficiency parameter/chemical activity adjustment (Fremlin et al. 2023; Gobas et al. 2023; Kelly et al. 2024) than concentration dependence. Further, to estimate a receptor concentration at 28 days of exposure, we advise utilizing the predictive models rather than transfer factors because if the diet concentration is known, estimating a dose simply requires knowing the weight of the receptor and amount of diet consumed. Regardless, we provide the backtransformed power function to demonstrate that the y-intercept parameters (α_i in Table 3.2) concur with a PFAS-to-PFAS magnification potential comparison specific to these mixtures.

With some algebra, the linear function in Model 2 can provide an untransformed scale, whole body concentration divided by dietary concentration analogous to $\frac{C_{Consumer}}{C_{Diet}}$. We focus on whole body as that would be the most informative parameter in a terrestrial food web model. To align units in whole body concentrations (ng/g to mg/kg) and convert daily dose to dietary concentration (mg/kg-d to mg/kg, assuming that mg/L in the dosing solution is equivalent to mg/kg in a diet) the whole-body concentration was divided by 1,000 and the dose divided by 100 and the Model was re-fit. Note that the result of this adjustment is "Cartesian," and the y-intercept is the only modified parameter in the model by subtraction. Exponentiating both sides of a log-log linear function (Model 2) generates a power function. We use the logarithm rule: $e^{a+b+c} = e^a e^b e^c$ to make $e^{(\alpha_i-11.1)+0.33Sex_M+0.91\ln(Diet_i)} = e^{(\alpha_i-11.1)}e^{0.33Sex_M}e^{0.91\ln(Diet_i)}$. Then we use the logarithm rule: $e^{c\ln(x)} = x^c$ to simplify $e^{(\alpha_i-11.1)}e^{0.33Sex_M}e^{0.91\ln(Diet_i)} = e^{(\alpha_i-11.1)}e^{0.33Sex_M}{Diet_i}^{0.91}$. This can further be simplified to $e^{(\alpha_i-11.1)}e^{0.33Sex_M}{Diet_i}^{0.91} = e^{(\alpha_i-11.1)+0.33Sex_M}{Diet_i}^{0.91}$. With $\alpha_i - 11.1$ being the result of diet and concentration unit conversion of α_i in Table 3.2 and $e^{0.33Sex_M}$ indicating male and the subsequent inclusion/exclusion of the 0.33 unit increase for male mice. Lastly, dividing the exponentiated whole body *i*th PFAS concentration by ${Diet_i}^{0.91}$ makes $\frac{Whole\ Body_i\ (\frac{mg}{kg})}{Diet_i\ (\frac{mg}{kg})^{0.91}} = e^{(\alpha_i-11.1)+0.33Sex_M}$

and expresses our predictive model in $\frac{C_{Consumer}}{C_{Diet}}$ terms. Accordingly, y-intercept parameters (α_i in Table 3.2) from provide sufficient PFAS-to-PFAS comparative basis and importantly, many of the PFAS (7 of 11) have similar potential for biomagnification. This observation provides some support for consistent potential for trophic magnification across various PFAS that is not likely to be influenced by mixtures. Several terrestrial food chains with vertebrate higher trophic levels observe generally consistent PFAS-to-PFAS potential for trophic magnification in the overlapping PFAS evaluated here—of specific importance are PFOS and PFOA (Müller et al. 2011; Huang et al. 2022; Fremlin et al. 2023; Ecke et al. 2024). The PFAS in our study that appear to be less likely to magnify (6:2 FTS, PFPeS, PFBS, and PFHxA in decreasing order) should be interpreted by either their lower potential to accumulate or elevated potential to eliminate and not that they are excluded by mixture interactions.

In conclusion, we have demonstrated an additive model of exposure and liver effects in mice exposed to military site-relevant PFAS. The study design provides simple predictions of whole body concentration, serum and tissue concentrations, and simple relative effect measures. While time-course data or other PFAS may expand the window of possible predictions, the observations reported and methods used herein are highly relevant to DoD sites, highly approachable, and efficiently address concerns associated with PFAS mixtures. We demonstrate the utility of our data via a worked example where a 10-fold difference between PFAS levels at a reference site and an exposed site may lead to overlapping PFAS-specific tissue concentrations, overlapping but potentially adverse relative liver weights, and detectable increases in a measurable liver enzyme.

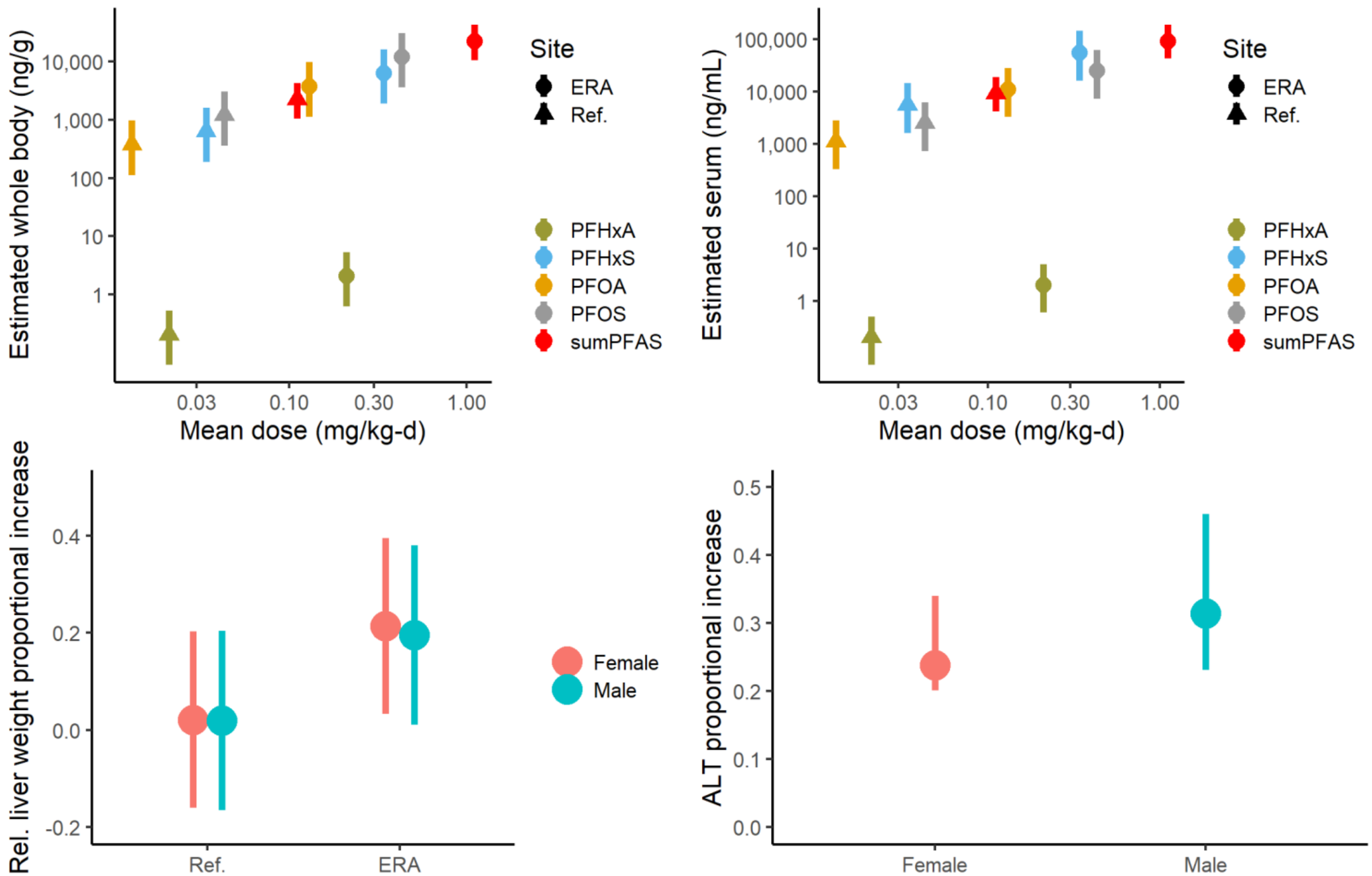


Figure 3.6. Using additive approaches, a hypothetical reference (Ref.) vs exposed (ERA) site doses lead to some overlap of estimated PFAS in trophic transfer (top left) and internal concentrations (top right), and these exposures lead to overlapping relative liver weight increases (bottom left), but likely detectable increases in ALT (bottom right).

Chapter 4: Dietary kinetics of a PFAS mixture in the American toad (*Anaxyrus americanus*): laboratory insights into trophic transfer of PFAS

Abstract

Per- and polyfluoroalkyl substances (PFAS) are ubiquitous in environmental media and are a concern for food web–driven exposure to ecological receptors. Terrestrial life stage amphibians concurrently represent taxa that have high potential for exposure but are generally data-poor in comparison to their aquatic life stages. Adult American toads (*Anaxyrus americanus*) likely have high dermal exposure to soil and eat terrestrial organisms that are likely to accumulate chemicals from soil. To better understand the relationship between dietary PFAS and toads in a trophic transfer context, toads were fed earthworms (*Eisenia andrei*) exposed to PFAS-spiked soil for 28 days and then were fed clean earthworms for 28 days—a 28-day uptake phase and 28-day elimination phase. Toad blood, liver, and remaining tissues were sampled weekly. Concentrations of PFAS were quantified in soil, earthworm diet, and toad tissues. Toxicokinetics of PFAS in toad livers, remainder, and estimated whole animal were evaluated using the methods of Organisation for Economic Co-operation and Development Test Guideline #305, a nonlinear regression approach, and a physiologically-based method. Definitive models were selected via a leave-one-out cross validation method and model parameters were used to determine kinetic trophic transfer coefficients (TTCs). Our TTC approach indicates perfluorooctane sulfonate, perfluoroundecanoic acid, and perfluorodecanoate are likely to magnify and 8:2 fluorotelomer sulfonate and perfluoroheptane sulfonic acid are likely to transfer or dilute in the worm-toad transition. Most PFAS have similar uptake rates, but elimination rates

are clustered, suggesting that kinetics are driven by elimination mechanisms. These laboratory data use field-representative exposure approaches and provide inference about internal kinetics of individual PFAS as well as the potential for trophic transfer from soil invertebrates to terrestrial life stage amphibian predators.

Introduction

Per- and polyfluoroalkyl substances (PFAS) are synthetic molecules defined by durable carbon-fluorine (C-F) polar covalent bonds generally considered ubiquitous in environmental media. One of the foundational works in PFAS observations in wildlife is based on samples collected globally with indications that higher trophic level organisms' tissue concentrations were likely the function of trophic magnification and bioaccumulative processes (Giesy and Kannan 2001). Early observations in aquatic systems in the field (i.e. Giesy and Kannan (2001)) were supported with laboratory work on dietary accumulation and aquatic bioconcentration of PFAS (perfluorooctane sulfonate (PFOS)) in fish and amphibians (Martin et al. 2003a; Martin et al. 2003b; Ankley et al. 2004). Observations of PFAS in terrestrial organisms in the field (i.e. Giesy and Kannan (2001)) were supported by laboratory observations of dietary accumulation (Newsted et al. 2006). More recent work has identified a number of field and laboratory observations of accumulative properties across a broadening range of PFAS (see review of Evich et al. (2022)).

Amphibians, as a group of organisms, are generally considered understudied in ecotoxicology. Regarding PFAS and amphibians, there is a substantial amount of data and information about a few PFAS in larval amphibians. Ankley et al. (2004) performed the first exposures of tadpoles to perfluorooctane sulfonate (PFOS) and observed toxicological effects and quantified accumulation of PFOS from water into tadpole tissues. Since that study, the combined works of Strategic Environmental Research and Development Program (SERDP) study ER-2626, "Development of Amphibian PFAS TRVs for Use in Ecological Risk Assessment at AFFF Sites" have resulted in four PFAS (PFOS, perfluorooctanoic acid (PFOA), perfluorohexane sulfonate (PFHxS), and 6:2 fluorotelomer sulfonate (6:2 FTS) in nine amphibian test species in two experimental settings, and four exposure routes. Larval amphibian toxicity and accumulation data from these studies is largely used to inform aquatic toxicity. However, as described by Flynn et al. (2021), some amphibian taxa spend substantial portions of their life in terrestrial life stages. To address this concern, Flynn et al. (2021) exposed post-metamorphic (terrestrial life stage) salamanders (*Ambystoma tigrinum*) to PFOS, PFOA, PFHxS, and 6:2 FTS via diet (crickets fed spiked food and water) for 30 days. Evidence for biomagnification is reported as "limited," but PFOS biomagnification factors (BMFs) are reported between 1.01 to 3.04 negatively correlated with diet concentration (Flynn et al. 2021). BMF values for PFOA, PFHxS, and 6:2 FTS are all less than 1 (range <0.001 to 0.072) suggesting that there is little accumulation of these PFAS in terrestrial life stage amphibians exposed via diet (Flynn et al. 2021).

In the interest of expanding available exposure data in terrestrial life stage amphibians in a time-efficient manner while retaining some ties to potentially mechanistic factors, a balance of complexity and resolution is needed. For instance, utilizing a relatively large range of PFAS types that are observed at field sites (East et al. 2025b), and exposure in a food web context (via diet). Data collected in such a manner could inform screening data (Zodrow et al. 2021), of which, terrestrial life stage amphibians remain a data gap. Further, given the dominance of terrestrial life stages in the lifespan of some amphibians, internal kinetics are likely highly informative. Toads may not reach sexual maturity until several years of age (Willson et al. 2012;

Willson and Hopkins 2013); this implies that any site with a stable population likely has toads that may experience years of exposure. Most studies on PFAS kinetics are focused on high resolution, so based on logistical constraints, require direct dosing of single PFAS (e.g. intravenous). In contrast, fully field observational studies of food web transfer (e.g. Müller et al. (2011); Huang et al. (2022)) do not generally consider internal kinetics, taxa life-history traits, or other spatially-temporally relevant factors. So, while a field study may be highly physico-chemically mechanistic and detailed (Fremlin et al. 2023), their applicability in a spatio-temporally explicit, individual-based scenario remains untested. i.e. we cannot confidently include or exclude characteristics such as animal age or length of exposure as influential factors in PFAS exposure.

Accordingly, there is a need for manipulative studies of moderate complexity. Causal inference requires an experimental approach (i.e. laboratory study) (Anderson 2008) but some ties to ecological risk assessment needs (complexity of PFAS mixture, exposure via diet) are needed. To attempt to address these issues, a series of studies have been performed where a large number of PFAS were spiked at a uniform nominal concentration in soil. Then plants and worms were grown in said soil. Plants were fed to rabbits and worms were fed to toads. Kuperman et al. (2025) and Lotufo et al. (2025) are the first publications to emerge. This work addresses the dietary exposure of toads to PFAS in their diet, where, critically, the dietary concentrations emerge from the processes that lead to PFAS moving into worms (described in Lotufo et al. (2025)). Accordingly, the approach in this study controls for diverse media concentrations seen in field sites and is specifically focused on the actual relationship in question—the toad and the PFAS—in isolation from other ecological/behavioral factors that may introduce variability observed at field sites.

To utilize these insights in an ecological risk assessment exposure estimate/characterization, we need to ensure that we can speak to common food web/exposure factor models (EPA 1993; Zodrow et al. 2021). These approaches are largely based on multiplicative factors—soil concentration times bioaccumulation factor equals worm concentration; worm concentration times biomagnification factor equals toad concentration, etc. As PFAS have highly variable kinetics, it is challenging to assert that steady state/dynamic equilibrium tissue concentrations have been reached in a laboratory setting with a PFAS mixture. To address this issue, we provide kinetic parameter-based trophic transfer coefficients (TTCs) that are intended to be analogous to trophic magnification factors (TMFs). The premise is that inclusion of kinetics captures time-dependent processes that may be influential on field observations.

More specifically, the objectives of this study were to (1) quantify the internal concentrations of PFAS in terrestrial amphibians exposed via diet to a mixture of PFAS and (2) use model parameters to inform the sense of trophic transfer in a soil-invertebrate-predator food chain. Few field data exist in these taxa, none account for internal kinetics, and laboratory control on external factors allow for evaluation of the actual relationship of interest in ecological risk assessment—the PFAS to animal relationship. The present study was part of a larger effort (Kuperman et al. 2025) to understand individually, and as a class, the movement of PFAS from soil or groundwater into worms, PFAS elimination from worms (Lotufo et al. 2025), and, here, the movement of PFAS from worms to toads and toads' elimination of PFAS. The closing insight around trophic transfer is intended to support food-web-based exposure estimates where data from the field may be lacking or highly variable or unclearly associated with explanatory factors.

Methods

PFAS Selection

The PFAS selection is described in detail in Kuperman et al. (2025). In brief, the PFAS selected for this study included those listed in the U.S. EPA's third Unregulated Contaminant Monitoring Rule (UCMR 3): perfluoroheptanoate (PFHpA), PFOA, perfluorononanoate (PFNA), perfluorobutanesulfonic acid (PFBS), perfluorohexane sulfonate (PFHxS), and PFOS. To explore the effects of chain length, we included perfluorobutanoate (PFBA), perfluoropentanoate (PFPeA), perfluorohexanoate (PFHxA), and perfluorodecanoate (PFDA). Precursors 8:2 fluorotelomer sulfonate (8:2 FTS) and perfluorooctane sulfonamide (PFOSA) were also included. The selected list captures chain length trends and the terminal transformation products of PFAS precursors and PFAS that are a primary focus of federal advisories and state regulations found on DoD installations. Analytical-grade PFAS were obtained from the U.S. EPA PFAS Chemical Library or Sigma-Aldrich (St. Louis, MO).

Test Soil

The test soil conditions are described in detail in Kuperman et al. (2025). In brief, test soil was Organisation for Economic Co-operation and Development (OECD; Paris, France) standard artificial soil (SAS) modified by lowering the peat content from 10 to 5% (75% fine sand, 20% kaolin clay, 5% finely ground sphagnum peat moss, and 1% pulverized lime) to increase bioavailability of the test compounds (OECD 2010; OECD 2012; OECD 2016). The measured concentrations of PFAS in SAS were low (0.07 ng/g and 0.09 ng/g for PFHxA and PFPeA), with no other PFAS compounds found above detection limits. Prior to the addition of earthworms, SAS (PFAS-spiked and control) were put through an aging process for 14 days that included wetting, drying and mixing the soil one time each week.

Diet Preparation

Thirteen PFAS (Table SI4.1) with earthworm bioaccumulation factor (BAF) ≥ 2 observed in preliminary studies of the PFAS described above (Kuperman et al. 2025) were spiked into the soil used to generate the toad diet earthworms. Selected PFAS were added to American Society for Testing and Materials (ASTM) Type I water (18 MΩ deionized water) to produce stock solutions of each PFAS, then added to soil to produce 0.1 mg/kg of each PFAS in soil as a uniform nominal mixture. This spiked soil was then used to expose the earthworms, which were subsequently used to feed the toads. Control soil was developed by wetting SAS with comparable volumes of ASTM Type I water. See Kuperman et al. (2025) for more details.

After aging spiked and unamended SAS, earthworms (*Eisenia andrei*) were exposed in each soil for 28 days. Upon collection, earthworms were rinsed with ASTM Type I water, counted, weighed *en masse*, placed in 800 mL glass jars, and kept at 4° C in the dark. Less than 24 hours after collection, earthworms were blended in batches, homogenized by mixing and blending batches, and dispensed into aliquots in 50 mL polypropylene conical vials, and frozen at -80° C. A subsample of thawed earthworm diet (blended, homogenized earthworm tissue) was retained for development of dosing standard curve (below).

American toads (*Anaxyrus americanus)* care, dosing, and sample collection

This animal use was reviewed and approved by the DCPH-A Institutional Animal Care and Use Committee (DCPH-A IACUC Protocol #: 06-22-02-02). The animal facility at DCPH-A is fully accredited by AALAC International, and all animal care and use was performed according to the Guide for the Care and Use of Laboratory Animals (National Research Council (U.S.) et al. 2011) and all applicable federal and DoD regulations.

Toads (n=64) were purchased from Carolina Biological Supply Company (Burlington, NC, USA), so are wild-caught animals from the eastern United States from unknown locations. Toads were quarantined and observed for 7 days prior to dosing to ensure all animals were eating and maintaining/gaining weight. Toads, prior to dosing, were fed live crickets (Fluker Farms, Port Allen, LA, USA) every other day. Crickets from this supplier have been measured as non-detect for PFOS and PFHxS (unpublished data) but published cricket ΣPFAS concentrations (Choi et al. 2023) are >100-fold lower than toad diet, so are unlikely to be influential on toad background PFAS. Toads were housed in acrylic cages 25.4 cm x 47 cm x 15.25 cm, with 5 cm wetted coco coir, a 1 L paper cup hide, a polypropylene petri dish with water, and approximately 500 mL of wetted sphagnum moss. All wetted materials were misted as needed (generally daily) using moderately hard synthetic freshwater (EPA 2002) and the petri dish water was replaced daily. Hide, bedding, and petri dishes were replaced as needed upon soiling or saturation. A cage was reserved with temperature and humidity monitors to ensure cage-level parameters were within target. Room and cage level temperature (target 15.6-24.4° C) and humidity (50-70%) were monitored and recorded daily. Light cycle was 12 hours on:12 hours off. Toads were weighed weekly (Tuesdays) and on their day of collection (Wednesdays).

Dosing was performed via a pseudo-gavage where a measured amount of worm homogenate from a press-fit syringe was dispensed into the back of the toads' mouths. Their mouths were held open by a blunt spatula and upon release of the dose and spatula, the toads swallowed the dose. This method is motivated by the pseudo-gavage methods for liquid dosing used in lizards (Weir et al. 2023). The dose in mass of worm per mass of toad (mg/kg) was determined by a standard curve generated by weighing a range of volumes where reasonable accuracy could be expected from a 3 mL disposable press-fit syringe (see Figure SI4.1 and Figure SI4.2 for mass per worm and mass per volume of worm homogenate). Toads were dosed in a manner that was intended to mimic natural foraging where toads would eat “a worm.” Accordingly, doses were delivered at volumes accurate for the syringe but approximating 1 worm per day in a time weighted average manner (2 worms Monday and Wednesday, 3 worms on Friday).

Samples were collected from toads after anesthetizing the toad in neutral-buffered MS-222 (tricaine methanesulfonate, brand name Tricaine-S (FDA approved)) at 3 g/L and then decapitating the toad and pithing the brain. The heart was exposed and a 1 mL insulin syringe was used to exsanguinate. Whole blood was gently expelled into prelabeled 1.8 mL cryovials. The liver was then excised and placed in an uncoated, prelabeled aluminum foil packet. The remainder of the organism was placed in a prelabeled 118 mL Nasco brand ‘Whirl-Pak’ and sealed. All tissues were frozen upon collection and stored in -80°C.

Study Design

The study design was based on the Organisation for Economic Cooperation and Development (OECD) Technical Guide (TG) # 305, Bioaccumulation in Fish: Aqueous and Dietary Exposure (OECD 2012). Exposure was strictly through the dosed diet. Toads were randomly selected for sampling dates from days 0, 7, 14, 21, 28, 35, 42, 49, or 56. Sixteen toads (n=16) were sampled on study day 0 and then six (n=6) at each timepoint thereafter. Study day 0 represents background concentrations, samples collected on study days 7, 14, 21, and 28 represent the uptake period. Study day 28 concurrently represents the start of elimination as the diet provided on day 28 is the control diet. The elimination period samples were from study days 28, 35, 42, 49, and 56.

Analytical determination of PFAS in diet and toads

Extended details of analytical determination of PFAS concentrations in earthworm homogenate and toad tissues (liver and remainder) are available in Kuperman et al. (2025). In short, PFAS were extracted from earthworms using a method that is based on extraction from fish tissue and earthworms (Malinsky et al. 2011; Rich et al. 2015). A small mass of dried earthworm homogenate was spiked with an extracted internal standard, acetonitrile was added, and tube was vortexed and shaken. Tubes were then frozen (-20° C) to precipitate lipid and protein. Extracts were separated by centrifugation and transferred to glass scintillation vial with dilute formic acid. The extracts were then evaporated to dryness under nitrogen. Samples were reconstituted in LC-MS grade methanol and transferred to tube with ENVI-Carb. Autosampler vials were prepared for analysis with a volume of extract and volume of method and water to reach a 70:30 water:methanol solution at 200 ng/L internal standard.

PFAS were extracted from toad liver and remainder using methods prior developed for animal tissues (Tomy et al. 2005; Houde et al. 2008; Zhao et al. 2013). A small mass of wet tissues were placed in a polypropylene tube and dried at 70°C. An internal standard was added to each tube, methanol was added to each tube, and tubes were sonicated at room temperature. Samples were centrifuged and evaporated to dryness under nitrogen. Extracts were reconstituted in LC-MS grade methanol, transferred to a tube with ENVI-Carb, vortexed, and centrifuged. An aliquot of the extract was transferred to an autosampler vial and amended with 70:30 water:methanol to achieve a final internal standard concentration of 200 ng/L.

Chromotographic separation was performed on a Gemini C18 analytical column coupled with a Gemini C18 guard column with a Sciex Exion high pressure liquid chromatography (HPLC) system. A Luna C18 delay column was installed between the mobile phase mixer and the sample injector to minimize background contamination. Columns were maintained at 40°C throughout the run. Aqueous phase was ammonium acetate solution and organic phase was 100% methanol. See Kuperman et al. (2025) for details on ramp schedule.

Quadrupole time-of-flight mass spectrometry (QTOF-MS) for targeted analyses were performed on a Sciex X500R QTOF MS system. Turbo ion spray was used as the ion source. Multiple reaction monitoring high-resolution (MRMHR) acquisition mode was used with two transitions (quantifier and qualifier) for each PFAS, where possible. Data were acquired and processed using versions 1.5 and 2.2 Sciex OS software. PFAS were quantified using isotope dilution over a calibration range of 0.5-5000 ng/L with (coefficient of determination > 0.99).

Toxicokinetic Modeling

Tissue concentrations (liver, remainder, and estimated whole body) were fit with several types of models, models were compared by predictive power, and the best performing model was selected to generate trophic transfer coefficients (TTCs).

Data handling

Liver and remainder data for each toad at each timepoint across 16 PFAS were used for toxicokinetic modeling—in contrast to utilizing timepoint-specific summary statistics. Non-detects observed in toads on the first timepoint (study day 0) were set to the PFAS-specific minimum observed across the study period. This increases the stability of background parameter estimates, but may lead to overestimates of background means. All other non-detect observations across toads (study day ≥ 7) were set to NaN (not a number). Data from timepoints ≥ study day 28 were also labeled with an elimination day which is study day – 28.

Worm diet aliquots' (n=5) PFAS-specific analytical estimates were summarized to a mean and used as the 'dose' parameter for the entirety of the uptake period or the whole study period per models' requirements. Control diet aliquots were all non-detect and set to zero to maintain mathematical continuity during elimination period per model requirements.

Liver and remainder concentrations were used to generate an estimated whole-body concentration. The liver of a toad represents approximately 5% bodyweight (Finkler et al. 2014) and lacking the serum data, the remainder was assumed to represent 90% of the bodyweight. Accordingly, the estimated whole animal concentration is $0.05[liver] + 0.90[remainder]$. Estimated whole body concentrations are per-animal and per-PFAS and were only calculated for those toads with concentrations above reporting limits for both tissues—those toads with only one quantified concentration for either liver or remainder would have an NaN (not a number) for estimated whole body. Reporting limits are different for these tissues and exclusion is critical to avoid highly biased estimates.

Nonlinear model

The nonlinear regression approach is defined by utilizing the model of highest performance for predicting tissue (serum) concentrations of PFOS in rabbits and chickens exposed via diet in Tarazona et al. (2015; 2016). Starting parameters were determined by using linear regression techniques of OECD TG#305 for elimination period and uptake period. Some modifications to the OCED TG#305 techniques were made during the uptake period estimation given the 'linear phase' of uptake was highly variable and the volume of distribution (Vd) was incorporated into the nonlinear models and likely captures the needed variability without forcing unrealistically high uptake rates based on day 0 to day 7 data alone.

The one compartment nonlinear model used here to evaluate PFAS-specific toxicokinetics:

$$C_t = background + \left[\frac{(D \times K_{01})}{\left(Vd \times (K_{01} - K_{10})\right)}\right] \times [e^{-K_{10} \times t} - e^{-K_{01} \times t}] \tag{1}$$

where concentration at study day (C_t) is a function of: the mean PFAS-specific concentration at study day 0 (*background*); the PFAS concentration in the diet times the time-weighted average dosing fraction ($(3/7)[diet] = D$); the volume of distribution (Vd); the uptake rate (K_{01}); the elimination rate (K_{10}); and time (study day, t).

Nonlinear model parameter estimation

All parameters were estimated using R (R Core Team 2024) and all parameters are estimated by PFAS and by tissue (liver, remainder, and estimated whole body). The first parameter estimation step was to estimate the elimination rate (K_{10}) using linear regression (least squares) of natural log of the concentration through 28 days of elimination period (study day 28 to 56 as elimination day 0 to 28). The slope of that linear regression is the estimated elimination rate. The second step was to fit Eq. 1 using nonlinear least squares and Port algorithm with the `nls()` (R Core Team 2024) function in R with the elimination rate set to the slope of elimination linear regression. The unknown parameters that were estimated were the uptake rate (K_{01}) and volume of distribution (Vd). K_{01} and Vd were bounded between 0 and 1 and 0 to 10, respectfully. For PFAS where tissue concentrations were difficult to distinguish from background, a Levenberg-Marquart algorithm was used (Elzhov et al. 2023). Bounds for K_{01} and Vd were also expanded to 0 to 2 and 0 to 100 in these cases. Note that the Levenberg-Marquart algorithm is robust in difficult to estimate parameter situations—like the cases we identified where peak concentrations were difficult to differentiate from background. Parameter estimate variability was quantified using bootstrap methods (Baty et al. 2015). Residuals are resampled 999 times and least-square estimates of parameters are used to provide confidence intervals of definitive parameters estimates. Bootstrapping incorporates some of the non-parametric characteristics of the observed data and does not assume parametric/Gaussian distributions, so is a more robust route to representing variability in parameter estimates.

The third stage of parameter estimation was to explore elimination rates in the nonlinear approach. Accordingly, a second round of fitting Eq. 1 was performed with the uptake rate set at the value identified in the first round of fitting Eq. 1. The elimination rate (K_{10}) and Vd were estimated using the `nls`() or `nlsLM`() function as needed to reach stable parameter estimates. These parameter estimates' variability is represented by the same bootstrap procedure as above to provide confidence intervals around estimates.

Ordinary differential equation (ODE) system

We differentiate this model from physiologically-based models as the whole blood concentration nor tissue volumes were determined, subsequently, explicit transport cannot be sufficiently tracked. However, a two-compartment model is physiologically-relevant as the remainder concentration is 'upstream' and 'downstream' of the liver concentration. The system of liver and remainder were described as two state variables and several flows. There was a dietary contribution (on a schedule, (D_i)) adjusted by an absorption factor (a) into the remainder, then fluxes into (k_{12}) and out (k_{21}) of the liver, and lastly elimination (k_{el}). These fluxes (Figure SI4.11) and their differential equation system:

$$\frac{dRemainder}{dt} = aD_i + k_{21}Liver - k_{12}Remainder - k_{el}Remainder,$$
$$with\ D_i = \begin{cases} D, & i = 0, 2,5,7,9,12,14,16,19,21,23,26,28 \\ 0, & i = 1,3,4,6,8,10,11,13,15,17,18,20,22,24,25,27,29 \ldots 56 \end{cases} \quad (2)$$

$$\frac{dLiver}{dt} = k_{12}Remainder - k_{21}Liver \quad (3)$$

where on the actual dates of dosing (M, W, F during uptake period, i) added to the remainder concentration is the diet concentration (D) multiplied by an absorption factor (a) and on all other timepoints remainder concentration is a function of input from liver ($k_{21}Liver$) and flux to liver ($k_{12}Remainder$) and elimination to wastes ($k_{el}Remainder$); and the liver is the balance of rates in ($k_{12}Remainder$) and out ($k_{21}Liver$).

ODE model parameter estimation

Parameter estimates were obtained for the system of Equations 2 and 3 by a model cost reduction algorithm, `modcost()` function in the FME package (Soetaert and Petzoldt 2010) in R. Residual error was the quantification of model cost. Model predictions were solved via the deSolve package in R (Soetaert et al. 2010). Starting parameters were based on nonlinear model uptake and elimination rates (elimination used for both liver and remainder).

Model selection via cross validation

As these two model types (nonlinear vs ODE) have vastly differing mathematical structures, it is inappropriate to utilize common model comparison strategies such as information criterion (Akaike's Information Criteria (AIC)) that rely on measures of model complexity and error from nested model structures. Leave-one-out cross-validation (LOOCV) is a maximal k-fold cross-validation technique where instead of a training and test dataset partitioning the dataset, each *i*th datapoint is used as a test dataset against a model developed from *n-i* data.

While many statistical descriptors of the resultant distribution of errors (*i*th prediction from *n-i* model – *i*th observed) are possible, here, the mean absolute error (MAE) was used.

The definitive model was selected based on lower relative MAE across liver concentrations of PFOS and 8:2 FTS. These PFAS, in these tissues, capture two extremes of concentration trajectories observed—very slow and very fast elimination. These were selected for computing efficiency and avoiding confounding interpretations from PFAS or tissues with concentrations indistinguishable from background. In summary, LOOCV provides a quantitative basis to compare models' predictive power and select the model with the best predictive power across models with no mathematical relation.

Trophic transfer coefficients (TTCs)

Utilizing laboratory data to speak to trophic transfer (considering the spectrum of trophic magnification to trophic dilution (Newman 2020)) requires ensuring careful handling of time or clear understanding of dynamic equilibrium/steady state of concentrations and fluxes. Presumably, field data are representative of dynamic equilibrium/steady state. Laboratory data are generally known to either be in a steady state or not. In these data, as PFAS were observed in both of these states at day 28, static representations of biomagnification (C_{toad}/C_{diet}) per-PFAS from these data would be inaccurate representations of field trophic transfer observations.

A kinetic approach was utilized to account for both time and internal kinetics (i.e. *Vd*) using the uptake and elimination rates. In short, *TTC=Uptake/Elimination*, where *Uptake* and *Elimination* represent parameters from the definitive model selected from the LOOCV procedure. To ensure sufficient capture of observed variability (as a measure of uncertainty), bootstrap parameter estimate distributions were resampled (with replacement) 10,000 times to generate probabilistic estimates of TTCs.

Results

Smoothed trajectories of PFAS concentrations in liver, remainder, and estimated whole animal (Figure 4.1, Figure 4.2) show that several toxicokinetic trajectories can be expected. While diet concentrations (Figure SI4.3) vary, it is clear that few of the PFAS have little uptake. Several of the PFAS have what appear to be fast elimination rates (e.g. 8:2 FTS) and several have slow elimination rates (e.g. PFOS). Importantly, the patterns across liver or remainder appear similar, but in general, liver concentrations are higher than remainder. Due to the estimation of whole body concentration approach, remainder drives the bulk of estimated whole body concentration, but given 'parallel' trajectories between liver and remainder, kinetics are similar across tissues.

An opening hypothesis is that internal kinetics and ultimately trophic transfer of PFAS in this diet to organism step is driven by elimination rate. There are no negative correlations of PFAS to PFAS in the toad tissues (Figure SI4.4), so it is unlikely that kinetics are a function of transformation or degradation processes. Relationships between day 28 toad tissue concentrations and diet are highly variable (Table SI4.2 and Table SI4.3), so there is further evidence that observed concentrations are a function of kinetics.

Definitive model selection

LOOCV was used to differentiate model techniques based upon their MAE as a measure of predictive power. Ultimately, TTCs should be determined based on the model type with the highest performing predictive capacity. PFOS and 8:2 FTS concentrations in liver were selected for this analysis. The ODE model type led to two-fold increases in mean absolute error over the nonlinear model type in both PFOS and 8:2 FTS liver concentration trajectories (Table 4.1). This suggests that the nonlinear model should be selected for definitive parameter estimation and subsequent TTC determination. Of note, regardless of the model type or chemical, there was little influence of removing individual data on MAE compared to full models (Table 4.1). The implications of this are that 'the data fit the model' and predicting liver concentrations as single compartment flux is likely accurate to biological processes. Accordingly, TTC estimates from either model are likely equivalently accurate, but the reduced amount of error in the nonlinear model increases the precision of the TTC estimate.

Toxicokinetic parameters and analysis

Toxicokinetic parameters were estimated in a stepwise fashion using guidance from OECD TG# 305 (2012) and Tarazona et al. (2015, 2016). The linear regression of $\log_e$(concentration) through elimination period (study day 28 through 56) provides a definitive elimination rate for all PFAS (Table 4.2). Importantly, these regression parameter estimates are of highly varying quality (see SE in Table 4.2 and Table SI4.2 through Table SI4.3). As the data may not be parametric and *Vd* may be influential, the bootstrapped nonlinear model elimination parameter estimates are likely the most appropriate representation of elimination rate. Estimates of half-life (days) are provided using these parameter estimates and their 95% confidence intervals (Table 4.2).

TTC estimates

The ratio of uptake and elimination here is intended to speak to the potential for trophic magnification/transfer/dilution in the diet to consumer (worm to toad) trophic step while considering internal kinetics. Less than the complete suite of PFAS were successfully modeled in the definitive nonlinear methods, so some TTCs (not definitive) from linear models (i.e. the OECD TG #305) were generated. Importantly, while the actual values may be inaccurate, the overarching patterns of potential for trophic magnification-transfer-dilution across PFAS appear consistent (Figure 4.3). PFOS is consistently observed to have TTCs that are greater than two and would be considered a likely trophic magnifier. PFDA and PFUdA also have TTCs above two (Figure 4.3Table 4.2). In contrast, 8:2 FTS and PFHpS are likely to be trophic diluters or simply transfer PFAS.

Table 4.1. Predicting liver concentrations of PFOS and 8:2 FTS via the ODE model increased MAE by more than two-fold[a] over the nonlinear model. Additionally, there is little influence of individual data[b] on predictive power regardless of the model choice.

		Full model	LOOCV models	Fold-change[b]
8:2 FTS	Nonlinear model MAE	15.9	16.5	1.04
	ODE model MAE	35.6	36	1.01
	Fold-change[a]	2.24	2.18	
PFOS	Nonlinear model MAE	277.2	293.5	1.06
	ODE model MAE	780.5	803.5	1.03
	Fold-change[a]	2.82	2.74	

Notes:
MAE: mean absolute error; LOOCV: leave-one-out cross-validation; ODE: ordinary differential equation; PFOS: perfluorooctanesulfonic acid; 8:2 FTS: 8:2 fluorotelomer sulfonate.
Fold-change[a] is ODE model MAE divided by nonlinear model MAE and fold-change[b] is LOOCV MAE divided by full model MAE.

Table 4.2. Summary of parameter estimates from linear and nonlinear models. NA indicates insufficient data or poorly performing model fit (e.g. concentrations are indistinguishable from background).

PFAS	Diet, mean, (SD)	Tissue	Linear Elimination Rate (K_{el}) Estimate, (SE)	Nonlinear Elimination Rate (K_{10})	Nonlinear Uptake Rate (K_{01}) Estimate, (lower, upper)	Nonlinear Volume of Distribution (Vd)	Half-life (days) ln(2)/K_{10}, (lower, upper)
PFHxS	1935.23, (354.98)	Liver	-0.068, (0.030)	-0.079, (-0.04, -0.156)	0.182, (0.049, 1)	30.301, (16.672, 35)	8.77, (17.33, 4.44)
		Remainder	-0.084, (0.045)	-0.149, (-0, -1)	0.118, (0.001, 1)	7.124, (0.34, 10)	4.65, (Inf, 0.69)
		Estimated Whole Body	-0.108, (0.058)	-0.154, (-0, -1)	0.139, (0.001, 1)	5.173, (0.175, 10)	4.5, (Inf, 0.69)
PFBS	1639.71, (219.4)	Liver	-0.064, (0.063)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Remainder	-0.055, (0.018)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Estimated Whole Body	-0.154, (0.082)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
PFHpS	1129.1, (204.72)	Liver	-0.097, (0.021)	-0.1, (-0.066, -0.147)	0.072, (0.049, 0.103)	0.32, (0.231, 0.421)	6.93, (10.5, 4.72)
		Remainder	-0.087, (0.020)	-0.097, (-0.03, -0.252)	0.063, (0.017, 0.124)	1.055, (0.431, 1.845)	7.15, (23.1, 2.75)
		Estimated Whole Body	-0.089, (0.019)	-0.095, (-0.038, -0.221)	0.061, (0.025, 0.117)	0.975, (0.476, 1.514)	7.3, (18.24, 3.14)
8:2 FTS	885.23, (153.27)	Liver	-0.088, (0.015)	-0.086, (-0.062, -0.115)	0.064, (0.047, 0.083)	1.31, (1.039, 1.622)	8.06, (11.18, 6.03)
		Remainder	-0.072, (0.014)	-0.074, (-0.039, -0.126)	0.081, (0.041, 0.136)	3.039, (1.914, 4.296)	9.37, (17.77, 5.5)
		Estimated Whole Body	-0.074, (0.013)	-0.077, (-0.043, -0.132)	0.078, (0.045, 0.134)	2.964, (1.931, 4.024)	9, (16.12, 5.25)
PFOSA	863.47, (127.96)	Liver	-0.033, (0.027)	-0.036, (-0.008, -0.069)	0.544, (0.095, 1)	2.952, (1.88, 4.353)	19.25, (86.64, 10.05)
		Remainder	-0.029, (0.032)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Estimated Whole Body	-0.027, (0.031)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
PFOS	697.14, (112.48)	Liver	-0.007, (0.008)	-0.009, (0.000, -0.021)	0.062, (0.028, 0.111)	0.213, (0.156, 0.266)	77.02, (Inf, 33.01)
		Remainder	-0.007, (0.009)	-0.008, (-0, -0.023)	0.073, (0.023, 0.175)	0.605, (0.404, 0.78)	86.64, (Inf, 30.14)
		Estimated Whole Body	-0.007, (0.008)	-0.008, (-0, -0.022)	0.065, (0.024, 0.132)	0.587, (0.393, 0.752)	86.64, (Inf, 31.51)
PFDA	629.43, (93.28)	Liver	-0.016, (0.010)	-0.017, (-0.007, -0.028)	0.065, (0.04, 0.099)	0.42, (0.336, 0.514)	40.77, (99.02, 24.76)
		Remainder	-0.023, (0.012)	-0.024, (-0.008, -0.04)	0.05, (0.024, 0.084)	0.742, (0.53, 0.99)	28.88, (86.64, 17.33)
		Estimated Whole Body	-0.022, (0.019)	-0.023, (-0.008, -0.039)	0.051, (0.026, 0.084)	0.755, (0.549, 0.994)	30.14, (86.64, 17.77)
PFNA	585.92, (111.88)	Liver	-0.049, (0.032)	-0.06, (-0.012, -0.123)	0.251, (0.032, 1)	5.234, (2.487, 7.954)	11.55, (57.76, 5.64)
		Remainder	-0.049, (0.038)	-0.078, (-0.014, -0.275)	0.169, (0.016, 1)	7.986, (2.416, 10)	8.89, (49.51, 2.52)
		Estimated Whole Body	-0.111, (0.063)	-0.214, (-0, -1)	0.064, (0.004, 0.211)	3.82, (0.345, 8.994)	3.24, (Inf, 0.69)
PFOA	276.81, (47.65)	Liver	0.043, (0.005)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Remainder	-0.158, (0.294)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Estimated Whole Body	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
PFUdA	192.97, (36.66)	Liver	-0.010, (0.010)	-0.012, (-0, -0.026)	0.051, (0.021, 0.092)	0.359, (0.252, 0.469)	57.76, (Inf, 26.66)
		Remainder	-0.010, (0.010)	-0.011, (-0, -0.027)	0.056, (0.019, 0.113)	0.909, (0.605, 1.215)	63.01, (Inf, 25.67)
		Estimated Whole Body	-0.010, (0.009)	-0.011, (-0, -0.025)	0.055, (0.023, 0.104)	0.899, (0.628, 1.177)	63.01, (Inf, 27.73)
PFBA	160.03, (354.4)	Liver	-0.024, (0.028)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Remainder	-0.024, (0.019)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Estimated Whole Body	-0.031, (0.025)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
PFHpA	90.69, (15.67)	Liver	0.005, (0.023)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Remainder	-0.173, (0.192)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Estimated Whole Body	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
PFTeDA	36.96, (4.96)	Liver	0.010, (0.017)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Remainder	0.011, (0.017)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Estimated Whole Body	0.011, (0.017)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
PFTrDA	13.31, (2.08)	Liver	-0.010, (0.018)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Remainder	-0.010, (0.019)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Estimated Whole Body	-0.023, (0.019)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
PFHxA	1.86, (0.33)	Liver	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)
		Remainder	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)

	Estimated Whole Body	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)	NA, (NA)

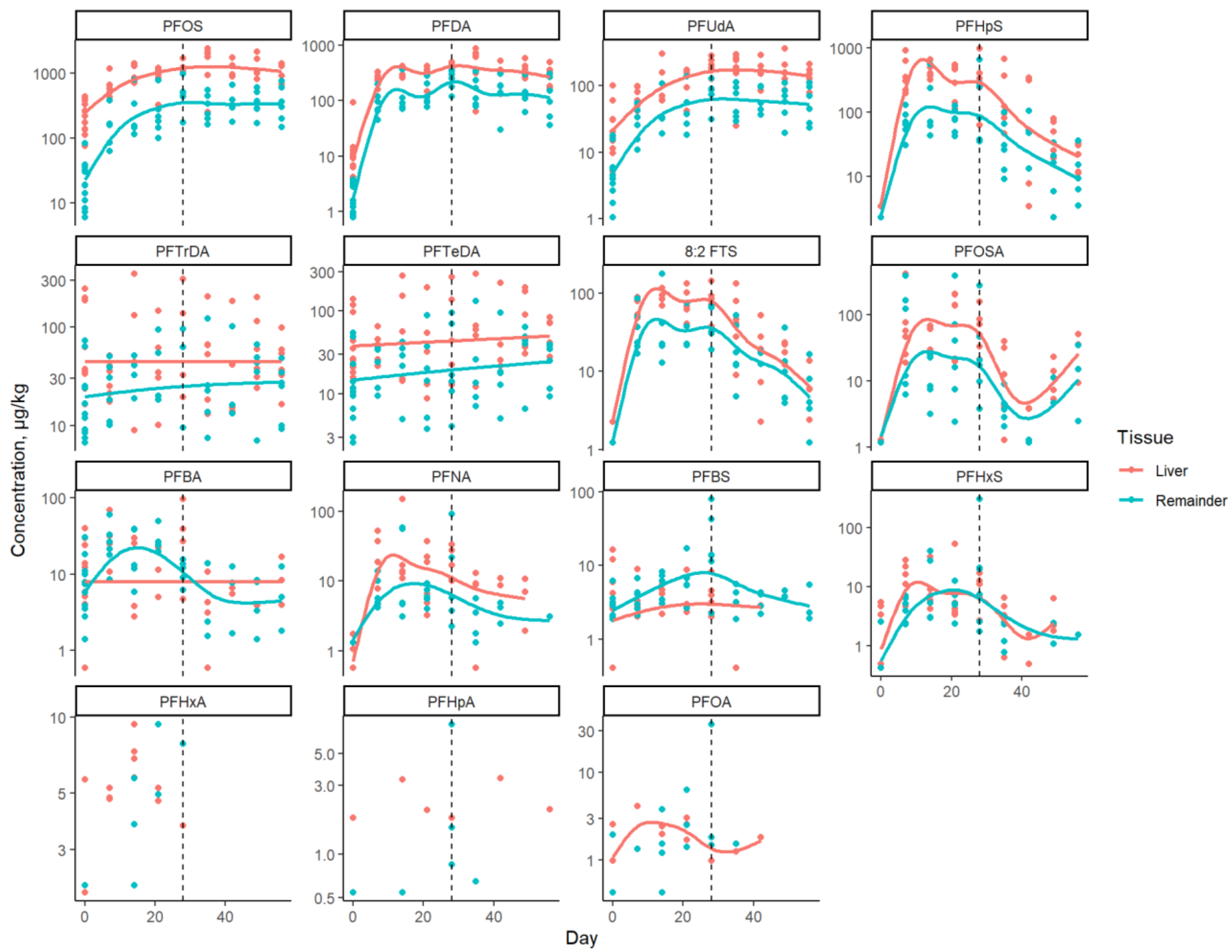


Figure 4.1 Liver (red) and remainder (green) PFAS concentrations with tissue- and PFAS-wise cubic spline smoothers. Points are individuals, lack of points indicates no data above reporting limit, dashed vertical line indicates day 28 transition from uptake to elimination. See SI for acronyms.

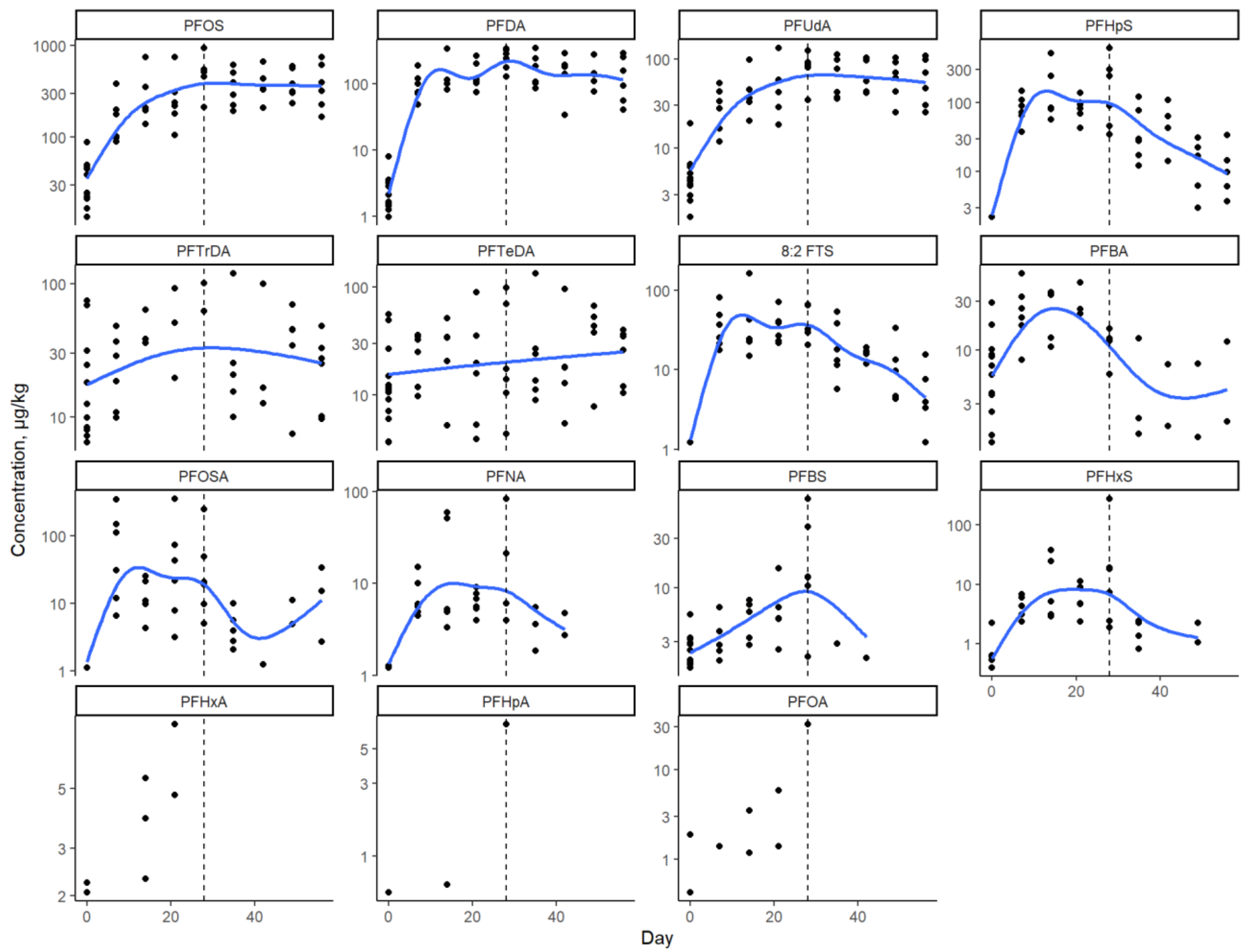


Figure 4.2. Estimated whole body PFAS concentrations with PFAS-wise cubic spline smoothers. Points are individuals, lack of points indicates no data above reporting limit, dashed vertical line indicates day 28 transition from uptake to elimination. See SI for acronyms.

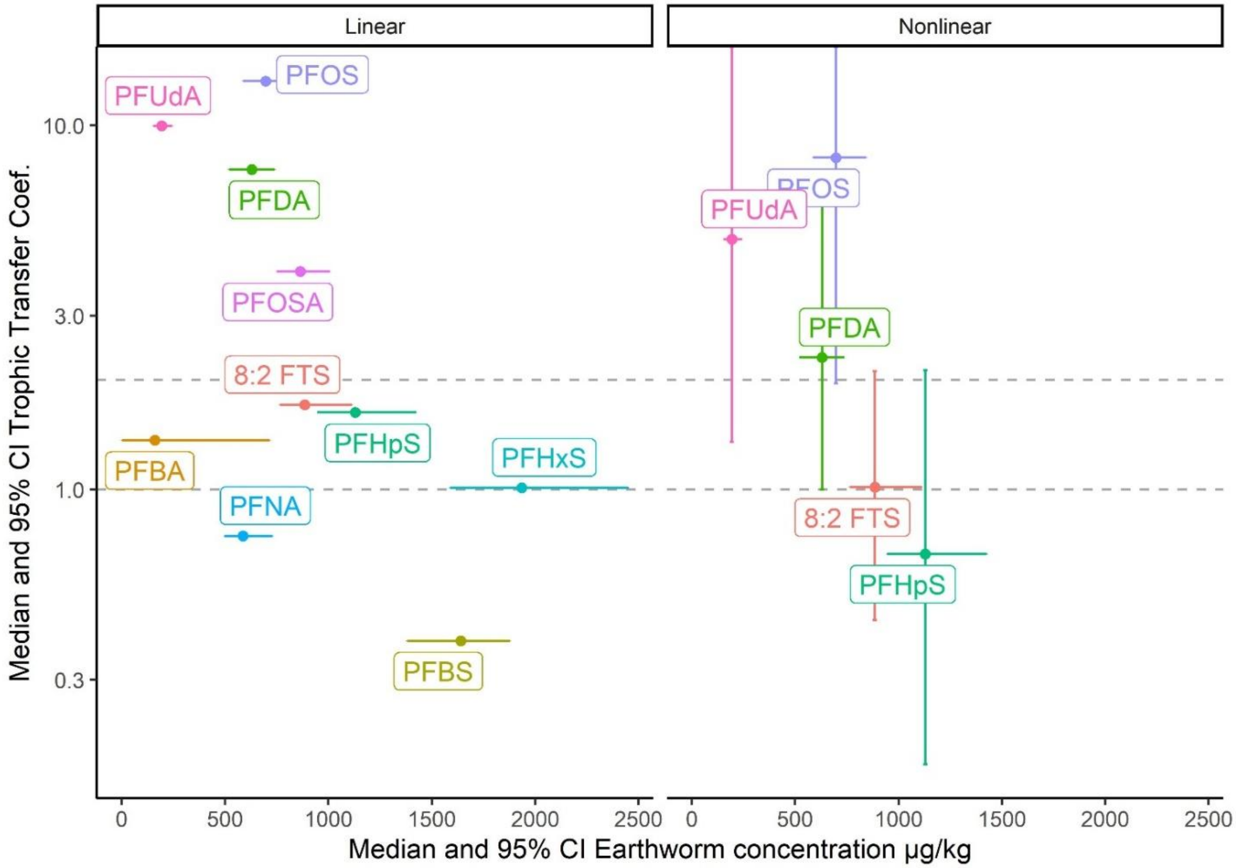


Figure 4.3 Trophic transfer coefficients (TTCs) in relation to diet concentration for either definitive nonlinear model (right) and informative but 'pilot' linear models (left). Points are estimates and lines are upper and lower 95% confidence intervals from diet data (horizontal) or resampled bootstrap parameter distributions (vertical). Dashed horizontal lines are at 1.0 and 2.0 and indicate a transition area where PFAS are more likely to be trophic magnifiers (y>2), trophic diluters (y<1), or simply transfer (1<y<2). See SI for acronyms.

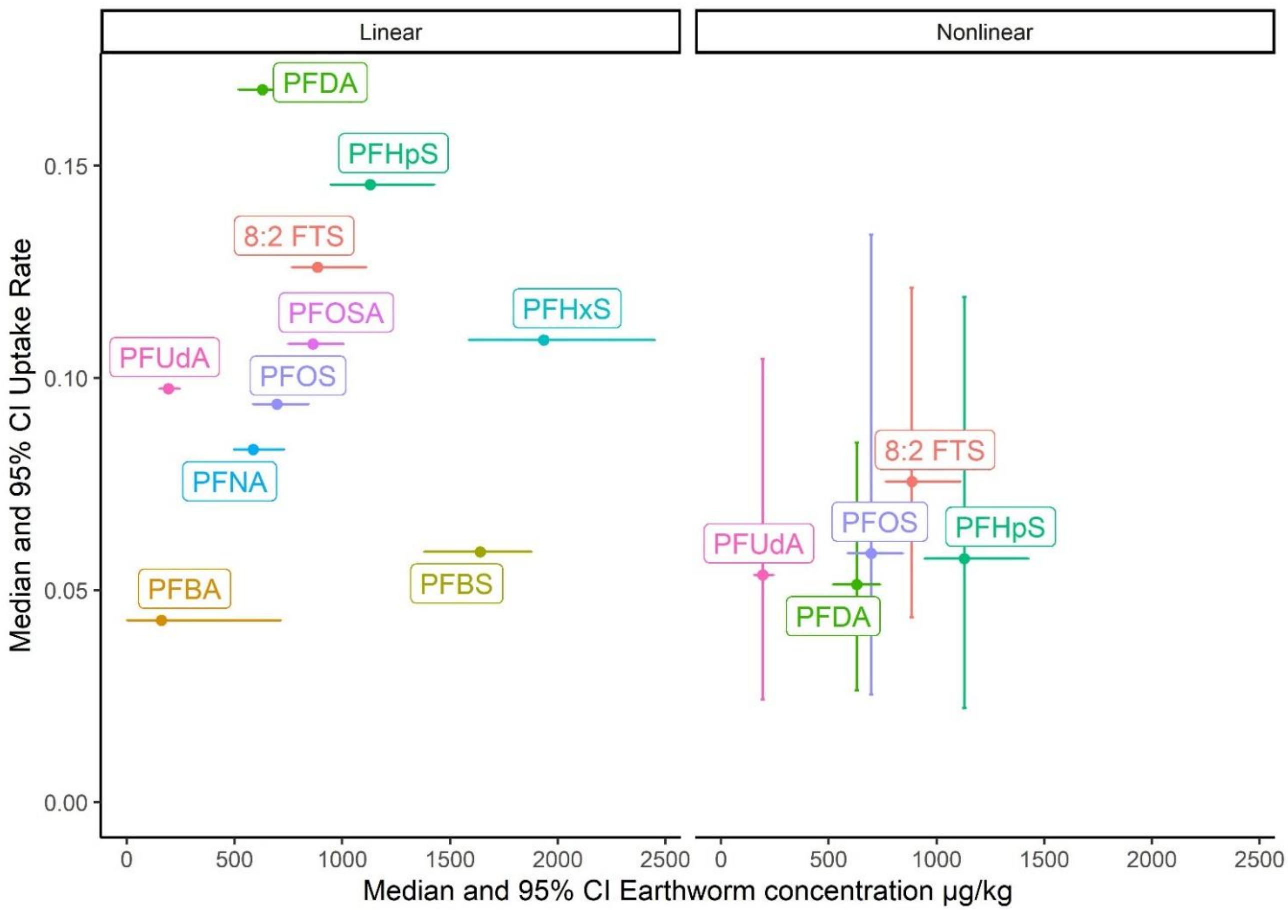


Figure 4.4 Uptake rates via definitive nonlinear models (right) and pilot linear models (left) in relation to diet concentration. Note that accounting for volume of distribution (Vd) lowers the uptake rate and indicates that uptake rates across PFAS are similar, but other parameters vary. Points are means, error bars are 95% confidence intervals. Horizontal errors bars based on sample size of 5, vertical error bars based on resampled bootstrap parameter estimates of uptake rate. See SI for acronyms.

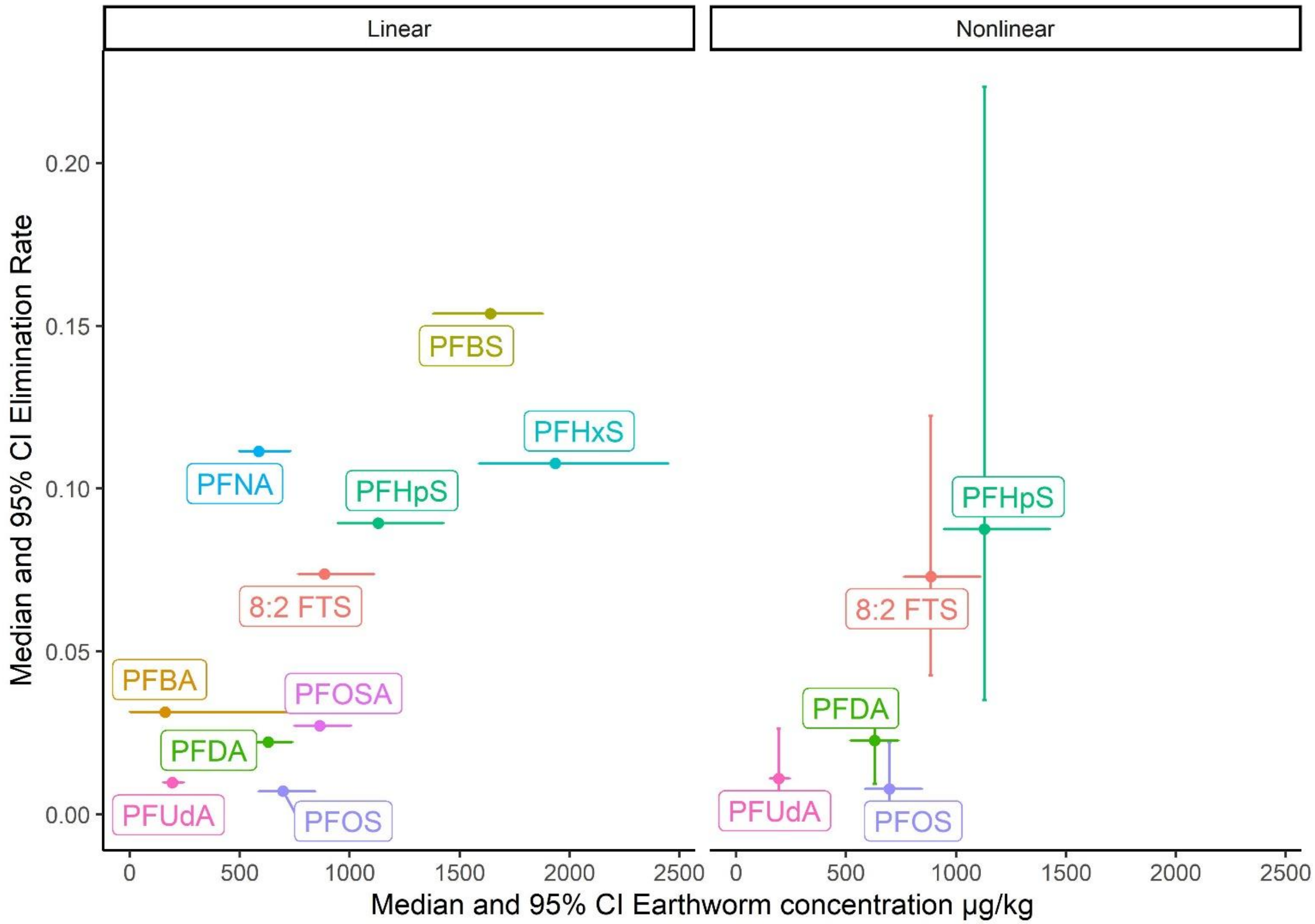


Figure 4.5 Elimination rates for definitive nonlinear models (right) and pilot linear models (left) in relation to diet concentration. Points are means, error bars are 95% confidence intervals. Horizontal errors bars based on sample size of 5, vertical error bars based on resampled bootstrap parameter estimates of uptake rate. See SI for acronyms.

Discussion

Toads were fed homogenized worms grown in a PFAS mixture-spiked soil for 28 days and then worms grown in control soil for another 28 days. Toads' livers and remaining bulk tissues were collected weekly and PFAS levels quantified. Two different toxicokinetic models were fit to liver, remainder, and estimated whole body concentration data through time. A model selection procedure was used to identify a modeling approach with relatively higher predictive power. The definitive model uptake and elimination parameters were used to generate trophic transfer coefficients (TTCs). TTCs are intended to inform potential for trophic transfer or trophic magnification, lacking field data.

The TTCs for PFOS, PFUdA, and PFDA are all above two and indicate that trophic magnification is possible in this kinetics-based screening approach. Note that lower confidence levels in all three of these PFAS fall below two but for PFOS and PFUdA the upper confidence limits are infinity. This is due to elimination rates for PFOS and PFUdA including 0 (see Table 4.2 rates and half-lives). In contrast, the PFAS that are expected to be trophic diluters (8:2 FTS and PFHpS) have nearly equivalent elimination and uptake rates. They also have widely varying TTCs which can likely be attributed to generating ratios from lower variability numerators and denominators—a 5-10% multiplicative uptake or elimination rate variation is less alarming than a many-fold TTC variation. While there are highly variable patterns in TTCs, we note the potential for dilution is less strong than magnification—TTC central estimates for 8:2 FTS and PFHpS are between 1 and 0.3, while PFOS and PFUdA are between 3 and 10. Across PFAS, uptake rates are somewhat clustered between 0.05 and 0.1 (Figure 4.4) and elimination rates are more variable, ranging from 0.01 to 0.1 (Figure 4.5). Further, elimination rates are somewhat clustered with PFOS, PFUdA, and PFDA below 0.05 and PFHpS and 8:2 FTS between 0.05 and

0.1. Accordingly, a plausible broad hypothesis is that TTC values are a function of elimination rate.

The relationship between diet concentration and TTC, uptake, or elimination rates are unclear (Figure 4.3). As the linear model for elimination rates are less problematic than linear uptake rates, the elimination rates are reasonably comparable to the nonlinear parameter estimates. Figure 4.5 demonstrates a potential relationship between elimination rate and diet—as concentrations rise, elimination tends to increase. Given that uptake is expected to be consistent across PFAS, it is plausible to hypothesize that TTCs are driven by elimination and elimination may be driven by a concentration dependent process.

Half-lives appear to be in several clusters with some central estimates at less than 28 days (e.g. 8:2 FTS), some very near 28 days (e.g. PFDA), and several much longer than 28 days (e.g. PFOS). These estimates (and their related parameter estimates) are unclearly related to diet concentration. Similarly, while there does appear to be a pattern of the increasing half-life with fluorinated carbon chain length, there is clearly a relationship with functional group as PFNA, PFOS, and 8:2 FTS have similar fluorinated carbon chain lengths, but capture the lowest, average, and highest half-lives (see Table 4.2). It should also be noted that these half-lives are based on the elimination rates determined in the nonlinear model effort and accordingly account for kinetics. Our expectation is that this representation of half-life is more inclusive of the multiple processes (uptake, volume of distribution, and elimination) that influence PFAS internal dose.

Another observation of the study is that PFAS that tend to move into worms may not necessarily move into toads. PFHxS, as the highest concentration PFAS observed in worms, had such large elimination rates that model parameter estimates were challenging (95% confidence intervals span 0 to 1). While there is concern about concentration-dependent elimination rate, PFAS such as PFOS may have a 'medium' categorized bioaccumulation factor (ratio of worm tissue concentration to soil concentration is a central observation) but 'high' categorized TTC (the highest TTC). Contrasting, 8:2 FTS has a 'medium' categorized bioaccumulation factor, but 'low' categorized TTC. So, while concentration-dependent elimination may be observed, these data indicate that the PFAS and its kinetics are the drivers. This is in alignment with the actual scientific question in mind—how do we better describe the PFAS-organism relationship in the lab such that we can better understand field observations?

Notable field observations from terrestrial systems generally do not include herptile taxa. Those studies that do include herptile taxa are often in single trophic steps and do not meet definitions of food web studies where trophic transfer would be quantified. But for comparison of the PFAS-to-PFAS patterns we discuss some works. In Müller et al. (2011), the food chain described was lichen to reindeer to wolves, in Huang et al. (2022) grass, pika, and eagle were sampled, and in Fremlin et al. (2023) invertebrates, songbirds, and hawk eggs were sampled. Heimstad et al. (2024) sampled invertebrates, songbird eggs, and hawk eggs (with other mammalian tissues in a nonlinear food web). So, while these studies don't provide a direct comparison of an invertebrate to toad, PFAS-specific comparisons may be useful. PFOS, in particular, shows the most potential for trophic magnification in these field data. This is also in alignment with short food web studies that tracked PFOS alone from soil through worms and plants to mice and identified BMFs greater than 1 for PFOS (D'Hollander et al. 2014) or multiple PFAS from soil through worms to voles and identified BMFs greater than 1 for PFOS alone (all other PFAS were < 1) (Grønnestad et al. 2019). Also note that long chain perfluoroalkyl carboxylates PFDA and PFUdA are high potential magnifiers in this study, but that principle may not be consistently observed in the field sites. In Müller et al. (2011), the larger PFAS have a reduction in trophic magnification factors, but in Huang et al. (2022) and Fremlin et al. (2023), these PFAS may show trophic magnification levels that are near to PFOS. In Heimstad et al. (2024), the long chain perfluorocarboxylates show an increase and then decreasing pattern with a peak at PFDoDA. Note that PFHxDA was indistinguishable from zero (Heimstad et al. 2024). Cui et al. (2018) evaluated adult Ranid frogs (*Pelophylax nigromaculatus*) living in wet agricultural habitats. Their bioconcentration factor values (frog tissue concentration / water concentration) (unclearly described as bioaccumulation factors—implying dietary exposure) increase with carbon chain length for perfluoroalkyl carboxylates and sulfonates and their chlorinated replacements (Cui et al. 2018). It remains untested how our individual trophic transition (diet to toad) could speak to larger food chains with multiple trophic transfers, but some alignment suggests that overall trophic transfer of PFAS may be a function of internal toxicokinetic rates—if bioaccumulation is informative of biomagnification, we should observe alignment of individual toxicokinetic rates and system level trophic magnification rates.

Herptile data largely exist for their aquatic, larval stages. The data are lower resolution across time but do allow for a comparative basis. For instance, Ankley et al. (2004) provide bioconcentration information in larval Ranids (*Lithobates pipiens,* formerly *Rana pipiens*) that were observed during a toxicity test. Values indicate bioconcentration factors based on ratios of estimated tissue concentrations and water concentrations to be lower than those bioconcentration factors based on ratio of kinetic parameters (uptake vs elimination). Importantly, given the range of concentrations in water and tissues, bioconcentration values ranged from 17.5 to 175 (Ankley et al. 2004). Assuming that our dietary TTCs represent one exposure route and magnitude at a terrestrial life stage and the bioconcentration another exposure route and magnitude in an aquatic life stage, across the full life of any given amphibian, the bioconcentration factor maybe higher than dietary accumulation. The implication is that PFAS burdens from aquatic systems are, at the least, equivalently important as dietary exposure during adulthood. However, the continuity of body burdens across life stages assumes continuous uptake and/or low elimination. Disregarding the difference between *Lithobates* (Ranid frog) and *Ambystoma* (Ambystomatid salamander), the data from Flynn et al. (2021) would concur; that for PFOS, a biomagnification factor based on diet to salamander tissue between 1 and 3 would be lower than bioaccumulation in larval *Lithobates*. Interestingly, as dermal exposure is highly relevant for taxa that have generally permeable skin (amphibians), data on dermal transfer indicates that PFAS may or may not have influential biota-sediment accumulation factors (BSAFs). Abercrombie et al. (2021) indicate that in *Ambystoma* PFOA, PFOS, PFHxS, and 6:2 FTS have BSAF values that are at or below 0.10—indicating that dermal routes are not routes of high accumulation. Note, however, that these values are similar to the dietary accumulation factors of Flynn et al. (2021) for PFOA, PFHxS, and 6:2 FTS. Accordingly, the more insightful observation is that dietary accumulation is only higher for PFOS. Further, Abercrombie et al. (2021) include *Anaxyrus americanus* data so a comparison can be directly made to our data. BSAF values for dermal exposure to PFOA, PFHxS, and 6:2 FTS are all below 0.1 and for PFOS range between 0.1 and 0.25 (Abercrombie et al. 2021). This indicates that the dietary exposure route is more accumulative than dermal for PFOS, but low TTCs for PFOA, PFHxS indicate that dermal accumulation may be comparable to dietary accumulation. The relationship between 8:2 FTS and 6:2 FTS remains untested in these taxa. Our data, in conjunction with some other amphibian data (Abercrombie et al. 2021; Flynn et al. 2021) suggest that PFOS is one PFAS that has high dietary accumulation during terrestrial life stages and low enough elimination in aquatic and terrestrial life stages to persist in an individual through an aquatic to terrestrial transition.

Data related to toxicity of PFOS, PFOA, and PFHxS, chlorinated polyfluorinated ether sulfonic acid (6:2 Cl-PFESA), and hexafluoropropylene oxide trimer acid (HFPO-TA) in terrestrial life stage amphibians is only available in dermal exposure routes (Cui et al. 2018; Abercrombie et al. 2021; Lin, Wu, et al. 2022) and via diet in salamanders (Flynn et al. 2021). Other PFAS studied here do not have data available. However, exposure via dermal routes to PFOS, PFOA, and PFHxS did not reveal detectable dose-response data effects up to 8000 ppb dry weight basis (Abercrombie et al. 2021). Yet, comparison back to control data suggests that potentially a no-effect concentration was unobserved and actually all treatments were indicative of toxic effects. While it remains unclear, at the least, PFOS and PFHxS appear to be more toxic than PFOA (6:2 FTS may be the most impactful) (Abercrombie et al. 2021). Flynn et al. (2021) indicate that PFOS significantly reduces growth using a marginal approach to control for mismatched starting weights. As summarized in Pandelides et al. (2023), this effect measure may not be one risk assessors are comfortable with. Regardless, the rejection of these impacts' relevance (by Pandelides et al. (2023)) is not compatible with modern statistical thinking nor is "weight at end of study" compatible with population-relevant models which would rely on growth rate (i.e. a marginal measure). Lin et al. (2022) identified increased hepatosomatic index and mechanistic signals of lipid dysregulation in adult Ranid frogs (*Pelophylax nigromaculatus*) exposed to 1 to 10 µg/L PFOA, PFOS, 6:2 Cl-PFESA, and HFPO-TA. Importantly, the interpretation was that replacement PFAS were equally toxic as legacy PFAS (Cui et al. 2018; Lin, Liu, et al. 2022). Uncertainty about comparability of strictly aquatic exposure versus dietary should be noted here as well as the general lack of utility for suborganismal data in risk assessments (Pandelides et al. 2023).

Exposure through contaminated bedding is not addressed here but is addressed by Abercrombie et al. (2021). However, it is likely important in real field settings as toads absorb moisture through their stomach skin. The toads in this study were observed resting in their petri dish water supplies regularly. The water provided is based on source water that is PFAS-free (Narizzano et al. 2024), but it is not determined if elimination and or uptake could be occurring through this dermal route in these organisms. Abercrombie et al. (2021) would likely suggest dermal exposure to any contamination is low, but this cannot be addressed as this study was not designed to answer these questions. In contrast, Cui et al. (2018) indicate that substantial portions of the PFAS burden in frogs may be in the skin tissue itself. While one could hypothesize that smaller and/or more water soluble PFAS would tend to move through the porous skin of amphibians, potentially the relatively lower flux observed by Abercrombie et al. (2021) can be explained by deposition into the skin. Elimination through feces or molting skin may increase variability in observed concentrations as fecal deposition is periodic (daily to several days between events) and molting of skin may occur sporadically and requires high quality laboratory care to occur in the laboratory.

Uncertainties in this dataset and analysis are largely related to corroboration with field data with multiple trophic levels with amphibians. There are also few laboratory data with terrestrial life stage amphibians, but further, there are limited PFAS trophic transfer studies in laboratory. McDermott et al. (2022) and Judy et al. (2022) describe the movement of PFAS from plants to invertebrates, so there is not a direct relation to this study as the invertebrates in our study were exposed directly to the soil, not via diet alone. Importantly, the McDermott et al.

(2022) and Judy et al. (2022) studies suggest (1) trophic dilution through this food chain and (2) PFOS is the highest trophic "magnification" factor. The worm, soil, PFAS combination described here (Kuperman et al. 2025) suggests that some PFAS are diluters in the soil-worm step (shorter chain PFAS), but others are accumulative (longer chain PFAS) and would suggest trophic magnification. The resultant hypothesis that could be explored to address this uncertainty is that water-plant transfer is where dilution emerges while soil+water-invert-predator is a magnifying pathway. While there are features of PFAS congeners that are influential, the features of the organism or food chain of interest and the abiotic media source are likely equally influential. As an example, Scearce et al. (2023) indicate that characteristics of the PFAS, soil, ground/surface water, and the plants are all interacting in a manner that has left predicting uptake into sessile organisms (plants) a challenge.

Another uncertainty that can't be resolved in this study design is the nonlinear TMF~CF-chain length patterns observed in the field (Müller et al. 2011; Huang et al. 2022; Fremlin et al. 2023) against the relatively linear BAF~CF-chain length patterns observed in single step transfers (Burkhard and Votava 2023). Importantly, however, it can easily be hypothesized that in the field, higher level organisms' diets, even with a relatively well defined/constrained food chain, are an integration of a variety of physico-chemical and biological processes. So, while a linear pattern may exist in a basal food chain step (soil to worm), at higher trophic levels, the CF-chain length may not be entirely explanatory. See mismatch in adult Ranid frog (*Pelophylax nigromaculatus*) field vs laboratory frog tissue concentration / water concentration in Lin et al. (2022) where field bioconcentration is substantially higher than observations in the laboratory.

In conclusion, we utilized internal toxicokinetics of dietary exposure to a PFAS mixture in a terrestrial life stage amphibian to identify PFAS trophic transfer coefficients. PFAS with relatively high TTCs are suggested to likely be trophic magnifiers (PFOS, PFUdA, and PFDA), 8:2 FTS is likely to equivalently transfer, and PFHpS a trophic diluter. These data are somewhat as expected from some field data (Müller et al. 2011; Huang et al. 2022; Fremlin et al. 2023) where PFOS is expected to by a trophic magnifier. The novel addition from this study is that in higher order organisms, this observation may be a function of very low elimination at the individual level. At the primary consumers, the trophic magnification of PFOS may be considered 'medium' in that our BAFs were in the middle of the span of BAFs observed (Kuperman et al. 2025). In concert, the field observations may be a function of uncaptured processes, specifically for PFOS.

Chapter 5: Trophic transfer and dietary kinetics of a PFAS mixture in rabbits (*Oryctolagus cuniculus*)

Abstract

Per- and polyfluoroalkyl substances (PFAS) are widely detected in soil, plants, and animals. On sites, PFAS are expected to be mixtures, and it remains unclear how regulations and risk assessments that are driven by single PFAS may be influenced by other associated PFAS. Further, given the magnitude of sites where ecological (or human) risk assessments may occur, there is a need to identify and highlight methods and PFAS where efficiency or prioritization are possible. In the interest of speaking to broader sites and food chains at large, we present data from laboratory studies where a uniform mixture of PFAS was monitored as it moved from environmental media through multiple trophic levels. In studies reported prior, soil was spiked with 16 nominally uniform PFAS and aged. Aged soil was used as growth media for timothy grass (*Phleum pratense*) and kale (*Brassica oleracea*). The plant data was used to prepare a PFAS-spiked plant diet for rabbits (*Oryctolagus cuniculus*) along with a control plant diet from timothy grass and kale grown in control growth media. Rabbits were fed the spiked diet for 28 days during the uptake phase and the control diet for 28 days during the elimination phase. Rabbit liver, kidney, and muscle tissues were collected via lethal sampling periodically through the study period. PFAS concentrations were quantified in the plant diets and rabbit tissues. A nonlinear regression toxicokinetic model was fit per-PFAS and per-tissue along with an estimated whole animal concentration. The uptake and elimination rates from this toxicokinetic model used to determine trophic transfer coefficients (TTCs). TTCs provide a kinetic comparative basis to relate PFAS' potential for trophic magnification. Results indicate that

perfluorooctane sulfonic acid, perfluoroheptane sulfonic acid, and 8:2 fluorotelomer sulfonic acid all have potential to be trophic magnifiers, while perfluorohexane sulfonic acid is more likely to be a trophic diluter. These results are compared and contrasted with other taxa and physiological specifics of rabbits and the soil-plant-rabbit food chain are discussed.

Introduction

Per- and polyfluoroalkyl substances (PFAS) are synthetic molecules that are generally considered widespread in the environment. Importantly, regardless of the breadth of research on their persistence, bioaccumulation, and toxicity, there remain few data that support ecological risk assessment in terrestrial systems (Ankley et al. 2021; Evich et al. 2022; Gkika et al. 2023). Specifically, exposure estimation in upper trophic levels with laboratory-quality stepwise quantification of transfer factors to support simple food web models as in Larson et al. (2018) and Zodrow et al. (2021). While field and laboratory data on individual PFAS exposure to terrestrial vertebrates are available (e.g. Death et al. (2021)) and field studies on multiple PFAS are available (e.g. Fremlin et al. (2023), Ecke et al. (2024)), few lab studies are available with the capacity to explore the importance of mixtures.

One area of PFAS exposure research relevant to terrestrial food webs that has a robust amount of data is the movement of PFAS into plants. Wang et al. (2020) provide a concise summary of several citations that suggests the understanding of PFAS movement into plants is largely a function of PFAS molecular weight (carbon chain length) with decreasing patterns in bioconcentration factor as molecular weight increases and no substantial effect of functional group (carboxylates (PFCAs) vs sulfonates (PFSAs)). Translocation of PFAS into plant shoots vs roots (translocation factor (TF)) indicate similar patterns with the added observation that sulfonates (PFSAs) are less likely to be found in shoots when controlling for molecular weight

(Wang et al. 2020). Few of the data summarized by Wang et al. (2020) are based on studies exploring PFAS uptake in plants as mixtures. Scearce et al. (2023) expand this observation by noting that the PFAS-plant linkage is compounded by PFAS-soil and plant-soil characteristics that limit the utility of PFAS-specific descriptors and subsequent interpretation to bins of "high" and "low" uptake with quantitative estimates as low precision.

In this work, the uptake of PFAS into plants is largely of note as plants are food for terrestrial herbivores. While there are a number of field studies based on evaluating PFAS exposure in terrestrial food webs with mammalian herbivores (e.g. D'Hollander et al. (2014)), there remain few lab studies related to this topic. Studies specifically addressing matrix to plant to consumer identified here were focused on invertebrate herbivores. McDermett et al. (2022) grew alfalfa with PFAS contaminated irrigation water and then exposed crickets to that alfalfa and irrigation water. The study used a mixture of seven PFAS at a uniform concentration in the water and observed that bioconcentration factors (BCFs) were above 1 in the water to plant step and that biomagnification factors (BMFs) were below 1 in the plant to cricket step. They did not detect mixture effects that influenced uptake into either organism. The BCF > 1 and BMF < 1 indicates that the movement of PFAS from irrigation water (representing ground/surface water) to plants and then to herbivorous invertebrates may not be a magnifying pathway. However, the relationship between water to cricket BCF mirrored plant to cricket BMF indicating that binding in the cricket is a key determinant of consumer uptake regardless of source (McDermett et al. 2022). Judy et al. (2022) spiked hydroponic media with seven PFAS, grew tomatoes in that media, and then fed contaminated tomato leaves to tobacco hornworm caterpillars in a uptake and elimination period (toxicokinetic) study design. The BCF values for media to plant are approximately in the same range as observed in McDermett et al. (2022), but in reverse order against C-chain length. However, similar to McDermett et al. (2022), the BMFs of plant to hornworm were less than the BCFs of media to plant (Judy et al. 2022). The broad interpretation is then that movement of PFAS into plants is clear, but movement into plant consumers may be less. However, given the highly specific relevance of plant consuming invertebrates and water-driven plant exposure, there remains a data gap to be addressed with soil-driven plant exposures and vertebrate consumers of plants.

The need for vertebrate exposure estimation data are largely driven by focus on mammalian sensitivity to PFAS and the low soil concentrations that emerge from the current understanding of food web exposure (Zodrow et al. 2021; Grippo et al. 2024). It is also known that PFAS observed on terrestrial ecological risk assessment relevant sites (such as Department of Defense (DoD) aqueous film-forming foam (AFFF) use areas (East et al. 2025b)) are mixtures. As such, there is interest in refining the data supporting stepwise food web exposure models by reliance on laboratory data and mixtures. Exposure data from vertebrates exposed in the laboratory to PFAS via plant diet are limited, vertebrates exposed to plants that have been grown in a contaminated media even less. Death et al. (2021) evaluated a series of field and some lab studies focused on livestock and describe several field studies focused on vertebrate wildlife. Due to the limited data aligned with the scenario of interest, there are limited insights, but it is likely that PFAS will be accumulated by vertebrates from plant material and likely there are tissue-specific affinities that may be relevant for upper trophic level predators that do not consume an entire prey animal (Kowalczyk et al. 2013; Death et al. 2021).

To address the lack of laboratory data on terrestrial consumer PFAS mixture exposure, we have conducted a series of studies. The overarching report is available in Kuperman et al. (2025) where we describe the stepwise potential for a PFAS mixture to move from soil to plants to vertebrate herbivores and from soil to worms to vertebrate amphibians. As described in Lotufo et al. (2025) a mixture of PFAS move into worms in a pattern related to C-chain length only in PFCAs with unclear/flat BAF values across PFSAs and two precursors. Interestingly this relationship appears driven by uptake rate as elimination rates do not have a clear correlation with C-chain length while uptake rate does (Lotufo et al. 2025). Notably, a kinetics-based bioaccumlation factor (BAF) as uptake rate divided by elimination rate provides BAFs that are nearly equivalent to BAFs determined by day 28 worm concentration divided by soil concentration. In East et al. (2025) (Chapter 4: Dietary kinetics of a PFAS mixture in the American toad (*Anaxyrus americanus*): laboratory insights into trophic transfer of PFAS), adult life stage toads were exposed to worms collected from Lotufo et al. (2025). Kinetics-based trophic transfer coefficients (TTCs) were reported for several PFAS, and critically, the potential for trophic transfer from worms to toads appears driven by elimination rates. In combined worms and toads, PFOS shows one of the highest average transfer factors and is expected to be a trophic magnifier based on consistent transfer factors > 1.

In this study, rabbits were exposed via diet to plants that were spiked in a manner to mimic plant concentrations that were observed in pilot studies where plants were grown in soil spiked with a uniform mixture of 16 PFAS (Kuperman et al. 2025). Concentrations of PFAS in rabbit tissues will be quantified during 28 days of uptake (exposed to the spiked diet) and 28 days of elimination (exposed to a control diet). These concentrations will be used to fit toxicokinetic models (Tarazona et al. 2015; Tarazona et al. 2016), estimate uptake and elimination parameters and provide trophic transfer coefficients (TTCs) (East et al. 2025a). TTCs provide a kinetics-driven quantification of potential for accumulation and trophic transfer in the plant to vertebrate herbivore step. The first objective of this work was to (1) describe the movement of PFAS into rabbit tissues from their diet and to (2) inform the potential for trophic magnification in a PFAS suite as it moves from soil to plant to vertebrate herbivore in the laboratory.

Methods

PFAS Selection

The PFAS selection is described in detail in Kuperman et al. (2025). In brief, the PFAS selected for this study included those with a shoot BCF > 1 in 28 (kale) or 32 days (timothy grass) uptake—perfluoroheptanoate (PFHpA), perfluorooctanoate (PFOA), perfluorobutanesulfonic acid (PFBS), perfluorohexane sulfonate (PFHxS), and PFOS. To explore the effects of chain length, we included perfluorobutanoate (PFBA), perfluoropentanoate (PFPeA), and perfluorohexanoate (PFHxA). Precursors 8:2 fluorotelomer sulfonate (8:2 FTS) and perfluorooctane sulfonamide (PFOSA) were also included. The selected list captures chain length trends and the terminal transformation products of PFAS precursors and PFAS that are a primary focus of federal advisories and state regulations found on DoD installations. Analytical-grade PFAS were obtained from the U.S. EPA PFAS Chemical Library or Sigma-Aldrich (St. Louis, MO).

Diet Preparation

The diet was a combination of plants with timothy grass (*Phleum pratense*) spiked to mirror concentrations determined in pilot studies (timothy grass grown in contaminated soil) (Kuperman et al. 2025) and kale (*Brassica oleracea*) grown in soil spiked with PFAS at a uniform concentration of 10 µg/kg. The test soil conditions are described in detail in Kuperman et al. (2025). In brief, test soil was Organisation for Economic Co-operation and Development

(OECD; Paris, France) standard artificial soil (SAS) modified by lowering the peat content from 10 to 5% (75% fine sand, 20% kaolin clay, 5% finely ground sphagnum peat moss, and 1% pulverized lime) to increase bioavailability of the test compounds (OECD 2010; OECD 2012; OECD 2016). The measured concentrations of PFAS in SAS were low (0.07 ng/g and 0.09 ng/g for PFHxA and PFPeA), with no other PFAS compounds found above detection limits.

A stock solution containing all PFAS in ASTM Type I water (deionized water) was prepared to spike timothy grass. These individual concentrations of each PFAS were based on concentrations of each compound in shoot dry mass determined in pilot plant uptake studies (Kuperman et al. 2025). The stock solution contained a mixture of PFAS with varying chain lengths to target final timothy grass concentrations of 67, 21, 1.5, 2, 6, 18, 14, 7, 9, 4, and 7 μg/kg for PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFHpS, PFOS, 8:2 FTS, and PFOSA, respectively. Timothy grass was spread in a large high-density polyethylene tub and sprayed with a mixture of stock solution or ASTM type I water (deionized water) using an atomizer, while turning with gloved hands under a fume hood. The grass was then spread on a greenhouse bench and dried for 24 h. The grass was placed in plastic bags in the dark at room temperature until feeding to rabbits. A stock solution containing all PFAS was prepared to spike soil for kale uptake. The stock solution contained sufficent PFAS mass to spike soil at a final wetted and aged concentration of 10 μg/kg of PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFHpS, PFOS, 8:2 FTS, and PFOSA. The final concentrations in the kale are a function of the accumulation into the plant material. Kale and timothy grass grown in control (unspiked) soil were used for the diets during the elimination period.

Rabbit care, exposure, and sample collection

This animal use was reviewed and approved by the DEVCOM Chemical Biological Center (CBC) Institutional Animal Care and Use Committee (DEVCOM IACUC Protocol #: 20-505). All animal care and use was performed according to the Guide for the Care and Use of Laboratory Animals (National Research Council (U.S.) et al. 2011) and all applicable federal and DoD regulations.

Dutch-belted rabbits (*Oryctolagus cuniculus domesticus*) weighing 1.8−2.3 kg were purchased from Robinson Services (Mocksville, NC). They were single-housed in a temperature and humidity-controlled room (12–24 °C and 30−70% humidity) with lights on from 0600 to 1800. Rabbits had access to nonconsumable enrichment items, and they were allowed at least 30 min of playtime outside their home cage each week.

A four-week pilot study was conducted to determine how much timothy grass a sexually mature rabbit would need to eat each day to maintain its body weight. A rabbit weighing 2 kg should consume 150−200 kcal/day; however, the nutritional content of grass varies so much that published sources do not comment on how much grass is required each day. For the first week, two rabbits (one male and one female) were fed timothy grass (Bio-Serv; Flemington, NJ) *ad libitum* along with 1 cup/day of leafy greens (Commissary; Aberdeen Proving Ground, MD). The type of greens (collard, kale, parsley, or spinach) was rotated daily to determine the preference of the rabbits. Rabbits were fed between 0800 and 1000, and the amount of timothy grass and greens consumed each day was recorded. Rabbits were weighed three times weekly, and daily observations were recorded on appearance, appetite, and activity level of each rabbit.

During the definitive study, diets were provided fresh daily (per pilot work) matched to individual consumption. Rabbits were weighed three times per week to monitor bodyweight and animal condition along with daily clinical monitoring. On date of sample collection, rabbits were restrained and intravenously injected with Fatal-Plus (Vortech Pharmaceuticals; Dearborn, MI) using their marginal ear veins. Blood samples were collected via a heart stick and analyzed using VetScan comprehensive diagnostic profile and thyroxine (T4)/cholesterol panel rotors (Zoetis; Parsippany, NJ). Brain, gonad, liver, kidney, muscle, skin, and spleen samples were also collected and weighed. A portion of each liver, kidney, and muscle sample was flash frozen with liquid nitrogen and stored at −80 °C until they could be shipped to Texas Tech University (TTU; Lubbock, TX) for analysis. The remaining tissue samples were preserved in 10% formalin for future pathology studies, and the carcass was skinned, cleaned, and stored at −80 °C.

Study Design

The study design was based on the Organisation for Economic Cooperation and Development (OECD) Technical Guide (TG) # 305, Bioaccumulation in Fish: Aqueous and Dietary Exposure (OECD 2012) (Figure 1). Exposure was strictly through the dosed diet. Three cohorts of rabbits (n = 1 per sex and timepoint per cohort, N=42) were exposed to PFAS mixtures via diet for 28 days and then a clean diet for another 28 days (56 days on study overall). Rabbits were randomly selected for sampling on 0, 1, 7, 14, 28, 29, 35, 42, or 56 days after the start of the study. Study day 0 represents background concentrations, samples collected on study days1, 7, 14, and 28 represent the uptake period. Study day 28 concurrently represents the start of elimination as the diet provided on day 28 is the control diet. The elimination period samples were collected on study days 28, 29, 35, 42, and 56.

Analytical determination of PFAS in diet and rabbits

Extended details of analytical determination of PFAS concentrations in plant diet and rabbit tissues (liver, kidney, and muscle) are available in Kuperman et al. (2025). In short, PFAS were extracted from plants using a method that is based on extraction from animal tissues and plants (Hansen et al. 2001; Taniyasu et al. 2003; Kannan et al. 2004; Martin et al. 2004; Gulkowska et al. 2006; Yeung et al. 2006; Spliethoff et al. 2008; Yoo et al. 2008; Pan et al. 2010; Zhang, Sun, et al. 2010; Zhang, Wu, et al. 2010; Felizeter et al. 2012; Wen et al. 2013; Zhao et al. 2014; Xiang et al. 2017; Lan et al. 2018; Zhao et al. 2018; Wang et al. 2020). A small mass of dried plant homogenate was spiked with an extracted internal standard, tetrabutyl ammonium hydrogen sulfate and sodium carbonate buffer was added, tube was vortexed, methyl tert-butyl ether was added, and the tube was shaken. Extracts were separated by centrifugation and transferred to glass scintillation vials. Extraction was repeated for a total of three times. The combined extracts were then evaporated to dryness under nitrogen. Samples were reconstituted in LC-MS grade methanol and transferred to tube with ENVI-Carb, vortexed, and centrifuged at 15,000 rpm for 30 minutes. Autosampler vials were prepared for analysis with a volume of extract and volume of methanol and water to reach a 70:30 water:methanol solution at 200 ng/L internal standard.

PFAS were extracted from rabbit liver, kidney, and muscle using methods prior developed for animal tissues (Tomy et al. 2005; Houde et al. 2008; Zhao et al. 2013). A small mass of wet tissues were placed in a polypropylene tube and dried at 70°C. An internal standard was added to each tube, methanol was added to each tube, and tubes were sonicated at room temperature. Samples were centrifuged and evaporated to dryness under nitrogen. Extracts were reconstituted in LC-MS grade methanol, transferred to a tube with ENVI-Carb, vortexed, and centrifuged. An aliquot of the extract was transferred to an autosampler vial and amended with 70:30 water:methanol to achieve a final internal standard concentration of 200 ng/L.

Chromotographic separation was performed on a Gemini C18 analytical column coupled with a Gemini C18 guard column with a Sciex Exion high pressure liquid chromatography (HPLC) system. A Luna C18 delay column was installed between the mobile phase mixer and the sample injector to minimize background contamination. Columns were maintained at 40°C throughout the run. Aqueous phase was ammonium acetate solution and organic phase was 100% methanol. See Kuperman et al. (2025) for details on ramp schedule.

Quadrupole time-of-flight mass spectrometry (QTOF-MS) for targeted analyses were performed on a Sciex X500R QTOF MS system. Turbo ion spray was used as the ion source. Multiple reaction monitoring high-resolution (MRMHR) acquisition mode was used with two transitions (quantifier and qualifier) for each PFAS, where possible. Data were acquired and processed using versions 1.5 and 2.2 Sciex OS software. PFAS were quantified using isotope dilution over a calibration range of 0.5-5000 ng/L with (coefficient of determination > 0.99).

Data handling

Liver, kidney, and muscle data for each rabbit at each timepoint across 11 PFAS were used for toxicokinetic modeling—in contrast to utilizing timepoint-specific summary statistics (i.e. just day 28). Non-detects observed in rabbits on the first timepoint (study day 0) were set to the PFAS-specific minimum observed across the study period. This increases the stability of background parameter estimates, but may lead to overestimates of background means. All other non-detect observations across rabbits (study day ≥ 7) were set to NaN (not a number) and are subsequently ignored during model fitting. Data from timepoints ≥ study day 28 were also labeled with an elimination day which is study day – 28. Plant diet aliquots' (collected concurrent with rabbit sampling timepoints) PFAS-specific analytical estimates were summarized to a mean and used as the 'dose' parameter per model requirements.

Each individual rabbit's kidney and liver were weighed and muscle assumed to represent 30% of bodyweight to generate an estimated whole animal concentration: $\left[\widehat{Whole\ Animal}\right] = \left([Liver]\frac{Liverweight}{Bodyweight}\right) + \left([Kidney]\frac{Kidneyweight}{Bodyweigh}\right) + ([Muscle]0.3)$. This value was estimated for rabbits and PFAS where the data were complete only, to avoid biasing based on incomplete detection. Importantly, as the liver and kidney combined represent approximately 3% of a rabbits weight, this estimate represents approximately 33% of the body mass. It is expected that liver and kidney capture substantial bulk of PFAS mass. Regardless, these whole animal estimated concentrations are likely underestimates. Additionally, muscle tissue represents the portion of an animal that often is consumed by a predator. Therefore, the estimated whole body concentration here is a high utility estimate for binding affinity and representative of predator exposure.

Due to substantial differences in reporting limits, PFOS data from a single cohort (first) were excluded. A single rabbit's data were also excluded as, based on the reported data, a labeling error may have occurred and tissue-specific measures are unlikely to be correct.

Nonlinear model

The nonlinear regression approach is based on utilizing the model of highest performance for predicting tissue (serum) concentrations of PFOS in rabbits and chickens exposed via diet in Tarazona et al. (2015, 2016). Starting parameters were determined by using linear regression techniques of OECD TG#305 for elimination period and uptake period. Some modifications to the OCED TG#305 techniques were made during the uptake period estimation given the 'linear phase' of uptake was observed inconsistently and the volume of distribution (Vd) was incorporated into the nonlinear models and likely captures the needed variability.

The one compartment nonlinear model used here to evaluate PFAS-specific toxicokinetics:

$$C_t = background + \left[\frac{(D \times K_{01})}{\left(Vd \times (K_{01} - K_{10})\right)}\right] \times [e^{-K_{10} \times t} - e^{-K_{01} \times t}] \quad (1)$$

where concentration at study day (C_t) is a function of: the mean PFAS-specific concentration at study day 0 (*background*); the mean PFAS concentration in the uptake period daily diet ($[diet] = D$); the volume of distribution (*Vd*); the uptake rate (K_{01}); the elimination rate (K_{10}); and time (study day, *t*).

Nonlinear model parameter estimation

All parameters were estimated using R (R Core Team 2024) and all parameters are estimated by PFAS and by tissue (liver, kidney, muscle, and estimated whole body). The first parameter estimation step was to estimate the elimination rate (K_{10}) using linear regression (least squares) of $\log_e$ concentration through 28 days of elimination period (study day 28 to 56 as elimination day 0 to 28). The slope of that linear regression is the estimated elimination rate. The second step was to fit Eq. 1 using nonlinear least squares and Port algorithm with the `nls()` (R Core Team 2024) function in R with the elimination rate set to the slope of elimination linear regression. The unknown parameters that were estimated were the uptake rate (K_{01}) and volume of distribution (*Vd*). K_{01} and *Vd* were bounded between 0 and 1 and 0 to 10, respectfully. For PFAS where tissue concentrations were difficult to distinguish from background, a Levenberg-Marquart algorithm (R function `nlsLM()`) was used (Elzhov et al. 2023). Bounds for K_{01} and *Vd* were also expanded to 0 to 2 and 0 to 100 in these cases. Note that the Levenberg-Marquart algorithm is robust in difficult to estimate parameter situations, like the cases we identified where peak concentrations were difficult to differentiate from background. Parameter estimate variability was quantified using bootstrap methods (Baty et al. 2015). Residuals are resampled 999 times and least-square estimates of parameters are used to provide confidence intervals of definitive parameters estimates. Bootstrapping incorporates some of the non-parametric characteristics of the observed data and does not assume parametric/Gaussian distributions, so is a more robust route to representing variability in parameter estimates.

The third stage of parameter estimation was to explore elimination rates in the nonlinear approach. Accordingly, a second round of fitting Eq. 1 was performed with the uptake rate set at the value identified in the first round of fitting Eq. 1. The elimination rate (K_{10}) and *Vd* were estimated using the `nls()` or `nlsLM()` function as needed to reach stable parameter estimates. These parameter estimates' variability is represented by the same bootstrap procedure as above to provide confidence intervals around estimates.

Trophic transfer coefficients (TTCs)

Utilizing laboratory data to speak to trophic transfer requires ensuring careful handling of time or clear understanding of dynamic equilibrium/steady state concentrations and fluxes. Presumably, field data are representative of dynamic equilibrium/steady state. Laboratory data are generally known to either be in a steady state or not. In these data, as PFAS were observed in both of these states at day 28, static representations of biomagnification (C_{rabbit}/C_{diet}) per-PFAS from these data would be inaccurate representations of field trophic transfer observations.

A kinetic approach was utilized to account for both time and internal kinetics (i.e. *Vd*) using the uptake and elimination rates. In short, *TTC=Uptake/Elimination*, where *Uptake* and *Elimination* represent parameters K_{01} and K_{10}. To ensure sufficient capture of observed variability (as a measure of uncertainty), bootstrap parameter estimate distributions were resampled (with replacement) 10,000 times to generate probabilistic estimates of TTCs. In situations where nonlinear fitting procedures produced low quality estimates the linear regression uptake and elimination rates were considered proxies. Generally, PFAS with indistinguishable concentrations from background levels produced poor parameter estimates and definitive TTCs from nonlinear model parameters are not reported.

Results

Three blocks of male and female rabbits were exposed to PFAS mixtures via diet for 28 days and then a clean diet for another 28 days (56 days on study overall). Samples of liver, kidney, and muscle were collected on days 0, 1, 7, 14, 28, 29, 35, 42, and 56. A control group of rabbits were fed a clean diet for the first 28 days of study and liver, kidney, and muscle tissues collected on day 0 and day 28. The diet was a combination of plants with timothy grass spiked to mirror concentrations observed in pilot studies (timothy grass grown in contaminated soil) and kale grown in soil spiked with PFAS at a uniform concentration (10 µg/kg) (Figure SI5.1, Figure SI5.2). A combination of toxicokinetic modeling approaches were evaluated to estimate definitive PFAS-specific uptake and elimination parameters (Figure SI5.4, Figure SI5.5, Figure SI5.7, Figure SI5.8). Uptake and elimination parameters support the derivation of kinetic trophic transfer coefficients that represent the potential movement of PFAS from diet to consumer (plants to rabbits in this case) and the integrated capacity of an organism to sorb PFAS.

In general, similar to the toads, PFAS dynamics in rabbit tissues are not outside the current understanding of PFAS kinetics (Figure 5.1, Figure 5.2). Some have fast dynamics (PFHxS, PFOA), and some have slow dynamics that indicate potential for trophic magnification (PFOS). A variety show limited dynamics or background concentrations that are seldom above reporting limits (e.g., PFHxA, PFOSA). A significant observation that does not follow the expected pattern is that of 8:2 FTS. The rabbit tissues appear to eliminate 8:2 FTS slowly, which deviates from the observations in toads and other mammals. In Narizzano et al. (2021) and East et al. (2024), *Peromyscus* spp. serum concentrations dropped during dosing with 6:2 FTS, implying elimination rates substantially higher than uptake rates. The patterns in kinetics are clear when observed in tissue-specific concentrations and estimated whole organism concentrations (Figure 5.1, Figure 5.2) and in rabbit-specific PFAS to PFAS correlations (Figure SI5.3).

Within rabbits, the tissue-to-tissue relationships are less parallel than in toads. Muscle tissues and specific PFAS appear to be driving the change (Figure 5.1). Note that kidney and liver are regularly parallel in PFAS dynamics with kidney at higher concentrations. PFOSA shows equivalent kidney and liver concentrations, but is also the lowest PFAS in the diet. In cases with clear dynamics, PFAS muscle concentrations are generally 100-fold below the liver and kidney which are approximately 10- to 3-fold from each other. The PFAS with unclear dynamics (e.g., PFBA, PFBS, PFHpA, PFPeA, PFHxA), generally have unclear relationships between tissues, but when kidney dynamics are present (PFBA and PFHpA) and given the proximity to reporting limits and unclear dynamics, it is difficult to infer further.

To date, a physiologically-based differential equation based uptake and elimination multi-tissue model has not been constructed, but given observed high predictive power in the ‘simpler’ modeling approaches following Tarazona et al. (2015, 2016) and in toads (East et al. 2025a) lends support for simpler approaches being effective in rabbits as well.

Uptake and elimination parameters from toxicokinetic models were derived via bootstrap methods and accordingly provide non-parametric estimates and confidence intervals. For brevity, kidney, liver, muscle, and estimated whole organism concentrations are presented for contrasting PFAS (PFOS, 8:2 FTS, and PFOA) in the Appendix (Figure SI5.6, Figure SI5.7, Figure SI5.8).

Estimated whole or 'combined' organism concentration kinetic uptake and elimination rates generate a trophic transfer coefficient (Figure 5.3) that does not appear to be related to diet concentration. This is different than the toads that show an untested potential tie to diet concentration. The likelihood for PFOS to magnify in a plant to mammal system is low; PFOA is likely to transfer (equivalent uptake and elimination when Vd adjusted), PFHxS likely to dilute across this trophic step, and 8:2 FTS and PFHpS likely to magnify. The omission of PFHpS from the linear analysis is based on a negative parameter estimate (Figure 5.4, Figure SI5.4). Boundary conditions or extreme parameters do remain a limitation of this method to infer likelihood of trophic magnification on the basis of kinetics. However, the simpler interpretation of "PFHpS is not eliminated" would inherently imply that potential for trophic magnification and quantification of a trophic transfer parameter estimate is method-dependent.

When looking at the estimated whole organism uptake and elimination rates individually (Figure 5.4, Figure 5.5), the core observation is that this plant to mammal system is different from the observations in the invertebrate to amphibian system above. In rabbits, uptake rates appear to vary rather than being extremely similar. While there are overlapping confidence intervals, the medians span approximately 2.5 to 10% (Figure 5.5, see also Figure SI5.10 for upper extreme bounds of PFHpS and 8:2 FTS) with no clear dependence on diet concentration or PFAS. It is noted that outside of PFOSA, the PFAS that are towards the lower end of the diet concentrations are those that have clear uptake; PFBA, PFPeA, PFBS, and PFHxA are not sufficient to estimate nonlinear parameters. That being said, elimination rates are still likely the differentiating factor across PFAS (Figure 5.4). There is a clear clustering between those that have high elimination rates (PFHxS and PFOA) and those that have lower elimination rates (PFOS, 8:2 FTS, and PFHpS).

In conclusion, kinetics of PFAS in mammals eating an affected diet suggest that 8:2 FTS and PFHpS are likely to magnify while PFOS and PFOA will at least transfer in this trophic step from plants to rabbits. There is substantial variability around PFOS, the central estimate appears likely to magnify, but some study blocks did eliminate. The PFHxS appears to dilute, and all others show either weak transfer or were unable to be distinguished from background. Importantly, for PFAS like PFOS and PFOA, their plant specific uptake is lower than other shorter chain PFAS, so there is a potential signal of trophic magnification in that with increase in trophic level, there is increase in binding affinity (Fremlin et al. 2023). Studies in higher trophic levels (i.e., predators of rabbits or amphibians) would inform this observation that cannot be resolved with a single trophic step (two biotic levels).

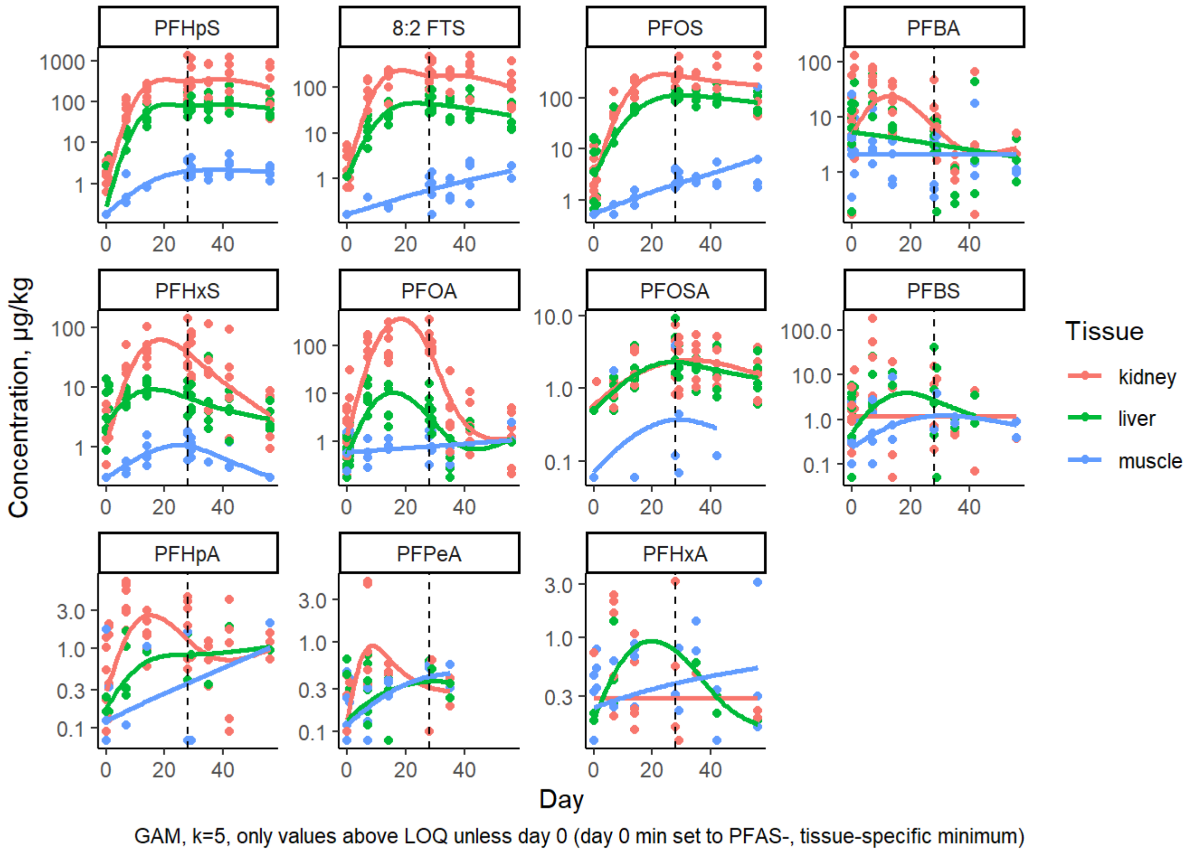


Figure 5.1. PFAS- and tissue-specific concentrations in rabbits through time for all PFAS with detections. Colors represent specific tissues, dots represent individual rabbit concentrations, solid lines are generalized additive models (using the {mgcv} package (Wood 2017)) fit with common knot number and thin-plate smoother, and dashed line indicates the change from spiked diet (days prior to 28) to clean diet (days 28 and after). Samples collected on day 28 represent the end of uptake and beginning of elimination period. Panels are sorted by median overall concentration from highest to lowest in row-wise fashion (top left is highest, bottom right is lowest). Note log-scaled y-axis. Group 1 and female animal 61 are excluded from the PFOS data.

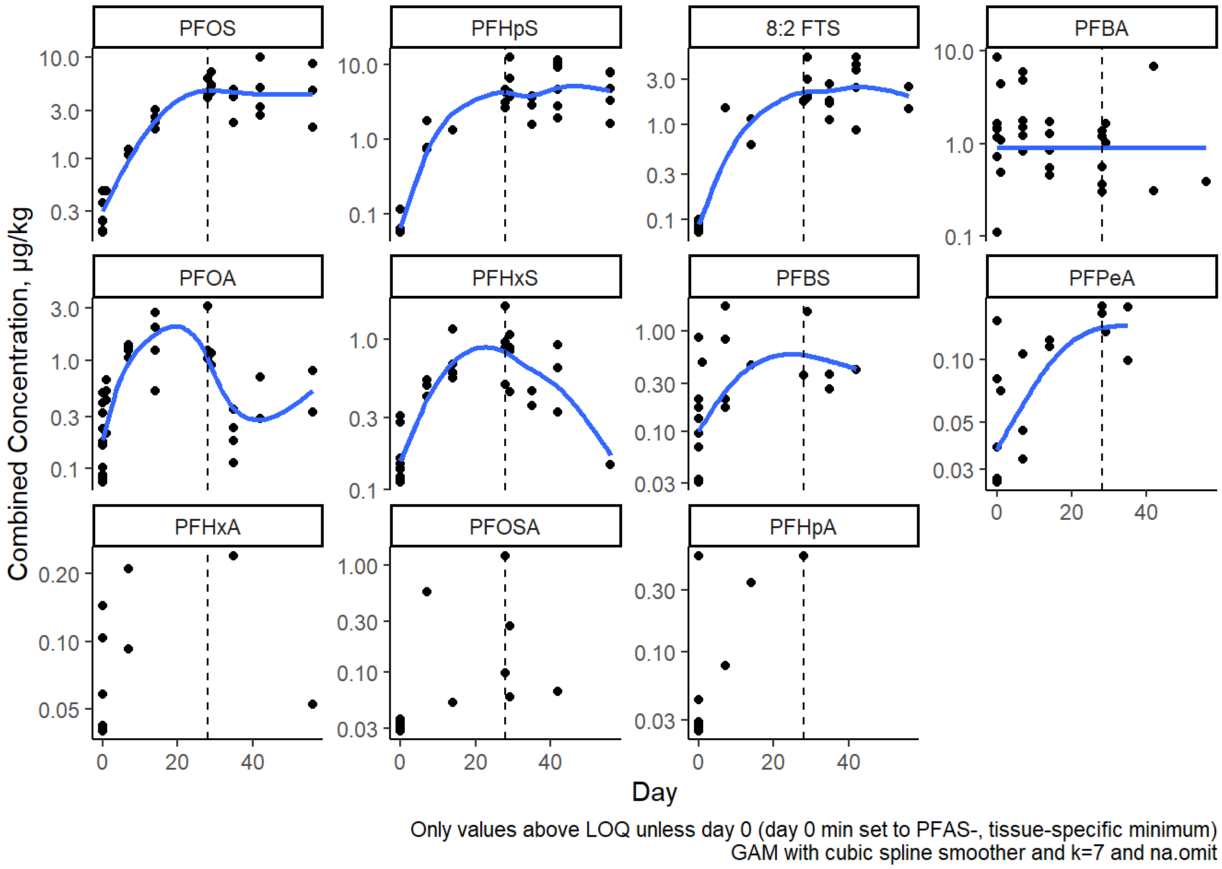


Figure 5.2. Combined concentrations of PFAS through time fit with generalized additive models. Only in cases where an individual rabbit had a detection for all three tissues was a combined estimate generated. Panels are sorted by median overall concentration from highest to lowest in row-wise fashion (top left is highest, bottom right is lowest). Note log-scaled y-axis. Group 1 and female animal 61 are excluded from the PFOS data.

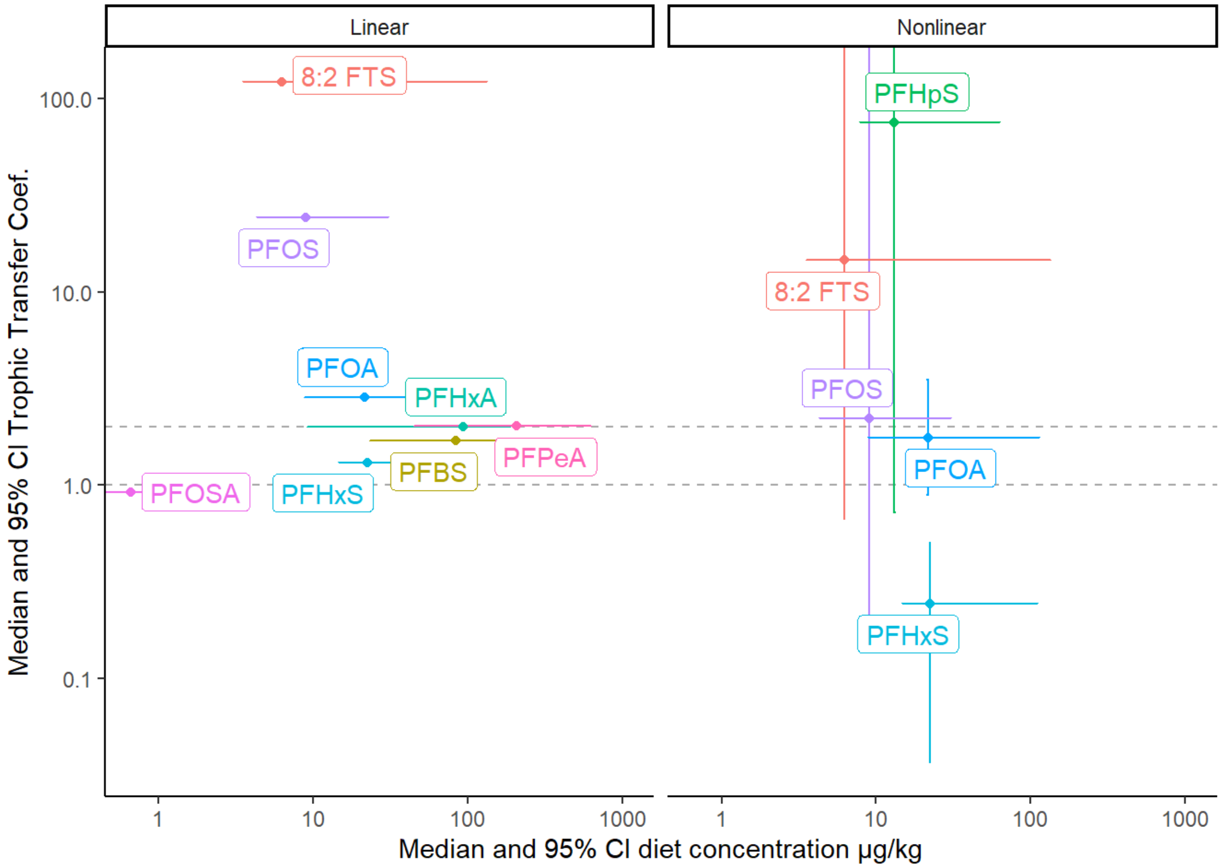


Figure 5.3. Trophic transfer coefficients of rabbits exposed via diet. Intersection (point) of error bars is median trophic transfer coefficient and diet concentration, extremes of error bars are 97.5th and 2.5th percentiles. Linear model elimination rate variation not shown for brevity (not definitive). Horizontal dashed lines at 1.0 and 2.0 indicate areas where uptake and elimination are equivalent (uptake/elimination =1) and where uptake is two-fold higher than elimination and individual bioaccumulation is likely (uptake/elimination >2). Note log-scaled y-axis (utility of transfer coefficient is multiplicative so distance away from 1 on log scale indicates equivalence (0.3 and 3 are equal multiplicative distances from 1).

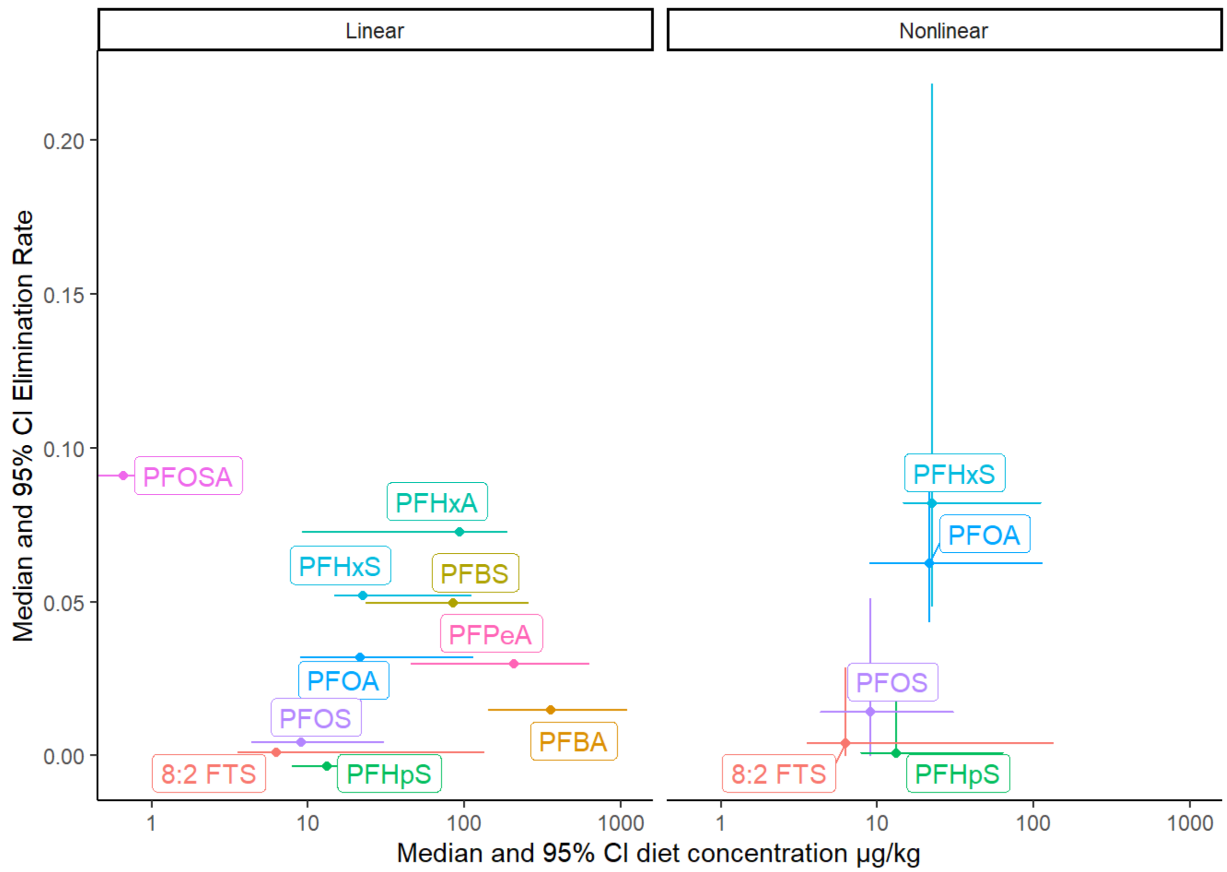


Figure 5.4. Elimination rate parameters for rabbits exposed via diet. Intersection (point) of error bars is median elimination rate and earthworm concentration, extremes of error bars are 97.5th and 2.5th percentiles. Linear model elimination rate variation not shown for brevity (not definitive).

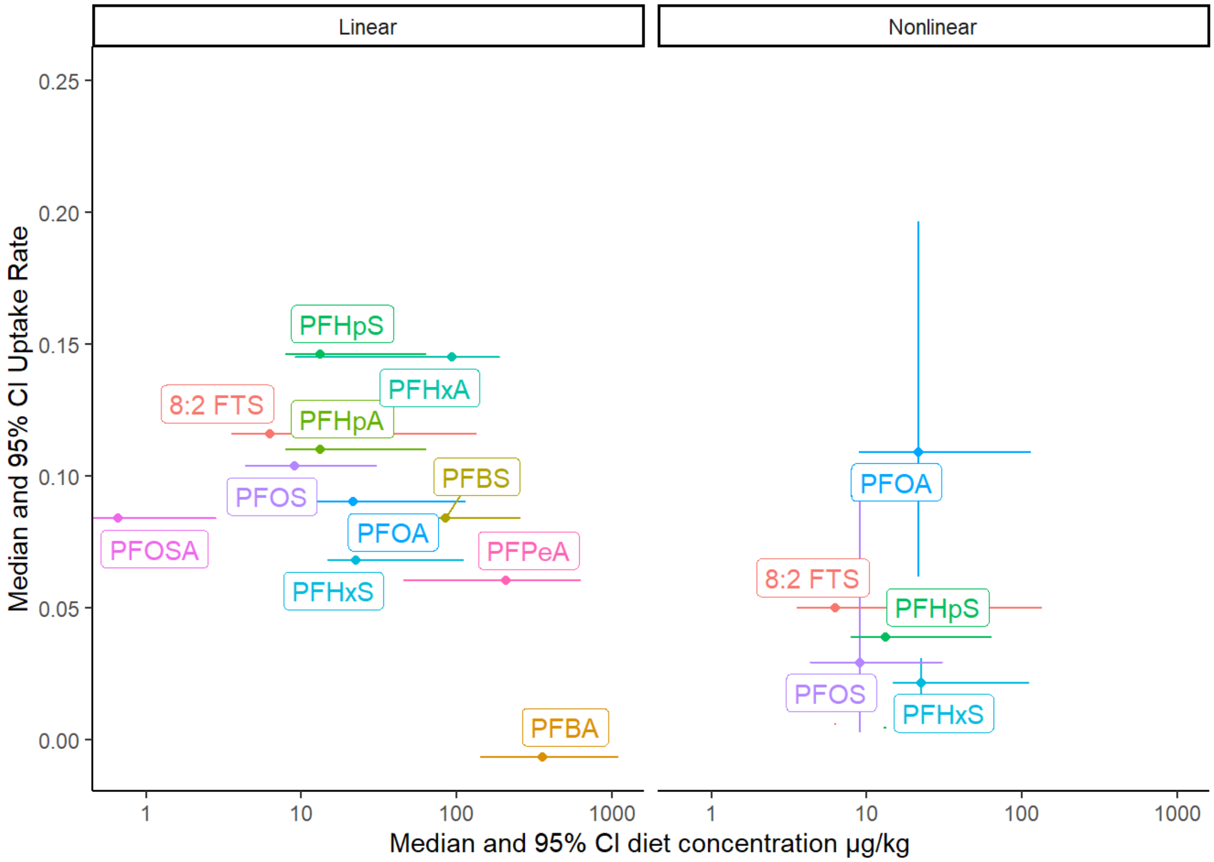


Figure 5.5. Uptake rate parameters for rabbits exposed via diet. Intersection (point) of error bars is median uptake rate and earthworm concentration, extremes of error bars are 97.5th and 2.5th percentiles. Linear model elimination rate variation (vertical error bars) not shown for brevity (not definitive).

Discussion

Rabbits were fed a diet of plants (kale and timothy grass) that contained PFAS (via direct uptake (kale) or spiked (timothy grass)) for 28 days and then control plants for 28 days. Kidney, liver, and muscle samples were collected throughout the uptake and elimination periods and PFAS quantified. An estimate of whole animal PFAS was calculated. This whole animal PFAS through time trajectory was fit with a nonlinear model to generate uptake and elimination parameters. These uptake and elimination parameters were used to estimate PFAS-specific trophic transfer coefficients (TTCs) that can be used to screen PFAS potential for trophic magnification. The downstream interpretation of TTCs in this mixture exposure will aid ecological risk assessors that have need of terrestrial vertebrate exposure estimate model transfer factors in addition to prioritization schemes to efficiently approach PFAS remediation at sites.

In the present studies, increased uptake of the lower molecular weight (MW) PFCAs such as PFBA, PFPeA, PFHxA, and PFHpA were concentrated more highly in plants than were the higher MW compounds. However, with the exception of PFBA, higher MW PFCAs correlated with higher concentrations in rabbit tissues. The greatest TTC from rabbit diet to kidneys and liver in rabbits was for PFAS with the longest chain lengths; five PFAS compounds had a TTC of >2. In muscle tissue, PFAS detections were sparse, and available TTCs were <0.17. Previous studies suggest the potential to transfer PFAS across trophic levels and possibly to biomagnify in terrestrial food webs (Conder et al. 2008; Zhao et al. 2016; McCarthy et al. 2017). Accumulation into biota was related to the length of the carbon–fluorine chain and functional groups. The PFSAs (e.g., PFOS) exhibited more bioaccumulation than PFCAs (e.g., PFOA), and PFAS with chains less than eight perfluorinated carbons were bioaccumulative at levels below some regulatory toxicity criteria (Conder et al. 2008). The results of the present studies agree with results from previous studies showing increased uptake of lower MW PFAS compounds in plants and increased uptake of higher MW PFAS compounds in mammals (Conder et al. 2008; Zhao et al. 2016; McCarthy et al. 2017). However, our studies have shown that the magnitude of TTC in rabbits depended on the individual PFAS compounds and was not correlated with the magnitude of BCF in rabbit food. The implication is that accounting for kinetics may influence the understanding of potential for trophic transfer.

Compared to field studies of multiple PFAS movement into food webs, the lack of observed relationship between molecular descriptors and TTCs may be corroborated. While the smallest and largest PFAS reported tend to have the smallest/lowest TMF values, the central carbon-chain length PFAS appear to have relatively stable TMFs (Müller et al. 2011; Huang et al. 2022; Fremlin et al. 2023; Heimstad et al. 2024). Importantly, generally, these TMFs are above 1 and suggest that PFAS tend to magnify in higher trophic levels. This observation is made using both classic definitions of TMF (increase in tissue concentrations with increase in trophic level) and chemical activity approaches (increase in concentration/solubility with increase in trophic level (Müller et al. 2011; Huang et al. 2022; Fremlin et al. 2023; Heimstad et al. 2024). Considering the simplified interpretation of TMF as an average of stepwise transfer factors (i.e. BSAF/BCF, BAF, BMF) (Burkhard et al. 2012), the expectation would be that either most stepwise transfer factors are >1 or some are very high, skewing the distribution >1. As field studies appear to indicate consistent levels of trophic magnification, our inconsistent observations of high TTCs (as one stepwise transfer) would indicate that some other feature of animal behavior in the field, not captured in our laboratory studies, is influential. Wildlife exposure models often account for animal mobility, age, varied diet, seasonality, home range, etc. in an attempt to capture these features (Sample et al. 2024).

Laboratory evaluation of specific movement of PFAS from soil through plants to plant consumers is only available with terrestrial invertebrates. McDermett et al. (2022) exposed plants and crickets to PFAS via a mimicked food web in the laboratory. A uniform mixture of seven PFAS was made in water, this water was then used to irrigate plants. The plants were then fed to crickets. Plant uptake (6-week BCF) decreases from 44 to 5 as molecular weight increases in the carboxylates (C4, C6, C7, C8, C9 PFCAs) and then is 1 for precursor PFOSA (C8 perfluorosulfonamide), and 2 for PFOS (C8 PFSA) (McDermett et al. 2022). Significantly, plant to cricket BAFs decrease drastically to less than 1 for all PFAS. Further, the pattern of relationship between transfer factor and molecular weight reverses with the larger molecules having higher cricket to plant ratios. PFOS has the highest single plant to cricket BCF at 0.11. A note from the study design is that when crickets are exposed to PFAS via water alone, BCFs are higher than for the plants—for instance, PFOS is 0.5 in cricket to water ratio. Judy et al. (2022) spiked hydroponic media with 7 PFAS (3 PFSAs and 4 PFCAs, C4 to C10 C-chain lengths), grew tomatoes in that media, and then fed contaminated tomato leaves to tobacco hornworm caterpillars in a uptake and elimination period (toxicokinetic) study design. In the tomato leaves, they observed a pattern reverse of prior studies in that larger PFAS appeared in higher concentrations than smaller PFAS with PFOS (representative large PFSA) having the highest concentration in the tomato leaves (and subsequently highest BCF). The BCF values would be in the same range as observed in McDermett et al. (2022). but just in reverse order against C-chain length. The authors attribute this to the soil-less exposure environment. Tomato leaves were freeze-dried and compressed to provide a controlled diet to the hornworms. In order to detect all PFAS above method detection limit, the hornworms exposed for 7 days are the main study group analyzed. Only PFOS has a BMF (hornworm concentration/leaf concentration) above 0.05, with a maximum of approximately 0.15. In short, given the lack of direct comparison to terrestrial invertebrates and rabbits, the takeaway message appears to be that PFAS may be trophic diluters into plants. Accordingly, field studies with higher trophic level organisms with TMFs >1 are likely based on (1) PFAS in soil vs water and (2) terrestrial vertebrates vs terrestrial invertebrates.

An uncertainty in the rabbit exposures, that would be observed in the field, is related to uncontrolled exposure via cecotrophy/coprophagy. Rabbits, per animal care protocols, were allowed to perform this behavior, so it is plausible (albeit not measured) that some PFAS excreted in feces would be consumed (Sokolowski et al. 2024). Given the unanticipated slow elimination of PFHpS and 8:2 FTS (unanticipated because of the observations in East et al. (2025a)), a hypothesized 'recycling' of PFAS could be occurring. This would be analogous to the PFOA and membrane transporters in humans and rats, where the variable affinity and directionality across various membrane transporters for PFOA (among other PFAS) exhibit variation driven by a host of factors across organisms and individuals, and are all influential processes contributing to the 'high variability' considered a problem in evaluating PFAS risk (Lin et al. 2023). In this case, it remains unknown if rabbits could maintain a steady state/dynamic equilibrium dose during the elimination phase and maintain a steady PFAS level in their tissues.

In conclusion, accumulation of PFAS into rabbit tissues via a diet that contains PFAS per the accumulation of PFAS into plants indicates that some PFAS, such as PFOS, 8:2 FTS, and PFHpS are have potential to magnify in this trophic step. Other PFAS such as PFOA and PFHxS appear likely to be trophic diluters or ~1:1 transfer. In rabbits, while there are clusters, uptake rate and elimination rate appear to have influence on TTCs. There are not clear patterns of uptake, elimination, or TTC on dietary concentration. As PFAS appear to move into plants in a C-chain-length dependent fashion, it is likely that different mechanisms are predictive of PFAS accumulation into rabbits. The expectation of PFAS-profile as it moves from soil to plant to terrestrial vertebrate is that it appears to move towards PFOS. This corroboration of laboratory and field observations (at the least specific to PFOS) lends support to the concept that a stepwise trophic transfer factor determined as a ratio of kinetics model uptake and elimination rate is informative to the potential for trophic magnification.

Chapter 6: Conclusions

At large, this work intends to advance the understanding of PFAS exposure to support ecological risk assessments of terrestrial organisms. In a more detailed sense, the estimation of PFAS mixture exposure to terrestrial vertebrates at military sites has been identified as a data gap and this dissertation aims to fill some portions of it. The specific approach is based on identification of a priority PFAS mixture relevant to AFFF-impacted surface soil on U.S. military lands (Chapter 2), exploration of the relationship between PFAS mixtures and tissues in mammals (Chapter 3), evaluation of kinetics of dietary PFAS mixture exposure in a relevant amphibian (Chapter 4), and evaluation of kinetics of dietary PFAS mixture exposure in a relevant mammal (Chapter 5).

Identification of a representative and prioritized mixture of PFAS in surface soil on DoD sites is a key component to efficiently addressing the magnitude of potential cleanup actions (Department of Defense 2024). This effort identifies that the bulk of PFAS mass in a sample (>90%), on average, is from three PFAS. The most common dominant PFAS in these mixtures is the eight carbon perfluorosulfonic acid, PFOS. PFOS is so dominant in samples taken from sites within DoD installations that the 3rd most common 'mixture' is PFOS detected alone. Other PFAS that contribute to the top four mixtures (by prevalence) include PFHxS (C6 PFSA), PFOA (C8 (7 fluorinated carbons) PFCA), PFHxA (C6 PFCA), and PFOSA (C8 perfluorosulfonamide). Other relevant PFAS such as the fluorotelomer sulfonates (FTS) were observed in top ten mixtures by prevalence and are considered priority for increased sampling due to their high concentrations. The dominance of 'terminal' PFAS such as PFOS is attributed to the long history of AFFF use at these sites when PFOS was an ingredient in AFFF and the potential transformation of fluorotelomers and fluorosulfonamides in fate and transport processes that have occurred over space and time between release and sampling. Of note, this prioritization to inform ecotoxicological study and ecological risk assessment is largely informative of problem formulation and conceptual models as measured receptor exposure would largely drive any specific risk assessment.

While this representative list generates a priority list of PFAS of importance for testing and risk assessment, there are opportunities to advance the effort. One known challenge in the effort to focus risk assessment efforts across mixtures is balancing exposure data with effect data. We discuss in Chapter 2 above some simplified comparisons of toxicological thresholds across PFAS and the premise that a given PFAS may need to be X-fold more toxic in order to be of equivalent risk given the Y-fold difference between PFAS concentrations in the mixture. This approach is highly simplified. A simple improvement would be using a food web model to connect environmental media to receptor diet concentrations using PFAS-specific transfer parameters (Larson et al. 2018; Zodrow et al. 2021). However, given some of the interest in more "mechanistic" approaches (Fremlin et al. 2023), a substantial amount of data would be required to extend this approach to the swath of taxa that may be of interest on terrestrial sites and meet high causal standards. One approach to explore exposure estimates that is more quantitative in nature, would be a sensitivity analysis. Consider the scope of biota-soil accumulation factors (BSAFs) that have been estimated across a range of PFAS (Burkhard and Votava 2023) and the scope of soil concentrations we report in Chapter 2. With a simple multiplicative transfer factor, the ~6 orders of magnitude of soil concentrations across sites would be multiplied by one of ~5 orders of magnitude of BSAF values. Accordingly, concentrations of PFAS with high BSAF values in worms at low soil concentration sites may easily overlap concentrations of PFAS with low BSAF values in worms at high soil concentrations, and any number of arrangements in between. It would be valuable to refine this approach via sensitivity analysis of a simulated food web and put bounds on the extremes of exposure estimates and better integrate the exposure observations with toxicity test results. The concern is that variation in risk may be driven more by variation in exposure than variation in toxicological effects.

To demonstrate the use of the priority PFAS identified in Chapter 2, mice were exposed to individual and mixtures of PFAS that were observed in surface soil samples and in surface water samples (Chapter 3). Mixtures included the C6-8 PFSAs and PFCAs (PFOS, PFHxS, PFOA, and PFHxA) and an FTS mixture with PFOS, 6:2 and 8:2 FTS. Quantification in whole mice, serum, liver, kidneys, and brain were related to dose (and concentrations in other tissues) in a dose additive manner. A hierarchical model demonstrates that there is a generic relationship between dose and tissue concentrations and only PFAS-specific variation in tissue affinity (y-intercept). Accordingly, an approachable statistical model can be used to estimate whole animal and specific tissue compartment concentrations for individual PFAS and ΣPFAS. Further, observations of increased liver weight and serum ALT were evaluated using a dose additive relative potency factor approach that indicates effects are likely dose additive in the C6-8 PFAS mixture at least. These models were applied to a hypothetical scenario where a reference site and an impacted site had 10-fold difference diet concentrations (i.e. dose). The subsequent tissue concentrations of individual PFAS at the high site may overlap with ΣPFAS at the low site and the liver weight increases potentially solicited have zero within their confidence intervals. This would indicate that the expectation to easily differentiate reference and impacted sites may be challenging. However, serum ALT increases at the expected liver weight increases are more likely to be detectable, which holds promise for nonlethal sampling on remedial investigation sites where mammals are receptors of interest.

While the methods used in Chapter 3 to demonstrate dose additivity exposure and effects imply a generalizable 'average' trend that applies across any number of PFAS, this should be interpreted with caution. The study was designed to capture a specific suite of PFAS and a specific length of exposure. Considering the known influence of kinetics and the variation across PFAS, it is reasonable to consider that PFAS or length of exposure outside the scope of the study may not follow similar trends. Importantly though, we do demonstrate that the tissue-specific affinity (y-intercept) is more variable than the influence of kinetics (among other factors) that influence the slope. This feature does support the idea that the trend of tissue by dose is generalizable across other PFAS; the actual prediction of tissue concentrations may not be however. Which suggests that the trend may actually function as a composite parameter for processes that lead to accumulation of PFAS in tissues. Compared to physiological-based pharmacokinetic (PBPK) approaches, the general understanding is that absorbance of PFAS from the stomach or gut into the blood stream is very high. One analysis of a PFOS PBPK model in mice, rats, monkeys, and humans utilized literature supported prior estimates > 1 for all stomach or gut to blood stream transfer factors (Chou and Lin 2019). Their posterior estimates are < 1, which supports our trend estimates for dose-based predictions (0.75 to 0.95). In the grand exercise of model parsimony, it seems as if we may have identified (again) that there is a balance to strike between simplicity and nuance. Our goal was to develop predictive models and explore additivity, but we have exposed a need to further our understanding of kinetics with some nuance if we intend to infer more broadly across PFAS.

Ecological receptors of interest to an ecological risk assessment are likely to be higher trophic level organisms. Accordingly, estimating their exposure is often through a food web model. To explore PFAS mixture trophic transfer commonly part of these food web models, the kinetics of a PFAS mixture in laboratory-held toads were utilized to provide quantitative estimates of the potential for trophic magnification. A leave-one-out-cross-validation exercise indicated that a nonlinear approach (one compartment, per tissue) had the best predictive performance and should be selected as the definitive toxicokinetic model. Probabilistic trophic transfer coefficients (TTCs) from the toxicokinetic model uptake and elimination parameters indicate that PFOS, PFUdA and PFDA are potential trophic magnifiers and 8:2 FTS and PFHpS are likely trophic diluters. There did not appear to be congener or dietary concentration trends, but we note the challenge with identifying such trends when the diet was determined by the worm-PFAS processes and are quite variable. Importantly, all PFAS with definitive TTCs have overlapping uptake rate confidence intervals while the elimination rates are clustered in 'high' and 'low' relatively. Accordingly, this is a signal of the importance of elimination in dietary accumulation of PFAS and subsequent exposure estimates via food web models. The extension of this idea in a risk assessment exposure estimate is that a mobile organism may have approximately equal intake of PFAS on arrival to a site with PFAS-laden diets, but have very unequal elimination on leaving that site and diet.

This effort to generalize the potential for trophic transfer through interpreting kinetic parameters could only be improved by longer exposures that do reach steady state, increased sampling of tissues (i.e. serum, macromolecule content), and subsequently building multiple types of models pointed at this scenario. The $\frac{C_{Organism}}{C_{Diet}}$ type of simplistic steady state model or a highly detailed PBPK or chemical activity model. The challenge in selecting between these approaches as one works across the scale of PFAS-wide assessment to a screening assessment to an actual site-specific assessment remains untested. Partially because different models are used at different parts of the scale. Comparing Zodrow et al. (2021) and Larson et al. (2018) to Kelly et al. (2024) and Sun et al. (2022) it is clear that one can build both a larger comparison across PFAS and a specific scenario prediction from methods that require substantially different amounts of data and have potentially substantially different takeaway messaging. Capturing animals and measuring their chemical content in a steady state approach is clearly a challenge, but quantifying the macromolecule content of broad swath of animals and parameterizing each PFAS' affinity for those macromolecules is likely an equal challenge even if one gains nuanced insight and can minimize animal capture in the field. Further, if we compare field data (Müller et al. 2011; Huang et al. 2022; Fremlin et al. 2023; Ecke et al. 2024; Ecke et al. 2025), it is important to note that many of the resultant TMFs are quite similar when using the chemical activity approach (Fremlin et al. 2023) or the $\frac{C_{Organism}}{C_{Diet}}$ approach (others). Most of the reported TMFs (or BMFs) are less than 10 but above 1 and approximately center around 5. Fremlin et al. (2023) specifically do this comparison in their work, and broadly, using a highly detailed physicochemically mechanistic approach will not return a meaningfully different prediction than a direct analytical chemistry measurement prediction. The inference is presumably then that, for the PFAS that have a potential for trophic magnification, one should move towards the simpler model. The assumption is that the direct chemical measures capture the affinity/chemical activity as a whole and we're simply observing that larger systems are collections of smaller systems. The core assumption in my work is that uptake and elimination rates would speak to the middle ground between a highly nuanced and a highly simplified approach. Importantly, this comparison of level of detail has not been performed with a single laboratory-based dataset.

Terrestrial mammalian ecological receptors may not necessarily be predators. Rabbits, for instance, consume plants and given the different mechanisms for plant accumulation compared to worms, are likely to experience a very different dietary exposure profile in PFAS mixtures than the toads described above. This was confirmed in pilot studies of plant accumulation, albeit with substantial overlap with some PFAS (e.g. PFOS) that are accumulated approximately equivalently in worms and plants. The kinetics of a PFAS mixture in rabbits was also used to generate uptake and elimination parameters to inform a trophic transfer coefficient (TTC). In rabbits, the observed trophic magnifiers were PFHpS, 8:2 FTS, and PFOS. PFOA is considered likely to transfer and PFHxS was likely a trophic diluter. The mismatch with PFHpS and 8:2 FTS in rabbits compared to toads is a critical observation. The dietary concentrations of these PFAS are not relatively high and there is no expected concentration dependence that is explanatory. On inspection of the uptake and elimination rates, there appear to be clusters in both the uptake and elimination rates (contrasting to just elimination in toads). While the mechanisms are unclear, there is concern about the coprophagy of rabbits and the 'recycling' of PFAS with high elimination rates. Given the persistence of PFAS, this recycling feature is a critical observation. The implication here for wildlife on the landscape is that they accumulate PFAS at varying rates on arrival to a PFAS-laden diet and eliminate at varying rates on emigration. Notably, the concern with coprophagy would lead to hypotheses of organism dependent movement of PFAS from a source zone to disparate sites (see Koch et al. (2020) reporting riparian organisms moving PFAS from aquatic systems to terrestrial systems).

The combination of behavioral, physiological, and ecological characteristics of specific receptors is challenging to encompass in risk assessment frameworks. There are approaches that have taken an individual-based approach to probabilistically account for movement (Wickwire et al. 2011). There are approaches that have taken an individual-based approach to probabilistically account for bioenergetics (Martin et al. 2013). There are approaches that are statistical in nature and focused on the spatial co-occurrence of stressors and receptors (Martin et al. 2018). There are approaches that aim for higher orders of biological organization (systems rather than populations or individuals) (Gredelj et al. 2018). But critically, even in approaches that attempt to capture cumulative representations of an organism's state (Pirotta et al. 2025), simplification remains influential. For instance, animal "health" is inherently non-specific or strictly a function of the modeled parameters (Pirotta et al. 2025) and subsequently inherently challenging to tie back to a mechanistic estimate of risk specific to a chemical exposure. Translating our observations of differences between rabbits and toads to a risk assessment would require both increasing the sub-organismal details to capture the movement of PFAS and increasing the meta-organismal details to capture behaviors, movements, the system that holds the organisms, etc. A model that fully integrates this level of detail and is workable with a variety of scenarios and scales of risk assessment is likely a model that exists in the future.

In closing, at large, it is expected that this work informs the understanding of PFAS movement through terrestrial food webs with lab-derived data that can answer specific hypotheses without the added noise of field data using approachable models and empirical observations. A major specific success of this work lies in identifying that PFAS of concern for their detection on sites, high relative affinity and potency, and overall kinetic characteristics are fewer in number than generally described. For instance, PFOS appears to be a driver of environmental media concentrations, tissue affinity and toxicity, and potential for trophic magnification across all the organisms and mixtures explored. Other PFAS that are near in their individual toxicity, PFOA for instance, do not appear in environmental media in comparable prevalence nor concentration and do not appear to have similar potential for trophic magnification given kinetics. In short, broadly, ecological risk of PFOS is likely greater than PFOA under the assumptions of this work. A specific area that could improve this work lies in increased resolution of the PFAS analyte list and both sub-organismal and meta-organismal processes. Increasing the analyte list would allow for capturing potential unexplored details in potential transformations (Evich et al. 2022) and ultra-short transformation products such as TFA (Arp et al. 2024). Increased resolution of sub-organismal data may inform active transport processes (Lin et al. 2023), and increased resolution of meta-organismal data may better translate this work to the ecological features of ecological risk assessments (see the most recent addition to the decadal history of describing challenges at the core of ecotoxicology as a science by McCarty (2025)).

Appendices

Chapter 2: Supplementary Information

Table SI2.1. Table of acronyms for PFAS in EPA Method 1633.

Perfluoroalkyl carboxylates	
PFBA	Perfluorobutanoic acid (PFBA, Perfluorobutanoate)
PFPeA	Perfluoropentanoic acid (PFPeA, Perfluoropentanoate)
PFHxA	Perfluorohexanoic acid (PFHxA, Perfluorohexanoate)
PFHpA	Perfluoroheptanoic acid (PFHpA, Perfluoroheptanoate)
PFOA	Perfluorooctanoic acid (PFOA, Perfluorooctanoate)
PFNA	Perfluorononanoic acid (PFNA, Perfluorononanoate)
PFDA	Perfluorodecanoic acid (PFDA, Perfluorodecanoate)
PFUnA	Perfluoroundecanoic acid (PFUnA, Perfluoroundecanoate)
PFDoA	Perfluorododecanoic acid (PFDoA, Perfluorododecanoate)
PFTrDA	Perfluorotridecanoic acid (PFTrDA, Perfluorotridecanoate)
PFTeDA	Perfluorotetradecanoic acid (PFTeDA, Perfluorotetradecanoate)
Perfluoroalkyl sulfonates	
PFBS	Perfluorobutanesulfonic acid (PFBS, Perfluorobutanesulfonate)
PFPeS	Perfluoropentanesulfonic acid (PFPeS, Perfluoropentanesulfonate)
PFHxS	Perfluorohexanesulfonic acid (PFHxS, Perfluorohexanesulfonate)
PFHpS	Perfluoroheptanesulfonic acid (PFHpS, Perfluoroheptanesulfonate)
PFOS	Perfluorooctanesulfonic acid (PFOS, Perfluorooctanesulfonate)
PFNS	Perfluorononanesulfonic acid (PFNS, Perfluorononanesulfonate)
PFDS	Perfluorodecanesulfonic acid (PFDS, Perfluorodecanesulfonate)
PFDoS	Perfluorododecanesulfonic acid (PFDoS, Perfluorododecanesulfonate)
Fluorotelomer sulfonates	
4:2 FTS	1H, 1H, 2H, 2H-perfluorohexane sulfonic acid (4:2 FTS, 1H, 1H, 2H, 2H-perfluorohexane sulfonate)
6:2 FTS	1H, 1H, 2H, 2H-perfluorooctane sulfonic acid (6:2 FTS, 1H, 1H, 2H, 2H-perfluorooctane sulfonate)
8:2 FTS	1H, 1H, 2H, 2H-perfluorodecane sulfonic acid (8:2 FTS, 1H, 1H, 2H, 2H-perfluorodecane sulfonate)
Fluorotelomer carboxylates	
3:3 FTCA	2H, 2H, 3H, 3H-perfluorohexanoic acid (3:3 FTCA, 2H, 2H, 3H, 3H-perfluorohexanoate)
5:3 FTCA	2H, 2H, 3H, 3H-perfluorooctanoic acid (5:3 FTCA, 2H, 2H, 3H, 3H-perfluorooctanoate)
7:3 FTCA	2H, 2H, 3H, 3H-perfluorodecanoic acid (7:3 FTCA, 2H, 2H, 3H, 3H-perfluorodecanoate)
Perfluorooctane sulfonamides	
PFOSA	Perfluorooctanesulfonamide (PFOSA or FOSA)
NMeFOSA	N-Methylperfluorooctanesulfonamide (NMeFOSA)
NEtFOSA	N-Ethylperfluorooctanesulfonamide (NEtFOSA)
Perfluorooctane sulfonamidoacetic acids	
NMeFOSAA	N-Methylperfluoro-1-octanesulfonamidoacetic acid (NMeFOSAA, N-Methylperfluoro-1-octanesulfonamidoacetate)
NEtFOSAA	N-Ethylperfluoro-1-octanesulfonamidoacetic acid (NEtFOSAA, N-Ethylperfluoro-1-octanesulfonamidoacetate)
Perfluorooctane sulfonamidoethanols	
NMeFOSE	N-Methylperfluoro-1-octanesulfonamidoethanol (NMeFOSE)
NEtFOSE	N-Ethylperfluoro-1-octanesulfonamidoethanol (NEtFOSE)
Ether carboxylates	
HFPO-DA	2,3,3,3-Tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)propionic acid (HFPO-DA, 2,3,3,3-Tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)propionoate)
ADONA	Decafluoro-3H-4,8-dioxanonoate (ADONA, DONA, Decafluoro-3H-4,8-dioxanonoic acid)
NFDHA	Perfluoro-3,6-dioxaheptanoate (NFDHA, Perfluoro-3,6-dioxaheptanoic acid)
PFMPA	Perfluoro-3-methoxypropanoate (PFMPA, Perfluoro-3-methoxypropanoic acid)
PFMBA	Perfluoro-4-methoxybutanoate (PFMBA, Perfluoro-4-methoxybutanoic acid)
Ether sulfonates	
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS, 9-chlorohexadecafluoro-3-oxanonane-1-sulfonate)
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS, 11-chloroeicosafluoro-3-oxaundecane-1-sulfonate)
PFEESA	Perfluoro(2-ethoxyethane)sulfonic acid (PFEESA, Perfluoro(2-ethoxyethane)sulfonate)

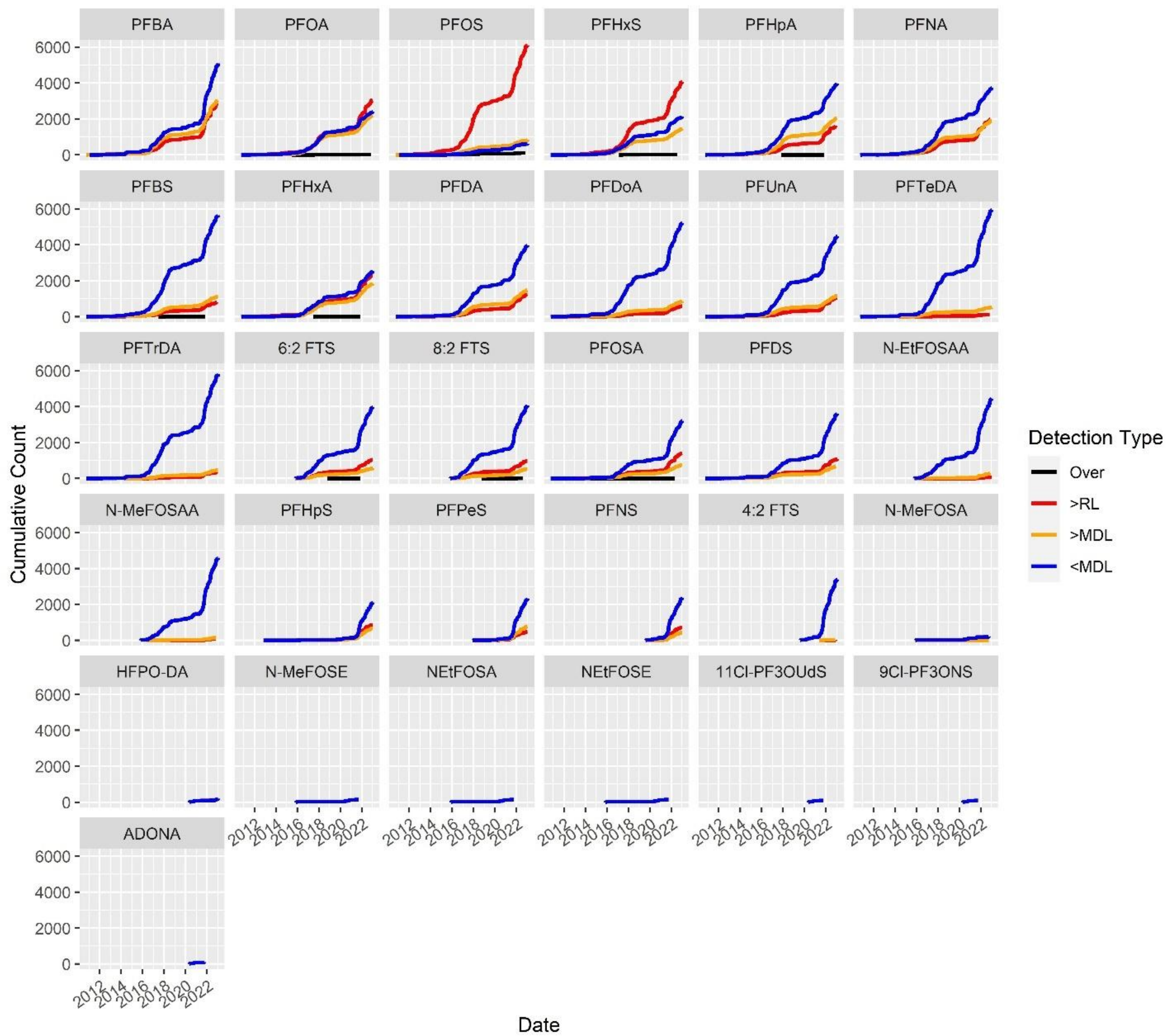


Figure SI2.1 The influence of time on number of samples and detection types in order of total magnitude by PFAS.

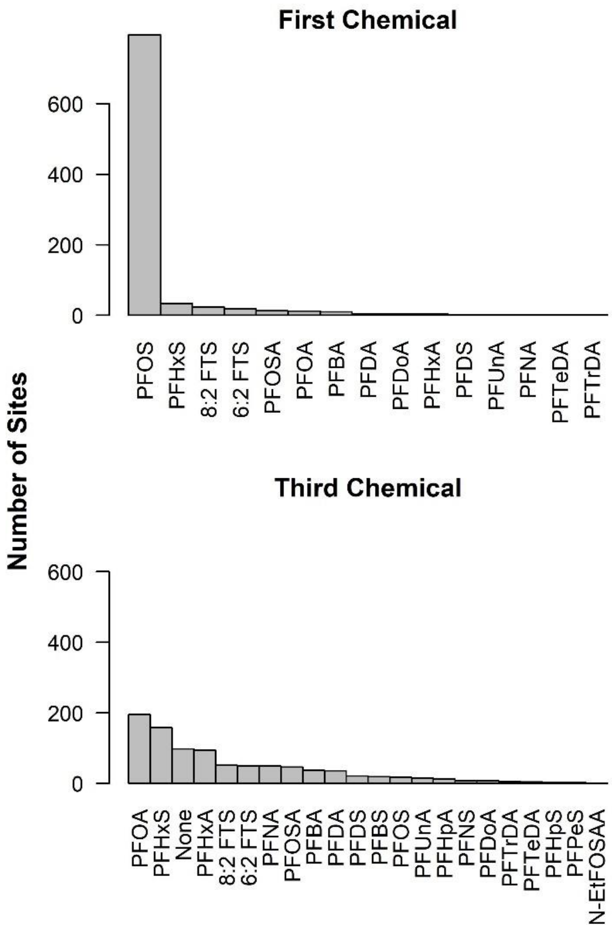


Figure SI2.2. The number of sample sites for which a given PFAS was measured as the highest concentration PFAS through the fourth highest ("Fourth Chemical") in surface soil samples. 'None' indicates that number of PFAS in sample was less than two, three, or four. Note the prevalence of 'None' indicating that many sites did not have complicated mixtures of PFAS. See also the dominance of PFOS as the most common maximum concentration PFAS.

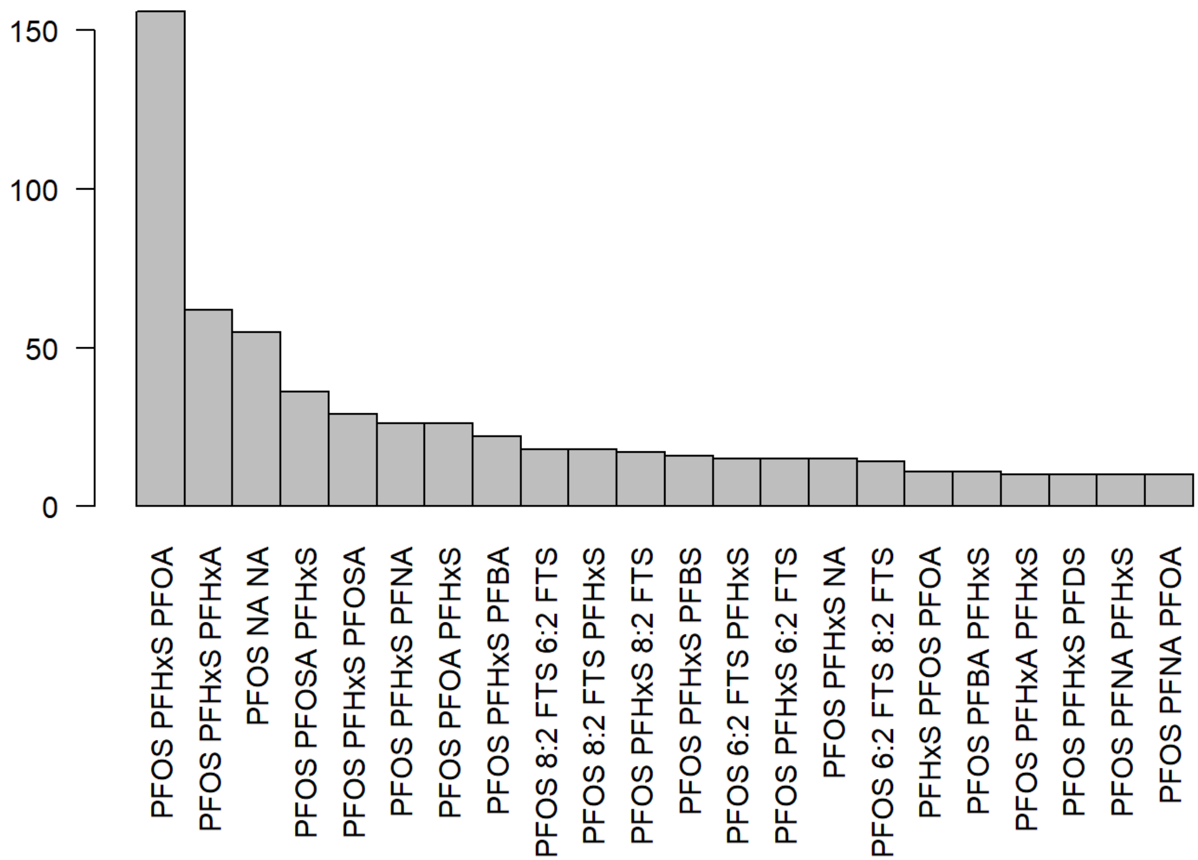


Figure SI2.3. The number of sites with each 3-PFAS combination in descending order. Combinations with less than 10 observations are trimmed for brevity. PFAS in label are listed in order of contribution to sum (i.e. PFOS, PFHxS, PFOA is rank 1, 2, 3) with any number of other PFAS contributing smaller amounts. ‘NA’ indicates less than three PFAS in a given 3-PFAS mixture.

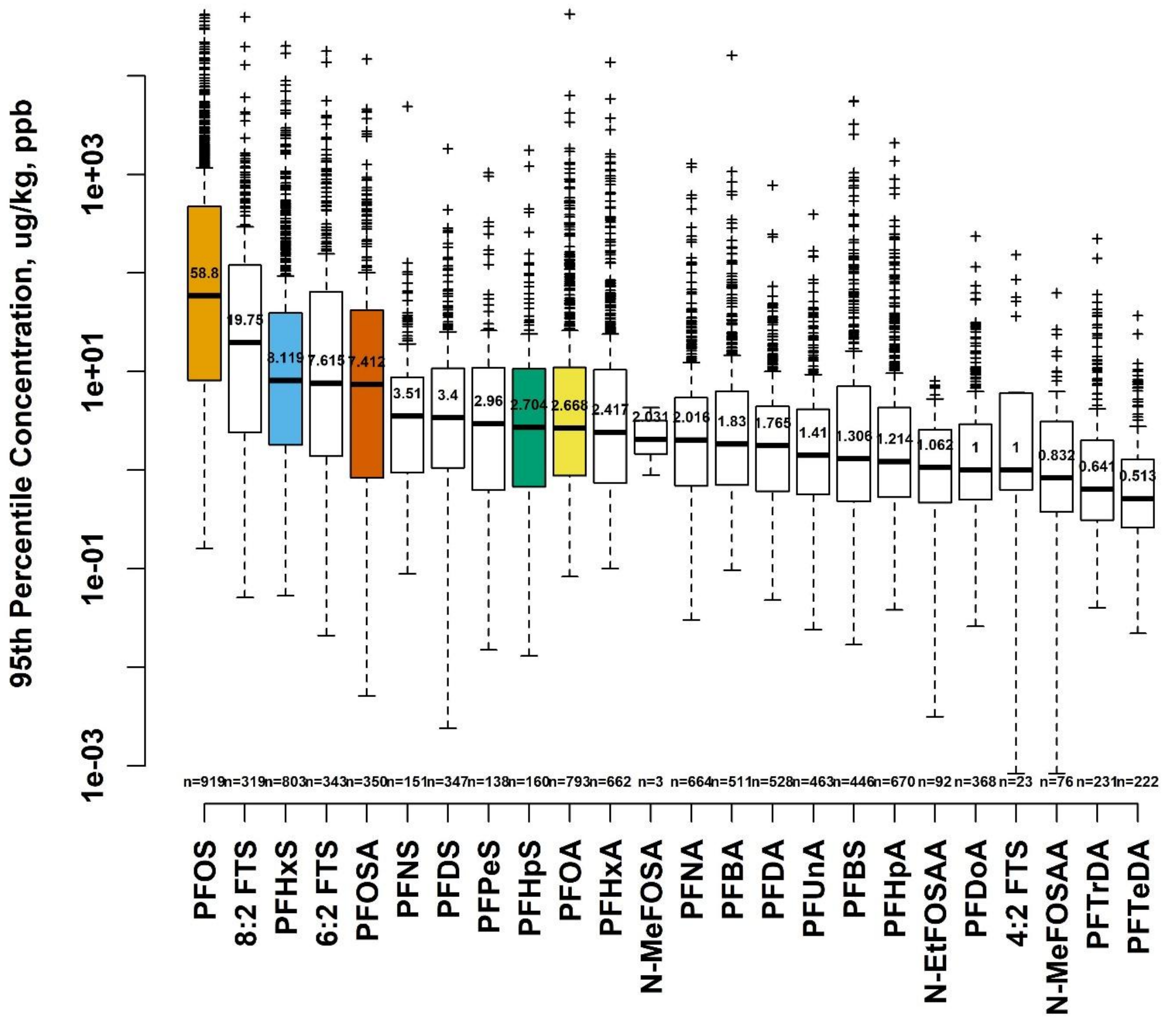


Figure SI2.4. Site-specific 95th percentile concentrations in surface soil (ppb), ranked high to low, for each PFAS. Colors correspond to Figure 4 in the main text, indicating high prevalence in common mixtures and confidence in sampling.

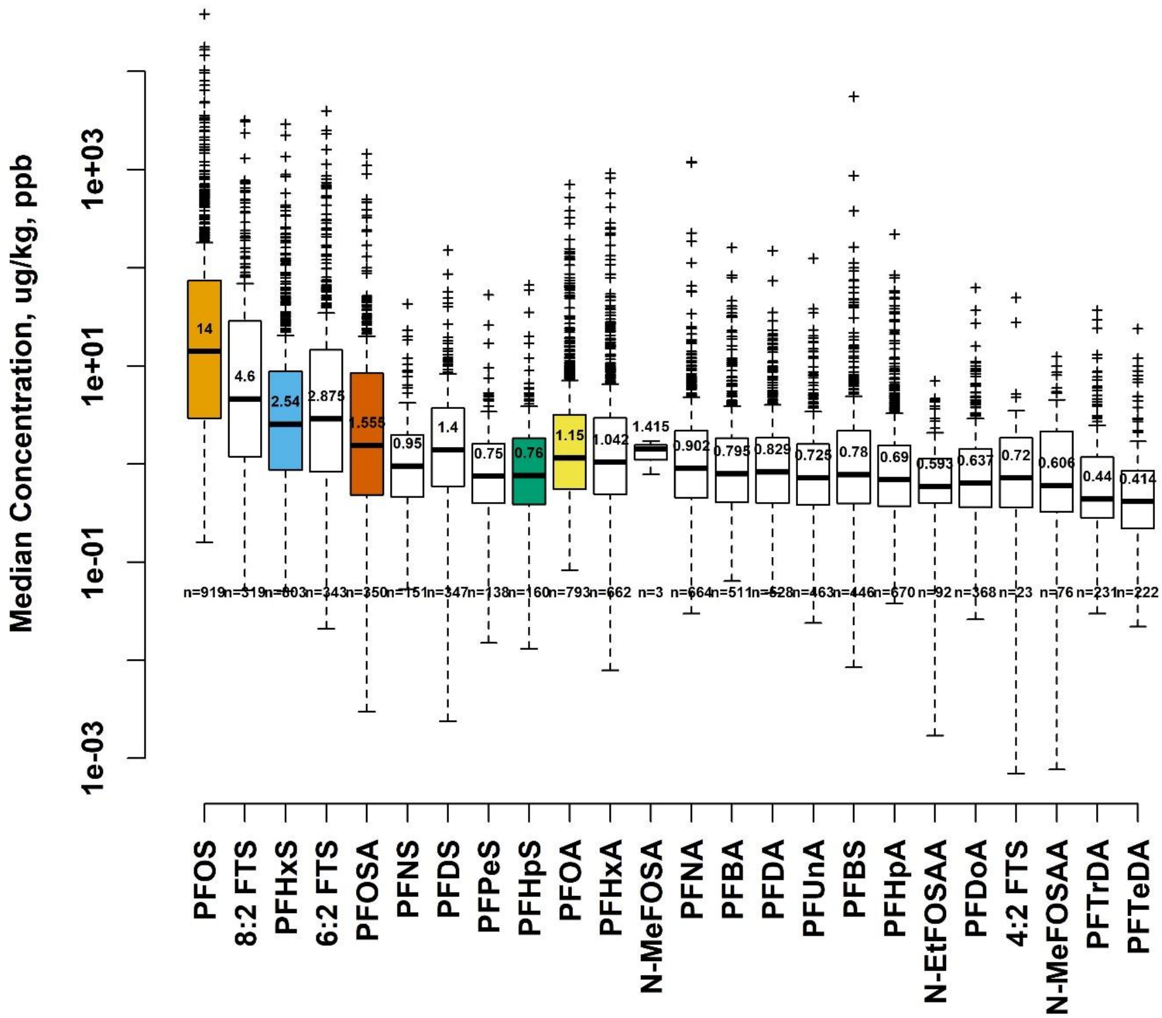


Figure SI2.5. Similar design boxplot as Figure S3, but of site-specific median concentrations. In order of median 95th percentile as Figure S3.

Example R Code with {tidyverse} to produce a figure of the distribution of mean concentrations by chemical for each site within installations:

```
datasummary <- data %>%
        filter(MATRIX == ”soil”, QUALITY != ”ND”) %>%
        group_by(INSTALLATION, SITE, LABEL) %>%
        summarize(
                mean = mean(VALUE),
                seven = quantile(VALUE, probs=0.75, names=F)
                )
boxplot(mean~LABEL, data=datasummary)
```

Table SI2.1. Summary data across samples <u>with detections</u> highlighting reporting limit (RL) and minimum detection limit (MDL) and their variability for surface soil samples by PFAS with median and maximum observations as well. Notice consistency across PFAS—all median RL are within one order of magnitude (max/min=~5-fold) and all median MDL max/min <3-fold. "-" indicates PFAS that did not have any detections and were filtered from the dataset used to produce summary statistics; see Table S2 for summary statistics on RL and MDL for these PFAS.

all units µg/kg (ppb)	**Measured**		**RL**			**MDL**		
	Median	**Maximum**	**Median**	**25th**	**75th**	**Median**	**25th**	**75th**
PFOS	18.694	47800	1	0.67	3.58	0.25	0.2	1.2
8:2 FTS	4.6	49500	2.9	1.06	3.9	0.6	0.3	1
6:2 FTS	3.5	19000	2	1	2.5	0.59	0.25	0.793
PFHxS	3.4	36000	0.92	0.64	1.3	0.23	0.2	0.43
PFOSA	2.3	20000	0.84	0.63	1.1	0.21	0.17	0.29
PFDS	1.4	2150	0.78	0.63	1.1	0.22	0.2	0.31
PFOA	1.36	50000	0.88	0.63	1.2	0.22	0.19	0.29
PFHxA	1.21	21000	0.91	0.64	1.2	0.21	0.17	0.25
PFNS	1.2	5750	0.66	0.61	1	0.22	0.2	0.25
PFBA	1.1	21000	1	0.67	1.5	0.23	0.2	0.5
PFBS	1.1	12000	1.4	0.92	2.2	0.285	0.16	0.47
PFPeS	1.1	8400	3.1	1.1	3.4	0.21	0.2	0.25
PFHpS	0.945	8500	0.66	0.61	0.99	0.21	0.2	0.24
PFNA	0.94	1300	0.83	0.63	1.1	0.21	0.15	0.25
N-MeFOSA	0.855	4.6	1.4	1	3.85	0.355	0.25	0.97
PFUnA	0.8315	710	0.89	0.64	1.2	0.22	0.19	0.3
PFDA	0.79	968	0.87	0.63	1.1	0.22	0.19	0.29
PFHpA	0.78	2500	0.86	0.63	1.1	0.21	0.17	0.25
4:2 FTS	0.775	170	1.96	0.99	2.1	0.493	0.24	0.62
N-EtFOSAA	0.66	10	2	1.88	2.2	0.21	0.2	0.24
PFDoA	0.66	277	0.88	0.63	1.18	0.22	0.19	0.26
PFTrDA	0.61	330	0.76	0.62	1.1	0.21	0.19	0.26
N-MeFOSAA	0.59	72	2	0.97	2.2	0.21	0.1	0.24
PFTeDA	0.373	38	0.955	0.64	1.94	0.21	0.1	0.25
11Cl-PF3OUdS	-	-	-	-	-	-	-	-
9Cl-PF3ONS	-	-	-	-	-	-	-	-
ADONA	-	-	-	-	-	-	-	-
HFPO-DA	-	-	-	-	-	-	-	-
N-MeFOSE	-	-	-	-	-	-	-	-
NEtFOSA	-	-	-	-	-	-	-	-
NEtFOSE	-	-	-	-	-	-	-	-

Table SI2.2. Summary data across all samples (with non-detects set to 0 and all trace detects considered quantitative) highlighting reporting limit (RL) and minimum detection limit (MDL) and their variability for surface soil samples by PFAS with median and maximum observations as well. Notice consistency across PFAS—all median RL and MDL are within one order of magnitude (max/min=<5-fold).

all units µg/kg (ppb)	**Measured**		**RL**			**MDL**		
	Median	**Maximum**	**Median**	**25th**	**75th**	**Median**	**25th**	**75th**
PFOS	14	47800	1	0.68	2.98	0.276	0.2	1.2
PFHxS	1.2	36000	0.95	0.65	1.85	0.273	0.21	0.59
PFOA	0.555	50000	0.94	0.65	1.4	0.25	0.2	0.59
PFHxA	0.39	21000	0.96	0.65	1.3	0.24	0.2	0.55
PFBA	0.2	21000	1	0.8	2	0.45	0.21	0.66
PFNA	0.053	1300	0.93	0.64	1.3	0.29	0.2	0.61
11Cl-PF3OUdS	0	0	2.2	1.825	23.5	0.78	0.54	7.05
4:2 FTS	0	170	2	1.3	2.2	0.87	0.59	1.7
6:2 FTS	0	19000	2	1	2.3	0.66	0.52	1.8
8:2 FTS	0	49500	2.8	1.07	3.4	0.68	0.54	1.8
9Cl-PF3ONS	0	0	2.2	1.825	23.5	0.78	0.54	7.05
ADONA	0	0	2.2	1.825	23.5	0.78	0.54	7.05
HFPO-DA	0	0	2.01	1.94	4.35	0.988	0.64	2.2
N-EtFOSAA	0	10	2.1	1.88	2.5	0.49	0.255	1.1
N-MeFOSA	0	4.6	2	1.8	6	1	0.72	2.45
N-MeFOSAA	0	72	2.1	1.87	2.5	0.5	0.25	1.1
N-MeFOSE	0	0	2	1.7	17.5	0.8	0.445	7.05
NEtFOSA	0	0	2	1.7	17.5	0.88	0.62	7.05
NEtFOSE	0	0	2	1.7	17.5	0.88	0.62	7.05
PFBS	0	12000	1.79	0.97	2.2	0.55	0.4	1.1
PFDA	0	968	0.97	0.65	1.3	0.39	0.21	0.61
PFDS	0	2150	0.9	0.64	1.1	0.41	0.21	0.59
PFDoA	0	277	0.98	0.65	1.88	0.45	0.22	0.72
PFHpA	0	2500	0.94	0.64	1.3	0.354	0.2	0.6
PFHpS	0	8500	0.7	0.62	1.1	0.38	0.21	0.55
PFNS	0	5750	0.7	0.62	1.1	0.4	0.21	0.54
PFOSA	0	20000	0.9	0.64	1.1	0.39	0.2	0.55
PFPeS	0	8400	3	1.1	3.3	0.4	0.21	0.55
PFTeDA	0	38	0.98	0.65	1.9	0.45	0.22	0.8
PFTrDA	0	330	0.96	0.65	1.3	0.44	0.23	0.78
PFUnA	0	710	0.96	0.65	1.3	0.42	0.22	0.65

Chapter 3: Supplementary Information

Evidence of additivity in risk-relevant PFAS exposure and effects in mice

Table SI3.1. PFAS, mixture ratios, nominal doses (mg/kg-d), and nominal ΣPFAS doses (mg/kg-d) for C6-8 and FTS mixtures. Mixtures were relative to PFOS as the dominant in the surface water and surface soil mixture profiles.

	C6-8 Mixture (surface water)					FTS Mixture (surface soil)			
	PFOS	PFHxS	PFHxA	PFOA	Sum (mg/kg-d)	PFOS	6:2 FTS	8:2 FTS	Sum (mg/kg-d)
Ratio	1	0.62	0.25	0.17		1	0.1	0.05	
High	**2.5**	1.6	0.6	0.425	5.10	**2.5**	0.3	0.125	**2.875**
Medium	1.3	0.8	0.3	0.213	**2.55**	1.3	0.1	0.063	1.438
Low	0.6	0.4	0.2	0.106	1.275	0.6	0.1	0.031	0.719

Table SI3.2. PFAS purchased and used for dosing solutions. Note that CAS numbers represent specific products/salts/forms obtained and they will not necessarily match CAS numbers in supplementary tables associated with analytical methods' anionic form or standards.

PFAS	Acronym	CAS	Source	SKU	Lot	Purity	Form
potassium perfluorooctanesulfonate	PFOS	2795-39-3	Matrix Scientific	9151	S26V	UR	K+ salt
tridecafluorohexane-1-sulfonic acid potassium salt	PFHxS	3871-99-6	Sigma-Aldrich	50929-10G-F	BCCF6962	≤100%	K+ salt
undecafluorohexanoic acid	PFHxA	307-24-4	TCI America	U0067	JFBDK-QP	>98.0%	liquid anion
perfluorooctanoic acid	PFOA	335-67-1	Sigma-Aldrich	171468-5G	WXBD6815V	≤100%	powder anion
heptadecafluorononanoic acid	PFNA	375-95-1	TCI America	H0843	J3YPD-SP	>95.0%	powder anion
potassium nonafluoro-1-butanesulfonate	PFBS	29420-49-3	Sigma-Aldrich	294209-10G	STBK2764	≤100%	K+ salt
1H,1H,2H,2H-perfluoooctanesulfonic acid	6:2 FTS	27619-97-2	BOC Sciences	no SKU	B22S02251)	≤100%	solid anion
3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecansesulfonic acid	8:2 FTS	39108-34-4	BOC Sciences	no SKU	B22S02252	≤100%	powder anion

UR: unreported

Table SI3.3. Table of detection limits by study, treatment, sample type, sex, and PFAS. Values are mean, (standard deviation), and [sample size]. Significant figures are reported as provided. NA indicates insufficient sample size to estimate standard deviation.

Study	Treatment	Sample Type	Sex	Units	11Cl-PF3OUdS	3:3 FTCA	4:2 FTS	5:3 FTCA	6:2 FTS	7:3 FTCA	8:2 FTS
Wholebody	PFOS	water	NA	ng/L	851000, (NA), [1]	850000, (NA), [1]	850000, (NA), [1]	5310000, (NA), [1]	766000, (NA), [1]	5310000, (NA), [1]	723000, (NA), [1]
Wholebody	PFOS	wholebody	F	ng/g	1.96, (0.03), [20]	1.95, (0.03), [20]	1.95, (0.03), [20]	12.21, (0.16), [20]	1.76, (0.02), [20]	12.21, (0.16), [20]	1.66, (0.02), [20]
Wholebody	PFOS	wholebody	M	ng/g	1.96, (0.03), [20]	1.96, (0.03), [20]	1.96, (0.03), [20]	12.26, (0.17), [20]	1.77, (0.03), [20]	12.26, (0.17), [20]	1.67, (0.03), [20]
Wholebody	PFOA	water	NA	ng/L	806000, (NA), [1]	805000, (NA), [1]	805000, (NA), [1]	5030000, (NA), [1]	725000, (NA), [1]	5030000, (NA), [1]	684000, (NA), [1]
Wholebody	PFOA	wholebody	F	ng/g	0.38, (0.01), [10]	0.38, (0.01), [10]	0.38, (0.01), [10]	2.37, (0.08), [10]	0.34, (0.01), [10]	2.37, (0.08), [10]	0.32, (0.01), [10]
Wholebody	PFOA	wholebody	M	ng/g	0.38, (0.01), [9]	0.38, (0.01), [9]	0.38, (0.01), [9]	2.35, (0.06), [9]	0.34, (0.01), [9]	2.35, (0.06), [9]	0.32, (0.01), [9]
Wholebody	PFHxS	water	NA	ng/L	715000, (NA), [1]	714000, (NA), [1]	714000, (NA), [1]	4460000, (NA), [1]	643000, (NA), [1]	4460000, (NA), [1]	607000, (NA), [1]
Wholebody	PFHxS	wholebody	F	ng/g	30.62, (1.04), [10]	30.23, (1.75), [3]	29.73, (0.98), [4]	190.71, (7.7), [7]	63.63, (55.37), [7]	309.86, (212.18), [7]	30, (7.54), [10]
Wholebody	PFHxS	wholebody	M	ng/g	30.56, (1.35), [10]	31.66, (0.92), [5]	31.7, (NA), [1]	244, (84.99), [9]	86.97, (49.35), [6]	273.56, (134.76), [9]	25.97, (1.14), [10]
Wholebody	PFHxA	water	NA	ng/L	861000, (NA), [1]	860000, (NA), [1]	860000, (NA), [1]	5380000, (NA), [1]	775000, (NA), [1]	5380000, (NA), [1]	731000, (NA), [1]
Wholebody	PFHxA	wholebody	F	ng/g	0.73, (0.02), [10]	0.73, (0.02), [10]	0.74, (0.05), [10]	4.58, (0.16), [10]	0.66, (0.02), [10]	4.58, (0.16), [10]	0.62, (0.02), [10]
Wholebody	PFHxA	wholebody	M	ng/g	0.74, (0.03), [10]	0.74, (0.03), [10]	0.74, (0.03), [10]	4.61, (0.2), [10]	0.66, (0.03), [10]	4.61, (0.2), [10]	0.63, (0.03), [10]
Wholebody	PFNA	water	NA	ng/L	840000, (NA), [1]	839000, (NA), [1]	839000, (NA), [1]	5240000, (NA), [1]	756000, (NA), [1]	5240000, (NA), [1]	713000, (NA), [1]
Wholebody	PFNA	wholebody	F	ng/g	30.18, (1.48), [10]	30.16, (1.51), [10]	30.16, (1.51), [10]	188.3, (9.37), [10]	27.13, (1.35), [10]	188.3, (9.37), [10]	25.64, (1.26), [10]
Wholebody	PFNA	wholebody	M	ng/g	30.1, (1.55), [10]	30.08, (1.57), [10]	30.08, (1.57), [10]	187.8, (9.72), [10]	27.05, (1.43), [10]	187.8, (9.72), [10]	25.56, (1.34), [10]
Wholebody	PFBS	water	NA	ng/L	734000, (NA), [1]	733000, (NA), [1]	733000, (NA), [1]	4580000, (NA), [1]	660000, (NA), [1]	4580000, (NA), [1]	623000, (NA), [1]
Wholebody	PFBS	wholebody	F	ng/g	7.61, (0.31), [10]	7.6, (0.31), [10]	7.6, (0.31), [10]	47.46, (1.96), [10]	6.84, (0.28), [10]	47.46, (1.96), [10]	6.46, (0.26), [10]
Wholebody	PFBS	wholebody	M	ng/g	7.5, (0.28), [10]	7.49, (0.28), [10]	7.49, (0.28), [10]	46.83, (1.79), [10]	7.02, (0.66), [10]	46.83, (1.79), [10]	6.37, (0.24), [10]
Wholebody	6:2 FTS	water	NA	ng/L	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	1330000, (NA), [1]	192000, (NA), [1]	1330000, (NA), [1]	181000, (NA), [1]
Wholebody	6:2 FTS	wholebody	F	ng/g	0.38, (0.01), [10]	0.38, (0.01), [10]	0.38, (0.01), [10]	2.4, (0.07), [10]	10.91, (16.09), [17]	2.4, (0.07), [10]	9.24, (14.18), [20]
Wholebody	6:2 FTS	wholebody	M	ng/g	0.38, (0.01), [10]	0.38, (0.01), [10]	0.38, (0.01), [10]	2.35, (0.08), [10]	47.52, (50.54), [20]	2.35, (0.08), [10]	44.86, (47.71), [20]
Wholebody	8:2 FTS	water	NA	ng/L	207000, (NA), [1]	207000, (NA), [1]	207000, (NA), [1]	1290000, (NA), [1]	186000, (NA), [1]	1290000, (NA), [1]	879000, (NA), [1]
Wholebody	8:2 FTS	wholebody	F	ng/g	0.39, (0.01), [9]	0.39, (0.01), [9]	0.39, (0.01), [9]	2.41, (0.08), [9]	0.35, (0.01), [9]	2.41, (0.08), [9]	82.11, (84.23), [18]
Wholebody	8:2 FTS	wholebody	M	ng/g	0.39, (0.01), [11]	0.39, (0.01), [11]	0.39, (0.01), [11]	2.42, (0.04), [11]	0.35, (0.01), [11]	2.42, (0.04), [11]	82.48, (84.11), [22]
Wholebody	C68LOW	water	NA	ng/L	77000, (NA), [1]	76900, (NA), [1]	76900, (NA), [1]	481000, (NA), [1]	69300, (NA), [1]	481000, (NA), [1]	65400, (NA), [1]
Wholebody	C68LOW	wholebody	F	ng/g	7.64, (0.27), [10]	8.34, (1.5), [10]	7.62, (0.28), [9]	47.67, (1.67), [10]	10.74, (8.65), [10]	51.43, (11.47), [10]	6.48, (0.23), [10]
Wholebody	C68LOW	wholebody	M	ng/g	7.64, (0.29), [10]	7.87, (0.77), [10]	7.63, (0.29), [10]	47.7, (1.82), [10]	9.88, (4.41), [10]	52.8, (11.72), [10]	6.49, (0.24), [10]
Wholebody	C68MED	water	NA	ng/L	438000, (NA), [1]	437000, (NA), [1]	437000, (NA), [1]	2730000, (NA), [1]	394000, (NA), [1]	2730000, (NA), [1]	372000, (NA), [1]
Wholebody	C68MED	wholebody	F	ng/g	7.82, (0.22), [10]	7.81, (0.22), [10]	7.81, (0.22), [10]	48.86, (1.36), [10]	7.03, (0.19), [10]	48.86, (1.36), [10]	6.64, (0.18), [10]
Wholebody	C68MED	wholebody	M	ng/g	7.82, (0.15), [9]	7.81, (0.15), [9]	7.81, (0.15), [9]	48.83, (0.94), [9]	7.03, (0.13), [9]	48.83, (0.94), [9]	6.64, (0.13), [9]
Wholebody	C68HIGH	water	NA	ng/L	443000, (NA), [1]	442000, (NA), [1]	442000, (NA), [1]	2770000, (NA), [1]	399000, (NA), [1]	2770000, (NA), [1]	376000, (NA), [1]
Wholebody	C68HIGH	wholebody	F	ng/g	26.89, (1.62), [10]	26.89, (1.62), [10]	26.89, (1.62), [10]	167.7, (10.22), [10]	24.22, (1.48), [10]	167.7, (10.22), [10]	22.86, (1.37), [10]
Wholebody	C68HIGH	wholebody	M	ng/g	28.34, (2.26), [10]	28.31, (2.25), [10]	28.31, (2.25), [10]	176.9, (14.04), [10]	29.81, (14.83), [10]	176.9, (14.04), [10]	24.07, (1.9), [10]
Wholebody	FTSLOW	water	NA	ng/L	68500, (NA), [1]	68400, (NA), [1]	68400, (NA), [1]	427000, (NA), [1]	61600, (NA), [1]	427000, (NA), [1]	58100, (NA), [1]
Wholebody	FTSLOW	wholebody	F	ng/g	15.33, (0.68), [10]	15.3, (0.67), [10]	15.3, (0.67), [10]	95.68, (4.18), [10]	13.77, (0.61), [10]	95.68, (4.18), [10]	13.02, (0.57), [10]
Wholebody	FTSLOW	wholebody	M	ng/g	15.07, (0.65), [10]	15.05, (0.64), [10]	15.05, (0.64), [10]	94.05, (4.01), [10]	13.66, (0.7), [10]	94.05, (4.01), [10]	12.79, (0.56), [10]
Wholebody	FTSMED	water	NA	ng/L	214000, (NA), [1]	214000, (NA), [1]	214000, (NA), [1]	1340000, (NA), [1]	193000, (NA), [1]	1340000, (NA), [1]	182000, (NA), [1]
Wholebody	FTSMED	wholebody	F	ng/g	7.54, (0.36), [10]	7.53, (0.36), [10]	7.53, (0.36), [10]	47.08, (2.26), [10]	6.78, (0.32), [10]	47.08, (2.26), [10]	6.4, (0.31), [10]
Wholebody	FTSMED	wholebody	M	ng/g	7.59, (0.3), [10]	7.58, (0.3), [10]	7.58, (0.3), [10]	47.37, (1.89), [10]	6.82, (0.27), [10]	47.37, (1.89), [10]	7.6, (3.8), [10]
Wholebody	FTSHIGH	water	NA	ng/L	433000, (NA), [1]	432000, (NA), [1]	432000, (NA), [1]	2700000, (NA), [1]	389000, (NA), [1]	2700000, (NA), [1]	367000, (NA), [1]
Wholebody	FTSHIGH	wholebody	F	ng/g	26.59, (1.71), [10]	26.56, (1.72), [10]	26.56, (1.72), [10]	166, (10.65), [10]	25.2, (3.74), [10]	166, (10.65), [10]	22.58, (1.44), [10]
Wholebody	FTSHIGH	wholebody	M	ng/g	27.02, (1.78), [10]	26.99, (1.79), [10]	26.99, (1.79), [10]	168.6, (11.15), [10]	24.27, (1.6), [10]	168.6, (11.15), [10]	22.93, (1.51), [10]
Wholebody	Control	water	NA	ng/L	44500, (NA), [1]	44400, (NA), [1]	44400, (NA), [1]	278000, (NA), [1]	40100, (NA), [1]	278000, (NA), [1]	37800, (NA), [1]
Wholebody	Control	wholebody	F	ng/g	0.39, (0.01), [10]	0.38, (0.01), [10]	0.38, (0.01), [10]	2.44, (0.17), [10]	0.43, (0.13), [10]	2.4, (0.06), [10]	0.33, (0.01), [10]
Wholebody	Control	wholebody	M	ng/g	0.39, (0.01), [10]	0.4, (0.02), [10]	0.39, (0.01), [10]	2.59, (0.33), [10]	0.89, (0.53), [10]	2.54, (0.14), [10]	0.33, (0), [10]
Serum	PFOS	serum	F	ng/mL	72.81, (4.11), [10]	72.71, (4.11), [10]	72.71, (4.11), [10]	454.5, (25.81), [10]	65.53, (3.7), [10]	454.5, (25.81), [10]	61.8, (3.5), [10]
Serum	PFOS	serum	M	ng/mL	66.66, (7.97), [9]	66.56, (7.97), [9]	66.56, (7.97), [9]	416.22, (49.96), [9]	60, (7.16), [9]	416.22, (49.96), [9]	56.58, (6.77), [9]
Serum	PFOS	water	NA	ng/L	383000, (NA), [1]	382000, (NA), [1]	382000, (NA), [1]	2390000, (NA), [1]	344000, (NA), [1]	2390000, (NA), [1]	325000, (NA), [1]
Serum	PFOA	serum	F	ng/mL	3.93, (0.16), [10]	3.93, (0.16), [10]	3.93, (0.16), [10]	24.57, (0.97), [10]	3.54, (0.14), [10]	24.57, (0.97), [10]	3.34, (0.13), [10]
Serum	PFOA	serum	M	ng/mL	3.93, (0.14), [10]	3.93, (0.14), [10]	3.93, (0.14), [10]	24.54, (0.88), [10]	3.54, (0.13), [10]	24.54, (0.88), [10]	3.34, (0.12), [10]
Serum	PFOA	water	NA	ng/L	798000, (NA), [1]	797000, (NA), [1]	797000, (NA), [1]	4980000, (NA), [1]	718000, (NA), [1]	4980000, (NA), [1]	677000, (NA), [1]
Serum	PFHxS	serum	F	ng/mL	4.46, (1.17), [10]	4.46, (1.17), [10]	4.46, (1.17), [10]	27.87, (7.31), [10]	4.02, (1.05), [10]	27.87, (7.31), [10]	3.79, (1), [10]
Serum	PFHxS	serum	M	ng/mL	4.35, (0.84), [10]	4.35, (0.83), [10]	4.35, (0.83), [10]	27.19, (5.22), [10]	3.92, (0.75), [10]	27.19, (5.22), [10]	3.7, (0.71), [10]
Serum	PFHxS	water	NA	ng/L	844000, (NA), [1]	843000, (NA), [1]	843000, (NA), [1]	5270000, (NA), [1]	760000, (NA), [1]	5270000, (NA), [1]	717000, (NA), [1]
Serum	PFHxA	serum	F	ng/mL	4.12, (0.42), [9]	4.12, (0.42), [9]	4.12, (0.42), [9]	25.71, (2.63), [9]	3.71, (0.38), [9]	25.71, (2.63), [9]	3.5, (0.36), [9]
Serum	PFHxA	serum	M	ng/mL	4.26, (0.57), [10]	4.26, (0.57), [10]	4.26, (0.57), [10]	26.61, (3.57), [10]	3.84, (0.52), [10]	26.61, (3.57), [10]	3.62, (0.49), [10]
Serum	PFHxA	water	NA	ng/L	816000, (NA), [1]	815000, (NA), [1]	815000, (NA), [1]	5090000, (NA), [1]	734000, (NA), [1]	5090000, (NA), [1]	692000, (NA), [1]

Serum	PFNA	serum	F	ng/mL	594.9, (19.15), [10]	594.4, (19.41), [10]	594.4, (19.41), [10]	3715, (119.37), [10]	535.4, (17.6), [10]	3715, (119.37), [10]	504.8, (16.25), [10]
Serum	PFNA	serum	M	ng/mL	575.9, (26.2), [10]	575.5, (26.25), [10]	575.5, (26.25), [10]	3596, (163.92), [10]	518.3, (23.64), [10]	3596, (163.92), [10]	488.9, (22.06), [10]
Serum	PFNA	water	NA	ng/L	738000, (NA), [1]	737000, (NA), [1]	737000, (NA), [1]	4600000, (NA), [1]	664000, (NA), [1]	4600000, (NA), [1]	626000, (NA), [1]
Serum	PFBS	serum	F	ng/mL	4.87, (1.56), [10]	4.87, (1.56), [10]	4.87, (1.56), [10]	30.42, (9.73), [10]	4.39, (1.4), [10]	30.42, (9.73), [10]	4.14, (1.33), [10]
Serum	PFBS	serum	M	ng/mL	4.74, (2.07), [10]	4.74, (2.07), [10]	4.74, (2.07), [10]	29.63, (12.94), [10]	4.27, (1.86), [10]	29.63, (12.94), [10]	4.03, (1.76), [10]
Serum	PFBS	water	NA	ng/L	806000, (NA), [1]	805000, (NA), [1]	805000, (NA), [1]	5030000, (NA), [1]	725000, (NA), [1]	5030000, (NA), [1]	684000, (NA), [1]
Serum	6:2 FTS	serum	F	ng/mL	3.4, (0.87), [10]	3.4, (0.87), [10]	3.4, (0.87), [10]	21.25, (5.41), [10]	11.03, (14.36), [14]	21.25, (5.41), [10]	2.89, (0.74), [10]
Serum	6:2 FTS	serum	M	ng/mL	3.45, (0.93), [10]	3.44, (0.93), [10]	3.44, (0.93), [10]	21.52, (5.78), [10]	49.51, (83.33), [20]	21.52, (5.78), [10]	2.92, (0.79), [10]
Serum	6:2 FTS	water	NA	ng/L	188000, (NA), [1]	188000, (NA), [1]	188000, (NA), [1]	1170000, (NA), [1]	1690000, (NA), [1]	1170000, (NA), [1]	160000, (NA), [1]
Serum	8:2 FTS	serum	F	ng/mL	3.45, (0.97), [10]	3.45, (0.97), [10]	3.45, (0.97), [10]	21.56, (6.07), [10]	3.11, (0.88), [10]	21.56, (6.07), [10]	85.44, (118.29), [20]
Serum	8:2 FTS	serum	M	ng/mL	2.98, (0.64), [10]	2.98, (0.64), [10]	2.98, (0.64), [10]	18.61, (4.03), [10]	2.68, (0.58), [10]	18.61, (4.03), [10]	32.15, (59.77), [20]
Serum	8:2 FTS	water	NA	ng/L	202000, (NA), [1]	202000, (NA), [1]	202000, (NA), [1]	1260000, (NA), [1]	182000, (NA), [1]	1260000, (NA), [1]	172000, (NA), [1]
Serum	C68LOW	serum	F	ng/mL	38.26, (1.83), [10]	38.17, (1.85), [10]	38.17, (1.85), [10]	238.8, (11.54), [10]	34.45, (1.64), [10]	238.8, (11.54), [10]	32.49, (1.56), [10]
Serum	C68LOW	serum	M	ng/mL	39.34, (1.78), [10]	39.28, (1.83), [10]	39.28, (1.83), [10]	245.6, (11.12), [10]	35.41, (1.61), [10]	245.6, (11.12), [10]	33.4, (1.51), [10]
Serum	C68LOW	water	NA	ng/L	80900, (NA), [1]	80800, (NA), [1]	80800, (NA), [1]	505000, (NA), [1]	72800, (NA), [1]	505000, (NA), [1]	68700, (NA), [1]
Serum	C68MED	serum	F	ng/mL	191.7, (8.84), [10]	191.7, (8.84), [10]	191.7, (8.84), [10]	1197, (56.18), [10]	173.1, (7.88), [10]	1197, (56.18), [10]	162.9, (7.55), [10]
Serum	C68MED	serum	M	ng/mL	191.4, (4.65), [10]	191.4, (4.65), [10]	191.4, (4.65), [10]	1196, (30.98), [10]	172.8, (4.13), [10]	1196, (30.98), [10]	162.8, (4.13), [10]
Serum	C68MED	water	NA	ng/L	196000, (NA), [1]	196000, (NA), [1]	196000, (NA), [1]	1220000, (NA), [1]	176000, (NA), [1]	1220000, (NA), [1]	166000, (NA), [1]
Serum	C68HIGH	serum	F	ng/mL	594.7, (14.01), [10]	594, (14.49), [10]	594, (14.49), [10]	3714, (86.95), [10]	535.1, (13.04), [10]	3714, (86.95), [10]	504.5, (12.08), [10]
Serum	C68HIGH	serum	M	ng/mL	590.11, (27.37), [9]	589.44, (27.2), [9]	589.44, (27.2), [9]	3684.44, (169.27), [9]	530.89, (24.7), [9]	3684.44, (169.27), [9]	500.78, (23.11), [9]
Serum	C68HIGH	water	NA	ng/L	422000, (NA), [1]	421000, (NA), [1]	421000, (NA), [1]	2630000, (NA), [1]	379000, (NA), [1]	2630000, (NA), [1]	358000, (NA), [1]
Serum	FTSLOW	serum	F	ng/mL	38.05, (1.5), [10]	37.96, (1.53), [10]	37.96, (1.53), [10]	237.6, (9.31), [10]	34.26, (1.35), [10]	237.6, (9.31), [10]	32.32, (1.27), [10]
Serum	FTSLOW	serum	M	ng/mL	37.87, (1.47), [10]	37.78, (1.5), [10]	37.78, (1.5), [10]	236.5, (9.12), [10]	34.1, (1.32), [10]	236.5, (9.12), [10]	32.17, (1.24), [10]
Serum	FTSLOW	water	NA	ng/L	78500, (NA), [1]	78400, (NA), [1]	78400, (NA), [1]	490000, (NA), [1]	70700, (NA), [1]	490000, (NA), [1]	66700, (NA), [1]
Serum	FTSMED	serum	F	ng/mL	178.3, (6.96), [10]	178.3, (6.96), [10]	178.3, (6.96), [10]	1112, (43.67), [10]	161.1, (6.37), [10]	1112, (43.67), [10]	151.3, (6.02), [10]
Serum	FTSMED	serum	M	ng/mL	183.9, (7.71), [10]	183.9, (7.71), [10]	183.9, (7.71), [10]	1148, (48.72), [10]	166.1, (6.95), [10]	1148, (48.72), [10]	156.2, (6.76), [10]
Serum	FTSMED	water	NA	ng/L	235000, (NA), [1]	235000, (NA), [1]	235000, (NA), [1]	1470000, (NA), [1]	211000, (NA), [1]	1470000, (NA), [1]	199000, (NA), [1]
Serum	FTSHIGH	serum	F	ng/mL	601.3, (28.22), [10]	601, (28.16), [10]	601, (28.16), [10]	3754, (175.07), [10]	346.53, (268.6), [10]	3754, (175.07), [10]	510.4, (23.82), [10]
Serum	FTSHIGH	serum	M	ng/mL	596, (32.55), [10]	595.5, (32.69), [10]	595.5, (32.69), [10]	3721, (202.23), [10]	536.5, (29.35), [10]	3721, (202.23), [10]	269.22, (249.48), [10]
Serum	FTSHIGH	water	NA	ng/L	4e+05, (NA), [1]	4e+05, (NA), [1]	4e+05, (NA), [1]	2500000, (NA), [1]	360000, (NA), [1]	2500000, (NA), [1]	340000, (NA), [1]
Serum	Control	serum	F	ng/mL	5.87, (2.73), [10]	5.86, (2.73), [10]	5.86, (2.73), [10]	36.64, (17), [10]	5.28, (2.45), [10]	36.64, (17), [10]	4.98, (2.31), [10]
Serum	Control	serum	M	ng/mL	4.2, (1.24), [10]	4.19, (1.23), [10]	4.19, (1.23), [10]	26.2, (7.71), [10]	3.78, (1.11), [10]	26.2, (7.71), [10]	3.56, (1.05), [10]
Serum	Control	water	NA	ng/L	42800, (NA), [1]	42800, (NA), [1]	42800, (NA), [1]	267000, (NA), [1]	38600, (NA), [1]	267000, (NA), [1]	36400, (NA), [1]
Serum	PFOS	Brain	F	ng/g	3457.14, (567.27), [7]	3454.29, (564.38), [7]	3454.29, (564.38), [7]	21585.71, (3526.3), [7]	3107.14, (508.26), [7]	21585.71, (3526.3), [7]	2937.14, (478.46), [7]
Serum	PFOS	Brain	M	ng/g	4008.57, (831.73), [7]	3998.57, (831.73), [7]	3998.57, (831.73), [7]	25028.57, (5202.47), [7]	3600, (750.07), [7]	25028.57, (5202.47), [7]	3401.43, (705.72), [7]
Serum	PFOS	Kidney	F	ng/g	2441.43, (268.73), [7]	2440, (270.31), [7]	2440, (270.31), [7]	15228.57, (1702.66), [7]	2195.71, (242.96), [7]	15228.57, (1702.66), [7]	2074.29, (226.85), [7]
Serum	PFOS	Kidney	M	ng/g	1712.86, (206.54), [7]	1712.86, (206.54), [7]	1712.86, (206.54), [7]	10707.14, (1288.55), [7]	1538.57, (184.7), [7]	10707.14, (1288.55), [7]	1454.29, (175.96), [7]
Serum	PFOS	Liver	F	ng/g	110, (3.32), [7]	109.86, (3.29), [7]	109.86, (3.29), [7]	685.86, (20.52), [7]	98.76, (2.87), [7]	685.86, (20.52), [7]	93.29, (2.77), [7]
Serum	PFOS	Liver	M	ng/g	110.14, (6.04), [7]	109.97, (5.93), [7]	109.97, (5.93), [7]	687.29, (37.8), [7]	99.14, (5.52), [7]	687.29, (37.8), [7]	93.49, (5.09), [7]
Serum	PFOA	Brain	F	ng/g	2691.43, (613.31), [7]	2688.57, (614.48), [7]	2688.57, (614.48), [7]	16785.71, (3858.94), [7]	2418.57, (552.61), [7]	16785.71, (3858.94), [7]	2282.86, (521.62), [7]
Serum	PFOA	Brain	M	ng/g	2814.29, (507.77), [7]	2811.43, (508.9), [7]	2811.43, (508.9), [7]	17585.71, (3157.23), [7]	2531.43, (458.02), [7]	17585.71, (3157.23), [7]	2390, (430.77), [7]
Serum	PFOA	Kidney	F	ng/g	2438.57, (238.57), [7]	2435.71, (236.7), [7]	2435.71, (236.7), [7]	15214.29, (1466.77), [7]	2194.29, (215.78), [7]	15214.29, (1466.77), [7]	2071.43, (202.68), [7]
Serum	PFOA	Kidney	M	ng/g	1640, (223.98), [7]	1637.14, (225.74), [7]	1637.14, (225.74), [7]	10230, (1389.42), [7]	1472.86, (203.61), [7]	10230, (1389.42), [7]	1391.43, (190.3), [7]
Serum	PFOA	Liver	F	ng/g	108.29, (3.9), [7]	108.14, (3.89), [7]	108.14, (3.89), [7]	676.14, (23.83), [7]	97.4, (3.48), [7]	676.14, (23.83), [7]	91.94, (3.26), [7]
Serum	PFOA	Liver	M	ng/g	111.86, (3.48), [7]	111.71, (3.59), [7]	111.71, (3.59), [7]	698.29, (22.25), [7]	100.61, (3.3), [7]	698.29, (22.25), [7]	94.97, (3.03), [7]
Serum	PFHxS	Brain	F	ng/g	437.43, (122.19), [7]	436.71, (121.97), [7]	436.71, (121.97), [7]	2727.14, (762.42), [7]	393.14, (110.12), [7]	2727.14, (762.42), [7]	371.43, (103.89), [7]
Serum	PFHxS	Brain	M	ng/g	411.86, (107.73), [7]	411.57, (107.37), [7]	411.57, (107.37), [7]	2572.86, (669.54), [7]	370.43, (96.8), [7]	2572.86, (669.54), [7]	349.71, (91.07), [7]
Serum	PFHxS	Kidney	F	ng/g	432.29, (59.73), [7]	431.43, (59.66), [7]	431.43, (59.66), [7]	2698.57, (370.6), [7]	388.43, (53.62), [7]	2698.57, (370.6), [7]	366.86, (50.59), [7]
Serum	PFHxS	Kidney	M	ng/g	252.86, (48.32), [7]	252.57, (47.88), [7]	252.57, (47.88), [7]	1578.57, (299.91), [7]	227.14, (43.21), [7]	1578.57, (299.91), [7]	214.86, (40.8), [7]
Serum	PFHxS	Liver	F	ng/g	114.29, (3.35), [7]	114.14, (3.34), [7]	114.14, (3.34), [7]	713.43, (20.7), [7]	102.8, (2.99), [7]	713.43, (20.7), [7]	97, (2.81), [7]
Serum	PFHxS	Liver	M	ng/g	113.57, (3.31), [7]	113.57, (3.31), [7]	113.57, (3.31), [7]	709.43, (19.84), [7]	102.11, (2.94), [7]	709.43, (19.84), [7]	96.51, (2.79), [7]
Serum	PFHxA	Brain	F	ng/g	5.71, (4.49), [7]	5.71, (4.49), [7]	5.71, (4.49), [7]	35.66, (28.01), [7]	5.13, (4.03), [7]	35.66, (28.01), [7]	4.85, (3.8), [7]
Serum	PFHxA	Brain	M	ng/g	3.5, (0.46), [7]	3.49, (0.46), [7]	3.49, (0.46), [7]	21.83, (2.89), [7]	3.14, (0.42), [7]	21.83, (2.89), [7]	2.97, (0.4), [7]
Serum	PFHxA	Kidney	F	ng/g	2.72, (0.36), [7]	2.72, (0.36), [7]	2.72, (0.36), [7]	17, (2.23), [7]	2.45, (0.32), [7]	17, (2.23), [7]	2.36, (0.34), [7]
Serum	PFHxA	Kidney	M	ng/g	1.56, (0.18), [7]	1.55, (0.19), [7]	1.55, (0.19), [7]	9.71, (1.17), [7]	1.4, (0.17), [7]	9.71, (1.17), [7]	1.32, (0.16), [7]
Serum	PFHxA	Liver	F	ng/g	0.92, (0.45), [7]	0.95, (0.44), [7]	0.92, (0.45), [7]	5.72, (2.78), [7]	0.82, (0.4), [7]	5.72, (2.78), [7]	0.78, (0.38), [7]
Serum	PFHxA	Liver	M	ng/g	0.84, (0.26), [7]	0.88, (0.27), [7]	0.84, (0.26), [7]	5.27, (1.61), [7]	0.76, (0.23), [7]	5.27, (1.61), [7]	0.72, (0.22), [7]
Serum	6:2 FTS	Brain	F	ng/g	178.79, (100.78), [7]	178.63, (100.64), [7]	178.63, (100.64), [7]	1116.84, (629.95), [7]	160.94, (90.71), [7]	1116.84, (629.95), [7]	152.02, (85.69), [7]
Serum	6:2 FTS	Brain	M	ng/g	265, (91.31), [7]	264.71, (91.3), [7]	264.71, (91.3), [7]	1652.86, (570.28), [7]	238.29, (82.01), [7]	1652.86, (570.28), [7]	224.71, (77.48), [7]
Serum	6:2 FTS	Kidney	F	ng/g	67.03, (9.01), [7]	66.97, (8.97), [7]	66.97, (8.97), [7]	418.71, (56.17), [7]	60.27, (8.1), [7]	418.71, (56.17), [7]	56.93, (7.63), [7]
Serum	6:2 FTS	Kidney	M	ng/g	45.16, (9.58), [7]	45.09, (9.6), [7]	45.09, (9.6), [7]	281.71, (59.77), [7]	40.57, (8.61), [7]	281.71, (59.77), [7]	38.31, (8.11), [7]
Serum	6:2 FTS	Liver	F	ng/g	39.59, (0.64), [7]	39.51, (0.61), [7]	39.51, (0.61), [7]	247.14, (4.06), [7]	35.59, (0.57), [7]	247.14, (4.06), [7]	33.6, (0.51), [7]

Serum	6:2 FTS	Liver	M	ng/g	39.46, (0.32), [7]	39.43, (0.34), [7]	39.43, (0.34), [7]	246.14, (2.12), [7]	35.47, (0.3), [7]	246.14, (2.12), [7]	33.51, (0.29), [7]
Serum	8:2 FTS	Brain	F	ng/g	2451.57, (2253.94), [7]	2448.71, (2250.8), [7]	2448.71, (2250.8), [7]	15297.14, (14058.39), [7]	2204.43, (2027.74), [7]	15297.14, (14058.39), [7]	2080.86, (1912.89), [7]
Serum	8:2 FTS	Brain	M	ng/g	558.57, (972.06), [7]	557, (968.33), [7]	557, (968.33), [7]	3483.29, (6056.61), [7]	502, (873.4), [7]	3483.29, (6056.61), [7]	473.71, (824.07), [7]
Serum	8:2 FTS	Kidney	F	ng/g	146.43, (22.99), [7]	146, (23.17), [7]	146, (23.17), [7]	913.29, (144.94), [7]	131.5, (20.87), [7]	913.29, (144.94), [7]	124.14, (19.66), [7]
Serum	8:2 FTS	Kidney	M	ng/g	92.11, (13.01), [7]	92.06, (13.02), [7]	92.06, (13.02), [7]	575.14, (81.2), [7]	82.83, (11.71), [7]	575.14, (81.2), [7]	78.23, (11.05), [7]
Serum	8:2 FTS	Liver	F	ng/g	39.04, (1.07), [7]	38.94, (1.07), [7]	38.94, (1.07), [7]	243.43, (6.45), [7]	35.07, (0.95), [7]	243.43, (6.45), [7]	165.57, (4.61), [7]
Serum	8:2 FTS	Liver	M	ng/g	39.19, (0.74), [7]	39.13, (0.78), [7]	39.13, (0.78), [7]	244.57, (4.65), [7]	35.21, (0.67), [7]	244.57, (4.65), [7]	166.14, (3.29), [7]
Serum	C6-8 Low	Brain	F	ng/g	621.71, (255.62), [7]	619.71, (252.85), [7]	619.71, (252.85), [7]	3877.14, (1588.18), [7]	558.29, (228.71), [7]	3877.14, (1588.18), [7]	527.29, (216.21), [7]
Serum	C6-8 Low	Brain	M	ng/g	502.71, (136.47), [7]	502.14, (136.26), [7]	502.14, (136.26), [7]	3137.14, (851.52), [7]	452, (122.84), [7]	3137.14, (851.52), [7]	426.57, (116.01), [7]
Serum	C6-8 Low	Kidney	F	ng/g	28.99, (3.52), [7]	28.97, (3.5), [7]	28.97, (3.5), [7]	181.14, (21.95), [7]	26.09, (3.18), [7]	181.14, (21.95), [7]	24.63, (2.98), [7]
Serum	C6-8 Low	Kidney	M	ng/g	17.13, (1.76), [7]	17.13, (1.76), [7]	17.13, (1.76), [7]	106.74, (10.94), [7]	15.37, (1.57), [7]	106.74, (10.94), [7]	14.54, (1.48), [7]
Serum	C6-8 Low	Liver	F	ng/g	18.91, (0.42), [10]	18.87, (0.38), [10]	18.87, (0.38), [10]	118.2, (2.74), [10]	16.99, (0.35), [10]	118.2, (2.74), [10]	16.06, (0.34), [10]
Serum	C6-8 Low	Liver	M	ng/g	19.18, (0.36), [10]	19.14, (0.35), [10]	19.14, (0.35), [10]	119.6, (2.32), [10]	17.24, (0.33), [10]	119.6, (2.32), [10]	16.27, (0.29), [10]
Serum	C6-8 Medium	Brain	F	ng/g	981.71, (64.42), [7]	979.86, (62.72), [7]	979.86, (62.72), [7]	6130, (400.5), [7]	882.86, (57.75), [7]	6130, (400.5), [7]	833.71, (54.6), [7]
Serum	C6-8 Medium	Brain	M	ng/g	1074, (96.11), [7]	1073.57, (96.64), [7]	1073.57, (96.64), [7]	6710, (603.49), [7]	966.29, (86.66), [7]	6710, (603.49), [7]	912.29, (82.07), [7]
Serum	C6-8 Medium	Kidney	F	ng/g	137, (18.68), [7]	136.86, (18.49), [7]	136.86, (18.49), [7]	854.57, (116.64), [7]	123.1, (16.61), [7]	854.57, (116.64), [7]	116.34, (15.94), [7]
Serum	C6-8 Medium	Kidney	M	ng/g	86.79, (12.96), [7]	86.69, (12.98), [7]	86.69, (12.98), [7]	541.86, (81.12), [7]	78.03, (11.68), [7]	541.86, (81.12), [7]	73.71, (11.01), [7]
Serum	C6-8 Medium	Liver	F	ng/g	38.01, (0.89), [10]	37.95, (0.89), [10]	37.95, (0.89), [10]	237.1, (5.63), [10]	34.16, (0.79), [10]	237.1, (5.63), [10]	32.26, (0.76), [10]
Serum	C6-8 Medium	Liver	M	ng/g	38.32, (0.9), [10]	38.27, (0.9), [10]	38.27, (0.9), [10]	239.3, (5.52), [10]	34.46, (0.81), [10]	239.3, (5.52), [10]	32.54, (0.78), [10]
Serum	C6-8 High	Brain	F	ng/g	5987.14, (581.31), [7]	5984.29, (579.48), [7]	5984.29, (579.48), [7]	37371.43, (3639.47), [7]	5382.86, (520.86), [7]	37371.43, (3639.47), [7]	5084.29, (492.34), [7]
Serum	C6-8 High	Brain	M	ng/g	5090, (2709.91), [7]	5085.71, (2711.39), [7]	5085.71, (2711.39), [7]	31742.86, (16838.24), [7]	4570, (2426.29), [7]	31742.86, (16838.24), [7]	4317.14, (2290.76), [7]
Serum	C6-8 High	Kidney	F	ng/g	141.71, (18.8), [7]	141.57, (18.86), [7]	141.57, (18.86), [7]	885.43, (118.62), [7]	127.43, (16.87), [7]	885.43, (118.62), [7]	120.17, (15.9), [7]
Serum	C6-8 High	Kidney	M	ng/g	88.41, (10.18), [7]	88.33, (10.2), [7]	88.33, (10.2), [7]	552, (63.58), [7]	79.49, (9.15), [7]	552, (63.58), [7]	75.09, (8.64), [7]
Serum	C6-8 High	Liver	F	ng/g	38.87, (1.14), [10]	38.81, (1.12), [10]	38.81, (1.12), [10]	242.5, (7.03), [10]	34.95, (1.03), [10]	242.5, (7.03), [10]	33, (0.96), [10]
Serum	C6-8 High	Liver	M	ng/g	38.13, (1.09), [9]	38.11, (1.1), [9]	38.11, (1.1), [9]	238, (6.98), [9]	34.27, (1), [9]	238, (6.98), [9]	32.38, (0.94), [9]
Serum	FTS Low	Brain	F	ng/g	547.86, (246.49), [7]	547, (246.81), [7]	547, (246.81), [7]	3421.43, (1547.02), [7]	492.57, (222.34), [7]	3421.43, (1547.02), [7]	465.29, (210.08), [7]
Serum	FTS Low	Brain	M	ng/g	1018.86, (412.44), [7]	1018.43, (412.52), [7]	1018.43, (412.52), [7]	6372.86, (2589.14), [7]	915.71, (370.81), [7]	6372.86, (2589.14), [7]	866.14, (351.56), [7]
Serum	FTS Low	Kidney	F	ng/g	71.43, (5.78), [7]	71.36, (5.76), [7]	71.36, (5.76), [7]	446, (36.12), [7]	64.21, (5.21), [7]	446, (36.12), [7]	60.66, (4.91), [7]
Serum	FTS Low	Kidney	M	ng/g	42.89, (6.78), [7]	42.79, (6.78), [7]	42.79, (6.78), [7]	267.43, (42.41), [7]	38.53, (6.07), [7]	267.43, (42.41), [7]	36.37, (5.76), [7]
Serum	FTS Low	Liver	F	ng/g	19.08, (0.37), [10]	19.04, (0.35), [10]	19.04, (0.35), [10]	119, (2.21), [10]	17.14, (0.32), [10]	119, (2.21), [10]	16.18, (0.32), [10]
Serum	FTS Low	Liver	M	ng/g	19, (0.41), [10]	18.98, (0.43), [10]	18.98, (0.43), [10]	118.6, (2.8), [10]	17.09, (0.39), [10]	118.6, (2.8), [10]	16.14, (0.35), [10]
Serum	FTS Medium	Brain	F	ng/g	176.14, (75.67), [7]	176.14, (75.67), [7]	176.14, (75.67), [7]	1101.57, (473.51), [7]	158.39, (67.9), [7]	1101.57, (473.51), [7]	149.71, (64.26), [7]
Serum	FTS Medium	Brain	M	ng/g	230.86, (93.41), [7]	230.43, (93.08), [7]	230.43, (93.08), [7]	1441.43, (580.44), [7]	207.43, (83.76), [7]	1441.43, (580.44), [7]	195.89, (79.3), [7]
Serum	FTS Medium	Kidney	F	ng/g	69.8, (7.93), [7]	69.7, (7.93), [7]	69.7, (7.93), [7]	435.71, (49.6), [7]	62.74, (7.13), [7]	435.71, (49.6), [7]	59.27, (6.76), [7]
Serum	FTS Medium	Kidney	M	ng/g	44.06, (7.03), [7]	43.99, (6.99), [7]	43.99, (6.99), [7]	275.14, (43.87), [7]	39.6, (6.28), [7]	275.14, (43.87), [7]	37.4, (5.97), [7]
Serum	FTS Medium	Liver	F	ng/g	19.18, (0.38), [10]	19.14, (0.36), [10]	19.14, (0.36), [10]	119.6, (2.32), [10]	17.22, (0.33), [10]	119.6, (2.32), [10]	16.27, (0.3), [10]
Serum	FTS Medium	Liver	M	ng/g	19.08, (0.58), [10]	19.05, (0.58), [10]	19.05, (0.58), [10]	119.1, (3.45), [10]	17.14, (0.53), [10]	119.1, (3.45), [10]	16.19, (0.51), [10]
Serum	FTS High	Brain	F	ng/g	255, (133), [7]	254.86, (132.81), [7]	254.86, (132.81), [7]	1592.14, (830.23), [7]	229.29, (119.67), [7]	1592.14, (830.23), [7]	216.5, (112.92), [7]
Serum	FTS High	Brain	M	ng/g	232.57, (63.77), [7]	232.29, (63.8), [7]	232.29, (63.8), [7]	1454.29, (398.87), [7]	209, (57.23), [7]	1454.29, (398.87), [7]	197.43, (54.05), [7]
Serum	FTS High	Kidney	F	ng/g	138.14, (26.34), [7]	138, (26.42), [7]	138, (26.42), [7]	862.29, (165.61), [7]	124.17, (23.93), [7]	862.29, (165.61), [7]	117.26, (22.46), [7]
Serum	FTS High	Kidney	M	ng/g	87.26, (10.87), [7]	87.17, (10.89), [7]	87.17, (10.89), [7]	545, (68.53), [7]	78.47, (9.86), [7]	545, (68.53), [7]	74.13, (9.33), [7]
Serum	FTS High	Liver	F	ng/g	38.9, (0.67), [10]	38.83, (0.68), [10]	38.83, (0.68), [10]	242.8, (4.44), [10]	34.95, (0.59), [10]	242.8, (4.44), [10]	33.02, (0.56), [10]
Serum	FTS High	Liver	M	ng/g	38.87, (1.02), [10]	38.84, (1.02), [10]	38.84, (1.02), [10]	242.7, (6.38), [10]	34.94, (0.91), [10]	242.7, (6.38), [10]	33, (0.86), [10]
Serum	Control	Brain	F	ng/g	2.67, (0.52), [7]	2.67, (0.52), [7]	2.67, (0.52), [7]	16.67, (3.27), [7]	2.4, (0.47), [7]	16.67, (3.27), [7]	2.27, (0.44), [7]
Serum	Control	Brain	M	ng/g	2.44, (0.21), [7]	2.43, (0.21), [7]	2.43, (0.21), [7]	15.2, (1.33), [7]	2.19, (0.19), [7]	15.2, (1.33), [7]	2.07, (0.18), [7]
Serum	Control	Kidney	F	ng/g	3.2, (0.28), [7]	3.19, (0.28), [7]	3.19, (0.28), [7]	19.96, (1.75), [7]	2.87, (0.25), [7]	19.96, (1.75), [7]	2.71, (0.24), [7]
Serum	Control	Kidney	M	ng/g	1.73, (0.17), [7]	1.73, (0.17), [7]	1.73, (0.17), [7]	10.82, (1.09), [7]	1.56, (0.15), [7]	10.82, (1.09), [7]	1.47, (0.15), [7]
Serum	Control	Liver	F	ng/g	0.67, (0.08), [7]	0.66, (0.08), [7]	0.66, (0.08), [7]	4.15, (0.49), [7]	0.6, (0.07), [7]	4.15, (0.49), [7]	0.56, (0.07), [7]
Serum	Control	Liver	M	ng/g	0.49, (0.03), [7]	0.72, (0.63), [7]	0.49, (0.03), [7]	3.05, (0.19), [7]	0.44, (0.03), [7]	3.05, (0.19), [7]	0.41, (0.03), [7]

Table SI3.4. Table SI3.3 continued.

Study	Treatment	Sample Type	Sex	Units	9Cl-PF3ONS	ADONA	EtFOSAA	HFPO-DA	MeFOSAA	N-EtFOSA	N-EtFOSE
Wholebody	PFOS	water	NA	ng/L	852000, (NA), [1]	850000, (NA), [1]	213000, (NA), [1]	850000, (NA), [1]	213000, (NA), [1]	595000, (NA), [1]	2130000, (NA), [1]
Wholebody	PFOS	wholebody	F	ng/g	1.96, (0.03), [20]	1.95, (0.03), [20]	0.49, (0.01), [20]	1.95, (0.03), [20]	0.49, (0.01), [20]	1.37, (0.02), [20]	4.89, (0.07), [20]
Wholebody	PFOS	wholebody	M	ng/g	1.97, (0.03), [20]	1.96, (0.03), [20]	0.49, (0.01), [20]	1.96, (0.03), [20]	0.49, (0.01), [20]	1.38, (0.02), [20]	4.91, (0.07), [20]
Wholebody	PFOA	water	NA	ng/L	807000, (NA), [1]	805000, (NA), [1]	201000, (NA), [1]	805000, (NA), [1]	201000, (NA), [1]	563000, (NA), [1]	2010000, (NA), [1]
Wholebody	PFOA	wholebody	F	ng/g	0.38, (0.01), [10]	0.38, (0.01), [10]	0.09, (0), [10]	0.38, (0.01), [10]	0.09, (0), [10]	0.27, (0.01), [10]	0.95, (0.03), [10]
Wholebody	PFOA	wholebody	M	ng/g	0.38, (0.01), [9]	0.38, (0.01), [9]	0.09, (0), [9]	0.38, (0.01), [9]	0.09, (0), [9]	0.26, (0.01), [9]	0.95, (0.02), [6]
Wholebody	PFHxS	water	NA	ng/L	715000, (NA), [1]	714000, (NA), [1]	178000, (NA), [1]	714000, (NA), [1]	178000, (NA), [1]	5e+05, (NA), [1]	1780000, (NA), [1]
Wholebody	PFHxS	wholebody	F	ng/g	30.69, (1.06), [10]	30.61, (1.07), [10]	7.65, (0.26), [10]	30.61, (1.07), [10]	7.65, (0.26), [10]	21.4, (0.75), [10]	76.5, (2.63), [10]

Wholebody	PFHxS	wholebody	M	ng/g	30.62, (1.39), [10]	30.55, (1.36), [10]	7.63, (0.34), [10]	30.55, (1.36), [10]	7.63, (0.34), [10]	21.38, (0.96), [10]	76.33, (3.39), [10]
Wholebody	PFHxA	water	NA	ng/L	862000, (NA), [1]	860000, (NA), [1]	215000, (NA), [1]	860000, (NA), [1]	215000, (NA), [1]	602000, (NA), [1]	2150000, (NA), [1]
Wholebody	PFHxA	wholebody	F	ng/g	0.73, (0.02), [10]	0.73, (0.02), [10]	0.18, (0.01), [10]	0.73, (0.02), [10]	0.18, (0.01), [10]	0.51, (0.02), [10]	1.83, (0.06), [10]
Wholebody	PFHxA	wholebody	M	ng/g	0.74, (0.03), [10]	0.74, (0.03), [10]	0.18, (0.01), [10]	0.74, (0.03), [10]	0.18, (0.01), [10]	0.52, (0.02), [10]	1.84, (0.08), [10]
Wholebody	PFNA	water	NA	ng/L	841000, (NA), [1]	839000, (NA), [1]	210000, (NA), [1]	839000, (NA), [1]	210000, (NA), [1]	587000, (NA), [1]	2100000, (NA), [1]
Wholebody	PFNA	wholebody	F	ng/g	30.23, (1.52), [10]	30.16, (1.51), [10]	7.54, (0.37), [10]	30.16, (1.51), [10]	7.54, (0.37), [10]	21.09, (1.06), [10]	75.37, (3.73), [10]
Wholebody	PFNA	wholebody	M	ng/g	30.14, (1.57), [10]	30.08, (1.57), [10]	7.52, (0.39), [10]	30.08, (1.57), [10]	7.52, (0.39), [10]	21.03, (1.09), [10]	75.18, (3.9), [10]
Wholebody	PFBS	water	NA	ng/L	734000, (NA), [1]	733000, (NA), [1]	183000, (NA), [1]	733000, (NA), [1]	183000, (NA), [1]	513000, (NA), [1]	1830000, (NA), [1]
Wholebody	PFBS	wholebody	F	ng/g	7.62, (0.31), [10]	7.6, (0.31), [10]	1.9, (0.08), [10]	7.6, (0.31), [10]	1.9, (0.08), [10]	5.32, (0.22), [10]	18.98, (0.79), [10]
Wholebody	PFBS	wholebody	M	ng/g	7.51, (0.28), [10]	7.49, (0.28), [10]	1.87, (0.07), [10]	7.49, (0.28), [10]	1.87, (0.07), [10]	5.24, (0.2), [10]	18.72, (0.69), [10]
Wholebody	6:2 FTS	water	NA	ng/L	213000, (NA), [1]	213000, (NA), [1]	53200, (NA), [1]	213000, (NA), [1]	53200, (NA), [1]	149000, (NA), [1]	532000, (NA), [1]
Wholebody	6:2 FTS	wholebody	F	ng/g	0.38, (0.01), [10]	0.38, (0.01), [10]	0.1, (0), [10]	0.38, (0.01), [10]	0.1, (0), [10]	0.29, (0.06), [10]	0.96, (0.03), [10]
Wholebody	6:2 FTS	wholebody	M	ng/g	0.38, (0.01), [10]	0.38, (0.01), [10]	0.09, (0), [10]	0.38, (0.01), [10]	0.09, (0), [10]	0.26, (0.01), [10]	0.94, (0.03), [10]
Wholebody	8:2 FTS	water	NA	ng/L	207000, (NA), [1]	207000, (NA), [1]	51700, (NA), [1]	207000, (NA), [1]	51700, (NA), [1]	145000, (NA), [1]	517000, (NA), [1]
Wholebody	8:2 FTS	wholebody	F	ng/g	0.39, (0.01), [9]	0.39, (0.01), [9]	0.1, (0), [9]	0.39, (0.01), [9]	0.1, (0), [9]	0.27, (0.01), [9]	0.96, (0.03), [9]
Wholebody	8:2 FTS	wholebody	M	ng/g	0.39, (0.01), [11]	0.39, (0.01), [11]	0.1, (0), [11]	0.39, (0.01), [11]	0.1, (0), [11]	0.27, (0), [11]	0.97, (0.02), [11]
Wholebody	C68LOW	water	NA	ng/L	77100, (NA), [1]	76900, (NA), [1]	19200, (NA), [1]	76900, (NA), [1]	19200, (NA), [1]	53800, (NA), [1]	192000, (NA), [1]
Wholebody	C68LOW	wholebody	F	ng/g	7.65, (0.27), [10]	7.63, (0.27), [10]	1.91, (0.07), [10]	7.63, (0.27), [10]	1.91, (0.07), [10]	5.34, (0.19), [10]	19.05, (0.66), [10]
Wholebody	C68LOW	wholebody	M	ng/g	7.65, (0.29), [10]	7.63, (0.29), [10]	1.93, (0.06), [10]	7.63, (0.29), [10]	1.91, (0.07), [10]	5.34, (0.2), [10]	19.08, (0.71), [10]
Wholebody	C68MED	water	NA	ng/L	438000, (NA), [1]	437000, (NA), [1]	109000, (NA), [1]	437000, (NA), [1]	109000, (NA), [1]	306000, (NA), [1]	1090000, (NA), [1]
Wholebody	C68MED	wholebody	F	ng/g	7.83, (0.22), [10]	7.81, (0.22), [10]	1.95, (0.06), [10]	7.81, (0.22), [10]	1.95, (0.06), [10]	5.47, (0.15), [10]	19.53, (0.55), [10]
Wholebody	C68MED	wholebody	M	ng/g	7.83, (0.15), [9]	7.81, (0.15), [9]	1.95, (0.04), [9]	7.81, (0.15), [9]	1.95, (0.04), [9]	5.47, (0.1), [9]	19.53, (0.35), [9]
Wholebody	C68HIGH	water	NA	ng/L	444000, (NA), [1]	442000, (NA), [1]	111000, (NA), [1]	442000, (NA), [1]	111000, (NA), [1]	310000, (NA), [1]	1110000, (NA), [1]
Wholebody	C68HIGH	wholebody	F	ng/g	26.94, (1.62), [10]	26.89, (1.62), [10]	7.16, (0.9), [10]	26.89, (1.62), [10]	6.72, (0.4), [10]	18.78, (1.14), [10]	67.18, (4.05), [10]
Wholebody	C68HIGH	wholebody	M	ng/g	28.39, (2.26), [10]	28.31, (2.25), [10]	7.21, (0.54), [10]	28.31, (2.25), [10]	7.08, (0.56), [10]	19.82, (1.59), [10]	70.77, (5.61), [10]
Wholebody	FTSLOW	water	NA	ng/L	68500, (NA), [1]	68400, (NA), [1]	17100, (NA), [1]	68400, (NA), [1]	17100, (NA), [1]	47900, (NA), [1]	171000, (NA), [1]
Wholebody	FTSLOW	wholebody	F	ng/g	15.34, (0.67), [10]	15.3, (0.67), [10]	3.83, (0.17), [10]	15.3, (0.67), [10]	3.83, (0.17), [10]	10.73, (0.47), [10]	38.27, (1.67), [10]
Wholebody	FTSLOW	wholebody	M	ng/g	15.08, (0.64), [10]	15.05, (0.64), [10]	3.76, (0.16), [10]	15.05, (0.64), [10]	3.76, (0.16), [10]	10.56, (0.45), [10]	37.62, (1.61), [10]
Wholebody	FTSMED	water	NA	ng/L	214000, (NA), [1]	214000, (NA), [1]	53400, (NA), [1]	214000, (NA), [1]	53400, (NA), [1]	150000, (NA), [1]	534000, (NA), [1]
Wholebody	FTSMED	wholebody	F	ng/g	7.55, (0.36), [10]	7.53, (0.36), [10]	1.88, (0.09), [10]	7.53, (0.36), [10]	1.88, (0.09), [10]	5.27, (0.25), [10]	18.83, (0.89), [10]
Wholebody	FTSMED	wholebody	M	ng/g	7.6, (0.31), [10]	7.58, (0.3), [10]	1.9, (0.08), [10]	7.58, (0.3), [10]	1.9, (0.08), [10]	5.3, (0.21), [10]	18.95, (0.76), [10]
Wholebody	FTSHIGH	water	NA	ng/L	433000, (NA), [1]	432000, (NA), [1]	108000, (NA), [1]	432000, (NA), [1]	108000, (NA), [1]	302000, (NA), [1]	1080000, (NA), [1]
Wholebody	FTSHIGH	wholebody	F	ng/g	26.65, (1.71), [10]	26.56, (1.72), [10]	6.73, (0.57), [10]	26.56, (1.72), [10]	6.64, (0.43), [10]	18.6, (1.18), [10]	66.42, (4.29), [10]
Wholebody	FTSHIGH	wholebody	M	ng/g	27.04, (1.81), [10]	26.99, (1.79), [10]	7.08, (0.88), [10]	26.99, (1.79), [10]	6.75, (0.45), [10]	18.88, (1.25), [10]	67.47, (4.48), [10]
Wholebody	Control	water	NA	ng/L	44600, (NA), [1]	44400, (NA), [1]	11100, (NA), [1]	44400, (NA), [1]	11100, (NA), [1]	31100, (NA), [1]	111000, (NA), [1]
Wholebody	Control	wholebody	F	ng/g	0.39, (0.01), [10]	0.38, (0.01), [10]	0.1, (0), [10]	0.38, (0.01), [10]	0.1, (0), [10]	0.27, (0.01), [10]	0.96, (0.02), [9]
Wholebody	Control	wholebody	M	ng/g	0.39, (0.01), [10]	0.39, (0.01), [10]	0.1, (0), [10]	0.39, (0.01), [10]	0.1, (0), [10]	0.28, (0), [10]	1.13, (0.26), [8]
Serum	PFOS	serum	F	ng/mL	72.9, (4.12), [10]	72.71, (4.11), [10]	18.19, (1.02), [10]	72.71, (4.11), [10]	18.19, (1.02), [10]	50.91, (2.87), [10]	181.9, (10.25), [10]
Serum	PFOS	serum	M	ng/mL	66.73, (7.99), [9]	66.56, (7.97), [9]	16.67, (1.99), [9]	66.56, (7.97), [9]	16.67, (1.99), [9]	46.6, (5.57), [9]	166.67, (19.89), [9]
Serum	PFOS	water	NA	ng/L	383000, (NA), [1]	382000, (NA), [1]	95500, (NA), [1]	382000, (NA), [1]	95500, (NA), [1]	267000, (NA), [1]	955000, (NA), [1]
Serum	PFOA	serum	F	ng/mL	3.94, (0.16), [10]	3.93, (0.16), [10]	0.98, (0.04), [10]	3.93, (0.16), [10]	0.98, (0.04), [10]	2.75, (0.11), [10]	9.81, (0.38), [10]
Serum	PFOA	serum	M	ng/mL	3.94, (0.14), [10]	3.93, (0.14), [10]	0.98, (0.04), [10]	3.93, (0.14), [10]	0.98, (0.04), [10]	2.74, (0.1), [10]	9.81, (0.36), [10]
Serum	PFOA	water	NA	ng/L	799000, (NA), [1]	797000, (NA), [1]	199000, (NA), [1]	797000, (NA), [1]	199000, (NA), [1]	558000, (NA), [1]	1990000, (NA), [1]
Serum	PFHxS	serum	F	ng/mL	4.47, (1.17), [10]	4.46, (1.17), [10]	1.11, (0.29), [10]	4.46, (1.17), [10]	1.11, (0.29), [10]	3.12, (0.82), [10]	11.15, (2.92), [10]
Serum	PFHxS	serum	M	ng/mL	4.36, (0.83), [10]	4.35, (0.83), [10]	1.09, (0.21), [10]	4.35, (0.83), [10]	1.09, (0.21), [10]	3.04, (0.58), [10]	10.87, (2.08), [10]
Serum	PFHxS	water	NA	ng/L	845000, (NA), [1]	843000, (NA), [1]	211000, (NA), [1]	843000, (NA), [1]	211000, (NA), [1]	590000, (NA), [1]	2110000, (NA), [1]
Serum	PFHxA	serum	F	ng/mL	4.13, (0.42), [9]	4.12, (0.42), [9]	1.03, (0.11), [9]	4.12, (0.42), [9]	1.03, (0.11), [9]	2.88, (0.3), [9]	10.29, (1.06), [9]
Serum	PFHxA	serum	M	ng/mL	4.27, (0.57), [10]	4.26, (0.57), [10]	1.06, (0.14), [10]	4.26, (0.57), [10]	1.06, (0.14), [10]	2.98, (0.4), [10]	10.62, (1.43), [10]
Serum	PFHxA	water	NA	ng/L	817000, (NA), [1]	815000, (NA), [1]	204000, (NA), [1]	815000, (NA), [1]	204000, (NA), [1]	570000, (NA), [1]	2040000, (NA), [1]
Serum	PFNA	serum	F	ng/mL	595.9, (19.15), [10]	594.4, (19.41), [10]	148.6, (4.99), [10]	594.4, (19.41), [10]	148.6, (4.99), [10]	416.1, (13.29), [10]	1486, (49.93), [10]
Serum	PFNA	serum	M	ng/mL	576.9, (26.2), [10]	575.5, (26.25), [10]	144, (6.46), [10]	575.5, (26.25), [10]	144, (6.46), [10]	402.8, (18.32), [10]	1440, (64.64), [10]
Serum	PFNA	water	NA	ng/L	738000, (NA), [1]	737000, (NA), [1]	184000, (NA), [1]	737000, (NA), [1]	184000, (NA), [1]	516000, (NA), [1]	1840000, (NA), [1]
Serum	PFBS	serum	F	ng/mL	4.88, (1.56), [10]	4.87, (1.56), [10]	1.22, (0.39), [10]	4.87, (1.56), [10]	1.22, (0.39), [10]	3.41, (1.09), [10]	12.16, (3.89), [10]
Serum	PFBS	serum	M	ng/mL	4.75, (2.06), [10]	4.74, (2.07), [10]	1.18, (0.52), [10]	4.74, (2.07), [10]	1.18, (0.52), [10]	3.32, (1.45), [10]	11.85, (5.18), [10]
Serum	PFBS	water	NA	ng/L	807000, (NA), [1]	805000, (NA), [1]	201000, (NA), [1]	805000, (NA), [1]	201000, (NA), [1]	563000, (NA), [1]	2010000, (NA), [1]
Serum	6:2 FTS	serum	F	ng/mL	3.41, (0.87), [10]	3.4, (0.87), [10]	0.85, (0.22), [10]	3.4, (0.87), [10]	0.85, (0.22), [10]	2.38, (0.61), [10]	8.5, (2.16), [10]
Serum	6:2 FTS	serum	M	ng/mL	3.45, (0.93), [10]	3.44, (0.93), [10]	0.86, (0.23), [10]	3.44, (0.93), [10]	0.86, (0.23), [10]	2.41, (0.65), [10]	8.6, (2.31), [10]
Serum	6:2 FTS	water	NA	ng/L	188000, (NA), [1]	188000, (NA), [1]	47000, (NA), [1]	188000, (NA), [1]	47000, (NA), [1]	132000, (NA), [1]	470000, (NA), [1]
Serum	8:2 FTS	serum	F	ng/mL	3.46, (0.97), [10]	3.45, (0.97), [10]	0.86, (0.24), [10]	3.45, (0.97), [10]	0.86, (0.24), [10]	2.42, (0.68), [10]	8.62, (2.42), [10]
Serum	8:2 FTS	serum	M	ng/mL	2.98, (0.64), [10]	2.98, (0.64), [10]	0.74, (0.16), [10]	2.98, (0.64), [10]	0.74, (0.16), [10]	2.08, (0.45), [10]	7.44, (1.6), [10]
Serum	8:2 FTS	water	NA	ng/L	202000, (NA), [1]	202000, (NA), [1]	50500, (NA), [1]	202000, (NA), [1]	50500, (NA), [1]	141000, (NA), [1]	505000, (NA), [1]
Serum	C68LOW	serum	F	ng/mL	38.27, (1.85), [10]	38.17, (1.85), [10]	9.54, (0.45), [10]	38.17, (1.85), [10]	9.54, (0.45), [10]	26.74, (1.28), [10]	95.41, (4.52), [10]

Serum	C68LOW	serum	M	ng/mL	39.38, (1.83), [10]	39.28, (1.83), [10]	9.8, (0.43), [10]	39.28, (1.83), [10]	9.8, (0.43), [10]	27.5, (1.28), [10]	98.02, (4.32), [10]
Serum	C68LOW	water	NA	ng/L	81000, (NA), [1]	80800, (NA), [1]	20200, (NA), [1]	80800, (NA), [1]	20200, (NA), [1]	56600, (NA), [1]	202000, (NA), [1]
Serum	C68MED	serum	F	ng/mL	192.5, (8.51), [10]	191.7, (8.84), [10]	47.97, (2.17), [10]	191.7, (8.84), [10]	47.97, (2.17), [10]	134.2, (6.09), [10]	479.7, (21.73), [10]
Serum	C68MED	serum	M	ng/mL	192.4, (4.65), [10]	191.4, (4.65), [10]	47.92, (1.14), [10]	191.4, (4.65), [10]	47.92, (1.14), [10]	134.2, (3.61), [10]	479.2, (11.36), [10]
Serum	C68MED	water	NA	ng/L	196000, (NA), [1]	196000, (NA), [1]	48900, (NA), [1]	196000, (NA), [1]	48900, (NA), [1]	137000, (NA), [1]	489000, (NA), [1]
Serum	C68HIGH	serum	F	ng/mL	595.7, (14.01), [10]	594, (14.49), [10]	148.4, (3.86), [10]	594, (14.49), [10]	148.4, (3.86), [10]	416, (9.66), [10]	1484, (38.64), [10]
Serum	C68HIGH	serum	M	ng/mL	591, (27.1), [9]	589.44, (27.2), [9]	147.33, (6.86), [9]	589.44, (27.2), [9]	147.33, (6.86), [9]	412.78, (19.04), [9]	1473.33, (68.56), [9]
Serum	C68HIGH	water	NA	ng/L	422000, (NA), [1]	421000, (NA), [1]	105000, (NA), [1]	421000, (NA), [1]	105000, (NA), [1]	295000, (NA), [1]	1050000, (NA), [1]
Serum	FTSLOW	serum	F	ng/mL	38.06, (1.53), [10]	37.96, (1.53), [10]	9.49, (0.37), [10]	37.96, (1.53), [10]	9.49, (0.37), [10]	26.6, (1.06), [10]	94.91, (3.66), [10]
Serum	FTSLOW	serum	M	ng/mL	37.88, (1.5), [10]	37.78, (1.5), [10]	9.45, (0.36), [10]	37.78, (1.5), [10]	9.45, (0.36), [10]	26.48, (1.03), [10]	94.47, (3.58), [10]
Serum	FTSLOW	water	NA	ng/L	78600, (NA), [1]	78400, (NA), [1]	19600, (NA), [1]	78400, (NA), [1]	19600, (NA), [1]	54900, (NA), [1]	196000, (NA), [1]
Serum	FTSMED	serum	F	ng/mL	179.1, (7.31), [10]	178.3, (6.96), [10]	44.6, (1.78), [10]	178.3, (6.96), [10]	44.6, (1.78), [10]	124.9, (4.84), [10]	446, (17.83), [10]
Serum	FTSMED	serum	M	ng/mL	184.8, (7.9), [10]	183.9, (7.71), [10]	46.02, (1.97), [10]	183.9, (7.71), [10]	46.02, (1.97), [10]	128.8, (5.57), [10]	460.2, (19.65), [10]
Serum	FTSMED	water	NA	ng/L	235000, (NA), [1]	235000, (NA), [1]	58600, (NA), [1]	235000, (NA), [1]	58600, (NA), [1]	164000, (NA), [1]	586000, (NA), [1]
Serum	FTSHIGH	serum	F	ng/mL	602.2, (28.03), [10]	601, (28.16), [10]	150.4, (7.11), [10]	601, (28.16), [10]	150.4, (7.11), [10]	420.5, (19.63), [10]	1504, (71.06), [10]
Serum	FTSHIGH	serum	M	ng/mL	596.9, (32.38), [10]	595.5, (32.69), [10]	149, (8.18), [10]	595.5, (32.69), [10]	149, (8.18), [10]	416.8, (22.71), [10]	1490, (81.79), [10]
Serum	FTSHIGH	water	NA	ng/L	401000, (NA), [1]	4e+05, (NA), [1]	1e+05, (NA), [1]	4e+05, (NA), [1]	1e+05, (NA), [1]	280000, (NA), [1]	1e+06, (NA), [1]
Serum	Control	serum	F	ng/mL	5.88, (2.72), [10]	5.86, (2.73), [10]	1.47, (0.68), [10]	5.86, (2.73), [10]	1.47, (0.68), [10]	4.11, (1.9), [10]	14.65, (6.8), [10]
Serum	Control	serum	M	ng/mL	4.2, (1.24), [10]	4.19, (1.23), [10]	1.05, (0.31), [10]	4.19, (1.23), [10]	1.05, (0.31), [10]	2.94, (0.86), [10]	10.5, (3.1), [10]
Serum	Control	water	NA	ng/L	42900, (NA), [1]	42800, (NA), [1]	10700, (NA), [1]	42800, (NA), [1]	10700, (NA), [1]	29900, (NA), [1]	107000, (NA), [1]
Serum	PFOS	Brain	F	ng/g	3462.86, (566.35), [7]	3454.29, (564.38), [7]	864.29, (142.59), [7]	3454.29, (564.38), [7]	864.29, (142.59), [7]	2418.57, (397.17), [7]	8642.86, (1425.86), [7]
Serum	PFOS	Brain	M	ng/g	4008.57, (831.73), [7]	3998.57, (831.73), [7]	1000.43, (208.03), [7]	3998.57, (831.73), [7]	1000.43, (208.03), [7]	2801.43, (581.71), [7]	10004.29, (2080.26), [7]
Serum	PFOS	Kidney	F	ng/g	2445.71, (272.63), [7]	2440, (270.31), [7]	609.86, (67.21), [7]	2440, (270.31), [7]	609.86, (67.21), [7]	1708.57, (189.69), [7]	6098.57, (672.1), [7]
Serum	PFOS	Kidney	M	ng/g	1714.29, (207.27), [7]	1712.86, (206.54), [7]	428, (51.53), [7]	1712.86, (206.54), [7]	428, (51.53), [7]	1197.14, (145.23), [7]	4280, (515.33), [7]
Serum	PFOS	Liver	F	ng/g	110, (3.32), [7]	109.86, (3.29), [7]	27.41, (0.8), [7]	109.86, (3.29), [7]	27.41, (0.8), [7]	76.81, (2.29), [7]	274.14, (7.97), [7]
Serum	PFOS	Liver	M	ng/g	110.3, (6.12), [7]	109.97, (5.93), [7]	27.5, (1.48), [7]	109.97, (5.93), [7]	27.5, (1.48), [7]	76.99, (4.19), [7]	275, (14.84), [7]
Serum	PFOA	Brain	F	ng/g	2694.29, (617.6), [7]	2688.57, (614.48), [7]	672.14, (153.72), [7]	2688.57, (614.48), [7]	672.14, (153.72), [7]	1882.86, (431.85), [7]	6721.43, (1537.19), [7]
Serum	PFOA	Brain	M	ng/g	2820, (510.07), [7]	2811.43, (508.9), [7]	702.86, (127.03), [7]	2811.43, (508.9), [7]	702.86, (127.03), [7]	1968.57, (357.14), [7]	7028.57, (1270.33), [7]
Serum	PFOA	Kidney	F	ng/g	2441.43, (240.72), [7]	2435.71, (236.7), [7]	609.14, (59.56), [7]	2435.71, (236.7), [7]	609.14, (59.56), [7]	1702.86, (168.1), [7]	6091.43, (595.63), [7]
Serum	PFOA	Kidney	M	ng/g	1641.43, (226.6), [7]	1637.14, (225.74), [7]	409.57, (56.39), [7]	1637.14, (225.74), [7]	409.57, (56.39), [7]	1143.86, (156.44), [7]	4095.71, (563.85), [7]
Serum	PFOA	Liver	F	ng/g	108.29, (3.9), [7]	108.14, (3.89), [7]	27.04, (0.98), [7]	108.14, (3.89), [7]	27.04, (0.98), [7]	75.71, (2.67), [7]	270.43, (9.78), [7]
Serum	PFOA	Liver	M	ng/g	112, (3.65), [7]	111.71, (3.59), [7]	27.94, (0.91), [7]	111.71, (3.59), [7]	27.94, (0.91), [7]	78.23, (2.52), [7]	279.43, (9.05), [7]
Serum	PFHxS	Brain	F	ng/g	437.86, (122.51), [7]	436.71, (121.97), [7]	109.24, (30.67), [7]	436.71, (121.97), [7]	109.24, (30.67), [7]	305.86, (85.52), [7]	1092.43, (306.66), [7]
Serum	PFHxS	Brain	M	ng/g	412.43, (107.5), [7]	411.57, (107.37), [7]	102.81, (26.69), [7]	411.57, (107.37), [7]	102.81, (26.69), [7]	288, (74.99), [7]	1028.14, (266.93), [7]
Serum	PFHxS	Kidney	F	ng/g	432.57, (59.8), [7]	431.43, (59.66), [7]	107.7, (14.92), [7]	431.43, (59.66), [7]	107.7, (14.92), [7]	302.14, (41.7), [7]	1077, (149.18), [7]
Serum	PFHxS	Kidney	M	ng/g	253.57, (47.88), [7]	252.57, (47.88), [7]	63.17, (12), [7]	252.57, (47.88), [7]	63.17, (12), [7]	177, (33.68), [7]	631.71, (120.04), [7]
Serum	PFHxS	Liver	F	ng/g	114.29, (3.35), [7]	114.14, (3.34), [7]	28.51, (0.82), [7]	114.14, (3.34), [7]	28.51, (0.82), [7]	79.89, (2.32), [7]	285.14, (8.21), [7]
Serum	PFHxS	Liver	M	ng/g	113.71, (3.25), [7]	113.57, (3.31), [7]	28.39, (0.79), [7]	113.57, (3.31), [7]	28.39, (0.79), [7]	79.46, (2.23), [7]	283.86, (7.9), [7]
Serum	PFHxA	Brain	F	ng/g	5.72, (4.49), [7]	5.71, (4.49), [7]	1.42, (1.12), [7]	5.71, (4.49), [7]	1.42, (1.12), [7]	4, (3.15), [7]	14.24, (11.21), [7]
Serum	PFHxA	Brain	M	ng/g	3.5, (0.46), [7]	3.49, (0.46), [7]	0.87, (0.12), [7]	3.49, (0.46), [7]	0.87, (0.12), [7]	2.45, (0.32), [7]	8.73, (1.16), [7]
Serum	PFHxA	Kidney	F	ng/g	2.73, (0.36), [7]	2.72, (0.36), [7]	0.68, (0.09), [7]	2.72, (0.36), [7]	0.68, (0.09), [7]	1.9, (0.25), [7]	6.8, (0.89), [7]
Serum	PFHxA	Kidney	M	ng/g	1.56, (0.19), [7]	1.55, (0.19), [7]	0.39, (0.05), [7]	1.55, (0.19), [7]	0.39, (0.05), [7]	1.09, (0.13), [7]	3.88, (0.47), [7]
Serum	PFHxA	Liver	F	ng/g	0.92, (0.45), [7]	0.92, (0.45), [7]	0.23, (0.11), [7]	0.92, (0.45), [7]	0.23, (0.11), [7]	0.64, (0.31), [7]	2.29, (1.12), [7]
Serum	PFHxA	Liver	M	ng/g	0.84, (0.26), [7]	0.84, (0.26), [7]	0.21, (0.06), [7]	0.84, (0.26), [7]	0.21, (0.06), [7]	0.59, (0.18), [7]	2.11, (0.64), [7]
Serum	6:2 FTS	Brain	F	ng/g	178.96, (100.93), [7]	178.63, (100.64), [7]	44.64, (25.16), [7]	178.63, (100.64), [7]	44.64, (25.16), [7]	125.08, (70.54), [7]	446.43, (251.6), [7]
Serum	6:2 FTS	Brain	M	ng/g	265.14, (91.62), [7]	264.71, (91.3), [7]	66.16, (22.86), [7]	264.71, (91.3), [7]	66.16, (22.86), [7]	185.29, (63.74), [7]	661.57, (228.56), [7]
Serum	6:2 FTS	Kidney	F	ng/g	67.13, (9.01), [7]	66.97, (8.97), [7]	16.73, (2.26), [7]	66.97, (8.97), [7]	16.73, (2.26), [7]	46.87, (6.28), [7]	167.29, (22.63), [7]
Serum	6:2 FTS	Kidney	M	ng/g	45.19, (9.6), [7]	45.09, (9.6), [7]	11.27, (2.41), [7]	45.09, (9.6), [7]	11.27, (2.41), [7]	31.57, (6.69), [7]	112.71, (24.06), [7]
Serum	6:2 FTS	Liver	F	ng/g	39.61, (0.61), [7]	39.51, (0.61), [7]	9.88, (0.16), [7]	39.51, (0.61), [7]	9.88, (0.16), [7]	27.66, (0.44), [7]	98.8, (1.63), [7]
Serum	6:2 FTS	Liver	M	ng/g	39.53, (0.34), [7]	39.43, (0.34), [7]	9.85, (0.08), [7]	39.43, (0.34), [7]	9.85, (0.08), [7]	27.6, (0.23), [7]	98.54, (0.81), [7]
Serum	8:2 FTS	Brain	F	ng/g	2456.14, (2257.26), [7]	2448.71, (2250.8), [7]	612.81, (564.51), [7]	2448.71, (2250.8), [7]	612.81, (564.51), [7]	1712.86, (1575), [7]	6128.14, (5645.1), [7]
Serum	8:2 FTS	Brain	M	ng/g	558.86, (971.92), [7]	557, (968.33), [7]	139.33, (242.27), [7]	557, (968.33), [7]	139.33, (242.27), [7]	390.56, (679.74), [7]	1393.29, (2422.68), [7]
Serum	8:2 FTS	Kidney	F	ng/g	146.86, (23.42), [7]	146, (23.17), [7]	36.56, (5.83), [7]	146, (23.17), [7]	36.56, (5.83), [7]	102.27, (16.32), [7]	365.57, (58.3), [7]
Serum	8:2 FTS	Kidney	M	ng/g	92.34, (13.15), [7]	92.06, (13.02), [7]	23.01, (3.24), [7]	92.06, (13.02), [7]	23.01, (3.24), [7]	64.41, (9.11), [7]	230.14, (32.4), [7]
Serum	8:2 FTS	Liver	F	ng/g	39.04, (1.07), [7]	38.94, (1.07), [7]	9.74, (0.27), [7]	38.94, (1.07), [7]	9.74, (0.27), [7]	27.24, (0.74), [7]	97.39, (2.66), [7]
Serum	8:2 FTS	Liver	M	ng/g	39.23, (0.78), [7]	39.13, (0.78), [7]	9.78, (0.18), [7]	39.13, (0.78), [7]	9.78, (0.18), [7]	27.39, (0.53), [7]	97.77, (1.82), [7]
Serum	C6-8 Low	Brain	F	ng/g	622.29, (255.62), [7]	619.71, (252.85), [7]	155.07, (63.46), [7]	619.71, (252.85), [7]	155.07, (63.46), [7]	434.14, (177.81), [7]	1550.71, (634.56), [7]
Serum	C6-8 Low	Brain	M	ng/g	503.43, (136.61), [7]	502.14, (136.26), [7]	125.49, (34.29), [7]	502.14, (136.26), [7]	125.49, (34.29), [7]	351.29, (95.42), [7]	1254.86, (342.87), [7]
Serum	C6-8 Low	Kidney	F	ng/g	29.03, (3.53), [7]	28.97, (3.5), [7]	7.24, (0.88), [7]	28.97, (3.5), [7]	7.24, (0.88), [7]	20.29, (2.47), [7]	72.4, (8.81), [7]
Serum	C6-8 Low	Kidney	M	ng/g	17.13, (1.76), [7]	17.13, (1.76), [7]	4.27, (0.44), [7]	17.13, (1.76), [7]	4.27, (0.44), [7]	11.96, (1.22), [7]	42.74, (4.4), [7]
Serum	C6-8 Low	Liver	F	ng/g	18.95, (0.4), [10]	18.87, (0.38), [10]	4.72, (0.1), [10]	18.87, (0.38), [10]	4.72, (0.1), [10]	13.22, (0.27), [10]	47.2, (0.98), [10]
Serum	C6-8 Low	Liver	M	ng/g	19.19, (0.37), [10]	19.14, (0.35), [10]	4.79, (0.09), [10]	19.14, (0.35), [10]	4.79, (0.09), [10]	13.41, (0.25), [10]	47.86, (0.89), [10]

Serum	C6-8 Medium	Brain	F	ng/g	983.57, (65.52), [7]	979.86, (62.72), [7]	245.29, (16.1), [7]	979.86, (62.72), [7]	245.29, (16.1), [7]	686.57, (44.89), [7]	2452.86, (161.01), [7]
Serum	C6-8 Medium	Brain	M	ng/g	1074.71, (95.24), [7]	1073.57, (96.64), [7]	268.29, (24.28), [7]	1073.57, (96.64), [7]	268.29, (24.28), [7]	751.43, (67.36), [7]	2682.86, (242.81), [7]
Serum	C6-8 Medium	Kidney	F	ng/g	137.14, (18.65), [7]	136.86, (18.49), [7]	34.19, (4.68), [7]	136.86, (18.49), [7]	34.19, (4.68), [7]	95.71, (13.09), [7]	341.86, (46.79), [7]
Serum	C6-8 Medium	Kidney	M	ng/g	86.87, (12.94), [7]	86.69, (12.98), [7]	21.67, (3.25), [7]	86.69, (12.98), [7]	21.67, (3.25), [7]	60.69, (9.08), [7]	216.71, (32.46), [7]
Serum	C6-8 Medium	Liver	F	ng/g	38.04, (0.91), [10]	37.95, (0.89), [10]	9.49, (0.22), [10]	37.95, (0.89), [10]	9.49, (0.22), [10]	26.56, (0.63), [10]	94.87, (2.24), [10]
Serum	C6-8 Medium	Liver	M	ng/g	38.36, (0.9), [10]	38.27, (0.9), [10]	9.57, (0.23), [10]	38.27, (0.9), [10]	9.57, (0.23), [10]	26.79, (0.63), [10]	95.68, (2.26), [10]
Serum	C6-8 High	Brain	F	ng/g	5994.29, (579.48), [7]	5984.29, (579.48), [7]	1497.14, (144.19), [7]	5984.29, (579.48), [7]	1497.14, (144.19), [7]	4187.14, (405), [7]	14971.43, (1441.89), [7]
Serum	C6-8 High	Brain	M	ng/g	5095.71, (2707.39), [7]	5085.71, (2711.39), [7]	1270.29, (674.45), [7]	5085.71, (2711.39), [7]	1270.29, (674.45), [7]	3554.29, (1888.31), [7]	12702.86, (6744.54), [7]
Serum	C6-8 High	Kidney	F	ng/g	141.86, (19.07), [7]	141.57, (18.86), [7]	35.39, (4.7), [7]	141.57, (18.86), [7]	35.39, (4.7), [7]	99.14, (13.28), [7]	353.86, (47.01), [7]
Serum	C6-8 High	Kidney	M	ng/g	88.5, (10.15), [7]	88.33, (10.2), [7]	22.07, (2.53), [7]	88.33, (10.2), [7]	22.07, (2.53), [7]	61.83, (7.11), [7]	220.71, (25.34), [7]
Serum	C6-8 High	Liver	F	ng/g	38.91, (1.12), [10]	38.81, (1.12), [10]	9.71, (0.29), [10]	38.81, (1.12), [10]	9.71, (0.29), [10]	27.17, (0.8), [10]	97.06, (2.86), [10]
Serum	C6-8 High	Liver	M	ng/g	38.2, (1.1), [9]	38.11, (1.1), [9]	9.52, (0.27), [9]	38.11, (1.1), [9]	9.52, (0.27), [9]	26.68, (0.79), [9]	95.19, (2.7), [9]
Serum	FTS Low	Brain	F	ng/g	548.14, (246.54), [7]	547, (246.81), [7]	136.77, (61.83), [7]	547, (246.81), [7]	136.77, (61.83), [7]	383, (173.13), [7]	1367.71, (618.28), [7]
Serum	FTS Low	Brain	M	ng/g	1022.43, (415.48), [7]	1018.43, (412.52), [7]	254.71, (103.33), [7]	1018.43, (412.52), [7]	254.71, (103.33), [7]	712.57, (287.93), [7]	2547.14, (1033.32), [7]
Serum	FTS Low	Kidney	F	ng/g	71.53, (5.78), [7]	71.36, (5.76), [7]	17.83, (1.43), [7]	71.36, (5.76), [7]	17.83, (1.43), [7]	49.94, (4.02), [7]	178.29, (14.28), [7]
Serum	FTS Low	Kidney	M	ng/g	42.89, (6.78), [7]	42.79, (6.78), [7]	10.7, (1.7), [7]	42.79, (6.78), [7]	10.7, (1.7), [7]	29.94, (4.73), [7]	107.01, (16.99), [7]
Serum	FTS Low	Liver	F	ng/g	19.1, (0.37), [10]	19.04, (0.35), [10]	4.76, (0.09), [10]	19.04, (0.35), [10]	4.76, (0.09), [10]	13.34, (0.24), [10]	47.6, (0.89), [10]
Serum	FTS Low	Liver	M	ng/g	19.02, (0.42), [10]	18.98, (0.43), [10]	4.75, (0.1), [10]	18.98, (0.43), [10]	4.75, (0.1), [10]	13.28, (0.3), [10]	47.46, (1.03), [10]
Serum	FTS Medium	Brain	F	ng/g	176.71, (75.81), [7]	176.14, (75.67), [7]	44.03, (18.88), [7]	176.14, (75.67), [7]	44.03, (18.88), [7]	123.26, (52.85), [7]	440.29, (188.79), [7]
Serum	FTS Medium	Brain	M	ng/g	231, (93.36), [7]	230.43, (93.08), [7]	57.6, (23.29), [7]	230.43, (93.08), [7]	57.6, (23.29), [7]	161.2, (65.25), [7]	576, (232.93), [7]
Serum	FTS Medium	Kidney	F	ng/g	69.89, (7.94), [7]	69.7, (7.93), [7]	17.41, (2), [7]	69.7, (7.93), [7]	17.41, (2), [7]	48.8, (5.57), [7]	174.14, (19.97), [7]
Serum	FTS Medium	Kidney	M	ng/g	44.13, (7.02), [7]	43.99, (6.99), [7]	11, (1.75), [7]	43.99, (6.99), [7]	11, (1.75), [7]	30.81, (4.9), [7]	109.99, (17.54), [7]
Serum	FTS Medium	Liver	F	ng/g	19.18, (0.38), [10]	19.14, (0.36), [10]	4.79, (0.09), [10]	19.14, (0.36), [10]	4.79, (0.09), [10]	13.39, (0.26), [10]	47.87, (0.93), [10]
Serum	FTS Medium	Liver	M	ng/g	19.11, (0.59), [10]	19.05, (0.58), [10]	4.77, (0.15), [10]	19.05, (0.58), [10]	4.77, (0.15), [10]	13.32, (0.4), [10]	47.65, (1.47), [10]
Serum	FTS High	Brain	F	ng/g	255.43, (133.22), [7]	254.86, (132.81), [7]	63.7, (33.18), [7]	254.86, (132.81), [7]	63.7, (33.18), [7]	178.16, (93.01), [7]	637, (331.78), [7]
Serum	FTS High	Brain	M	ng/g	232.86, (63.97), [7]	232.29, (63.8), [7]	58.07, (15.94), [7]	232.29, (63.8), [7]	58.07, (15.94), [7]	162.71, (44.7), [7]	580.71, (159.43), [7]
Serum	FTS High	Kidney	F	ng/g	138.14, (26.34), [7]	138, (26.42), [7]	34.49, (6.63), [7]	138, (26.42), [7]	34.49, (6.63), [7]	96.4, (18.35), [7]	344.86, (66.32), [7]
Serum	FTS High	Kidney	M	ng/g	87.49, (11.13), [7]	87.17, (10.89), [7]	21.8, (2.74), [7]	87.17, (10.89), [7]	21.8, (2.74), [7]	61.06, (7.69), [7]	218, (27.38), [7]
Serum	FTS High	Liver	F	ng/g	38.92, (0.68), [10]	38.83, (0.68), [10]	9.71, (0.17), [10]	38.83, (0.68), [10]	9.71, (0.17), [10]	27.18, (0.47), [10]	97.07, (1.68), [10]
Serum	FTS High	Liver	M	ng/g	38.93, (1.02), [10]	38.84, (1.02), [10]	9.7, (0.25), [10]	38.84, (1.02), [10]	9.7, (0.25), [10]	27.18, (0.7), [10]	97.05, (2.54), [10]
Serum	Control	Brain	F	ng/g	2.67, (0.52), [7]	2.67, (0.52), [7]	0.67, (0.13), [7]	2.67, (0.52), [7]	0.67, (0.13), [7]	1.86, (0.36), [7]	6.66, (1.3), [7]
Serum	Control	Brain	M	ng/g	2.44, (0.21), [7]	2.43, (0.21), [7]	0.61, (0.05), [7]	2.43, (0.21), [7]	0.61, (0.05), [7]	1.7, (0.15), [7]	6.08, (0.53), [7]
Serum	Control	Kidney	F	ng/g	3.2, (0.28), [7]	3.19, (0.28), [7]	0.8, (0.07), [7]	3.19, (0.28), [7]	0.8, (0.07), [7]	2.23, (0.2), [7]	7.98, (0.71), [7]
Serum	Control	Kidney	M	ng/g	1.74, (0.17), [7]	1.73, (0.17), [7]	0.43, (0.04), [7]	1.73, (0.17), [7]	0.43, (0.04), [7]	1.21, (0.12), [7]	4.33, (0.43), [7]
Serum	Control	Liver	F	ng/g	0.67, (0.08), [7]	0.66, (0.08), [7]	0.17, (0.02), [7]	0.66, (0.08), [7]	0.17, (0.02), [7]	0.46, (0.05), [7]	1.66, (0.2), [7]
Serum	Control	Liver	M	ng/g	0.49, (0.03), [7]	0.49, (0.03), [7]	0.12, (0.01), [7]	0.49, (0.03), [7]	0.12, (0.01), [7]	0.38, (0.08), [7]	1.22, (0.08), [7]

Table SI3.5. Table SI3.3 continued.

Study	Treatment	Sample Type	Sex	Units	N-MeFOSA	N-MeFOSE	NFDHA	PFBA	PFBS	PFDA	PFDoA
Wholebody	PFOS	water	NA	ng/L	213000, (NA), [1]	2130000, (NA), [1]	425000, (NA), [1]	850000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	170000, (NA), [1]
Wholebody	PFOS	wholebody	F	ng/g	0.49, (0.01), [20]	4.89, (0.07), [20]	0.98, (0.01), [20]	2.24, (0.61), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.39, (0.01), [20]
Wholebody	PFOS	wholebody	M	ng/g	0.49, (0.01), [20]	4.91, (0.07), [20]	0.98, (0.01), [20]	1.96, (0.03), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.39, (0.01), [20]
Wholebody	PFOA	water	NA	ng/L	201000, (NA), [1]	2010000, (NA), [1]	402000, (NA), [1]	805000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	161000, (NA), [1]
Wholebody	PFOA	wholebody	F	ng/g	0.09, (0), [10]	0.94, (0.03), [9]	0.24, (0.1), [10]	0.48, (0.15), [10]	0.09, (0), [10]	0.1, (0), [10]	0.08, (0), [10]
Wholebody	PFOA	wholebody	M	ng/g	0.09, (0), [9]	0.94, (0.03), [5]	0.19, (0), [9]	0.47, (0.18), [9]	0.09, (0), [9]	0.09, (0), [9]	0.08, (0), [9]
Wholebody	PFHxS	water	NA	ng/L	178000, (NA), [1]	1780000, (NA), [1]	357000, (NA), [1]	714000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]	143000, (NA), [1]
Wholebody	PFHxS	wholebody	F	ng/g	7.65, (0.26), [10]	76.3, (2.94), [8]	54.57, (39.59), [7]	200.5, (119.5), [2]	7.64, (0.28), [9]	16.26, (12.82), [10]	6.12, (0.21), [10]
Wholebody	PFHxS	wholebody	M	ng/g	7.63, (0.34), [10]	76.33, (3.39), [10]	52.63, (40.11), [9]	196.43, (55.02), [7]	7.63, (0.34), [10]	8.75, (3.51), [10]	6.11, (0.27), [10]
Wholebody	PFHxA	water	NA	ng/L	215000, (NA), [1]	2150000, (NA), [1]	430000, (NA), [1]	860000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]	172000, (NA), [1]
Wholebody	PFHxA	wholebody	F	ng/g	0.18, (0.01), [10]	1.83, (0.06), [10]	0.45, (0.27), [10]	0.73, (0.02), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.15, (0.01), [10]
Wholebody	PFHxA	wholebody	M	ng/g	0.18, (0.01), [10]	1.84, (0.08), [10]	0.37, (0.02), [10]	0.74, (0.03), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.15, (0.01), [10]
Wholebody	PFNA	water	NA	ng/L	210000, (NA), [1]	2100000, (NA), [1]	419000, (NA), [1]	839000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]	168000, (NA), [1]
Wholebody	PFNA	wholebody	F	ng/g	7.54, (0.37), [10]	75.37, (3.73), [10]	15.06, (0.74), [10]	49.97, (30.98), [10]	7.54, (0.37), [10]	7.54, (0.37), [10]	6.03, (0.3), [10]
Wholebody	PFNA	wholebody	M	ng/g	7.52, (0.39), [10]	75.18, (3.9), [10]	15.03, (0.78), [10]	31.76, (4.71), [10]	7.52, (0.39), [10]	7.52, (0.39), [10]	6.01, (0.31), [10]
Wholebody	PFBS	water	NA	ng/L	183000, (NA), [1]	1830000, (NA), [1]	366000, (NA), [1]	733000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]	147000, (NA), [1]
Wholebody	PFBS	wholebody	F	ng/g	1.9, (0.08), [10]	18.98, (0.79), [10]	3.8, (0.16), [10]	7.6, (0.31), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.52, (0.06), [10]
Wholebody	PFBS	wholebody	M	ng/g	1.87, (0.07), [10]	18.72, (0.69), [10]	3.75, (0.14), [10]	10.03, (3.2), [10]	1.87, (0.07), [10]	1.87, (0.07), [10]	1.5, (0.06), [10]
Wholebody	6:2 FTS	water	NA	ng/L	53200, (NA), [1]	532000, (NA), [1]	106000, (NA), [1]	213000, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]	42600, (NA), [1]
Wholebody	6:2 FTS	wholebody	F	ng/g	0.1, (0), [10]	0.96, (0.03), [10]	0.19, (0.01), [10]	0.38, (0.01), [10]	0.1, (0), [10]	0.1, (0), [10]	0.08, (0), [10]
Wholebody	6:2 FTS	wholebody	M	ng/g	0.09, (0), [9]	0.94, (0.03), [10]	0.19, (0.01), [10]	0.38, (0.03), [10]	0.09, (0), [10]	0.09, (0), [10]	0.08, (0), [10]

Wholebody	8:2 FTS	water	NA	ng/L	51700, (NA), [1]	517000, (NA), [1]	103000, (NA), [1]	207000, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]	41400, (NA), [1]
Wholebody	8:2 FTS	wholebody	F	ng/g	0.1, (0), [9]	0.96, (0.03), [9]	0.2, (0.04), [9]	0.45, (0.1), [9]	0.1, (0), [9]	0.1, (0), [9]	0.08, (0), [9]
Wholebody	8:2 FTS	wholebody	M	ng/g	0.1, (0), [11]	0.98, (0.05), [11]	0.23, (0.09), [11]	0.47, (0.21), [11]	0.1, (0), [11]	0.1, (0), [11]	0.08, (0), [11]
Wholebody	C68LOW	water	NA	ng/L	19200, (NA), [1]	192000, (NA), [1]	38500, (NA), [1]	76900, (NA), [1]	19200, (NA), [1]	19200, (NA), [1]	15400, (NA), [1]
Wholebody	C68LOW	wholebody	F	ng/g	1.91, (0.07), [10]	19.05, (0.66), [10]	7.45, (3.55), [10]	48.41, (24.92), [8]	1.91, (0.07), [10]	2, (0.15), [10]	1.52, (0.05), [10]
Wholebody	C68LOW	wholebody	M	ng/g	1.91, (0.07), [10]	19.08, (0.71), [10]	5.79, (2.82), [10]	35.65, (10), [10]	1.91, (0.07), [10]	1.96, (0.14), [10]	1.53, (0.06), [10]
Wholebody	C68MED	water	NA	ng/L	109000, (NA), [1]	1090000, (NA), [1]	219000, (NA), [1]	437000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]	87500, (NA), [1]
Wholebody	C68MED	wholebody	F	ng/g	1.95, (0.06), [10]	19.53, (0.55), [10]	3.92, (0.12), [10]	18.89, (9.47), [10]	1.95, (0.06), [10]	1.95, (0.06), [10]	1.56, (0.04), [10]
Wholebody	C68MED	wholebody	M	ng/g	1.95, (0.04), [9]	19.53, (0.35), [9]	3.9, (0.07), [9]	12.41, (6.81), [9]	1.95, (0.04), [9]	1.95, (0.04), [9]	1.56, (0.03), [9]
Wholebody	C68HIGH	water	NA	ng/L	111000, (NA), [1]	1110000, (NA), [1]	221000, (NA), [1]	442000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]	88500, (NA), [1]
Wholebody	C68HIGH	wholebody	F	ng/g	6.72, (0.4), [10]	67.18, (4.05), [10]	13.41, (0.8), [10]	37.57, (13.29), [10]	6.72, (0.4), [10]	6.72, (0.4), [10]	5.37, (0.32), [10]
Wholebody	C68HIGH	wholebody	M	ng/g	7.08, (0.56), [10]	70.77, (5.61), [10]	14.38, (1.17), [10]	35.23, (19.73), [10]	7.08, (0.56), [10]	7.08, (0.56), [10]	5.66, (0.45), [10]
Wholebody	FTSLOW	water	NA	ng/L	17100, (NA), [1]	171000, (NA), [1]	34200, (NA), [1]	68400, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]	13700, (NA), [1]
Wholebody	FTSLOW	wholebody	F	ng/g	3.83, (0.17), [10]	38.27, (1.67), [10]	7.66, (0.33), [10]	15.3, (0.67), [10]	3.83, (0.17), [10]	3.83, (0.17), [10]	3.06, (0.13), [10]
Wholebody	FTSLOW	wholebody	M	ng/g	3.76, (0.16), [10]	37.62, (1.61), [10]	7.53, (0.32), [10]	15.05, (0.64), [10]	3.76, (0.16), [10]	3.76, (0.16), [10]	3.01, (0.13), [10]
Wholebody	FTSMED	water	NA	ng/L	53400, (NA), [1]	534000, (NA), [1]	107000, (NA), [1]	214000, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]	42700, (NA), [1]
Wholebody	FTSMED	wholebody	F	ng/g	1.88, (0.09), [10]	18.83, (0.89), [10]	3.77, (0.18), [10]	7.53, (0.36), [10]	1.88, (0.09), [10]	1.88, (0.09), [10]	1.51, (0.07), [10]
Wholebody	FTSMED	wholebody	M	ng/g	1.9, (0.08), [10]	18.95, (0.76), [10]	3.79, (0.15), [10]	7.58, (0.3), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.52, (0.06), [10]
Wholebody	FTSHIGH	water	NA	ng/L	108000, (NA), [1]	1080000, (NA), [1]	216000, (NA), [1]	432000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]	86400, (NA), [1]
Wholebody	FTSHIGH	wholebody	F	ng/g	6.64, (0.43), [10]	66.42, (4.29), [10]	13.29, (0.87), [10]	55.2, (32.72), [10]	6.64, (0.43), [10]	6.64, (0.43), [10]	5.31, (0.34), [10]
Wholebody	FTSHIGH	wholebody	M	ng/g	6.75, (0.45), [10]	67.47, (4.48), [10]	13.49, (0.91), [10]	26.99, (1.79), [10]	6.75, (0.45), [10]	6.75, (0.45), [10]	5.39, (0.36), [10]
Wholebody	Control	water	NA	ng/L	11100, (NA), [1]	111000, (NA), [1]	22200, (NA), [1]	44400, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]	8890, (NA), [1]
Wholebody	Control	wholebody	F	ng/g	0.1, (0), [10]	0.97, (0.03), [6]	0.49, (0.48), [10]	0.63, (0.31), [10]	0.1, (0), [10]	0.11, (0.02), [10]	0.08, (0), [10]
Wholebody	Control	wholebody	M	ng/g	0.1, (0), [10]	0.99, (0.01), [6]	0.84, (0.54), [10]	0.88, (0.21), [10]	0.1, (0), [10]	0.13, (0.06), [10]	0.08, (0), [10]
Serum	PFOS	serum	F	ng/mL	18.19, (1.02), [10]	181.9, (10.25), [10]	36.37, (2.05), [10]	72.71, (4.11), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]	14.54, (0.83), [10]
Serum	PFOS	serum	M	ng/mL	16.67, (1.99), [9]	166.67, (19.89), [9]	33.28, (3.96), [9]	66.56, (7.97), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]	13.31, (1.6), [9]
Serum	PFOS	water	NA	ng/L	95500, (NA), [1]	955000, (NA), [1]	191000, (NA), [1]	382000, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]	76400, (NA), [1]
Serum	PFOA	serum	F	ng/mL	0.98, (0.04), [10]	9.81, (0.38), [10]	1.96, (0.08), [10]	3.93, (0.16), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.79, (0.03), [10]
Serum	PFOA	serum	M	ng/mL	0.98, (0.04), [10]	9.81, (0.36), [10]	1.96, (0.07), [10]	3.93, (0.14), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.78, (0.03), [10]
Serum	PFOA	water	NA	ng/L	199000, (NA), [1]	1990000, (NA), [1]	398000, (NA), [1]	797000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]	159000, (NA), [1]
Serum	PFHxS	serum	F	ng/mL	1.11, (0.29), [10]	11.15, (2.92), [10]	2.23, (0.59), [10]	4.46, (1.17), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]	0.89, (0.23), [10]
Serum	PFHxS	serum	M	ng/mL	1.09, (0.21), [10]	10.87, (2.08), [10]	2.17, (0.42), [10]	4.35, (0.83), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	0.87, (0.17), [10]
Serum	PFHxS	water	NA	ng/L	211000, (NA), [1]	2110000, (NA), [1]	422000, (NA), [1]	843000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]	169000, (NA), [1]
Serum	PFHxA	serum	F	ng/mL	1.03, (0.11), [9]	10.29, (1.06), [9]	2.06, (0.21), [9]	4.12, (0.42), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]	0.82, (0.08), [9]
Serum	PFHxA	serum	M	ng/mL	1.06, (0.14), [10]	10.62, (1.43), [10]	2.13, (0.29), [10]	4.26, (0.57), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]	0.85, (0.11), [10]
Serum	PFHxA	water	NA	ng/L	204000, (NA), [1]	2040000, (NA), [1]	407000, (NA), [1]	815000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]	163000, (NA), [1]
Serum	PFNA	serum	F	ng/mL	148.6, (4.99), [10]	1486, (49.93), [10]	297.2, (9.45), [10]	594.4, (19.41), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]	118.9, (3.84), [10]
Serum	PFNA	serum	M	ng/mL	144, (6.46), [10]	1440, (64.64), [10]	287.6, (13.17), [10]	575.5, (26.25), [10]	144, (6.46), [10]	144, (6.46), [10]	115.2, (5.16), [10]
Serum	PFNA	water	NA	ng/L	184000, (NA), [1]	1840000, (NA), [1]	368000, (NA), [1]	737000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]	147000, (NA), [1]
Serum	PFBS	serum	F	ng/mL	1.22, (0.39), [10]	12.16, (3.89), [10]	2.43, (0.78), [10]	4.87, (1.56), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	0.97, (0.31), [10]
Serum	PFBS	serum	M	ng/mL	1.18, (0.52), [10]	11.85, (5.18), [10]	2.37, (1.03), [10]	4.74, (2.07), [10]	2.56, (1.89), [16]	1.18, (0.52), [10]	0.95, (0.41), [10]
Serum	PFBS	water	NA	ng/L	201000, (NA), [1]	2010000, (NA), [1]	402000, (NA), [1]	805000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	161000, (NA), [1]
Serum	6:2 FTS	serum	F	ng/mL	0.85, (0.22), [10]	8.5, (2.16), [10]	1.7, (0.43), [10]	3.4, (0.87), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.68, (0.17), [10]
Serum	6:2 FTS	serum	M	ng/mL	0.86, (0.23), [10]	8.6, (2.31), [10]	1.72, (0.46), [10]	3.44, (0.93), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.69, (0.19), [10]
Serum	6:2 FTS	water	NA	ng/L	47000, (NA), [1]	470000, (NA), [1]	93900, (NA), [1]	188000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]	37600, (NA), [1]
Serum	8:2 FTS	serum	F	ng/mL	0.86, (0.24), [10]	8.62, (2.42), [10]	1.72, (0.49), [10]	3.45, (0.97), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]	0.69, (0.19), [10]
Serum	8:2 FTS	serum	M	ng/mL	0.74, (0.16), [10]	7.44, (1.6), [10]	1.49, (0.32), [10]	2.98, (0.64), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]	0.6, (0.13), [10]
Serum	8:2 FTS	water	NA	ng/L	50500, (NA), [1]	505000, (NA), [1]	101000, (NA), [1]	202000, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]	40400, (NA), [1]
Serum	C68LOW	serum	F	ng/mL	9.54, (0.45), [10]	95.41, (4.52), [10]	19.09, (0.91), [10]	38.17, (1.85), [10]	9.54, (0.45), [10]	9.54, (0.45), [10]	7.64, (0.36), [10]
Serum	C68LOW	serum	M	ng/mL	9.8, (0.43), [10]	98.02, (4.32), [10]	19.64, (0.91), [10]	39.28, (1.83), [10]	9.8, (0.43), [10]	9.8, (0.43), [10]	7.85, (0.36), [10]
Serum	C68LOW	water	NA	ng/L	20200, (NA), [1]	202000, (NA), [1]	40400, (NA), [1]	80800, (NA), [1]	20200, (NA), [1]	20200, (NA), [1]	16200, (NA), [1]
Serum	C68MED	serum	F	ng/mL	47.97, (2.17), [10]	479.7, (21.73), [10]	95.8, (4.21), [10]	191.7, (8.84), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]	38.34, (1.77), [10]
Serum	C68MED	serum	M	ng/mL	47.92, (1.14), [10]	479.2, (11.36), [10]	95.74, (2.27), [10]	191.4, (4.65), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]	38.28, (0.93), [10]
Serum	C68MED	water	NA	ng/L	48900, (NA), [1]	489000, (NA), [1]	97800, (NA), [1]	196000, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]	39100, (NA), [1]
Serum	C68HIGH	serum	F	ng/mL	148.4, (3.86), [10]	1484, (38.64), [10]	297.2, (6.76), [10]	594, (14.49), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]	118.8, (2.9), [10]
Serum	C68HIGH	serum	M	ng/mL	147.33, (6.86), [9]	1473.33, (68.56), [9]	294.78, (13.51), [9]	589.44, (27.2), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]	117.89, (5.28), [9]
Serum	C68HIGH	water	NA	ng/L	105000, (NA), [1]	1050000, (NA), [1]	211000, (NA), [1]	421000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]	84200, (NA), [1]
Serum	FTSLOW	serum	F	ng/mL	9.49, (0.37), [10]	94.91, (3.66), [10]	18.98, (0.76), [10]	37.96, (1.53), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]	7.6, (0.3), [10]
Serum	FTSLOW	serum	M	ng/mL	9.45, (0.36), [10]	94.47, (3.58), [10]	18.89, (0.75), [10]	37.78, (1.5), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]	7.56, (0.29), [10]
Serum	FTSLOW	water	NA	ng/L	19600, (NA), [1]	196000, (NA), [1]	39200, (NA), [1]	78400, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]	15700, (NA), [1]
Serum	FTSMED	serum	F	ng/mL	44.6, (1.78), [10]	446, (17.83), [10]	89.2, (3.56), [10]	178.3, (6.96), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]	35.65, (1.4), [10]
Serum	FTSMED	serum	M	ng/mL	46.02, (1.97), [10]	460.2, (19.65), [10]	92, (3.88), [10]	183.9, (7.71), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]	36.77, (1.56), [10]

Serum	FTSMED	water	NA	ng/L	58600, (NA), [1]	586000, (NA), [1]	117000, (NA), [1]	235000, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]	46900, (NA), [1]
Serum	FTSHIGH	serum	F	ng/mL	150.4, (7.11), [10]	1504, (71.06), [10]	300.2, (13.96), [10]	601, (28.16), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]	120.2, (5.49), [10]
Serum	FTSHIGH	serum	M	ng/mL	149, (8.18), [10]	1490, (81.79), [10]	297.6, (16.14), [10]	595.5, (32.69), [10]	149, (8.18), [10]	149, (8.18), [10]	119.1, (6.4), [10]
Serum	FTSHIGH	water	NA	ng/L	1e+05, (NA), [1]	1e+06, (NA), [1]	2e+05, (NA), [1]	4e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]	80000, (NA), [1]
Serum	Control	serum	F	ng/mL	1.47, (0.68), [10]	14.65, (6.8), [10]	2.93, (1.36), [10]	5.86, (2.73), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.17, (0.54), [10]
Serum	Control	serum	M	ng/mL	1.05, (0.31), [10]	10.5, (3.1), [10]	2.1, (0.62), [10]	4.19, (1.23), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	0.84, (0.25), [10]
Serum	Control	water	NA	ng/L	10700, (NA), [1]	107000, (NA), [1]	21400, (NA), [1]	42800, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	8560, (NA), [1]
Serum	PFOS	Brain	F	ng/g	864.29, (142.59), [7]	8642.86, (1425.86), [7]	1725.71, (283.25), [7]	3454.29, (564.38), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]	691, (112.89), [7]
Serum	PFOS	Brain	M	ng/g	1000.43, (208.03), [7]	10004.29, (2080.26), [7]	2001.43, (413.9), [7]	3998.57, (831.73), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]	800.14, (166.1), [7]
Serum	PFOS	Kidney	F	ng/g	609.86, (67.21), [7]	6098.57, (672.1), [7]	1218.57, (133.22), [7]	2440, (270.31), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]	487.71, (54.03), [7]
Serum	PFOS	Kidney	M	ng/g	428, (51.53), [7]	4280, (515.33), [7]	855.29, (101.72), [7]	1712.86, (206.54), [7]	428, (51.53), [7]	428, (51.53), [7]	342.43, (40.97), [7]
Serum	PFOS	Liver	F	ng/g	27.41, (0.8), [7]	274.14, (7.97), [7]	54.87, (1.64), [7]	109.86, (3.29), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]	21.94, (0.65), [7]
Serum	PFOS	Liver	M	ng/g	27.5, (1.48), [7]	275, (14.84), [7]	54.97, (3.01), [7]	109.97, (5.93), [7]	27.5, (1.48), [7]	27.5, (1.48), [7]	21.99, (1.2), [7]
Serum	PFOA	Brain	F	ng/g	672.14, (153.72), [7]	6721.43, (1537.19), [7]	1345, (307.37), [7]	2688.57, (614.48), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]	537.57, (123.03), [7]
Serum	PFOA	Brain	M	ng/g	702.86, (127.03), [7]	7028.57, (1270.33), [7]	1404.29, (252.84), [7]	2811.43, (508.9), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]	562.29, (101.34), [7]
Serum	PFOA	Kidney	F	ng/g	609.14, (59.56), [7]	6091.43, (595.63), [7]	1219.86, (119.9), [7]	2435.71, (236.7), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]	487.14, (47.61), [7]
Serum	PFOA	Kidney	M	ng/g	409.57, (56.39), [7]	4095.71, (563.85), [7]	818.86, (112.11), [7]	1637.14, (225.74), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]	327.57, (44.77), [7]
Serum	PFOA	Liver	F	ng/g	27.04, (0.98), [7]	270.43, (9.78), [7]	54.09, (1.91), [7]	108.14, (3.89), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]	21.63, (0.77), [7]
Serum	PFOA	Liver	M	ng/g	27.94, (0.91), [7]	279.43, (9.05), [7]	55.86, (1.77), [7]	111.71, (3.59), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]	22.33, (0.73), [7]
Serum	PFHxS	Brain	F	ng/g	109.24, (30.67), [7]	1092.43, (306.66), [7]	218.43, (61.06), [7]	436.71, (121.97), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]	87.4, (24.55), [7]
Serum	PFHxS	Brain	M	ng/g	102.81, (26.69), [7]	1028.14, (266.93), [7]	205.57, (53.78), [7]	411.57, (107.37), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]	82.23, (21.35), [7]
Serum	PFHxS	Kidney	F	ng/g	107.7, (14.92), [7]	1077, (149.18), [7]	216, (29.78), [7]	431.43, (59.66), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]	86.33, (11.93), [7]
Serum	PFHxS	Kidney	M	ng/g	63.17, (12), [7]	631.71, (120.04), [7]	126.23, (23.94), [7]	252.57, (47.88), [7]	63.17, (12), [7]	63.17, (12), [7]	50.53, (9.6), [7]
Serum	PFHxS	Liver	F	ng/g	28.51, (0.82), [7]	285.14, (8.21), [7]	57.07, (1.69), [7]	114.14, (3.34), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]	22.81, (0.67), [7]
Serum	PFHxS	Liver	M	ng/g	28.39, (0.79), [7]	283.86, (7.9), [7]	56.76, (1.6), [7]	113.57, (3.31), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]	22.7, (0.63), [7]
Serum	PFHxA	Brain	F	ng/g	1.42, (1.12), [7]	14.24, (11.21), [7]	2.85, (2.24), [7]	5.71, (4.49), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]	1.14, (0.9), [7]
Serum	PFHxA	Brain	M	ng/g	0.87, (0.12), [7]	8.73, (1.16), [7]	1.75, (0.23), [7]	3.49, (0.46), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]	0.7, (0.09), [7]
Serum	PFHxA	Kidney	F	ng/g	0.68, (0.09), [7]	6.8, (0.89), [7]	1.36, (0.18), [7]	2.72, (0.36), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]	0.54, (0.07), [7]
Serum	PFHxA	Kidney	M	ng/g	0.39, (0.05), [7]	3.88, (0.47), [7]	0.78, (0.09), [7]	1.55, (0.19), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]	0.33, (0.06), [7]
Serum	PFHxA	Liver	F	ng/g	0.23, (0.11), [7]	2.29, (1.12), [7]	0.46, (0.22), [7]	0.92, (0.45), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.18, (0.09), [7]
Serum	PFHxA	Liver	M	ng/g	0.21, (0.06), [7]	2.11, (0.64), [7]	0.42, (0.13), [7]	0.84, (0.26), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.17, (0.05), [7]
Serum	6:2 FTS	Brain	F	ng/g	44.64, (25.16), [7]	446.43, (251.6), [7]	89.23, (50.24), [7]	178.63, (100.64), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]	35.72, (20.14), [7]
Serum	6:2 FTS	Brain	M	ng/g	66.16, (22.86), [7]	661.57, (228.56), [7]	132.33, (45.67), [7]	264.71, (91.3), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]	52.93, (18.24), [7]
Serum	6:2 FTS	Kidney	F	ng/g	16.73, (2.26), [7]	167.29, (22.63), [7]	33.49, (4.48), [7]	66.97, (8.97), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]	13.4, (1.8), [7]
Serum	6:2 FTS	Kidney	M	ng/g	11.27, (2.41), [7]	112.71, (24.06), [7]	22.54, (4.76), [7]	45.09, (9.6), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]	9.02, (1.91), [7]
Serum	6:2 FTS	Liver	F	ng/g	9.88, (0.16), [7]	98.8, (1.63), [7]	19.76, (0.33), [7]	39.51, (0.61), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]	7.9, (0.12), [7]
Serum	6:2 FTS	Liver	M	ng/g	9.85, (0.08), [7]	98.54, (0.81), [7]	19.7, (0.18), [7]	39.43, (0.34), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]	7.88, (0.06), [7]
Serum	8:2 FTS	Brain	F	ng/g	612.81, (564.51), [7]	6128.14, (5645.1), [7]	1225.71, (1125.43), [7]	2448.71, (2250.8), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]	489.44, (449.49), [7]
Serum	8:2 FTS	Brain	M	ng/g	139.33, (242.27), [7]	1393.29, (2422.68), [7]	279.21, (486.05), [7]	557, (968.33), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]	111.54, (194.04), [7]
Serum	8:2 FTS	Kidney	F	ng/g	36.56, (5.83), [7]	365.57, (58.3), [7]	73.1, (11.64), [7]	146, (23.17), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]	29.23, (4.64), [7]
Serum	8:2 FTS	Kidney	M	ng/g	23.01, (3.24), [7]	230.14, (32.4), [7]	46.01, (6.53), [7]	92.06, (13.02), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]	18.43, (2.6), [7]
Serum	8:2 FTS	Liver	F	ng/g	9.74, (0.27), [7]	97.39, (2.66), [7]	19.5, (0.52), [7]	38.94, (1.07), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]	7.79, (0.21), [7]
Serum	8:2 FTS	Liver	M	ng/g	9.78, (0.18), [7]	97.77, (1.82), [7]	19.57, (0.38), [7]	39.13, (0.78), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]	7.83, (0.15), [7]
Serum	C6-8 Low	Brain	F	ng/g	155.07, (63.46), [7]	1550.71, (634.56), [7]	310.14, (127.1), [7]	619.71, (252.85), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]	124.13, (50.89), [7]
Serum	C6-8 Low	Brain	M	ng/g	125.49, (34.29), [7]	1254.86, (342.87), [7]	251.14, (68.14), [7]	502.14, (136.26), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]	100.4, (27.22), [7]
Serum	C6-8 Low	Kidney	F	ng/g	7.24, (0.88), [7]	72.4, (8.81), [7]	14.49, (1.76), [7]	28.97, (3.5), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]	5.79, (0.7), [7]
Serum	C6-8 Low	Kidney	M	ng/g	4.27, (0.44), [7]	42.74, (4.4), [7]	8.55, (0.88), [7]	17.13, (1.76), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]	3.42, (0.35), [7]
Serum	C6-8 Low	Liver	F	ng/g	4.72, (0.1), [10]	47.2, (0.98), [10]	9.44, (0.2), [10]	18.87, (0.38), [10]	4.72, (0.1), [10]	4.72, (0.1), [10]	3.78, (0.08), [10]
Serum	C6-8 Low	Liver	M	ng/g	4.79, (0.09), [10]	47.86, (0.89), [10]	9.57, (0.18), [10]	19.14, (0.35), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	3.83, (0.07), [10]
Serum	C6-8 Medium	Brain	F	ng/g	245.29, (16.1), [7]	2452.86, (161.01), [7]	490.29, (32.02), [7]	979.86, (62.72), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]	196.14, (13.06), [7]
Serum	C6-8 Medium	Brain	M	ng/g	268.29, (24.28), [7]	2682.86, (242.81), [7]	536.86, (48.2), [7]	1073.57, (96.64), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]	214.57, (19.16), [7]
Serum	C6-8 Medium	Kidney	F	ng/g	34.19, (4.68), [7]	341.86, (46.79), [7]	68.39, (9.35), [7]	136.86, (18.49), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]	27.36, (3.74), [7]
Serum	C6-8 Medium	Kidney	M	ng/g	21.67, (3.25), [7]	216.71, (32.46), [7]	43.34, (6.47), [7]	86.69, (12.98), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]	17.34, (2.6), [7]
Serum	C6-8 Medium	Liver	F	ng/g	9.49, (0.22), [10]	94.87, (2.24), [10]	18.97, (0.44), [10]	37.95, (0.89), [10]	9.49, (0.22), [10]	9.49, (0.22), [10]	7.59, (0.18), [10]
Serum	C6-8 Medium	Liver	M	ng/g	9.57, (0.23), [10]	95.68, (2.26), [10]	19.14, (0.45), [10]	38.27, (0.9), [10]	9.57, (0.23), [10]	9.57, (0.23), [10]	7.65, (0.18), [10]
Serum	C6-8 High	Brain	F	ng/g	1497.14, (144.19), [7]	14971.43, (1441.89), [7]	2988.57, (289.33), [7]	5984.29, (579.48), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1198.57, (115.68), [7]
Serum	C6-8 High	Brain	M	ng/g	1270.29, (674.45), [7]	12702.86, (6744.54), [7]	2538.57, (1348.94), [7]	5085.71, (2711.39), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1016.29, (538.61), [7]
Serum	C6-8 High	Kidney	F	ng/g	35.39, (4.7), [7]	353.86, (47.01), [7]	70.8, (9.44), [7]	141.57, (18.86), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]	28.3, (3.77), [7]
Serum	C6-8 High	Kidney	M	ng/g	22.07, (2.53), [7]	220.71, (25.34), [7]	44.19, (5.1), [7]	88.33, (10.2), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]	17.66, (2.04), [7]
Serum	C6-8 High	Liver	F	ng/g	9.71, (0.29), [10]	97.06, (2.86), [10]	19.42, (0.58), [10]	38.81, (1.12), [10]	9.71, (0.29), [10]	9.71, (0.29), [10]	7.76, (0.23), [10]
Serum	C6-8 High	Liver	M	ng/g	9.52, (0.27), [9]	95.19, (2.7), [9]	19.04, (0.53), [9]	38.11, (1.1), [9]	9.52, (0.27), [9]	9.52, (0.27), [9]	7.62, (0.22), [9]
Serum	FTS Low	Brain	F	ng/g	136.77, (61.83), [7]	1367.71, (618.28), [7]	273.71, (123.59), [7]	547, (246.81), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]	109.39, (49.29), [7]

Serum	FTS Low	Brain	M	ng/g	254.71, (103.33), [7]	2547.14, (1033.32), [7]	509.43, (206.32), [7]	1018.43, (412.52), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]	203.73, (82.49), [7]
Serum	FTS Low	Kidney	F	ng/g	17.83, (1.43), [7]	178.29, (14.28), [7]	35.69, (2.9), [7]	71.36, (5.76), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]	14.26, (1.16), [7]
Serum	FTS Low	Kidney	M	ng/g	10.7, (1.7), [7]	107.01, (16.99), [7]	21.4, (3.36), [7]	42.79, (6.78), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]	8.56, (1.35), [7]
Serum	FTS Low	Liver	F	ng/g	4.76, (0.09), [10]	47.6, (0.89), [10]	9.52, (0.18), [10]	19.04, (0.35), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]	3.81, (0.07), [10]
Serum	FTS Low	Liver	M	ng/g	4.75, (0.1), [10]	47.46, (1.03), [10]	9.49, (0.21), [10]	18.98, (0.43), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]	3.8, (0.08), [10]
Serum	FTS Medium	Brain	F	ng/g	44.03, (18.88), [7]	440.29, (188.79), [7]	88.03, (37.78), [7]	176.14, (75.67), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]	35.23, (15.09), [7]
Serum	FTS Medium	Brain	M	ng/g	57.6, (23.29), [7]	576, (232.93), [7]	115.39, (46.73), [7]	230.43, (93.08), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]	46.09, (18.61), [7]
Serum	FTS Medium	Kidney	F	ng/g	17.41, (2), [7]	174.14, (19.97), [7]	34.86, (3.99), [7]	69.7, (7.93), [7]	17.41, (2), [7]	17.41, (2), [7]	13.91, (1.59), [7]
Serum	FTS Medium	Kidney	M	ng/g	11, (1.75), [7]	109.99, (17.54), [7]	22, (3.53), [7]	43.99, (6.99), [7]	11, (1.75), [7]	11, (1.75), [7]	8.8, (1.39), [7]
Serum	FTS Medium	Liver	F	ng/g	4.79, (0.09), [10]	47.87, (0.93), [10]	9.57, (0.19), [10]	19.14, (0.36), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	3.83, (0.08), [10]
Serum	FTS Medium	Liver	M	ng/g	4.77, (0.15), [10]	47.65, (1.47), [10]	9.53, (0.29), [10]	19.05, (0.58), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]	3.81, (0.12), [10]
Serum	FTS High	Brain	F	ng/g	63.7, (33.18), [7]	637, (331.78), [7]	127.37, (66.46), [7]	254.86, (132.81), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]	50.96, (26.57), [7]
Serum	FTS High	Brain	M	ng/g	58.07, (15.94), [7]	580.71, (159.43), [7]	116.11, (31.85), [7]	232.29, (63.8), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]	46.46, (12.75), [7]
Serum	FTS High	Kidney	F	ng/g	34.49, (6.63), [7]	344.86, (66.32), [7]	68.99, (13.26), [7]	138, (26.42), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]	27.6, (5.29), [7]
Serum	FTS High	Kidney	M	ng/g	21.8, (2.74), [7]	218, (27.38), [7]	43.59, (5.47), [7]	87.17, (10.89), [7]	21.8, (2.74), [7]	21.8, (2.74), [7]	17.44, (2.19), [7]
Serum	FTS High	Liver	F	ng/g	9.71, (0.17), [10]	97.07, (1.68), [10]	19.43, (0.33), [10]	38.83, (0.68), [10]	9.71, (0.17), [10]	9.71, (0.17), [10]	7.76, (0.14), [10]
Serum	FTS High	Liver	M	ng/g	9.7, (0.25), [10]	97.05, (2.54), [10]	19.41, (0.51), [10]	38.84, (1.02), [10]	9.7, (0.25), [10]	9.7, (0.25), [10]	7.77, (0.21), [10]
Serum	Control	Brain	F	ng/g	0.67, (0.13), [7]	6.66, (1.3), [7]	1.33, (0.26), [7]	2.67, (0.52), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]	0.53, (0.1), [7]
Serum	Control	Brain	M	ng/g	0.61, (0.05), [7]	6.08, (0.53), [7]	1.22, (0.11), [7]	2.43, (0.21), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]	0.49, (0.04), [7]
Serum	Control	Kidney	F	ng/g	0.8, (0.07), [7]	7.98, (0.71), [7]	1.6, (0.14), [7]	3.19, (0.28), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]	0.64, (0.06), [7]
Serum	Control	Kidney	M	ng/g	0.43, (0.04), [7]	4.33, (0.43), [7]	0.87, (0.09), [7]	1.73, (0.17), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]	0.35, (0.03), [7]
Serum	Control	Liver	F	ng/g	0.17, (0.02), [7]	1.66, (0.2), [7]	0.33, (0.04), [7]	0.66, (0.08), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]	0.13, (0.02), [7]
Serum	Control	Liver	M	ng/g	0.12, (0.01), [7]	1.22, (0.08), [7]	0.25, (0.04), [7]	0.53, (0.14), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]	0.1, (0.01), [7]

Table SI3.6. Table SI3.3 continued.

Study	Treatment	Sample Type	Sex	Units	PFDoS	PFDS	PFEESA	PFHpA	PFHpS	PFHxA	PFHxS
Wholebody	PFOS	water	NA	ng/L	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]
Wholebody	PFOS	wholebody	F	ng/g	0.49, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.02), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]
Wholebody	PFOS	wholebody	M	ng/g	0.49, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.52, (0.1), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]
Wholebody	PFOA	water	NA	ng/L	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]
Wholebody	PFOA	wholebody	F	ng/g	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]	0.13, (0.06), [10]	0.09, (0), [10]	0.21, (0.15), [10]	0.09, (0), [10]
Wholebody	PFOA	wholebody	M	ng/g	0.09, (0), [9]	0.09, (0), [9]	0.09, (0), [9]	0.09, (0), [9]	0.09, (0), [9]	0.1, (0.01), [9]	0.09, (0), [9]
Wholebody	PFHxS	water	NA	ng/L	178000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]
Wholebody	PFHxS	wholebody	F	ng/g	7.65, (0.26), [10]	7.65, (0.26), [10]	7.74, (0.42), [7]	33.75, (16.45), [7]	7.65, (0.26), [10]	55.49, (27.14), [7]	6.99, (2.12), [10]
Wholebody	PFHxS	wholebody	M	ng/g	7.63, (0.34), [10]	7.63, (0.34), [10]	7.97, (1.11), [9]	28.99, (18.3), [10]	7.63, (0.34), [10]	66.57, (53.45), [9]	6.95, (2.28), [10]
Wholebody	PFHxA	water	NA	ng/L	215000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]
Wholebody	PFHxA	wholebody	F	ng/g	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]
Wholebody	PFHxA	wholebody	M	ng/g	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]
Wholebody	PFNA	water	NA	ng/L	210000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]
Wholebody	PFNA	wholebody	F	ng/g	7.54, (0.37), [10]	7.54, (0.37), [10]	7.54, (0.37), [10]	7.54, (0.37), [10]	7.54, (0.37), [10]	7.54, (0.37), [10]	7.54, (0.37), [10]
Wholebody	PFNA	wholebody	M	ng/g	7.52, (0.39), [10]	7.52, (0.39), [10]	7.52, (0.39), [10]	7.52, (0.39), [10]	7.52, (0.39), [10]	7.52, (0.39), [10]	7.52, (0.39), [10]
Wholebody	PFBS	water	NA	ng/L	183000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]
Wholebody	PFBS	wholebody	F	ng/g	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]
Wholebody	PFBS	wholebody	M	ng/g	1.87, (0.07), [10]	1.87, (0.07), [10]	1.87, (0.07), [10]	1.9, (0.09), [10]	1.87, (0.07), [10]	2.47, (1.14), [10]	1.87, (0.07), [10]
Wholebody	6:2 FTS	water	NA	ng/L	53200, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]
Wholebody	6:2 FTS	wholebody	F	ng/g	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]
Wholebody	6:2 FTS	wholebody	M	ng/g	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]	0.12, (0.09), [10]	0.09, (0), [10]
Wholebody	8:2 FTS	water	NA	ng/L	51700, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]
Wholebody	8:2 FTS	wholebody	F	ng/g	0.1, (0), [9]	0.1, (0), [9]	0.1, (0), [9]	0.1, (0), [9]	0.1, (0), [9]	0.11, (0.03), [9]	0.1, (0), [9]
Wholebody	8:2 FTS	wholebody	M	ng/g	0.1, (0), [11]	0.1, (0), [11]	0.1, (0), [11]	0.1, (0.01), [11]	0.1, (0), [11]	0.13, (0.08), [11]	0.1, (0), [11]
Wholebody	C68LOW	water	NA	ng/L	19200, (NA), [1]	19200, (NA), [1]	19200, (NA), [1]	19200, (NA), [1]	19200, (NA), [1]	19200, (NA), [1]	96200, (NA), [1]
Wholebody	C68LOW	wholebody	F	ng/g	1.91, (0.07), [10]	1.91, (0.07), [10]	1.91, (0.07), [10]	4.6, (3.45), [10]	1.97, (0.22), [10]	7.4, (5.1), [10]	1.92, (0.08), [10]
Wholebody	C68LOW	wholebody	M	ng/g	1.91, (0.07), [10]	1.91, (0.07), [10]	1.91, (0.07), [10]	3.7, (1.61), [10]	1.91, (0.07), [10]	7.35, (3.82), [10]	1.91, (0.07), [10]
Wholebody	C68MED	water	NA	ng/L	109000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]
Wholebody	C68MED	wholebody	F	ng/g	1.95, (0.06), [10]	1.95, (0.06), [10]	1.95, (0.06), [10]	2.02, (0.24), [10]	1.95, (0.06), [10]	2.15, (0.41), [10]	1.99, (0.16), [10]
Wholebody	C68MED	wholebody	M	ng/g	1.95, (0.04), [9]	1.95, (0.04), [9]	1.95, (0.04), [9]	1.95, (0.04), [9]	2.14, (0.37), [9]	1.98, (0.09), [9]	1.95, (0.04), [9]
Wholebody	C68HIGH	water	NA	ng/L	111000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]
Wholebody	C68HIGH	wholebody	F	ng/g	6.72, (0.4), [10]	6.72, (0.4), [10]	6.72, (0.4), [10]	6.73, (0.41), [10]	6.73, (0.41), [10]	8.68, (3.78), [10]	6.72, (0.4), [10]
Wholebody	C68HIGH	wholebody	M	ng/g	7.08, (0.56), [10]	7.08, (0.56), [10]	7.08, (0.56), [10]	7.08, (0.56), [10]	7.99, (2.58), [10]	7.7, (1.65), [10]	15.24, (21.24), [10]
Wholebody	FTSLOW	water	NA	ng/L	17100, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]

Wholebody	FTSLOW	wholebody	F	ng/g	3.83, (0.17), [10]	3.83, (0.17), [10]	3.83, (0.17), [10]	3.83, (0.17), [10]	3.83, (0.17), [10]	3.83, (0.17), [10]	3.83, (0.17), [10]
Wholebody	FTSLOW	wholebody	M	ng/g	3.76, (0.16), [10]	3.76, (0.16), [10]	3.76, (0.16), [10]	3.76, (0.16), [10]	3.76, (0.16), [10]	3.76, (0.16), [10]	3.76, (0.16), [10]
Wholebody	FTSMED	water	NA	ng/L	53400, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]
Wholebody	FTSMED	wholebody	F	ng/g	1.88, (0.09), [10]	1.88, (0.09), [10]	1.88, (0.09), [10]	1.88, (0.09), [10]	1.96, (0.29), [10]	1.88, (0.09), [10]	1.88, (0.09), [10]
Wholebody	FTSMED	wholebody	M	ng/g	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	2.07, (0.32), [10]	1.9, (0.08), [10]	1.97, (0.13), [10]
Wholebody	FTSHIGH	water	NA	ng/L	108000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]
Wholebody	FTSHIGH	wholebody	F	ng/g	6.64, (0.43), [10]	6.64, (0.43), [10]	6.64, (0.43), [10]	6.68, (0.4), [10]	6.64, (0.43), [10]	9.32, (5.25), [10]	7.17, (1.17), [10]
Wholebody	FTSHIGH	wholebody	M	ng/g	6.75, (0.45), [10]	6.75, (0.45), [10]	6.75, (0.45), [10]	6.75, (0.45), [10]	7.67, (1.79), [10]	6.75, (0.45), [10]	6.75, (0.45), [10]
Wholebody	Control	water	NA	ng/L	11100, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]
Wholebody	Control	wholebody	F	ng/g	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.14, (0.04), [10]	0.1, (0), [10]	0.26, (0.14), [10]	0.1, (0), [10]
Wholebody	Control	wholebody	M	ng/g	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.31, (0.12), [10]	0.1, (0), [10]	0.52, (0.26), [10]	0.1, (0), [10]
Serum	PFOS	serum	F	ng/mL	18.19, (1.02), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]
Serum	PFOS	serum	M	ng/mL	16.67, (1.99), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]
Serum	PFOS	water	NA	ng/L	95500, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]
Serum	PFOA	serum	F	ng/mL	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]
Serum	PFOA	serum	M	ng/mL	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]
Serum	PFOA	water	NA	ng/L	199000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]
Serum	PFHxS	serum	F	ng/mL	1.11, (0.29), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]	5.38, (1.57), [10]
Serum	PFHxS	serum	M	ng/mL	1.09, (0.21), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	5.21, (1.75), [10]
Serum	PFHxS	water	NA	ng/L	211000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]
Serum	PFHxA	serum	F	ng/mL	1.03, (0.11), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]
Serum	PFHxA	serum	M	ng/mL	1.06, (0.14), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]	1.94, (2.75), [10]
Serum	PFHxA	water	NA	ng/L	204000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]
Serum	PFNA	serum	F	ng/mL	148.6, (4.99), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]
Serum	PFNA	serum	M	ng/mL	144, (6.46), [10]	144, (6.46), [10]	144, (6.46), [10]	144, (6.46), [10]	144, (6.46), [10]	144, (6.46), [10]	144, (6.46), [10]
Serum	PFNA	water	NA	ng/L	184000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]
Serum	PFBS	serum	F	ng/mL	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]
Serum	PFBS	serum	M	ng/mL	1.18, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]
Serum	PFBS	water	NA	ng/L	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]
Serum	6:2 FTS	serum	F	ng/mL	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]
Serum	6:2 FTS	serum	M	ng/mL	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]
Serum	6:2 FTS	water	NA	ng/L	47000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]
Serum	8:2 FTS	serum	F	ng/mL	0.86, (0.24), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]
Serum	8:2 FTS	serum	M	ng/mL	0.74, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]
Serum	8:2 FTS	water	NA	ng/L	50500, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]
Serum	C68LOW	serum	F	ng/mL	9.54, (0.45), [10]	9.54, (0.45), [10]	9.54, (0.45), [10]	9.54, (0.45), [10]	9.54, (0.45), [10]	9.54, (0.45), [10]	52.48, (44.16), [20]
Serum	C68LOW	serum	M	ng/mL	9.8, (0.43), [10]	9.8, (0.43), [10]	9.8, (0.43), [10]	9.8, (0.43), [10]	9.8, (0.43), [10]	9.8, (0.43), [10]	53.91, (45.35), [20]
Serum	C68LOW	water	NA	ng/L	20200, (NA), [1]	20200, (NA), [1]	20200, (NA), [1]	20200, (NA), [1]	20200, (NA), [1]	20200, (NA), [1]	202000, (NA), [1]
Serum	C68MED	serum	F	ng/mL	47.97, (2.17), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]	93.67, (49.71), [19]
Serum	C68MED	serum	M	ng/mL	47.92, (1.14), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]	87.25, (48.5), [17]
Serum	C68MED	water	NA	ng/L	48900, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]
Serum	C68HIGH	serum	F	ng/mL	148.4, (3.86), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]
Serum	C68HIGH	serum	M	ng/mL	147.33, (6.86), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]
Serum	C68HIGH	water	NA	ng/L	105000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]
Serum	FTSLOW	serum	F	ng/mL	9.49, (0.37), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]
Serum	FTSLOW	serum	M	ng/mL	9.45, (0.36), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]
Serum	FTSLOW	water	NA	ng/L	19600, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]
Serum	FTSMED	serum	F	ng/mL	44.6, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]
Serum	FTSMED	serum	M	ng/mL	46.02, (1.97), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]
Serum	FTSMED	water	NA	ng/L	58600, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]
Serum	FTSHIGH	serum	F	ng/mL	150.4, (7.11), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]
Serum	FTSHIGH	serum	M	ng/mL	149, (8.18), [10]	149, (8.18), [10]	149, (8.18), [10]	149, (8.18), [10]	149, (8.18), [10]	149, (8.18), [10]	149, (8.18), [10]
Serum	FTSHIGH	water	NA	ng/L	1e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]
Serum	Control	serum	F	ng/mL	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]
Serum	Control	serum	M	ng/mL	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]
Serum	Control	water	NA	ng/L	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]
Serum	PFOS	Brain	F	ng/g	864.29, (142.59), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]
Serum	PFOS	Brain	M	ng/g	1000.43, (208.03), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]
Serum	PFOS	Kidney	F	ng/g	609.86, (67.21), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]	701, (77.78), [7]
Serum	PFOS	Kidney	M	ng/g	428, (51.53), [7]	428, (51.53), [7]	428, (51.53), [7]	428, (51.53), [7]	428, (51.53), [7]	428, (51.53), [7]	492.29, (59.31), [7]
Serum	PFOS	Liver	F	ng/g	27.41, (0.8), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]
Serum	PFOS	Liver	M	ng/g	27.5, (1.48), [7]	27.5, (1.48), [7]	27.5, (1.48), [7]	27.5, (1.48), [7]	28.36, (3.25), [7]	27.5, (1.48), [7]	27.5, (1.48), [7]

Serum	PFOA	Brain	F	ng/g	672.14, (153.72), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]
Serum	PFOA	Brain	M	ng/g	702.86, (127.03), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]
Serum	PFOA	Kidney	F	ng/g	609.14, (59.56), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]	700.29, (68.35), [7]
Serum	PFOA	Kidney	M	ng/g	409.57, (56.39), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]	470.71, (64.53), [7]
Serum	PFOA	Liver	F	ng/g	27.04, (0.98), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]
Serum	PFOA	Liver	M	ng/g	27.94, (0.91), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]
Serum	PFHxS	Brain	F	ng/g	109.24, (30.67), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]
Serum	PFHxS	Brain	M	ng/g	102.81, (26.69), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]
Serum	PFHxS	Kidney	F	ng/g	107.7, (14.92), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]	124.14, (16.94), [7]
Serum	PFHxS	Kidney	M	ng/g	63.17, (12), [7]	63.17, (12), [7]	63.17, (12), [7]	63.17, (12), [7]	63.17, (12), [7]	63.17, (12), [7]	72.64, (13.8), [7]
Serum	PFHxS	Liver	F	ng/g	28.51, (0.82), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]	95.13, (2.78), [7]
Serum	PFHxS	Liver	M	ng/g	28.39, (0.79), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]	94.57, (2.68), [7]
Serum	PFHxA	Brain	F	ng/g	1.42, (1.12), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]
Serum	PFHxA	Brain	M	ng/g	0.87, (0.12), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]
Serum	PFHxA	Kidney	F	ng/g	0.68, (0.09), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]
Serum	PFHxA	Kidney	M	ng/g	0.39, (0.05), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]
Serum	PFHxA	Liver	F	ng/g	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]
Serum	PFHxA	Liver	M	ng/g	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]
Serum	6:2 FTS	Brain	F	ng/g	44.64, (25.16), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]
Serum	6:2 FTS	Brain	M	ng/g	66.16, (22.86), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]
Serum	6:2 FTS	Kidney	F	ng/g	16.73, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]
Serum	6:2 FTS	Kidney	M	ng/g	11.27, (2.41), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]
Serum	6:2 FTS	Liver	F	ng/g	9.88, (0.16), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]
Serum	6:2 FTS	Liver	M	ng/g	9.85, (0.08), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]
Serum	8:2 FTS	Brain	F	ng/g	612.81, (564.51), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]
Serum	8:2 FTS	Brain	M	ng/g	139.33, (242.27), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]
Serum	8:2 FTS	Kidney	F	ng/g	36.56, (5.83), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]
Serum	8:2 FTS	Kidney	M	ng/g	23.01, (3.24), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]
Serum	8:2 FTS	Liver	F	ng/g	9.74, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]
Serum	8:2 FTS	Liver	M	ng/g	9.78, (0.18), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]
Serum	C6-8 Low	Brain	F	ng/g	155.07, (63.46), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]
Serum	C6-8 Low	Brain	M	ng/g	125.49, (34.29), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]
Serum	C6-8 Low	Kidney	F	ng/g	7.24, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]
Serum	C6-8 Low	Kidney	M	ng/g	4.27, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]
Serum	C6-8 Low	Liver	F	ng/g	4.72, (0.1), [10]	4.72, (0.1), [10]	4.72, (0.1), [10]	4.72, (0.1), [10]	4.72, (0.1), [10]	4.72, (0.1), [10]	94.42, (1.99), [10]
Serum	C6-8 Low	Liver	M	ng/g	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	95.71, (1.78), [10]
Serum	C6-8 Medium	Brain	F	ng/g	245.29, (16.1), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]
Serum	C6-8 Medium	Brain	M	ng/g	268.29, (24.28), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]
Serum	C6-8 Medium	Kidney	F	ng/g	34.19, (4.68), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]
Serum	C6-8 Medium	Kidney	M	ng/g	21.67, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]
Serum	C6-8 Medium	Liver	F	ng/g	9.49, (0.22), [10]	9.49, (0.22), [10]	9.49, (0.22), [10]	9.49, (0.22), [10]	9.49, (0.22), [10]	9.49, (0.22), [10]	189.7, (4.42), [10]
Serum	C6-8 Medium	Liver	M	ng/g	9.57, (0.23), [10]	9.57, (0.23), [10]	9.57, (0.23), [10]	9.57, (0.23), [10]	9.57, (0.23), [10]	9.57, (0.23), [10]	191.4, (4.53), [10]
Serum	C6-8 High	Brain	F	ng/g	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]
Serum	C6-8 High	Brain	M	ng/g	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]
Serum	C6-8 High	Kidney	F	ng/g	35.39, (4.7), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]
Serum	C6-8 High	Kidney	M	ng/g	22.07, (2.53), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]
Serum	C6-8 High	Liver	F	ng/g	9.71, (0.29), [10]	9.71, (0.29), [10]	9.71, (0.29), [10]	9.71, (0.29), [10]	9.71, (0.29), [10]	9.71, (0.29), [10]	242.5, (7.03), [10]
Serum	C6-8 High	Liver	M	ng/g	9.52, (0.27), [9]	10.87, (4.14), [9]	9.52, (0.27), [9]	9.52, (0.27), [9]	9.52, (0.27), [9]	9.52, (0.27), [9]	238, (6.98), [9]
Serum	FTS Low	Brain	F	ng/g	136.77, (61.83), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]
Serum	FTS Low	Brain	M	ng/g	254.71, (103.33), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]
Serum	FTS Low	Kidney	F	ng/g	17.83, (1.43), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]	20.51, (1.67), [7]
Serum	FTS Low	Kidney	M	ng/g	10.7, (1.7), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]	12.31, (1.96), [7]
Serum	FTS Low	Liver	F	ng/g	4.76, (0.09), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]
Serum	FTS Low	Liver	M	ng/g	4.75, (0.1), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]
Serum	FTS Medium	Brain	F	ng/g	44.03, (18.88), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]
Serum	FTS Medium	Brain	M	ng/g	57.6, (23.29), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]
Serum	FTS Medium	Kidney	F	ng/g	17.41, (2), [7]	17.41, (2), [7]	17.41, (2), [7]	17.41, (2), [7]	17.41, (2), [7]	17.41, (2), [7]	20.03, (2.27), [7]
Serum	FTS Medium	Kidney	M	ng/g	11, (1.75), [7]	11, (1.75), [7]	11, (1.75), [7]	11, (1.75), [7]	11, (1.75), [7]	11, (1.75), [7]	12.66, (2.03), [7]
Serum	FTS Medium	Liver	F	ng/g	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]
Serum	FTS Medium	Liver	M	ng/g	4.77, (0.15), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]
Serum	FTS High	Brain	F	ng/g	63.7, (33.18), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]
Serum	FTS High	Brain	M	ng/g	58.07, (15.94), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]

Serum	FTS High	Kidney	F	ng/g	34.49, (6.63), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]	39.67, (7.62), [7]
Serum	FTS High	Kidney	M	ng/g	21.8, (2.74), [7]	21.8, (2.74), [7]	21.8, (2.74), [7]	21.8, (2.74), [7]	21.8, (2.74), [7]	21.8, (2.74), [7]	25.07, (3.16), [7]
Serum	FTS High	Liver	F	ng/g	9.71, (0.17), [10]	9.71, (0.17), [10]	9.71, (0.17), [10]	9.71, (0.17), [10]	9.83, (0.5), [10]	9.71, (0.17), [10]	9.71, (0.17), [10]
Serum	FTS High	Liver	M	ng/g	9.7, (0.25), [10]	9.7, (0.25), [10]	9.7, (0.25), [10]	9.7, (0.25), [10]	9.91, (0.71), [10]	9.7, (0.25), [10]	9.7, (0.25), [10]
Serum	Control	Brain	F	ng/g	0.67, (0.13), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]
Serum	Control	Brain	M	ng/g	0.61, (0.05), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]
Serum	Control	Kidney	F	ng/g	0.8, (0.07), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]
Serum	Control	Kidney	M	ng/g	0.43, (0.04), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]
Serum	Control	Liver	F	ng/g	0.17, (0.02), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]
Serum	Control	Liver	M	ng/g	0.12, (0.01), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]	0.13, (0.03), [7]	0.12, (0.01), [7]

Table SI3.7. Table SI3.3 continued.

Study	Treatment	Sample Type	Sex	Units	PFMBA	PFMPA	PFNA	PFNS	PFOA	PFOS	PFOSA
Wholebody	PFOS	water	NA	ng/L	213000, (NA), [1]	425000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]
Wholebody	PFOS	wholebody	F	ng/g	0.49, (0.01), [20]	0.98, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.5, (0.04), [20]	0.49, (0.01), [20]
Wholebody	PFOS	wholebody	M	ng/g	0.49, (0.01), [20]	0.98, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.53, (0.08), [20]	0.49, (0.01), [20]
Wholebody	PFOA	water	NA	ng/L	201000, (NA), [1]	402000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]
Wholebody	PFOA	wholebody	F	ng/g	0.1, (0.01), [10]	0.19, (0.01), [10]	0.1, (0), [10]	0.09, (0), [10]	0.88, (0.18), [10]	0.09, (0), [10]	0.09, (0), [10]
Wholebody	PFOA	wholebody	M	ng/g	0.09, (0), [9]	0.19, (0), [9]	0.09, (0), [9]	0.09, (0), [9]	1.2, (0.4), [9]	0.09, (0), [9]	0.09, (0), [9]
Wholebody	PFHxS	water	NA	ng/L	178000, (NA), [1]	357000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]
Wholebody	PFHxS	wholebody	F	ng/g	7.49, (0.42), [3]	15, (0.8), [3]	16.71, (9.71), [8]	7.65, (0.26), [10]	125.29, (93.58), [10]	7.65, (0.26), [10]	7.65, (0.26), [10]
Wholebody	PFHxS	wholebody	M	ng/g	7.69, (0.32), [5]	15.38, (0.63), [5]	13.92, (10.9), [9]	7.63, (0.34), [10]	68.17, (61.93), [10]	7.63, (0.34), [10]	7.63, (0.34), [10]
Wholebody	PFHxA	water	NA	ng/L	215000, (NA), [1]	430000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]
Wholebody	PFHxA	wholebody	F	ng/g	0.18, (0.01), [10]	0.37, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]
Wholebody	PFHxA	wholebody	M	ng/g	0.18, (0.01), [10]	0.37, (0.02), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]
Wholebody	PFNA	water	NA	ng/L	210000, (NA), [1]	419000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]
Wholebody	PFNA	wholebody	F	ng/g	7.54, (0.37), [10]	15.06, (0.74), [10]	38.05, (70.87), [10]	7.54, (0.37), [10]	7.58, (0.32), [10]	7.54, (0.37), [10]	7.54, (0.37), [10]
Wholebody	PFNA	wholebody	M	ng/g	7.52, (0.39), [10]	15.03, (0.78), [10]	35.46, (32.1), [10]	7.52, (0.39), [10]	7.68, (0.47), [10]	7.52, (0.39), [10]	7.52, (0.39), [10]
Wholebody	PFBS	water	NA	ng/L	183000, (NA), [1]	366000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]
Wholebody	PFBS	wholebody	F	ng/g	1.9, (0.08), [10]	3.8, (0.16), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]
Wholebody	PFBS	wholebody	M	ng/g	1.87, (0.07), [10]	3.75, (0.14), [10]	1.87, (0.07), [10]	1.87, (0.07), [10]	4.16, (3.19), [10]	1.87, (0.07), [10]	1.87, (0.07), [10]
Wholebody	6:2 FTS	water	NA	ng/L	53200, (NA), [1]	106000, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]
Wholebody	6:2 FTS	wholebody	F	ng/g	0.1, (0), [10]	0.19, (0.01), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]
Wholebody	6:2 FTS	wholebody	M	ng/g	0.09, (0), [10]	0.19, (0.01), [10]	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]
Wholebody	8:2 FTS	water	NA	ng/L	51700, (NA), [1]	103000, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]
Wholebody	8:2 FTS	wholebody	F	ng/g	0.1, (0), [9]	0.19, (0.01), [9]	0.22, (0.26), [9]	0.1, (0), [9]	0.1, (0), [9]	0.1, (0), [9]	0.1, (0), [9]
Wholebody	8:2 FTS	wholebody	M	ng/g	0.1, (0), [11]	0.19, (0), [11]	0.2, (0.21), [13]	0.1, (0), [11]	0.1, (0.02), [11]	0.1, (0), [11]	0.1, (0), [11]
Wholebody	C68LOW	water	NA	ng/L	19200, (NA), [1]	38500, (NA), [1]	19200, (NA), [1]	19200, (NA), [1]	19200, (NA), [1]	96200, (NA), [1]	19200, (NA), [1]
Wholebody	C68LOW	wholebody	F	ng/g	1.91, (0.07), [10]	3.81, (0.13), [10]	2.17, (0.48), [10]	1.91, (0.07), [10]	7.81, (5.05), [10]	1.91, (0.07), [10]	1.91, (0.07), [10]
Wholebody	C68LOW	wholebody	M	ng/g	1.91, (0.07), [10]	3.82, (0.14), [10]	2.06, (0.35), [10]	1.91, (0.07), [10]	7.34, (4.91), [10]	2.3, (1.24), [10]	1.91, (0.07), [10]
Wholebody	C68MED	water	NA	ng/L	109000, (NA), [1]	219000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]
Wholebody	C68MED	wholebody	F	ng/g	1.95, (0.06), [10]	3.91, (0.11), [10]	1.96, (0.06), [10]	1.95, (0.06), [10]	2.49, (1.06), [10]	1.95, (0.06), [10]	1.95, (0.06), [10]
Wholebody	C68MED	wholebody	M	ng/g	1.95, (0.04), [9]	3.9, (0.07), [9]	1.95, (0.04), [9]	1.95, (0.04), [9]	2.06, (0.28), [9]	1.95, (0.04), [9]	1.95, (0.04), [9]
Wholebody	C68HIGH	water	NA	ng/L	111000, (NA), [1]	221000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]	553000, (NA), [1]	111000, (NA), [1]
Wholebody	C68HIGH	wholebody	F	ng/g	6.72, (0.4), [10]	13.41, (0.8), [10]	6.72, (0.4), [10]	6.72, (0.4), [10]	14.49, (5.48), [10]	8.67, (6.03), [10]	6.72, (0.4), [10]
Wholebody	C68HIGH	wholebody	M	ng/g	7.08, (0.56), [10]	14.14, (1.12), [10]	7.08, (0.56), [10]	7.08, (0.56), [10]	9.72, (3.42), [10]	7.08, (0.56), [10]	7.08, (0.56), [10]
Wholebody	FTSLOW	water	NA	ng/L	17100, (NA), [1]	34200, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]	85500, (NA), [1]	17100, (NA), [1]
Wholebody	FTSLOW	wholebody	F	ng/g	3.83, (0.17), [10]	7.66, (0.33), [10]	3.83, (0.17), [10]	3.83, (0.17), [10]	4.12, (0.75), [10]	4.28, (1.5), [10]	3.83, (0.17), [10]
Wholebody	FTSLOW	wholebody	M	ng/g	3.76, (0.16), [10]	7.53, (0.32), [10]	3.76, (0.16), [10]	3.76, (0.16), [10]	3.77, (0.17), [10]	3.76, (0.16), [10]	3.76, (0.16), [10]
Wholebody	FTSMED	water	NA	ng/L	53400, (NA), [1]	107000, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]	267000, (NA), [1]	53400, (NA), [1]
Wholebody	FTSMED	wholebody	F	ng/g	1.88, (0.09), [10]	3.77, (0.18), [10]	1.88, (0.09), [10]	1.88, (0.09), [10]	1.91, (0.12), [10]	1.88, (0.09), [10]	1.88, (0.09), [10]
Wholebody	FTSMED	wholebody	M	ng/g	1.9, (0.08), [10]	3.79, (0.15), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]	2.07, (0.43), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]
Wholebody	FTSHIGH	water	NA	ng/L	108000, (NA), [1]	216000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]	540000, (NA), [1]	108000, (NA), [1]
Wholebody	FTSHIGH	wholebody	F	ng/g	6.64, (0.43), [10]	13.29, (0.87), [10]	6.64, (0.43), [10]	6.64, (0.43), [10]	11.87, (5.47), [10]	6.68, (0.51), [10]	6.64, (0.43), [10]
Wholebody	FTSHIGH	wholebody	M	ng/g	6.75, (0.45), [10]	13.49, (0.91), [10]	6.75, (0.45), [10]	6.75, (0.45), [10]	7.19, (0.97), [10]	6.75, (0.45), [10]	6.75, (0.45), [10]
Wholebody	Control	water	NA	ng/L	11100, (NA), [1]	22200, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]
Wholebody	Control	wholebody	F	ng/g	0.1, (0), [10]	0.19, (0), [10]	0.1, (0.01), [10]	0.1, (0), [10]	0.2, (0.1), [10]	0.1, (0), [10]	0.1, (0), [10]
Wholebody	Control	wholebody	M	ng/g	0.11, (0.02), [10]	0.2, (0), [10]	0.15, (0.06), [10]	0.1, (0), [10]	0.39, (0.23), [10]	0.1, (0), [10]	0.1, (0), [10]
Serum	PFOS	serum	F	ng/mL	18.19, (1.02), [10]	36.37, (2.05), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]	100.04, (84.28), [20]	18.19, (1.02), [10]
Serum	PFOS	serum	M	ng/mL	16.67, (1.99), [9]	33.28, (3.96), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]	91.67, (78.38), [18]	16.67, (1.99), [9]

Serum	PFOS	water	NA	ng/L	95500, (NA), [1]	191000, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]	955000, (NA), [1]	95500, (NA), [1]
Serum	PFOA	serum	F	ng/mL	0.98, (0.04), [10]	1.96, (0.08), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	50.99, (48.43), [20]	0.98, (0.04), [10]	0.98, (0.04), [10]
Serum	PFOA	serum	M	ng/mL	0.98, (0.04), [10]	1.96, (0.07), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	51.15, (48.22), [20]	0.98, (0.04), [10]	0.98, (0.04), [10]
Serum	PFOA	water	NA	ng/L	199000, (NA), [1]	398000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]
Serum	PFHxS	serum	F	ng/mL	1.11, (0.29), [10]	2.23, (0.59), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]
Serum	PFHxS	serum	M	ng/mL	1.09, (0.21), [10]	2.17, (0.42), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]
Serum	PFHxS	water	NA	ng/L	211000, (NA), [1]	422000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]
Serum	PFHxA	serum	F	ng/mL	1.03, (0.11), [9]	2.06, (0.21), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]	1.19, (0.33), [9]	1.17, (0.34), [9]	1.03, (0.11), [9]
Serum	PFHxA	serum	M	ng/mL	1.06, (0.14), [10]	2.13, (0.29), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]
Serum	PFHxA	water	NA	ng/L	204000, (NA), [1]	407000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]
Serum	PFNA	serum	F	ng/mL	148.6, (4.99), [10]	297.2, (9.45), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]
Serum	PFNA	serum	M	ng/mL	144, (6.46), [10]	287.6, (13.17), [10]	144, (6.46), [10]	144, (6.46), [10]	144, (6.46), [10]	144, (6.46), [10]	144, (6.46), [10]
Serum	PFNA	water	NA	ng/L	184000, (NA), [1]	368000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]
Serum	PFBS	serum	F	ng/mL	1.22, (0.39), [10]	2.43, (0.78), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]
Serum	PFBS	serum	M	ng/mL	1.18, (0.52), [10]	2.37, (1.03), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]
Serum	PFBS	water	NA	ng/L	201000, (NA), [1]	402000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]
Serum	6:2 FTS	serum	F	ng/mL	0.85, (0.22), [10]	1.7, (0.43), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]
Serum	6:2 FTS	serum	M	ng/mL	0.86, (0.23), [10]	1.72, (0.46), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]
Serum	6:2 FTS	water	NA	ng/L	47000, (NA), [1]	93900, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]
Serum	8:2 FTS	serum	F	ng/mL	0.86, (0.24), [10]	1.72, (0.49), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]	0.89, (0.22), [10]	0.86, (0.24), [10]
Serum	8:2 FTS	serum	M	ng/mL	0.74, (0.16), [10]	1.49, (0.32), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]
Serum	8:2 FTS	water	NA	ng/L	50500, (NA), [1]	101000, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]
Serum	C68LOW	serum	F	ng/mL	9.54, (0.45), [10]	19.09, (0.91), [10]	9.54, (0.45), [10]	9.54, (0.45), [10]	9.54, (0.45), [10]	52.48, (44.16), [20]	9.54, (0.45), [10]
Serum	C68LOW	serum	M	ng/mL	9.8, (0.43), [10]	19.64, (0.91), [10]	9.8, (0.43), [10]	9.8, (0.43), [10]	9.8, (0.43), [10]	53.91, (45.35), [20]	9.8, (0.43), [10]
Serum	C68LOW	water	NA	ng/L	20200, (NA), [1]	40400, (NA), [1]	20200, (NA), [1]	20200, (NA), [1]	20200, (NA), [1]	202000, (NA), [1]	20200, (NA), [1]
Serum	C68MED	serum	F	ng/mL	47.97, (2.17), [10]	95.8, (4.21), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]
Serum	C68MED	serum	M	ng/mL	47.92, (1.14), [10]	95.74, (2.27), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]
Serum	C68MED	water	NA	ng/L	48900, (NA), [1]	97800, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]	489000, (NA), [1]	48900, (NA), [1]
Serum	C68HIGH	serum	F	ng/mL	148.4, (3.86), [10]	297.2, (6.76), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]
Serum	C68HIGH	serum	M	ng/mL	147.33, (6.86), [9]	294.78, (13.51), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]
Serum	C68HIGH	water	NA	ng/L	105000, (NA), [1]	211000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]	1050000, (NA), [1]	105000, (NA), [1]
Serum	FTSLOW	serum	F	ng/mL	9.49, (0.37), [10]	18.98, (0.76), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]	52.2, (43.89), [20]	9.49, (0.37), [10]
Serum	FTSLOW	serum	M	ng/mL	9.45, (0.36), [10]	18.89, (0.75), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]	51.96, (43.69), [20]	9.45, (0.36), [10]
Serum	FTSLOW	water	NA	ng/L	19600, (NA), [1]	39200, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]	196000, (NA), [1]	19600, (NA), [1]
Serum	FTSMED	serum	F	ng/mL	44.6, (1.78), [10]	89.2, (3.56), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]
Serum	FTSMED	serum	M	ng/mL	46.02, (1.97), [10]	92, (3.88), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]
Serum	FTSMED	water	NA	ng/L	58600, (NA), [1]	117000, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]
Serum	FTSHIGH	serum	F	ng/mL	150.4, (7.11), [10]	300.2, (13.96), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]
Serum	FTSHIGH	serum	M	ng/mL	149, (8.18), [10]	297.6, (16.14), [10]	149, (8.18), [10]	149, (8.18), [10]	149, (8.18), [10]	149, (8.18), [10]	149, (8.18), [10]
Serum	FTSHIGH	water	NA	ng/L	1e+05, (NA), [1]	2e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]	5e+05, (NA), [1]	1e+05, (NA), [1]
Serum	Control	serum	F	ng/mL	1.47, (0.68), [10]	2.93, (1.36), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]
Serum	Control	serum	M	ng/mL	1.05, (0.31), [10]	2.1, (0.62), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]
Serum	Control	water	NA	ng/L	10700, (NA), [1]	21400, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]
Serum	PFOS	Brain	F	ng/g	864.29, (142.59), [7]	1725.71, (283.25), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]
Serum	PFOS	Brain	M	ng/g	1000.43, (208.03), [7]	2001.43, (413.9), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]
Serum	PFOS	Kidney	F	ng/g	609.86, (67.21), [7]	1218.57, (133.22), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]
Serum	PFOS	Kidney	M	ng/g	428, (51.53), [7]	855.29, (101.72), [7]	428, (51.53), [7]	428, (51.53), [7]	428, (51.53), [7]	428, (51.53), [7]	428, (51.53), [7]
Serum	PFOS	Liver	F	ng/g	27.41, (0.8), [7]	54.87, (1.64), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]	548.71, (16.44), [7]	27.41, (0.8), [7]
Serum	PFOS	Liver	M	ng/g	27.5, (1.48), [7]	54.97, (3.01), [7]	27.5, (1.48), [7]	27.5, (1.48), [7]	27.5, (1.48), [7]	549.71, (30.06), [7]	27.5, (1.48), [7]
Serum	PFOA	Brain	F	ng/g	672.14, (153.72), [7]	1345, (307.37), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]
Serum	PFOA	Brain	M	ng/g	702.86, (127.03), [7]	1404.29, (252.84), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]
Serum	PFOA	Kidney	F	ng/g	609.14, (59.56), [7]	1219.86, (119.9), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]
Serum	PFOA	Kidney	M	ng/g	409.57, (56.39), [7]	818.86, (112.11), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]
Serum	PFOA	Liver	F	ng/g	27.04, (0.98), [7]	54.09, (1.91), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]	213.14, (74.63), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]
Serum	PFOA	Liver	M	ng/g	27.94, (0.91), [7]	55.86, (1.77), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]	279.43, (9.05), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]
Serum	PFHxS	Brain	F	ng/g	109.24, (30.67), [7]	218.43, (61.06), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]
Serum	PFHxS	Brain	M	ng/g	102.81, (26.69), [7]	205.57, (53.78), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]
Serum	PFHxS	Kidney	F	ng/g	107.7, (14.92), [7]	216, (29.78), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]
Serum	PFHxS	Kidney	M	ng/g	63.17, (12), [7]	126.23, (23.94), [7]	63.17, (12), [7]	63.17, (12), [7]	63.17, (12), [7]	63.17, (12), [7]	63.17, (12), [7]
Serum	PFHxS	Liver	F	ng/g	28.51, (0.82), [7]	57.07, (1.69), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]
Serum	PFHxS	Liver	M	ng/g	28.39, (0.79), [7]	56.76, (1.6), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]
Serum	PFHxA	Brain	F	ng/g	1.42, (1.12), [7]	2.85, (2.24), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]

Serum	PFHxA	Brain	M	ng/g	0.87, (0.12), [7]	1.75, (0.23), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]
Serum	PFHxA	Kidney	F	ng/g	0.68, (0.09), [7]	1.36, (0.18), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]
Serum	PFHxA	Kidney	M	ng/g	0.39, (0.05), [7]	0.78, (0.09), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]
Serum	PFHxA	Liver	F	ng/g	0.23, (0.11), [7]	0.46, (0.22), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]
Serum	PFHxA	Liver	M	ng/g	0.21, (0.06), [7]	0.42, (0.13), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]
Serum	6:2 FTS	Brain	F	ng/g	44.64, (25.16), [7]	89.23, (50.24), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]
Serum	6:2 FTS	Brain	M	ng/g	66.16, (22.86), [7]	132.33, (45.67), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]
Serum	6:2 FTS	Kidney	F	ng/g	16.73, (2.26), [7]	33.49, (4.48), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]
Serum	6:2 FTS	Kidney	M	ng/g	11.27, (2.41), [7]	22.54, (4.76), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]
Serum	6:2 FTS	Liver	F	ng/g	9.88, (0.16), [7]	19.76, (0.33), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]
Serum	6:2 FTS	Liver	M	ng/g	9.85, (0.08), [7]	19.7, (0.18), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]
Serum	8:2 FTS	Brain	F	ng/g	612.81, (564.51), [7]	1225.71, (1125.43), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]
Serum	8:2 FTS	Brain	M	ng/g	139.33, (242.27), [7]	279.21, (486.05), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]
Serum	8:2 FTS	Kidney	F	ng/g	36.56, (5.83), [7]	73.1, (11.64), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]
Serum	8:2 FTS	Kidney	M	ng/g	23.01, (3.24), [7]	46.01, (6.53), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]
Serum	8:2 FTS	Liver	F	ng/g	9.74, (0.27), [7]	19.5, (0.52), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]
Serum	8:2 FTS	Liver	M	ng/g	9.78, (0.18), [7]	19.57, (0.38), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]
Serum	C6-8 Low	Brain	F	ng/g	155.07, (63.46), [7]	310.14, (127.1), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]
Serum	C6-8 Low	Brain	M	ng/g	125.49, (34.29), [7]	251.14, (68.14), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]
Serum	C6-8 Low	Kidney	F	ng/g	7.24, (0.88), [7]	14.49, (1.76), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]
Serum	C6-8 Low	Kidney	M	ng/g	4.27, (0.44), [7]	8.55, (0.88), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]
Serum	C6-8 Low	Liver	F	ng/g	4.72, (0.1), [10]	9.44, (0.2), [10]	4.72, (0.1), [10]	4.72, (0.1), [10]	94.42, (1.99), [10]	94.79, (1.68), [10]	4.72, (0.1), [10]
Serum	C6-8 Low	Liver	M	ng/g	4.79, (0.09), [10]	9.57, (0.18), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	95.71, (1.78), [10]	95.71, (1.78), [10]	4.79, (0.09), [10]
Serum	C6-8 Medium	Brain	F	ng/g	245.29, (16.1), [7]	490.29, (32.02), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]
Serum	C6-8 Medium	Brain	M	ng/g	268.29, (24.28), [7]	536.86, (48.2), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]
Serum	C6-8 Medium	Kidney	F	ng/g	34.19, (4.68), [7]	68.39, (9.35), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]
Serum	C6-8 Medium	Kidney	M	ng/g	21.67, (3.25), [7]	43.34, (6.47), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]
Serum	C6-8 Medium	Liver	F	ng/g	9.49, (0.22), [10]	18.97, (0.44), [10]	9.49, (0.22), [10]	9.49, (0.22), [10]	189.7, (4.42), [10]	189.7, (4.42), [10]	9.49, (0.22), [10]
Serum	C6-8 Medium	Liver	M	ng/g	9.57, (0.23), [10]	19.14, (0.45), [10]	9.57, (0.23), [10]	9.57, (0.23), [10]	191.4, (4.53), [10]	191.4, (4.53), [10]	9.57, (0.23), [10]
Serum	C6-8 High	Brain	F	ng/g	1497.14, (144.19), [7]	2988.57, (289.33), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]
Serum	C6-8 High	Brain	M	ng/g	1270.29, (674.45), [7]	2538.57, (1348.94), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]
Serum	C6-8 High	Kidney	F	ng/g	35.39, (4.7), [7]	70.8, (9.44), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]
Serum	C6-8 High	Kidney	M	ng/g	22.07, (2.53), [7]	44.19, (5.1), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]
Serum	C6-8 High	Liver	F	ng/g	9.71, (0.29), [10]	19.42, (0.58), [10]	9.71, (0.29), [10]	9.71, (0.29), [10]	242.5, (7.03), [10]	242.5, (7.03), [10]	9.71, (0.29), [10]
Serum	C6-8 High	Liver	M	ng/g	9.52, (0.27), [9]	19.04, (0.53), [9]	9.52, (0.27), [9]	9.52, (0.27), [9]	238, (6.98), [9]	238, (6.98), [9]	9.52, (0.27), [9]
Serum	FTS Low	Brain	F	ng/g	136.77, (61.83), [7]	273.71, (123.59), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]
Serum	FTS Low	Brain	M	ng/g	254.71, (103.33), [7]	509.43, (206.32), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]
Serum	FTS Low	Kidney	F	ng/g	17.83, (1.43), [7]	35.69, (2.9), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]
Serum	FTS Low	Kidney	M	ng/g	10.7, (1.7), [7]	21.4, (3.36), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]
Serum	FTS Low	Liver	F	ng/g	4.76, (0.09), [10]	9.52, (0.18), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]	95.24, (1.79), [10]	4.76, (0.09), [10]
Serum	FTS Low	Liver	M	ng/g	4.75, (0.1), [10]	9.49, (0.21), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]	94.91, (2.07), [10]	4.75, (0.1), [10]
Serum	FTS Medium	Brain	F	ng/g	44.03, (18.88), [7]	88.03, (37.78), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]
Serum	FTS Medium	Brain	M	ng/g	57.6, (23.29), [7]	115.39, (46.73), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]
Serum	FTS Medium	Kidney	F	ng/g	17.41, (2), [7]	34.86, (3.99), [7]	17.41, (2), [7]	17.41, (2), [7]	17.41, (2), [7]	17.41, (2), [7]	17.41, (2), [7]
Serum	FTS Medium	Kidney	M	ng/g	11, (1.75), [7]	22, (3.53), [7]	11, (1.75), [7]	11, (1.75), [7]	11, (1.75), [7]	16.02, (12.38), [7]	11, (1.75), [7]
Serum	FTS Medium	Liver	F	ng/g	4.79, (0.09), [10]	9.57, (0.19), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	2991, (58.96), [10]	4.79, (0.09), [10]
Serum	FTS Medium	Liver	M	ng/g	4.77, (0.15), [10]	9.53, (0.29), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]	2977, (91.41), [10]	4.77, (0.15), [10]
Serum	FTS High	Brain	F	ng/g	63.7, (33.18), [7]	127.37, (66.46), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]	1218.57, (634.39), [7]	63.7, (33.18), [7]
Serum	FTS High	Brain	M	ng/g	58.07, (15.94), [7]	116.11, (31.85), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]	1127.14, (295.55), [7]	58.07, (15.94), [7]
Serum	FTS High	Kidney	F	ng/g	34.49, (6.63), [7]	68.99, (13.26), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]
Serum	FTS High	Kidney	M	ng/g	21.8, (2.74), [7]	43.59, (5.47), [7]	21.8, (2.74), [7]	21.8, (2.74), [7]	21.8, (2.74), [7]	24.7, (9.84), [7]	21.8, (2.74), [7]
Serum	FTS High	Liver	F	ng/g	9.71, (0.17), [10]	19.43, (0.33), [10]	9.71, (0.17), [10]	9.71, (0.17), [10]	9.71, (0.17), [10]	194.3, (3.33), [10]	9.71, (0.17), [10]
Serum	FTS High	Liver	M	ng/g	9.7, (0.25), [10]	19.41, (0.51), [10]	9.7, (0.25), [10]	9.7, (0.25), [10]	9.7, (0.25), [10]	194.1, (5.07), [10]	9.7, (0.25), [10]
Serum	Control	Brain	F	ng/g	0.67, (0.13), [7]	1.33, (0.26), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]	0.67, (0.13), [7]
Serum	Control	Brain	M	ng/g	0.61, (0.05), [7]	1.22, (0.11), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]	0.61, (0.05), [7]
Serum	Control	Kidney	F	ng/g	0.8, (0.07), [7]	1.6, (0.14), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]
Serum	Control	Kidney	M	ng/g	0.43, (0.04), [7]	0.87, (0.09), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]
Serum	Control	Liver	F	ng/g	0.17, (0.02), [7]	0.33, (0.04), [7]	0.35, (0.48), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]
Serum	Control	Liver	M	ng/g	0.12, (0.01), [7]	0.24, (0.02), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]

Table SI3.8. Table SI3.3 continued.

Study	Treatment	Sample Type	Sex	Units	PFPeA	PFPeS	PFTeDA	PFTrDA	PFUnA
Wholebody	PFOS	water	NA	ng/L	425000, (NA), [1]	214000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]	213000, (NA), [1]
Wholebody	PFOS	wholebody	F	ng/g	1, (0.05), [20]	0.49, (0.01), [20]	0.5, (0.03), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]
Wholebody	PFOS	wholebody	M	ng/g	0.98, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]	0.49, (0.01), [20]
Wholebody	PFOA	water	NA	ng/L	402000, (NA), [1]	202000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]
Wholebody	PFOA	wholebody	F	ng/g	0.32, (0.17), [10]	0.1, (0), [10]	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]
Wholebody	PFOA	wholebody	M	ng/g	0.2, (0.03), [9]	0.09, (0), [9]	0.09, (0), [9]	0.09, (0), [9]	0.09, (0), [9]
Wholebody	PFHxS	water	NA	ng/L	357000, (NA), [1]	179000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]	178000, (NA), [1]
Wholebody	PFHxS	wholebody	F	ng/g	53.33, (16.33), [3]	7.69, (0.26), [10]	14.99, (5.38), [9]	7.85, (0.47), [9]	7.65, (0.26), [10]
Wholebody	PFHxS	wholebody	M	ng/g	50.1, (11.4), [5]	7.67, (0.34), [10]	15.11, (4.64), [10]	7.72, (0.44), [10]	7.63, (0.34), [10]
Wholebody	PFHxA	water	NA	ng/L	430000, (NA), [1]	216000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]	215000, (NA), [1]
Wholebody	PFHxA	wholebody	F	ng/g	0.37, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]
Wholebody	PFHxA	wholebody	M	ng/g	0.37, (0.02), [10]	0.19, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]	0.18, (0.01), [10]
Wholebody	PFNA	water	NA	ng/L	419000, (NA), [1]	211000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]	210000, (NA), [1]
Wholebody	PFNA	wholebody	F	ng/g	15.06, (0.74), [10]	7.57, (0.38), [10]	9.73, (1.72), [10]	7.54, (0.37), [10]	7.54, (0.37), [10]
Wholebody	PFNA	wholebody	M	ng/g	15.03, (0.78), [10]	7.55, (0.39), [10]	8.82, (1.82), [10]	7.52, (0.39), [10]	7.52, (0.39), [10]
Wholebody	PFBS	water	NA	ng/L	366000, (NA), [1]	184000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]	183000, (NA), [1]
Wholebody	PFBS	wholebody	F	ng/g	3.8, (0.16), [10]	1.91, (0.08), [10]	2.01, (0.27), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]
Wholebody	PFBS	wholebody	M	ng/g	5.1, (1.9), [10]	1.88, (0.07), [10]	2.13, (0.41), [10]	1.87, (0.07), [10]	1.87, (0.07), [10]
Wholebody	6:2 FTS	water	NA	ng/L	106000, (NA), [1]	53500, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]	53200, (NA), [1]
Wholebody	6:2 FTS	wholebody	F	ng/g	0.19, (0.01), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]
Wholebody	6:2 FTS	wholebody	M	ng/g	0.19, (0.01), [10]	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]	0.09, (0), [10]
Wholebody	8:2 FTS	water	NA	ng/L	103000, (NA), [1]	52000, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]	51700, (NA), [1]
Wholebody	8:2 FTS	wholebody	F	ng/g	0.2, (0.02), [9]	0.1, (0), [9]	0.1, (0), [9]	0.1, (0), [9]	0.1, (0), [9]
Wholebody	8:2 FTS	wholebody	M	ng/g	0.24, (0.12), [11]	0.1, (0), [11]	0.1, (0), [11]	0.1, (0), [11]	0.1, (0), [11]
Wholebody	C68LOW	water	NA	ng/L	38500, (NA), [1]	19300, (NA), [1]	19200, (NA), [1]	19200, (NA), [1]	19200, (NA), [1]
Wholebody	C68LOW	wholebody	F	ng/g	14.46, (5.3), [10]	1.92, (0.07), [10]	2.71, (0.6), [10]	1.93, (0.09), [10]	1.91, (0.07), [10]
Wholebody	C68LOW	wholebody	M	ng/g	14.17, (3.46), [10]	1.92, (0.07), [10]	3.08, (0.65), [10]	1.96, (0.14), [10]	1.91, (0.07), [10]
Wholebody	C68MED	water	NA	ng/L	219000, (NA), [1]	110000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]	109000, (NA), [1]
Wholebody	C68MED	wholebody	F	ng/g	5.02, (2.47), [10]	1.96, (0.06), [10]	2.41, (0.68), [10]	1.95, (0.06), [10]	1.95, (0.06), [10]
Wholebody	C68MED	wholebody	M	ng/g	4.25, (1.08), [9]	1.96, (0.04), [9]	2.13, (0.37), [9]	1.95, (0.04), [9]	1.95, (0.04), [9]
Wholebody	C68HIGH	water	NA	ng/L	221000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]	111000, (NA), [1]
Wholebody	C68HIGH	wholebody	F	ng/g	15.39, (3.67), [10]	6.75, (0.41), [10]	10.28, (6.36), [10]	6.72, (0.4), [10]	6.72, (0.4), [10]
Wholebody	C68HIGH	wholebody	M	ng/g	15.38, (3.78), [10]	7.11, (0.56), [10]	7.93, (1.62), [10]	7.08, (0.56), [10]	7.08, (0.56), [10]
Wholebody	FTSLOW	water	NA	ng/L	34200, (NA), [1]	17200, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]	17100, (NA), [1]
Wholebody	FTSLOW	wholebody	F	ng/g	7.66, (0.33), [10]	3.85, (0.17), [10]	4.68, (1.17), [10]	3.83, (0.17), [10]	3.83, (0.17), [10]
Wholebody	FTSLOW	wholebody	M	ng/g	7.53, (0.32), [10]	3.78, (0.16), [10]	3.95, (0.21), [10]	3.76, (0.16), [10]	3.76, (0.16), [10]
Wholebody	FTSMED	water	NA	ng/L	107000, (NA), [1]	53700, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]	53400, (NA), [1]
Wholebody	FTSMED	wholebody	F	ng/g	3.77, (0.18), [10]	1.89, (0.09), [10]	2.3, (0.49), [10]	1.88, (0.09), [10]	1.88, (0.09), [10]
Wholebody	FTSMED	wholebody	M	ng/g	3.79, (0.15), [10]	1.91, (0.08), [10]	1.91, (0.06), [10]	1.9, (0.08), [10]	1.9, (0.08), [10]
Wholebody	FTSHIGH	water	NA	ng/L	216000, (NA), [1]	109000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]	108000, (NA), [1]
Wholebody	FTSHIGH	wholebody	F	ng/g	17.38, (6.83), [10]	6.67, (0.43), [10]	10.12, (2.84), [10]	6.69, (0.44), [10]	6.64, (0.43), [10]
Wholebody	FTSHIGH	wholebody	M	ng/g	13.49, (0.91), [10]	6.78, (0.45), [10]	8.1, (1.58), [10]	6.75, (0.45), [10]	6.75, (0.45), [10]
Wholebody	Control	water	NA	ng/L	22200, (NA), [1]	11200, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]	11100, (NA), [1]
Wholebody	Control	wholebody	F	ng/g	0.45, (0.23), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]	0.1, (0), [10]
Wholebody	Control	wholebody	M	ng/g	0.78, (0.12), [10]	0.1, (0), [10]	0.1, (0.01), [10]	0.1, (0), [10]	0.1, (0), [10]
Serum	PFOS	serum	F	ng/mL	36.37, (2.05), [10]	18.27, (1.03), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]	18.19, (1.02), [10]
Serum	PFOS	serum	M	ng/mL	33.28, (3.96), [9]	16.7, (2.01), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]	16.67, (1.99), [9]
Serum	PFOS	water	NA	ng/L	191000, (NA), [1]	96000, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]	95500, (NA), [1]
Serum	PFOA	serum	F	ng/mL	1.96, (0.08), [10]	0.99, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]
Serum	PFOA	serum	M	ng/mL	1.96, (0.07), [10]	0.99, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]	0.98, (0.04), [10]
Serum	PFOA	water	NA	ng/L	398000, (NA), [1]	2e+05, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]	199000, (NA), [1]
Serum	PFHxS	serum	F	ng/mL	2.23, (0.59), [10]	1.12, (0.29), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]	1.11, (0.29), [10]
Serum	PFHxS	serum	M	ng/mL	2.17, (0.42), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]	1.09, (0.21), [10]
Serum	PFHxS	water	NA	ng/L	422000, (NA), [1]	212000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]	211000, (NA), [1]
Serum	PFHxA	serum	F	ng/mL	2.06, (0.21), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]	1.03, (0.11), [9]
Serum	PFHxA	serum	M	ng/mL	2.13, (0.29), [10]	1.07, (0.14), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]	1.06, (0.14), [10]
Serum	PFHxA	water	NA	ng/L	407000, (NA), [1]	205000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]	204000, (NA), [1]
Serum	PFNA	serum	F	ng/mL	297.2, (9.45), [10]	149.1, (4.72), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]	148.6, (4.99), [10]
Serum	PFNA	serum	M	ng/mL	287.6, (13.17), [10]	144.3, (6.58), [10]	144, (6.46), [10]	144, (6.46), [10]	144, (6.46), [10]

Serum	PFNA	water	NA	ng/L	368000, (NA), [1]	185000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]	184000, (NA), [1]
Serum	PFBS	serum	F	ng/mL	2.43, (0.78), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]	1.22, (0.39), [10]
Serum	PFBS	serum	M	ng/mL	2.37, (1.03), [10]	1.19, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]	1.18, (0.52), [10]
Serum	PFBS	water	NA	ng/L	402000, (NA), [1]	202000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]	201000, (NA), [1]
Serum	6:2 FTS	serum	F	ng/mL	1.7, (0.43), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]	0.85, (0.22), [10]
Serum	6:2 FTS	serum	M	ng/mL	1.72, (0.46), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]	0.86, (0.23), [10]
Serum	6:2 FTS	water	NA	ng/L	93900, (NA), [1]	47200, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]	47000, (NA), [1]
Serum	8:2 FTS	serum	F	ng/mL	1.72, (0.49), [10]	0.87, (0.24), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]	0.86, (0.24), [10]
Serum	8:2 FTS	serum	M	ng/mL	1.49, (0.32), [10]	0.75, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]	0.74, (0.16), [10]
Serum	8:2 FTS	water	NA	ng/L	101000, (NA), [1]	50700, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]	50500, (NA), [1]
Serum	C68LOW	serum	F	ng/mL	19.09, (0.91), [10]	9.6, (0.46), [10]	9.54, (0.45), [10]	9.54, (0.45), [10]	9.54, (0.45), [10]
Serum	C68LOW	serum	M	ng/mL	19.64, (0.91), [10]	9.87, (0.46), [10]	9.8, (0.43), [10]	9.8, (0.43), [10]	9.8, (0.43), [10]
Serum	C68LOW	water	NA	ng/L	40400, (NA), [1]	20300, (NA), [1]	20200, (NA), [1]	20200, (NA), [1]	20200, (NA), [1]
Serum	C68MED	serum	F	ng/mL	95.8, (4.21), [10]	48.2, (2.19), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]	47.97, (2.17), [10]
Serum	C68MED	serum	M	ng/mL	95.74, (2.27), [10]	48.12, (1.14), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]	47.92, (1.14), [10]
Serum	C68MED	water	NA	ng/L	97800, (NA), [1]	49100, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]	48900, (NA), [1]
Serum	C68HIGH	serum	F	ng/mL	297.2, (6.76), [10]	149.1, (3.38), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]	148.4, (3.86), [10]
Serum	C68HIGH	serum	M	ng/mL	294.78, (13.51), [9]	148, (7.02), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]	147.33, (6.86), [9]
Serum	C68HIGH	water	NA	ng/L	211000, (NA), [1]	106000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]	105000, (NA), [1]
Serum	FTSLOW	serum	F	ng/mL	18.98, (0.76), [10]	9.54, (0.38), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]	9.49, (0.37), [10]
Serum	FTSLOW	serum	M	ng/mL	18.89, (0.75), [10]	9.5, (0.37), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]	9.45, (0.36), [10]
Serum	FTSLOW	water	NA	ng/L	39200, (NA), [1]	19700, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]	19600, (NA), [1]
Serum	FTSMED	serum	F	ng/mL	89.2, (3.56), [10]	44.85, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]	44.6, (1.78), [10]
Serum	FTSMED	serum	M	ng/mL	92, (3.88), [10]	46.25, (1.94), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]	46.02, (1.97), [10]
Serum	FTSMED	water	NA	ng/L	117000, (NA), [1]	58900, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]	58600, (NA), [1]
Serum	FTSHIGH	serum	F	ng/mL	300.2, (13.96), [10]	150.7, (7.17), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]	150.4, (7.11), [10]
Serum	FTSHIGH	serum	M	ng/mL	297.6, (16.14), [10]	149.4, (8.25), [10]	149, (8.18), [10]	149, (8.18), [10]	149, (8.18), [10]
Serum	FTSHIGH	water	NA	ng/L	2e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]	1e+05, (NA), [1]
Serum	Control	serum	F	ng/mL	2.93, (1.36), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]	1.47, (0.68), [10]
Serum	Control	serum	M	ng/mL	2.1, (0.62), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]	1.05, (0.31), [10]
Serum	Control	water	NA	ng/L	21400, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]	10700, (NA), [1]
Serum	PFOS	Brain	F	ng/g	1725.71, (283.25), [7]	867.86, (141.77), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]	864.29, (142.59), [7]
Serum	PFOS	Brain	M	ng/g	2001.43, (413.9), [7]	1004.86, (208.92), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]	1000.43, (208.03), [7]
Serum	PFOS	Kidney	F	ng/g	1218.57, (133.22), [7]	612.86, (68.01), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]	609.86, (67.21), [7]
Serum	PFOS	Kidney	M	ng/g	855.29, (101.72), [7]	430.14, (51.87), [7]	428, (51.53), [7]	428, (51.53), [7]	428, (51.53), [7]
Serum	PFOS	Liver	F	ng/g	54.87, (1.64), [7]	27.59, (0.82), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]	27.41, (0.8), [7]
Serum	PFOS	Liver	M	ng/g	54.97, (3.01), [7]	27.64, (1.51), [7]	27.5, (1.48), [7]	27.5, (1.48), [7]	27.5, (1.48), [7]
Serum	PFOA	Brain	F	ng/g	1345, (307.37), [7]	675.29, (154.29), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]	672.14, (153.72), [7]
Serum	PFOA	Brain	M	ng/g	1404.29, (252.84), [7]	706.29, (127.76), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]	702.86, (127.03), [7]
Serum	PFOA	Kidney	F	ng/g	1219.86, (119.9), [7]	612, (59.88), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]	609.14, (59.56), [7]
Serum	PFOA	Kidney	M	ng/g	818.86, (112.11), [7]	411.57, (56.39), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]	409.57, (56.39), [7]
Serum	PFOA	Liver	F	ng/g	54.09, (1.91), [7]	27.17, (0.95), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]	27.04, (0.98), [7]
Serum	PFOA	Liver	M	ng/g	55.86, (1.77), [7]	28.07, (0.91), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]	27.94, (0.91), [7]
Serum	PFHxS	Brain	F	ng/g	218.43, (61.06), [7]	109.66, (30.53), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]	109.24, (30.67), [7]
Serum	PFHxS	Brain	M	ng/g	205.57, (53.78), [7]	103.36, (26.9), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]	102.81, (26.69), [7]
Serum	PFHxS	Kidney	F	ng/g	216, (29.78), [7]	108.56, (15.06), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]	107.7, (14.92), [7]
Serum	PFHxS	Kidney	M	ng/g	126.23, (23.94), [7]	63.47, (12.05), [7]	63.17, (12), [7]	63.17, (12), [7]	63.17, (12), [7]
Serum	PFHxS	Liver	F	ng/g	57.07, (1.69), [7]	28.7, (0.84), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]	28.51, (0.82), [7]
Serum	PFHxS	Liver	M	ng/g	56.76, (1.6), [7]	28.51, (0.81), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]	28.39, (0.79), [7]
Serum	PFHxA	Brain	F	ng/g	2.85, (2.24), [7]	1.43, (1.13), [7]	1.47, (1.1), [7]	1.42, (1.12), [7]	1.42, (1.12), [7]
Serum	PFHxA	Brain	M	ng/g	1.75, (0.23), [7]	0.88, (0.12), [7]	1.13, (0.16), [7]	0.87, (0.12), [7]	0.87, (0.12), [7]
Serum	PFHxA	Kidney	F	ng/g	1.36, (0.18), [7]	0.68, (0.09), [7]	0.73, (0.18), [7]	0.68, (0.09), [7]	0.68, (0.09), [7]
Serum	PFHxA	Kidney	M	ng/g	0.78, (0.09), [7]	0.39, (0.05), [7]	0.4, (0.07), [7]	0.39, (0.05), [7]	0.39, (0.05), [7]
Serum	PFHxA	Liver	F	ng/g	0.46, (0.22), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]	0.23, (0.11), [7]
Serum	PFHxA	Liver	M	ng/g	0.42, (0.13), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]	0.21, (0.06), [7]
Serum	6:2 FTS	Brain	F	ng/g	89.23, (50.24), [7]	44.87, (25.3), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]	44.64, (25.16), [7]
Serum	6:2 FTS	Brain	M	ng/g	132.33, (45.67), [7]	66.41, (22.79), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]	66.16, (22.86), [7]
Serum	6:2 FTS	Kidney	F	ng/g	33.49, (4.48), [7]	16.83, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]	16.73, (2.26), [7]
Serum	6:2 FTS	Kidney	M	ng/g	22.54, (4.76), [7]	11.33, (2.38), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]	11.27, (2.41), [7]
Serum	6:2 FTS	Liver	F	ng/g	19.76, (0.33), [7]	9.92, (0.15), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]	9.88, (0.16), [7]
Serum	6:2 FTS	Liver	M	ng/g	19.7, (0.18), [7]	9.9, (0.07), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]	9.85, (0.08), [7]
Serum	8:2 FTS	Brain	F	ng/g	1225.71, (1125.43), [7]	614.73, (564.2), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]	612.81, (564.51), [7]

Serum	8:2 FTS	Brain	M	ng/g	279.21, (486.05), [7]	140.09, (243.7), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]	139.33, (242.27), [7]
Serum	8:2 FTS	Kidney	F	ng/g	73.1, (11.64), [7]	36.74, (5.85), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]	36.56, (5.83), [7]
Serum	8:2 FTS	Kidney	M	ng/g	46.01, (6.53), [7]	23.13, (3.26), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]	23.01, (3.24), [7]
Serum	8:2 FTS	Liver	F	ng/g	19.5, (0.52), [7]	9.79, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]	9.74, (0.27), [7]
Serum	8:2 FTS	Liver	M	ng/g	19.57, (0.38), [7]	9.83, (0.19), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]	9.78, (0.18), [7]
Serum	C6-8 Low	Brain	F	ng/g	310.14, (127.1), [7]	155.84, (64.01), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]	155.07, (63.46), [7]
Serum	C6-8 Low	Brain	M	ng/g	251.14, (68.14), [7]	126.13, (34.43), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]	125.49, (34.29), [7]
Serum	C6-8 Low	Kidney	F	ng/g	14.49, (1.76), [7]	7.28, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]	7.24, (0.88), [7]
Serum	C6-8 Low	Kidney	M	ng/g	8.55, (0.88), [7]	4.29, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]	4.27, (0.44), [7]
Serum	C6-8 Low	Liver	F	ng/g	9.44, (0.2), [10]	4.75, (0.1), [10]	4.72, (0.1), [10]	4.72, (0.1), [10]	4.72, (0.1), [10]
Serum	C6-8 Low	Liver	M	ng/g	9.57, (0.18), [10]	4.81, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]
Serum	C6-8 Medium	Brain	F	ng/g	490.29, (32.02), [7]	246.43, (15.96), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]	245.29, (16.1), [7]
Serum	C6-8 Medium	Brain	M	ng/g	536.86, (48.2), [7]	269.71, (24.07), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]	268.29, (24.28), [7]
Serum	C6-8 Medium	Kidney	F	ng/g	68.39, (9.35), [7]	34.37, (4.71), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]	34.19, (4.68), [7]
Serum	C6-8 Medium	Kidney	M	ng/g	43.34, (6.47), [7]	21.77, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]	21.67, (3.25), [7]
Serum	C6-8 Medium	Liver	F	ng/g	18.97, (0.44), [10]	9.54, (0.24), [10]	9.49, (0.22), [10]	9.49, (0.22), [10]	9.49, (0.22), [10]
Serum	C6-8 Medium	Liver	M	ng/g	19.14, (0.45), [10]	9.62, (0.23), [10]	9.57, (0.23), [10]	9.57, (0.23), [10]	9.57, (0.23), [10]
Serum	C6-8 High	Brain	F	ng/g	2988.57, (289.33), [7]	1501.43, (145.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]	1497.14, (144.19), [7]
Serum	C6-8 High	Brain	M	ng/g	2538.57, (1348.94), [7]	1276.43, (676.13), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]	1270.29, (674.45), [7]
Serum	C6-8 High	Kidney	F	ng/g	70.8, (9.44), [7]	35.56, (4.73), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]	35.39, (4.7), [7]
Serum	C6-8 High	Kidney	M	ng/g	44.19, (5.1), [7]	22.19, (2.56), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]	22.07, (2.53), [7]
Serum	C6-8 High	Liver	F	ng/g	19.42, (0.58), [10]	9.75, (0.29), [10]	9.71, (0.29), [10]	9.71, (0.29), [10]	9.71, (0.29), [10]
Serum	C6-8 High	Liver	M	ng/g	19.04, (0.53), [9]	9.57, (0.28), [9]	9.52, (0.27), [9]	9.52, (0.27), [9]	9.52, (0.27), [9]
Serum	FTS Low	Brain	F	ng/g	273.71, (123.59), [7]	137.6, (62.01), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]	136.77, (61.83), [7]
Serum	FTS Low	Brain	M	ng/g	509.43, (206.32), [7]	256.14, (103.77), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]	254.71, (103.33), [7]
Serum	FTS Low	Kidney	F	ng/g	35.69, (2.9), [7]	17.91, (1.45), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]	17.83, (1.43), [7]
Serum	FTS Low	Kidney	M	ng/g	21.4, (3.36), [7]	10.75, (1.69), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]	10.7, (1.7), [7]
Serum	FTS Low	Liver	F	ng/g	9.52, (0.18), [10]	4.78, (0.09), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]	4.76, (0.09), [10]
Serum	FTS Low	Liver	M	ng/g	9.49, (0.21), [10]	4.77, (0.11), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]	4.75, (0.1), [10]
Serum	FTS Medium	Brain	F	ng/g	88.03, (37.78), [7]	44.26, (18.97), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]	44.03, (18.88), [7]
Serum	FTS Medium	Brain	M	ng/g	115.39, (46.73), [7]	57.9, (23.4), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]	57.6, (23.29), [7]
Serum	FTS Medium	Kidney	F	ng/g	34.86, (3.99), [7]	17.5, (2), [7]	17.41, (2), [7]	17.41, (2), [7]	17.41, (2), [7]
Serum	FTS Medium	Kidney	M	ng/g	22, (3.53), [7]	11.07, (1.77), [7]	11, (1.75), [7]	11, (1.75), [7]	11, (1.75), [7]
Serum	FTS Medium	Liver	F	ng/g	9.57, (0.19), [10]	4.81, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]	4.79, (0.09), [10]
Serum	FTS Medium	Liver	M	ng/g	9.53, (0.29), [10]	4.79, (0.15), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]	4.77, (0.15), [10]
Serum	FTS High	Brain	F	ng/g	127.37, (66.46), [7]	64, (33.36), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]	63.7, (33.18), [7]
Serum	FTS High	Brain	M	ng/g	116.11, (31.85), [7]	58.37, (16), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]	58.07, (15.94), [7]
Serum	FTS High	Kidney	F	ng/g	68.99, (13.26), [7]	34.66, (6.65), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]	34.49, (6.63), [7]
Serum	FTS High	Kidney	M	ng/g	43.59, (5.47), [7]	21.9, (2.74), [7]	21.8, (2.74), [7]	21.8, (2.74), [7]	21.8, (2.74), [7]
Serum	FTS High	Liver	F	ng/g	19.43, (0.33), [10]	9.75, (0.16), [10]	9.71, (0.17), [10]	9.71, (0.17), [10]	9.71, (0.17), [10]
Serum	FTS High	Liver	M	ng/g	19.41, (0.51), [10]	9.76, (0.26), [10]	9.7, (0.25), [10]	9.7, (0.25), [10]	9.7, (0.25), [10]
Serum	Control	Brain	F	ng/g	1.33, (0.26), [7]	0.67, (0.13), [7]	0.96, (0.35), [7]	0.69, (0.11), [7]	0.67, (0.13), [7]
Serum	Control	Brain	M	ng/g	1.22, (0.11), [7]	0.61, (0.05), [7]	1.02, (0.17), [7]	0.66, (0.07), [7]	0.61, (0.05), [7]
Serum	Control	Kidney	F	ng/g	1.6, (0.14), [7]	0.8, (0.07), [7]	0.84, (0.08), [7]	0.8, (0.07), [7]	0.8, (0.07), [7]
Serum	Control	Kidney	M	ng/g	0.87, (0.09), [7]	0.44, (0.04), [7]	0.47, (0.06), [7]	0.43, (0.04), [7]	0.43, (0.04), [7]
Serum	Control	Liver	F	ng/g	0.33, (0.04), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]	0.17, (0.02), [7]
Serum	Control	Liver	M	ng/g	0.28, (0.09), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]	0.12, (0.01), [7]

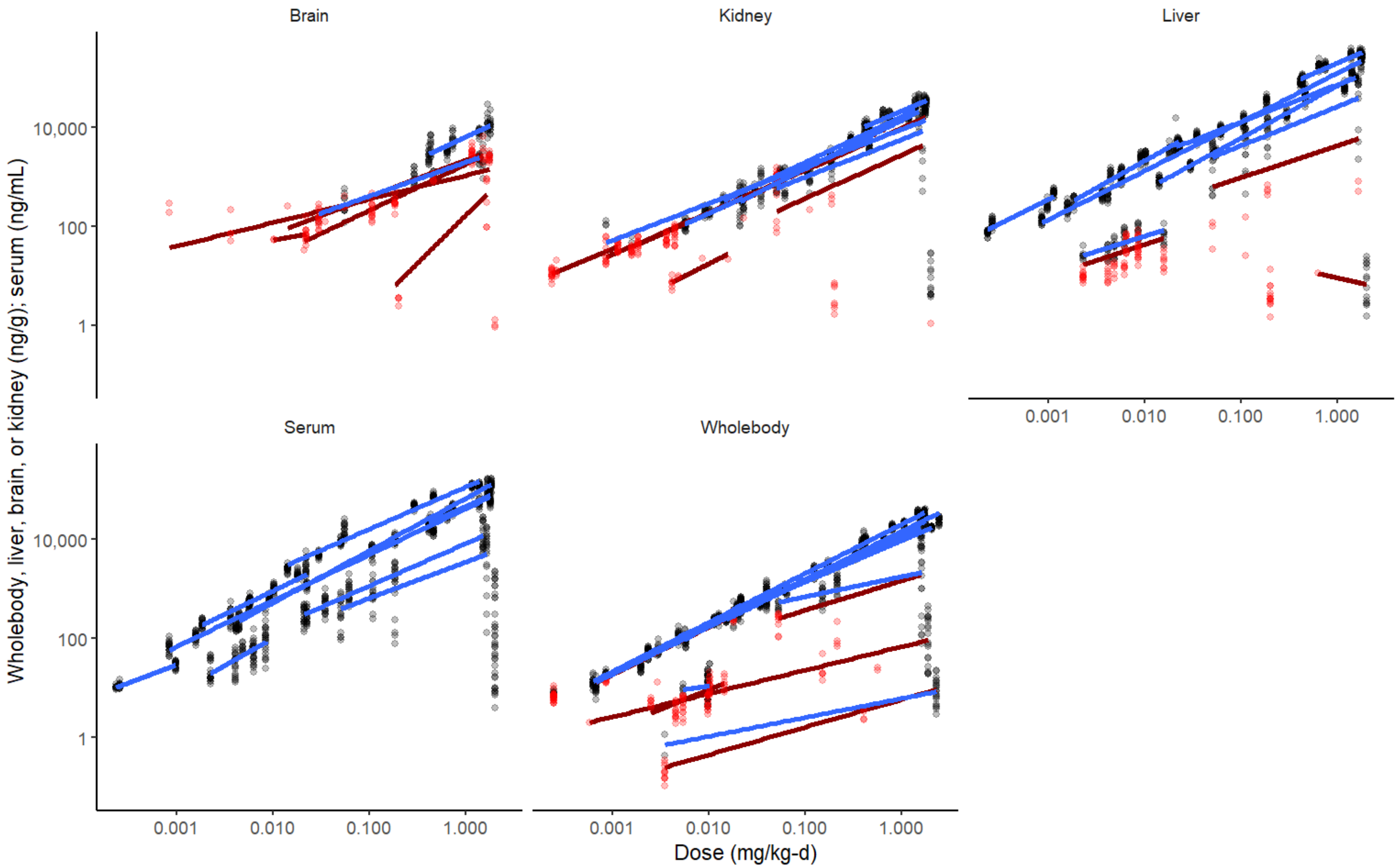


Figure SI3.1. Tissue concentrations by dose and by above reporting limit (black) or above detection limit (J-flag) (red) with regressions (blue only quantitative data, red all data) to indicate biasing by inclusion or exclusion of J-flag data. Relative concentrations and overlap of quantitative and J-flag data indicate that rarely is meaningful bias outweigh the value of including additional individual-level data. Note that relative concentration patterns in serum are all quantitative data, so other tissues are unlikely uncertain detections. However, in the brain samples, few samples are above detection and the assertion of low bias cannot be made. Accordingly, only in the brain are J-flag data excluded.

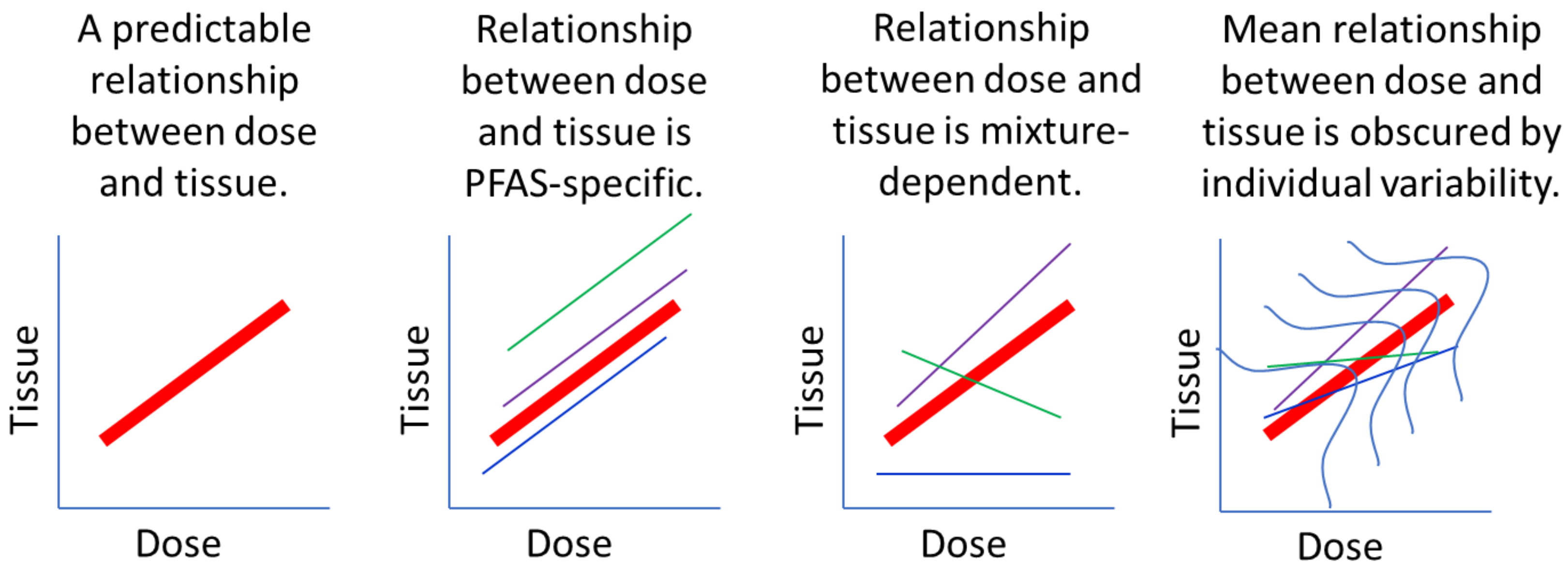


Figure SI3.2. Graphical description of how mixed effects models that explain relationship between dose and tissue with overall fixed model (left), varying intercept (center-left), varying intercept and slopes (center-right), and how individually-driven residual distributions can mask false 'mixture effects' (right). Red is the overall fixed model, green, purple, and blue indicate potential PFAS-specific models, and the light blue represents residual distributions.

Table SI3.9. PFAS doses (mg/kg-d) based on <u>measured</u> dosing solutions by treatment type, treatment, dose level, and study. n=1 for all. Bold indicates intentionally dosed PFAS, others are impurities. PFAS in Method 1633 Analyte list that are not shown here had no detections. Values are reported with number of significant digits as provided in analytical reports. Dash (-) indicates non-detect.

Type	Treatment	Dose Level	Study	PFOS	PFHxS	PFHxA	PFOA	6:2 FTS	8:2 FTS	PFBS	PFNA	PFPeS	PFHpS	PFNS	PFHpA	4:2 FTS	NFDHA
Mixtures	C6-8	Low	Whole Body	**0.428**	**0.3350**	**0.207**	**0.125**	-	-	0.000579	-	0.00455	0.00585	0.000245	0.000316	-	-
			Serum	**0.416**	**0.2980**	**0.144**	**0.107**	-	-	0.000618	-	0.00413	0.00568	0.000236	0.000284	-	-
		Medium	Whole Body	**1.08**	**0.6610**	**0.410**	**0.173**	-	-	0.00121	-	0.00973	0.0128	-	-	-	-
			Serum	**0.649**	**0.4690**	**0.219**	**0.185**	-	-	0.000859	-	0.00618	0.00917	-	-	-	-
		High	Whole Body	**1.76**	**1.070**	**0.566**	**0.391**	-	-	0.00182	-	0.0145	0.02160	-	0.00130	-	-
			Serum	**1.83**	**1.190**	**0.636**	**0.469**	-	-	0.00232	-	0.0158	0.0227	-	0.00143	-	-
	FTS	Low	Whole Body	**0.407**	0.0152	0.000375	0.000863	**0.0530**	**0.0201**	0.000301	-	0.00251	0.0057	0.000246	0.000213	-	-
			Serum	**0.438**	0.0143	0.000339	0.000850	**0.0509**	**0.0229**	0.000281	-	0.00227	0.00577	0.000260	0.000217	-	-
		Medium	Whole Body	**0.817**	0.0346	0.000731	0.00199	**0.153**	**0.0403**	0.000622	-	0.00540	0.0114	-	-	-	-
			Serum	**0.750**	0.0299	0.000858	0.00159	**0.111**	**0.0349**	-	-	0.00488	0.0103	-	-	-	-
		High	Whole Body	**1.49**	0.0620	0.00131	0.00302	**0.218**	**0.0398**	0.00121	-	0.0103	0.0196	-	-	-	-
			Serum	**1.73**	0.0558	0.00144	0.00365	**0.188**	**0.0620**	0.00104	-	0.00850	0.0222	0.00114	-	-	-
Singles	PFOS	High	Whole Body	**1.75**	0.0642	-	0.00237	-	-	-	-	0.00982	0.0215	-	-	-	-
			Serum	**1.39**	0.0513	0.001130	0.00415	-	-	-	-	0.00848	0.0180	0.000978	0.00096	-	-
	PFHxS	High	Whole Body	-	**1.780**	-	0.00296	-	-	0.00207	-	0.00950	-	-	-	-	-
			Serum	-	**1.410**	-	-	-	-	-	-	0.00637	-	-	-	-	-
	PFHxA	High	Whole Body	-	-	**2.33**	-	-	-	-	-	-	-	-	-	-	-
			Serum	-	-	**2.04**	-	0.203	-	-	-	-	-	-	-	-	-
	PFOA	High	Whole Body	-	-	0.003510	**2.46**	-	-	-	-	-	-	-	-	-	-
			Serum	-	-	-	**1.78**	-	-	-	-	-	-	-	-	-	-
	6:2 FTS	High	Whole Body	-	-	-	-	**1.62**	0.0182	-	-	-	-	-	-	0.00477	-
			Serum	-	-	-	-	**1.67**	0.0212	-	-	-	-	-	-	0.00469	-
	8:2 FTS	High	Whole Body	0.000626	-	-	0.000669	-	**1.60**	-	0.00485	-	-	-	-	-	-
			Serum	-	-	-	-	-	**1.54**	-	0.00446	-	0.00185	-	-	-	-
	PFBS	High	Whole Body	-	-	-	-	-	-	**1.91**	-	-	-	-	-	-	-
			Serum	-	-	-	-	-	-	**2.02**	-	-	-	-	-	-	0.00611
	PFNA	High	Whole Body	-	-	-	-	-	-	-	**2.09**	-	-	-	0.00326	-	-
			Serum	-	-	-	-	-	-	-	**1.86**	-	-	-	0.00320	-	-
		Control	Whole Body	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			Serum	-	-	-	-	-	-	-	-	-	-	-	-	-	-

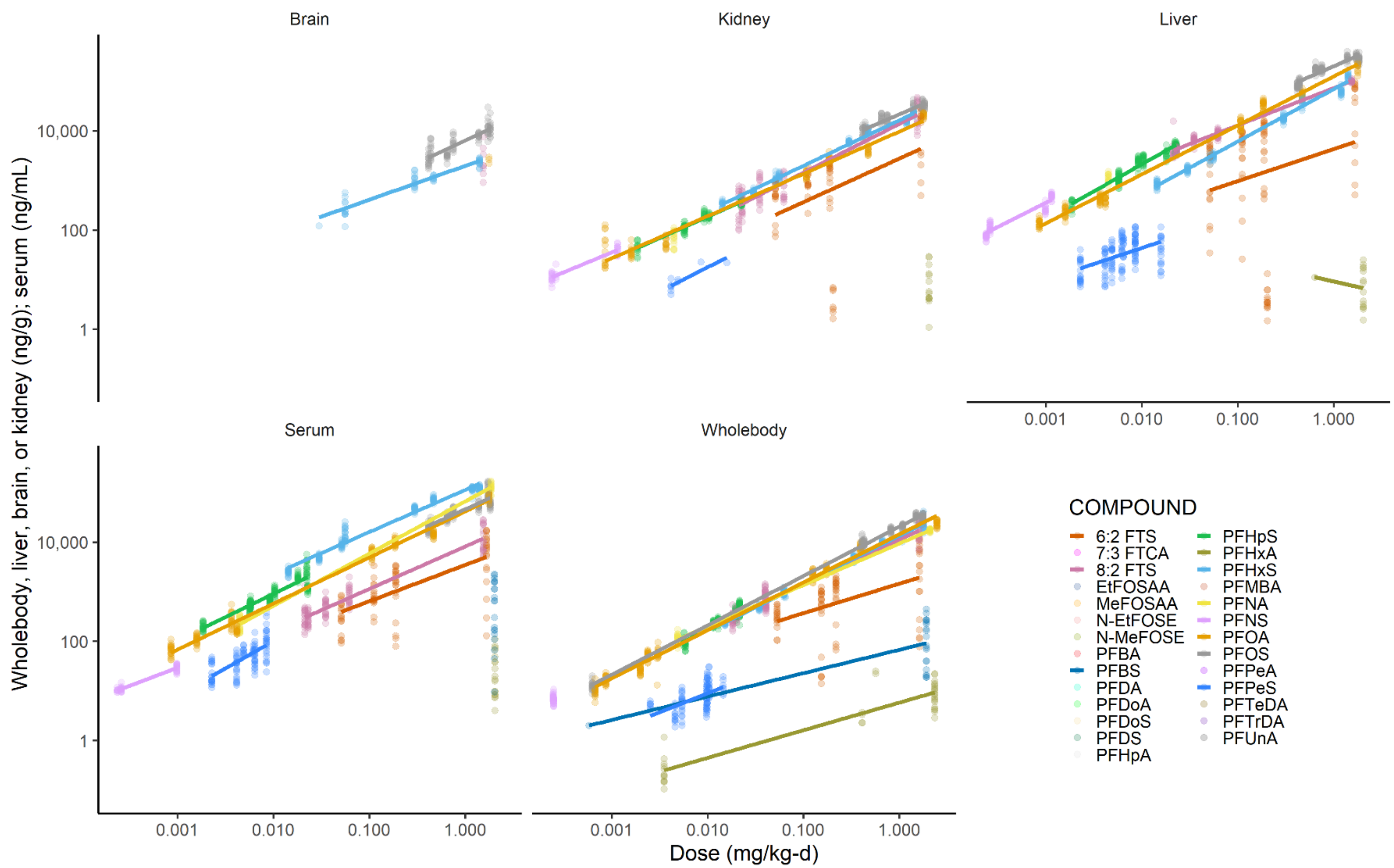


Figure SI3.3. Relationships between tissue concentration (ng/g or ng/mL) and dose (mg/kg-d) by PFAS with PFAS-specific linear models. Points are individual PFAS data (higher color intensity indicates more data overlapping) and all treatments and sexes are combined. The overall appearance of parallel lines indicate that relationship between dose and tissue is PFAS-specific and independent of mixtures and supports an ‘additive’ approach to estimating tissue concentrations of PFAS mixtures. Some data (e.g., PFHxA, PFPeS) are considered ‘trace’ data (above detection, below reporting limit) and may introduce variability on the extremes. Points without lines indicate that PFAS was not present in multiple doses.

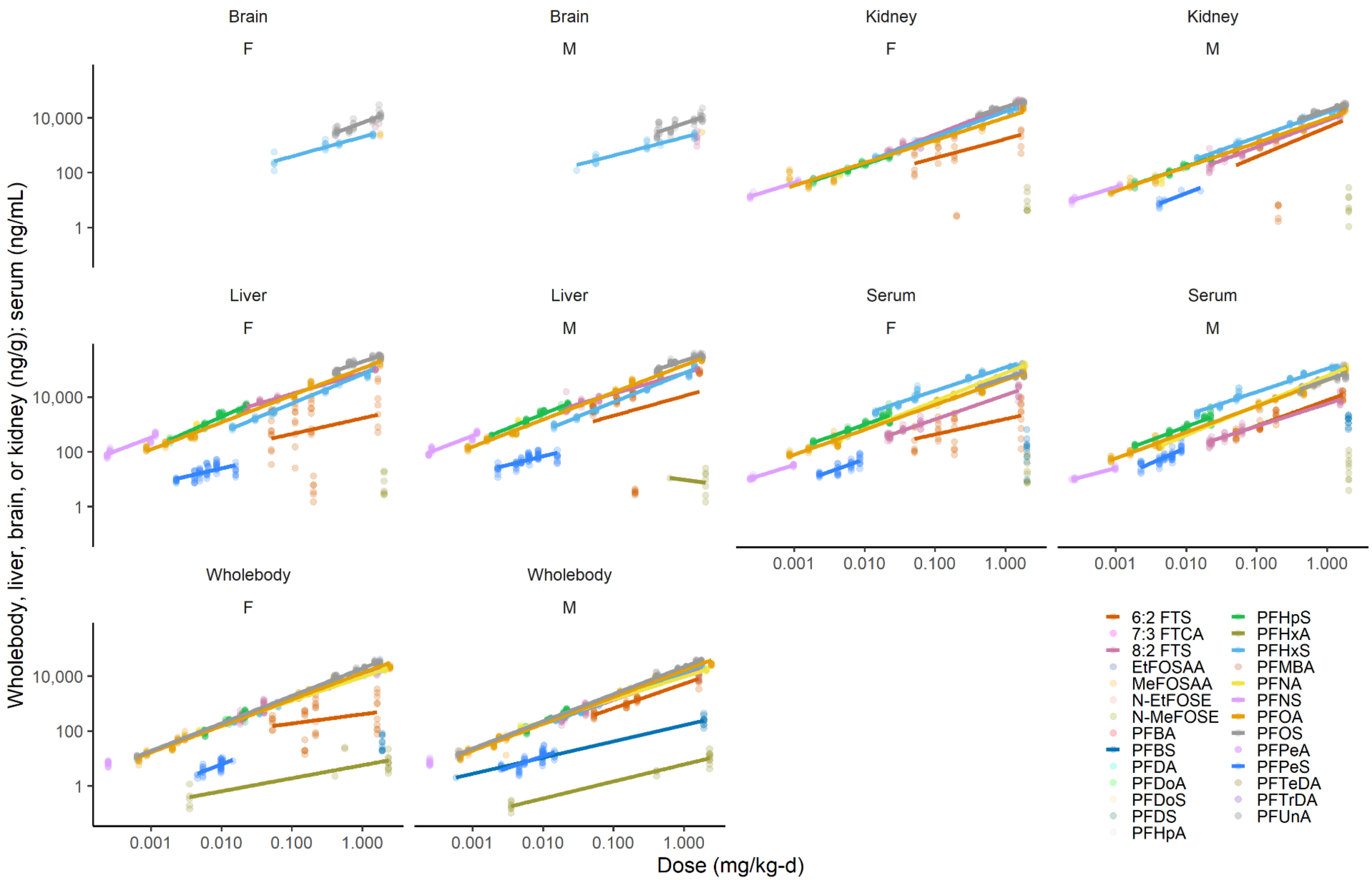


Figure SI3.4. Data from Figure SI3.3but grouped by sex. Note 6:2 FTS appears to be the only PFAS meaningfully influenced by sex.

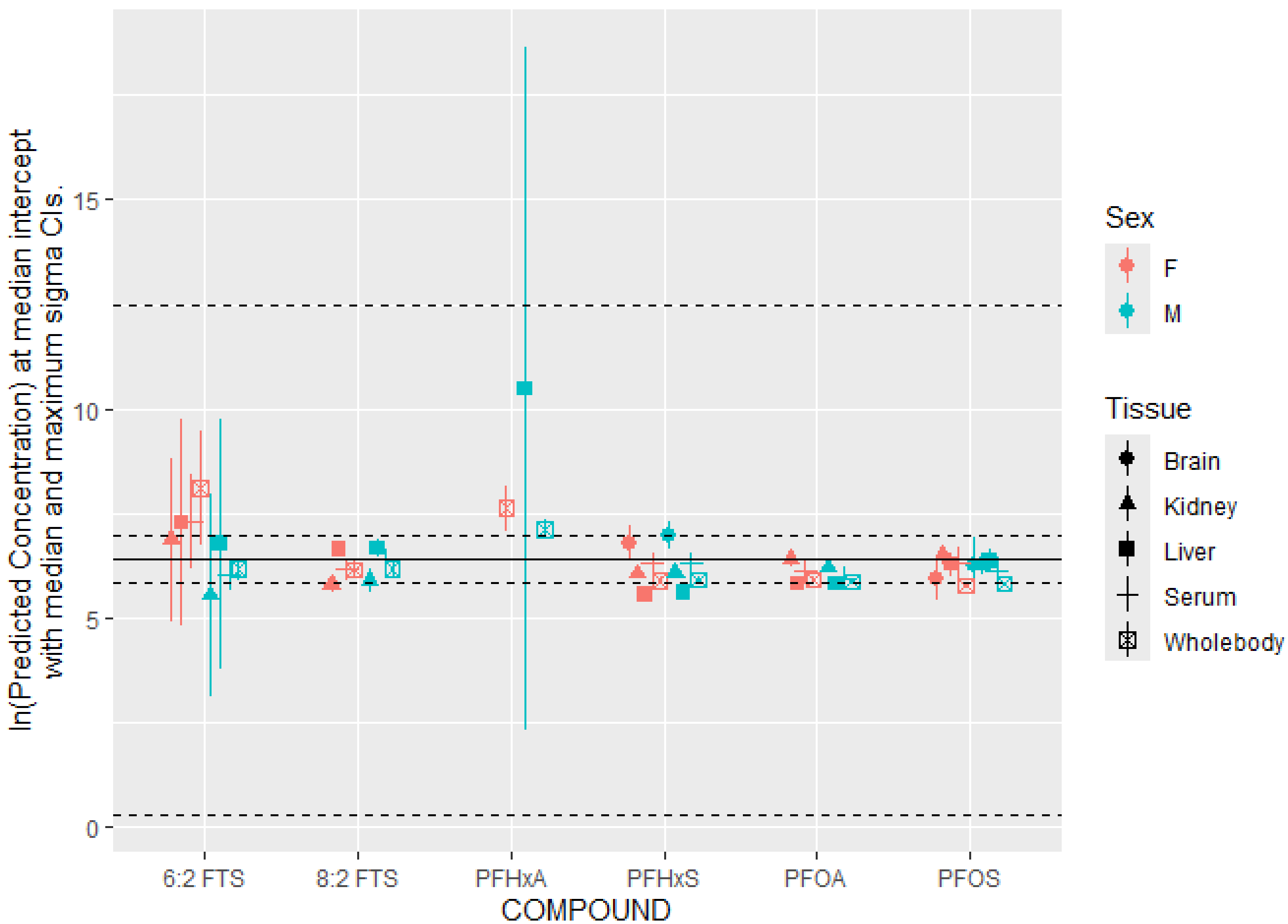


Figure SI3.5. Log_e predicted tissue concentrations (with confidence intervals) assuming median y-intercept and median log_e dose (points) around mean ± 1.97*median and maximum regression sigmas. The interpretation is that few predicted concentrations are distinguishable when accounting for individuals and tissue-specific slopes. i.e. the slopes produce similar estimates and approximately parallel on a log_e scale.

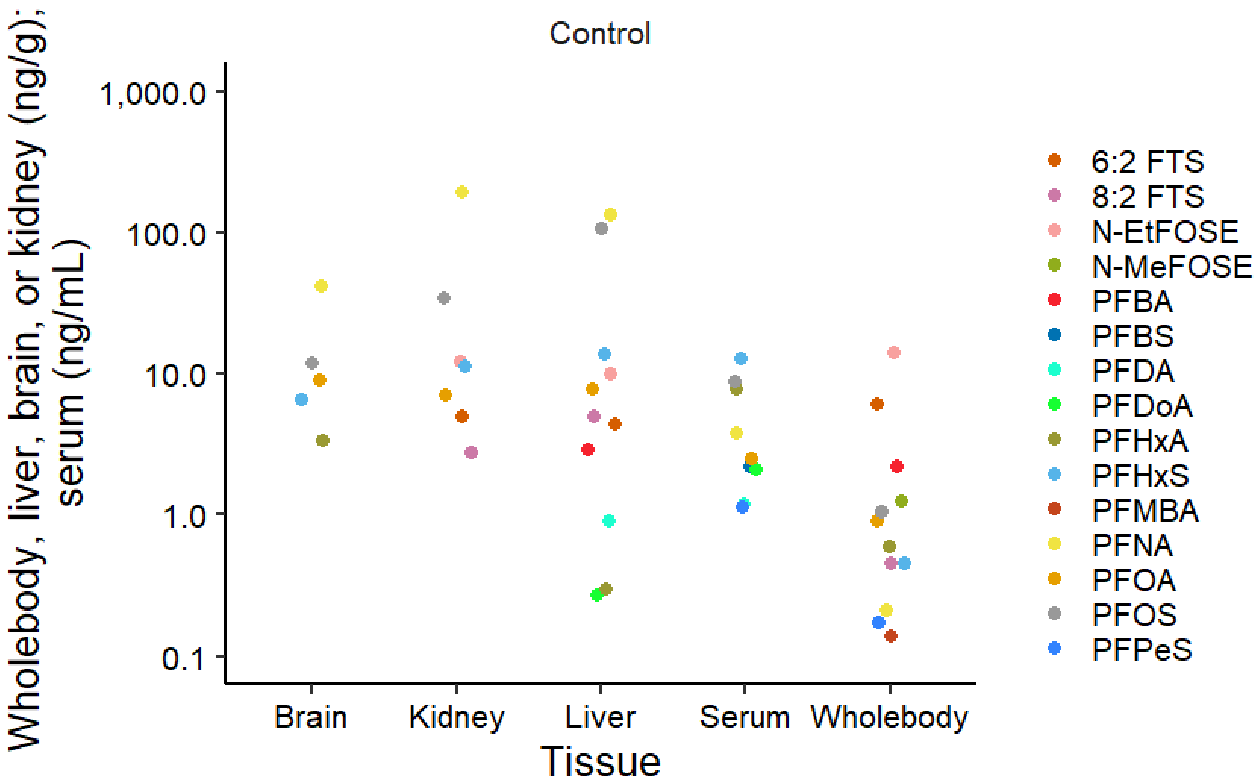


Figure SI3.6. Mean concentration of PFAS detected in tissues of control mice. All PFAS were non-detect in control dosing solutions (see Table SI3.9).

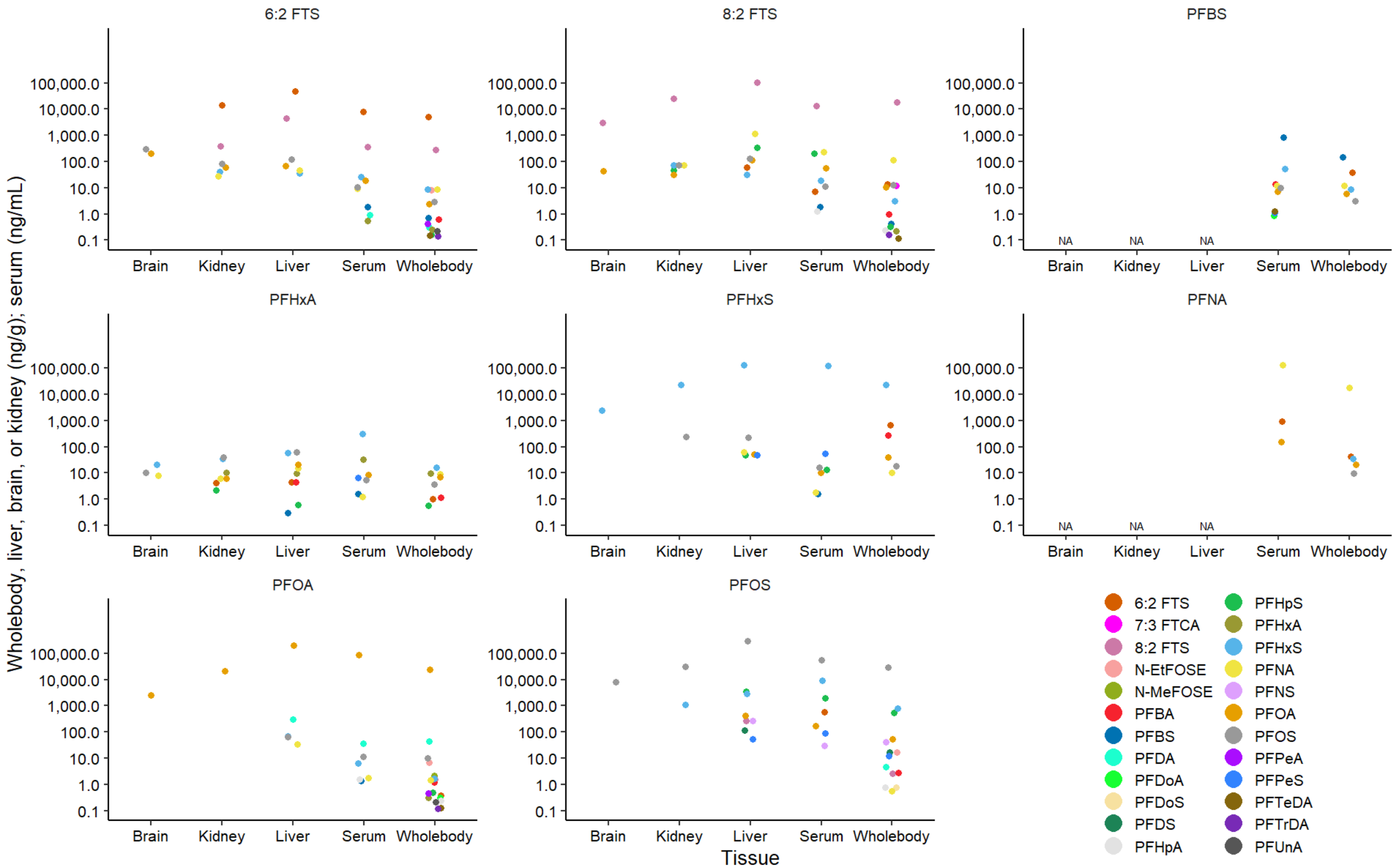


Figure SI3.7. Mean PFAS concentrations in tissues of mice exposed to single PFAS. See Table SI3.1 for nominal and Table SI3.9 for measured doses.

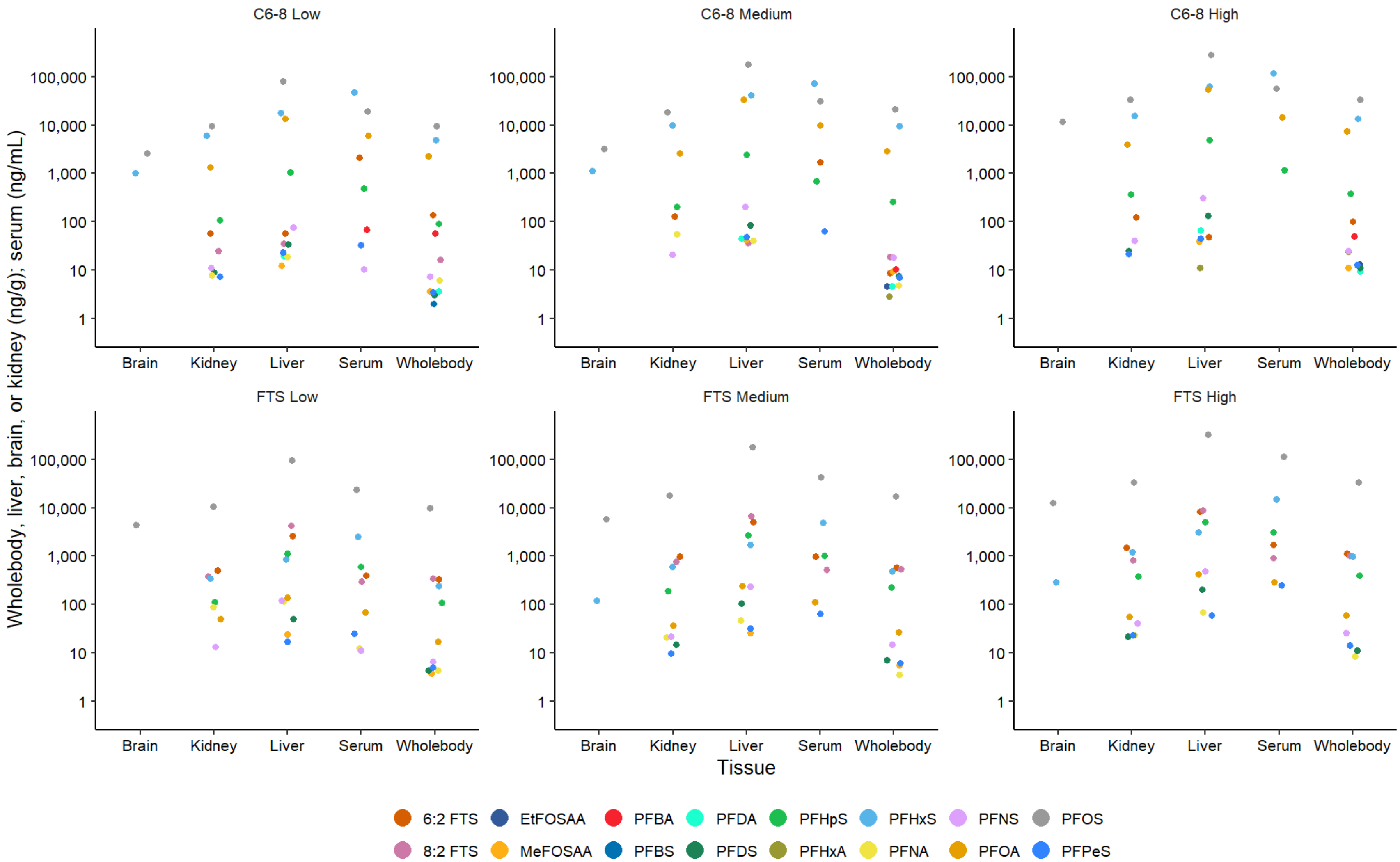


Figure SI3.8. Mean PFAS concentrations in tissues of mice exposed to mixtures of PFAS at low, medium, and high dose groups, respectively. See Table SI3.1 for nominal and Table SI3.9 for measured doses.

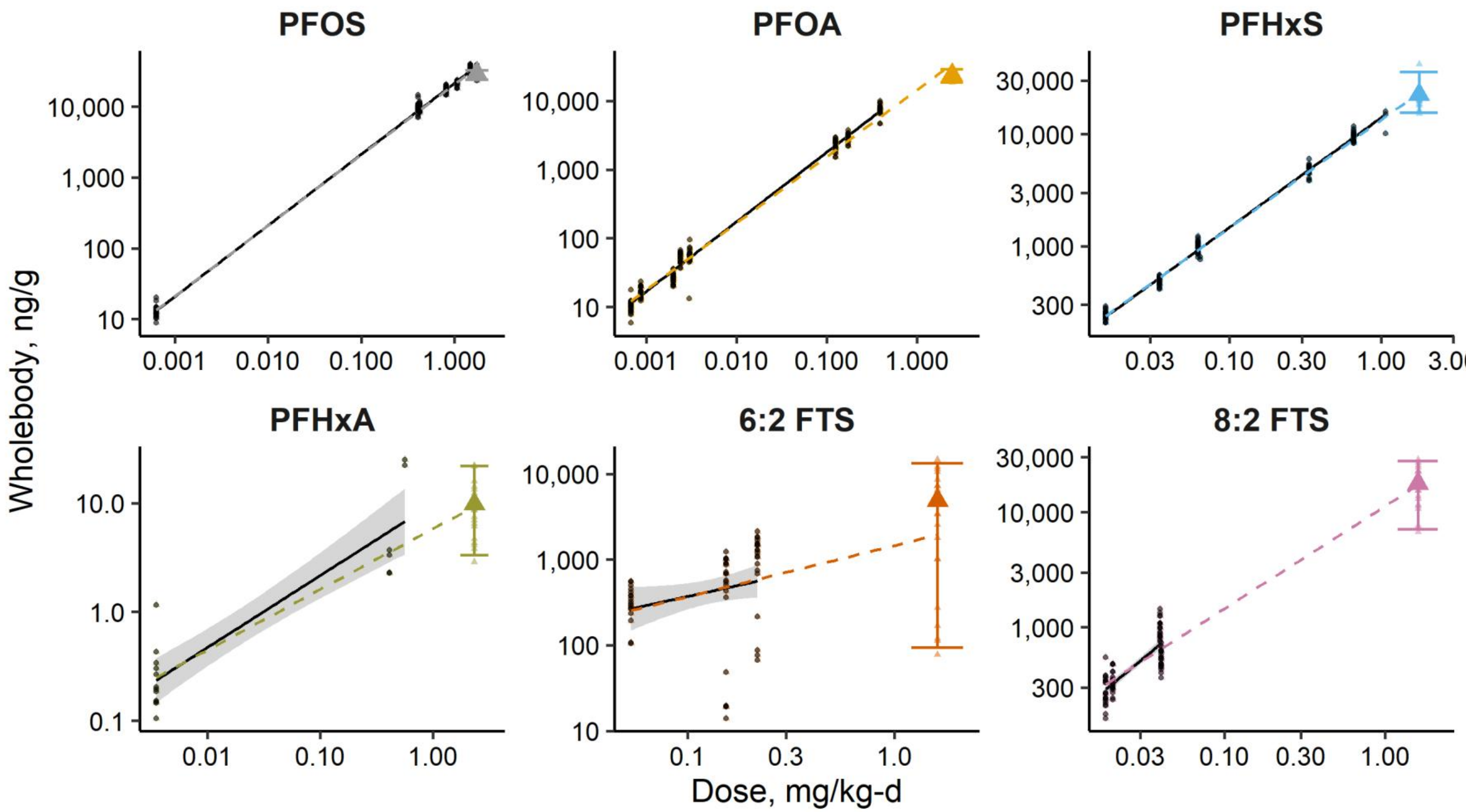


Figure SI3.9 Replica of Figure 3.4 in text but with mixture and impurity-based model (black and gray) not extrapolated throughout the full dose range. Color-matched dashed line is the model fit with all data, triangle is the mean of singleton treatment, and error bars are 95% confidence intervals of the singleton treatments.

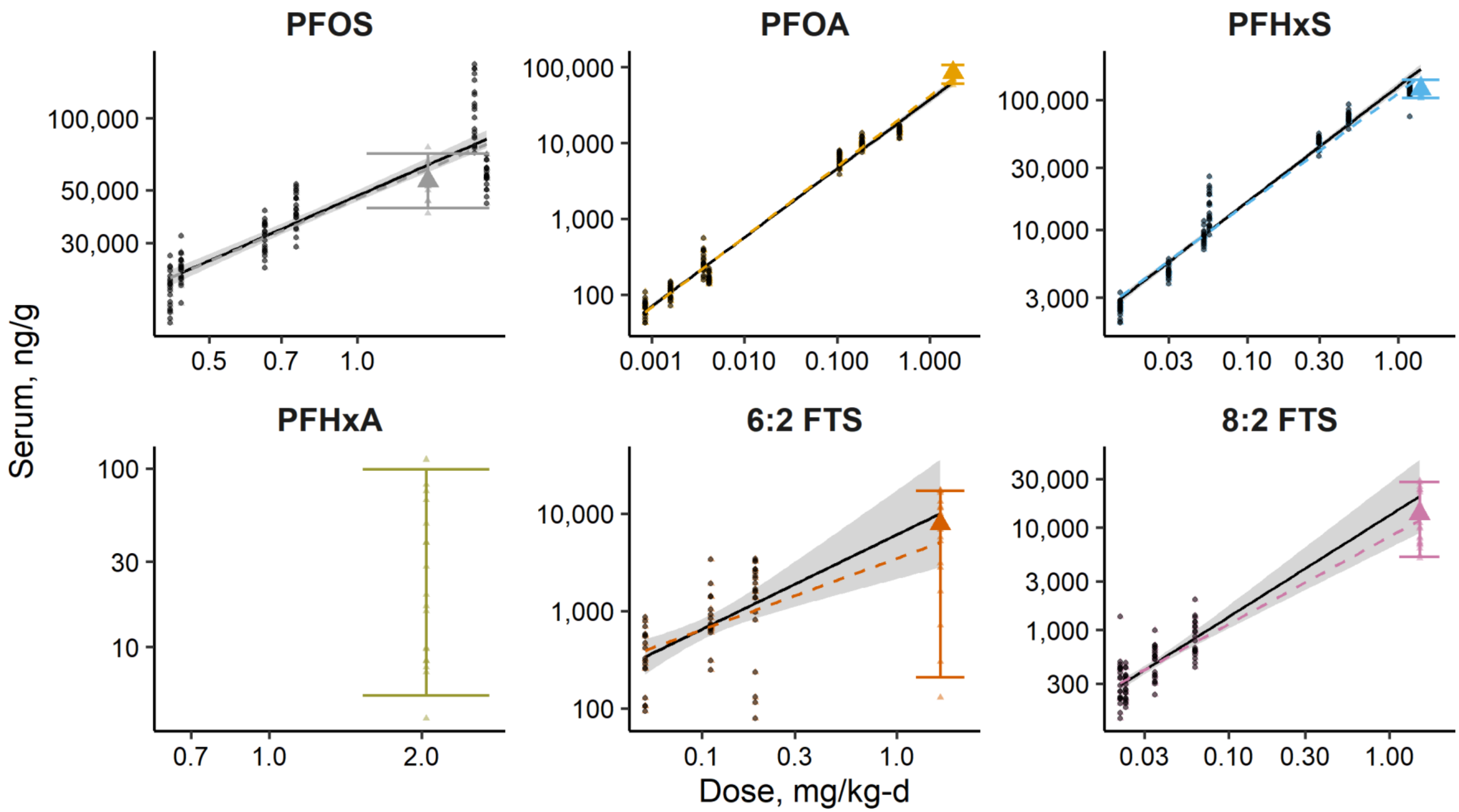


Figure SI3.10. Extrapolated relationship between dose (mg/kg-d) and serum (ng/mL) when predicted from mixture treatments or impure mixtures (black points, black line, gray confidence intervals) are consistent with models that utilize all data (dashed color-matched line).

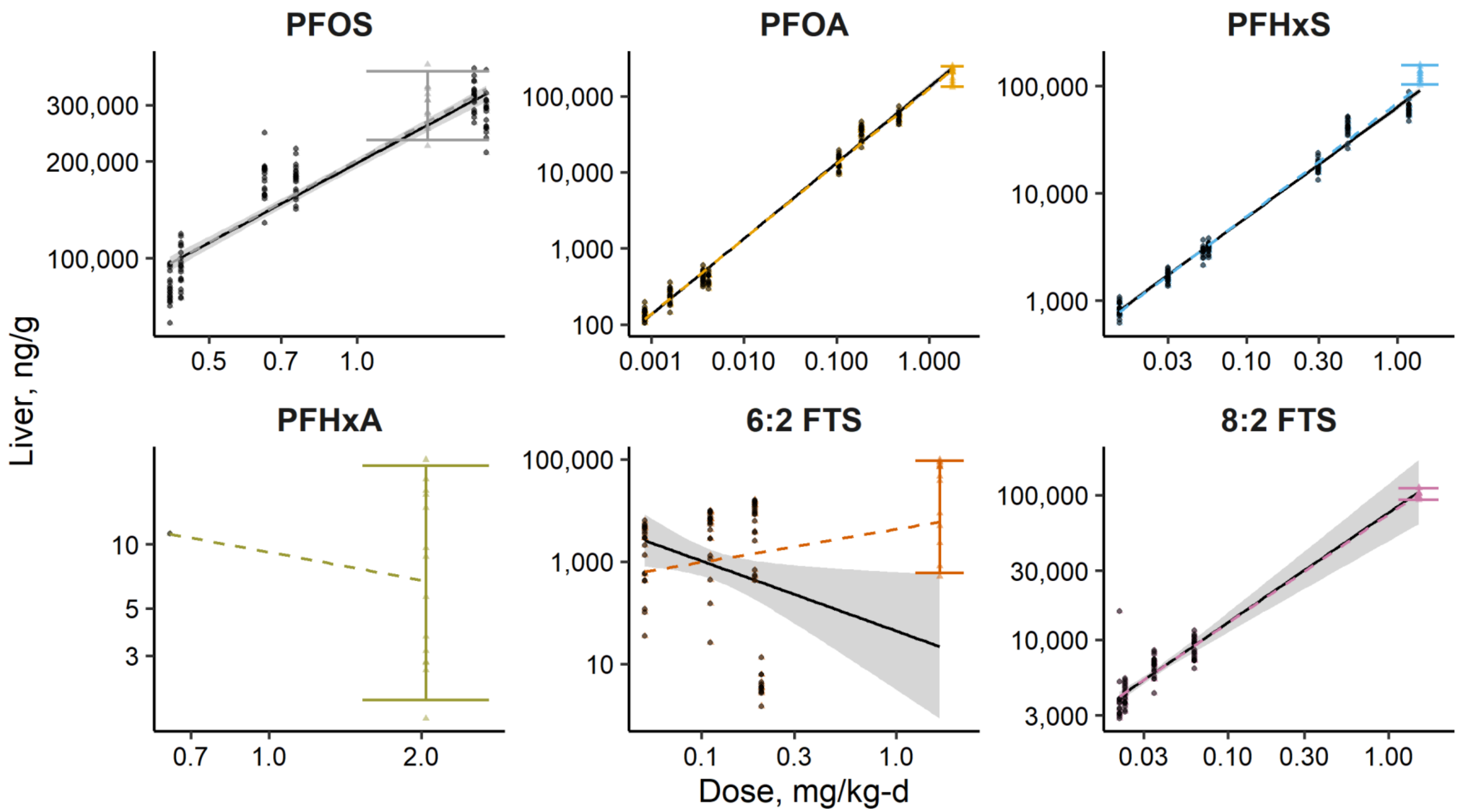


Figure SI3.11. Extrapolated relationship between dose (mg/kg-d) and liver (ng/g) when predicted from mixture treatments or impure mixtures (black points, black line, gray confidence intervals) are consistent with models that utilize all data (dashed color-matched line). Mismatch in 6:2 FTS is due to female mice elimination, detection limits, and not likely representative of an actual mixture interaction.

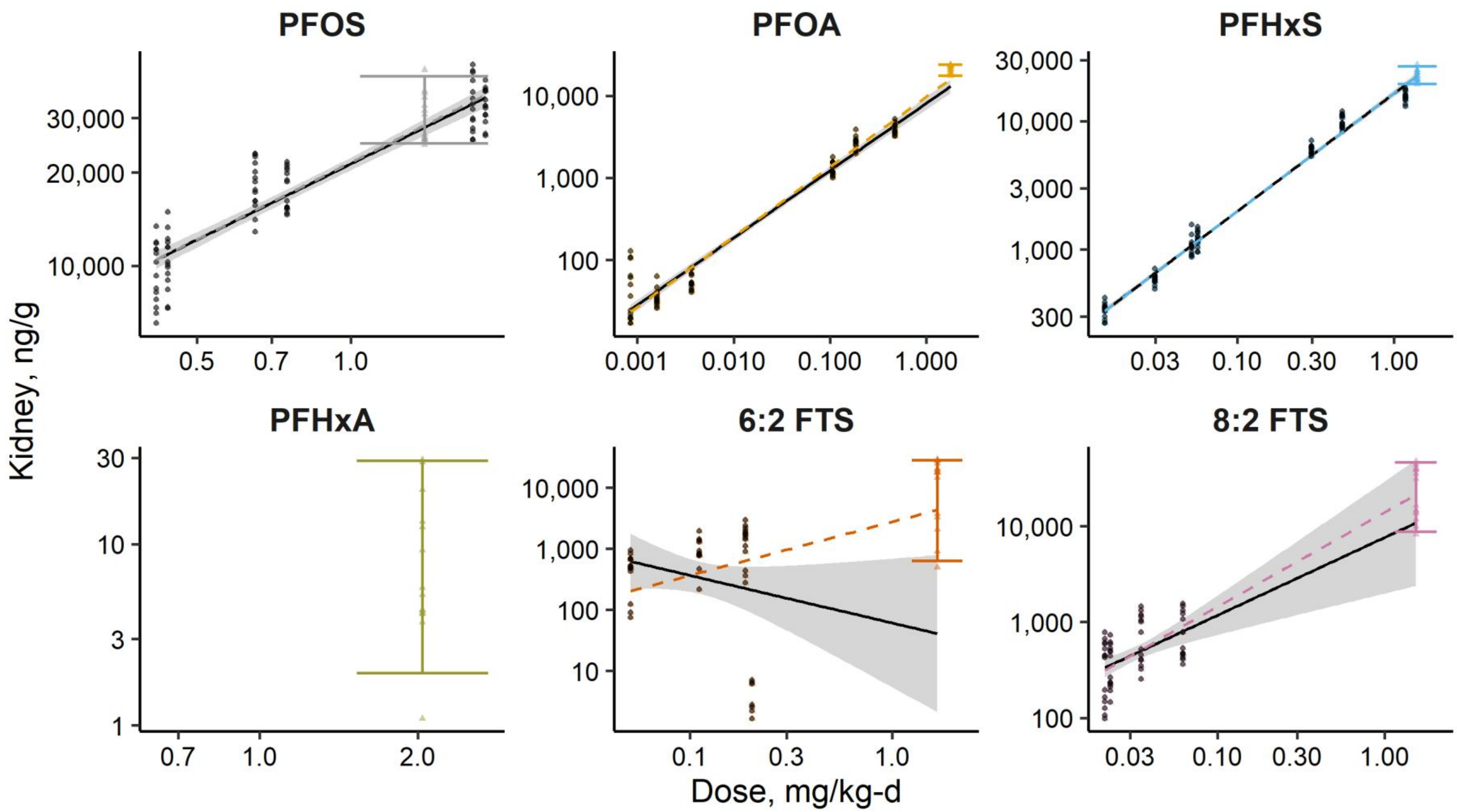


Figure SI3.12. Extrapolated relationship between dose (mg/kg-d) and kidney (ng/g) when predicted from mixture treatments or impure mixtures (black points, black line, gray confidence intervals) are consistent with models that utilize all data (dashed color-matched line). Mismatch in 6:2 FTS is due to female mice elimination, detection limits, and not likely representative of an actual mixture interaction.

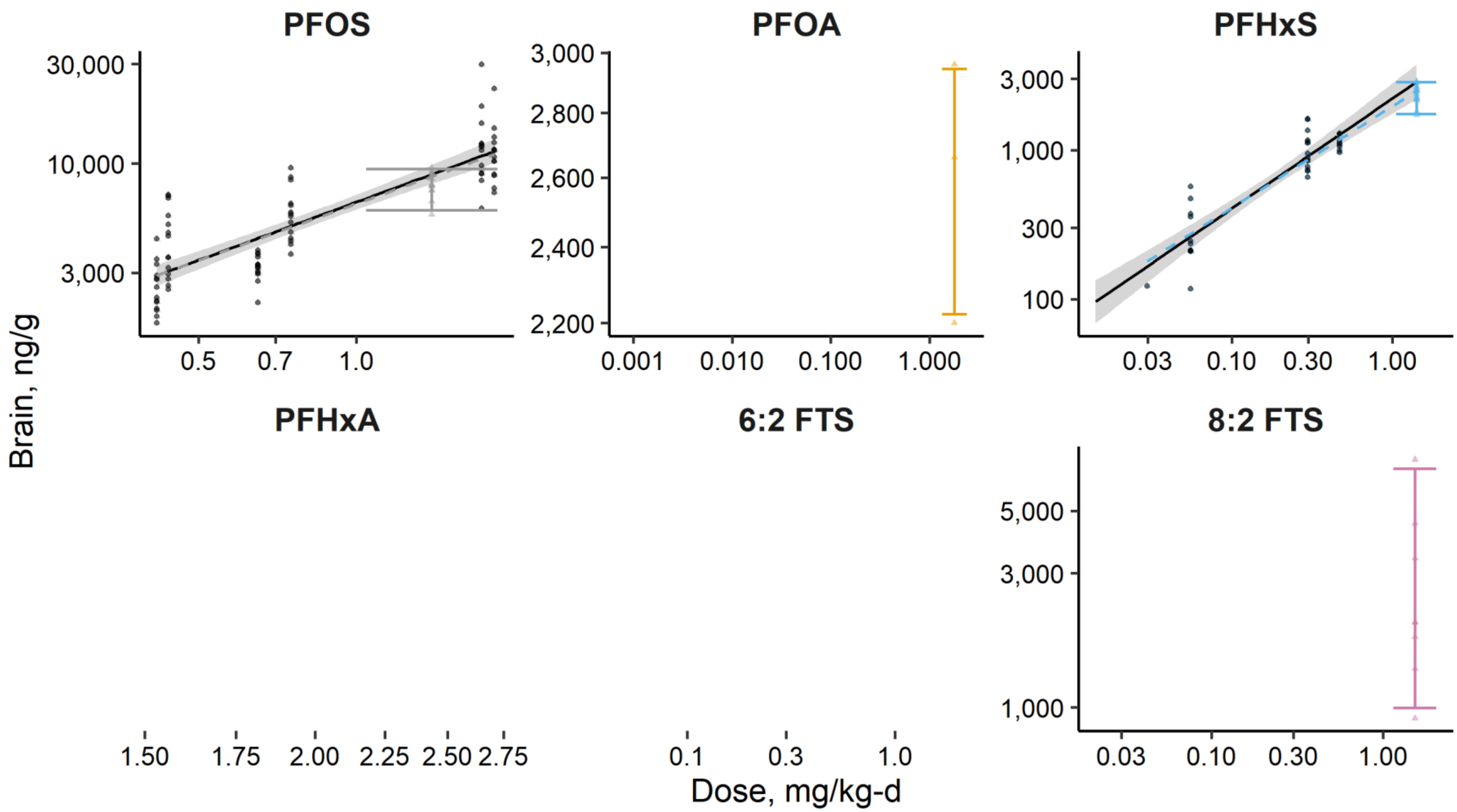


Figure SI3.13. Extrapolated relationship between dose (mg/kg-d) and brain (ng/g) when predicted from mixture treatments or impure mixtures (black points, black line, gray confidence intervals) are consistent with models that utilize all data (dashed color-matched line). Note few data are above quantification/reporting.

Example selection of R code.

For exposure modeling:

```
library(tidyverse)
library(lme4)

dataframe <- data.frame(
            animalID=c(1,1,1,1,1,2,2,2,2),
            treatment=c(rep("C68Low",9)),
            sex=c(rep("M",9),
            PFAS=c("PFOS","PFHxS","PFOA","PFHxA","PFPeS","PFOS",
            "PFHxS","PFOA","PFHxA"),
            Dose=c(0.428, 0.3350, 0.125, 0.207  ,NA, 0.428, 0.3350, 0.125,
            0.207),
            Wholebody=c(3,2,1,2,1,3,2,1,2)
            ) # example vectors showing 2 animals.

mixturemodel <- lmer(log(Wholebody)~log(Dose)+Sex+(log(Dose)|PFAS),
data=dataframe, REML=T)
summary(mixturemodel)
coef(mixturemodel)

additivemodel <- lmer(log(Wholebody)~log(Dose)+Sex+(1PFAS), data=dataframe,
REML=T)
summary(additivemodel)
coef(additivemodel)
```

Example selection of R code.

For effects modeling:

```
library(tidyverse)

dataframe <- data.frame(
            animalID=c(1,1,1,1,1,2,2,2,2),
            treatment=c(rep("C68Low",9)),
            sex=c(rep("M",9),
            PFAS=c("PFOS","PFHxS","PFOA","PFHxA","PFPeS","PFOS",
            "PFHxS","PFOA","PFHxA"),
            Dose=c(0.428, 0.3350, 0.125, 0.207  ,NA, 0.428, 0.3350, 0.125,
            0.207),
            Wholebody=c(3,2,1,2,1,3,2,1,2),
            relliv=c(0.6, 0.6, 0.6, 0.6, 0.6, 0.5, 0.5, 0.5, 0.5), #relative
            liver weight
            sumdose=c(1.095, 1.095, 1.095, 1.095, 1.095, 1.095, 1.095, 1.095,
            1.095) #sumdose
            ) # example vectors showing 2 animals.

dataframe |>
      filter(treatment=="PFOS")|>
      group_by(sex)|>
      summarize(PFOSmeanreliv=mean(relliv, na.rm=T)) # to display the sex-
wise mean relative liverweights for the PFOS treatment
```

```
dataframe <- dataframe |>
      mutate(
      PFOSmeanrelliv=case_when(sex.y=="Female"~0.08009670, #these means are
      from above
                        sex.y=="Male"~0.08663098),
      PFOSproprelliv=relliv/PFOSmeanrelliv,
      propdose=Dose/sumdose
      )

dataframesumm <- dataframe |>
      dplyr::select(-c(Dose, Wholebody))|>
      group_by(AnimalID,treatment,sex) |>
      summarize(across(where(is.numeric), ~ mean(.x, na.rm = TRUE)))

malelm <- lm(PFOSproprelliv~sumdose, data= dataframesumm
|>filter(treatment%in%c("C6-8 Low","C6-8 Medium","C6-8 High","FTS Low","FTS
Medium","FTS High"), sex.y=="Male")) #extract model parameters predicting
proportional liver weight (to PFOS treatment mean) in mixture treatments for
male mice

femalelm <- lm(PFOSproprelliv~sumdose, data= dataframesumm
|>filter(treatment%in%c("C6-8 Low","C6-8 Medium","C6-8 High","FTS Low","FTS
Medium","FTS High"), sex.y=="Female")) #extract model parameters predicting
proportional liver weight (to PFOS treatment mean) in mixture treatments for
female mice

RPFwide <- dataframesumm |>
      filter(!treatment%in%c("C6-8 Low","C6-8 Medium","C6-8 High","FTS
Low","FTS Medium","FTS High"))|>
      group_by(treatment,sex.y) |>
      summarize(meanPFOSproprelliv=mean(PFOSproprelliv, na.rm=T)) |>
      pivot_wider(names_from=treatment, values_from=meanPFOSproprelliv) |>
      rename(PFOSRPF=PFOS,PFOARPF=PFOA,PFHxSRPF=PFHxS,PFHxARPF=PFHxA,FTS62RPF
=`6:2 FTS`,FTS82RPF=`8:2 FTS`,ControlRPF=Control)

dataframelivselect <- dataframe |>
      merge(RPFwide, by="sex",all=T) |>
      pivot_wider(names_from=PFAS, values_from=c(Dose))|>
      mutate(
            intercept=case_when(
                  sex=="Male" ~ coef(malelm)[[1]],
                  sex=="Female" ~ coef(femalelm)[[1]]
                  ),
            slope=case_when(
                  sex=="Male" ~ coef(malelm)[[2]],
                  sex=="Female" ~ coef(femalelm)[[2]]
            )
      ) |>
      rowwise() |>
      mutate(estimatedpropPFOSrelliv=intercept+sum(
                                    PFOSRPF*PFOS*slope,
                                    PFOARPF*PFOA*slope,
                                    PFHxSRPF*PFHxS*slope,
                                    PFHxARPF*PFHxA*slope,
                                    FTS62RPF*`6:2 FTS`*slope,
                                    FTS82RPF*`8:2 FTS`*slope, na.rm=T))
```

Table SI3.10. Evidence of additivity is based on the small relative contribution of PFAS-specific slope ($\boldsymbol{\sigma_{\beta i}}$), in relation to individual-specific deviation ($\boldsymbol{\sigma_{ij}}$) using a mixed effects model (Model 1) that allows a correlated PFAS-specific slope and intercept around an overall linear model between ln-transformed dose and tissue or tissue:tissue or a mixed effects model (Model 2) that allows only a PFAS-specific intercept. Bold indicates the larger source of variation between individuals and a non-additivity effect (only relevant for Model 1).

			Random effects		**Residuals**	**Fixed effects**		
			Non-additivity effect	**PFAS-effect**	**Individual-effect**	**Overall relationship**		**Sex-effect**
Model	**Predictor**	**Estimate**	**Slope $\sigma_{\beta i}$**	**Intercept $\sigma_{\alpha i}$**	**σ_{ij}**	**Slope β**	**Intercept α**	**β_{Sex}**
1	Dose	Whole body	0.20	2.83	**0.48**	0.83	7.68	0.32
	Dose	Serum	0.16	2.73	**0.50**	0.84	8.92	0.03
	Dose	Liver	0.29	3.55	**0.90**	0.82	9.86	0.40
	Dose	Kidney	0.16	2.59	**0.74**	0.82	8.33	-0.26
	Dose	Brain	0.12	0.63	**0.35**	0.73	7.87	-0.06
	Serum	Liver	0.27	1.79	**0.48**	0.94	0.76	0.44
	Serum	Kidney	0.28	1.56	**0.57**	0.77	0.64	-0.06
	Serum	Brain	0.12	1.02	**0.56**	0.62	1.55	0.14
	Liver	Kidney	0.10	0.62	**0.50**	0.75	0.25	-0.40
	Liver	Brain	0.11	1.03	**0.58**	0.67	0.09	-0.06
	Kidney	Brain	0.16	0.97	**0.51**	0.77	0.02	0.22
2	Dose	Whole body	-	2.56	0.55	0.91	7.72	0.33
	Dose	Serum	-	2.80	0.51	0.92	8.96	0.03
	Dose	Liver	-	3.41	0.92	0.95	9.98	0.40
	Dose	Kidney	-	2.58	0.74	0.88	8.38	-0.26
	Dose	Brain	-	0.63	0.36	0.75	7.86	-0.06
	Serum	Liver	-	1.68	0.53	0.91	0.82	0.44
	Serum	Kidney	-	0.96	0.66	0.75	0.96	-0.11
	Serum	Brain	-	0.98	0.61	0.67	1.09	0.22
	Liver	Kidney	-	0.61	0.52	0.80	0.02	-0.41
	Liver	Brain	-	0.19	0.65	0.76	-0.66	0.01
	Kidney	Brain	-	0.32	0.59	0.90	-0.86	0.32

Table SI3.11. Predicting tissues (ng/g or ng/mL) based on daily dose (mg/kg-d) for 28 days via oral gavage in CD-1 mice. $\boldsymbol{Sex}_{M}=1$ for male mice and $\boldsymbol{Sex_M = 0}$ for female mice. $\boldsymbol{N(\mu_i, 0.55)}$ is a normal distribution with mean $\boldsymbol{\mu_i}$ and standard deviation 0.55 as an example.

Predictor	Estimate	$\boldsymbol{\mu}$ Function	Prediction
Dose (mg/kg-d)	Whole Body (ng/g)	$\mu_i = \begin{bmatrix} 6{:}2\,FTS & 7.55 \\ 8{:}2\,FTS & 9.22 \\ PFBS & 3.94 \\ PFHpS & 9.30 \\ PFHxA & 2.11 \\ PFHxS & 9.25 \\ PFNA & 9.14 \\ PFNS & 9.31 \\ PFOA & 9.17 \\ PFOS & 9.68 \\ PFPeS & 6.22 \end{bmatrix} + 0.91\,ln(Dose_i) + 0.33Sex_M$	$\ln\left(\widehat{Whole\,Body_i}\right) \sim N(\mu_i, 0.55)$
Dose (mg/kg-d)	Serum (ng/mL)	$\mu = \begin{bmatrix} 6{:}2\,FTS & 8.41 \\ 8{:}2\,FTS & 9.15 \\ PFBS & 5.34 \\ PFHpS & 11.01 \\ PFHxA & 2.40 \\ PFHxS & 11.74 \\ PFNA & 10.75 \\ PFNS & 9.83 \\ PFOA & 10.57 \\ PFOS & 10.73 \\ PFPeS & 8.68 \end{bmatrix} + 0.91\,ln(Dose) + 0.03Sex_M$	$\ln\left(\widehat{Serum}\right) \sim N(\mu, 0.51)$

Predictor	Estimate	μ Function	Prediction
Dose (mg/kg-d)	Liver (ng/g)	$\mu = \begin{bmatrix} 6{:}2\ FTS & 8.69 \\ 8{:}2\ FTS & 11.56 \\ PFHpS & 11.84 \\ PFHxA & 1.17 \\ PFHxS & 10.75 \\ PFNA & 11.96 \\ PFNS & 12.23 \\ PFOA & 11.41 \\ PFOS & 12.03 \\ PFPeS & 8.11 \end{bmatrix} + 0.95\,ln(Dose) + 0.40 Sex_M$	$\ln(\widehat{Liver}) \sim N(\mu, 0.92)$
Dose (mg/kg-d)	Kidney (ng/g)	$\mu = \begin{bmatrix} 6{:}2\ FTS & 8.07 \\ 8{:}2\ FTS & 9.40 \\ PFHpS & 9.42 \\ PFHxA & 1.51 \\ PFHxS & 9.77 \\ PFNA & 9.13 \\ PFNS & 9.86 \\ PFOA & 9.41 \\ PFOS & 10.11 \\ PFPeS & 7.14 \end{bmatrix} + 0.88\,ln(Dose) + -0.26 Sex_M$	$\ln(\widehat{Kidney}) \sim N(\mu, 0.74)$
Dose (mg/kg-d)	Brain (ng/g)	$\mu = \begin{bmatrix} 8{:}2\ FTS & 7.51 \\ PFHxS & 7.69 \\ PFOA & 7.48 \\ PFOS & 8.77 \end{bmatrix} + 0.75\,ln(Dose) \pm 0.05 Sex_M$	$\ln(\widehat{Brain}) \sim N(\mu, 0.36)$

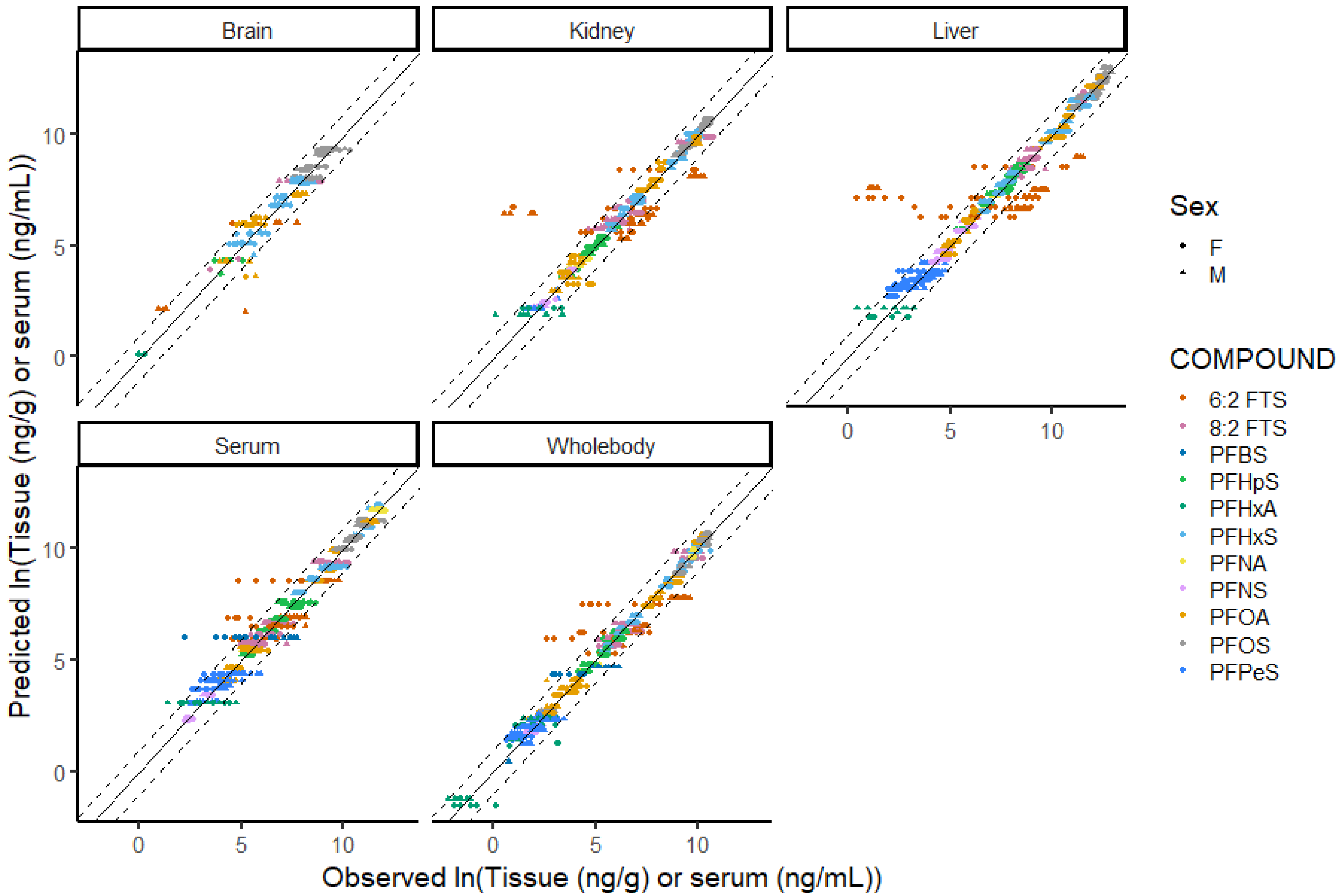


Figure SI3.14. Predicted (using a $\log_e$(dose (mg/kg-d)) predictor) tissue concentrations (y-axis) vs observed tissue concentrations (x-axis) across tissues by PFAS and sex using the varying slope and varying intercept mixed effects model (Model 1). Solid line is 1:1 and dashed are ±1 $\log_e$. Note that data outside dashed lines are largely 6:2 FTS data and this is largely attributed to the 6:2 FTS kinetics, which are extremely nonlinear at the grab sample study timepoint.

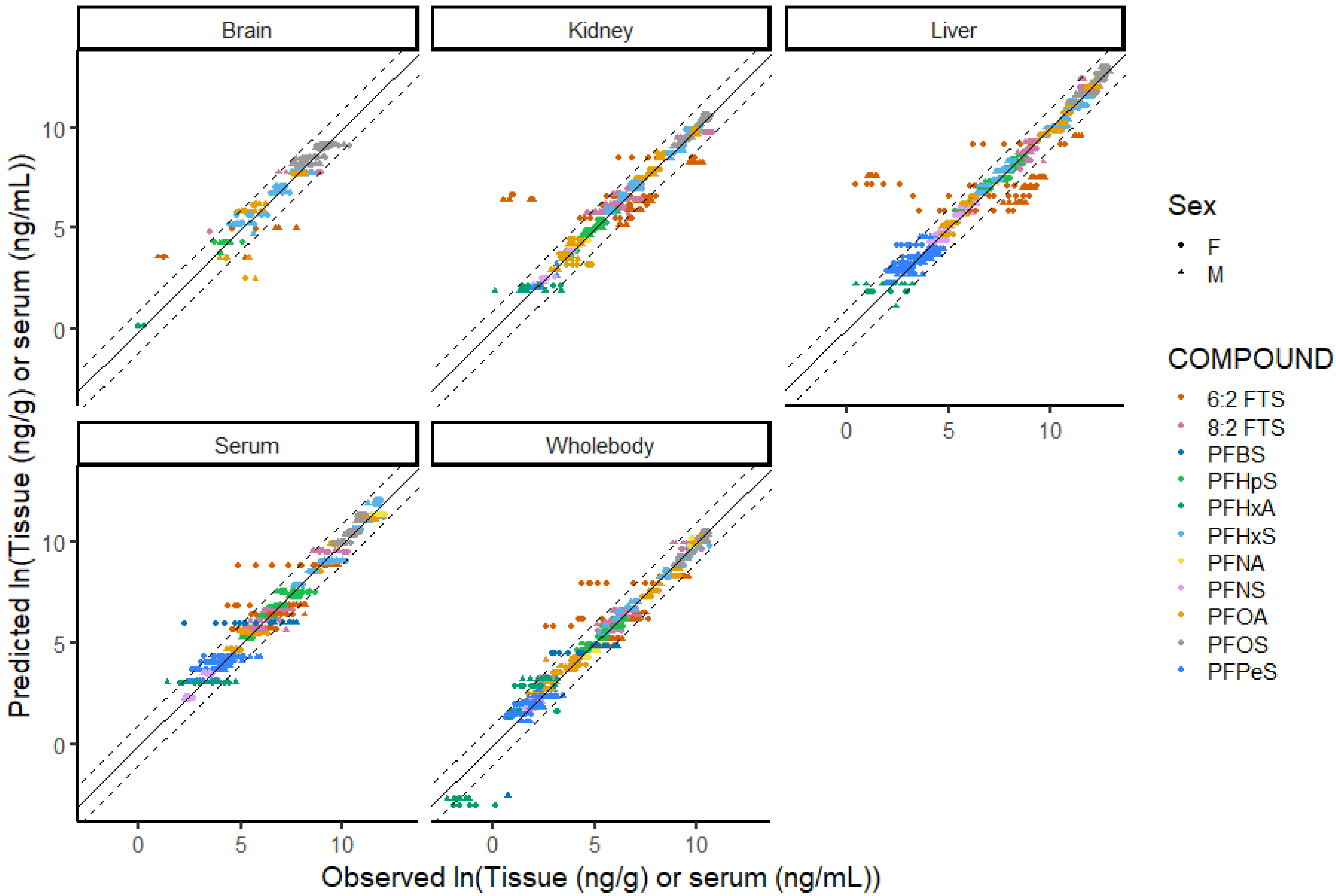


Figure SI3.15. Predicted (using a $\log_e$(dose (mg/kg-d)) predictor) tissue concentrations (y-axis) vs observed tissue concentrations (x-axis) across tissues by PFAS and sex using the varying intercept only mixed effects model (Model 2). Solid line is 1:1 and dashed are ±1 $\log_e$. Note that data outside dashed lines are largely 6:2 FTS data and this is largely attributed to the 6:2 FTS kinetics, which are extremely nonlinear at the grab sample study timepoint.

Table SI3.12. Predicting tissue concentrations (ng/g) based on serum sample (ng/mL) after 28 days PFAS exposure in CD-1 mice. $\boldsymbol{Sex_M = 1}$ for male mice and $\boldsymbol{Sex_M = 0}$ for female mice. $\boldsymbol{N(\mu, 0.53)}$ is a normal distribution with mean $\boldsymbol{\mu}$ and standard deviation 0.53 as an example.

Predictor	Estimate	$\boldsymbol{\mu}$ Function	Prediction
Serum (ng/mL)	Liver (ng/g)	$\mu = \begin{bmatrix} 6{:}2\ FTS & 2.08 \\ 8{:}2\ FTS & 2.86 \\ PFBS & -1.88 \\ PFDA & 1.49 \\ PFDoA & -2.19 \\ PFHpS & 1.27 \\ PFHxA & -0.72 \\ PFHxS & -0.02 \\ PFNA & 2.28 \\ PFNS & 2.29 \\ PFOA & 1.28 \\ PFOS & 2.28 \\ PFPeS & -0.32 \end{bmatrix} + 0.91\ ln(Serum) + 0.44 Sex_M$	$\ln\left(\widehat{Liver}\right) \sim N(\mu, 0.53)$
Serum (ng/mL)	Kidney (ng/g)	$\mu = \begin{bmatrix} 6{:}2\ FTS & 2.04 \\ 8{:}2\ FTS & 1.91 \\ PFHpS & 0.20 \\ PFHxA & 0.10 \\ PFHxS & 0.62 \\ PFNA & 1.70 \\ PFNS & 0.83 \\ PFOA & 0.77 \\ PFOS & 2.09 \\ PFPeS & -0.69 \end{bmatrix} + 0.75\ ln(Serum) + -0.11 Sex_M$	$\ln\left(\widehat{Kidney}\right) \sim N(\mu, 0.66)$

Serum (ng/mL)	Brain (ng/g)	$\mu = \begin{bmatrix} 8{:}2\ FTS & 1.41 \\ PFHxS & -0.37 \\ PFNA & 2.23 \\ PFOA & 0.84 \\ PFOS & 1.33 \end{bmatrix} + 0.67\ ln(Serum) + 0.22 Sex_M$	$\ln(\widehat{Brain}) \sim N(\mu, 0.61)$

Table SI3.13. Predicting tissue concentrations (ng/g) based on tissue concentrations (ng/g) after 28 days PFAS exposure in CD-1 mice. $\boldsymbol{Sex_M = 1}$ for male mice and $\boldsymbol{Sex_M = 0}$ for female mice. $\boldsymbol{N(\mu, 0.52)}$ is a normal distribution with mean $\boldsymbol{\mu}$ and standard deviation 0.52 as an example.

Predictor	Estimate	$\boldsymbol{\mu}$ Function	Prediction
Liver (ng/g)	Kidney (ng/g)	$\mu = \begin{bmatrix} 6{:}2\ FTS & 0.71 \\ 8{:}2\ FTS & -0.25 \\ NEtFOSE & 0.73 \\ PFDA & -0.56 \\ PFHpS & -0.70 \\ PFHxA & 0.61 \\ PFHxS & 0.76 \\ PFNA & 0.11 \\ PFNS & -0.91 \\ PFOA & -0.18 \\ PFOS & 0.33 \\ PFPeS & -0.37 \end{bmatrix} + 0.80\ ln(Liver) + -0.41 Sex_M$	$\ln(\widehat{Kidney}) \sim N(\mu, 0.52)$
Liver (ng/g)	Brain (ng/g)	$\mu = \begin{bmatrix} 8{:}2\ FTS & -0.81 \\ PFHxS & -0.75 \\ PFNA & -0.44 \\ PFOA & -0.59 \\ PFOS & -0.71 \end{bmatrix} + 0.76\ ln(Liver) + 0.01 Sex_M$	$\ln(\widehat{Brain}) \sim N(\mu, 0.65)$

Kidney (ng/g)	Brain (ng/g)	$\mu = \begin{bmatrix} 8{:}2\ FTS & -1.12 \\ PFHxS & -1.12 \\ PFNA & -0.95 \\ PFOA & -0.56 \\ PFOS & -0.55 \end{bmatrix} + 0.90\ ln(Kidney) + 0.32 Sex_M$	$\ln\left(\widehat{Brain}\right) \sim N(\mu, 0.59)$

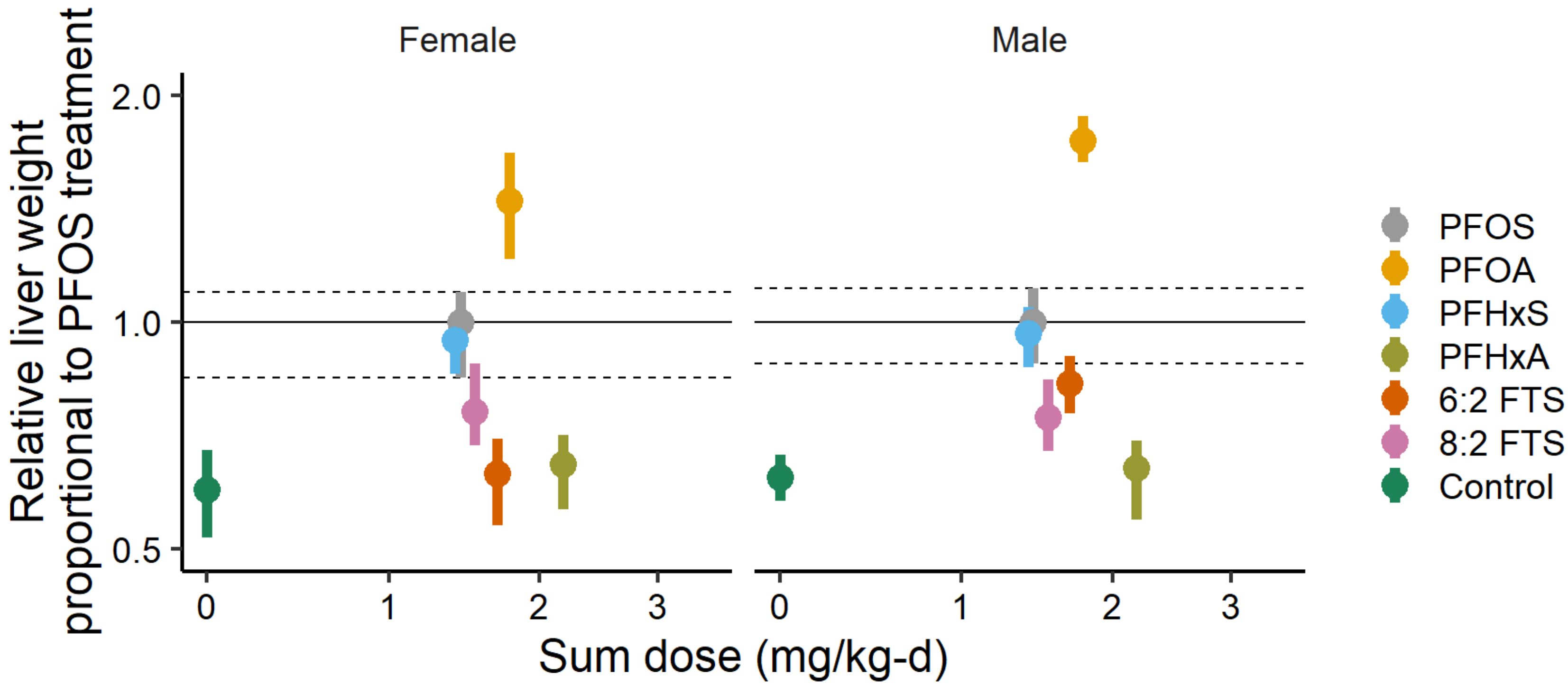


Figure SI3.16. Singleton treatment relative liver weights proportional to PFOS treatment are effective relative potency factors (RPF_i). Points are means and error bars 95% confidence limits. Horizontal line is at 1 with dashed lines at PFOS treatment 97.5th and 2.5th percentiles. Y-axis is log_{10}-scaled (fold-change interpretation) and x-axis is log_e-scaled with modified 0 to ensure plotting of Control treatment. Inclusion of Control treatment is for context and is not used as an RPF. See Table SI3.14 for RPF estimates.

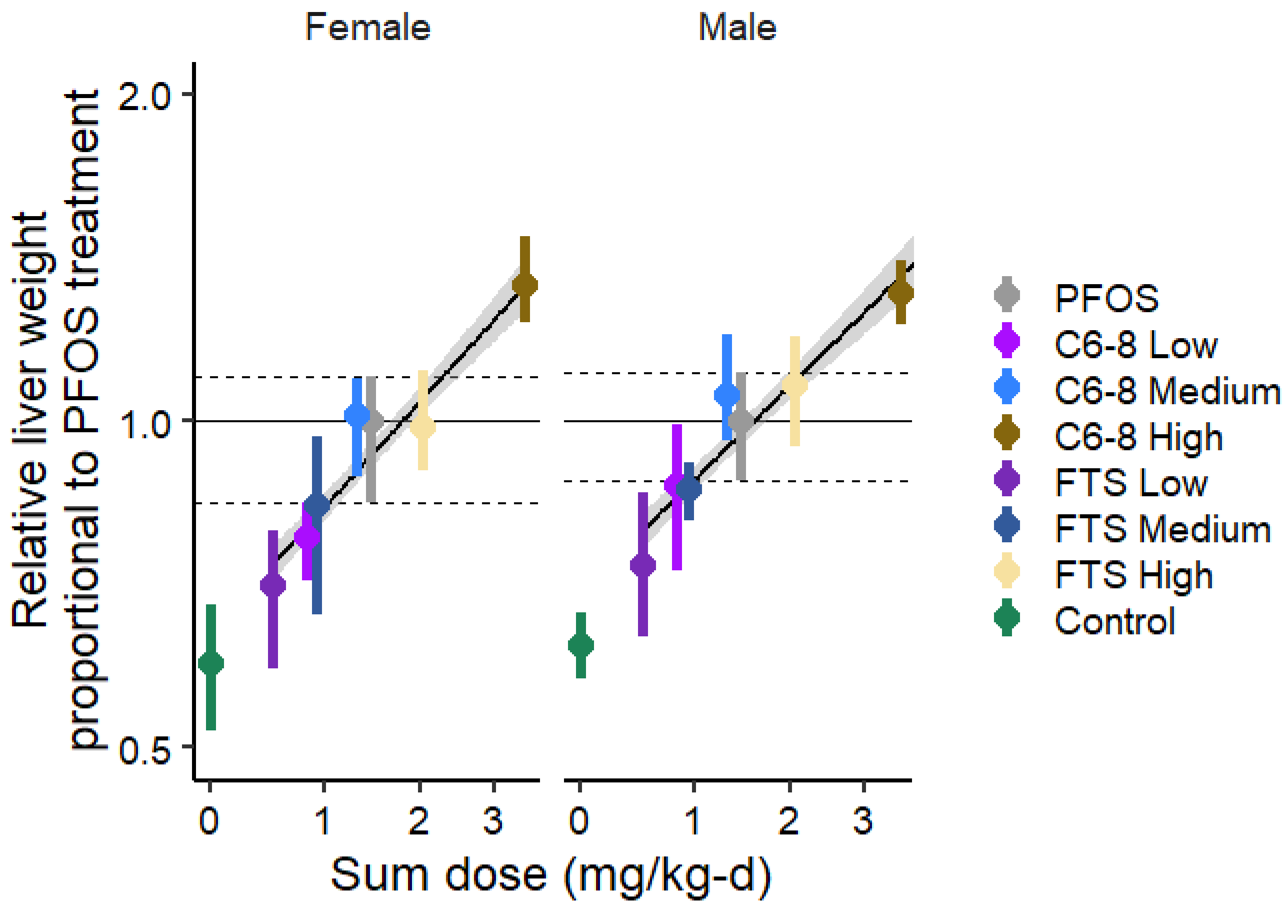


Figure SI3.17. Mixture treatment relative liver weights proportional to PFOS treatment by sum dose. Regression line with confidence intervals overlaid (predicted only from mixture groups). Note the overlap of C6-8 Medium and FTS High with PFOS which all have approximately the same sum PFAS. This indicates that a mixture effect outside of additivity is unlikely for these PFAS and this effect. Points are means and error bars 95% confidence limits. Horizontal line is at 1 with dashed lines at PFOS treatment 97.5th and 2.5th percentiles. Y-axis is log_{10}-scaled (fold-change interpretation) and x-axis is log_e-scaled with modified 0 to ensure plotting of Control treatment. Inclusion of Control treatment is for context and only generically represents y-intercept.

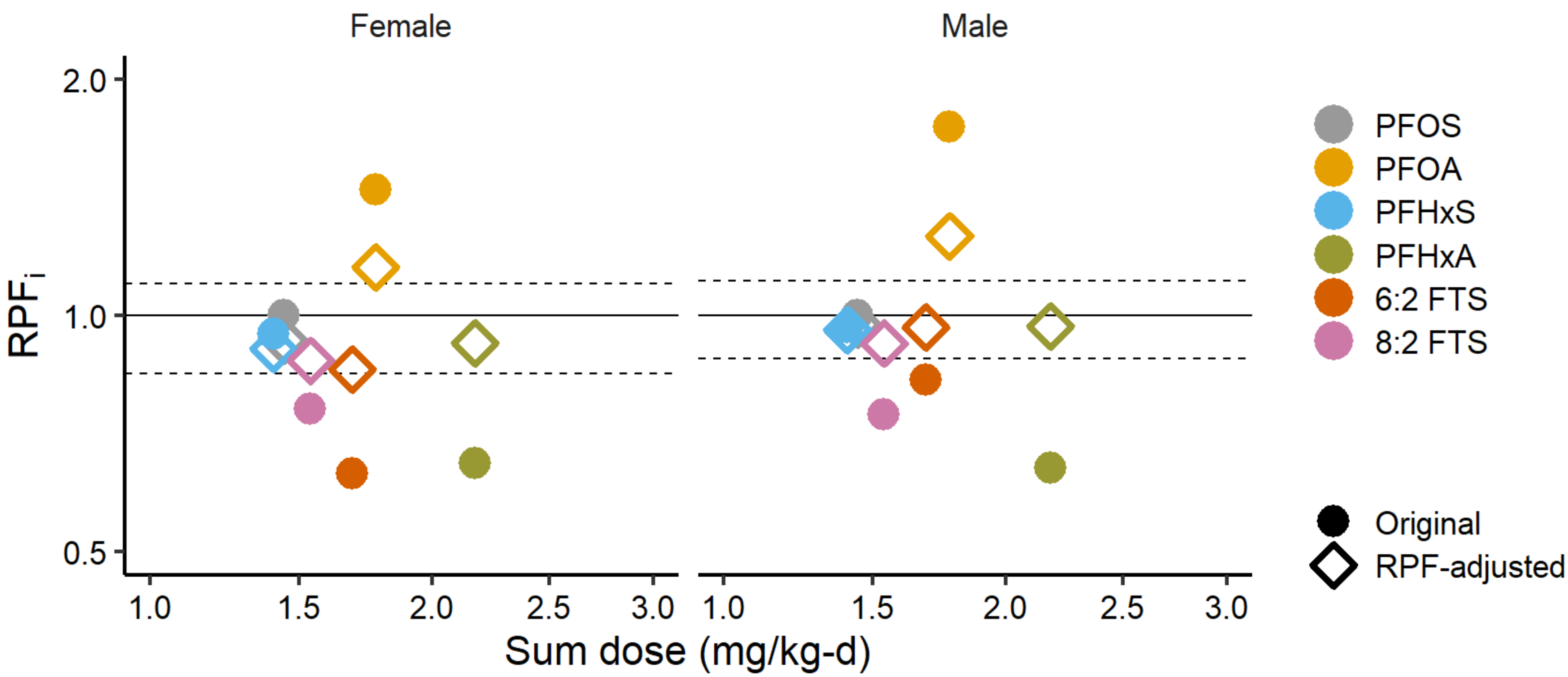


Figure SI3.18. When RPF-adjusted relative liver weights are compared back to PFOS, most fall within the confidence limits of PFOS, indicating that non-additive interactions are unlikely. Only PFOA appears insufficiently adjusted—PFOA's effect on relative liver weight may be potentiated in a C6-8 mixture. Points are means. Horizontal line is at 1 with dashed lines at PFOS treatment 97.5th and 2.5th percentiles. Y-axis is $\log_{10}$-scaled (fold-change interpretation) and x-axis is $\log_e$-scaled.

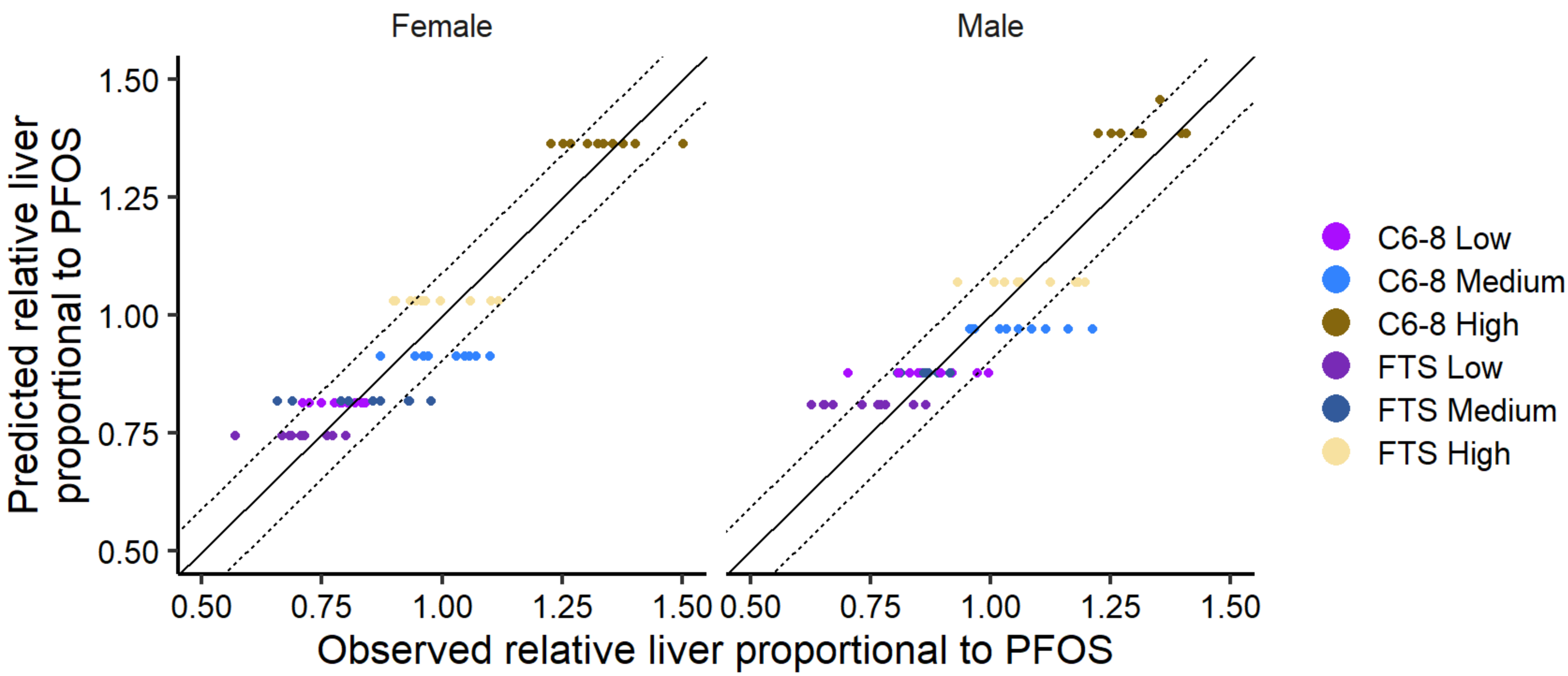


Figure SI3.19. Predicted (y-axis) vs observed (x-axis) relative liver weight as a proportion of mean relative liver weight in PFOS treatment. Solid line is 1:1 and dashed are +sigma and -sigma.

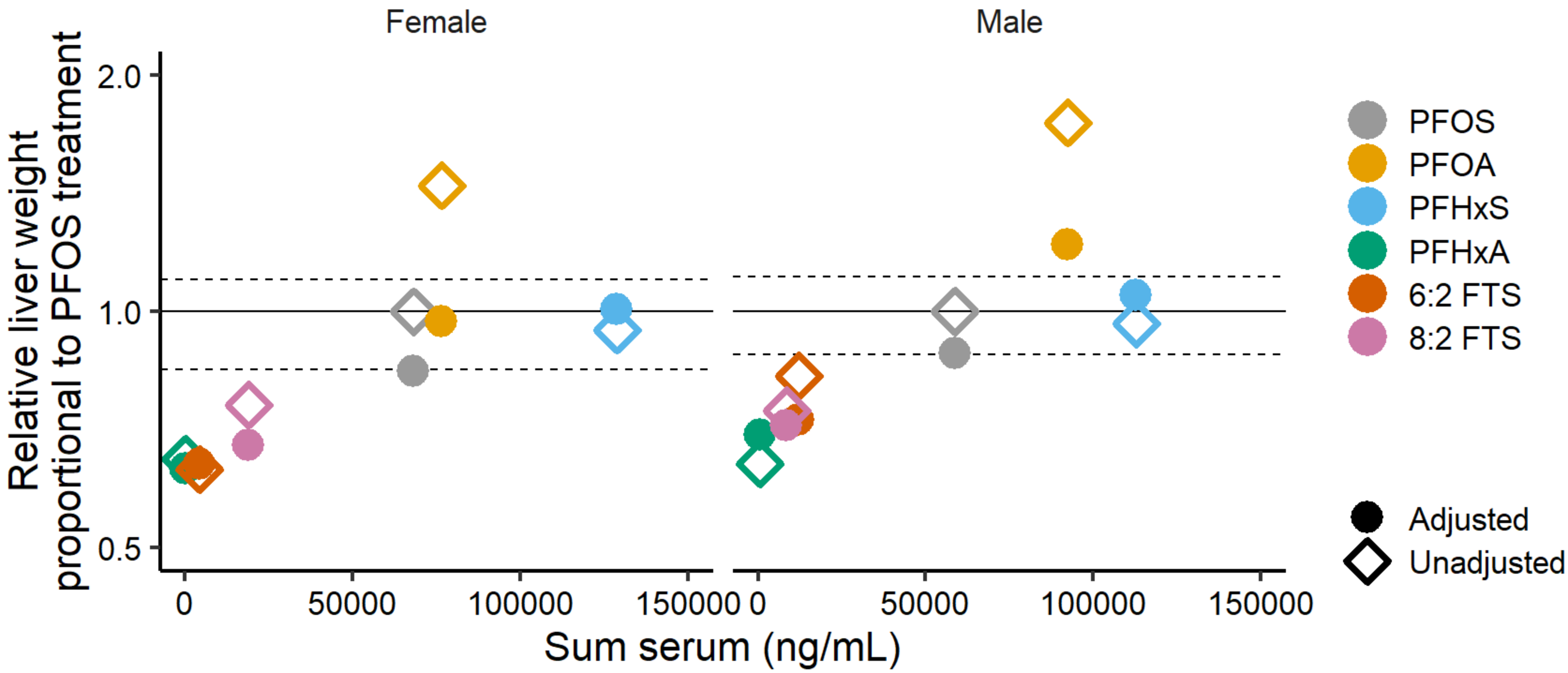


Figure SI3.20. RPF adjusted relative liver weights for singletons using sum serum bring estimated liver weights closer to the expected serum-predicted relationship, however, due to the large range of serum concentrations (as compared to dose), the data do not necessarily converge to the PFOS treatment confidence intervals. Points are means. Horizontal line is at 1 with dashed lines at PFOS treatment 97.5th and 2.5th percentiles. Y-axis is $\log_{10}$-scaled (fold-change interpretation) and x-axis is $\log_e$-scaled.

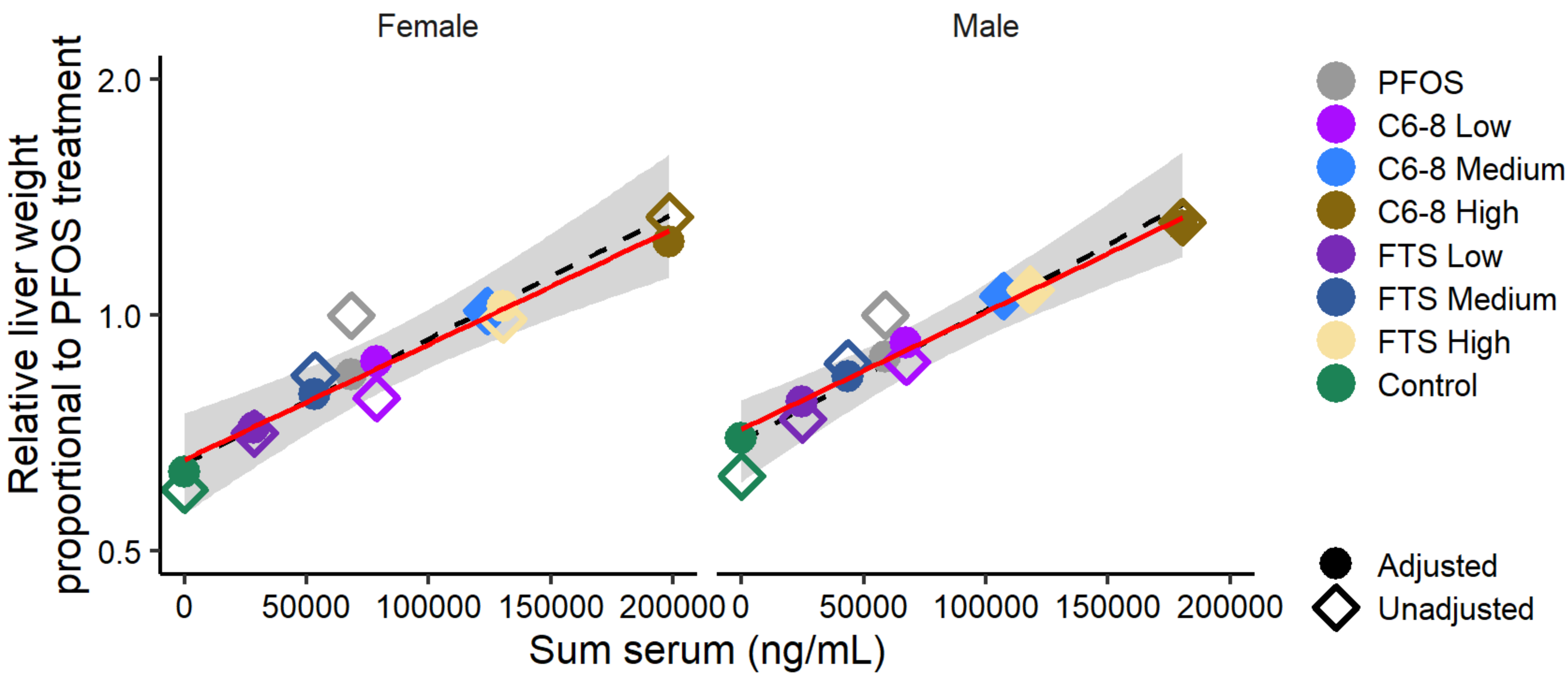


Figure SI3.21. Adjusted mean relative liver weight dose response (red line, solid points) in C6-8 and FTS mixtures are not outside the confidence intervals for unadjusted mixtures (dashed line, gray confidence intervals, diamonds)—supporting the additive hypothesis for serum concentrations to predict relative liver effects. Points are means. Y-axis is $\log_{10}$-scaled (fold-change interpretation) and x-axis is $\log_e$-scaled.

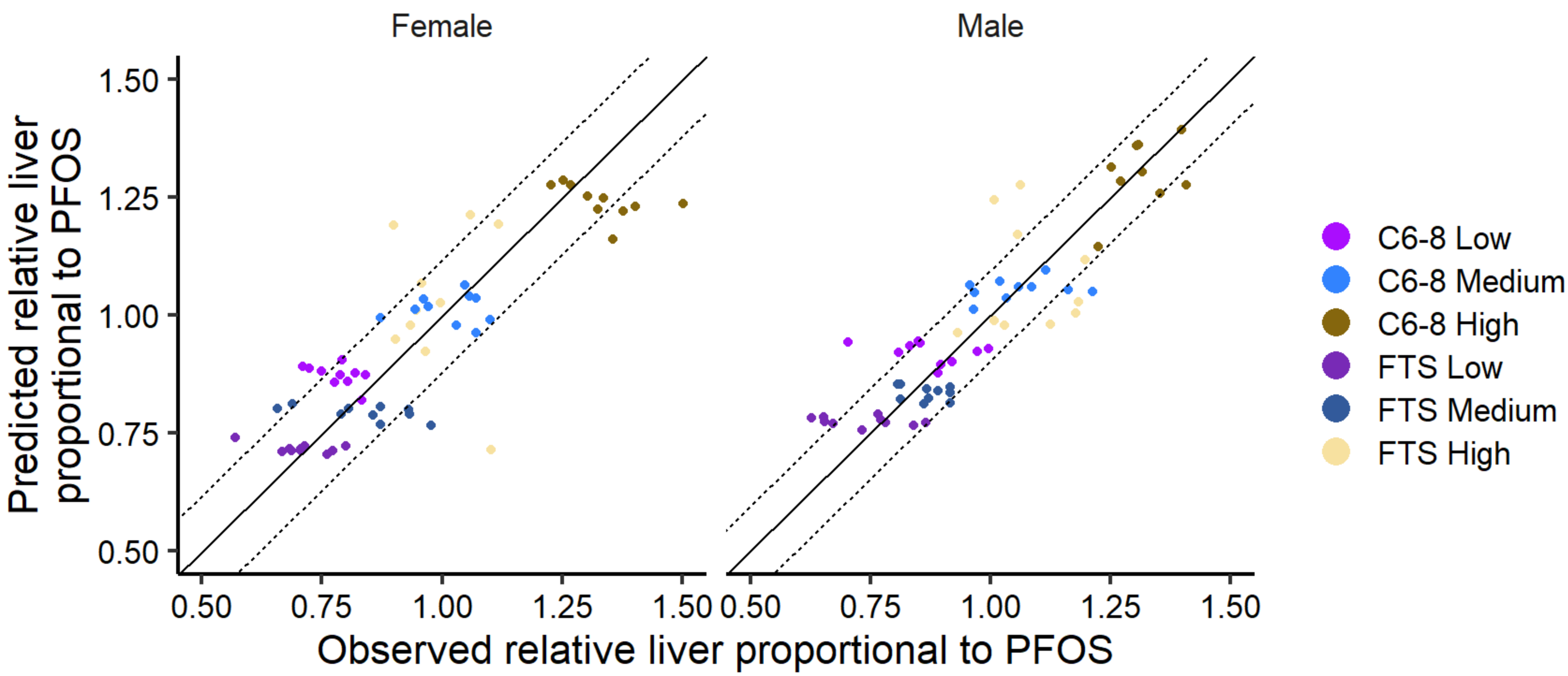


Figure SI3.22. Predicted vs observed for serum predicting relative liver weights proportional to the PFOS treatment.

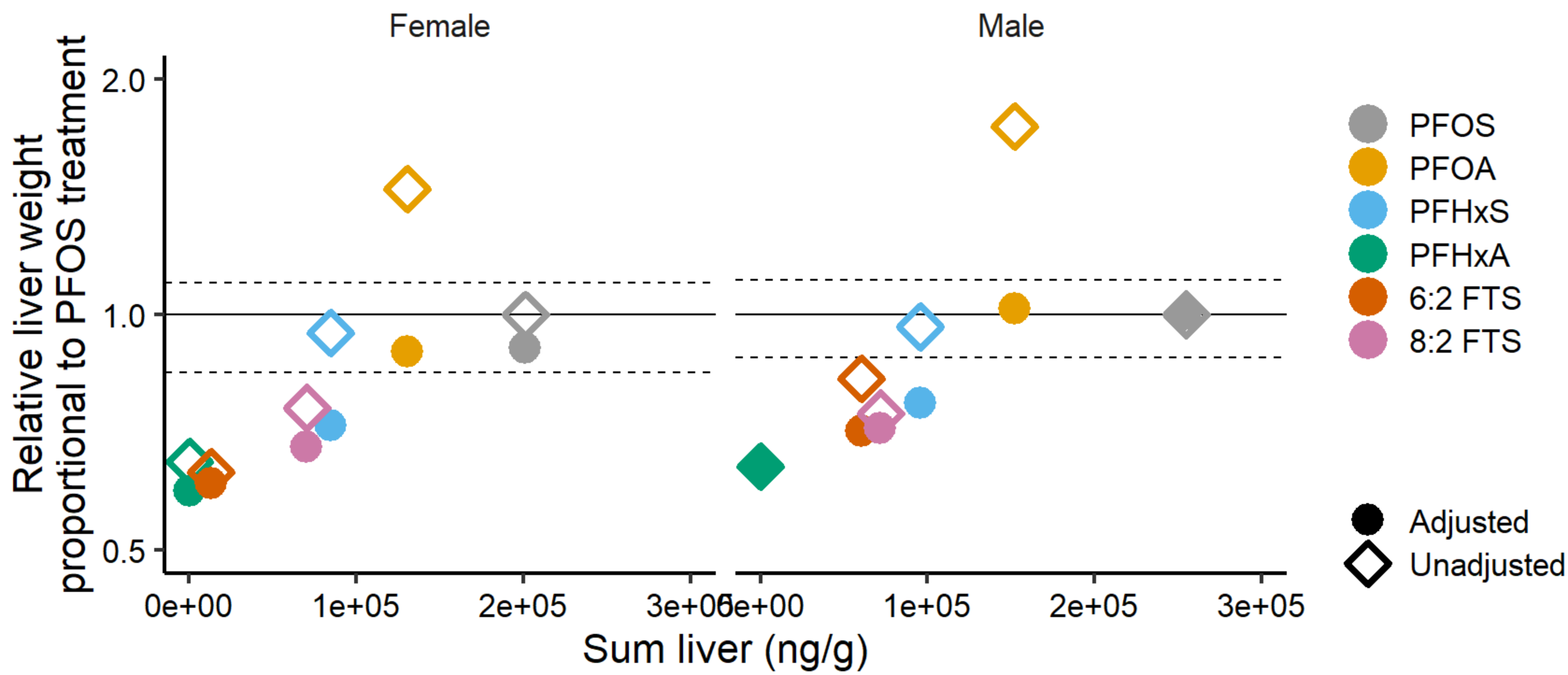


Figure SI3.23. RPF adjusted relative liver weights for singletons using sum liver bring estimated liver weights closer to the expected liver-predicted relationship, however, due to the large range of liver concentrations (as compared to dose), the data do not necessarily converge to the PFOS treatment confidence intervals. Points are means. Horizontal line is at 1 with dashed lines at PFOS treatment 97.5th and 2.5th percentiles. Y-axis is $\log_{10}$-scaled (fold-change interpretation) and x-axis is $\log_e$-scaled.

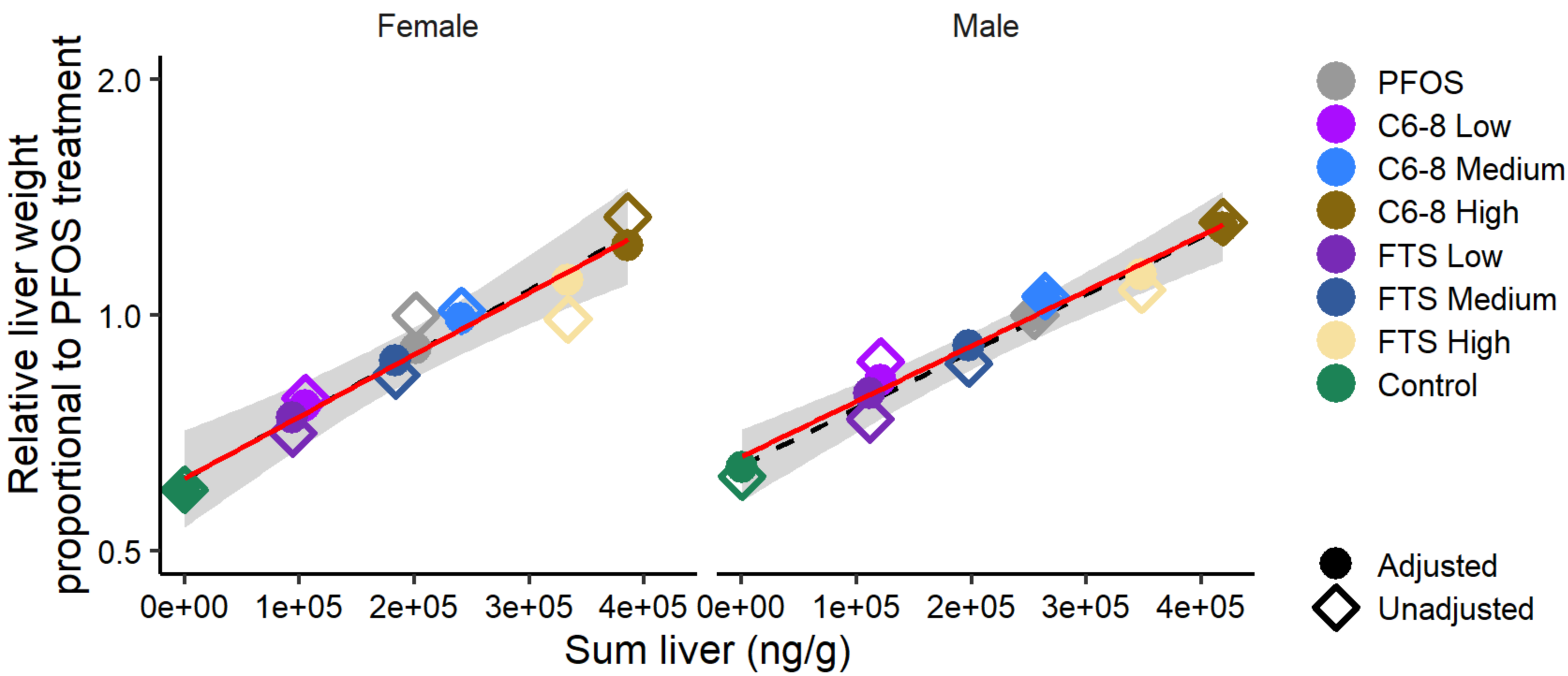


Figure SI3.24. Adjusted mean relative liver weight dose response (red line, solid points) in C6-8 and FTS mixtures are not outside the confidence intervals for unadjusted mixtures (dashed line, gray confidence intervals, diamonds)—supporting the additive hypothesis for liver concentrations to predict relative liver effects. Points are means. Y-axis is $\log_{10}$-scaled (fold-change interpretation) and x-axis is $\log_e$-scaled.

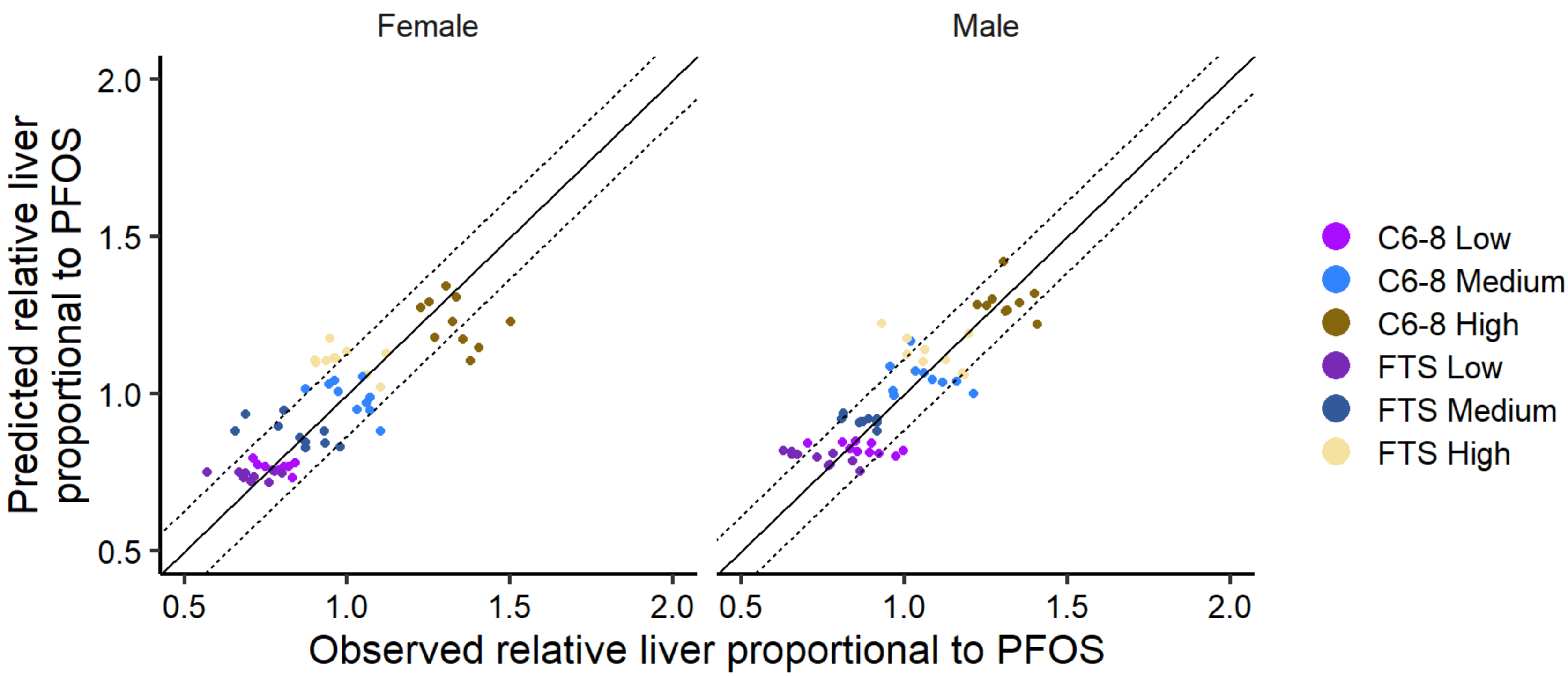


Figure SI3.25. Predicted vs observed for liver predicting relative liver weight proportional to PFOS.

Table SI3.14. Relative liver weights expressed as proportion of specific treatment means. PFOS-relative effects, in singletons, are the $\boldsymbol{RPF_i}$ used in Model 3 and, in mixtures, are indicators of additive effects. Control-relative effects are indicators of overall ΣPFAS effect as singletons and mixtures. Bold highlights the common relative effects of PFOS and mixture treatments with similar ΣPFAS (C6-8 Medium, FTS High).

		PFOS-relative effects Rel. Liv/mean(Rel. Liv PFOS)		**Control-relative effects Rel. Liv/mean(Rel. Liv CONTROL)**
Treatment	**Sex**	$\boldsymbol{RPF_i}$ **Mean, (97.5th, 2.5th)**	**Mean, (97.5th, 2.5th)**	**Mean, (97.5th, 2.5th)**
Control	Female	0.60, (0.68, 0.52)	-	1.00, (1.13, 0.86)
Control	Male	0.62, (0.67, 0.58)	-	1.00, (1.07, 0.93)
PFOS	Female	**1.00, (1.10, 0.84)**	-	**1.67, (1.83, 1.40)**
PFOS	Male	**1.00, (1.11, 0.88)**	-	**1.61, (1.78, 1.42)**
PFOA	Female	1.45, (1.68, 1.21)	-	2.41, (2.80, 2.02)
PFOA	Male	1.74, (1.88, 1.63)	-	2.80, (3.02, 2.62)
PFHxS	Female	0.95, (1.02, 0.85)	-	1.58, (1.70, 1.42)
PFHxS	Male	0.97, (1.05, 0.87)	-	1.55, (1.68, 1.40)
PFHxA	Female	0.65, (0.71, 0.57)	-	1.08, (1.18, 0.94)
PFHxA	Male	0.64, (0.70, 0.55)	-	1.03, (1.12, 0.88)
6:2 FTS	Female	0.63, (0.70, 0.54)	-	1.05, (1.17, 0.90)
6:2 FTS	Male	0.83, (0.90, 0.76)	-	1.33, (1.45, 1.22)
8:2 FTS	Female	0.76, (0.88, 0.69)	-	1.27, (1.47, 1.14)
8:2 FTS	Male	0.75, (0.84, 0.67)	-	1.20, (1.35, 1.08)
C6-8 Low	Female	-	0.78, (0.84, 0.71)	1.31, (1.40, 1.19)
C6-8 Low	Male	-	0.87, (0.99, 0.73)	1.40, (1.59, 1.17)
C6-8 Medium	Female	-	**1.01, (1.09, 0.89)**	**1.69, (1.82, 1.48)**
C6-8 Medium	Male	-	**1.06, (1.20, 0.96)**	**1.70, (1.93, 1.54)**
C6-8 High	Female	-	1.34, (1.48, 1.23)	2.22, (2.47, 2.05)
C6-8 High	Male	-	1.32, (1.41, 1.23)	2.11, (2.26, 1.98)
FTS Low	Female	-	0.71, (0.79, 0.59)	1.18, (1.32, 0.99)
FTS Low	Male	-	0.74, (0.86, 0.63)	1.18, (1.38, 1.02)
FTS Medium	Female	-	0.84, (0.97, 0.66)	1.40, (1.61, 1.11)
FTS Medium	Male	-	0.87, (0.92, 0.81)	1.40, (1.47, 1.30)
FTS High	Female	-	**0.99, (1.12, 0.90)**	**1.65, (1.86, 1.50)**
FTS High	Male	-	**1.08, (1.20, 0.95)**	**1.73, (1.92, 1.53)**

Table SI3.15. Original linear model parameters based on mixture data ($\boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\sigma}$) and RPF-adjusted using singleton data ($\boldsymbol{\beta}'$). If $\boldsymbol{\beta}'$is inside the 95% confidence intervals of the original $\boldsymbol{\beta}$, then additive effects are observed.

Predictor	Estimate	Sex	α	Original β, (97.5th, 2.5th)	σ	RPF-adjusted β'
Dose	proportion of PFOS rel liv	Female	0.644	0.197, (0.150, 0.199)	0.092	0.206
Dose	proportion of PFOS rel liv	Male	0.721	0.175, (0.174, 0.221)	0.094	0.188
Serum	proportion of PFOS rel liv	Female	0.630	0.00000307, (0.00000256, 0.00000359)	0.119	0.00000308
Serum	proportion of PFOS rel liv	Male	0.698	0.00000324, (0.00000277, 0.00000370)	0.096	0.00000334
Liver	proportion of PFOS rel liv	Female	0.594	0.00000156, (0.00000126, 0.00000186)	0.132	0.00000162
Liver	proportion of PFOS rel liv	Male	0.639	0.00000143, (0.00000117, 0.00000169)	0.113	0.00000153

Table SI3.16. Predicting fold-change ALT (units/L) in relation to control treatment by the fold-change relative liver weight in relation to control treatment indicates that females have approximately 40% more increase in ALT per unit increase in relative liver weight. These values are specific to C6-8 mixture PFAS and control; see Figure SI3.26.

Predictor	Estimate	Sex	α, (97.5th, 2.5th)	β, (97.5th, 2.5th)	σ
Rel. Liver/Rel. Liv Control	ALT/ALT Control	Male	-0.226, (-0.309, -0.143)	1.516, (1.173, 1.860)	0.215
Rel. Liver/Rel. Liv Control	ALT/ALT Control	Female	-0.203, (-0.285, -0.120)	2.118, (1.762, 2.473)	0.208

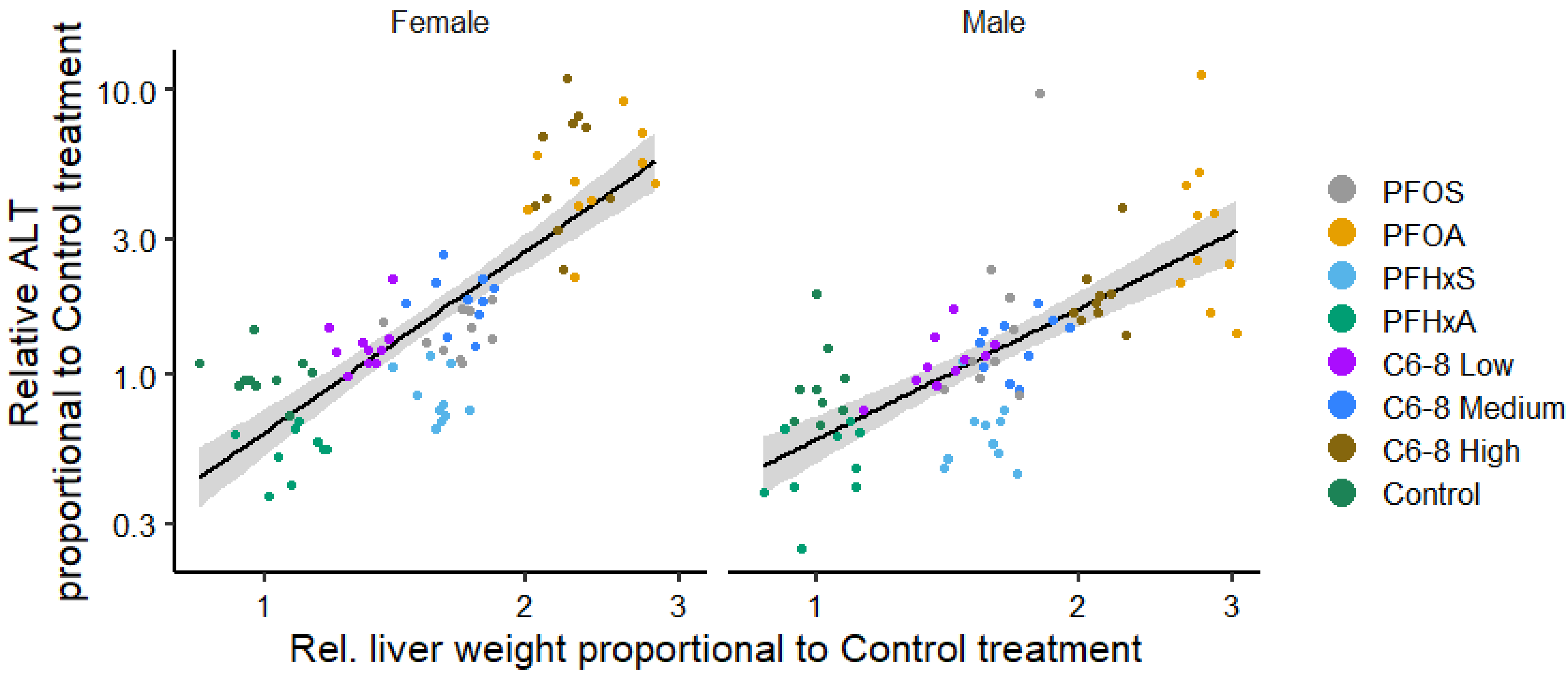


Figure SI3.26. Linear dose response between proportional to Control liver weight and proportional to Control ALT across C6-8 mixture and matching singleton PFAS and Control.

Table SI3.17. Tissue concentration data summarized by treatment, sex, and PFAS. Values are mean, (standard deviation), [sample size]. "-" indicates no quantified data reported, NA indicates insufficient sample size to estimate standard deviation.

Singleton Treatment?	Treatment	Sex	PFAS	Brain	Kidney	Liver	Serum	Wholebody
no	PFOS	F	6:2 FTS	-	-	-	566, (NA), [1]	-
no	PFOS	F	PFDS	-	-	105.94, (19.87), [7]	-	15.1, (2.03), [10]
no	PFOS	F	PFHpS	-	-	3035.71, (434.2), [7]	2126, (299.3), [10]	506.7, (69.3), [10]
no	PFOS	F	PFHxS	-	1089.57, (230.22), [7]	2714.29, (349.42), [7]	8973, (1370.66), [10]	783.5, (33.23), [2]
no	PFOS	F	PFNS	-	-	237.57, (31.5), [7]	32.71, (2.64), [10]	38.68, (5.52), [10]
no	PFOS	F	PFOA	-	-	357.29, (47.66), [7]	177.6, (24.76), [10]	46.38, (6.61), [10]
no	PFOS	F	PFPeS	-	-	34.95, (7.62), [4]	56.18, (22.39), [10]	6.69, (2.06), [10]
no	PFOS	F	N-EtFOSE	-	-	-	-	24.86, (12.14), [6]
no	PFOS	F	PFDoS	-	-	-	-	0.71, (0.17), [9]
no	PFOS	F	PFHpA	-	-	-	-	0.56, (0.06), [3]
no	PFOS	F	PFNA	-	-	-	-	0.65, (NA), [1]
no	PFOS	M	PFDS	-	-	131.57, (18.89), [7]	-	17.48, (1.53), [10]
no	PFOS	M	PFHpS	-	-	3987.14, (594.19), [7]	1825.56, (175.15), [9]	606.6, (36.76), [10]
no	PFOS	M	PFHxS	-	1068.57, (123.35), [7]	3064.29, (304.35), [7]	8744.44, (836.83), [9]	-
no	PFOS	M	PFNS	-	-	293.71, (49.72), [7]	25.51, (3.12), [9]	44.24, (3.54), [10]
no	PFOS	M	PFOA	-	-	461.57, (33.3), [7]	157.56, (19.33), [9]	60.02, (3.89), [9]
no	PFOS	M	PFPeS	-	-	63.67, (10.16), [7]	119.54, (23.41), [9]	16.77, (4.18), [10]
no	PFOS	M	8:2 FTS	-	-	263, (NA), [1]	-	2.55, (NA), [1]
no	PFOS	M	N-EtFOSE	-	-	-	-	11.54, (4.81), [8]
no	PFOS	M	PFBA	-	-	-	-	2.73, (0.51), [8]
no	PFOS	M	PFDA	-	-	-	-	4.51, (NA), [1]
no	PFOS	M	PFDoS	-	-	-	-	0.81, (0.13), [10]
no	PFOS	M	PFHpA	-	-	-	-	0.79, (0.15), [10]
no	PFOS	M	PFNA	-	-	-	-	0.53, (0.06), [3]
no	PFOA	F	PFBS	-	-	-	1.35, (0.2), [6]	-
no	PFOA	F	PFDA	-	-	325.57, (38.37), [7]	40.87, (2.87), [10]	42.87, (2.75), [10]
no	PFOA	F	PFHxS	-	-	-	8.89, (2.93), [10]	1.05, (1.07), [8]
no	PFOA	F	PFNA	-	-	-	2, (0.23), [10]	1.42, (0.17), [10]
no	PFOA	F	PFOS	-	-	86.24, (20.67), [7]	15.43, (4.41), [10]	6.59, (6.42), [10]
no	PFOA	F	8:2 FTS	-	-	-	-	1.95, (1.11), [10]
no	PFOA	F	N-EtFOSE	-	-	-	-	5.8, (2.09), [10]
no	PFOA	F	PFBA	-	-	-	-	1.39, (0.76), [10]
no	PFOA	F	PFDoA	-	-	-	-	0.32, (0.04), [10]
no	PFOA	F	PFHpS	-	-	-	-	0.45, (0.02), [2]
no	PFOA	F	PFHxA	-	-	-	-	0.45, (0.41), [5]
no	PFOA	F	PFTeDA	-	-	-	-	0.13, (NA), [1]
no	PFOA	F	PFTrDA	-	-	-	-	0.1, (NA), [1]
no	PFOA	M	PFBS	-	-	-	1.44, (0.31), [7]	-
no	PFOA	M	PFDA	-	-	275.14, (9.46), [7]	33.12, (6.01), [10]	47.69, (4.07), [9]
no	PFOA	M	PFHpA	-	-	-	1.56, (0.44), [4]	0.24, (0.07), [8]
no	PFOA	M	PFHxS	-	-	67.97, (37.14), [4]	4.01, (3.32), [10]	2.29, (1.19), [7]
no	PFOA	M	PFNA	-	-	33.92, (6.51), [4]	1.61, (0.4), [10]	1.52, (0.13), [9]
no	PFOA	M	PFOS	-	-	34.8, (4.8), [5]	7.37, (1.46), [10]	13.93, (11.35), [9]
no	PFOA	M	6:2 FTS	-	-	-	-	0.37, (NA), [1]
no	PFOA	M	8:2 FTS	-	-	-	-	1.02, (0.52), [9]
no	PFOA	M	N-EtFOSE	-	-	-	-	8.02, (3.11), [6]
no	PFOA	M	N-MeFOSE	-	-	-	-	2.14, (NA), [1]
no	PFOA	M	PFBA	-	-	-	-	0.95, (0.47), [9]
no	PFOA	M	PFDoA	-	-	-	-	0.28, (0.05), [8]
no	PFOA	M	PFHpS	-	-	-	-	0.48, (0.23), [6]
no	PFOA	M	PFHxA	-	-	-	-	0.19, (0.07), [7]
no	PFOA	M	PFPeA	-	-	-	-	0.45, (0.24), [2]
no	PFOA	M	PFTrDA	-	-	-	-	0.13, (0.06), [3]
no	PFOA	M	PFUnA	-	-	-	-	0.21, (0.05), [3]
no	PFHxS	F	PFBS	-	-	-	1.48, (0.39), [9]	-
no	PFHxS	F	PFHpS	-	-	42.49, (6.88), [7]	14.69, (1.2), [10]	-
no	PFHxS	F	PFOA	-	-	56.07, (9.33), [7]	14.99, (3.14), [10]	-
no	PFHxS	F	PFOS	-	241.5, (123.74), [2]	253.71, (43.49), [7]	18.82, (3.14), [10]	11.76, (3.83), [6]
no	PFHxS	F	PFPeS	-	-	28.93, (0.7), [3]	34.93, (9.83), [10]	-
no	PFHxS	F	6:2 FTS	-	-	-	-	696, (309.89), [6]
no	PFHxS	F	PFNA	-	-	-	-	10.6, (NA), [1]
no	PFHxS	M	PFBS	-	-	-	1.64, (0.51), [9]	-
no	PFHxS	M	PFHpS	-	-	53.8, (7.42), [7]	11.87, (1.32), [10]	-
no	PFHxS	M	PFNA	-	-	60.47, (36.03), [6]	1.75, (NA), [1]	9.41, (NA), [1]
no	PFHxS	M	PFOA	-	-	47.38, (23.96), [5]	5.64, (3.35), [10]	38.73, (23.08), [3]
no	PFHxS	M	PFOS	-	-	204.43, (20.13), [7]	12.69, (2.06), [10]	24.98, (12.74), [5]
no	PFHxS	M	PFPeS	-	-	57.67, (13.12), [7]	76.8, (31.45), [10]	-
no	PFHxS	M	6:2 FTS	-	-	-	-	565.67, (318.26), [3]
no	PFHxS	M	PFBA	-	-	-	-	268, (19.8), [2]
no	PFHxA	F	PFBA	-	-	4.78, (2.09), [7]	-	1.14, (0.21), [2]
no	PFHxA	F	PFBS	-	-	0.3, (0.18), [3]	1.76, (0.49), [9]	-
no	PFHxA	F	PFHpS	-	2.19, (0.42), [2]	0.83, (0.29), [7]	-	-
no	PFHxA	F	PFHxS	15.71, (16.96), [2]	19.19, (5.54), [7]	33.17, (10.22), [7]	52.41, (8.49), [9]	14.68, (18.44), [10]
no	PFHxA	F	PFNA	-	4.2, (1.46), [7]	8.77, (5.84), [7]	1.24, (0.15), [5]	17.7, (NA), [1]
no	PFHxA	F	PFOA	-	9.13, (2.17), [7]	23.97, (6.66), [7]	12.67, (2.58), [9]	8, (5.72), [10]
no	PFHxA	F	PFOS	14.51, (10.3), [7]	63.49, (45.91), [7]	83.93, (20.29), [7]	6.62, (2.66), [9]	2.13, (0.7), [10]
no	PFHxA	F	6:2 FTS	-	2.68, (0.16), [2]	5.58, (4.22), [6]	-	1.04, (NA), [1]
no	PFHxA	M	PFBA	-	-	4.33, (1.47), [7]	-	1.13, (0.2), [9]
no	PFHxA	M	PFBS	-	-	-	1.45, (0.29), [7]	-

no	PFHxA	M	PFHxS	21.98, (11.78), [7]	50.99, (21.31), [7]	86.2, (55.47), [7]	546.19, (1179.99), [10]	17.75, (24.99), [10]
no	PFHxA	M	PFNA	8.06, (7.27), [2]	8.38, (2.24), [7]	21.71, (9.58), [7]	-	0.45, (NA), [1]
no	PFHxA	M	PFOA	-	3.41, (1.64), [7]	18.77, (3.36), [7]	4.91, (1.18), [10]	6.1, (7.52), [10]
no	PFHxA	M	PFOS	5.53, (3.24), [7]	13.44, (5.23), [7]	41.33, (5), [7]	2.8, (0.25), [4]	4.98, (7.16), [10]
no	PFHxA	M	PFPeS	-	-	-	6.58, (6.39), [2]	-
no	PFHxA	M	6:2 FTS	-	4.67, (2.53), [5]	3.46, (0.58), [7]	-	-
no	PFHxA	M	PFHpS	-	-	0.34, (0.08), [7]	-	0.57, (NA), [1]
no	PFBS	F	PFBA	-	-	-	14.34, (5.93), [10]	-
no	PFBS	F	PFHxS	-	-	-	59.97, (6.92), [10]	5.52, (1.51), [9]
no	PFBS	F	PFNA	-	-	-	18.8, (2.9), [10]	7.84, (3.3), [10]
no	PFBS	F	PFOA	-	-	-	9.47, (1.51), [10]	5.05, (2.36), [9]
no	PFBS	F	PFOS	-	-	-	10.94, (4.31), [10]	2.37, (0.09), [2]
no	PFBS	F	PFPeS	-	-	-	1.09, (0.06), [2]	-
no	PFBS	F	PFTeDA	-	-	-	1.23, (NA), [1]	-
no	PFBS	M	PFBA	-	-	-	13.47, (5.33), [10]	-
no	PFBS	M	PFDoA	-	-	-	0.87, (0.07), [3]	-
no	PFBS	M	PFHxS	-	-	-	46.48, (5.09), [10]	11.8, (12.4), [9]
no	PFBS	M	PFNA	-	-	-	5.88, (3.27), [10]	17.05, (11.6), [8]
no	PFBS	M	PFOA	-	-	-	5.09, (1.73), [10]	8.77, (6.16), [3]
no	PFBS	M	PFOS	-	-	-	8.84, (2.88), [10]	3.26, (1.29), [6]
no	PFBS	M	PFPeS	-	-	-	1.1, (0.15), [4]	-
no	PFBS	M	6:2 FTS	-	-	-	-	38.89, (19.27), [5]
no	PFNA	F	6:2 FTS	-	-	-	623, (NA), [1]	41.6, (NA), [1]
no	PFNA	F	PFOA	-	-	-	151, (NA), [1]	20.56, (2.85), [8]
no	PFNA	F	PFHxS	-	-	-	-	33.04, (28.85), [7]
no	PFNA	F	PFOS	-	-	-	-	10.67, (2.87), [2]
no	PFNA	M	6:2 FTS	-	-	-	1190, (NA), [1]	-
no	PFNA	M	PFHxS	-	-	-	-	36.75, (47.46), [7]
no	PFNA	M	PFOA	-	-	-	-	20.98, (3.87), [10]
no	PFNA	M	PFOS	-	-	-	-	8.43, (NA), [1]
no	6:2 FTS	F	8:2 FTS	-	532, (94.75), [7]	3814.29, (647.14), [7]	395.3, (69.87), [10]	317, (107.8), [10]
no	6:2 FTS	F	PFBS	-	-	-	1.64, (0.61), [10]	0.83, (0.51), [10]
no	6:2 FTS	F	PFDA	-	-	-	0.94, (0.23), [6]	0.3, (0.08), [9]
no	6:2 FTS	F	PFHxA	-	-	-	0.55, (NA), [1]	0.23, (NA), [1]
no	6:2 FTS	F	PFHxS	-	29.6, (NA), [1]	19.79, (13.51), [7]	31.15, (3.84), [10]	8.46, (6.28), [10]
no	6:2 FTS	F	PFNA	-	28.3, (NA), [1]	51.71, (14.87), [7]	13.64, (3.22), [10]	6.64, (5.07), [10]
no	6:2 FTS	F	PFOA	204, (NA), [1]	110.03, (172.35), [4]	69.79, (53.44), [7]	24.65, (6.53), [10]	2.12, (0.98), [10]
no	6:2 FTS	F	PFOS	20.8, (NA), [1]	58.42, (79.44), [6]	106.67, (125.82), [7]	11.8, (1.35), [7]	3.4, (1.62), [10]
no	6:2 FTS	F	N-EtFOSE	-	-	-	-	9.06, (2.24), [10]
no	6:2 FTS	F	PFBA	-	-	-	-	0.4, (NA), [1]
no	6:2 FTS	F	PFDoA	-	-	-	-	0.09, (0.02), [2]
no	6:2 FTS	F	PFHpS	-	-	-	-	0.16, (NA), [1]
no	6:2 FTS	F	PFPeA	-	-	-	-	0.5, (0.15), [8]
no	6:2 FTS	F	PFTeDA	-	-	-	-	0.14, (0.01), [2]
no	6:2 FTS	F	PFTrDA	-	-	-	-	0.12, (0.01), [6]
no	6:2 FTS	F	PFUnA	-	-	-	-	0.26, (0.1), [2]
no	6:2 FTS	M	8:2 FTS	-	231.39, (243.45), [7]	4985.71, (4736.84), [7]	323.2, (363.33), [10]	260.4, (63.78), [10]
no	6:2 FTS	M	PFBS	-	-	-	2.03, (0.42), [10]	0.48, (0.33), [7]
no	6:2 FTS	M	PFHxS	-	43.04, (12.24), [7]	49.56, (17.89), [7]	20.8, (2.1), [10]	8.46, (9.42), [9]
no	6:2 FTS	M	PFNA	-	-	41.19, (19.46), [7]	4.42, (2.92), [10]	10.96, (12.83), [10]
no	6:2 FTS	M	PFOA	-	29.64, (10.31), [7]	68.53, (11.8), [7]	14.06, (2.82), [10]	2.66, (1.09), [10]
no	6:2 FTS	M	PFOS	594, (NA), [1]	104.51, (50.07), [7]	141.34, (63.57), [7]	9.56, (2.7), [9]	2.43, (1.93), [10]
no	6:2 FTS	M	N-EtFOSE	-	-	-	-	6.71, (3.24), [10]
no	6:2 FTS	M	PFBA	-	-	-	-	0.72, (0.43), [2]
no	6:2 FTS	M	PFDA	-	-	-	-	0.33, (0.04), [10]
no	6:2 FTS	M	PFDoA	-	-	-	-	0.08, (0.01), [6]
no	6:2 FTS	M	PFHxA	-	-	-	-	0.26, (0.03), [2]
no	6:2 FTS	M	PFPeA	-	-	-	-	0.31, (0.12), [6]
no	6:2 FTS	M	PFTeDA	-	-	-	-	0.15, (0), [2]
no	6:2 FTS	M	PFTrDA	-	-	-	-	0.15, (0.05), [10]
no	6:2 FTS	M	PFUnA	-	-	-	-	0.21, (0.01), [5]
no	8:2 FTS	F	6:2 FTS	-	-	46.2, (8.55), [5]	9.66, (5.2), [6]	7.93, (7), [9]
no	8:2 FTS	F	PFBS	-	-	-	2.16, (0.43), [10]	0.46, (0.16), [9]
no	8:2 FTS	F	PFHpA	-	-	-	1.63, (NA), [1]	0.17, (0.04), [8]
no	8:2 FTS	F	PFHpS	-	52.39, (9.84), [7]	268.43, (37.81), [7]	227, (25.17), [10]	0.28, (0.04), [9]
no	8:2 FTS	F	PFHxS	-	91.55, (34.58), [2]	43.7, (53.86), [7]	23.72, (7.82), [10]	2.88, (0.92), [9]
no	8:2 FTS	F	PFNA	-	91.71, (12.38), [7]	956.29, (92.64), [7]	296.1, (35.21), [10]	92.97, (11.34), [9]
no	8:2 FTS	F	PFOA	-	34.25, (8.7), [2]	97.1, (15.43), [7]	67.5, (9.65), [10]	8.97, (1.66), [9]
no	8:2 FTS	F	PFOS	-	70.2, (43.42), [4]	130.87, (127.58), [7]	13.01, (2.21), [10]	11.44, (1.31), [9]
no	8:2 FTS	F	7:3 FTCA	-	-	-	-	9.87, (4), [9]
no	8:2 FTS	F	PFBA	-	-	-	-	1.15, (0.36), [3]
no	8:2 FTS	F	PFHxA	-	-	-	-	0.3, (0.1), [4]
no	8:2 FTS	F	PFTeDA	-	-	-	-	0.13, (0.04), [2]
no	8:2 FTS	F	PFTrDA	-	-	-	-	0.13, (0.01), [2]
no	8:2 FTS	M	6:2 FTS	-	-	68.17, (8.36), [7]	5.31, (1.19), [10]	18.87, (5.67), [11]
no	8:2 FTS	M	PFBS	-	-	-	1.61, (0.42), [10]	0.4, (0.27), [10]
no	8:2 FTS	M	PFHpA	-	-	-	1.17, (0.25), [8]	0.29, (0.18), [11]
no	8:2 FTS	M	PFHpS	-	38.56, (8.32), [7]	397.43, (14.99), [7]	170.7, (14.5), [10]	0.36, (0.07), [11]
no	8:2 FTS	M	PFHxS	-	31.3, (NA), [1]	19.83, (11.42), [7]	13.78, (1.17), [10]	3.11, (2.76), [10]
no	8:2 FTS	M	PFNA	-	53.59, (13.32), [7]	1317.14, (118), [7]	168.5, (19.57), [10]	126.51, (21.28), [11]
no	8:2 FTS	M	PFOA	44.3, (NA), [1]	31.7, (8.75), [6]	130.43, (12.08), [7]	43.69, (4.83), [10]	11.32, (2.46), [11]
no	8:2 FTS	M	PFOS	-	73.59, (23.87), [7]	131.91, (39.41), [7]	9.71, (2.07), [9]	14.33, (2.75), [11]
no	8:2 FTS	M	7:3 FTCA	-	-	-	-	13.65, (8.44), [11]
no	8:2 FTS	M	PFBA	-	-	-	-	0.88, (0.51), [5]
no	8:2 FTS	M	PFHxA	-	-	-	-	0.15, (0.03), [5]
no	8:2 FTS	M	PFTeDA	-	-	-	-	0.1, (NA), [1]

no	8:2 FTS	M	PFTrDA	-	-	-	-	0.18, (0.07), [7]
no	C6-8 Low	F	6:2 FTS	-	-	-	2140, (NA), [1]	168.73, (130.11), [3]
no	C6-8 Low	F	8:2 FTS	-	24.85, (3.46), [2]	43.18, (15.91), [10]	-	19.2, (NA), [1]
no	C6-8 Low	F	PFBA	-	-	-	65.86, (12.08), [10]	57.5, (NA), [1]
no	C6-8 Low	F	PFDA	-	-	18.6, (2.54), [10]	-	2.77, (NA), [1]
no	C6-8 Low	F	PFDS	-	10.63, (1.62), [7]	31.85, (3.41), [10]	-	2.92, (0.44), [10]
no	C6-8 Low	F	PFHpS	-	122, (13.3), [7]	917.9, (111.6), [10]	531.9, (75.89), [10]	83.71, (15.18), [10]
no	C6-8 Low	F	PFHxS	1046.71, (318.68), [7]	6152.86, (528.86), [7]	16490, (1623.75), [10]	49830, (4127.97), [10]	4825.56, (731.1), [9]
no	C6-8 Low	F	PFNA	-	7.86, (0.5), [2]	21.11, (2.89), [10]	-	6.21, (3.43), [7]
no	C6-8 Low	F	PFNS	-	12.99, (1.26), [7]	71.54, (8.83), [10]	10.41, (0.75), [7]	7.18, (0.78), [10]
no	C6-8 Low	F	PFOA	-	1500, (199.33), [7]	11242, (1171.37), [10]	6899, (947.76), [10]	1962, (342.14), [10]
no	C6-8 Low	F	PFOS	2907.14, (737.74), [7]	11571.43, (965.6), [7]	77650, (9039.94), [10]	21650, (2930.78), [10]	9357, (1043.53), [10]
no	C6-8 Low	F	PFPeS	-	-	13, (5.44), [10]	22.29, (9.29), [10]	2.33, (0.4), [3]
no	C6-8 Low	F	MeFOSAA	-	-	11.28, (1.72), [10]	-	3.64, (1.77), [4]
no	C6-8 Low	M	PFBA	-	-	-	73.3, (14.32), [10]	-
no	C6-8 Low	M	PFDA	-	-	21.06, (1.94), [10]	-	3.96, (0.85), [3]
no	C6-8 Low	M	PFDS	-	7.66, (1.08), [7]	35.87, (2.31), [10]	-	3.09, (0.42), [10]
no	C6-8 Low	M	PFHpS	-	95.79, (9.21), [7]	1171, (113.96), [10]	425.9, (44.79), [10]	95.6, (12.9), [10]
no	C6-8 Low	M	PFHxS	1008.14, (335.75), [7]	5941.43, (382.82), [7]	19550, (2111.48), [10]	45170, (4088.21), [10]	4895.71, (394.75), [7]
no	C6-8 Low	M	PFNA	-	-	16.4, (5.75), [10]	-	5.87, (5.49), [4]
no	C6-8 Low	M	PFNS	-	9.31, (1.3), [7]	78.71, (4.42), [10]	9.84, (0.65), [2]	7.37, (0.81), [10]
no	C6-8 Low	M	PFOA	-	1142, (118.38), [7]	16190, (1748.3), [10]	5290, (837.46), [10]	2574, (268), [10]
no	C6-8 Low	M	PFOS	2290, (630.93), [7]	7801.43, (933.17), [7]	84910, (8617.35), [10]	16900, (2139.05), [10]	9971, (1011.67), [10]
no	C6-8 Low	M	PFPeS	-	7.26, (1.91), [6]	33.6, (8.14), [10]	44.33, (12.4), [10]	3.88, (1.15), [10]
no	C6-8 Low	M	6:2 FTS	-	57, (23.84), [4]	57.58, (20.88), [10]	-	53.8, (NA), [1]
no	C6-8 Low	M	8:2 FTS	-	-	24.26, (6.92), [7]	-	14, (NA), [1]
no	C6-8 Low	M	MeFOSAA	-	-	13.06, (1.74), [10]	-	-
no	C6-8 Low	M	PFBS	-	-	-	-	2, (NA), [1]
no	C6-8 Medium	F	6:2 FTS	-	152.25, (30.74), [4]	-	1535.5, (1364.01), [2]	9.95, (NA), [1]
no	C6-8 Medium	F	MeFOSAA	-	-	41.03, (6.24), [10]	-	8.91, (1.72), [10]
no	C6-8 Medium	F	PFDA	-	-	43.3, (6.8), [10]	-	3.97, (0.66), [6]
no	C6-8 Medium	F	PFDS	-	-	83.29, (12.82), [10]	-	7.4, (0.74), [10]
no	C6-8 Medium	F	PFHpS	-	226.71, (29.07), [7]	2279, (429.22), [10]	746.2, (50.65), [10]	237.9, (30.19), [10]
no	C6-8 Medium	F	PFHxS	1111.83, (109.53), [6]	10377.14, (1337.93), [7]	39990, (8375.82), [10]	77100, (7780.89), [10]	9358, (1104.09), [10]
no	C6-8 Medium	F	PFNA	-	76.6, (22.34), [2]	53.05, (32.6), [10]	-	4.69, (3.56), [4]
no	C6-8 Medium	F	PFNS	-	-	200.9, (38.91), [10]	-	17.87, (1.53), [10]
no	C6-8 Medium	F	PFOA	-	2894.29, (531.13), [7]	30320, (5947.51), [10]	11209, (1244.6), [10]	2721, (380.45), [10]
no	C6-8 Medium	F	PFOS	3332.86, (363.67), [7]	21128.57, (1795.1), [7]	170700, (21659.23), [10]	35230, (2943.18), [10]	20330, (1658.68), [10]
no	C6-8 Medium	F	PFPeS	-	-	22.77, (11.99), [9]	-	4.82, (1.9), [10]
no	C6-8 Medium	F	8:2 FTS	-	-	36.93, (2.32), [3]	-	-
no	C6-8 Medium	F	EtFOSAA	-	-	-	-	4.67, (1.41), [4]
no	C6-8 Medium	F	PFHxA	-	-	-	-	2.26, (NA), [1]
no	C6-8 Medium	M	6:2 FTS	-	112.78, (16.43), [6]	-	2120, (NA), [1]	7.3, (NA), [1]
no	C6-8 Medium	M	MeFOSAA	-	-	42.85, (3.85), [10]	-	9.85, (1.81), [9]
no	C6-8 Medium	M	PFDA	-	-	47.86, (4.02), [10]	-	5.04, (0.87), [9]
no	C6-8 Medium	M	PFDS	-	-	88.87, (10.79), [10]	-	7.84, (0.9), [9]
no	C6-8 Medium	M	PFHpS	-	181.29, (24.12), [7]	2627, (367.18), [10]	634.1, (68.85), [10]	280.67, (19.99), [9]
no	C6-8 Medium	M	PFHxS	1187.33, (169.24), [3]	9621.43, (834.71), [7]	42510, (4769.92), [10]	69770, (4911.9), [10]	9864.44, (750.34), [9]
no	C6-8 Medium	M	PFNA	-	36.5, (6.51), [2]	27.66, (7.87), [10]	-	4.95, (0.27), [2]
no	C6-8 Medium	M	PFNS	-	21.17, (4.53), [3]	203.5, (30.16), [10]	-	18.78, (0.98), [9]
no	C6-8 Medium	M	PFOA	-	2358.57, (347.92), [7]	37870, (4493.71), [10]	8724, (723.57), [10]	3240, (249.23), [8]
no	C6-8 Medium	M	PFOS	3078.57, (494.15), [7]	15714.29, (1686.64), [7]	183700, (25807.19), [10]	28460, (3581.81), [10]	22333.33, (917.88), [9]
no	C6-8 Medium	M	PFPeS	-	-	70.91, (18.05), [10]	64.47, (10.45), [7]	9.76, (3.4), [9]
no	C6-8 Medium	M	8:2 FTS	-	-	-	-	18.6, (NA), [1]
no	C6-8 Medium	M	PFBA	-	-	-	-	10.5, (NA), [1]
no	C6-8 Medium	M	PFHxA	-	-	-	-	3.11, (0.72), [3]
no	C6-8 High	F	MeFOSAA	-	-	38.85, (7.46), [10]	-	10.83, (2.85), [9]
no	C6-8 High	F	PFDA	-	-	63.86, (9.22), [10]	-	9.06, (1.5), [5]
no	C6-8 High	F	PFDS	-	33.7, (NA), [1]	130.9, (19.74), [10]	-	10.87, (1.47), [10]
no	C6-8 High	F	PFHpS	-	395.43, (27.02), [7]	4719, (611.44), [10]	1205, (100.14), [10]	328.6, (47.67), [10]

no	C6-8 High	F	PFHxS	-	15985.71, (1588.95), [7]	62800, (10967.22), [10]	123300, (8083.59), [10]	13733.33, (3178.57), [3]
no	C6-8 High	F	PFNS	-	46.48, (3.62), [6]	301.7, (41.04), [10]	-	23.56, (3.99), [10]
no	C6-8 High	F	PFOA	-	4414.29, (617.71), [7]	50900, (6655.82), [10]	15240, (1243.83), [10]	7008, (1486.82), [10]
no	C6-8 High	F	PFOS	11957.14, (1713.53), [7]	36071.43, (2631.04), [7]	272000, (37019.51), [10]	59990, (5416.53), [10]	31230, (4387.62), [10]
no	C6-8 High	F	PFPeS	-	-	22.34, (10.05), [8]	-	8.13, (NA), [1]
no	C6-8 High	F	6:2 FTS	-	174.67, (29.74), [3]	49.31, (18.89), [7]	-	106.7, (50.63), [8]
no	C6-8 High	F	EtFOSAA	-	-	-	-	13.82, (4.99), [4]
no	C6-8 High	F	PFBA	-	-	-	-	50.4, (NA), [1]
no	C6-8 High	F	PFHxA	-	-	-	-	23.65, (2.05), [2]
no	C6-8 High	M	6:2 FTS	-	99.32, (18.82), [6]	48.94, (9.68), [5]	1150, (NA), [1]	84.6, (59.4), [4]
no	C6-8 High	M	MeFOSAA	-	-	39.87, (4.61), [9]	-	11.7, (0.99), [10]
no	C6-8 High	M	PFDA	-	-	66.89, (3.71), [9]	-	9.36, (1.37), [8]
no	C6-8 High	M	PFDS	-	22.33, (1.53), [3]	135.56, (16.21), [9]	-	11.62, (1.46), [10]
no	C6-8 High	M	PFHpS	-	346.86, (35.8), [7]	5140, (350.89), [9]	1113.44, (137.15), [9]	431.9, (46.97), [10]
no	C6-8 High	M	PFHxS	-	15257.14, (1208.11), [7]	62244.44, (7257.6), [9]	112166.67, (15972.63), [9]	NA
no	C6-8 High	M	PFNS	-	36.19, (4.14), [7]	319.44, (31.85), [9]	-	26.47, (1.44), [10]
no	C6-8 High	M	PFOA	-	3642.86, (305.76), [7]	59388.89, (7042.98), [9]	13566.67, (1574.8), [9]	8237.78, (983.71), [9]
no	C6-8 High	M	PFOS	11268.57, (5426.3), [7]	30114.29, (2981.29), [7]	297000, (38124.8), [9]	54600, (7520.14), [9]	36750, (2380.13), [10]
no	C6-8 High	M	PFPeS	-	21.9, (NA), [1]	65.94, (23.72), [9]	-	13.42, (3.92), [6]
no	C6-8 High	M	PFHxA	-	-	11.2, (NA), [1]	-	-
no	C6-8 High	M	EtFOSAA	-	-	-	-	13.24, (2.75), [10]
no	FTS Low	F	6:2 FTS	-	430.59, (357.88), [7]	999.28, (1223.22), [10]	334.46, (339.74), [7]	226.29, (99.93), [7]
no	FTS Low	F	8:2 FTS	-	559.43, (97.29), [7]	4028, (568.82), [10]	358.3, (68.57), [10]	347.4, (75.81), [10]
no	FTS Low	F	MeFOSAA	-	-	21.99, (2.37), [10]	-	-
no	FTS Low	F	PFDS	-	-	47.1, (6.64), [10]	-	-
no	FTS Low	F	PFHpS	-	121.1, (16.59), [7]	934.5, (136.99), [10]	648, (81.86), [10]	97.38, (10.66), [10]
no	FTS Low	F	PFHxS	-	347.43, (52.12), [7]	787.5, (90.4), [10]	2683, (296.01), [10]	230.1, (19.91), [10]
no	FTS Low	F	PFNA	-	-	26.88, (4.86), [10]	9.69, (NA), [1]	4.38, (1), [2]
no	FTS Low	F	PFNS	-	20.5, (NA), [1]	108.82, (16.66), [10]	11.74, (1.48), [7]	6.2, (1.03), [10]
no	FTS Low	F	PFOA	-	79.24, (34.67), [7]	139.4, (26.68), [10]	80.59, (12.28), [10]	15.39, (2.28), [10]
no	FTS Low	F	PFOS	3680, (875.6), [7]	12174.29, (1568.64), [7]	88220, (8272.55), [10]	25290, (2978.24), [10]	9119, (1432.32), [10]
no	FTS Low	F	PFPeS	-	-	9.32, (1.17), [10]	15.28, (2.11), [10]	-
no	FTS Low	M	6:2 FTS	-	574.86, (102.86), [7]	4218, (1284.53), [10]	442.7, (148.72), [10]	409, (103.72), [10]
no	FTS Low	M	8:2 FTS	-	215.43, (37.52), [7]	4390, (734.8), [10]	230.4, (51.17), [10]	341.4, (76.72), [10]
no	FTS Low	M	MeFOSAA	-	-	25.27, (3.69), [10]	-	3.78, (NA), [1]
no	FTS Low	M	PFDS	-	-	54.49, (8.86), [10]	-	4.32, (0.26), [2]
no	FTS Low	M	PFHpS	-	102.34, (16.71), [7]	1336.6, (233.37), [10]	540.5, (55.86), [10]	117.6, (16.71), [10]
no	FTS Low	M	PFHxS	-	328.14, (38.24), [7]	909.2, (127.41), [10]	2405, (333.51), [10]	256.8, (20.86), [10]
no	FTS Low	M	PFNA	-	88.5, (49.03), [7]	207.34, (115.07), [10]	13.66, (5.42), [2]	-
no	FTS Low	M	PFNS	-	11.62, (1.26), [4]	128.75, (21.91), [10]	10.37, (0.84), [8]	6.93, (1.78), [10]
no	FTS Low	M	PFOA	-	20, (2.7), [7]	139.4, (20.67), [10]	55.03, (9.64), [10]	18.92, (2.81), [10]
no	FTS Low	M	PFOS	5158.57, (2007.56), [7]	8844.29, (1216.76), [7]	101930, (14500.58), [10]	21730, (2540.8), [10]	10580, (1916.69), [10]
no	FTS Low	M	PFPeS	-	-	24.08, (7.71), [10]	33.88, (10.68), [10]	5.05, (0.79), [7]
no	FTS Medium	F	6:2 FTS	-	861.6, (667.29), [5]	2643.9, (2589.65), [10]	886.86, (608.68), [7]	254.1, (249.4), [10]
no	FTS Medium	F	8:2 FTS	-	1137.43, (218.07), [7]	6853, (841.89), [10]	664.4, (131.19), [10]	555.5, (94.25), [10]
no	FTS Medium	F	PFDS	-	17.33, (1.23), [4]	98.44, (16.44), [10]	-	6.44, (0.83), [10]
no	FTS Medium	F	PFHpS	-	202.57, (18.02), [7]	2328, (386.34), [10]	1133.7, (145.73), [10]	210.2, (25.53), [10]
no	FTS Medium	F	PFHxS	-	604.43, (63.01), [7]	1616, (193.92), [10]	5095, (472.82), [10]	475, (43.82), [10]
no	FTS Medium	F	PFNA	-	-	41.63, (6.91), [10]	-	3.6, (0.7), [10]
no	FTS Medium	F	PFNS	-	24.54, (1.93), [7]	213.3, (32.11), [10]	-	13.73, (1.84), [10]
no	FTS Medium	F	PFOA	-	33.54, (5.3), [7]	197.7, (28.44), [10]	125.68, (16.44), [10]	23.38, (2.84), [10]
no	FTS Medium	F	PFOS	5595.71, (2042.57), [7]	20214.29, (1109.7), [7]	172600, (26746.55), [10]	46950, (4807.69), [10]	16480, (1889.03), [10]
no	FTS Medium	F	PFPeS	-	-	17.83, (5.33), [10]	-	3.87, (1.38), [9]
no	FTS Medium	F	MeFOSAA	-	-	25.04, (2.84), [10]	-	5.06, (0.97), [10]
no	FTS Medium	M	6:2 FTS	-	1050.86, (293.62), [7]	7660, (1632.31), [10]	1063.1, (838.35), [10]	906.3, (176.92), [10]
no	FTS Medium	M	8:2 FTS	-	387.86, (87.92), [7]	6477, (1199.07), [10]	363.9, (91.01), [10]	510.9, (101.02), [10]
no	FTS Medium	M	PFDS	-	12.52, (1.64), [5]	114.01, (11.18), [10]	-	7.77, (0.76), [10]
no	FTS Medium	M	PFHpS	-	174.71, (10.45), [7]	3058, (236.77), [10]	903.3, (119.01), [10]	244, (11.86), [10]
no	FTS Medium	M	PFHxS	122, (NA), [1]	579, (41.45), [7]	1757, (175.06), [10]	4607, (507.06), [10]	497.8, (40.23), [10]
no	FTS Medium	M	PFNA	-	20.95, (2.47), [2]	52.49, (9.89), [10]	-	3.42, (0.67), [10]
no	FTS Medium	M	PFNS	-	18.9, (1.85), [7]	247.4, (22.47), [10]	-	15.27, (1.19), [10]
no	FTS Medium	M	PFOA	-	38.71, (12.65), [7]	284.6, (33.41), [10]	96.31, (15.16), [10]	29.49, (3.64), [10]
no	FTS Medium	M	PFOS	6230, (1624.9), [7]	15300, (519.62), [7]	181300, (9522.49), [10]	37290, (4771.08), [10]	18530, (1076.05), [10]

no	FTS Medium	M	PFPeS	-	9.58, (0.74), [2]	45.54, (8.71), [10]	64.13, (12.17), [10]	8.13, (1.96), [10]
no	FTS Medium	M	MeFOSAA	-	-	27.21, (2.95), [10]	-	5.85, (0.85), [10]
no	FTS High	F	6:2 FTS	-	1261.14, (1040.02), [7]	3791.4, (3682.75), [10]	1116.79, (990.53), [10]	745.44, (683.56), [10]
no	FTS High	F	8:2 FTS	-	1171.14, (309.1), [7]	8971, (1375.21), [10]	1141.1, (386.87), [10]	1127.9, (195.83), [10]
no	FTS High	F	PFDS	-	-	193.8, (24.65), [10]	-	11.04, (1.19), [10]
no	FTS High	F	PFHpS	-	409.29, (58.78), [7]	4664, (590.03), [10]	3392, (1109.85), [10]	359.4, (53.15), [10]
no	FTS High	F	PFHxS	269.8, (172.8), [5]	1240, (165.43), [7]	3003, (316.62), [10]	15980, (4735.63), [10]	976.9, (108.71), [10]
no	FTS High	F	PFNA	-	-	63.48, (4.94), [10]	-	7.76, (0.25), [2]
no	FTS High	F	PFNS	-	47.57, (5.24), [7]	461.5, (58.79), [10]	-	25.08, (2.23), [10]
no	FTS High	F	PFOA	-	55.47, (12.47), [7]	370.2, (36.58), [10]	317.6, (102.91), [10]	60.11, (14.9), [10]
no	FTS High	F	PFOS	14272.86, (7908.47), [7]	38671.43, (4841.73), [7]	317500, (25979.69), [10]	124244.44, (32586.73), [9]	33020, (3347.9), [10]
no	FTS High	F	PFPeS	-	-	32.52, (12.4), [10]	-	8.59, (1.32), [6]
no	FTS High	M	6:2 FTS	-	1708.57, (413.46), [7]	12663, (2628.54), [10]	2287.7, (851.71), [10]	1473, (254.74), [10]
no	FTS High	M	8:2 FTS	-	448.86, (55), [7]	8701, (1656.38), [10]	661.3, (201.01), [10]	872.2, (121.23), [10]
no	FTS High	M	PFDS	-	21.45, (2.12), [4]	216.3, (20.33), [10]	-	11.43, (1.62), [10]
no	FTS High	M	PFHpS	-	339.71, (50), [7]	5553, (416.36), [10]	2714, (963.39), [10]	422.3, (54.56), [10]
no	FTS High	M	PFHxS	310, (107.15), [6]	1187.43, (172.26), [7]	3275, (232.77), [10]	13799, (4572.04), [10]	1014.1, (132.16), [10]
no	FTS High	M	PFNA	-	23.6, (NA), [1]	72.59, (6.76), [10]	-	8.84, (2.99), [4]
no	FTS High	M	PFNS	-	33, (3.61), [7]	510.9, (45.46), [10]	-	25.71, (3.08), [10]
no	FTS High	M	PFOA	-	57.34, (14.8), [7]	490.3, (49.01), [10]	252.1, (86.35), [10]	59.35, (4.91), [10]
no	FTS High	M	PFOS	10934.29, (2577.14), [7]	28571.43, (3162.13), [7]	322900, (39042.57), [10]	101090, (31366.88), [10]	34690, (3770.48), [10]
no	FTS High	M	PFPeS	-	22.9, (NA), [1]	88.4, (22.1), [10]	250.6, (94.63), [5]	17.62, (7.27), [10]
no	Control	F	8:2 FTS	-	3.71, (0.93), [2]	5.9, (1.25), [7]	-	0.46, (NA), [1]
no	Control	F	PFBA	-	-	3.05, (1.57), [7]	-	2.14, (0.98), [9]
no	Control	F	PFBS	-	-	-	2.13, (0.86), [8]	-
no	Control	F	PFDA	-	-	0.73, (0.09), [7]	1.27, (0.4), [4]	-
no	Control	F	PFDoA	-	-	0.25, (0.06), [7]	2.57, (1.36), [10]	-
no	Control	F	PFHxA	3.37, (NA), [1]	-	-	-	-
no	Control	F	PFHxS	-	15.64, (9.46), [7]	12.56, (4.81), [7]	13.6, (1.32), [10]	0.47, (0.13), [10]
no	Control	F	PFNA	54.83, (77.97), [7]	340.41, (436.57), [7]	221.06, (268.71), [7]	4.1, (2.72), [8]	0.21, (0.04), [9]
no	Control	F	PFOA	-	11.25, (3.94), [7]	6.74, (1.76), [7]	2.95, (0.93), [9]	0.76, (1.04), [7]
no	Control	F	PFOS	6.15, (1.16), [7]	26.26, (10.95), [7]	94.06, (13.19), [7]	9.41, (1.99), [10]	1.05, (0.47), [10]
no	Control	F	6:2 FTS	-	3.18, (0.2), [6]	2.46, (1.34), [7]	-	3.39, (2.38), [9]
no	Control	F	N-EtFOSE	-	16.82, (5.12), [7]	10.88, (2.56), [7]	-	14.43, (4.89), [9]
no	Control	M	8:2 FTS	-	2.29, (0.64), [4]	4.1, (1), [7]	-	-
no	Control	M	PFBA	-	-	2.76, (3.17), [7]	-	2.35, (0.46), [9]
no	Control	M	PFBS	-	-	-	2.26, (0.95), [10]	-
no	Control	M	PFDA	-	-	1.12, (0.1), [7]	1.09, (0.17), [3]	-
no	Control	M	PFDoA	-	-	0.29, (0.05), [7]	1.71, (0.54), [10]	-
no	Control	M	PFHxA	-	-	0.3, (NA), [1]	7.87, (NA), [1]	0.61, (NA), [1]
no	Control	M	PFHxS	6.53, (5.78), [3]	7.03, (1.51), [7]	14.88, (10.56), [7]	12.24, (10.77), [10]	0.44, (0.21), [10]
no	Control	M	PFNA	28.73, (40.95), [7]	49.33, (38.86), [7]	48.86, (18.77), [7]	2.95, (1.27), [2]	-
no	Control	M	PFOA	9.07, (NA), [1]	3.05, (1.01), [7]	8.85, (8.4), [7]	1.93, (1.49), [7]	1.06, (1.49), [7]
no	Control	M	PFOS	17.55, (18.31), [7]	42.04, (14.63), [7]	122.84, (37.14), [7]	8.01, (2.09), [5]	1.08, (1.3), [10]
no	Control	M	PFPeS	-	-	-	1.13, (NA), [1]	0.17, (NA), [1]
no	Control	M	6:2 FTS	NA	6.63, (3.7), [7]	6.48, (2.55), [7]	-	9.24, (5.45), [8]
no	Control	M	N-EtFOSE	NA	7.87, (2.19), [7]	9.23, (1.02), [7]	-	14.06, (3.36), [8]
no	Control	M	N-MeFOSE	-	-	-	-	1.26, (NA), [1]
no	Control	M	PFMBA	-	-	-	-	0.14, (NA), [1]
yes	PFOS	F	PFOS	8171.43, (930.24), [7]	35114.29, (4095.7), [7]	284428.57, (41688.76), [7]	59020, (7789.57), [10]	27620, (2515.64), [10]
yes	PFOS	M	PFOS	7915.71, (1235.65), [7]	25657.14, (626.78), [7]	324000, (41880.78), [7]	49888.89, (5294.44), [9]	31230, (1273.71), [10]
yes	PFOA	F	PFOA	2430, (325.27), [2]	21814.29, (1643.6), [7]	186428.57, (45558.96), [7]	76590, (12053.63), [10]	21440, (2011.19), [10]
yes	PFOA	M	PFOA	2960, (NA), [1]	20485.71, (2595.78), [7]	217285.71, (16337.22), [7]	92390, (13657.59), [10]	27066.67, (1650.76), [9]
yes	PFHxS	F	PFHxS	2417.14, (192.59), [7]	23800, (2095.23), [7]	120714.29, (13524.23), [7]	128800, (8941.79), [10]	22266.67, (8022.31), [9]
yes	PFHxS	M	PFHxS	2321.43, (458.53), [7]	21671.43, (1964.45), [7]	136571.43, (14987.3), [7]	112900, (9848.29), [10]	22900, (3047.25), [8]
yes	PFHxA	F	PFHxA	-	10.98, (9.84), [7]	8.49, (7.58), [7]	28.13, (27.91), [9]	7.96, (5.53), [10]
yes	PFHxA	M	PFHxA	-	9.78, (9.39), [7]	10.91, (8.56), [7]	38.15, (35.78), [9]	11.62, (5.25), [10]
yes	PFBS	F	PFBS	-	-	-	186.16, (186.08), [10]	41.07, (24.83), [10]
yes	PFBS	M	PFBS	-	-	-	1477.4, (550.54), [10]	256, (97.18), [10]
yes	PFNA	F	PFNA	-	-	-	142600, (18361.8), [10]	17630, (855.12), [10]
yes	PFNA	M	PFNA	-	-	-	116180, (19203.06), [10]	17230, (1002.28), [10]
yes	6:2 FTS	F	6:2 FTS	-	6929.29, (8351.46), [7]	14524.57, (19267.52), [7]	3808.6, (3477.95), [10]	1051.36, (1169.57), [10]
yes	6:2 FTS	M	6:2 FTS	-	21914.29, (5381.27), [7]	80942.86, (10544.17), [7]	11805, (4106.43), [10]	8753, (3386.4), [10]
yes	8:2 FTS	F	8:2 FTS	6055, (2184.96), [2]	39400, (5462.91), [7]	100171.43, (5765.62), [7]	18837, (8326.82), [10]	18655.56, (6452.15), [9]
yes	8:2 FTS	M	8:2 FTS	1910.83, (837.5), [6]	12672.86, (2851.65), [7]	102528.57, (5917.97), [7]	8512, (4000.59), [10]	17059.09, (6711.44), [11]

Table SI3.18. Clinical chemistry summarized data by sex and treatment. Data are mean, (standard deviation), [sample size]. Note incomplete suite of treatments. "-" is not analyzed, "NA" indicates insufficient sample size to calculate standard deviation. * indicates p-value < 0.05 in ANOVA test of contrast against control treatment by sex and endpoint.

Treatment	Sex	ALB	ALB_div_GLOB	ALT	AST	BUN	BUN_div_CREA
C68HIGH	Female	3.4, (0.21), [9]	1.59, (0.12), [9]	172, (79.86), [10]	213.8, (56.65), [10]	22, (2.71), [10]	200, (28.28), [2]
C68HIGH	Male	3.24, (0.21), [9]	1.44, (0.13), [9]*	97.56, (36.09), [9]	158.56, (46.35), [9]	45.89, (28.7), [9]	209.7, (88.31), [5]
C68LOW	Female	3.39, (0.25), [8]	1.62, (0.2), [8]	38.4, (9.83), [10]	153.5, (24.47), [10]	35.4, (34.62), [10]	155.9, (80.45), [5]
C68LOW	Male	3.3, (0.21), [10]	1.38, (0.09), [10]	55.9, (13.16), [10]	157.4, (29.36), [10]	30.2, (16.89), [10]	229.17, (72.28), [4]
C68MED	Female	3.27, (0.2), [7]	1.53, (0.21), [7]	54.6, (11.74), [10]	168.9, (20.11), [10]	20.56, (6.97), [9]	174, (25.1), [5]
C68MED	Male	3.21, (0.18), [8]	1.51, (0.11), [8]*	64.3, (14.31), [10]	146.5, (38.07), [10]	32.6, (16.65), [10]	181.66, (82.5), [2]
Control	Female	3.37, (0.2), [9]	1.44, (0.13), [9]	29.5, (5.38), [10]	148, (34.05), [10]	37.89, (41.43), [9]	141.67, (42.47), [6]
Control	Male	3.11, (0.23), [9]	1.26, (0.07), [9]	48.33, (19.47), [9]	121.56, (16.44), [9]	37.78, (27.28), [9]	166.2, (96.37), [5]
PFBS	Female	3.44, (0.21), [10]	1.54, (0.2), [10]	17.2, (3.29), [10]	150.2, (22.1), [10]	17.1, (2.6), [10]	125, (55.08), [4]
PFBS	Male	3.06, (0.18), [10]	1.27, (0.16), [10]	24.5, (9.71), [10]	140.6, (17.98), [10]	24.8, (7.25), [10]	280, (NA), [1]
PFHxA	Female	3.41, (0.09), [9]	1.67, (0.21), [9]*	16, (3), [9]	144.56, (27.43), [9]	16.67, (2.87), [9]	-
PFHxA	Male	3.08, (0.16), [10]	1.31, (0.18), [10]	25.2, (7.35), [10]	145.1, (32.95), [10]	24.2, (4.02), [10]	-
PFHxS	Female	3.57, (0.26), [10]*	1.64, (0.14), [10]*	24.9, (5.43), [10]	183, (50.21), [10]	20.6, (4.6), [10]	235, (54.47), [4]*
PFHxS	Male	3.39, (0.26), [10]*	1.48, (0.17), [10]*	31.7, (9.68), [10]	148.6, (24.72), [10]	26.8, (3.26), [10]	305, (7.07), [2]
PFNA	Female	3.88, (0.21), [10]*	1.8, (0.18), [10]*	132.9, (125.25), [10]*	312, (202.31), [10]*	31.5, (8.42), [10]	121.43, (68.69), [2]
PFNA	Male	3.77, (0.34), [10]*	1.63, (0.19), [10]*	101.7, (62.16), [10]	284.8, (212.53), [10]*	35.4, (21.25), [10]	233.75, (65.75), [4]*
PFOA	Female	3.55, (0.21), [10]	1.7, (0.26), [10]*	149.8, (56.53), [10]*	275, (83.27), [10]*	26.4, (10.89), [10]	114, (NA), [1]
PFOA	Male	3.68, (0.24), [10]*	1.63, (0.22), [10]*	190.2, (143.1), [10]*	280.1, (148.12), [10]*	35.9, (16.29), [10]	379.44, (228.11), [3]
PFOS	Female	3.37, (0.15), [6]	1.54, (0.15), [6]	41.9, (7.52), [10]	144.7, (23.21), [10]	47.5, (82.25), [8]	156.64, (46.48), [4]
PFOS	Male	3.29, (0.24), [9]	1.46, (0.15), [9]*	111, (139.06), [9]	154.22, (59.41), [9]	37, (28.72), [9]	185.07, (60.57), [5]

ALB=Albumin (g/dL); ALB_div_GLOB=Albumin (g/dL) / Globulin (g/dL); ALT= Alanine aminotransferase (units/L); AST=aspartate aminotransferase (units/L); BUN=blood urea nitrogen (mg/dL); BUN_div_CREA=blood urea nitrogen (mg/dL) / creatinine (mg/dL).

Table SI3.19. Continued clinical chemistry summarized data by sex and treatment. Data are mean, (standard deviation), [sample size]. Note incomplete suite of treatments.

Treatment	Sex	CHOL	CREA	GLOB calc.	GLU	TP	TRIG
C68HIGH	Female	158.3, (44.75), [10]	0.1, (0), [10]	2.14, (0.17), [9]	163.6, (17.77), [10]	5.54, (0.3), [10]	113.4, (39), [10]*
C68HIGH	Male	167.44, (51.41), [9]	0.27, (0.3), [9]	2.27, (0.22), [9]	140.56, (23.62), [9]	5.51, (0.36), [9]	164.22, (26.77), [9]
C68LOW	Female	140.33, (19.75), [9]	0.35, (0.53), [10]	2.11, (0.26), [8]*	162.8, (22.11), [10]	5.52, (0.37), [10]	115.6, (32.51), [10]*
C68LOW	Male	191, (36.48), [10]	0.15, (0.16), [10]	2.39, (0.19), [10]	169.8, (26.02), [10]	5.69, (0.36), [10]	157.4, (54.77), [10]
C68MED	Female	136.38, (34.9), [8]	0.12, (0.06), [10]	2.17, (0.24), [7]	156.6, (12.4), [10]	5.47, (0.24), [10]	108.9, (37.88), [10]
C68MED	Male	162.38, (24.67), [8]	0.16, (0.16), [10]	2.14, (0.24), [8]*	178.4, (16.79), [10]	5.39, (0.39), [10]	166.6, (45.4), [10]
Control	Female	140, (28.22), [10]	0.41, (0.5), [10]	2.34, (0.16), [9]	154.2, (14.62), [10]	5.72, (0.24), [10]	150.1, (33.69), [10]
Control	Male	187.89, (44.76), [9]	0.3, (0.37), [9]	2.47, (0.17), [9]	167.11, (21.97), [9]	5.58, (0.36), [9]	162.33, (52.12), [9]
PFBS	Female	147.8, (23.96), [10]	0.12, (0.04), [10]	2.25, (0.22), [10]	171.5, (15.11), [10]	5.69, (0.26), [10]	140.7, (40.82), [10]
PFBS	Male	227, (42.06), [10]	0.1, (0), [10]*	2.43, (0.21), [10]	167.2, (30.15), [10]	5.49, (0.15), [10]	187.8, (71.58), [10]
PFHxA	Female	133.11, (28.36), [9]	0.1, (0), [9]	2.08, (0.32), [9]*	159, (12.69), [9]	5.49, (0.39), [9]	160.78, (58.67), [9]
PFHxA	Male	217.7, (52.73), [10]	0.1, (0), [10]*	2.39, (0.31), [10]	183.5, (41.11), [10]	5.47, (0.39), [10]	186, (57.54), [10]
PFHxS	Female	161.5, (25.05), [10]	0.19, (0.28), [10]	2.19, (0.21), [10]	160.1, (19.92), [10]	5.76, (0.41), [10]	151.2, (42.62), [10]
PFHxS	Male	183.5, (55.71), [10]	0.1, (0), [10]*	2.31, (0.32), [10]	166.8, (40.53), [10]	5.7, (0.52), [10]	172.5, (45.15), [10]
PFNA	Female	184.1, (37.63), [10]*	0.17, (0.19), [10]	2.17, (0.25), [10]	131.6, (44.75), [10]*	6.05, (0.41), [10]	135.6, (46.41), [10]
PFNA	Male	192.5, (27.06), [10]	0.25, (0.31), [10]	2.33, (0.28), [10]	130.8, (31.65), [10]*	6.1, (0.52), [10]*	172.1, (63.66), [10]
PFOA	Female	147.6, (42.38), [10]	0.14, (0.13), [10]	2.15, (0.31), [10]	149.3, (29.22), [10]	5.7, (0.29), [10]*	147.1, (40.19), [10]
PFOA	Male	192.1, (46.73), [10]	0.15, (0.16), [10]	2.28, (0.23), [10]	133.3, (23.16), [10]*	5.96, (0.33), [10]*	170.5, (51.35), [10]
PFOS	Female	160.43, (50.64), [7]	0.36, (0.79), [10]	2.2, (0.18), [6]	171, (23.23), [9]	5.57, (0.18), [10]	118.7, (21.26), [10]
PFOS	Male	149.56, (37.39), [9]	0.23, (0.28), [9]	2.27, (0.25), [9]	184, (20.63), [9]	5.56, (0.38), [9]	133.33, (56.82), [9]

CHOL=cholesterol (mg/dL); CREA=creatinine (mg/dL); GLOB calc=globulin (calculated) (g/dL); GLU=glucose (mg/dL); TP=total protein (g/dL); TRIG=triglycerides (g/dL).

Table SI3.20. Body weight mean, (standard deviation), and [sample size] in grams by study, treatment, sex, and time. * indicates significant (p-value < 0.05) ANCOVA comparison against control of treatment-wise body weight over time interaction.

Study	Treatment	Sex	SD0	SD7	SD14	SD21	SD28
Serum	6:2 FTS	F	28.27, (2.73), [10]	28.5, (3.16), [10]	29.02, (2.63), [10]	29.67, (3.51), [10]	30.09, (3.75), [10]
Serum	6:2 FTS	M	34.31, (2.64), [10]	34.41, (2.7), [10]	34.69, (2.93), [10]	35.42, (3.23), [10]	36.21, (3.21), [10]
Serum	8:2 FTS	F	29.36, (2.76), [10]	28.9, (2.8), [10]	29.31, (2.67), [10]	30.65, (3.32), [10]	30.26, (3.2), [10]
Serum	8:2 FTS	M	35.09, (2.36), [10]	34.72, (2.31), [10]	35.24, (2.22), [10]	35.66, (2.25), [10]	36.06, (2.33), [10]
Serum	C6-8 High	F	27.97, (3.08), [10]	27.52, (2.44), [10]	28.29, (3.09), [10]	29.8, (2.98), [10]	29.7, (2.4), [10]
Serum	C6-8 High	M	33.41, (2.82), [10]	34.18, (1.97), [9]	34.63, (2.38), [9]	35.56, (2.6), [9]	36.4, (2.7), [9]
Serum	C6-8 Low	F	27.59, (3.56), [10]	26.87, (2.95), [10]	27.46, (3.04), [10]	28.69, (3.81), [10]	28.88, (3.2), [10]
Serum	C6-8 Low	M	34.19, (2.44), [10]	33.86, (2.24), [10]	34.13, (2.1), [10]	34.68, (2.08), [10]	35.22, (2.13), [10]
Serum	C6-8 Medium	F	28.59, (2.14), [10]	29.22, (2.48), [10]	29.74, (2.25), [10]	31.48, (3.74), [10]	31.73, (3.52), [10]
Serum	C6-8 Medium	M	34.74, (2.61), [10]	34.91, (2.15), [10]	34.85, (2.77), [10]	35.58, (2.66), [10]	36.3, (2.92), [10]
Serum	Control	F	28.96, (2.18), [10]	29.16, (2.44), [10]	29.48, (3.25), [10]	29.82, (3.18), [10]	30.27, (2.72), [10]
Serum	Control	M	34.63, (1.99), [10]	34.67, (2.04), [10]	34.87, (1.9), [10]	35.46, (2.04), [10]	35.76, (1.84), [10]
Serum	FTS High	F	28.34, (1.83), [10]	28.19, (1.53), [10]	28.89, (2.27), [10]	30.09, (2.09), [10]	30.78, (2.81), [10]
Serum	FTS High	M	34.7, (2.18), [10]	34.75, (2.01), [10]	34.72, (2.41), [10]	35.04, (1.96), [10]	35.52, (2.5), [10]
Serum	FTS Low	F	28.44, (3), [10]	28.27, (3.17), [10]	28.68, (2.81), [10]	29.68, (2.37), [10]	30.34, (2.8), [10]
Serum	FTS Low	M	34.75, (2.5), [10]	34.59, (2.76), [10]	35.04, (2.85), [10]	35.66, (2.86), [10]	36.05, (2.4), [10]
Serum	FTS Medium	F	29.66, (4.05), [10]	28.8, (3.07), [10]	30.05, (3.72), [10]	31.22, (3.51), [10]	31.32, (3.46), [10]
Serum	FTS Medium	M	34.91, (2.53), [10]	34.9, (2.56), [10]	34.76, (2.74), [10]	35.58, (3), [10]	36.09, (2.77), [10]
Serum	PFBS	F	28.57, (2.97), [10]	28.77, (2.77), [10]	29.6, (3.72), [10]	30.95, (3.27), [10]	30.5, (2.96), [10]
Serum	PFBS	M	35.1, (2.09), [10]	34.79, (2.24), [10]	34.9, (2.36), [10]	35.28, (2.16), [10]	35.78, (2.56), [10]
Serum	PFHxA	F	28.43, (3.07), [10]	28.32, (3.73), [9]	29.48, (3.05), [9]	31.09, (3.08), [9]	31, (2.99), [9]
Serum	PFHxA	M	34.87, (2.11), [10]	34.7, (2.11), [10]	34.68, (2.11), [10]	35.44, (2.13), [10]	35.95, (2.08), [10]
Serum	PFHxS	F	28.56, (2.16), [10]	28.77, (3.3), [10]	28.86, (2.37), [10]	30.92, (3.75), [10]	31.22, (2.68), [10]
Serum	PFHxS	M	33.72, (4.48), [10]	34.72, (2.7), [10]	35.24, (3.04), [10]	35.9, (3.11), [10]	36.41, (3.5), [10]
Serum	PFNA	F	28.49, (1.88), [10]	28.57, (2.34), [10]	30.41, (2.43), [10]	30.24, (2.83), [10]	28.06, (2.81), [10]
Serum	PFNA	M	34.24, (2.63), [10]	34.69, (2.59), [10]	35.22, (3.04), [10]	35.28, (2.65), [10]	34.05, (2.41), [10]
Serum	PFOA	F	28.82, (2.13), [10]	30.16, (2.48), [10]	32.41, (3.11), [10]	32.66, (3.08), [10]	32.43, (1.98), [10]
Serum	PFOA	M	34.73, (2.86), [10]	35.6, (2.79), [10]	36.3, (2.57), [10]	37.03, (2.26), [10]	37.16, (2.29), [10]
Serum	PFOS	F	29.41, (2.92), [10]	30.22, (2.37), [10]	31.24, (2.96), [10]	31.72, (3.55), [10]	33.15, (2.91), [10]
Serum	PFOS	M	35.18, (2.6), [10]	35.46, (2.9), [10]	35.23, (2.86), [10]	36.4, (3.24), [9]	37.31, (3.68), [9]
Whole Body	6:2 FTS	F	27.91, (2.39), [10]	28.43, (2.7), [10]	30.13, (2.92), [10]	28.01, (5.07), [10]	31.65, (3.37), [10]
Whole Body	6:2 FTS	M	34.21, (2.54), [10]	34.52, (2.93), [10]	35.36, (3.21), [10]	36.7, (2.86), [10]	37.31, (3.12), [10]
Whole Body	8:2 FTS	F	28.54, (3.25), [10]	30.39, (2.49), [10]	30.31, (3.3), [10]	31.53, (3.57), [10]	33.62, (3.85), [10]
Whole Body	8:2 FTS	M	35.06, (2.85), [10]	35.39, (2.57), [10]	36.08, (2.99), [10]	37.09, (3.25), [10]	37.83, (3.61), [10]
Whole Body	C6-8 High	F	28.19, (2.46), [10]	28.78, (2.75), [10]	30.65, (2.06), [10]	31.9, (3.37), [10]	32.97, (3.04), [10]
Whole Body	C6-8 High	M	34.24, (3.4), [10]	35.13, (3.02), [10]	36.34, (2.93), [10]	37.7, (2.79), [10]	38.59, (2.49), [10]
Whole Body	C6-8 Low	F	27.39, (2.22), [10]	27.9, (1.76), [10]	29.53, (2.2), [10]	30.81, (2.54), [10]	32.79, (2.24), [10]
Whole Body	C6-8 Low	M	33.98, (2.84), [10]	34.68, (2.26), [10]	35.67, (2.55), [10]	36.85, (2.21), [10]	37.52, (2.72), [10]
Whole Body	C6-8 Medium	F	28.22, (2.17), [10]	29.02, (2.42), [10]	30.82, (3.13), [10]	32.66, (2.9), [10]	33.66, (2.37), [10]
Whole Body	C6-8 Medium	M	34.98, (2.87), [10]	36.19, (3), [9]	36.94, (3.29), [9]	37.63, (2.64), [9]	38.49, (2.65), [9]
Whole Body	Control	F	28.32, (2.03), [10]	29.61, (1.63), [10]	29.67, (1.79), [10]	31.05, (1.57), [10]	32.01, (1.76), [10]
Whole Body	Control	M	34.6, (2.41), [10]	35.46, (3.02), [10]	35.93, (3.08), [10]	36.73, (3.15), [10]	38.11, (3.15), [10]
Whole Body	FTS High	F	28.55, (2.11), [10]	29.56, (2.35), [10]	29.67, (2.12), [10]	32.42, (2.94), [10]	33.03, (3.08), [10]
Whole Body	FTS High	M	34.66, (2.59), [10]	35.77, (2.5), [10]	36.58, (2.74), [10]	37.78, (2.16), [10]	38.49, (2.45), [10]
Whole Body	FTS Low	F	27.72, (2.42), [10]	28.55, (2.43), [10]	29.34, (1.81), [10]	31.06, (2.84), [10]	32.06, (2.9), [10]
Whole Body	FTS Low	M	34.26, (2.64), [10]	35.34, (2.37), [10]	35.99, (2.44), [10]	36.91, (2.42), [10]	37.46, (2.47), [10]
Whole Body	FTS Medium	F	28.76, (2.91), [10]	29.08, (2.66), [10]	30.14, (3.72), [10]	32.07, (3.65), [10]	32.66, (2.56), [10]
Whole Body	FTS Medium	M	34.43, (2.64), [10]	35.29, (3.32), [10]	36.08, (3.29), [10]	36.83, (3.15), [10]	37.6, (3.47), [10]
Whole Body	PFBS	F	28.74, (2.05), [10]	29.95, (1.96), [10]	30.23, (1.59), [10]	30.75, (1.72), [10]	32.19, (1.87), [10]
Whole Body	PFBS	M	35.18, (2.79), [10]	35.62, (3), [10]	36.31, (3.05), [10]	37.29, (2.81), [10]	37.86, (2.97), [10]
Whole Body	PFHxA	F	27.73, (2.38), [10]	28.69, (2.44), [10]	29.36, (2.71), [10]	30.37, (2.32), [10]	31.46, (2.56), [10]
Whole Body	PFHxA	M	34.88, (2.6), [10]	36.1, (2.63), [10]	36.78, (2.67), [10]	37.52, (2.84), [10]	38.51, (3.11), [10]
Whole Body	PFHxS	F	27.76, (1.48), [10]	29.82, (1.96), [10]	29.93, (1.48), [10]	31.14, (1.76), [10]	33.03, (2.59), [10]
Whole Body	PFHxS	M	34.4, (3.15), [10]	35.46, (3.11), [10]	35.9, (3.02), [10]	36.48, (2.81), [10]	37.62, (2.97), [10]
Whole Body	PFNA	F*	28.71, (1.46), [10]	30.03, (1.45), [10]	32.11, (2.06), [10]	30.87, (1.95), [10]	28.16, (3.61), [10]
Whole Body	PFNA	M*	34.64, (2.52), [10]	36.21, (2.92), [10]	37.17, (2.98), [10]	36.58, (3.77), [10]	34.29, (5.17), [10]
Whole Body	PFOA	F	29.26, (2.16), [10]	29.49, (2.06), [10]	30.97, (1.78), [10]	33.02, (2.71), [10]	32.63, (2.16), [10]
Whole Body	PFOA	M	35.23, (2.5), [9]	36.81, (2.75), [9]	38.46, (2.98), [9]	39.63, (3.17), [9]	39.99, (3.13), [9]
Whole Body	PFOS	F	29.25, (0.72), [10]	29.7, (1.63), [10]	31.48, (1.35), [10]	33.6, (2.25), [10]	34.09, (2.46), [10]
Whole Body	PFOS	M	35.25, (3.64), [10]	35.92, (3.28), [10]	37.06, (3.33), [10]	38.14, (3.47), [10]	38.97, (3.25), [10]

Table SI3.21. Mean, (standard deviation), and [sample size] for organ weights by treatment and sex. These animals are from serum study. * indicate significant difference from control (ANOVA with each treatment contrasted against control by sex). Note that comparison to PFOS treatment was the comparison of interest for the test of additivity rejection.

Treatment	Sex	Brain	Kidney	Liver
6:2 FTS	F	0.52, (0.03), [10]	0.35, (0.04), [10]	1.45, (0.27), [10]
6:2 FTS	M	0.54, (0.02), [10]	0.58, (0.1), [10]	2.43, (0.31), [10]*
8:2 FTS	F	0.51, (0.03), [10]	0.34, (0.05), [10]	1.74, (0.29), [10]*
8:2 FTS	M	0.52, (0.01), [10]	0.55, (0.07), [10]	2.2, (0.26), [10]*
C6-8 High	F	0.52, (0.03), [10]	0.34, (0.03), [10]	2.87, (0.24), [10]*
C6-8 High	M	0.52, (0.02), [9]	0.58, (0.07), [9]	3.72, (0.35), [9]*
C6-8 Low	F	0.53, (0.03), [10]	0.34, (0.04), [10]	1.71, (0.22), [10]*
C6-8 Low	M	0.52, (0.02), [10]	0.57, (0.06), [10]	2.47, (0.24), [10]*
C6-8 Medium	F	0.52, (0.01), [10]	0.36, (0.04), [10]	2.39, (0.38), [10]*
C6-8 Medium	M	0.53, (0.02), [10]	0.57, (0.06), [10]	3.05, (0.33), [10]*
Control	F	0.51, (0.02), [10]	0.33, (0.03), [10]	1.39, (0.21), [10]
Control	M	0.52, (0.02), [10]	0.56, (0.07), [10]	1.83, (0.14), [10]
FTS High	F	0.54, (0.02), [10]*	0.35, (0.03), [10]	2.27, (0.35), [10]*
FTS High	M	0.54, (0.02), [10]*	0.55, (0.05), [10]	3.03, (0.34), [10]*
FTS Low	F	0.52, (0.02), [10]	0.35, (0.03), [10]	1.63, (0.24), [10]
FTS Low	M	0.53, (0.03), [10]	0.58, (0.08), [10]	2.16, (0.28), [10]*
FTS Medium	F	0.53, (0.03), [10]	0.34, (0.06), [10]	1.98, (0.4), [10]*
FTS Medium	M	0.52, (0.03), [10]	0.55, (0.07), [10]	2.53, (0.27), [10]*
PFBS	F	0.53, (0.03), [10]	0.35, (0.05), [10]	1.35, (0.2), [10]
PFBS	M	0.53, (0.02), [10]	0.59, (0.05), [10]	1.88, (0.22), [10]
PFHxA	F	0.52, (0.04), [9]	0.36, (0.04), [9]	1.53, (0.21), [9]
PFHxA	M	0.52, (0.03), [10]	0.6, (0.09), [10]	1.88, (0.17), [10]
PFHxS	F	0.52, (0.03), [10]	0.35, (0.04), [10]	2.21, (0.28), [10]*
PFHxS	M	0.52, (0.03), [10]	0.58, (0.09), [10]	2.82, (0.4), [10]*
PFNA	F	0.52, (0.04), [10]	0.36, (0.04), [10]	3.62, (0.54), [10]*
PFNA	M	0.52, (0.02), [10]	0.54, (0.08), [10]	4.92, (0.5), [10]*
PFOA	F	0.52, (0.03), [10]	0.39, (0.03), [10]*	3.37, (0.47), [10]*
PFOA	M	0.51, (0.03), [10]	0.59, (0.06), [10]	4.86, (0.36), [10]*
PFOS	F	0.54, (0.01), [10]*	0.37, (0.04), [10]*	2.46, (0.3), [10]*
PFOS	M	0.53, (0.03), [9]	0.58, (0.06), [9]	2.98, (0.43), [9]*

Chapter 4: Supplementary Information

Table SI4.1. PFAS with earthworm BAF ≥ 2 and selected for toad study. See Kuperman et al. (2025) for more details.

		CAS Number
Perfluoroalkyl carboxylic acids		
Perfluoroheptanoic acid	PFHpA	375-85-9
Perfluorooctanoic acid	PFOA	335-67-1
Perfluorononanoic acid	PFNA	375-95-1
Perfluorodecanoic acid	PFDA	335-76-2
Perfluoroundecanoic acid	PFUnA	2058-94-8
Perfluorotridecanoic acid	PFTrDA	7269-94-8
Perfluorotetradecanoic acid	PFTeDA	376-06-7
Perfluoroalkane sulfonic acids		
Perfluorobutanesulfonic acid	PFBS	375-73-5
Perfluorohexanesulfonic acid	PFHxS	355-46-4
Perfluoroheptanesulfonic acid	PFHpS	357-92-8
Perfluorooctanesulfonic acid	PFOS	1763-23-1
Fluorotelomer sulfate and perfluoroalkane sulfonamido		
Perfluorooctanesulfonamide	PFOSA	754-91-6
8:2 Fluorotelomer sulfonate	8:2 FTS	39108-34-4

Predict dosing volume based on weight per worm and weight of homogenate

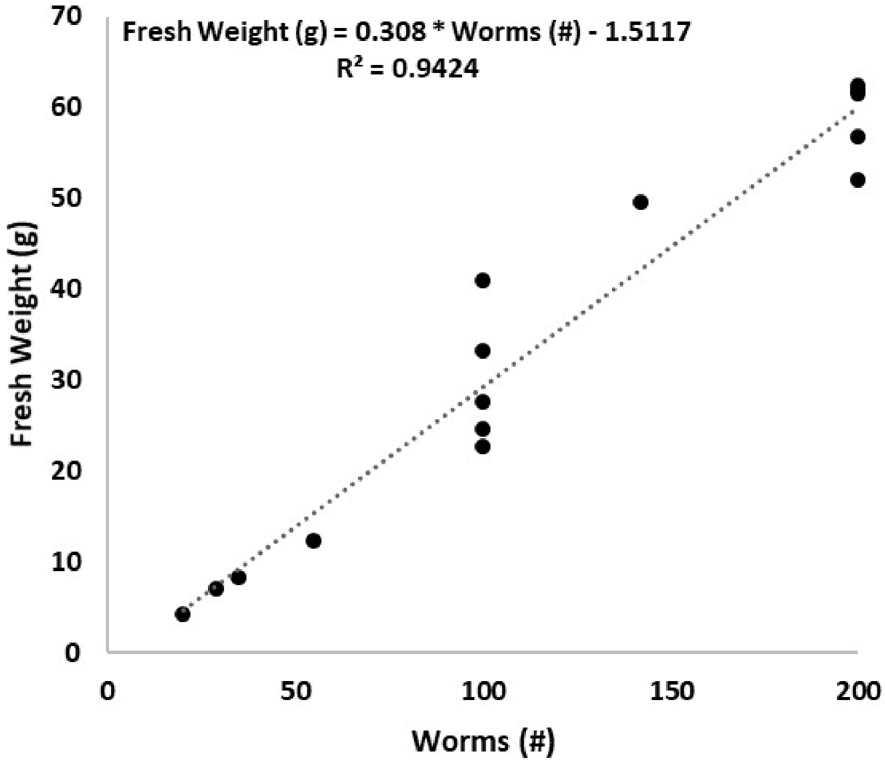


Figure SI4.1. Weight of fresh worms (g) and number of worms in sample. The observation of note is that the average per worm weight is 0.3 grams.

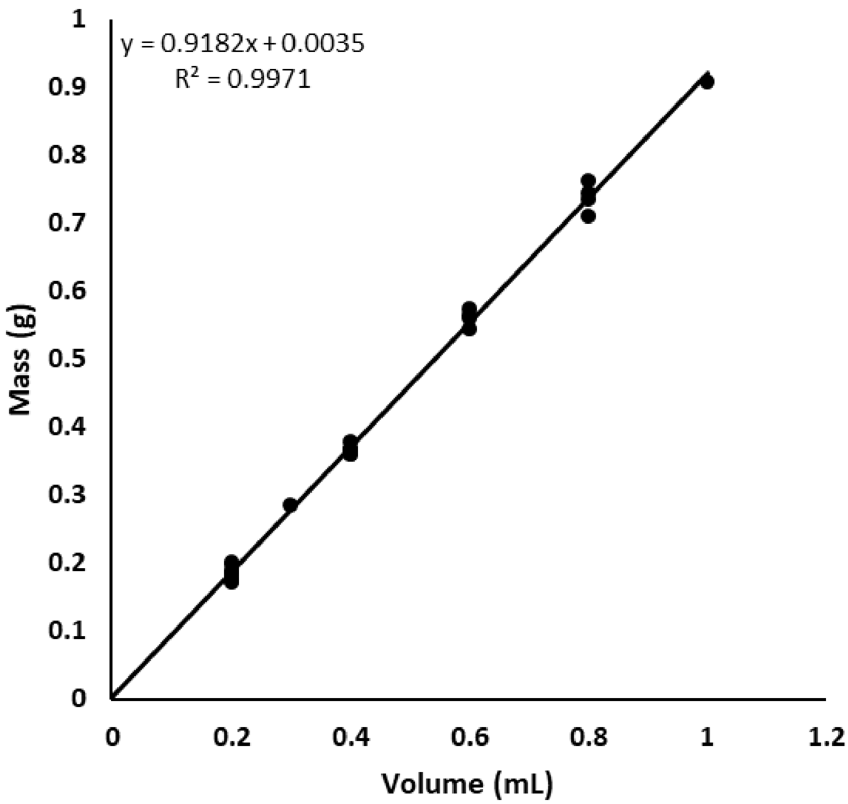


Figure SI4.2. Mass (g) of worm homogenate per volume (mL) of worm homogenate. The observation of note here is that 0.92 g/mL is the density of the worm homogenate.

Delivery of a dose of "one worm" would require a dose volume of approximately 0.3 mL, given the precision available in 3 mL disposable syringes.

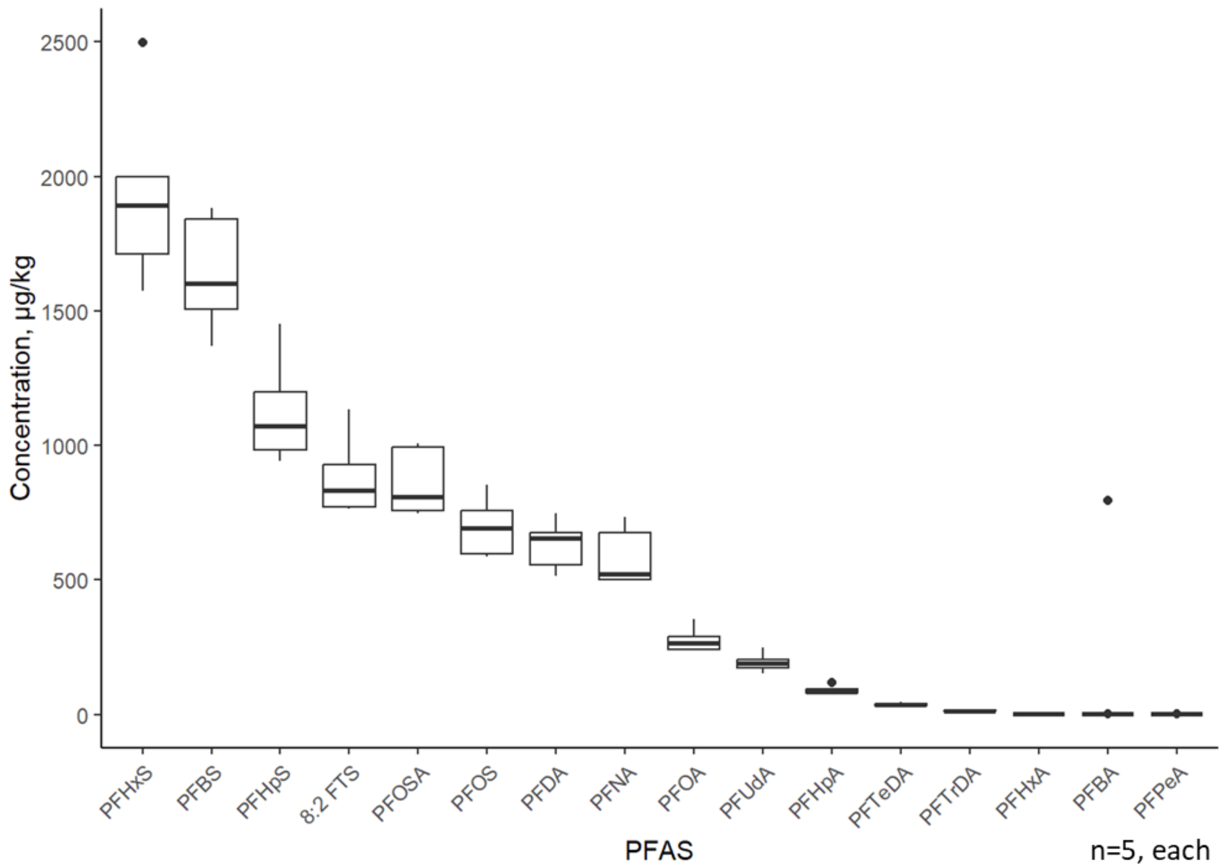


Figure SI4.3. Concentration (µg/kg) of PFAS in worm homogenate (five subsamples taken from pooled aliquots). PFAS not listed are non-detect. Center line is median, extent of boxes are 25th and 75th percentile (interquartile range), extent of lines are shorter of data maximum/minimum or 1.5*interquartile range ± the 25th or 75th percentile, and points outside lines are data beyond extent of lines.

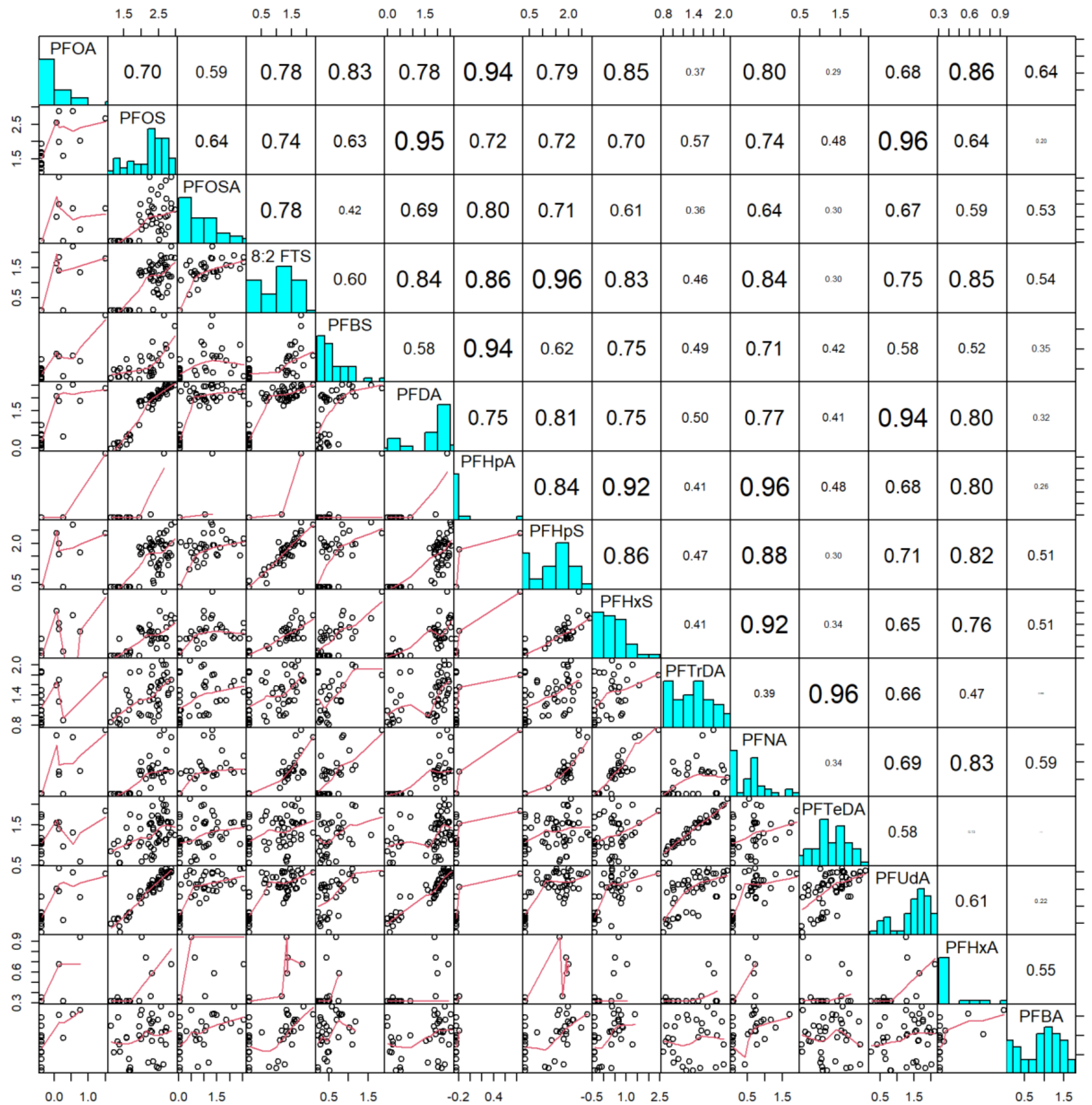


Figure SI4.4. Correlation plot of toad-wise estimated whole animal PFAS concentrations. Points are toad-wise concentrations, red lines are local regression smoothers, histograms are distribution of PFAS-specific concentrations, and top right boxes indicate correlation coefficients for all complete pairs with the text scaled by the magnitude of the correlation. The observation of note here is that none of the PFAS pairs appear to show strong negative correlation and it is unlikely the biotransformation is impacting concentrations.

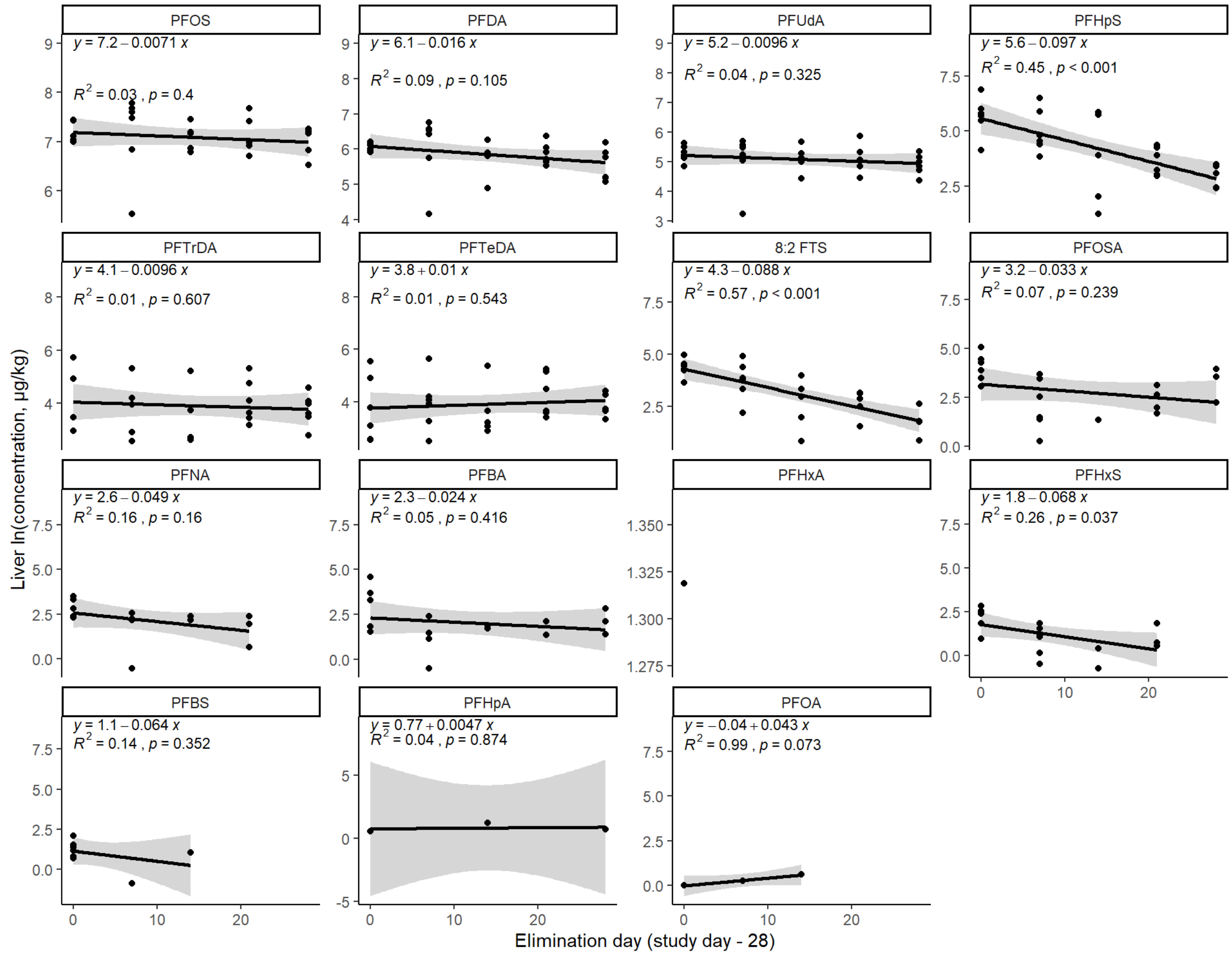


Figure SI4.5. Natural log-transformed liver concentrations (ln(μg/kg)) by elimination day and elimination rates (slope of linear regression) with summary statistics.

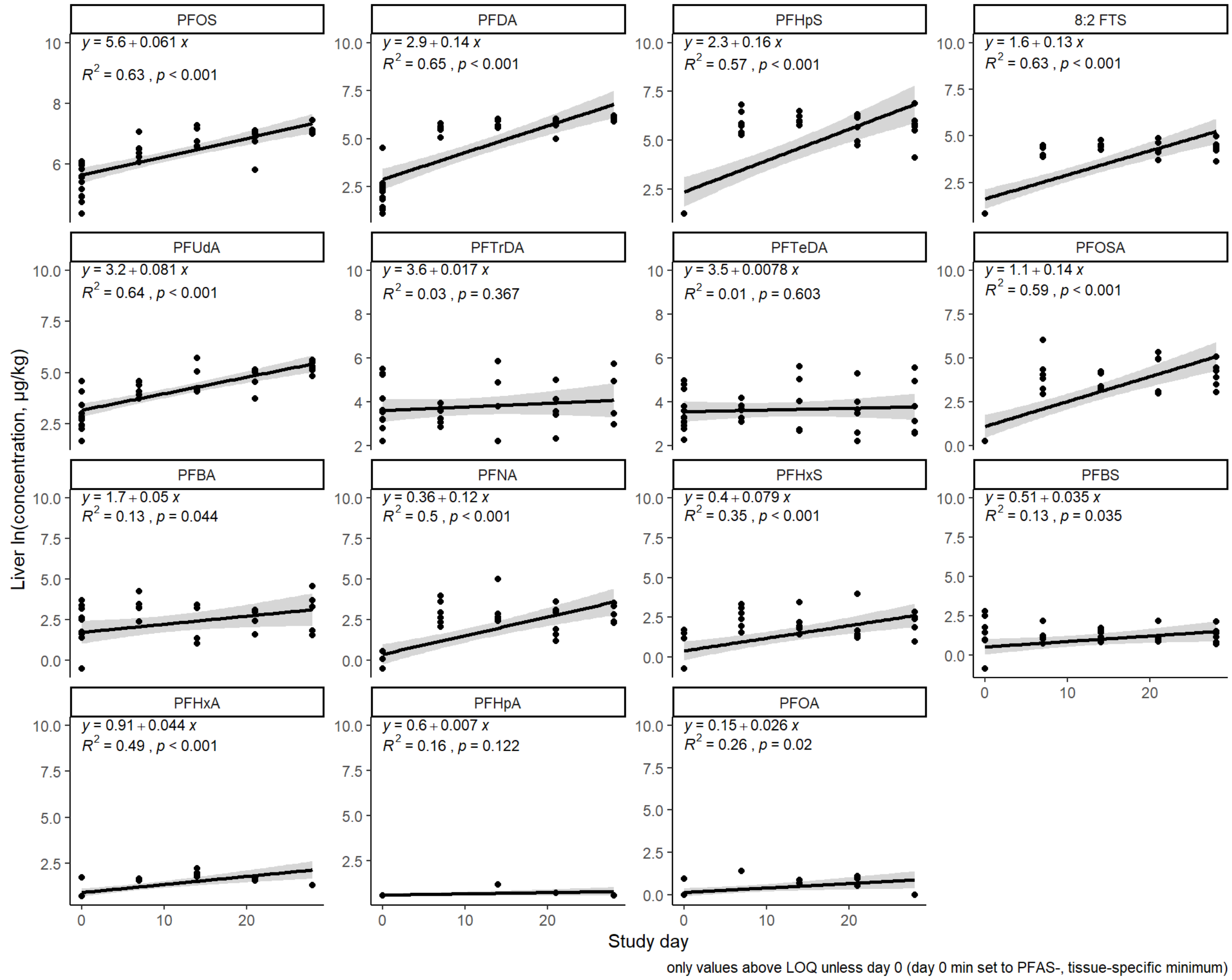


Figure SI4.6. Natural log-transformed liver concentrations (ln(µg/kg)) by study day and uptake rates (slope of linear regression) with summary statistics.

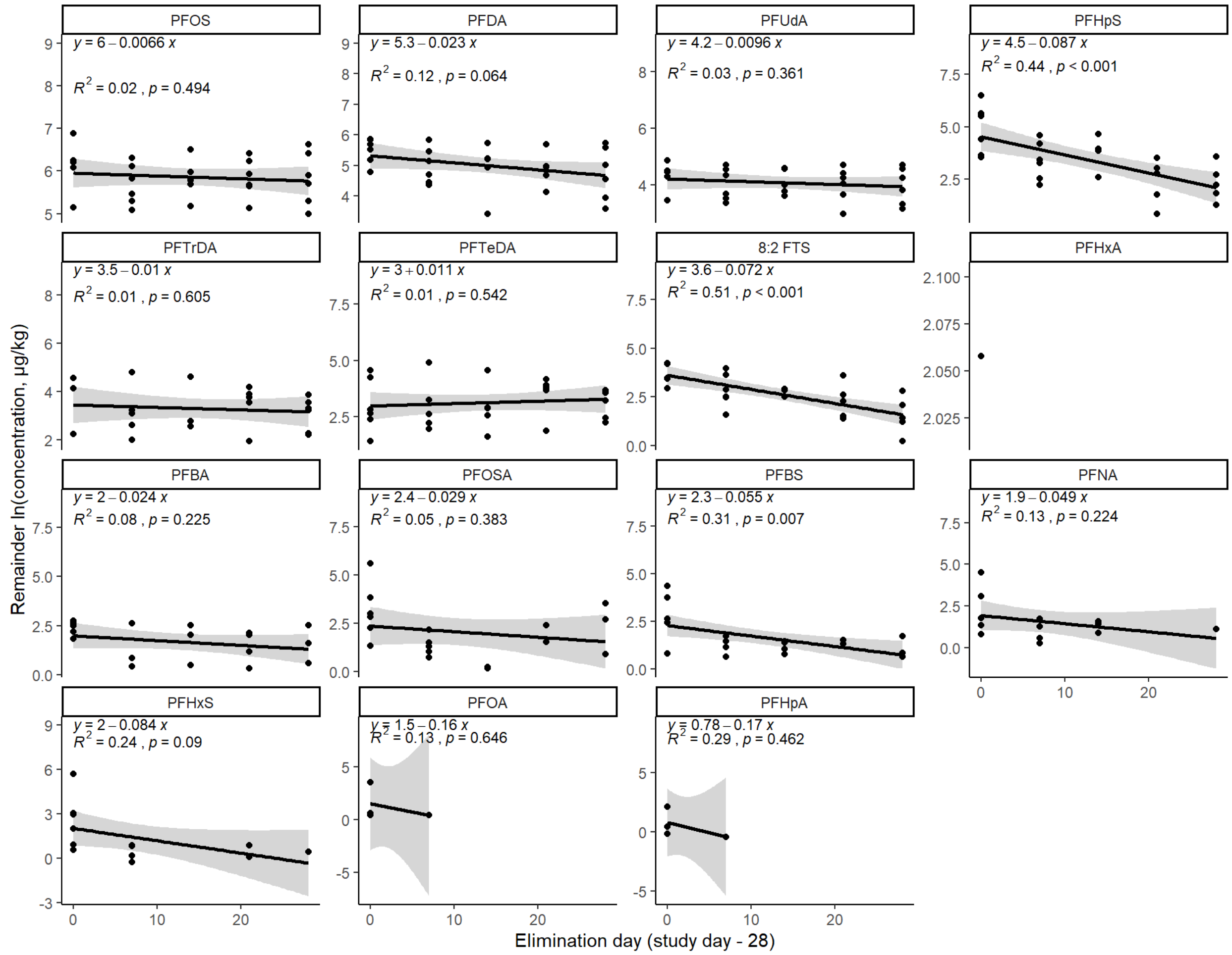


Figure SI4.7. Natural log-transformed remainder concentrations (ln(µg/kg)) by elimination day and elimination rates (slope of linear regression) with summary statistics.

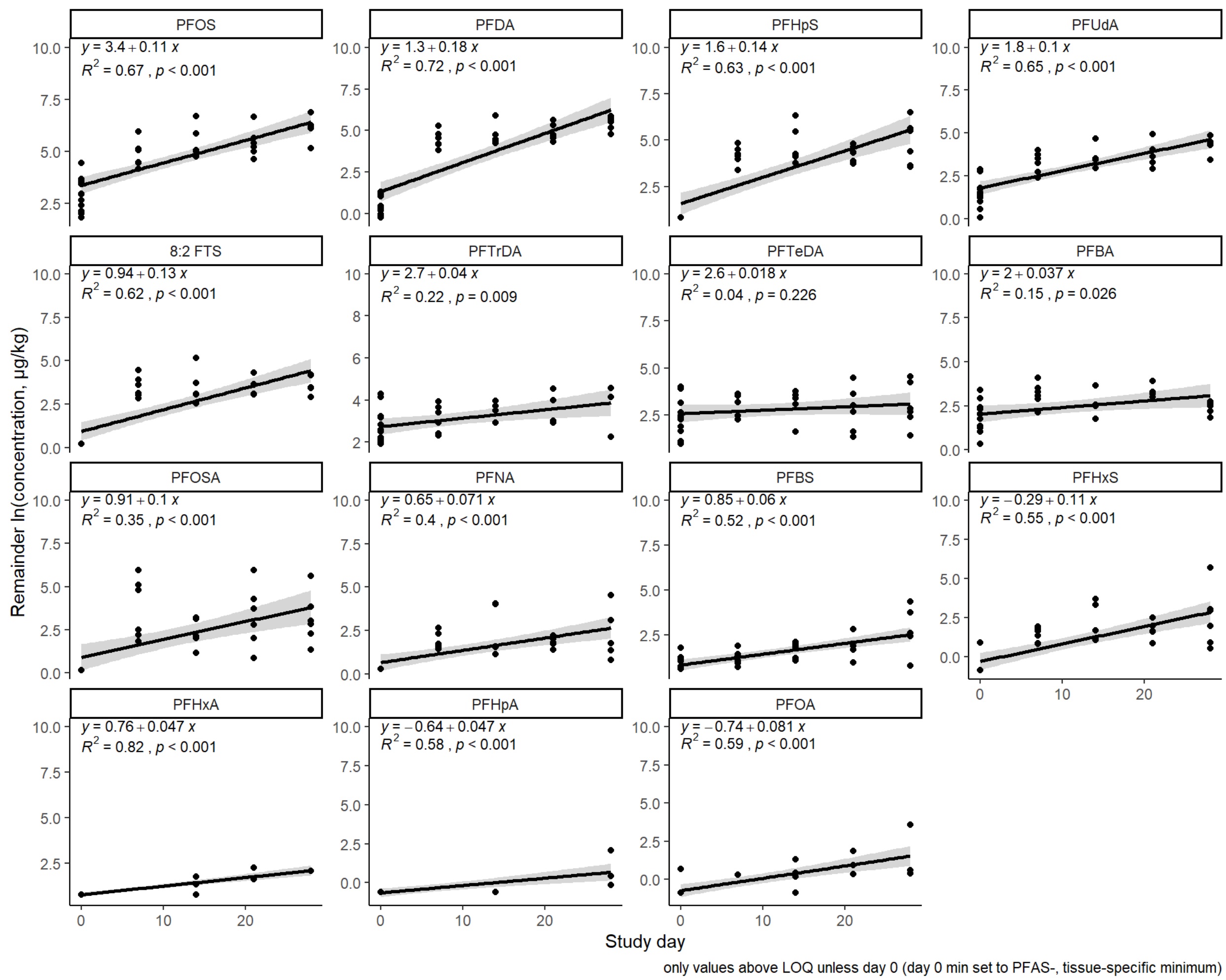


Figure SI4.8. Natural log-transformed remainder concentrations (ln(µg/kg)) by study day and uptake rates (slope of linear regression) with summary statistics.

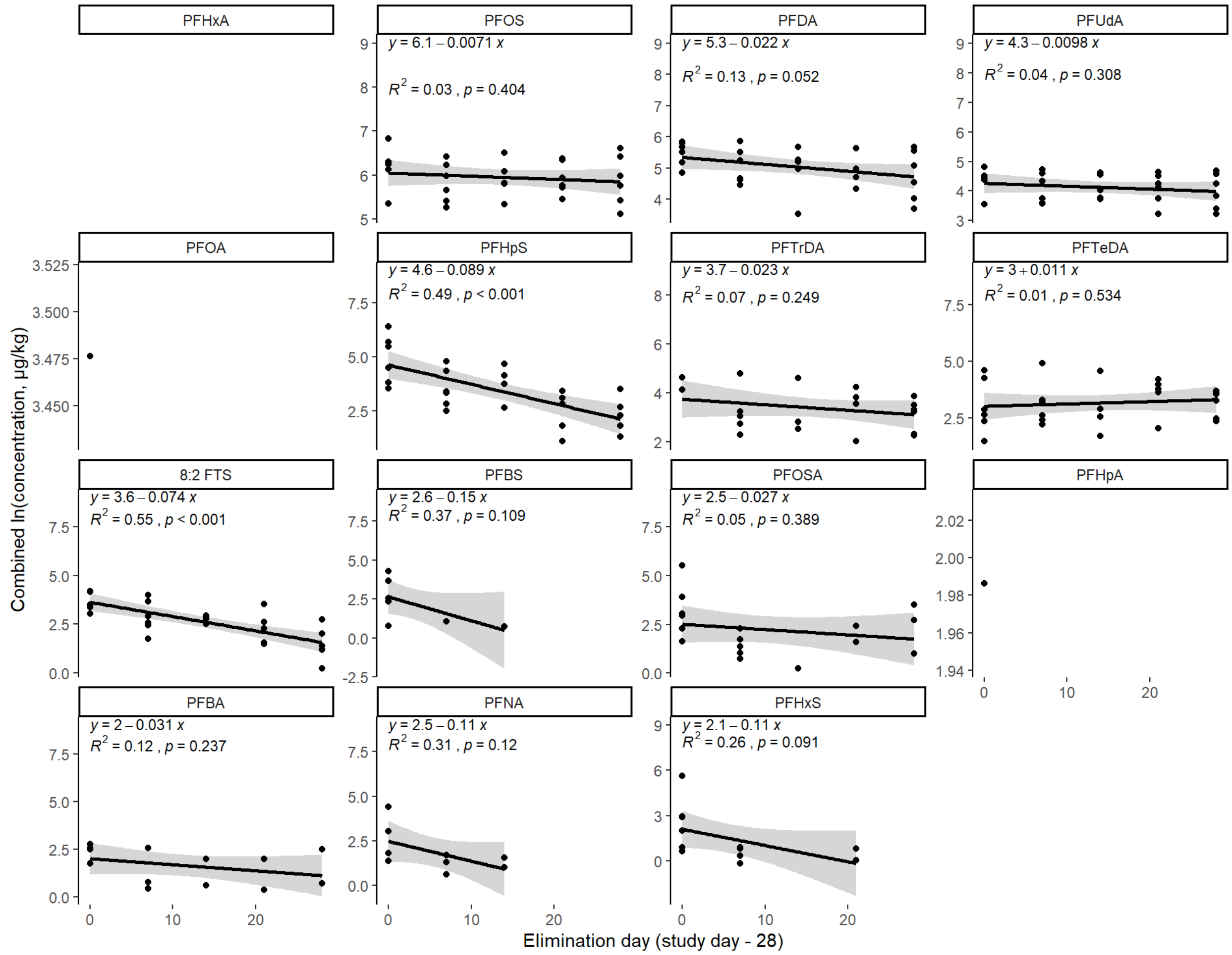


Figure SI4.9. Natural log-transformed estimated whole animal concentrations ("Combined," ln(µg/kg)) by elimination day and elimination rates (slope of linear regression) with summary statistics. PFHxA had no complete liver and remainder pairs during these timepoints, PFOA and PFHpA had only one observation on elimination day 0.

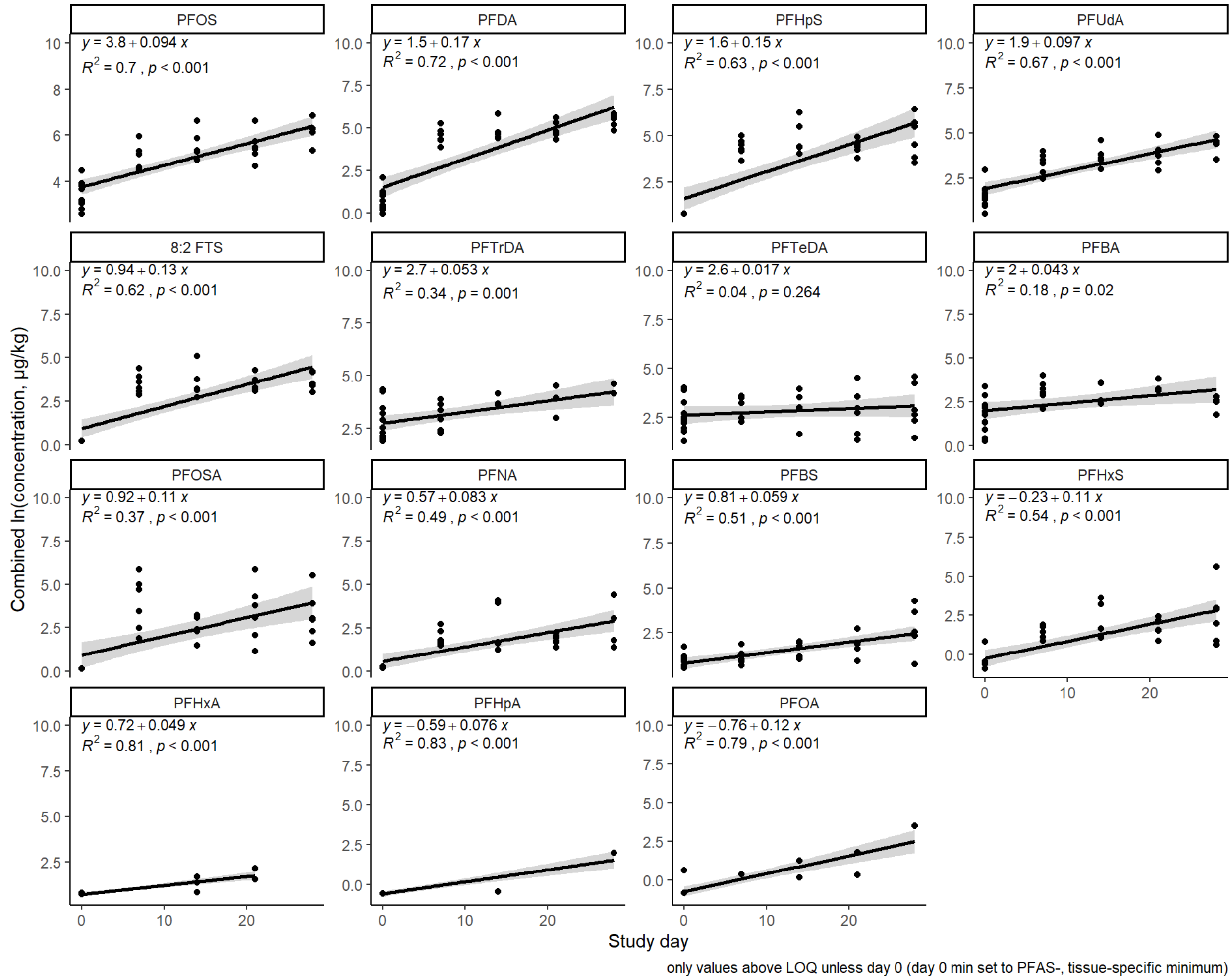


Figure SI4.10. Natural log-transformed estimated whole animal concentrations (“Combined,” ln(µg/kg)) by study day and uptake rates (slope of linear regression) with summary statistics.

Table SI4.2. Summary of diet concentrations (mean, (SD)) and toad tissue concentrations (mean, (SD), [n]) through study day 28. Sorted by diet concentration. *indicates assumed background value of minimum PFAS- and tissue-specific value observed in study. NA = not applicable through non-detection or insufficient sample size.

	Diet; mean, (SD)	Toad; mean, (SD), [n]	Day 0	Day 7	Day 14	Day 21	Day 28
PFHxS	1935.23, (354.98)	Liver	1.39, (1.79), [3]	14.62, (8.88), [6]	11.48, (11.26), [5]	12.17, (19.98), [6]	10.08, (4.95), [6]
		Remainder	0.58, (0.57), [2]	4.47, (1.94), [6]	15.64, (16.87), [5]	6.15, (3.4), [6]	59.16, (119.82), [6]
		Estimated Whole Body	0.59, (0.51), [5]	4.76, (1.76), [6]	14.65, (15.59), [5]	6.15, (3.32), [6]	53.75, (107.87), [6]
PFBS	1639.71, (219.4)	Liver	3.57, (5.09), [6]	3.96, (2.77), [5]	3.91, (1.3), [5]	3.93, (2.68), [5]	4.03, (2.26), [6]
		Remainder	2.63, (1.22), [8]	3.78, (1.67), [6]	5.64, (2.33), [5]	7.31, (4.92), [6]	27.25, (29.09), [6]
		Estimated Whole Body	2.55, (1.08), [10]	3.5, (1.79), [5]	5.27, (2.12), [5]	6.87, (4.94), [5]	24.73, (26.12), [6]
PFHpS	1129.1, (204.72)	Liver	3.4*, (NA), [0]	436.42, (283.12), [6]	449.75, (133.86), [5]	345.3, (192.1), [6]	383.35, (308.14), [6]
		Remainder	2.27*, (NA), [0]	72.39, (33.81), [6]	192.36, (215.76), [5]	78.85, (31.54), [6]	223.47, (238.38), [6]
		Estimated Whole Body	2.21*, (NA), [0]	86.97, (38.05), [6]	195.61, (192.71), [5]	88.23, (32.26), [6]	220.29, (218.75), [6]
8:2 FTS	885.23, (153.27)	Liver	2.27*, (NA), [0]	73.01, (18.14), [6]	86.72, (19.95), [5]	89.59, (38.88), [6]	82.84, (34.87), [6]
		Remainder	1.23*, (NA), [0]	38.77, (25.76), [6]	54.78, (68.65), [5]	36.21, (20.73), [6]	47.06, (22.21), [6]
		Estimated Whole Body	1.22*, (NA), [0]	38.54, (23.75), [6]	53.63, (62.14), [5]	37.07, (18.47), [6]	46.5, (21.2), [6]
PFOSA	863.47, (127.96)	Liver	1.28*, (NA), [0]	105.96, (151.79), [6]	49.49, (20.21), [5]	121.68, (83.53), [6]	70.06, (49.57), [6]
		Remainder	1.18*, (NA), [0]	116.76, (147.83), [6]	13.28, (9.71), [5]	87.22, (148.08), [6]	62.28, (105.55), [6]
		Estimated Whole Body	1.13*, (NA), [0]	110.38, (130.57), [6]	14.42, (8.71), [5]	84.58, (135.91), [6]	59.55, (95.73), [6]
PFOS	697.14, (112.48)	Liver	259.77, (128.03), [13]	663.67, (262.01), [6]	999.18, (331.3), [5]	929.61, (321.31), [6]	1330.91, (291.61), [6]
		Remainder	26.57, (21), [13]	157.51, (119.51), [6]	310.65, (285.33), [5]	282.95, (247.88), [6]	516.52, (257.54), [6]
		Estimated Whole Body	36.9, (20.02), [13]	174.94, (110.68), [6]	329.55, (248.37), [5]	301.13, (230.96), [6]	531.41, (231.68), [6]
PFDA	629.43, (93.28)	Liver	14.54, (23.73), [13]	254.6, (56.9), [6]	329.81, (68.12), [5]	330.64, (101.08), [6]	426.38, (52), [6]
		Remainder	1.94, (1.09), [13]	99.04, (56.2), [6]	143.23, (125.4), [5]	144.55, (80.24), [6]	256.72, (93.35), [6]
		Estimated Whole Body	2.47, (1.89), [13]	101.87, (50.96), [6]	145.4, (111.8), [5]	146.63, (73.38), [6]	252.37, (85.16), [6]
PFNA	585.92, (111.88)	Liver	0.71, (0.34), [2]	23.22, (17.46), [6]	40.77, (60.45), [5]	15.52, (13.26), [6]	19.69, (10.38), [5]
		Remainder	1.32*, (NA), [0]	7.26, (3.91), [6]	25.26, (28.84), [5]	6.31, (1.78), [6]	24.98, (37.95), [5]
		Estimated Whole Body	1.22, (0.02), [2]	7.69, (4.16), [6]	24.77, (27.94), [5]	6.45, (1.88), [6]	28.7, (37.43), [4]
PFOA	276.81, (47.65)	Liver	1.1, (0.43), [1]	4.12, (NA), [1]	2.21, (0.3), [2]	2.43, (0.68), [3]	0.98, (NA), [1]
		Remainder	0.54, (0.42), [1]	1.33, (NA), [1]	1.73, (1.43), [4]	3.43, (2.61), [3]	13.06, (19.77), [3]
		Estimated Whole Body	0.54, (0.4), [1]	1.41, (NA), [1]	2.35, (1.64), [2]	3.64, (3.17), [2]	32.35, (NA), [1]
PFUdA	192.97, (36.66)	Liver	26.37, (25.79), [13]	70.57, (23.72), [6]	129.34, (104.48), [5]	128.86, (50.58), [6]	199.43, (54.19), [6]
		Remainder	5.72, (5.1), [13]	30.42, (16.62), [6]	44.49, (34.76), [5]	55.21, (42.93), [6]	81.42, (34.87), [5]
		Estimated Whole Body	6.46, (5.73), [13]	30.9, (15.74), [6]	46.5, (30.29), [5]	56.13, (39.95), [6]	83.22, (32.15), [5]
PFBA	160.03, (354.4)	Liver	10.58, (12.94), [8]	31.52, (20.1), [6]	15.52, (14.27), [4]	14.49, (7.85), [4]	34.87, (37.69), [5]
		Remainder	8.07, (8.28), [10]	27.94, (17.93), [6]	21.63, (15.88), [5]	30.08, (13.42), [4]	11.33, (3.75), [5]
		Estimated Whole Body	7.79, (7.85), [11]	26.73, (16.43), [6]	23.81, (13.69), [4]	31.02, (12.47), [3]	11.8, (4.29), [4]
PFHpA	90.69, (15.67)	Liver	1.79*, (NA), [0]	NA, (NA), [0]	3.29, (NA), [1]	2.02, (NA), [1]	1.79, (NA), [1]
		Remainder	0.54*, (NA), [0]	NA, (NA), [0]	0.54, (NA), [1]	NA, (NA), [0]	3.46, (3.95), [3]
		Estimated Whole Body	0.58*, (NA), [0]	NA, (NA), [0]	0.65, (NA), [1]	NA, (NA), [0]	7.29, (NA), [1]
PFTeDA	36.96, (4.96)	Liver	46.17, (43.34), [13]	38.96, (15.46), [6]	101.47, (109.44), [5]	56.92, (69.65), [6]	80.94, (97.72), [6]
		Remainder	16.4, (16.65), [13]	25.51, (12.46), [6]	26.68, (14.34), [5]	28.28, (32.08), [6]	35.14, (37.73), [6]
		Estimated Whole Body	17.07, (16.91), [13]	24.91, (11.62), [6]	29.08, (17.38), [5]	28.3, (32.2), [6]	35.68, (38.76), [6]
PFTrDA	13.31, (2.08)	Liver	70.56, (82.08), [11]	31.84, (12.99), [6]	133.23, (152.1), [4]	56.81, (53.84), [5]	125.09, (134.18), [4]
		Remainder	20.93, (21.9), [11]	26.6, (16.37), [6]	35.94, (13.84), [4]	46.89, (35.83), [4]	55.68, (43.36), [3]
		Estimated Whole Body	22.36, (23.31), [12]	25.53, (15.25), [6]	46.23, (15.37), [3]	45.63, (34.47), [4]	82.15, (27.14), [2]
PFHxA	1.86, (0.33)	Liver	2.31, (1.02), [2]	4.94, (0.28), [3]	7.32, (1.49), [4]	4.96, (0.42), [2]	3.74, (NA), [1]
		Remainder	2.17*, (NA), [0]	NA, (NA), [0]	3.9, (1.79), [3]	7.17, (3.13), [2]	7.83, (NA), [1]

	Estimated Whole Body	2.07, (0.05), [2]	NA, (NA), [0]	3.88, (1.57), [3]	6.7, (2.79), [2]	NA, (NA), [0]

Table SI4.3. Continued from Table SI4.2 study days 35 through 56 and static study day 28 trophic transfer coefficients (TTCs). ND is non-detect, NA is not applicable based on non-detection or insufficient sample size.

	Diet; mean, (SD)	Toad; mean, (SD), [n]	Day 35	Day 42	Day 49	Day 56	Static Mean TTC Day 28	Static Mean TTC Day 28, background adjusted
PFHxS	ND	Liver	3.18, (2.17), [6]	1, (0.73), [2]	3.4, (2.5), [3]	NA, (NA), [0]	0.005	0.004
		Remainder	1.67, (0.83), [4]	NA, (NA), [0]	1.73, (0.93), [2]	1.53, (NA), [1]	0.031	0.030
		Estimated Whole Body	1.72, (0.74), [4]	NA, (NA), [0]	1.66, (0.85), [2]	NA, (NA), [0]	0.028	0.027
PFBS	ND	Liver	0.41, (NA), [1]	2.85, (NA), [1]	NA, (NA), [0]	NA, (NA), [0]	0.002	0.000
		Remainder	3.85, (1.4), [5]	3.48, (0.92), [5]	4.02, (0.44), [3]	3.24, (1.97), [3]	0.017	0.015
		Estimated Whole Body	2.89, (NA), [1]	2.11, (NA), [1]	NA, (NA), [0]	NA, (NA), [0]	0.015	0.014
PFHpS	ND	Liver	229.96, (244.44), [6]	144.49, (171.49), [5]	43.92, (26.46), [6]	21.38, (9.98), [5]	0.340	0.337
		Remainder	40.37, (34.99), [6]	54.06, (37.45), [4]	15.66, (12.44), [5]	14.01, (13.04), [5]	0.198	0.196
		Estimated Whole Body	47.83, (43.28), [6]	57.64, (39.99), [4]	16.03, (11.67), [5]	13.68, (12.11), [5]	0.195	0.193
8:2 FTS	ND	Liver	56.31, (44.22), [6]	21.84, (19.88), [5]	17.12, (7.42), [6]	6.74, (4.14), [5]	0.094	0.091
		Remainder	22.85, (18.33), [6]	16.35, (2.73), [4]	12.11, (12.43), [6]	6.65, (6.05), [5]	0.053	0.052
		Estimated Whole Body	23.38, (18.59), [6]	16.05, (3), [4]	11.75, (11.37), [6]	6.32, (5.64), [5]	0.053	0.051
PFOSA	ND	Liver	15.61, (16.21), [6]	3.88, (0.04), [2]	12.38, (7.93), [4]	32.02, (21.27), [3]	0.081	0.080
		Remainder	4.42, (2.66), [5]	1.23, (0.07), [2]	7.98, (4.69), [2]	17.31, (16.16), [3]	0.072	0.071
		Estimated Whole Body	4.9, (3.15), [5]	1.25, (NA), [1]	8.11, (4.54), [2]	17.18, (15.57), [3]	0.069	0.068
PFOS	ND	Liver	1589.24, (823.35), [6]	1242.34, (334.86), [5]	1258.11, (539.46), [6]	1100.9, (298.81), [6]	1.909	1.536
		Remainder	322.94, (152.52), [6]	372.53, (183.65), [5]	374.34, (163.21), [6]	395.92, (237.8), [6]	0.741	0.703
		Estimated Whole Body	370.11, (165.82), [6]	397.4, (172.86), [5]	399.81, (147.95), [6]	411.37, (225.51), [6]	0.762	0.709
PFDA	ND	Liver	542.17, (295.31), [6]	339.04, (138.76), [5]	369.29, (122.03), [6]	282.38, (131.6), [6]	0.677	0.654
		Remainder	169.4, (101.65), [6]	168.99, (99.04), [5]	146.03, (79.28), [6]	151.04, (112.97), [6]	0.408	0.405
		Estimated Whole Body	179.57, (102.62), [6]	169.04, (93.3), [5]	149.89, (69.39), [6]	150.06, (105.72), [6]	0.401	0.397
PFNA	ND	Liver	7.93, (5.25), [4]	9.86, (1.63), [2]	6.59, (4.41), [3]	NA, (NA), [0]	0.034	0.032
		Remainder	3.06, (1.95), [4]	3.81, (1.24), [3]	NA, (NA), [0]	3.09, (NA), [1]	0.043	0.040
		Estimated Whole Body	3.66, (1.84), [3]	3.77, (1.45), [2]	NA, (NA), [0]	NA, (NA), [0]	0.049	0.047
PFOA	ND	Liver	1.25, (NA), [1]	1.8, (NA), [1]	NA, (NA), [0]	NA, (NA), [0]	0.004	0.000
		Remainder	1.52, (NA), [1]	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	0.047	0.045
		Estimated Whole Body	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	0.117	0.115
PFUdA	ND	Liver	192.95, (96.39), [6]	177.21, (75.09), [5]	179.85, (93.74), [6]	140.45, (45.58), [6]	1.033	0.897
		Remainder	63.69, (34.29), [6]	65.33, (28.94), [5]	62.85, (32), [6]	61.83, (35.99), [6]	0.422	0.392
		Estimated Whole Body	66.97, (33.59), [6]	67.66, (29.07), [5]	65.56, (29.22), [6]	62.67, (34.47), [6]	0.431	0.398
PFBA	ND	Liver	4.7, (4.37), [4]	6.04, (0.81), [2]	6.02, (3.08), [2]	9.67, (6.5), [3]	0.218	0.152
		Remainder	5.03, (5.88), [4]	7.36, (5.52), [3]	5.2, (3.39), [4]	6.42, (5.49), [3]	0.071	0.020
		Estimated Whole Body	5.56, (6.44), [3]	4.53, (3.83), [2]	4.42, (4.23), [2]	7.06, (7.1), [2]	0.074	0.025
PFHpA	ND	Liver	NA, (NA), [0]	3.36, (NA), [1]	NA, (NA), [0]	2.04, (NA), [1]	0.020	0.000
		Remainder	0.65, (NA), [1]	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	0.038	0.032
		Estimated Whole Body	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	0.080	0.074
PFTeDA	ND	Liver	82.7, (99.35), [6]	64.51, (86.16), [5]	93.93, (73.12), [6]	56, (22.51), [6]	2.190	0.941
		Remainder	35.77, (48.37), [6]	29.94, (37.01), [5]	41.64, (19.07), [6]	26.39, (13.35), [6]	0.951	0.507
		Estimated Whole Body	36.33, (48.3), [6]	30.17, (37.59), [5]	42.17, (19.75), [6]	26.55, (12.79), [6]	0.965	0.504
PFTrDA	ND	Liver	70.22, (69.89), [6]	63.89, (81.56), [4]	78.53, (69.18), [6]	49.71, (28.59), [6]	9.398	4.097
		Remainder	38.15, (47.34), [5]	43.54, (50.06), [3]	40.21, (21.85), [5]	25.7, (14.91), [6]	4.183	2.611
		Estimated Whole Body	38.37, (45.96), [5]	43.22, (49.58), [3]	40.59, (22.61), [5]	25.62, (14.58), [6]	6.172	4.492
PFHxA	ND	Liver	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	2.011	0.769
		Remainder	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	4.210	3.043

	Estimated Whole Body	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	NA, (NA), [0]	NA	NA

Leave-one-out Cross Validation and Definitive Model Selection

Physiologically-relevant ordinary differential equation system to predict concentrations in tissues through dosing and elimination periods.

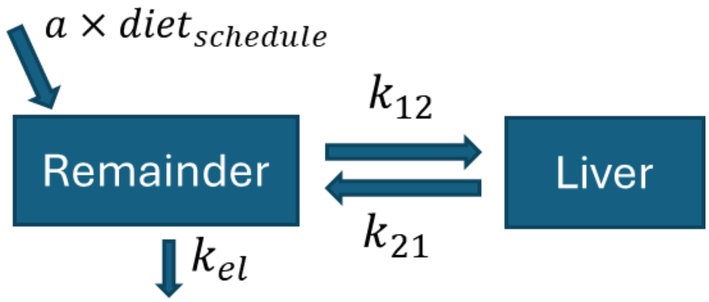


Figure SI4.11. PFAS fluxes and parameters in physiologically-relevant model of PFAS movement into and out of the liver concurrent to the intake and elimination of PFAS from the remainder of the toad.

The algorithm used to generate the MAE for nonlinear model predictions and ODE model predictions for liver PFOS and liver 8:2 FTS is described in the below R pseudocode:

```
for(i in 1:n){
   ys <- y[-i]
   xs <- x[-i]
   ms <- model(xs, ys, params)
   abserr[i] <- abs(y[i]-predict(ms,x[i]))
}
MAE <- mean(abserr)
```

where `i` represents an index of a `for` loop that starts at 1 for the first of `n` datapoints in the dataset; `y` represents the PFAS concentrations; `x` represents the corresponding timepoints; and `s` indicates subsets of the original datasets with the `i`th datapoint excluded; `model` represents the function that would be used to estimate the parameters (`params`) for either the nonlinear or ODE models; `ms` the saved model parameter estimates; `abs` the absolute value; and `y[i]-predict(ms,x[i])` the difference between the observed `i`th concentration and the predicted concentration at the `i`th timepoint using the subset model parameter estimates; and `MAE`, outside the `for` loop, saves to an object the mean of the vector of absolute errors.

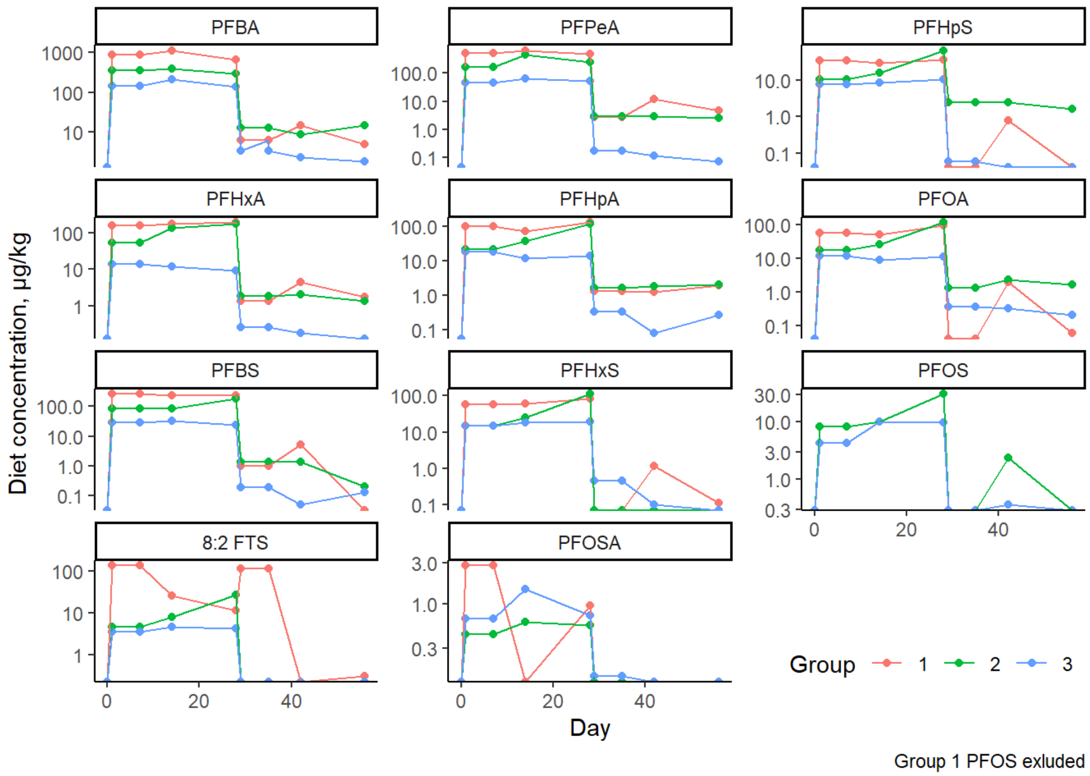


Figure SI5.1. Weekly average combined kale and timothy grass diet concentration of PFAS (µg/kg), by study block, through time. Points indicate sample collection points. Group 1 PFOS is excluded as reporting limit for rabbit tissues was 1000-fold higher than other PFAS and study blocks.

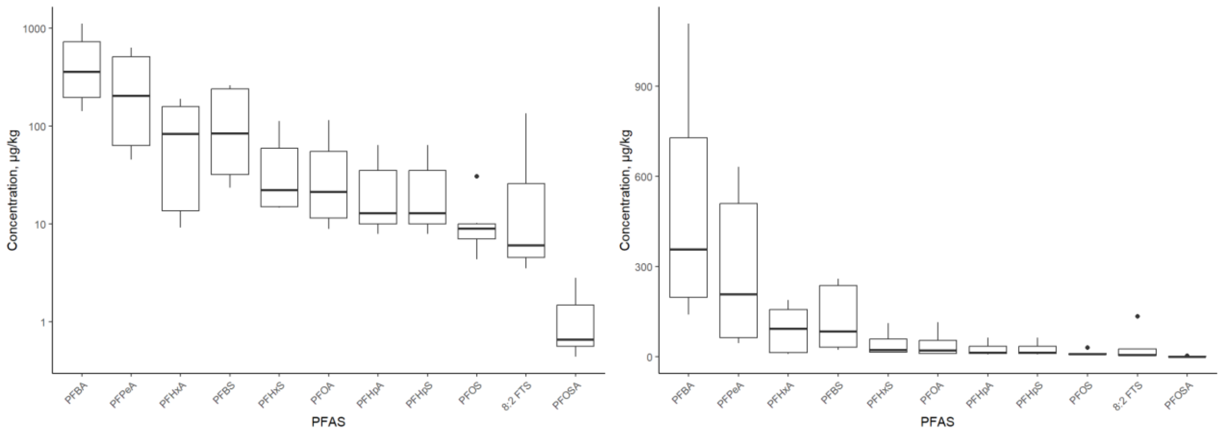


Figure SI5.2. Rabbit diet concentration (µg/kg) distributions during uptake period (study days 1-28). All study blocks (except group 1 PFOS) combined here. Left shows data on log-scaled y-axis and right untransformed. PFAS are listed on x-axis in order of median (thick line). Boxes represent 75th and 25th percentiles, whiskers either the extent of data or 1.5*IQR beyond the extremes of the IQR. Dots alone represent outliers.

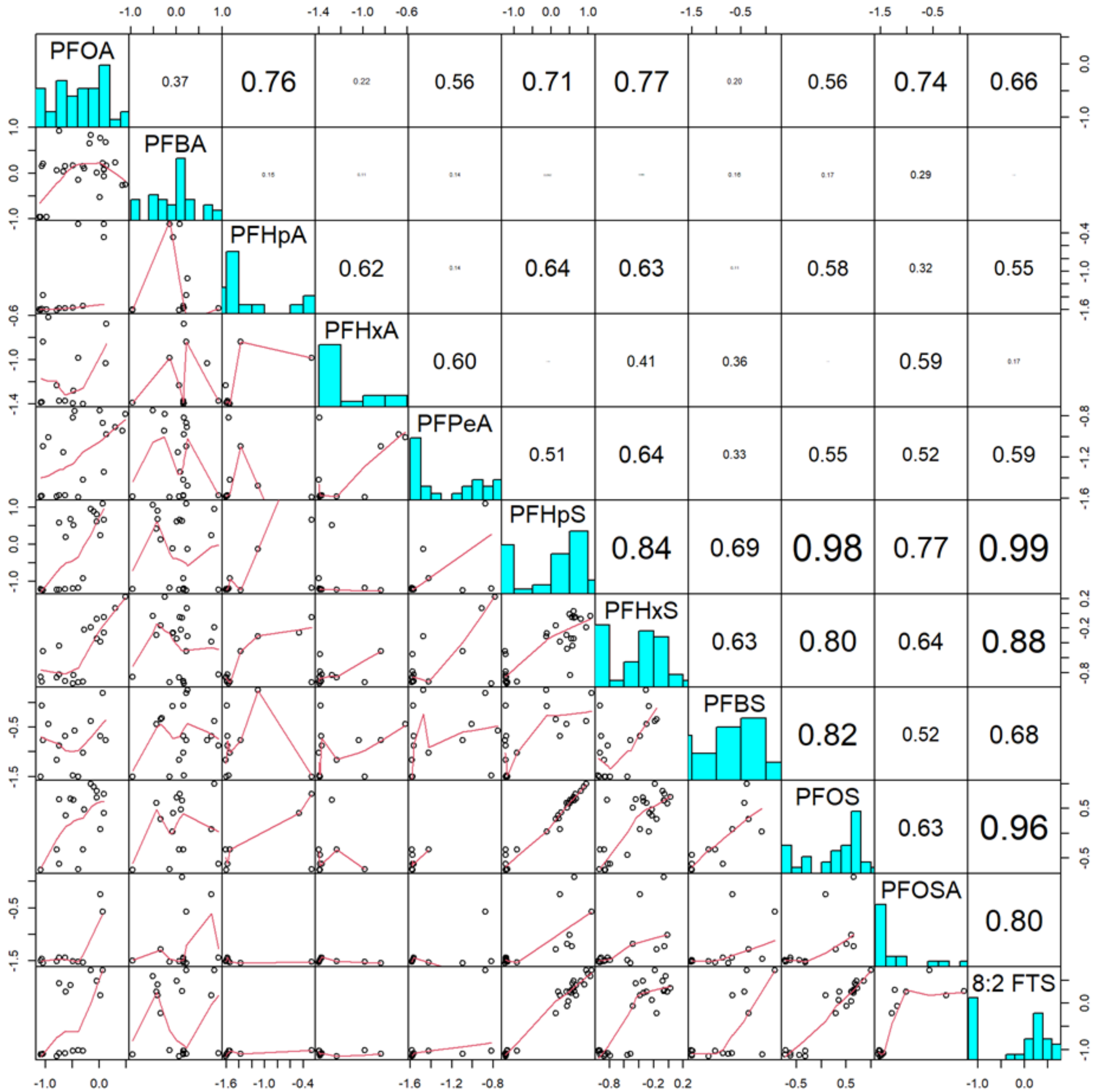


Figure SI5.3. Correlation plot of combined rabbit-specific PFAS natural log transformed concentrations. Values in top right corners are correlation coefficients, points are individual values, red lines smoothers, and central boxes show frequency histograms of PFAS distributions.

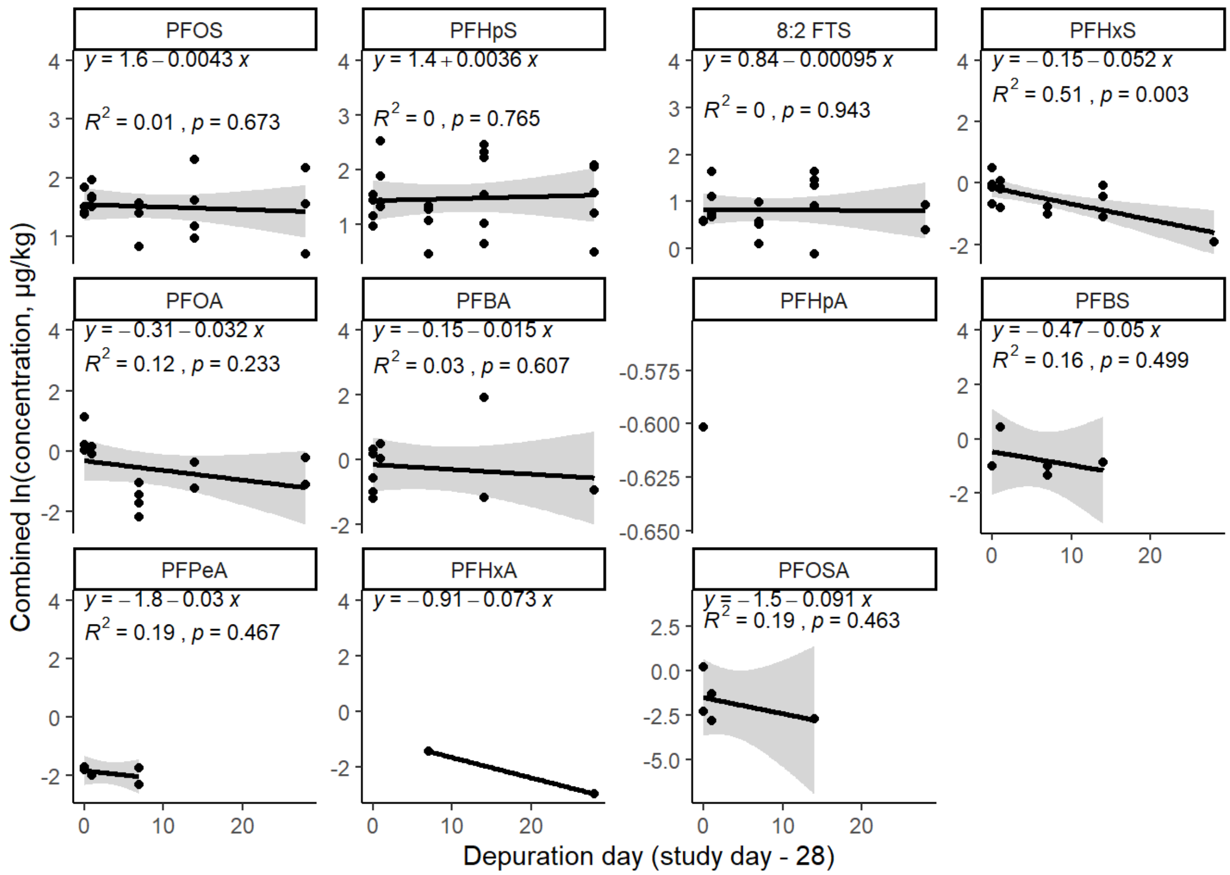


Figure SI5.4. Rabbit whole organism concentration ('combined') elimination rates estimated using the linear regression techniques of OECD TG#305.Those PFAS with limited data above detection limit (e.g., PFHpA, PFHxA) were fit to data available.

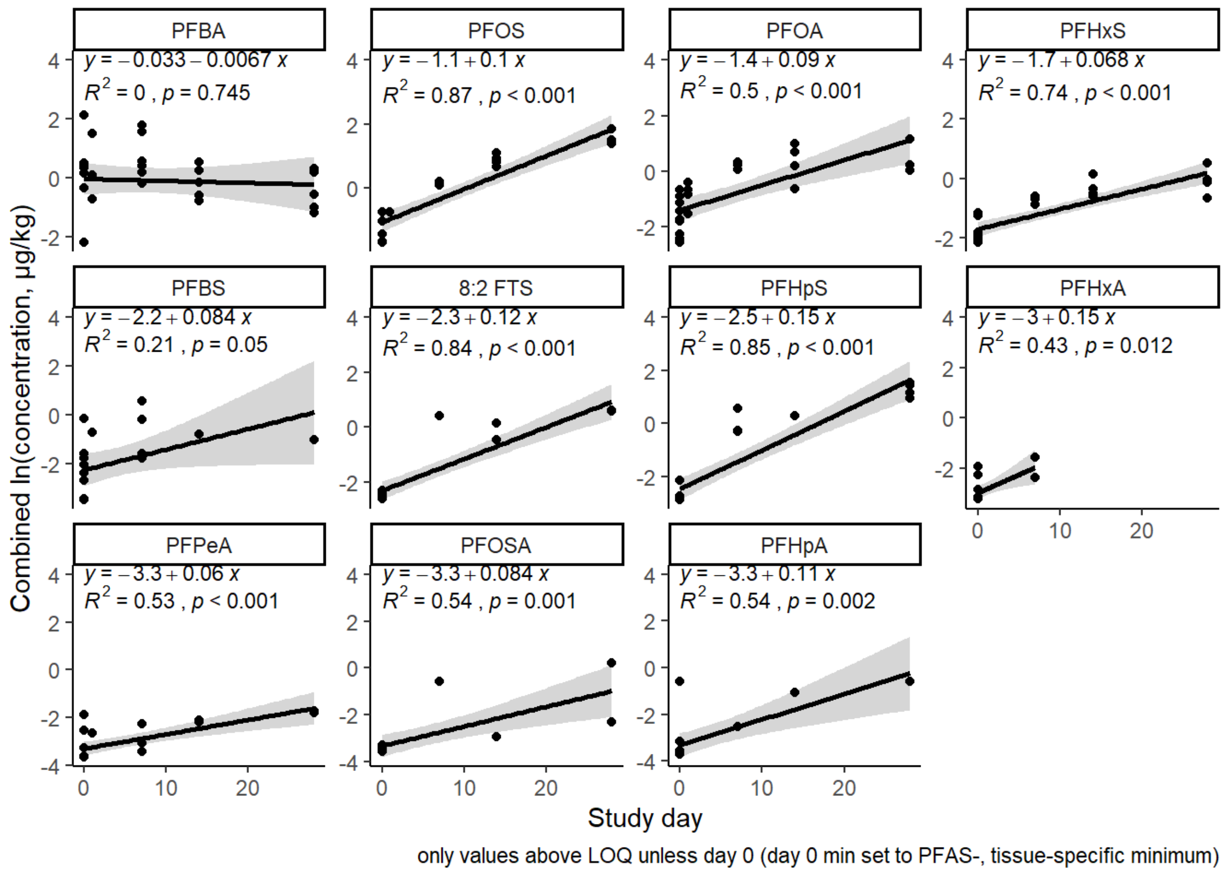
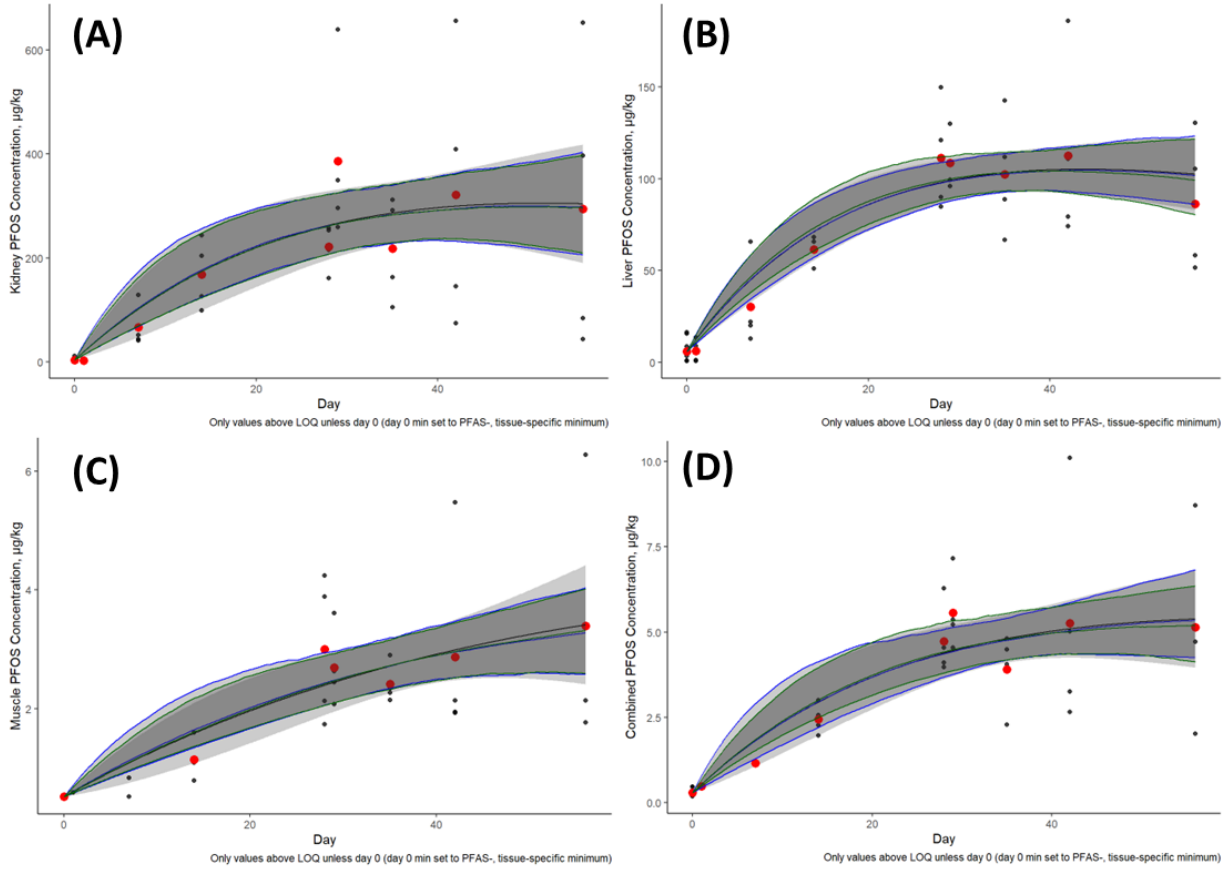
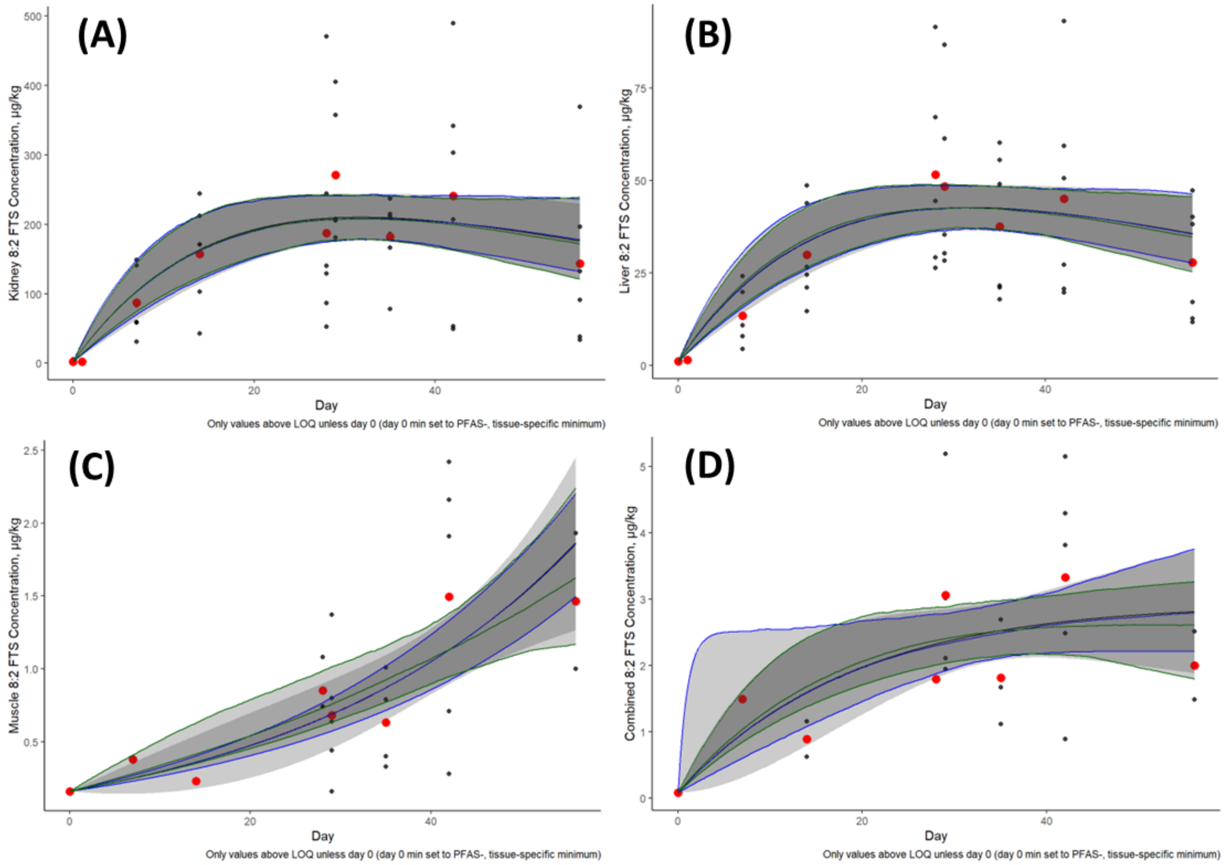


Figure SI5.5. Rabbit whole organism concentration (‘combined’) uptake rates estimated using the linear regression techniques of OECD TG#305. Those PFAS with limited data above detection limit on day 0 had the samples populated with the PFAS- and tissue-specific minimum to ensure starting value for regression was as near the limit of quantification as possible.



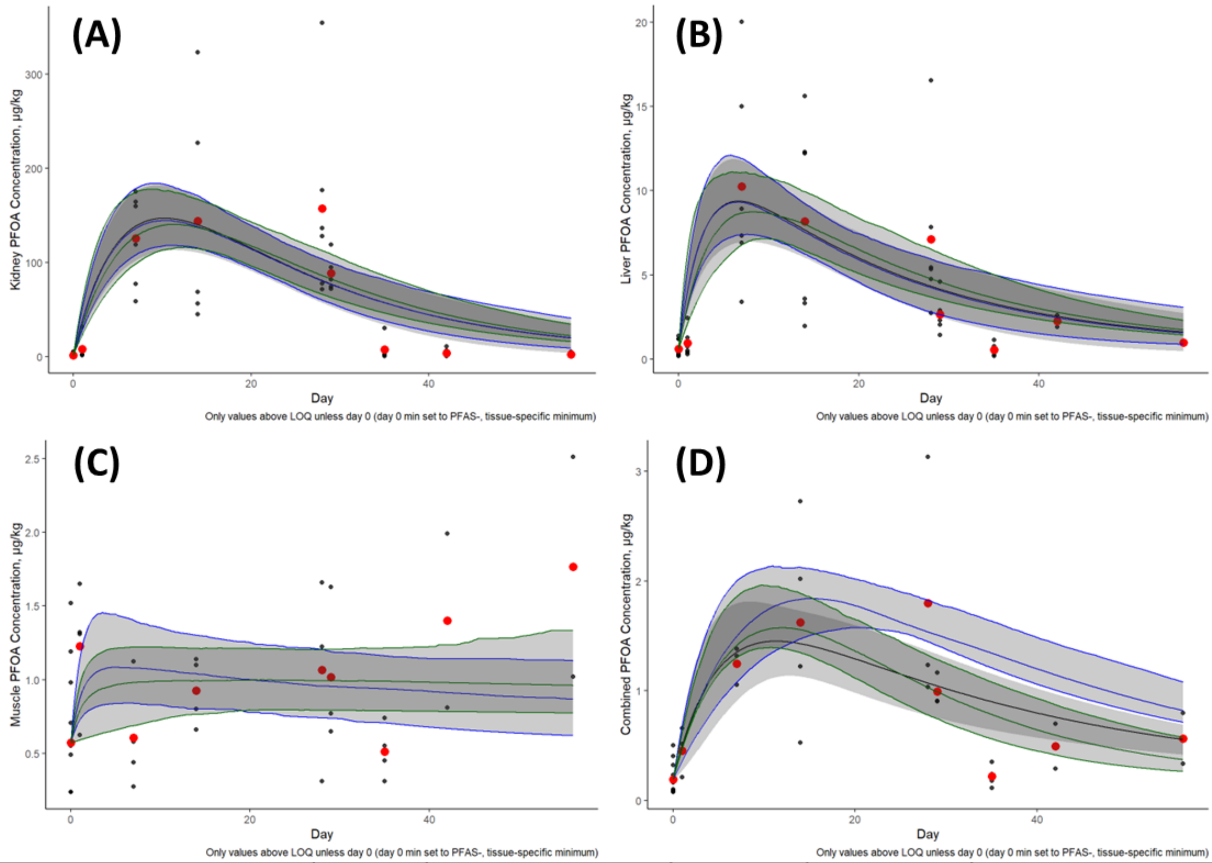
PFOS, bootstrap	Diet	Background	Vd	Uptake	Elimination
Kidney (A)	7.1	3.69	0.011	0.026	0.016
Liver (B)		5.90	0.045	0.044	0.012
Muscle (C)		0.52	1.13	0.020	0.006
Combined (D)		0.293	1.00	0.042	0.007

Figure SI5.6. Rabbit PFOS kinetic model parameterization. PFOS kinetic model mean parameter estimates via least squares (black line) and bootstrap (uptake parameter blue, elimination parameter green) for kidney (A), liver (B), muscle (C) and combined (D) estimated whole organism concentration. Datapoints for individual rabbits are black points and daily mean is large red point. Note varying y-axes and that day 28 was switch to clean diet. Units of diet and background are µg/kg, Vd are L/kg, and uptake and elimination are unitless and represent multiplicative rates. Group 1 and female animal 61 are excluded from these analyses.



8:2 FTS, bootstrap	Diet	Background	Vd	Uptake	Elimination
Kidney (A)	20.3	2.06	0.05	0.050	0.021
Liver (B)		1.09	0.25	0.046	0.023
Muscle (C)		*0.16*	*7-10**	*0.006**	*-0.019**
Combined (D)		0.084	6.4	0.052	0.004

Figure SI5.7. Rabbit 8:2 FTS kinetic model parameterization. 8:2 FTS kinetic model mean parameter estimates via least squares (black line) and bootstrap (uptake parameter blue, elimination parameter green) for kidney (A), liver (B), muscle (C) and combined (D) estimated whole organism concentration. Datapoints for individual rabbits are black points and daily mean is large red point. Note varying y-axes and that day 28 was switch to clean diet. Units of diet and background are µg/kg, Vd are L/kg, and uptake and elimination are unitless and represent multiplicative rates. *indicates low quality fits—negative elimination is nonsensical.



PFOA, bootstrap	Diet	Background	Vd	Uptake	Elimination
Kidney (A)	26.3	1.57	0.035	0.054	0.134
Liver (B)		0.609	0.30	0.048	0.24
Muscle (C)		*0.571*	*0.7**	*0.010**	*1.00**
Combined (D)		0.193	9.8	0.112	0.061

Figure SI5.8. Rabbit PFOA kinetic model parameterization. PFOA kinetic model mean parameter estimates via least squares (black line) and bootstrap (uptake parameter blue, elimination parameter green) for kidney (A), liver (B), muscle (C) and combined (D) estimated whole organism concentration. Datapoints for individual rabbits are black points and daily mean is large red point. Note varying y-axes and that day 28 was switch to clean diet. Units of diet and background are µg/kg, Vd are L/kg, and uptake and elimination are unitless and represent multiplicative rates. *indicates low quality fits—elimination set at boundary of 1 improves fit from nonsensical negative, but does not provide precise estimates. Note also variation in Vd from tissues to combined and relationship between uptake and elimination parameters and deviation between uptake fit (blue) and elimination fit (green) to capture highly dynamic data.

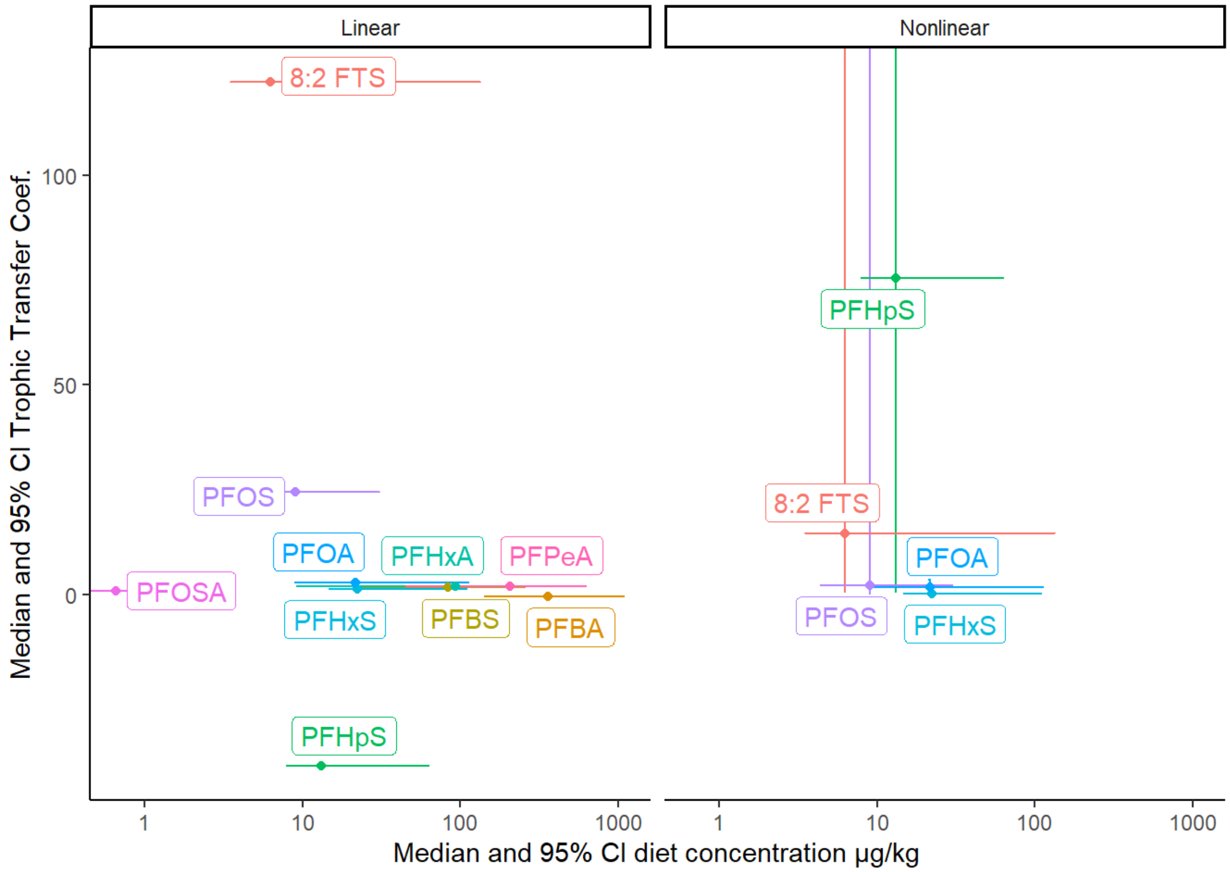


Figure SI5.9. Rabbit combined trophic transfer coefficients on untransformed scale. Note negative value for PFHpS using linear methods. Implication here is that there is an increase in concentration during elimination period using linear methods, which confounds the interpretation. See Figure 11 for log-scaled y-axis version of figure. Intersection (point) of error bars is median trophic transfer coefficient and diet concentration, extremes of error bars are 97.5th and 2.5th percentiles. Linear model elimination rate variation not shown for brevity (not definitive). Horizontal dashed lines at 1.0 and 2.0 indicate areas where uptake and elimination are equivalent (uptake/elimination=1) and where uptake is two-fold higher than elimination and individual bioaccumulation is likely (uptake/elimination>2).

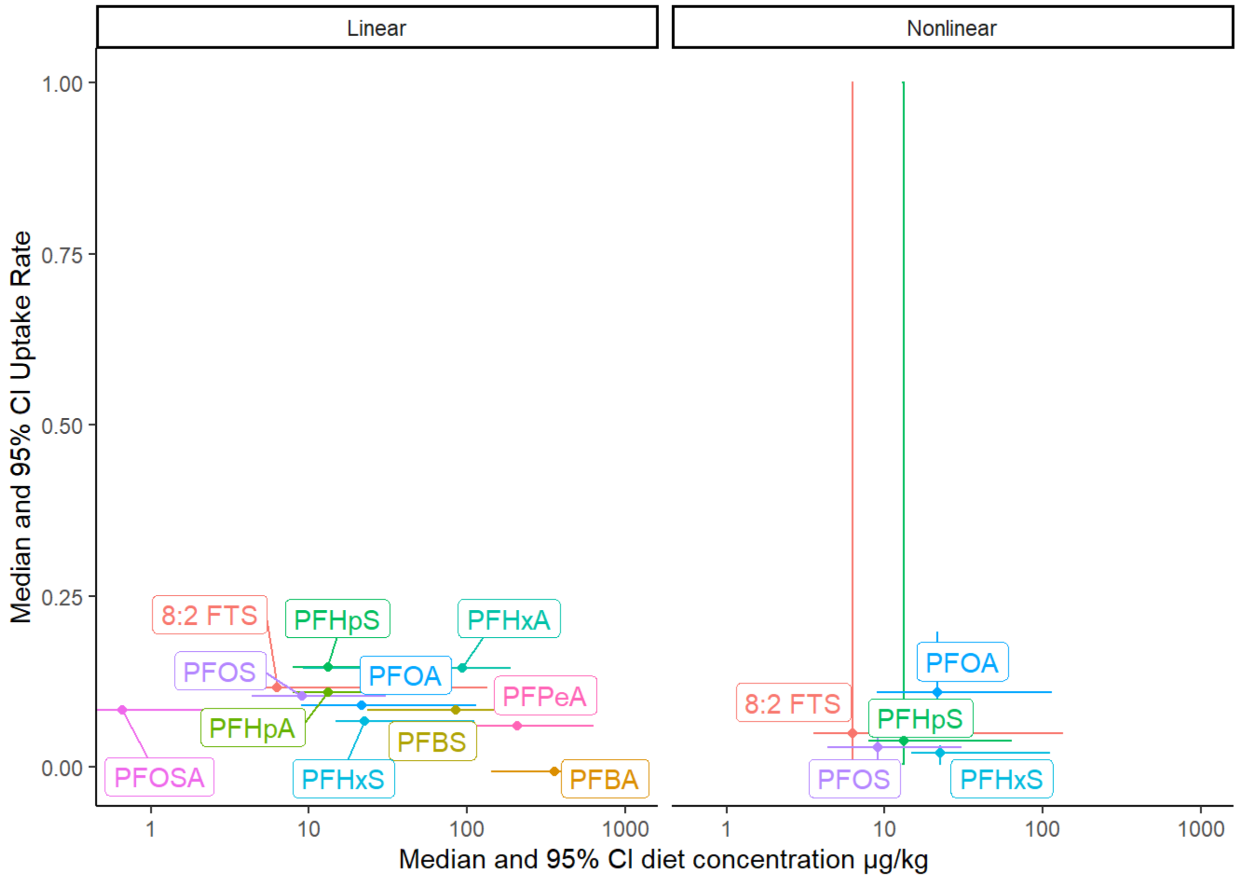


Figure SI5.10. Rabbit combined uptake rates on untransformed scale. See Figure 11 for log-scaled y-axis version of figure. Intersection (point) of error bars is median trophic transfer coefficient and diet concentration, extremes of error bars are 97.5th and 2.5th percentiles. Linear model elimination rate variation not shown for brevity (not definitive). Horizontal dashed lines at 1.0 and 2.0 indicate areas where uptake and elimination are equivalent (uptake/elimination=1) and where uptake is two-fold higher than elimination and individual bioaccumulation is likely (uptake/elimination>2).

Glossary

PFAS: Per- and polyfluoroalkyl substances. Fluorinated (complete=per, incomplete=poly), anionic (generally), surfactants (carbon chain tail (hydrocarbon with H replaced with F) and head group (carboxylate or sulfonate are common terminal groups)).

Multiple PFAS (PFOS, PFHxS, PFOA, 6:2 FTS, etc.): See Table SI2.1.

Precursor: A PFAS that has the potential to transform into other PFAS. Of particular importance as many PFAS that have potential to breakdown simply lead to recalcitrant "terminal" PFAS. For instance, PFOSA (perfluoroalkyl sulfonamide) can be deaminated and oxidated to become PFOS (perfluoroalkyl sulfonate). Precursors are relevant as they can be (1) intentionally added to products as the desired molecules, (2) be a result of low efficiency synthesis and cooccur with desired molecules, (3) released as wastes from lengthy synthesis processes, (4) released as side chain degradants from fluoropolymers and lead to complexity in relating expected vs measured PFAS concentrations in environmental media.

PFSA, PFCA: Perfluorosulfonate, perfluorocarboxylate. Fully fluorinated anionic surfactants with sulfate or carboxylate head groups. Legacy, terminal PFAS such as PFOS (perfluorooctane sulfonate) and PFOA (perfluorooctanoic acid) are a model C8 PFSA and C8 PFCA (note 7 carbons are fluorinated).

DoD: Department of Defense (U.S.)

AFFF: Aqueous film-forming foam. Generally referring to PFAS-containing foams used to suppress liquid fuel fires. See mil-spec.

Mil-spec: Military Specification. Relevant here as military performance specifications for AFFF products historically required the presence of PFAS and then transitioned to setting an upper limit of PFOS and PFOA.

NDAA: National Defense Authorization Act (U.S.). Effectively sets the budget for the U.S. DoD. Relevant here in that NDAA for FY20 and FY21 set requirements to end PFAS use in AFFF and transition to PFAS-free firefighting foams. See F3.

F3: Fire fighting foam. Often described as fluorine-free foam. Misleading as background municipal water in products will likely have fluorine added. PFAS-free is also misleading as NDAA limit is 10 ppb PFAS in targeted analysis.

TES: Threatened and endangered species. Acronym often used in ecological risk assessment literature associated with Endangered Species Act (ESA) work.

RL, LOQ, LOD, MDL, ND: Reporting limit, limit of quantification, limit of detection, non-detect. Determined by specific details of analytical method, but on a number line, a non-detect is the lowest concentration and may be as low as 0 but not able to differentiate signal from noise so may be above zero, the limit of detection or minimum/method detection limit is the threshold when some signal can be identified from chromatographic noise and it is unlikely that the true value is zero, but confidence is low, the limit of quantification can identify both a reportable value or a signal that can be differentiated from chromatographic noise but is of low confidence, the reporting limit is where confidence is sufficiently high to report quantified concentrations. Values may be labeled “trace” if they are above LOD (or LOQ) but below LOQ (or RL). Note again the importance of method-specific definitions.

CD-1: CD-1® IGS mouse strain from Charles River, Inc; full strain name: Crl:CD1(ICR). An outbred strain derived from albino Swiss mice (*Mus musculus*). IGS here is Charles River acronym for International Genetic Standardization. ICR indicates the original source of the mice from the Institute for Cancer Research (strain establish in 1948). See https://www.criver.com/products-services/find-model/cd-1r-igs-mouse for more details.

C6-8 and FTS: Six through 8 carbon chain length perfluoroalkyl carboxylates or sulfonates (PFOS, PFHxS, PFHxA, and PFOA) and fluorotelomer sulfonates (6:2 FTS and 8:2 FTS). See Chapter 3 for more details.

IACUC, AAALAC, ACURO: Institutional Animal Care and Use Committee, Association for Assessment and Accreditation of Laboratory Animal Care, Animal Care and Use Review Office. IACUC is the local animal use authority, AAALAC may provide 3rd party accreditation, and ACURO is the DoD level animal use authority. AAALAC International no longer considers its name an acronym, this acronym is included for reference.

GLP: Good Laboratory Practices. In this work, references 40 CFR part 160 and part 792 (FIFRA and TSCA) that motivate DCPH-A’s quality assurance program. FIFRA is Federal Fungicide, Insecticide, and Rodenticide Act and TSCA is Toxic Substances Control Act; both are U.S. regulations that drive pesticide registration (FIFRA) and general toxic chemical management (TSCA). Organization of Economic Cooperation and Development (OECD) GLP guidance is also considered.

EPA Method 1633 (4th draft): A PFAS quantification method for a variety of matrices and 40 analytes reviewed by EPA and stakeholders, required by DoD quality standards manual (QSM) and DoD Environmental Lab Accreditation Program (ELAP) labs. See https://www.epa.gov/cwa-methods/cwa-analytical-methods-and-polyfluorinated-alkyl-substances-pfas for more details and method protocols.

BCF: Bioconcentration factor. Traditionally derived in aquatic laboratory studies and the concentration of a chemical in animal tissue divided by concentration of the same chemical in the surrounding water (Cfish/Cwater). Assumed that chemical kinetics in/out of organism are at steady state (dynamic equilibrium).

BAF: Bioaccumulation factor. Derived in field and lab settings in aquatic and terrestrial (air-breathing) organisms and based on concentration of a chemical in tissue divided by the sum of the chemical in surrounding media plus diet (Cfish/(Cwater+Cdiet)). Assumed that chemical kinetics in/out of organism are at steady state (dynamic equilibrium).

BMF, TMF: Biomagnification factor, trophic magnification factor. The biomagnification factor is often estimated as Canimal/Cdiet and with the animal and diet being one trophic level apart. Traditionally TMF is the antilog of the slope of tissue concentrations across multiple trophic levels derived from field observations. This approach is demonstrated as effective for systems where trophic level can be identified via stable nitrogen isotopes as a continuous distribution. Further, this method was developed with highly lipophilic chemicals and likely does not perform well for PFAS, see (Fremlin et al. 2023). Regardless, it is important to note that trophic magnification suggests an increase in individual accumulation rates with an increase in trophic position (i.e. the slope value is positive). Note that magnification in the name confounds/obfuscates/ignores cases where accumulation may not increase with trophic level and the antilog of the slope of tissue concentrations across multiple trophic levels may be near or below 1.

TTC: Trophic transfer coefficient. A stepwise transfer factor (diet to organism) based on toxicokinetic model uptake and elimination parameters (uptake / elimination). Laboratory-based stepwise transfer factors (BAFs, BMFs) generally require steady-state tissue concentrations. In cases without steady state concentrations, evaluation of the rates (while controlling for the features of the toxicokinetic model) allows for a comparative basis to identify PFAS that are more or less likely to be trophic magnifiers. Importantly, sans field data or other stepwise transfer factors in a food web model, this is a screening/comparative representation of the potential for trophic magnification and should not be explicitly used to estimate organism tissue concentrations.

TWA: Time weighted average. If animals are dosed every other day at 0.2 mg/kg-d their daily dose is 0.1 mg/kg-d.

LOOCV: Leave one out cross validation. One of several cross validation methods to evaluate model performance—in this case, predictive performance with "new" data. Performed by removing *i*th datapoint from data set, fitting *i*th model, and evaluating error (any method) of *i*th model's estimate of the *i*th observation. This is performed across all datapoints and the distribution of error is evaluated to determine model's overall predictive performance.

MAE: Mean absolute error. Can be others, median absolute error, etc but mean in this work. Average of *n* absolute errors (|obs-pred|). Used to represent center of error distribution identified in LOOCV.

ODE: Ordinary differential equation.

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Curriculum Vita

Andrew G. East, M.S.
Biologist, Toxicology Directorate, Defense Center for Public Health-Aberdeen
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Education:

University of Maryland | PhD in Environmental Science and Technology
Expected 2025 | Advancing understanding of terrestrial receptor exposure to PFAS mixtures.

Towson University | MS in Environmental Science
2016 | A modeling framework to explore bioenergetic effects of environmental stress and interspecific interactions.

Northland College | BS in Fish and Wildlife Ecology and Management
2010 | Magna cum laude | Meadow vole density in northern shrike winter habitat in Bayfield and Ashland counties, WI.

Professional Experience:

2020-current	*Biologist*	Defense Centers for Public Health-Aberdeen
2017-2019	*Senior Research Associate*	Towson University
2014-2016	*Graduate Research Assistant*	Towson University
2013-2014	*Research Technician*	Texas Tech University
2012	*Research Technician*	WI Dept. of Natural Resources
2012	*Field Biologist*	Earthwatch Institute
2011	*Experimental Biological Aide*	Oregon Dept. of Fish and Wildlife
2011	*Cormorant Capture Technician*	Oregon State University
2011	*Field Biologist*	BioDiversity Research Institute
2010	*Research Technician*	WI Dept. of Natural Resources
2010	*Experimental Biological Aide*	Oregon Dept. of Fish and Wildlife
2009	*Research Technician*	WI Dept. of Natural Resources
2008	*Biological Technician (Wildlife)*	U.S. Forest Service

Research Foci:

Quantitative ecotoxicology in support of ecological risk assessments.
Hazard assessment in support of alternatives assessments.

Funding:

(PI): Strategic Environmental Research and Development Program (SERDP) ER22-3388: Body Compartment Partitioning and Ecological Effects of Per- and Polyfluoroalkyl Substances (PFAS) Mixtures in a Multi-Species System. ($1.5M total budget, 50% to DCPH-A, 2022-2026)

(Co-I) SERDP ER18-1626: Investigating Potential Risk to Threatened and Endangered Species from PFAS on DoD Sites. ($1.2M total budget, 2% to DCPH-A, 2021-2026)

(Co-I) SERDP ER20-1508: Assessing the Ecotoxicity of PFAS-free Surfactant Formulations in Wild Mice. ($1.2M total budget, 100% to DCPH-A, 2020-2024)

(Co-I) SERDP ER19-1041: Determination of Biomagnification Potentials for PFAS Substances in Terrestrial Food Webs. ($1.2M total budget, 10% to DCPH-A, 2019-2023)

Professional Service:
IACUC Scientist (2022 – current) DCPH-A
Grant Reviewer (2021 – current) DoD SMART Scholarship-for-Service Program
Proposal Reviewer (2025 – current) SERDP Environmental Restoration Program
Ad-hoc Journal Reviews:
- Environmental Toxicology and Chemistry
- Ecotoxicology and Environmental Safety
- Drug and Chemical Toxicology
- Ecological Modelling
- PLOSone

Society Membership and Participation
- Society of Environmental Toxicology and Chemistry (SETAC)
  - Regional Chapter Board of Directors (gov't representative) 2022-2025
  - National Meeting Session Chair (2022)
  - Young Environmental Scientists Session Chair (2018)
- Society of Toxicology (SOT)

Teaching:
Guest Lectures
- University of Maryland
  - Intro to PFAS (2024, 2024) (ENST436, ENST334)
  - Biomarkers and Biochemical Endpoints (2025) (ENST334

Lab Assistant
- Towson University
  - Aquatic Toxicology Lab (2017) (Ind. Study)
  - Conservation Biology Lab (2015) (BIOL310/510)

Awards:
DCPH-A Performance awards
- Quality Step Improvement, Time-off/Financial Award: 2021, 2022, 2023, 2024, 2025.

Regional Chapter of SETAC 3rd place student presentation. 2025.
SETAC Young Environmental Scientists Travel Award. 2018.
Towson University Graduate Student Association Travel Award. 2016.
SETAC Student Travel Award. 2015.

Publications:
1. **A.G. East**, A.M. Narizzano, S.S. Thomas, B. Chandramouli, M.A. Bazar, L.A. Holden, *pending decision*. Evidence of additivity observed in mice exposed to a risk-relevant PFAS mixture. *ACS Environmental Au*.
2. Narizzano A.M*, **A.G. East***, C.L. Procell, M.A. Bazar, M.E. Bohannon, D. Pervitsky, M.J. Quinn, *pending decision.* Screening potential reproductive and developmental effects of fire extinguishing agents in mice. *Reproductive Toxicology*. *equal first authorship.
3. **A.G. East**, M. Simini, E.E. Stricklin, G.R. Lotufo, J.L. Guelfo, Z. Yang, T. Gallo, M.J. Quinn, R.G. Kuperman. Dietary kinetics of a PFAS mixture in the American toad (*Anaxyrus*

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4. Kuperman R.G., M. Simini, L.K. Wright, R. Moretz, E.E. Stricklin, G.R. Lotufo, R. Boyd, **A.G. East**, M.J. Quinn, J. Guelfo, Z. Yang. 2025. Determination of Biomagnification Potentials for Per- and Polyfluoroalkyl Substances in Terrestrial Food Webs: Final Report. U.S. Army Combat Capabilities Development Command Chemical Biological Center Report No.: DEVCOM CBC-TR-1919. DTIC Accession Number: AD1301142.
5. **A.G. East**, 2023-2025. (Controlled Toxicology Assessments (**7**) of PFAS-free Firefighting Foams per Military Specification (MIL-PRF-32725)). *Government Reports*
6. Salice, C.J., **A.G. East**, C. Weible, C.D. Furst, J. Rewerts, C. Heron, J. Field, 2025. Effects of perfluorooctane sulfonate (PFOS) on a novel reptilian toxicity test species, the brown anole (*Anolis sagrei*). *Environmental Toxicology and Chemistry*, doi:10.1093/etojnl/vgaf038.
7. **A.G. East**, R.H. Anderson, C.M. Duncan, C.J. Salice, 2025. Surface soil per- and polyfluoroalkyl substance mixtures dominated by perfluorooctane sulfonate: prioritization for ecotoxicity testing and ecological risk assessment at current and former U.S. Air Force bases. *Environmental Toxicology and Chemistry*, doi:10.1093/etojnl/vgaf001.
8. Narizzano, A.M., E.M. Lent, **A.G. East**, M.E. Bohannon, M.J. Quinn, 2024. Threshold for increased liver weight is protective of other effects in *Peromyscus* exposed to PFNA. Toxicological Sciences. doi:10.1093/toxsci/kfae077.
9. **A.G. East**, A.M. Narizzano, M.J. Quinn, 2024. Analysis of Kinetics and Potential Biotransformation of PFAS in *Peromyscus* with an Updated Dataset. Defense Centers for Public Health-Aberdeen. Report. DTIC accession #: AD1228881
10. **A.G. East**, A.M. Narizzano, L.A. Holden, M.A. Bazar, M.E. Bohannon, D. Pervitsky, V.H. Adams, E.N. Reinke, M.J. Quinn, 2023. Comparative toxicity of seven aqueous film forming foams (AFFFs) to *in vitro* systems and *Mus*. *Environmental Toxicology and Chemistry*, doi:10.1002/etc.5714.
11. Narizzano, A.M., M.E. Bohannon, **A.G. East**, B.A. Guigni, M.J. Quinn, 2023. Reproductive and immune effects emerge at similar thresholds of PFHxS in deer mice. *Reproductive Toxicology*, doi:10.1016/j.reprotox.2023.108421.
12. Holden, L.A., **A.G. East**, A.M. Narizzano, M.J. Quinn, 2023. Toxicology assessment for six per- and polyfluoroalkyl (PFAS)-free aqueous film forming foam (AFFF) products. *Integrated Environmental Assessment and Management*, doi:10.1002/ieam.4750.
13. Bohannon, M.E., A.M. Narizzano, B.A. Guigni, **A.G. East**, M.J. Quinn, 2023. Next-Generation PFAS 6:2 fluorotelomer sulfonate reduces plaque formation in exposed white-footed mice. *Toxicological Sciences*, doi:10.1093/toxsci/kfad006.
14. Narizzano, A.M., E.M. Lent, J.M. Hanson, **A.G. East**, M.E. Bohannon, M.J. Quinn, 2022. Reproductive and developmental toxicity of perfluorooctane sulfonate (PFOS) in the white-footed mouse (*Peromyscus leucopus*). *Reproductive Toxicology*, doi:10.1016/j.reprotox.2022.08.011.
15. Lanasa, S., M. Niedzwiecki, K. P. Reber, **A.G. East**, J. Sivey, C.J. Salice, 2022. Comparative Toxicity of Herbicide Active Ingredients, Safener Additives and Commercial Formulations to

Non-Target Algae, *Raphidocelis subcapitata*. *Environmental Toxicology and Chemistry*, doi:10.1002/etc.5327.

16. Narizzano, A.M., M.E. Bohannon, **A.G. East**, M.J. Quinn, 2021. Reproductive and developmental toxicity of per- and polyfluoroalkyl substances (PFAS) in *Peromyscus spp.* APHC Toxicological Report No. S.0073458-18.
17. Narizzano, A.M., M.E. Bohannon, **A.G. East**, C. McDonough, S. Choyke, C.P. Higgins, M.J. Quinn, 2021. Patterns in Serum Toxicokinetics in *Peromyscus* Exposed to Per- and Polyfluoroalkyl Substances. *Environmental Toxicology and Chemistry*, doi:10.1002/etc.5151.
18. **East, A.**, R.H. Anderson, C.J. Salice, 2021. Per- and Polyfluoroalkyl Substances (PFAS) in Surface Water Near U.S. Air Force Bases: Prioritizing Individual Chemicals and Mixtures for Toxicity Testing and Risk Assessment. *Environmental Toxicology and Chemistry*, doi:10.1002/etc.4893.
19. Woo, T.J., **A. East**, C.J. Salice, 2020. Intraspecific interactions affect outcomes of pulse toxicity at different *Daphnia magna* population phases. *Environmental Pollution*, doi:10.1016/j.envpol.2020.115398.
20. Green, F.B., **A. East**, C.J. Salice, 2019. Will temperature increases associated with climate change potentiate toxicity of environmentally relevant concentrations of chloride on larval green frogs (*Lithobates clamitans*)? *Science of the Total Environment*, doi:10.1016/j.scitotenv.2019.05.018.
21. Paruk, J.D., M.D. Chickering, D. Long, H. Uher-Koch, **A. East**, D. Poleschook, V. Gumm, W. Hanson, E.M. Adams, K.A. Kovach, and D.C. Evers, 2015. Winter site fidelity and winter movements in common loons (*Gavia immer*) across North America. *The Condor*, doi:10.1650/CONDOR-15-6.1.
22. Paruk, J.D., D. Long, C. Perkins, **A. East**, B.J. Sigel, and D.C. Evers, 2014. Polycyclic aromatic hydrocarbons detected in Common Loons (*Gavia immer*) wintering off coastal Louisiana. *Waterbirds*, doi:10.1675/063.037.sp111.

Invited Presentations and Seminars:

Movement of PFAS in terrestrial food webs; summary and insights from laboratory studies. USGS PFAS Research Strategy meeting. 2024.

Movement of PFAS in terrestrial food webs; summary and insights from laboratory studies. U.S. EPA Great Lakes Toxicology and Ecology Division seminar. 2024.

Developments in the understanding of biomagnification of per- and polyfluoroalkyl substances (PFAS) in terrestrial food webs. SERDP & ESTCP DOD Energy & Environment Innovation Symposium. 2023.

Toxicology Assessment of PFAS-free Fire Fighting Foam Products. Webinar. Association for the Advancement of Alternatives Assessment Mixtures and Safer Alternatives Workshop. 2023.

Phased Toxicology Approach to PFAS-free AFFFs. Webinar. One Health Week, Defense Centers for Public Health-Aberdeen. (with A.M. Narizanno) 2022.

Lessons in PFAS prioritization: strategies and methods. California DTSC. 2019.

A modelling framework to explore energetic effects of environmental stress and interspecific interactions. U.S. EPA Mid-continent Ecology Division Seminar Series. 2017.

Conference Presentations:

A. East 2025. Advancing understanding of terrestrial receptor exposure to mixtures of per- and polyfluoroalkyl substances. Chesapeake-Potomac Regional Chapter of SETAC annual meeting. Won 3rd place student presentation.

A. East 2025. Comparative product-level hazard assessments of PFAS-containing and PFAS-free firefighting foams. Society of Toxicology National Meeting.

A. East, N. Karouna-Renier, A. Narizzano, D. Haskins, M. Quinn 2024. Status update on ER22-3388 Body compartment partitioning and ecological effects of PFAS mixtures in a multi-species system. Tri-Service Toxicology Consortium.

A. East 2024. Quantifying additivity of PFAS mixtures in mice tissues. Tri-Services Toxicology Consortium.

A. East, R. Kuperman, M. Simini, G. Lotufo, L.K. Wright, J. Guelfo, M. Quinn, and T. Gallo 2024. Trophic transfer and dietary kinetics of per- and polyfluoroalkyl substance mixtures in amphibians and mammalian consumers. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

C. Procell, A. Narizzano, **A. East**, M. Quinn 2024. Comparative reproductive and developmental effects in mice exposed to a PFAS-containing AFFF and PFAS-free firefighting foam. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

N. Fuller, A. Brown, C. Custer, P. Dummer, C. Salice, **A. East**, J. Suski 2024. Assessing potential risks to insectivorous birds from per- and polyfluoroalkyl substances on Department of Defense sites: Exposure dynamics and metabolomic impacts. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

A. East, M. Quinn, M. Simini, R. Kuperman 2023. Dietary per- and polyfluoroaklyl substances (PFAS) mixture uptake and elimination in the American toad (*Anaxyrus americanus*). North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

A. East, N. Karouna-Renier, A. Narizzano, M. Quinn 2023. Body compartment partitioning and ecological effects of PFAS mixtures in a multispecies system. SERDP & ESTCP Symposium.

M. Quinn, **A. East**, A. Narizzano 2023. Assessing the ecotoxicity of PFAS-free firefighting foams in mice. SERDP& ESTCP Symposium.

K. Oyler, J. Stear, V. Adams, **A. East**, R. Damavarapu, D. Kafrouni, P. Anderson, A. Paraskos, R. Gill 2023. Alternatives to comp B in a printed grenade. SERDP & ESTCP Symposium.

A. East, L. Holden, A. Narizzano, M. Quinn 2022. Toxicity assessment of alternative aqueous film forming foams. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

R. Kuperman, L. Wright, M. Simini, R. Moretz, **A. East**, M. Quinn, G. Lotufo, R. Boyd, J. Guelfo, Z. Yang, E. Reinders 2022. Assessment of biomagnification potential for per/polyfluoroalkyl substances in terrestrial food-webs using mammalian and amphibian models. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

LA. Holden, AM. Narizzano, **A. East**, NK. Karouna-Renier 2022. Body compartment partitioning and ecological effects of PFAS mixtures in a multi-species system. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

A. East, AM. Narizzano, LA. Holden, and MJ. Quinn, Jr. 2021. Assessing the ecotoxicity of PFAS-free surfactant formulations in mice. SERDP Symposium.

A. East, LA. Holden, AM. Narizzano, and MJ. Quinn, Jr. 2021. Screening Level Hazard

Ranking in a Data-Poor Environment: A Case Study Using Fluorine-Free AFFFs. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting. A. Narizzano, M. Bohannon, **A. East**, CA. McDonough, S. Chokye, C.P. Higgins, MJ. Quinn, Jr. 2021. Kinetics and Toxicity of PFAS in Peromyscus. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Holden, L., **A. East,** A. Narizzano, C Procell, M. Quinn Jr. 2021.Toxicity Assessment of Fluorine-Free Aqueous Film- Forming Foams. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Narizzano A., **A. East**, L. Holden, M. Bazar, M. Bohannon, C. Procell, M. Quinn Jr. 2021. Acute and Subacute Toxicity Tests with Six Fluorine-Free Foams. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Procell C., M. Bazar, A. Narizzano, **A. East**, L. Holden, M. Quinn, Jr. 2021. Impact of Fluorine-Free Replacement Formulations on Clinical Chemistry and Hematology Parameters. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Anderson TS, C.D. Furst, **A. East**, C. Salice, 2021. Assessing the ecotoxicity of PFAS (Per- and Polyfluoroalkyl substances) to house crickets (*Acheta domesticus*) via a novel model system. SERDP Symposium.

Narizzano A., **A. East**, M. Bohannon, and M. Quinn, Jr. 2021. Development of Toxicity Data to support toxicity reference values for PFAS. SERDP Symposium

A. East, 2020. Putting Bounds on the PFAS Problem: Sensitivity Analysis of an Uptake Model. Tri-Services Toxicology Consortium.

A. East, 2020. Putting Bounds on the PFAS Problem: Sensitivity Analysis of an Uptake Model. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

A. East, 2020. Screening Prioritization at the Dataset Level: PFAS in AFFF Impacted Surface Water. Tri-Services Toxicology Consortium.

A. East, R.H. Anderson, C.J. Salice, 2019. Estimates and perspectives on the risk of PFAS to terrestrial and aquatic ecological receptors. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Barry, M., A.M. Isabella, **A. East**, C.J. Salice, 2019. The Protective Effects of Carbon: Why are carbon sources effective at reducing toxicity of common fungicide? North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Lanasa, S., C.J. Salice, **A. East**, J. Sivey, M. Niedzwiecki, 2019. Are "safeners" safe? Effects of unregulated inert safeners on population growth and size of non-target algae. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Huber, J.F., **A. East**, C.J. Salice, 2019. Considering behavioral endpoints to gain an improved understanding of neonicitinoid effects in aquatic systems. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Furst, C., C. Weible, **A. East**, C.J., Salice, 2019. Exploring the effects of exposure from common perfluoroalkyl substances (PFAS) on Brown Anoles (*Anolis sagrei*). North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Ribeiro, P., F. Green, **A. East**, C.J. Salice, 2019. Do standard toxicity tests reflect ecologically relevant conditions? *Xenopus laevis* vs. native *Anuran* sensitivity to chloride with varied resources. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.

Isabella, A.M., **A. East**, C.J. Salice, 2019. Building a bigger picture: Exploring effects of

realistic resource and chemical environments on population-level ecotoxicology of *D. magna*. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
Salice, C. J., **A. East**, H. Anderson, 2019. PFAS in the Environment: A Survey of Occurrence, Relevant Concentrations, and Observed Effects. SETAC Environmental Risk Assessment of Per- and Polyfluorolalkyl Substances (PFAS) Focused Topic Meeting.
Salice, C. J., **A. East**, C. Weible., C. Furst, 2019. Ecotoxicity, Exposure and Ecological Risk of Per- and Polyfluoroalkyl Substances to Terrestrial Reptiles. SETAC Environmental Risk Assessment of Per- and Polyfluorolalkyl Substances (PFAS) Focused Topic Meeting.
East, A., H. Anderson, C. J. Salice, 2019. Estimates and Perspectives on Risk of PFOS to Aquatic and Terrestrial Receptors. SETAC Environmental Risk Assessment of Per- and Polyfluorolalkyl Substances (PFAS) Focused Topic Meeting.
Lanasa, S., **A. East**, C.J. Salice, 2018. What's in your herbicide? Unregulated "safeners" modify effects of S-metolachlor on non-target algal species. Maryland Water Monitoring Council Conference.
Barry, M., A. Isabella, **A. East**, C.J. Salice, 2018. Increasing environmental realism: *Daphnia magna* toxicity tests with locally relevant stressors and resource environments. Maryland Water Monitoring Council Conference.
Salice, C.J., **A. East**, C. Weible, C.D. Furst, 2018. Ecological risk of per- and polyfluoroalkyl substances to terrestrial receptors: Are reptiles relevant receptors? SERDP & ESTCP Symposium.
East, A., R.H. Anderson, C.J. Salice, 2018. Prioritization and risk profile of per- and polyfluoroalkyl substances for terrestrial ecological receptors. SERDP & ESTCP Symposium.
East, A., R.H. Anderson, C.J. Salice, 2018. Per- and polyfluoroalkyl substance (PFAS) prioritization and risk factors for terrestrial ecological receptors. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
Weible, C., **A. East**, C.J. Salice, 2018. Exposure and effects of common perfluoroalkyl substances (PFASs) on Brown Anoles (*Anolis sagrei*). North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
Salice, C. J., **A. East**, 2018. Prioritizing PFASs mixtures and sites for focused ecotoxicology, ecological risk assessment and risk communication. Emerging Contaminants Summit.
East, A., 2018. Updating individual-based avian exposure and effect modelling. Young Environmental Scientists Annual Meeting.
East, A., C.J. Salice, 2017. Strategies to prioritize PFASs mixture identification for ecotoxicity testing and risk assessment. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
East, A., M. Smith, C.J. Salice, 2017. Bridging the gap between multiple stressor data and reality: A case study with *Daphnia* population dynamics and individual-based modeling. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
East, A., C.J. Salice, 2017. Prioritizing PFAS mixtures and sites for focused ecotoxicology, ecological risk assessment, and risk communication. SERDP & ESTCP Symposium.
Smith, M., **A. East**, K. McCreesh, J. Moore, C.J. Salice, 2017. Bioenergetic signatures of stress in caddisfly larvae from streams along an urban to rural gradient. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
Green, F., R. Morin, **A. East**, C.J. Salice, 2017. Effects of road deicing salt and temperature on larval green frogs in central Maryland. Maryland Water Monitoring Council Annual Meeting.

East, A., V. Pereira, C.J. Salice, 2017. Mathematical Approaches to Predicting Population Level Effects of Anthropogenic Stressors. Towson University Environmental Conference.
Pereira, V., **A. East**, C.J. Salice, 2017. Effects of environmentally relevant concentration of PFOS on population dynamics of *Daphnia magna*. Chesapeake and Potomac Regional Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
East, A., T. Woo, and C.J. Salice, 2016. Predicting toxic effects of ion pulses from urban streams in Baltimore County, MD. Maryland Water Monitoring Council Annual Meeting.
Smith, M., **A. East**, and C.J. Salice, 2016. Bioenergetic Response to Stress: Lipid Content in Surface Water and Caddisfly Larvae across a Rural to Urban Gradient. Maryland Water Monitoring Council Annual Meeting. ***Won Best Student Poster Contest***
East, A. and C.J. Salice. 2016. Individual-based and system dynamic modeling frameworks to explore a complex energetic process in aquatic communities. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
East, A. and C.J. Salice. 2016. Simulating system level effects of stress on aquatic systems through linked dynamic energy budget individual-based models (DEB-IBMs) in Netlogo. International Society of Ecological Modelling Annual Meeting.
East, A. and C.J. Salice. 2016. An individual-based model to link organismal energetic stress to population level effects. Young Environmental Scientists Annual Meeting.
Lockett, L, **A. East**, and C.J. Salice, 2016. An examination of the impacts of temperature on standard toxicological protocols using pyraclostrobin and *Daphnia magna*. Maryland Water Monitoring Council Annual Meeting.
Woo, T., **A. East**, and C.J. Salice, 2016. Timing is everything: assessing the effects of pulse exposure patterns on salt toxicity in *Daphnia magna*. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
Lockett, L., **A. East**, and C.J. Salice, 2016. Exploring the impacts of multiple anthropogenic and environmental stressors: data needs for predicting ecological effects. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
Pererira, V., T. Woo, **A. East**, and C.J. Salice. 2015. Effects of common anthropogenic pollutants on the surrogate freshwater invertebrate, *Daphnia magna*. Maryland Water Monitoring Council Annual Meeting.
East, A. and C.J. Salice. 2015. A mechanistic bioenergetic model to understand effects of anthropogenic stressors on multiple species aquatic systems. Chesapeake and Potomac Regional Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.
East, A. and C.J. Salice. 2014. Developing a bioenergetic framework for sentinel species and predicting effects of disturbance on Maryland streams. Maryland Water Monitoring Council Annual Meeting.
Salice, C.J., **A. East**, A. Olson, B. Perkins, and E. Reategui-Zirena. 2014. A Bioenergetic-Based Approach to Identify and Understand the Effects of Pesticides on Ground Nesting Birds. North American Chapter of the Society of Environmental Toxicology and Chemistry Annual Meeting.