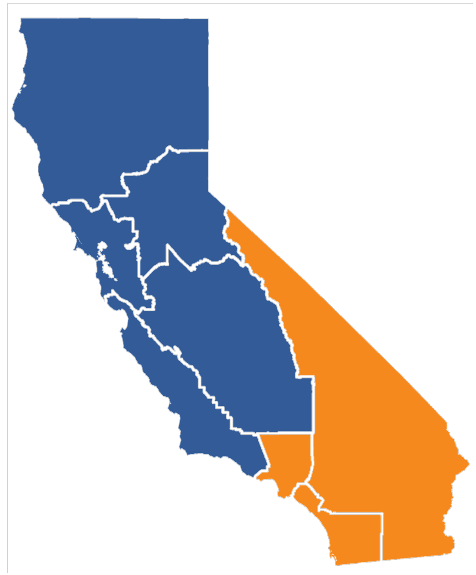
Exposure to legacy PFAS from diet and drinking water in California adults, 2018-2020



Biomonitoring California, Scientific Guidance Panel Meeting

March 25, 2025

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Disclosure

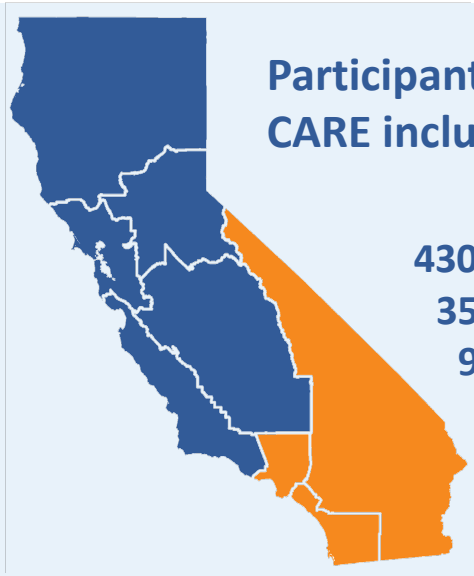
- **The authors declare no conflicts of interest**

CARE Study

- California adult residents (n=879)
- 12 PFAS measured in serum
- Survey questionnaires
- Geocoded residential addresses

BIOMONITORING CALIFORNIA

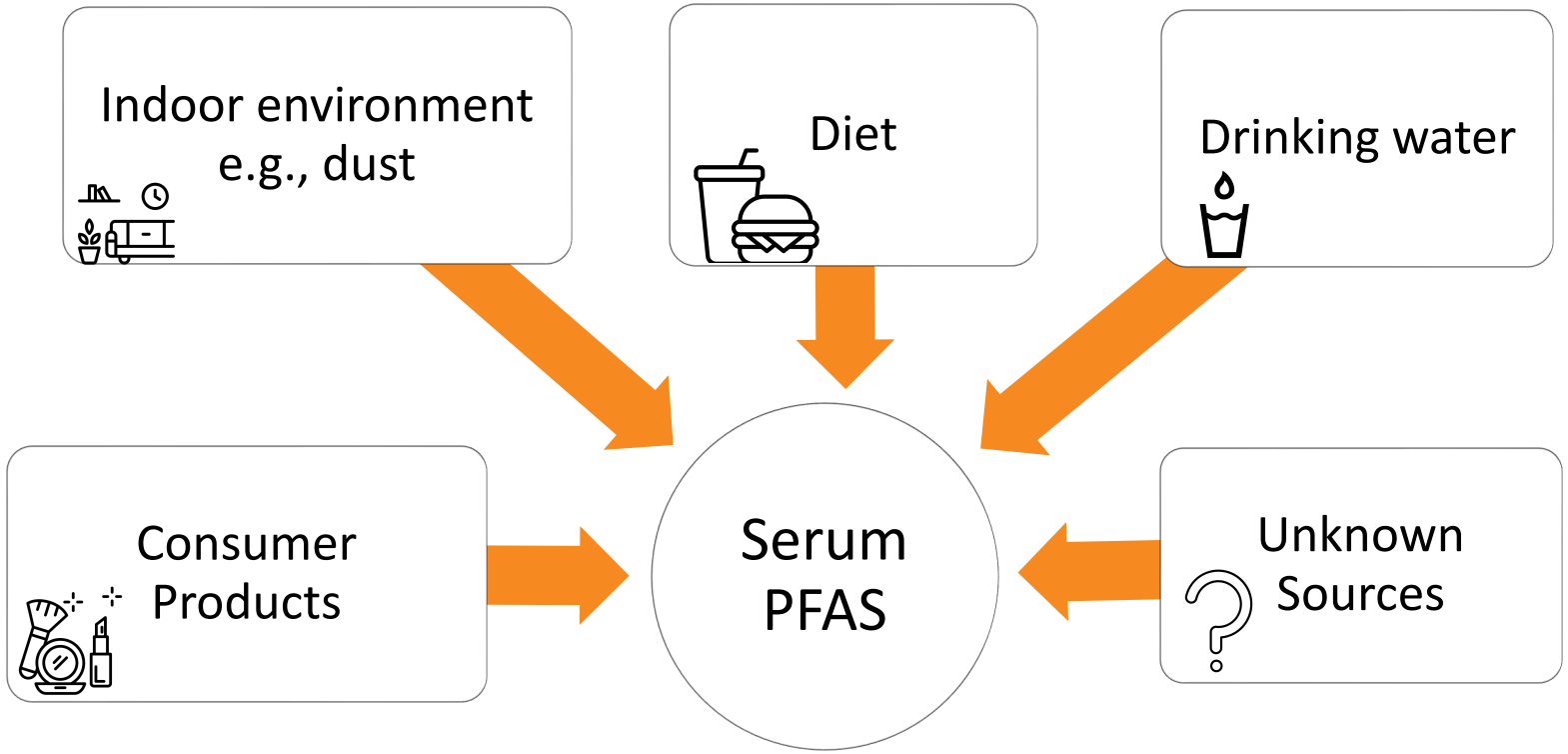
MEASURING CHEMICALS IN CALIFORNIANS



Participants in 3 regions of CARE included:

430 in CARE-LA (2018)
359 in CARE-2 (2019)
90 in CARE-3 (2020)

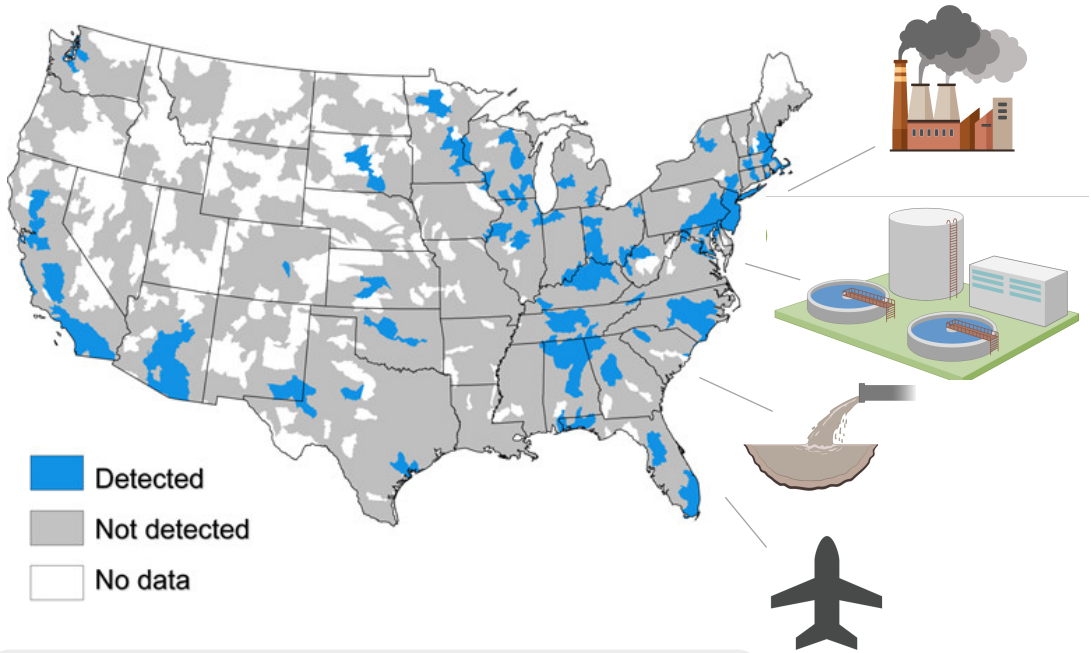
People are exposed to PFAS from multiple sources



Linear relationship between water and serum

Haug et al., 2011; Schrenk et al., 2020; Hoffman et al., 2011; Hu et al., 2019; Makey et al., 2017; Bartell et al., 2010; Kotthoff et al., 2015; Schultes et al., 2018

Legacy PFAS in U.S. public water supplies



UCMR 3: U.S. EPA Third Unregulated Contaminant Monitoring Rule.

Image adapted from Hu et al., 2016 and BioRender.com

Relatively low levels of exposure to legacy PFAS in drinking water linked to elevated levels in serum in the general population

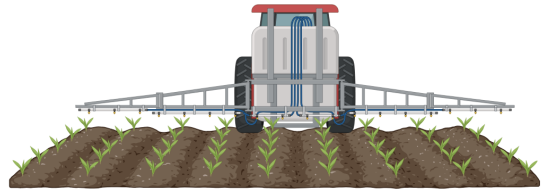
- Nurses Health Study (1989-1990)
- California Teacher's Study (2011-2013)
- Child Health and Development Studies (2010-2013)

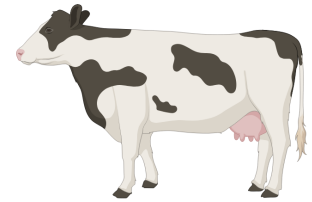
Hu et al., 2019; Hurley et al., 2016; Boronow et al., 2019

Legacy PFAS in food

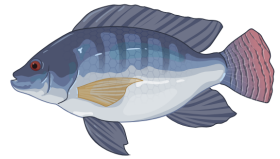
1. Grease repellant food packaging

2. Soils amended with biosolids





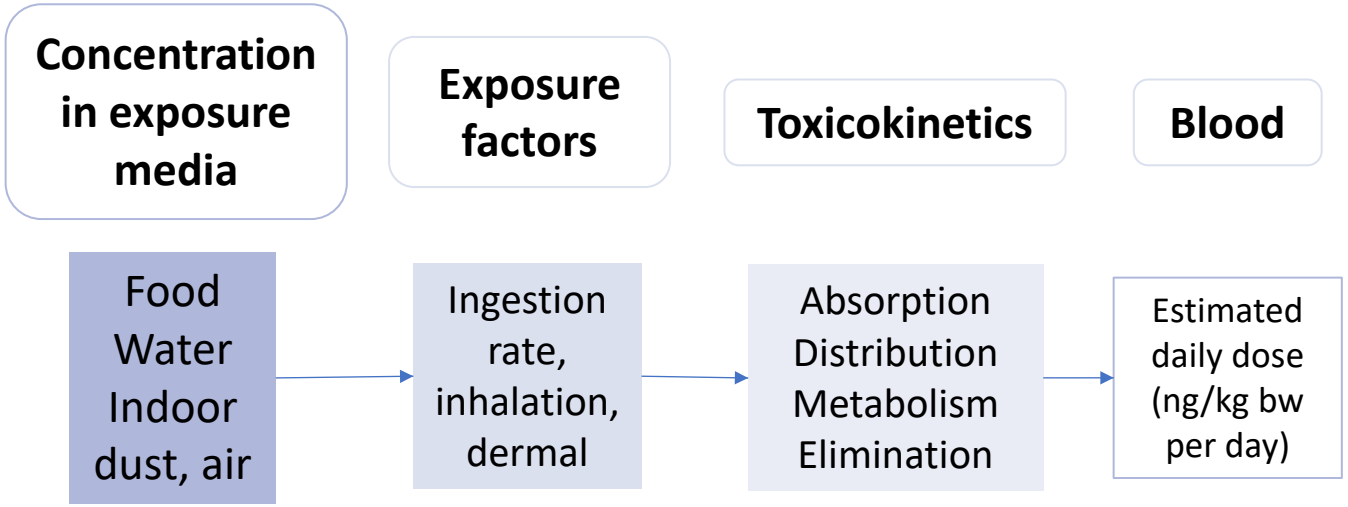
3. Environmental uptake



Begley et al., 2008; Phelps et al., 2024; Hamid et al., 2016; Johnson, 2022; Simones et al., 2024; Pickard et al., 2022; Giffard et al., 2023; Barbo et al., 2023

Created with BioRender.com

Estimating sources of exposure



Schematic adapted from De Silva et al., 2021

Diet estimated to be major source of exposure in the general population

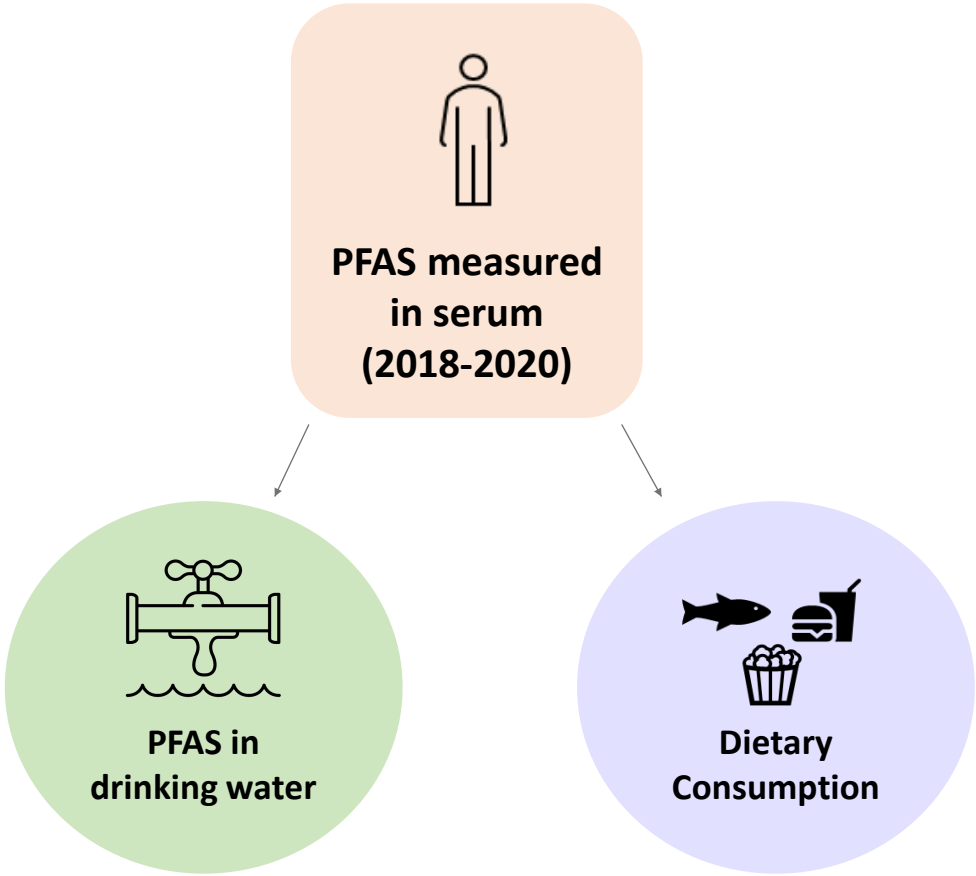
- Europe
- Canada

Food data in the U.S. are limited

- Commercial seafood
- Freshwater fish

Schrenk et al., 2020; Haug et al., 2010; Poothong et al., 2020; Tittlemeier et al., 2007; Young et al., 2022; Schecter et al., 2010; Ruffle et al., 2020; Barbo et al., 2019; Stahl et al., 2014

Epidemiological Approach



Elevated serum concentrations associated with consumption of seafood, red meat, dairy, and fast food

Objective: Characterize PFAS body burden in CARE and estimate the relationship between serum PFAS with diet and drinking water.

Christensen et al., 2017; Susmann et al., 2019; Eick et al., 2021; Lin et al., 2020

Dietary assessment

CARE Study
California Regional Exposure Study

Food Frequency Questionnaire:

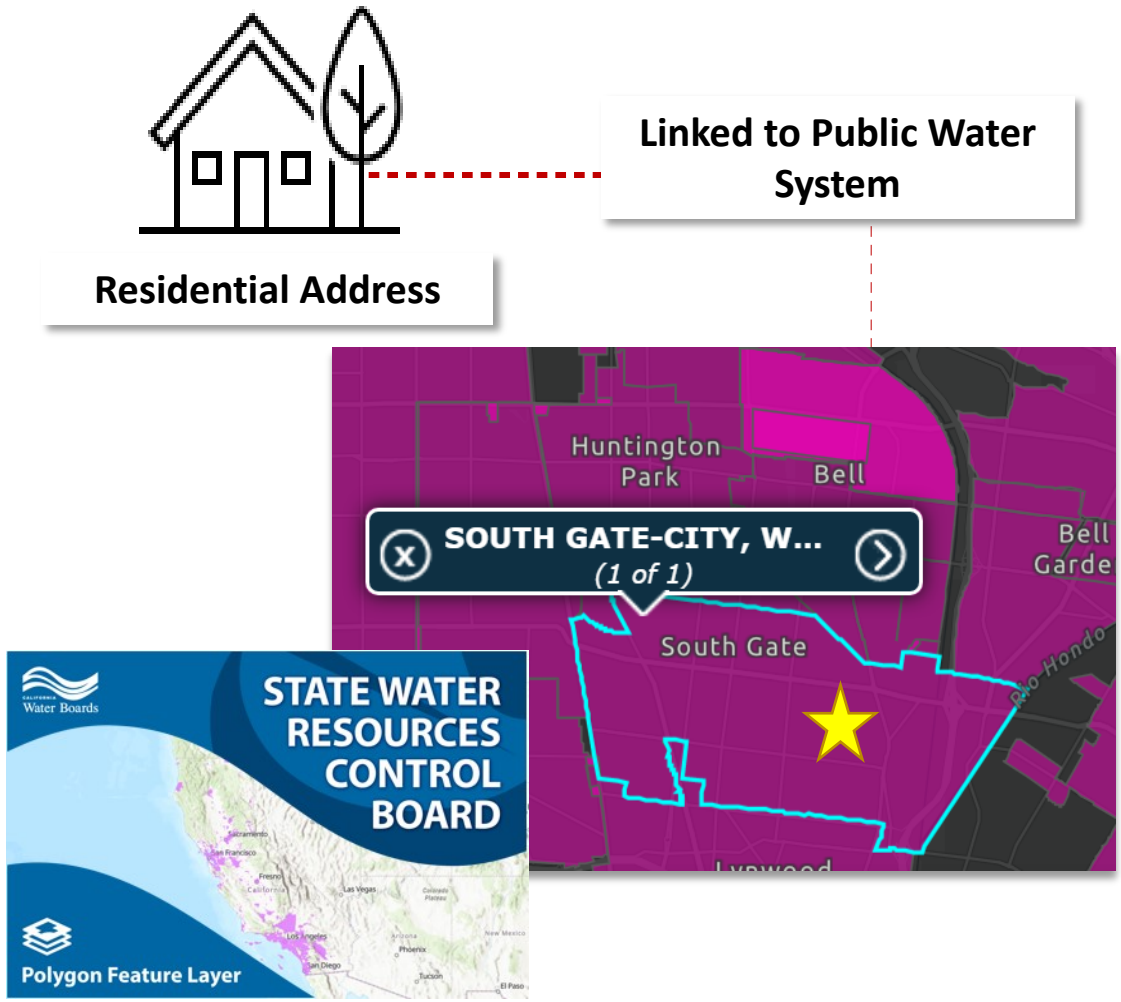
- Participants asked how often they eat certain foods in a typical week.
- Questionnaire typically completed within 3 weeks prior to serum collection.

As part of your diet in a typical week, how often do you eat each of the following meat, poultry, and fish? Please check the appropriate box.

Food	I don't eat this food	Yes, I eat this food				Don't know	Prefer not to answer
		Rarely (Less than once per week)	1–3 days per week	4–6 days per week	Every day		

Drinking water

- PFAS measured in **UCMR 3** (2013-2015)
- Binary detect/non-detect exposure



Comparison with other CARE analyses

	UCMR 3 (2013-2015)	CA Water Boards PFAS Monitoring (2019-2022)
		THIS ANALYSIS
Water Source	Finished water	Mostly source wells
Sample Area	All PWS serving >10,000*	Areas with suspected PFAS contamination
Reporting Limits	20-40 ppt	2-4 ppt
Participants	700	563

* Plus 800 additional representative PWSs serving ≤10,000 people

Statistical analysis

Goal: Estimate the relationship between two exposures, diet and water, and levels of PFAS in serum

Approach: Multivariate robust linear regression

- Down-weight extreme values
- Model additive relationship between multiple exposures and non-transformed serum concentrations
- Absolute vs relative (%) measure of effect

- Select potential confounders *a priori* based on the literature and directed acyclic graphs (DAGs)

Study population

- 700 participants with complete serum and survey data successfully matched to a public water system monitored in UCMR 3
- Majority female, having completed some education above high school, Hispanic or Latino or White

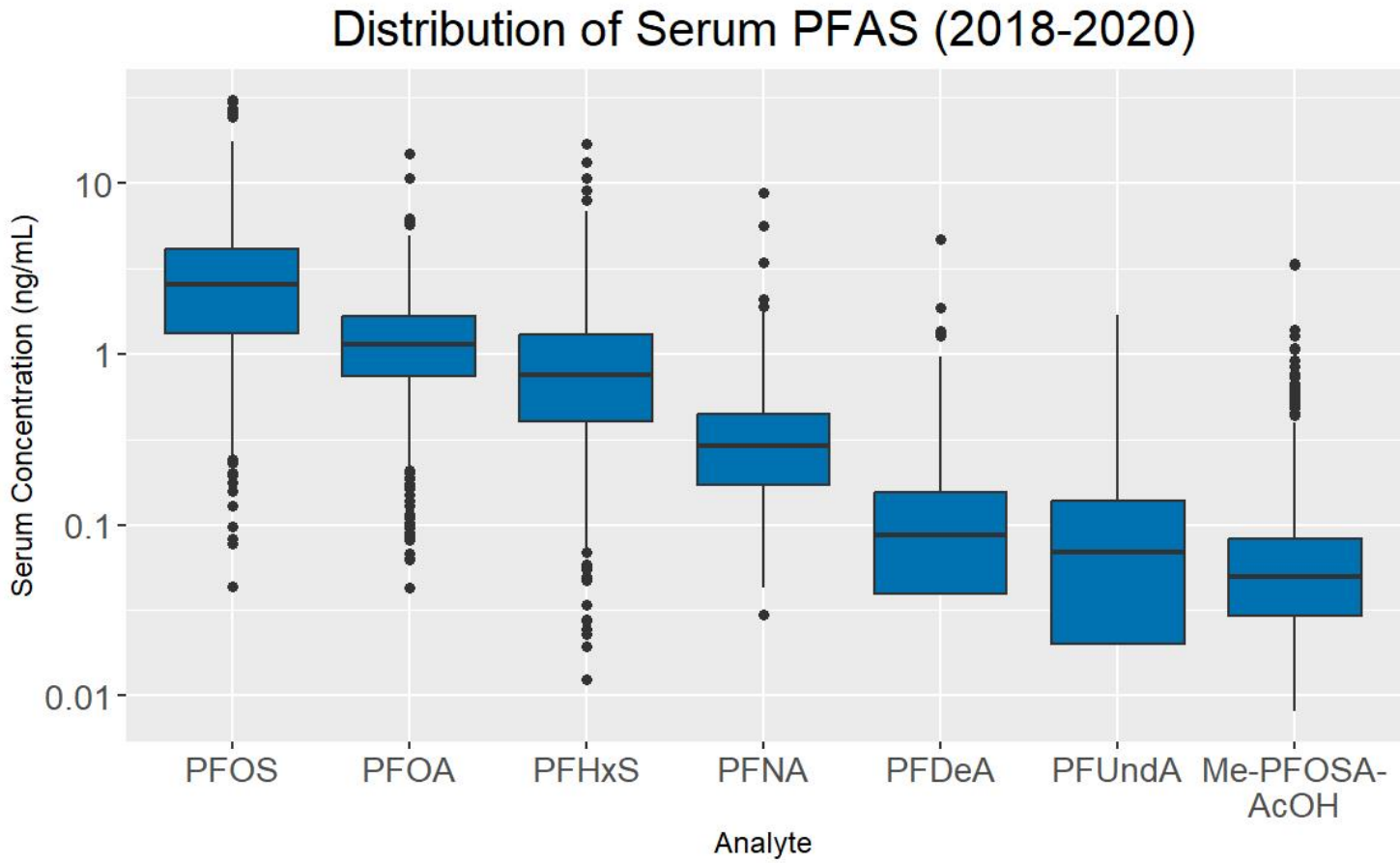
Summary Statistics for CARE Population Analyzed

	N	Percent
Sex & Parity		
Male	286	41%
Female & nulliparous	160	23%
Female & 1⁺ pregnancies brought to term	254	36%
Education		
High School or Below	107	15%
Above High School	693	85%
Race/Ethnicity		
Hispanic or Latino	274	39%
White	240	34%
Asian	89	13%
Black	63	9%
Non-Hispanic Multi-Racial and Other	34	5%
Household Income		
$25K or less	183	26%
$25,001 to $75,000	273	39%
$75,001 to $150,000	172	25%
More than $150K	72	10%

Unweighted data shown; weighted data are available.

Serum PFAS

- Serum analyzed by Environmental Chemistry Laboratory at California Department of Toxic Substances Control
- 7 PFAS detected in >65% of study population and included in analysis



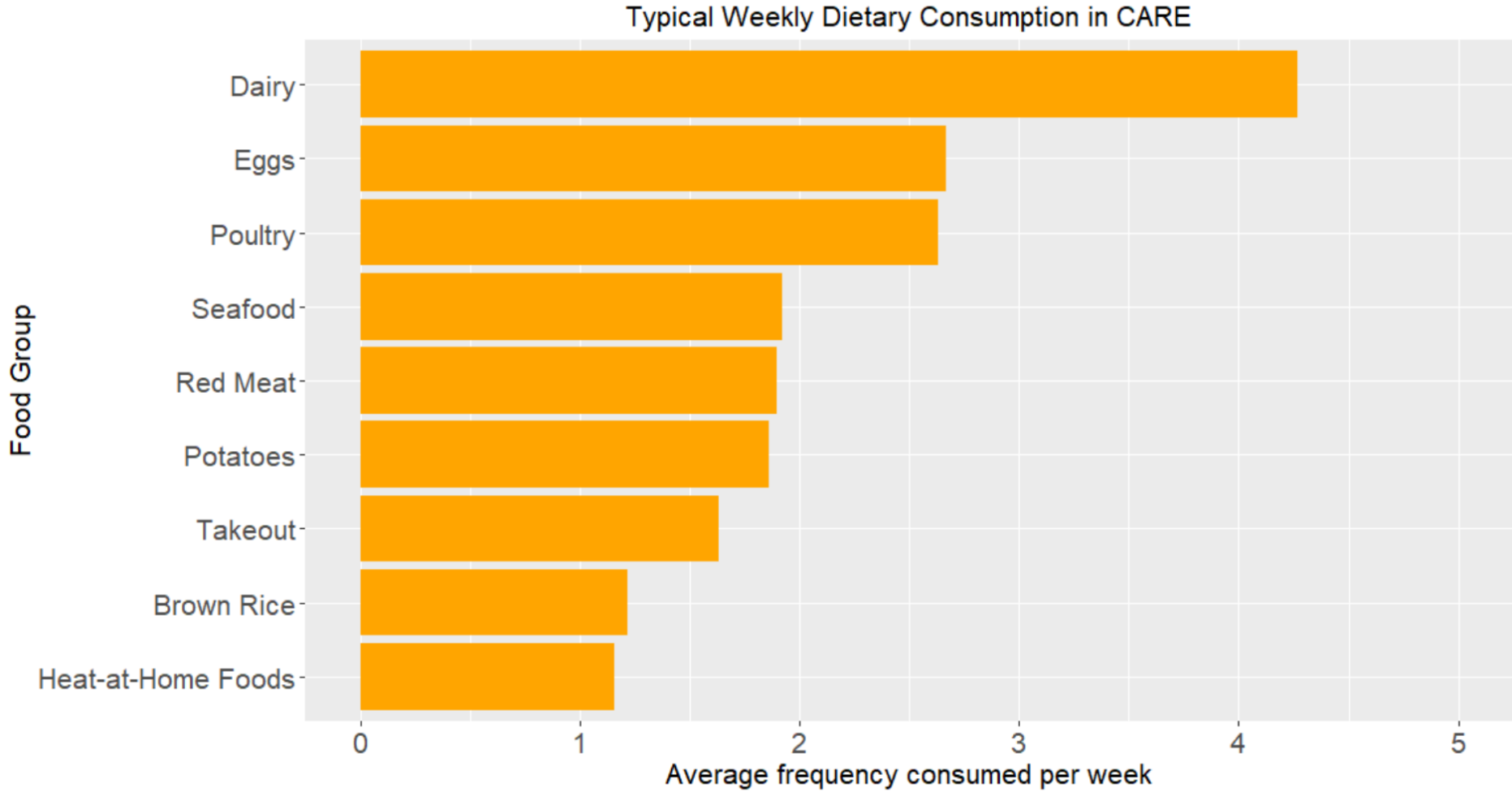
Values below LOD were replaced with LOD divided by $\sqrt{2}$

Detection of PFAS in public drinking water

	Minimum reporting level (µg/L)	Participants with analytes above detection in water supply, UCMR 3 data[1] N out of 700 (%)	Participants with analytes above detection in water supply, CA WB data[2] N out of 563 (%)
PFOA	0.02	47 (6.7%)	217 (38.5%)
PFOS	0.04	51 (7.3%)	207 (36.8%)
PFHxS	0.03	26 (3.7%)	218 (38.7%)
PFNA	0.02	0 (0%)	103 (18.3%)
At least 1 of 4 analytes detected	-	57 (8.1%)	237 (42.1%)

[1] *Select analytes corresponding to those detected in >65% of participants*
[2] *MRL for selected analytes in CA Water Boards (WB) data: 0.004* (µg/L)

Dietary consumption



Associations between serum, diet, and water

	Drinking Water	Red Meat	Dairy	Seafood	Eggs	Brown Rice	Heat-At-Home
PFOA	+						
PFHxS	+						
PFOS		+	+	+	+	+	−
PFNA				+	+		
PFDeA				+	+		−
PFUnDA				+			−
Me-PFOSA-AcOH						+	

+ $p < 0.05$

+ $p > 0.05$

Dietary factors associated with changes in serum PFAS per meal of food item per week (ng/mL)

	Red Meat	Dairy	Seafood	Eggs	Brown Rice	Heat-At-Home
PFOA						
PFHxS						
PFOS	0.083 (-0.019, 0.19)	0.022 (-0.015, 0.059)	0.014 (-0.046, 0.074)	0.044 (-0.024, 0.11)	0.11 (-0.0016, 0.21)	-0.11 (-0.22, -0.011)
PFNA			0.013 (0.0058, 0.021)	0.0073 (0.00017, 0.014)		
PFDeA			0.0059 (0.0026, 0.0092)	0.0035 (0.0001, 0.0069)		-0.0039 (-0.0072, -0.00057)
PFUnDA			0.010 (0.0054, 0.015)			-0.0042 (-0.0076, -0.00083)
Me-PFOSA-AcOH					0.0030 (0.00056, 0.0054)	

Models for each PFAS were run separately and adjusted for drinking water, if available, additional food items, sex, age, race , *income,* education, and nativity. *(Note: This slide was edited after the meeting. Income was added to the list of model variables.)*

Associations between water and serum

Higher levels seen in serum among people with detectable levels of PFAS in drinking water compared to those without.

PFHxS: 0.64 ng/mL (95% CI: 0.058, 1.23)

PFOA: 0.26 ng/mL (95% CI: 0.077, 0.43)

PFOS: 0.39 ng/mL (95% CI: -0.076, 0.86)

Conclusions

- Drinking water is a source of exposure to PFOA and PFHxS in this general population
- Dietary effects observed for PFNA, PFUnDA, PFDeA, Me-PFOSA-AcOH
- Changing production and use of PFAS may be impacting dietary levels in the U.S.
  - Removal from food contact materials
  - Low levels in FDA Total Diet Study

Strengths

- Large diverse study population
- Recent biomonitoring data
- Robust methods
- Data on PFDeA and PFUndA

Limitations

- Semi-quantitative FFQ
- High reporting limits for UCMR 3
- Potential for residual confounding
- Generalizability

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Songmei Gao

Sabrina Smith

June-Soo Park

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T32 304 ES014562

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