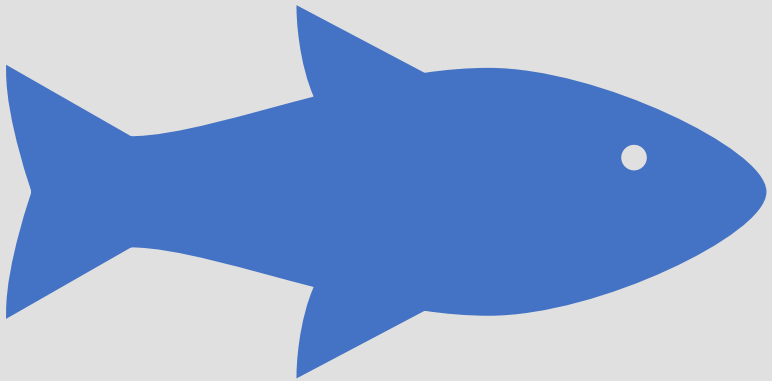

Perfluoroalkyl Substances and Fish Consumption in the Great Lakes Fish Consumer Study

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Disclosures/Acknowledgements

- ATSDR 75/ATH598322
- US EPA STAR Program Grant RD-83025401-1
- NIEHS R21 ES030792
- Wisconsin Dept. of Health Services Collaborators: Henry Anderson, Jon Meiman, Pamela Imm, Linda Knobleoch

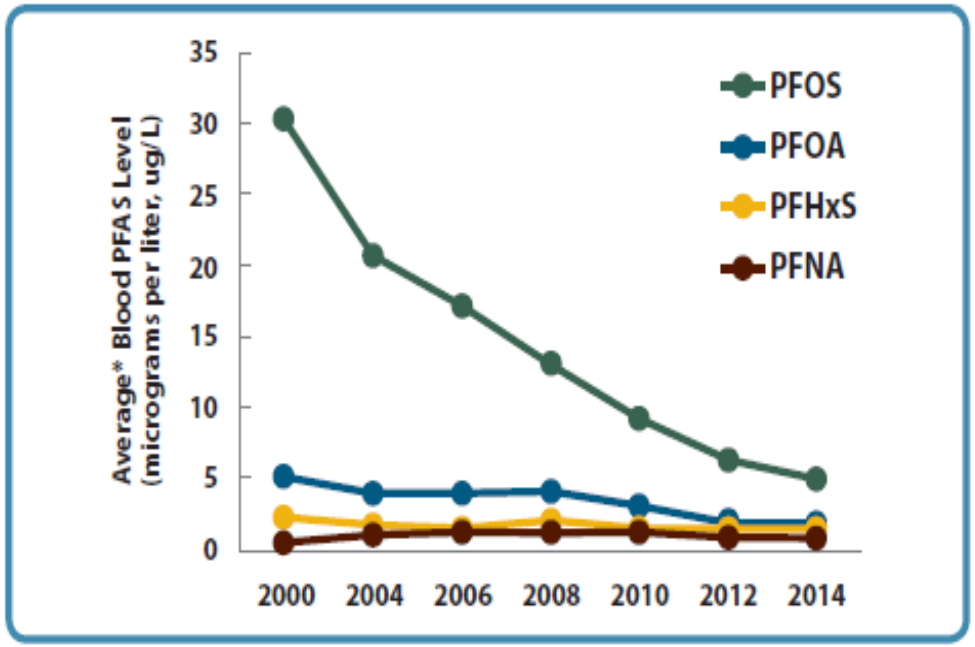
Background: Perfluoroalkyl Substances (PFAS)

- PFAS are a very large group of man-made chemicals
  - **Do not occur naturally in the environment**
- Many industrial applications due to PFAS properties:
  - **Very stable** chemicals with low volatility (due to the carbon-fluorine bond)
  - Hydrophobic & oleophobic
- Properties that make PFAS attractive for industry use are bad for the environment
  - The stability and long half-lives causes **PFAS to persist in the environment**
  - Bioaccumulative
- PFAS detected in every type of environmental media
  - Air, water, soil, food
- PFAS have been detected globally – including the Arctic

Background: Human Exposure to PFAS

- PFAS are frequently detected in serum samples identified in National Health And Nutrition Examination Survey (NHANES)
  - Studies have shown trends of decreasing PFAS (mainly PFOA and PFOS) levels detected in US serum samples
  - Other PFAS chemicals are increasing
  - Kato et al. 2011, Environ. Sci. Technol
- PFAS have a long half life in humans (ATSDR, 2021)
  - PFOA: 2-10 years
  - PFOS: 3.3-27 years
  - PFHxS: 4.7-35 years
- PFAS exposure linked to several adverse health effects including cancer and disruption of hormone and metabolic function

Blood Levels of the Most Common PFAS in People in the United States from 2000-2014



* Average = geometric mean

Data Source: Centers for Disease Control and Prevention. Fourth Report on Human Exposure to Environmental Chemicals, Updated Tables, (January 2017). Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention.

Background: PFAS Biomarkers in Fish Consumers

- Seafood consumption from contaminated waters may be a source of PFAS exposure
  - PFAS biomarkers have been associated with consumption of fin fish and shellfish
  - Christensen et al. 2017, Environ Res
  - Ruffle et al. 2020, Environ Res

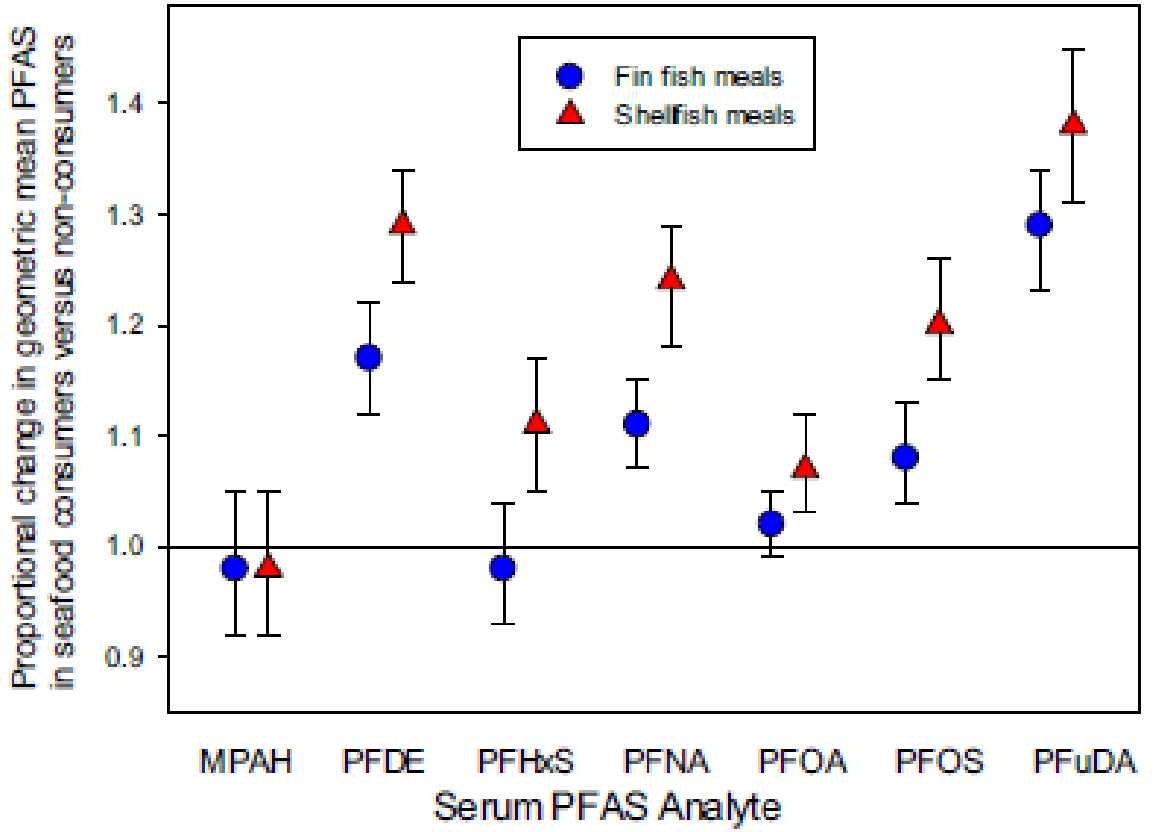
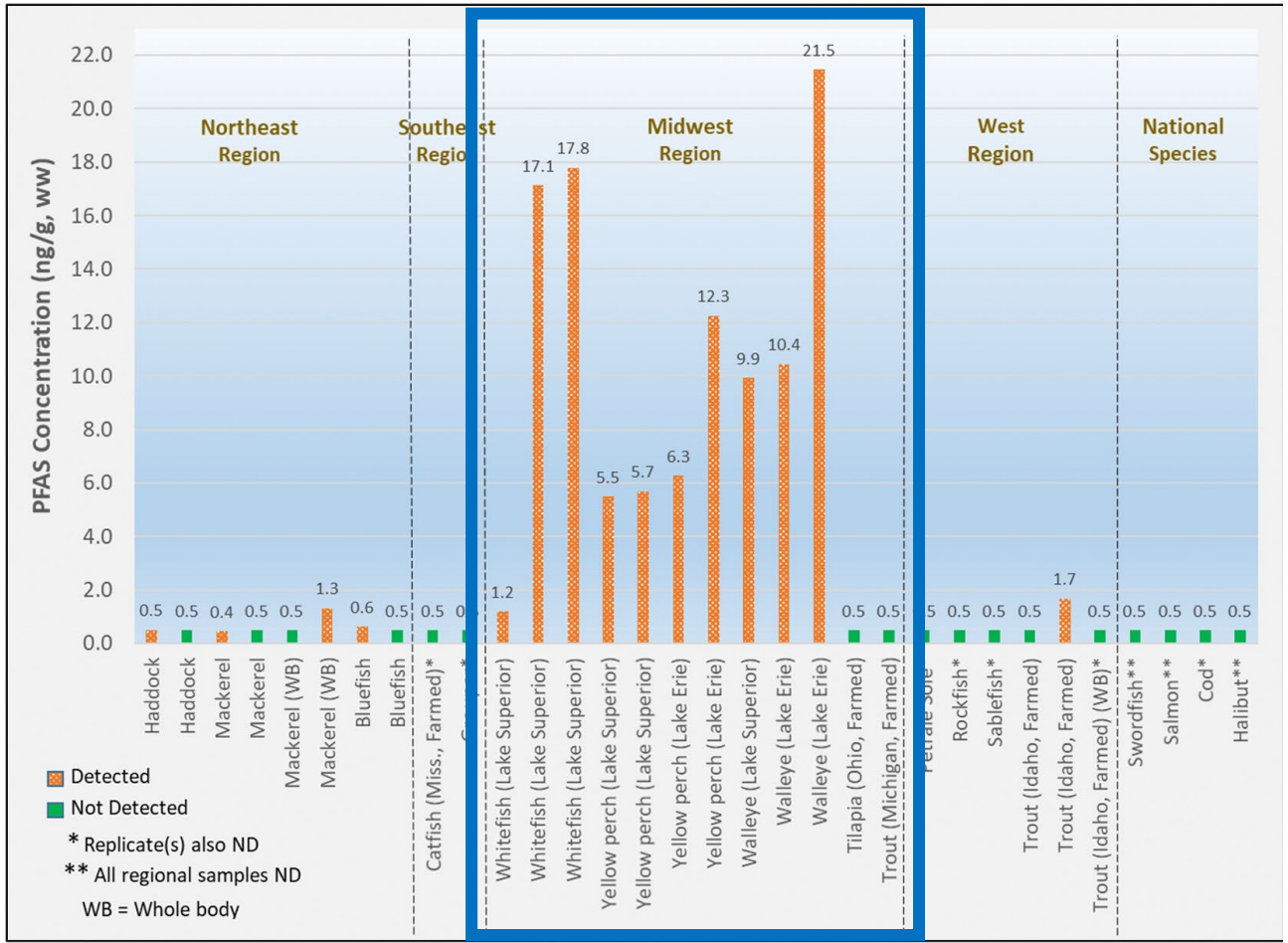
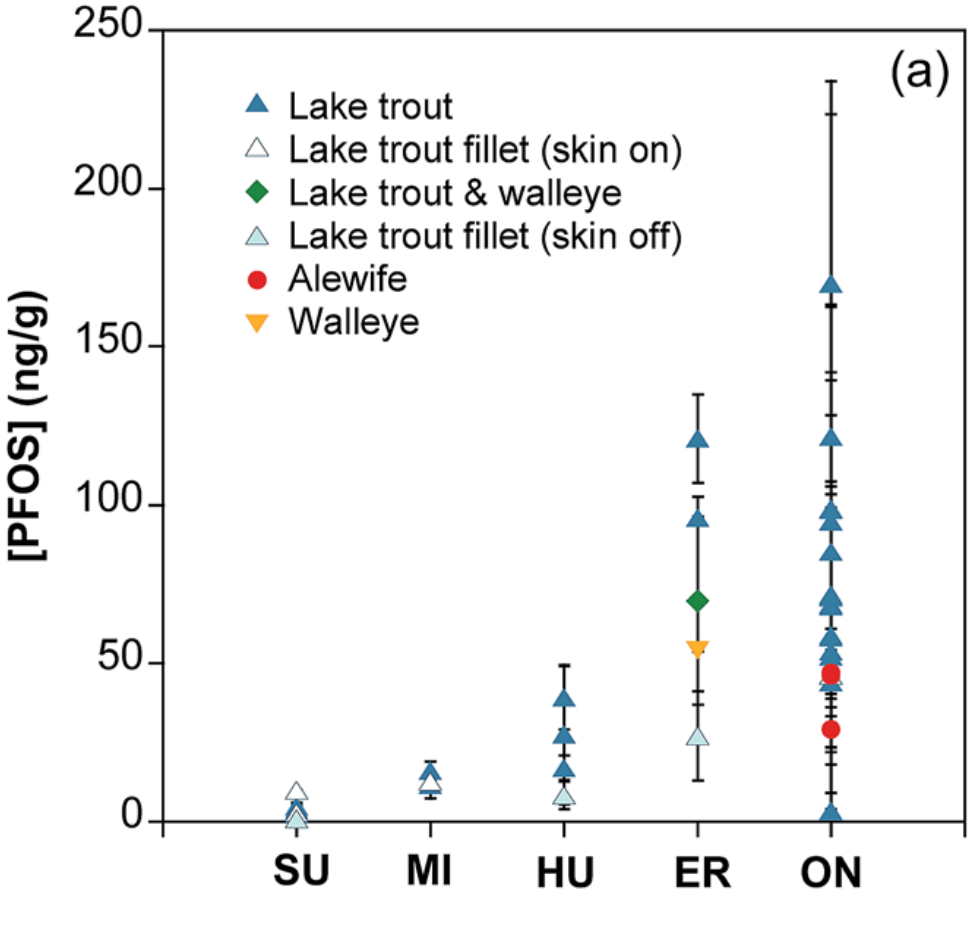


Fig. 1. Associations between seafood consumption in the last 30 days and PFAS concentrations, after adjusting for age, BMI, sex, race/ethnicity and survey cycle.

Background: PFAS Contamination in GL Fish

- PFAS are ubiquitous in water, sediment and biota in the Great Lakes
  - PFAS levels were highest in purchased fish sourced from the GL (Ruffle et al, Environ Res 2020)
  - Contamination in lake trout is highest Lakes Erie and Ontario and lowest in Lake Superior (Remucal, Environ Sci Processes 2019)





Background: Great Lakes Fish Consumption Study (GLFCS)

- In the US states bordering the Great Lakes, **about 4.2 million adults** consume Great Lakes fish
  - 500,000 consuming ≥2 meals/month
- Five State Health Departments (WI, IL, IN, OH, MI), led by Dr. Henry Anderson, formed the **Great Lakes Consortium** in 1992 to look at critical pollutants in Great Lakes fish consumers
  - Participants were recruited from licensed Great Lake charter boat captains
  - Referent participants were recruited from people who lived in the same geographic areas and had little-to-none Great Lake fish consumption
  - Subgroup of Wisconsin anglers enrolled who fish other inland lakes (not Great Lakes)
  - Follow-up for exposure and health biomarkers through 2004
- Great Lakes fish consumption shown to be a **significant exposure source of PCBs and DDE**
  - Hanrahan et al. 1999, Environ Res

Objective

Assess if serum PFAS levels are associated with self-reported fish meals in a cohort of frequent and infrequent Great Lakes sport fish consumers

Methods: Study Population

- A cross-sectional analysis of the GLFCS cohort of frequent and infrequent Great Lakes sport fish consumers in 2004 (Anderson et al. 2008, Chemosphere)
- 474 stored blood serum samples were tested for 12 PFAS by the Centers for Disease Control
  - On-line solid phase extraction-HPLC-isotope dilution-MS/MS methods (Kato et al. 2018, Chemosphere 209:338)
  - Observations below the LOD were imputed as LOD/√2
  - 6 observations removed missing covariates: Final N=468
- Participants completed detailed questionnaires on their fish consumption and health history
  - Fish meals consumed in the past year by fish species and source
    - Great Lakes sport caught, other inland bodies of water sport caught, commercially purchased

Methods: Study Variables Used in Linear Regression Models

PFAS Compounds (log_2 transformed for analysis):

- 2-(N-Ethyl-perfluorooctane sulfonamido) acetic acid (**EtFOSAA**)
- Perfluorooctane sulfonamide (**FOSA**)
- 2-(N-Methyl-perfluorooctane sulfonamido) acetic acid (**MeFOSAA**)
- n-Perfluorooctanoic acid (**n_PFOA**)
- n-Perfluorooctane sulfonic acid (**n_PFOS**)
- Perfluorodecanoic acid (**PFDA**)
- Perfluoroheptane sulfonic acid (**PFHpS**)
- Perfluorohexane sulfonic acid (**PFHxS**)
- Perfluorononanoic acid (**PFNA**)
- Perfluoroundecanoic acid (**PFUnDA**)
- Branched Perfluoromethylheptane sulfonic acid isomers (**Sm_PFOS**)
- Branched isomers of perfluorooctanoate (**Sb_PFOA**)

Predictors:

- Great Lake sport fish meals
- Commercial fish meals
- Sport fish meals from other inland bodies of water
- Age, Sex, Body Mass Index (BMI), and Education level

Results: Demographics

Variable	Total Cohort (n=468)
	Median (IQR)
Age (years)	58.0 (13.0)
BMI (kg/m^2)	28.9 (6.9)
Sex	**N (%)**
Male	326 (69.7)
Female	142 (30.3)
Group	**N (%)**
Referent	84 (18.0)
Angler	47 (10.0)
Captain	337 (72.0)
Education	**N (%)**
Highschool/GED	132 (28.2)
Undergraduate College	195 (41.7)
Graduate School	141 (30.1)

Variable*	Male	Female	p
Total Great Lake Fish Meals	12.0 (31.0)	4.0 (25.0)	<.0001
Total Commercially Purchased Fish Meals	14.0 (48.0)	15.0 (46.0)	0.15
Inland Fish Meals (Not Great Lakes)	0 (5.0)	0 (1.0)	0.057

*Median (IQR)

Results: Geometric Means and Percentiles of Total Commercially Purchased Sport Fish Meals & Sport Caught Fish Meals from the Great Lakes

Number of Sport Fish Meals Consumed Over the Past Year	Geometric Mean (COV%)*	50th Percentile	75th Percentile	90th Percentile	95th Percentile
Total Sport Fish Meals from the Great Lakes	6.1 (5.6)	10.0	30.0	53.0	71.0
Total Commercial Fish Meals	12.0 (4.7)	15.0	52.0	103.0	115.0
Other Inland Water Bodies Fish Meals	NA	0	3.0	22.0	40.0

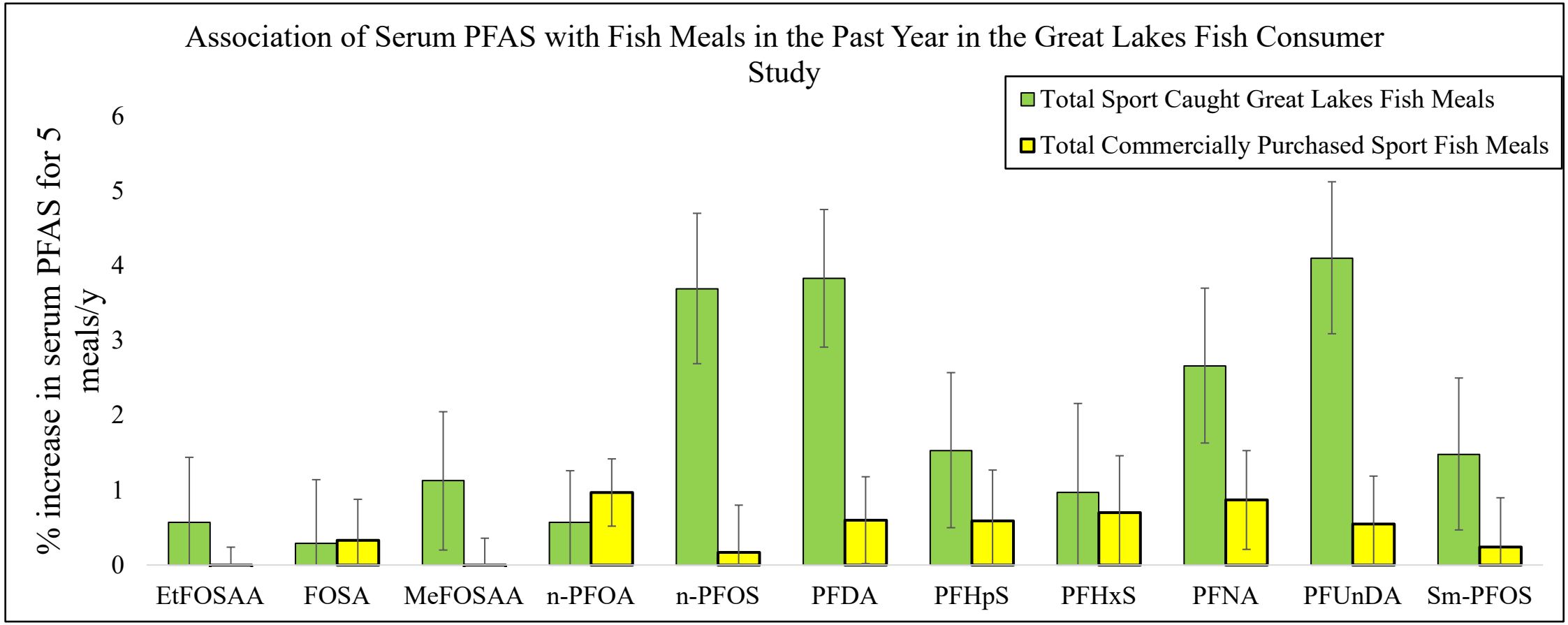
*COV=Coefficient of Variation

Results: Geometric Means and Percentiles for PFAS Serum Concentration in the GLFCS Cohort

Chemical	% Below LOD	Geometric Mean (COV%)*	50th Percentile	75th Percentile	90th Percentile	95th Percentile
EtFOSAA	7.2	0.16 (61.4)	0.2	0.2	0.3	0.4
FOSA	17.2	0.15 (59.5)	0.2	0.2	0.4	0.6
MeFOSAA	0.0	0.54 (65.0)	0.5	0.8	1.2	1.6
n-PFOA	0.0	4.45 (47.6)	4.6	5.9	7.7	9.1
n-PFOS	0.0	20.72 (81.7)	20.9	33.6	52	67.3
PFDA	0.0	0.47 (70.6)	0.4	0.7	1.1	1.5
PFHpS	3.6	0.59 (78.2)	0.6	0.9	1.2	1.5
PFHxS	0.0	2.84 (92.2)	2.7	4.4	7.5	11.3
PFNA	1.5	0.90 (78.0)	0.9	1.4	2	2.4
PFUnDA	2.1	0.30 (77.6)	0.3	0.5	0.7	0.9
Sm-PFOS	0.0	7.98 (71.9)	8.2	12.3	17.9	20.6
Sb-PFOA	100.0	-	-	-	-	-

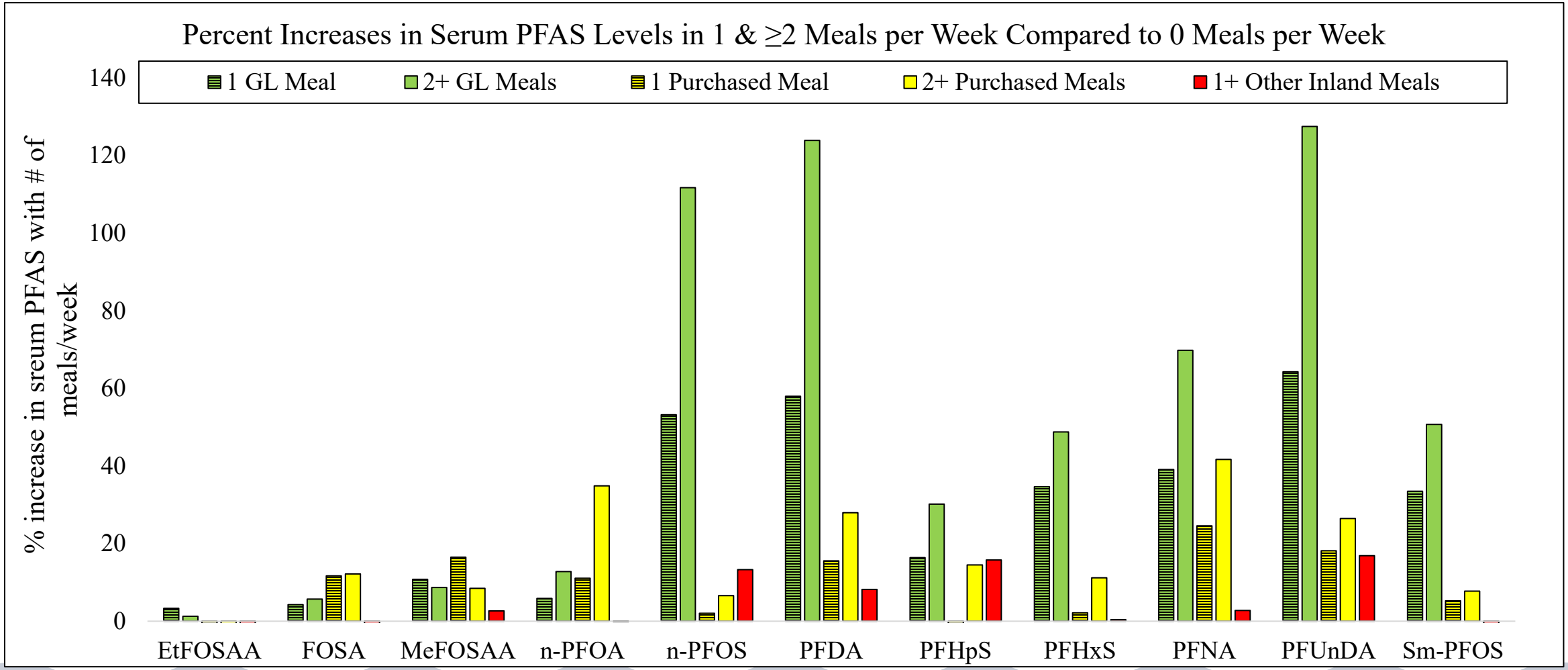
- Measurement units – ng/mL *COV=Coefficient of Variation

Results: Percent Serum PFAS Levels for Increases in 5 Sport Fish Meals per Year



- Each linear regression model adjusted for Age, Education, BMI, and Sex
- Great Lakes and Commercial Fish meals modeled together as continuous variables

Results: Percent Increases in Serum PFAS Levels for 1 & for ≥2 Meals per Week Compared to 0 Meals per Week



- Each model adjusted for Age, Education, BMI, and Sex
- Great Lakes (GL), Commercial Fish, and Other Inland meals modeled together as categorical variables

Limitations

- Cross-sectional
- Data was collected in 2004
  - Unclear if there have been changes in PFAS levels in Great Lakes fish from Lakes Erie, Michigan and Huron
- Recall bias may be present as fish consumption was self-reported on questionnaires
- Potential residual confounding due to other unmeasured exposures
  - Occupation
  - Drinking Water
  - Proximity to industrial sites with PFAS emissions

Conclusions

- Significant increases in serum concentrations of several PFAS were seen for increasing meals of both Great Lakes sport caught fish and commercially purchased fish
  - Larger increases for Great Lakes than commercial fish meals
- Future analyses will examine
  - Fish types and Great Lake of capture where sample size permits
  - Correlations of PFAS biomarkers with other measured contaminant biomarkers (PCBs, PBDEs, DDE, mercury) in study participants

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Thank You!