Unintentional cycles of persistent and mobile chemicals in the global food system

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Associate Professor, Civil & Environmental Engineering

University of Pittsburgh

GETA Fall Symposium, October 21, 2025

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The Ideal

FOOD&WINE

A New Study Found Cancer-Causing Flame Retardants on Black Plastic Kitchen Utensils and Food Containers

Another Company Recalls Frozen Shrimp Due to Radioactive Contamination

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OCT 18, 2025 AT 06:45 PM EDT

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OCT 18, 2025 AT 06:47 PM EDT

OCTOBER 20, 2025 The GIST

Invisible poison: Airborne mercury from gold mining is contaminating African food crops, study warns

by European Geosciences Union

The Reality

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Part I: The Omnivore’s Dilemma

(with apologies to Michael Pollan)

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Organic
Conventional
Regenerative
Artisanal
Raw
Probiotic
Prebiotic
Wild-Caught
Responsibly Farmed
Free Range
Pasture Raised
Hormone-free
No antibiotics
Not animal tested
Gluten Free
Gluten Conscious
…

Image credit: Harrison Keely - Own work, CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=164117908

The 2025 Dirty Dozen™

Of the 47 items included in our analysis, these 12 fruits and vegetables were most contaminated with pesticides:

Spinach

Spinach has more pesticide residues by weight than any other type of produce

LEARN MORE

02

Strawberries

The average American eats about eight pounds of fresh strawberries a year – and with them, dozens of pesticides

03

Kale, Collard, and Mustard Greens

More than half of kale samples tainted by possibly cancer-causing pesticide

04

Grapes

05

Peaches

Peaches pack a punch when it comes to pesticide contamination

06

Cherries

07

Nectarines

08

Pears

Pears among the most pesticide-contaminated fruit in EWG's Dirty Dozen™

09

Apples

Apples doused with chemical after harvest

10

Blackberries

Blackberries' newcomer status on the Dirty Dozen comes after the USDA tested the fruit for the first time, in 2023.

12

Potatoes

Potatoes – the most consumed vegetable in the U.S. – join this year's Dirty Dozen

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https://www.ewg.org/foodnews/dirty-dozen.php

Cover story

Linking pollution and infectious disease

Chemicals and pathogens interact to weaken the immune system, reduce vaccine efficacy, and increase pathogen virulence

BRITT E. ERICKSON, C&EN WASHINGTON

In brief

Environmental pollutants can interact with pathogens to change how people and wildlife respond to infectious diseases. Decades ago, researchers showed that persistent organic pollutants, such as polychlorinated biphenyls and dioxins, make mice less resistant to an influenza virus. New research suggests that other contaminants—including fluorochemicals, arsenic, and mercury—can also interfere with the immune response in laboratory animals, as well as in people. In some cases, pollutants decrease the immune response to vaccines, making people more susceptible to infectious diseases. In other cases, environmental pollutants increase the virulence of pathogens, such as making certain bacteria more resistant to antibiotics. Researchers are calling for more interdisciplinary work at the intersection between environmental health and infectious disease to help unravel some of the mechanisms behind these interactions. Such work is needed to fully understand how chemicals in the environment affect public health.

Thousands of seals died along the coasts of the heavily polluted Baltic Sea in the late 1980s. Scientists traced the deaths to a virus similar to the one that causes distemper in dogs. Last year, the same virus struck hundreds of seals in Maine. In both instances, researchers believe that persistent organic pollutants, such as polychlorinated biphenyls (PCBs), dioxins, and furans, played an indirect role in the seals' demise.

The seals are one example of a phenomenon of increasing importance to toxicologists: the interplay between exposure to environmental contaminants and infectious disease. More than two decades ago, researchers reported that exposure to low levels of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), the most toxic of the dioxins, decreases resistance to an influenza virus in mice (Fundam. Appl. Toxicol. 1996, DOI: 10.1006/faat.1996.0004).

Scientists have since shown that exposure to other chemicals, including perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), mercury, and arsenic, can also alter the immune response and increase susceptibility to infectious diseases in multiple species of laboratory animals. Epidemiology studies in humans have linked exposure to various chemicals in the womb with reduced levels of antibodies triggered by childhood vaccines and increased risk of infectious diseases.

Chemicals also affect pathogens and in some cases can make them more dangerous. Researchers have shown a link between multidrug-resistant bacteria and exposure to zinc, lead, and disinfectants. Epidemiologists are investigating whether exposure to phthalates is also associated with multidrug-resistant bacteria.

"Environmental pollutants affect how we are infected," Linda Birnbaum, director of the US National Institute of Environmental Health Sciences, said during opening remarks at a January workshop on the interactions between chemicals and pathogens sponsored by the US National Academies of Sciences, Engineering, and Medicine. Studies so far have revealed tantalizing clues about the scope and mechanisms of these interactions, but more work needs to be done to understand the full effects of chemical exposure on public health, said Birnbaum and other toxicologists, epidemiologists, and infectious disease experts who attended the workshop.

Hundreds of dead seals like this one washed up on the shores of Maine in August 2018. Scientists believe a virus and chemical pollution are to blame.

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Thousands of seals died along the coasts of the heavily polluted Baltic Sea in the late 1980s. Scientists traced the deaths to a virus similar to the one that causes distemper in dogs. Last year, the same virus struck hundreds of seals in Maine. In both instances, researchers believe that persistent organic pollutants, such as polychlorinated biphenyls (PCBs), dioxins, and furans, played an indirect role in the seals' demise.

How do (did?) we know there's a problem?

National Biomonitoring Programs

About The National Biomonitoring Program

National Biomonitoring Program

nhanes™

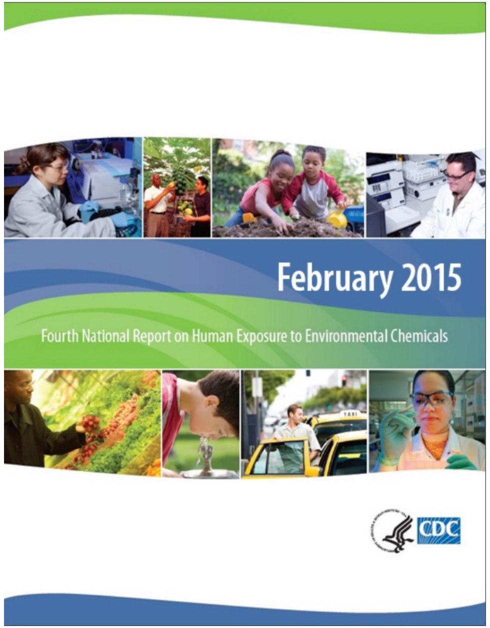
About NHANES

Learn about the only national health survey that includes health exams and laboratory tests

https://www.cdc.gov/nchs/nhanes/index.html

Human Exposure to Environmental Chemicals

>200 Chemicals routinely measured in blood of U.S. population



Selection of Chemicals for the *Fourth Report*

Chemicals presented in the *Fourth Report* were selected on the basis of scientific data that suggested exposure in the U.S. population; the seriousness of health effects known or suspected to result from exposure; the need to assess the efficacy of public health actions to reduce exposure to a chemical; the availability of a biomonitoring analytical method with adequate accuracy, precision, sensitivity, specificity, and speed; the availability of sufficient quantity of blood or urine samples; and the incremental analytical cost to perform the analyses. More information is available at http://www.cdc.gov/exposurereport/chemical_selection.htm.

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Human Exposure to Environmental Chemicals

>200 Chemicals routinely measured in blood of U.S. population

- Tobacco smoke
- Fungicides & metabolites
- Herbicides & metabolites
- Sulfonylurea herbicides
- Carbamate pesticides & metabolites
- Organochlorine pesticides & metabolites
- Other pesticides & metabolites
- Organophosphate insecticides & metabolites
- Pyrethroid metabolites
- Metals & metalloids
- Parabens
- Perchlorate & other anions
- Perfluorinated compounds
- Phthalate & phthalate alternative metabolites
- Phytoestrogens & metabolites
- PAH metabolites
- VOCs & metabolites
- PBDEs & PBB-153
- PCBs

Human Exposure to Environmental Chemicals: *Food as Example of Globalization*

- Tobacco smoke
- Fungicides & metabolites
- Herbicides & metabolites
- Sulfonylurea herbicides
- Carbamate pesticides & metabolites
- Organochlorine pesticides & metabolites
- Other pesticides & metabolites
- Organophosphate insecticides & metabolites
- Pyrethroid metabolites
- Metals & metalloids
- Parabens
- Perchlorate & other anions
- Perfluorinated compounds
- Phthalate & phthalate alternative metabolites
- Phytoestrogens & metabolites
- PAH metabolites
- VOCs & metabolites
- PBDEs & PBB-153
- PCBs

For many of these chemicals **food** is a major exposure pathway.

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Food as Exposure Pathway

Methyl mercury in tuna

Pesticides on apples

— production

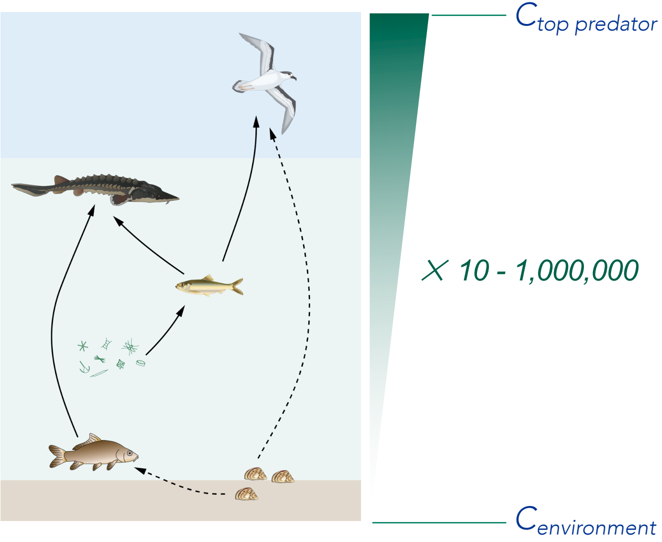
Acrylamide in French fries — processing

Per- and polyfluorinated substances in popcorn — packaging

production, processing, packaging — intentional or inadvertent

Role of Bioaccumulation vs. Mobility

Bioaccumulation leads to concerning levels, even for micropollutants



Classic examples: DDT, PCBs, PBDEs.

Mobility, when coupled with persistence, leads to ubiquitous and continuous exposure

FEATURE | August 29, 2016

Mind the Gap: Persistent and Mobile Organic Compounds—Water Contaminants That Slip Through

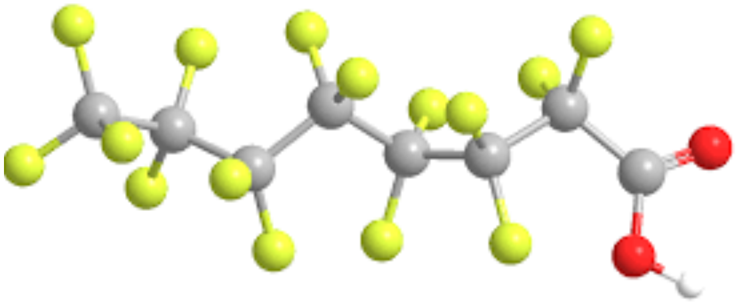
Thorsten Reemtsma[*†], Urs Berger[†], Hans Peter H. Arp[‡], Hervé Gallard[§], Thomas P. Knepper[ǁ], Michael Neumann[⊥], José Benito Quintana[#], and Pim de Voogt[∇○]

Identified classes of emerging compounds missed by regulatory approaches. Now we have PMT in addition to PBT.

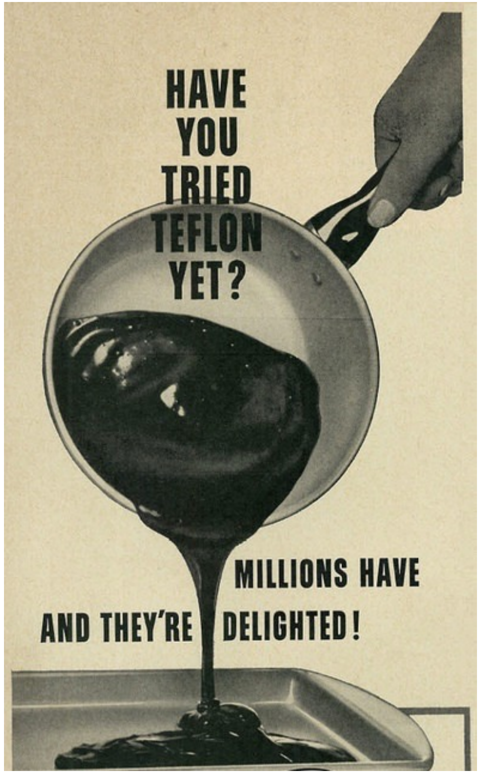
Part II: How did we get here?

Key Mobile and Persistent Chemical Classes

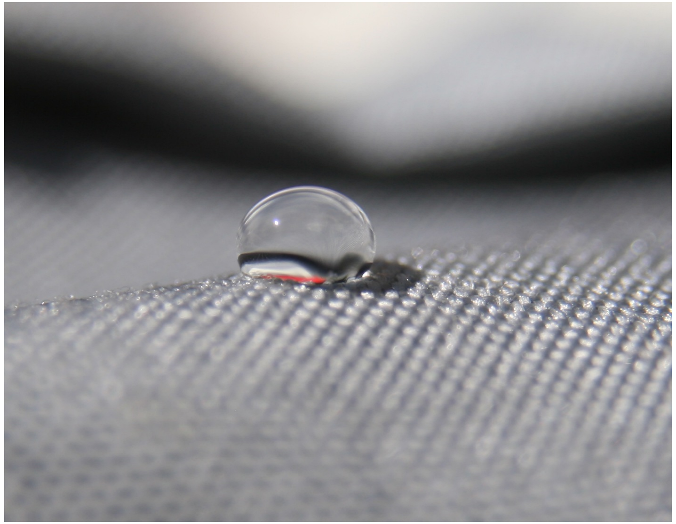
Case 1: per- and polyfluoroalkyl substances (PFAS)

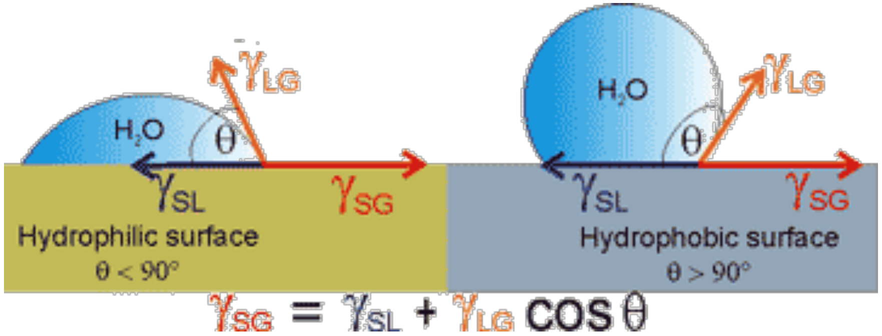


PFAS are **organofluorine** substances. Built on a backbone that would have been an organic chemical (having carbon-hydrogen bonds, but with the hydrogens replaced by fluorine.



What’s so special about PFAS?





Unlike most other substances, PFAS are **both** *hydrophobic* **and *oil-phobic***. This means that they are both water and stain repellent!

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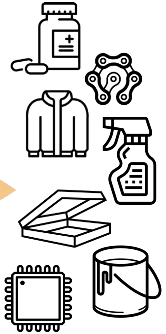
How did we get here?

A brief PFAS timeline

1938:
PTFE discovered

2000:
PFOS phased out of class A foams (PFAS still in class B foams)

1940s | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s



1941: PTFE patented

2006:
US EPA Stewardship Agreement (voluntary phase-out)

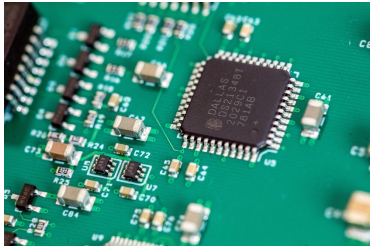
Useful Properties → Wide Uses

Safety

Food Packaging

Personal Care Products

Technological



Pharmaceutical

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Not at all exhaustive!

How did we get here?

A brief PFAS timeline

Environ. Sci.: Processes Impacts, 2020, **22**, 2345–2373

An overview of the uses of per- and polyfluoroalkyl substances (PFAS)†

Juliane Glüge,[*a] Martin Scheringer,[a] Ian T. Cousins,[b] Jamie C. DeWitt,[c] Gretta Goldenman,[d] Dorte Herzke,[ef] Rainer Lohmann,[g] Carla A. Ng,[h] Xenia Trier[i] and Zhanyun Wang[j]

function; we also specify which PFAS have been used and discuss the magnitude of the uses. Despite being non-exhaustive, our study clearly demonstrates that PFAS are used in almost all industry branches and many consumer products. In total, more than 200 use categories and subcategories are identified for more than 1400 individual PFAS. In addition to well-known categories such as textile impregnation, fire-fighting foam, and electroplating, the identified use categories also include many categories not described in the scientific literature, including PFAS in ammunition, climbing ropes, guitar strings, artificial turf, and soil remediation. We further discuss several use categories that may be prioritised for finding PFAS-free alternatives. Besides the detailed description of use categories, the present study also provides a list of the identified PFAS per use category, including their exact masses for future analytical studies aiming to identify additional PFAS.

PFAS: How People Are Exposed

If you live near a contaminated site, drinking water is usually the major exposure route.

Without drinking water contamination*, **food is usually the major source of PFAS exposure.**

Research is ongoing to better understand other sources (e.g. indoor exposures via cleaning/ personal care products, carpets, outdoor air).

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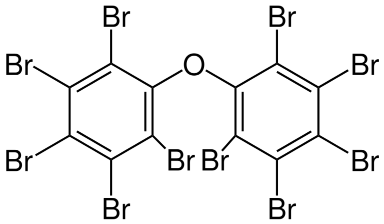
*most water has low levels of PFAS; contaminated sites have high levels

Case 2: the Waste-to-Food chain of industrial and agricultural chemicals

BASEL CONVENTION

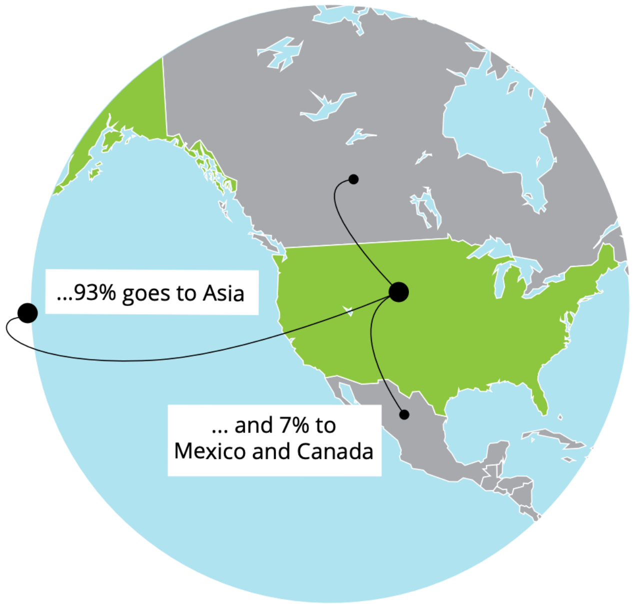
the world environmental agreement on wastes

Example of an "E-Waste POP":



Polybrominated diphenyl ethers (PBDEs) – persistent, bioaccumulative, toxic, and now largely banned. Still present in legacy equipment at high weight percent.

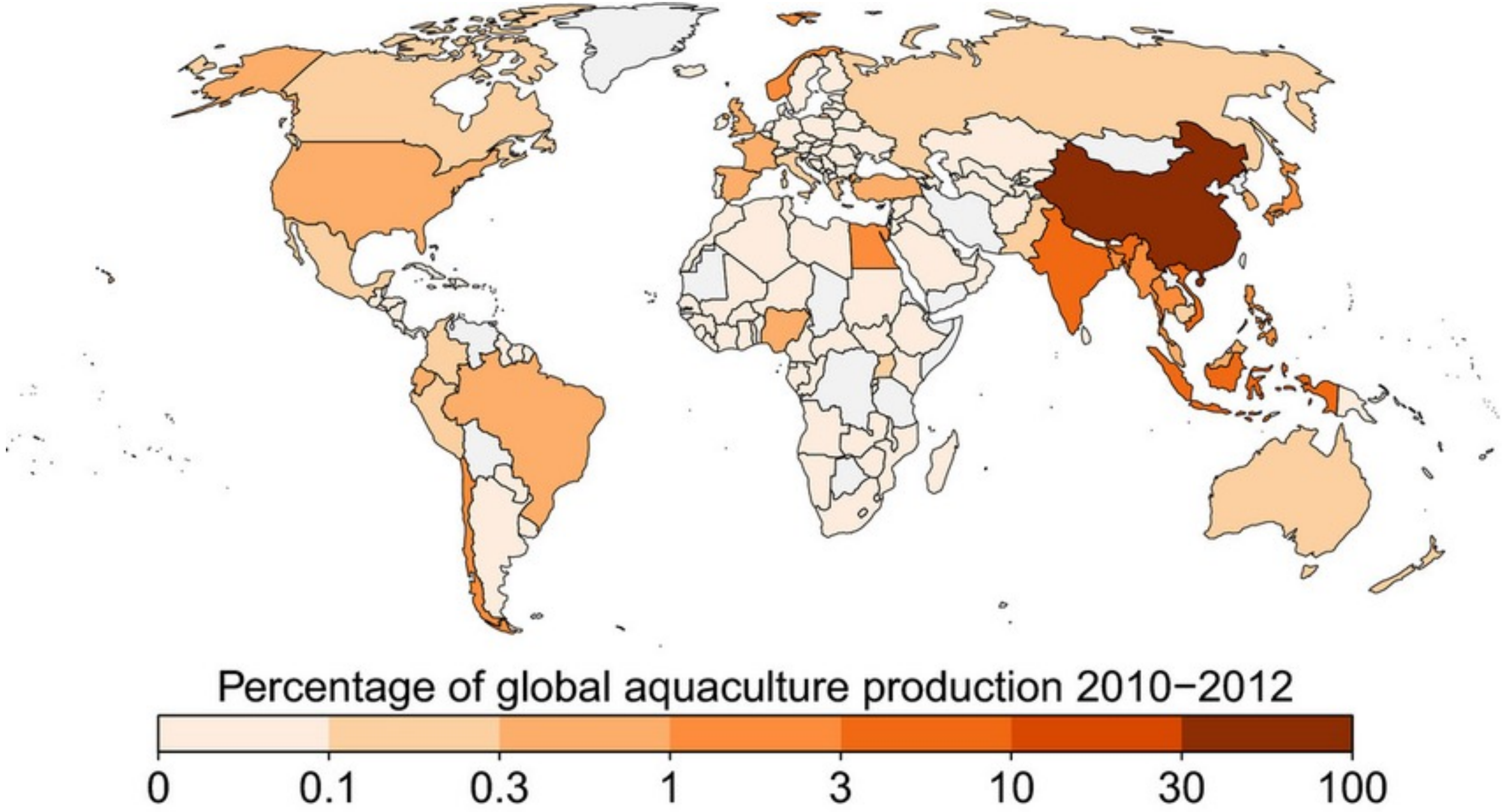
E-waste: global trade in toxic chemicals.

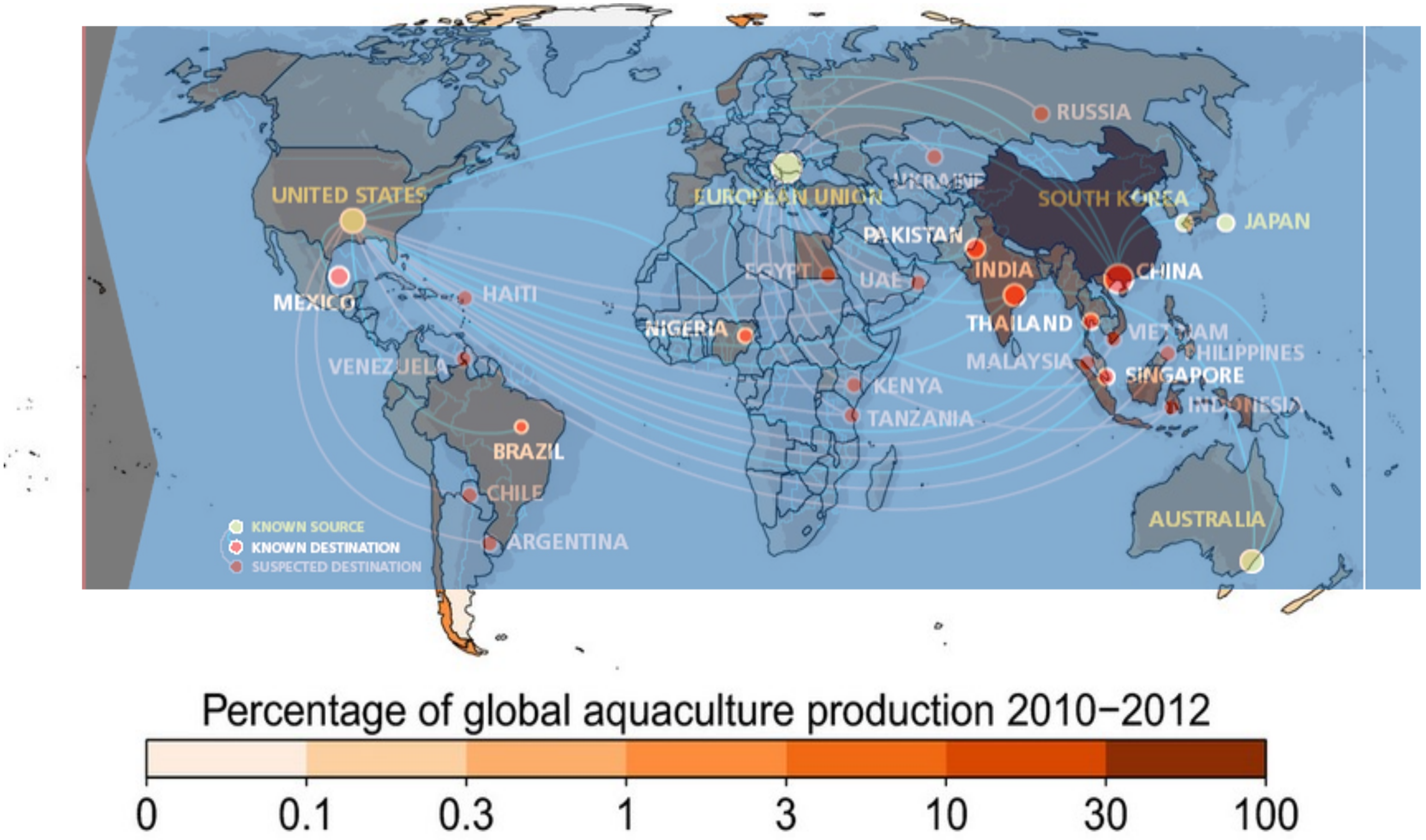


Source: Baldé et al.: The Global E-Waste Monitor 2017, United Nations University, ITU and ISWA.

Known and Suspected Routes of e-waste Dumping

There is currently no system for tracking legal or illegal (under international law) shipments of electronic waste, and therefore, there is no quantitative data on volumes or even all of the true destinations. Some electronic waste is shipped as "working equipment" only to end-up as waste upon arrival. This map indicates information collected through investigations by organizations such as the Basel Action Network, Silicon Valley Toxics Coalition, Toxics Link India, SCOPE (in Pakistan), Greenpeace and others.


Percentage of global aquaculture production 2010−2012
0
0.1
0.3
1
3
10
30
100


RUSSIA
UKRAINE
UNITED STATES
EUROPEAN UNION
SOUTH KOREA
JAPAN
PAKISTAN
INDIA
CHINA
EGYPT
UAE
MEXICO
HAITI
NIGERIA
THAILAND
VIETNAM
PHILIPPINES
MALAYSIA
SINGAPORE
INDONESIA
VENEZUELA
KENYA
TANZANIA
BRAZIL
CHILE
ARGENTINA
AUSTRALIA
KNOWN SOURCE
KNOWN DESTINATION
SUSPECTED DESTINATION
Percentage of global aquaculture production 2010−2012
0
0.1
0.3
1
3
10
30
100

A Consistent Result:
Persistent Chemicals in Fish and Seafood

How can we understand chemical cycling in the modern food system?

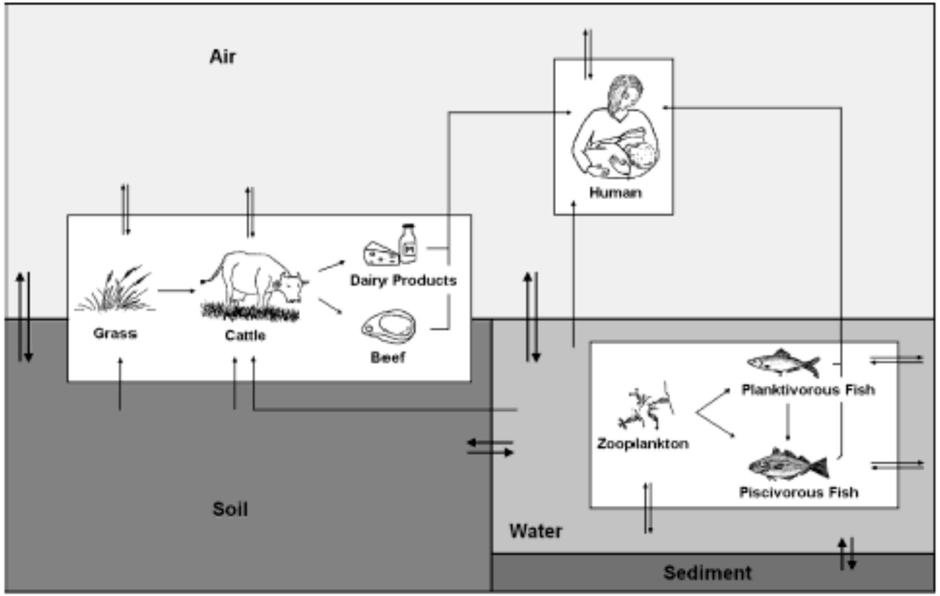
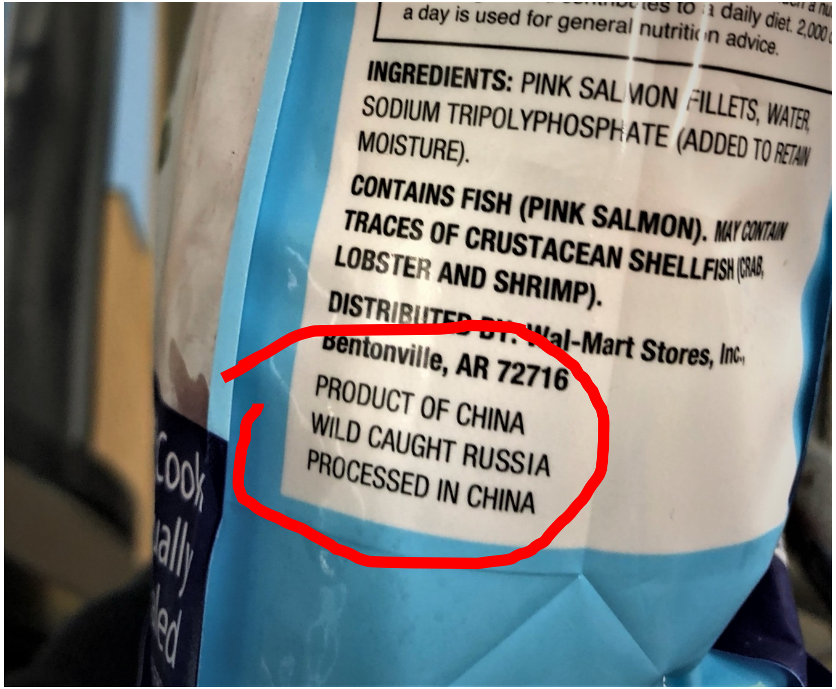


FIGURE 1. Model structure.

Czub & McLachlan (2004) ES&T.

Traditional Approach: the "Unit World"
Assumes only local contamination/exposure

Challenge: Where does our food come from?



SOURCE: Photos taken by Megha Bedi, PhD Candidate.

PFAS in Seafood: origin, type, cost

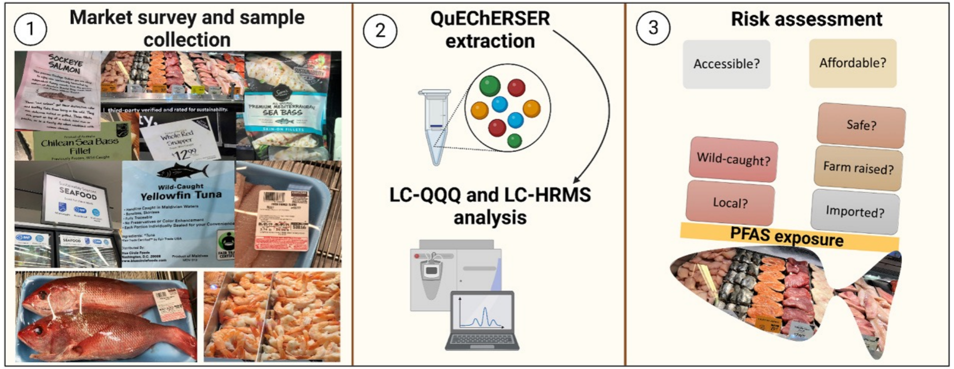
How do consumer choices affect exposure to contaminants in food?

Journal of Hazardous Materials
Volume 459, 5 October 2023, 132062

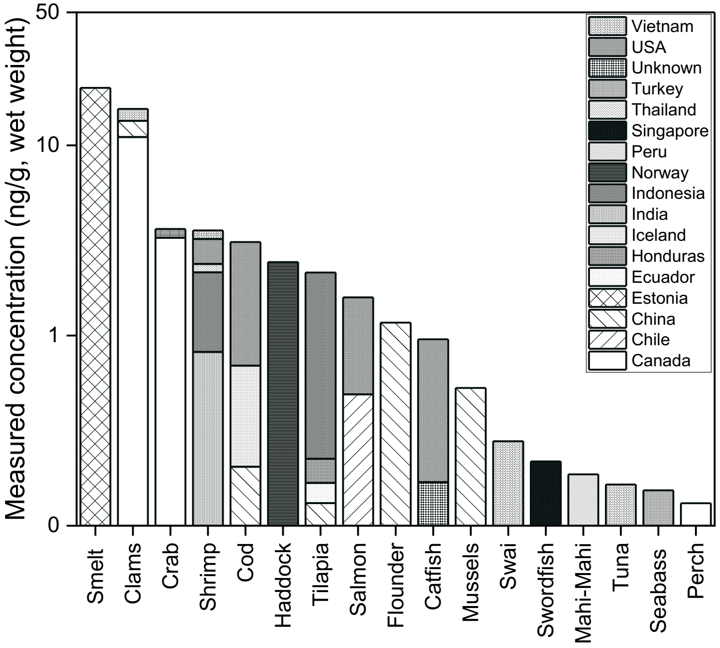
Per- and polyfluoroalkyl substances (PFAS) measured in seafood from a cross-section of retail stores in the United States

Megha Bedi [a], Yelena Sapozhnikova [b], Raegyn B. Taylor [b], Carla Ng [a c]

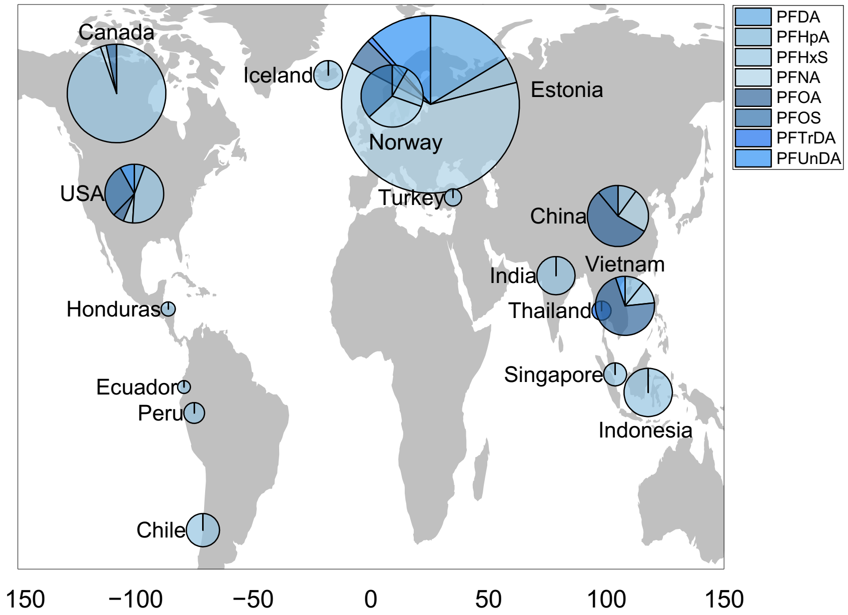
Megha Bedi, PhD 2023



PFAS in Seafood: by origin and type



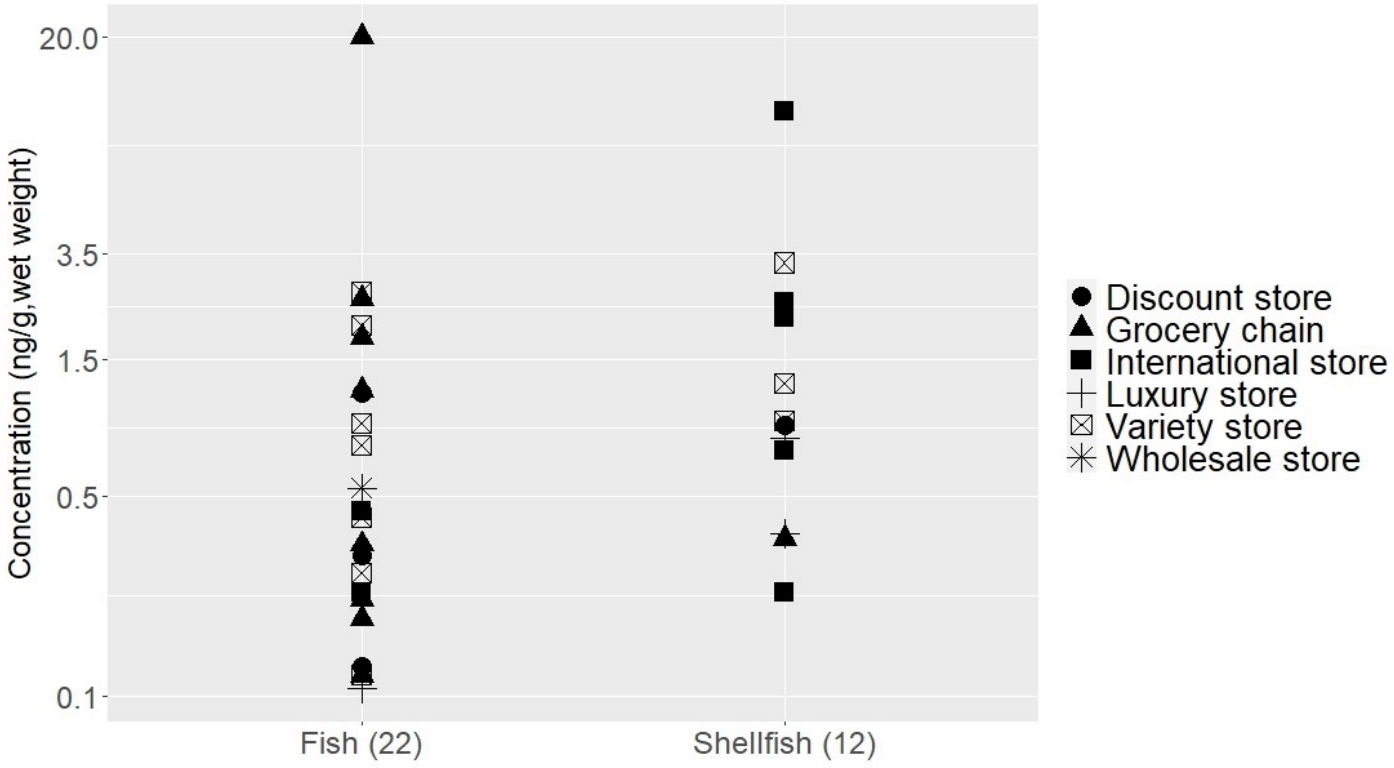
Seafood type-specific total PFAS concentration distributed by origin.



Origin-specific PFAS distribution.

Bedi et al. 2021, https://www.sciencedirect.com/science/article/abs/pii/S0304389423013456?via%3Dihub

PFAS in Seafood: No effect of $/$$/$$$



Modeling Exposure in Seafood

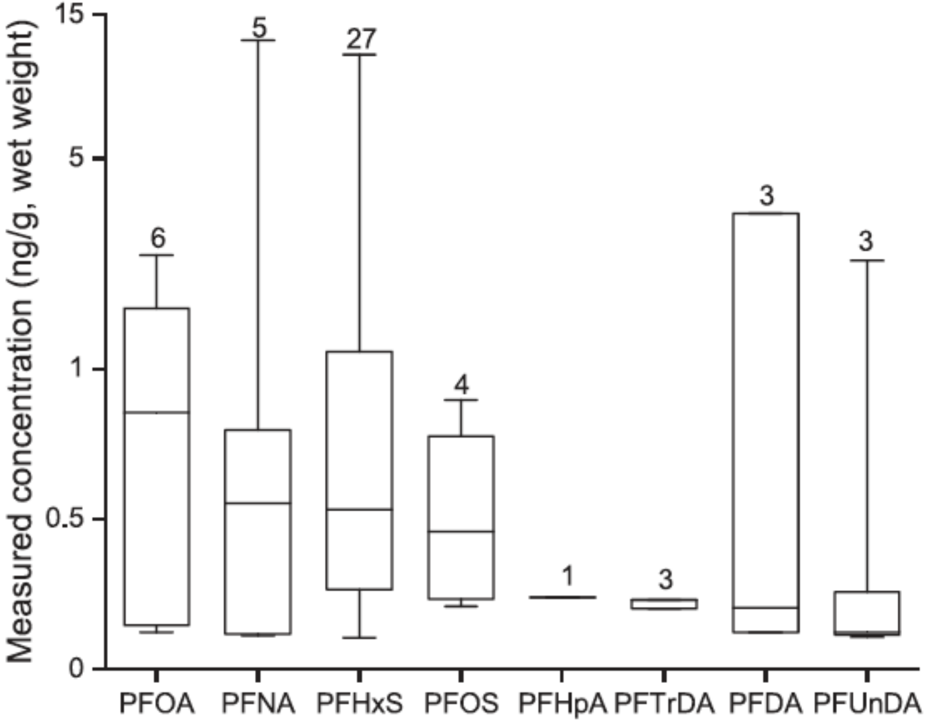
$$EWI = \left(\frac{Conc_{fish} \times MS \times MF}{BW}\right)$$

EWI: estimated weekly intake (ng/kg bw/week)

$Conc_{fish}$: total of PFOS, PFOA, PFHxS, and PFNA levels (ng/g)

MS: amount of seafood (g/meal)

MF: meal frequency (meals/week)



Behavior also drives exposure

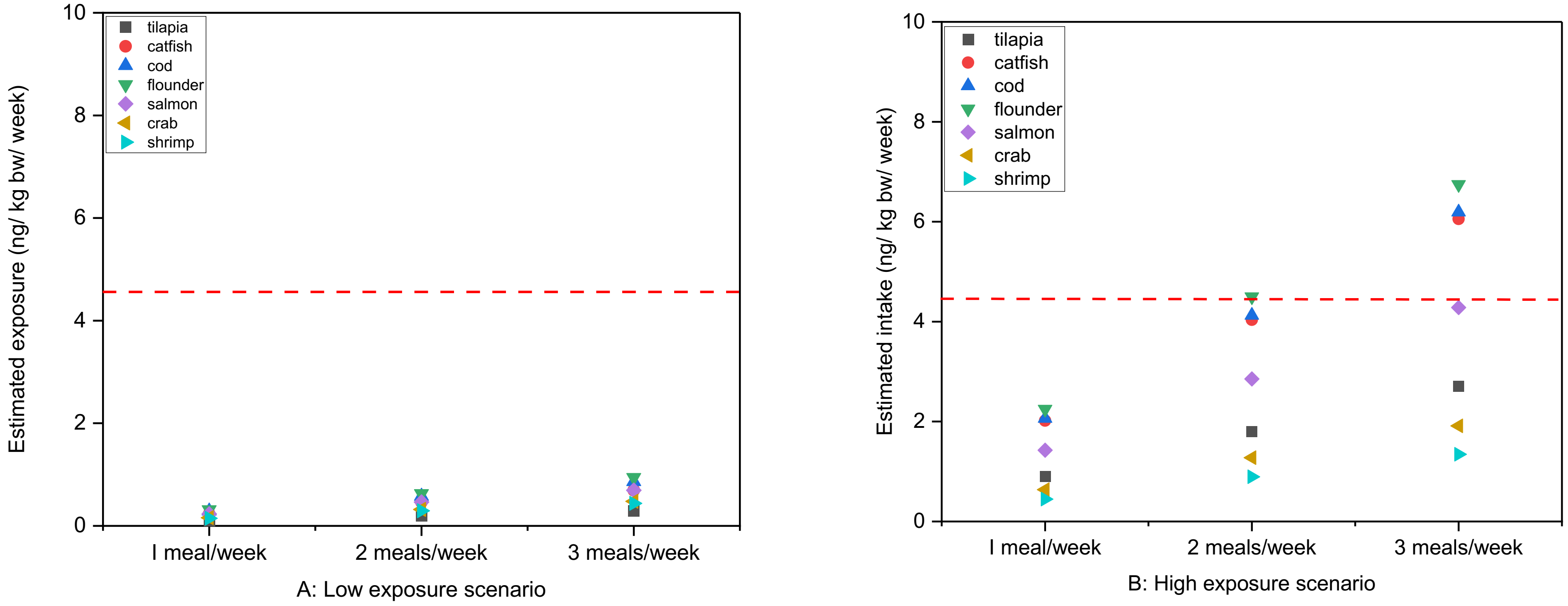


Fig. 6. Estimated PFAS intake (ng/ kg bw/week) *(A)* low-exposure scenario and *(B)* high exposure scenario. Geometric mean concentrations were used for number of samples > 1. Estimates are based on the sum of PFOA, PFNA, PFOS, and PFHxS. Non-detects were set at LOQ/2 (0.05 ng/g). The red dotted line is the TWI established by EFSA (4.4 ng/kg bw/week).

What about other chemicals?

Articles

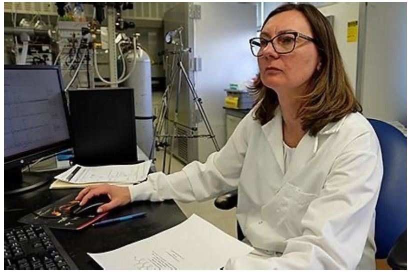
Evaluating contamination of seafood purchased from U.S. retail stores by persistent environmental pollutants, pesticides and veterinary drugs

Megha Bedi, Yelena Sapozhnikova & Carla Ng

Pages 325-338 | Received 27 Nov 2023, Accepted 21 Jan 2024, Published online: 05 Feb 2024

Cite this article https://doi.org/10.1080/19440049.2024.2310128 Check for updates

Megha Bedi, PhD 2023

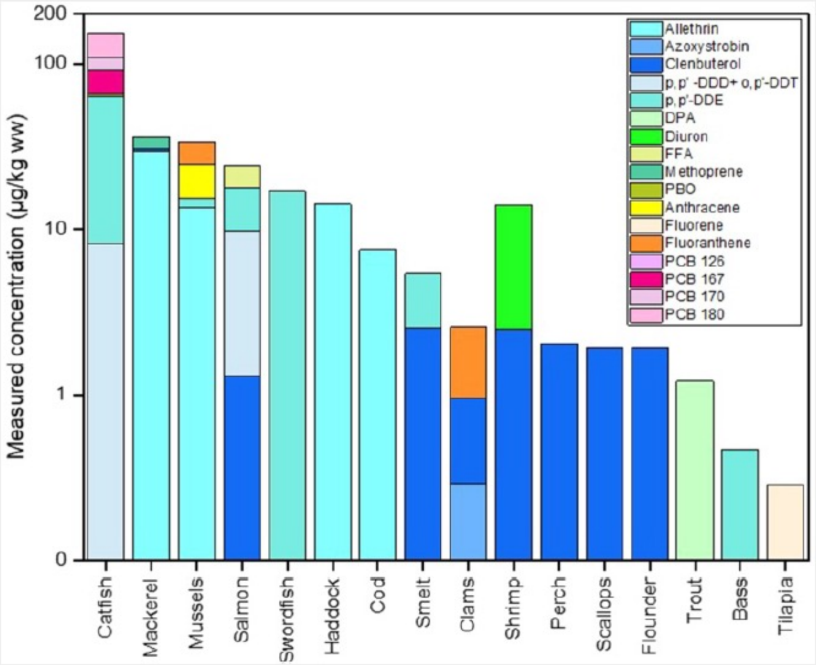


Yelena Sapozhnikova, USDA

University of Pittsburgh

Industrial, Agricultural and Pharmaceutical Chemicals in Seafood

Figure 1. Total chemical residue profile in seafood. Shades of blue/green represent pesticides and veterinary drugs, shades of orange/yellow represent PAHs, and shades of pink/purple represent PCBs.



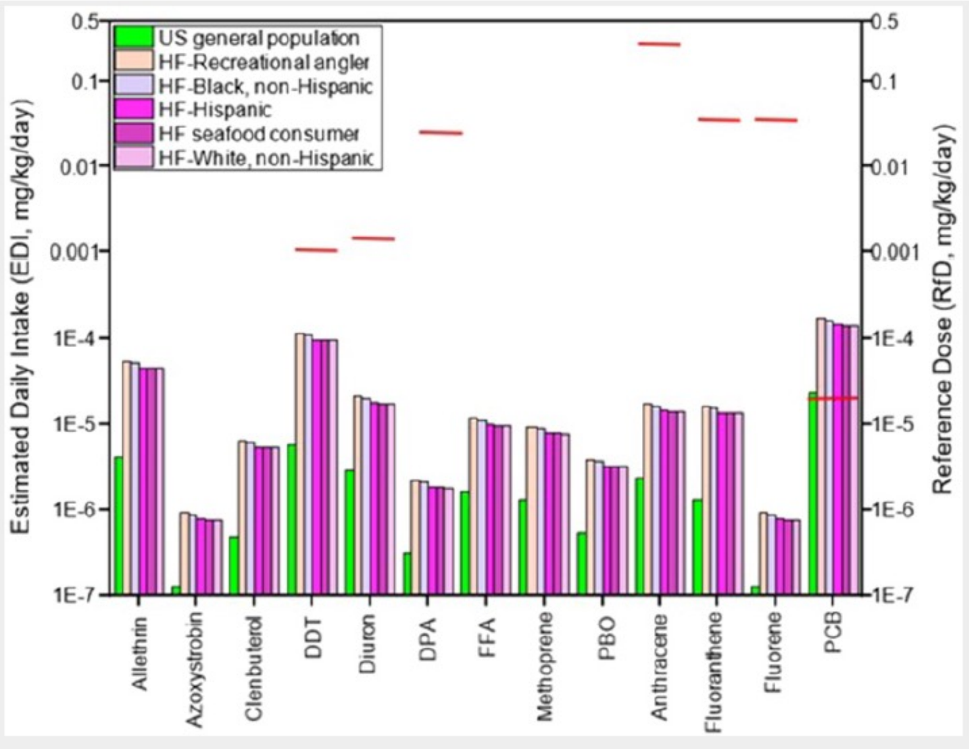
Distribution of current and legacy chemicals differed by seafood type.

Clenbuterol: bronchodilator, sometimes used illegally to improve market value by increasing lean mass.

Allethrin: pyrethroid insecticide.

Note legacy signal ***(DDTs, PCBs)*** in catfish.

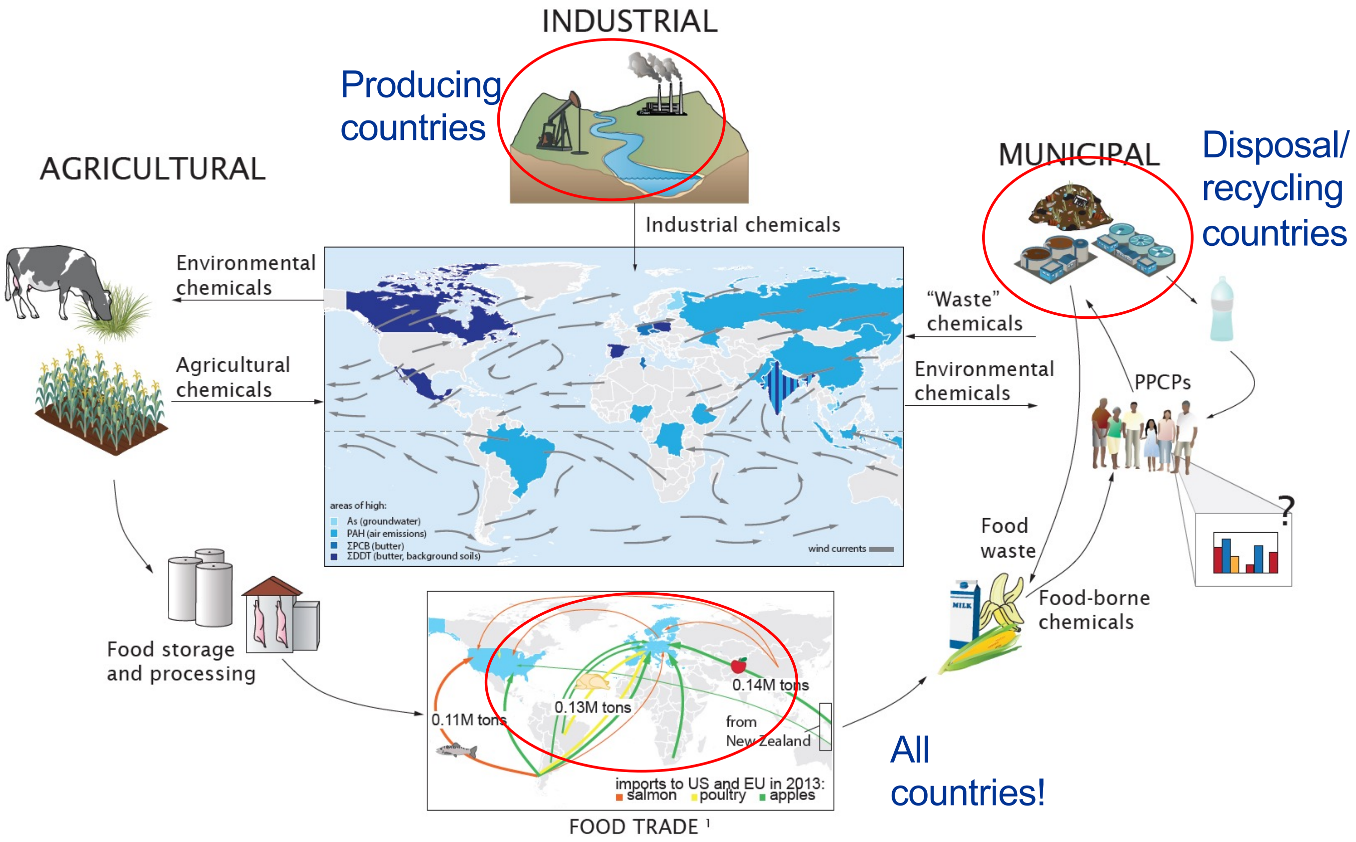
Current and Legacy Chemicals in Seafood



Both seafood species and chemical properties matter!

Legacy chemicals' higher toxicity can lead to exceeding limits even at relatively low concentrations (here, for dioxin-like PCBs).

Only a small part of the picture!



Part III: What Do We Do Now?

Learning from the past, protecting the future.

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The enduring legacy of highly persistent chemicals

- Based on what we already know from a long history of contamination, technology will not save us.

- Once remote environments are highly contaminated, they serve as ongoing sources to the environment and, eventually, our food.

https://www.science.org/content/article/extraordinary-levels-pollutants-found-deepest-parts-sea

No escaping PFAS and other PMT…

Rainwater in parts of US contains high levels of PFAS chemical, says study

Levels high enough to potentially impact human health and trigger regulatory action, which only targets two of 4,700 variants

ACS MEETING NEWS

US rainwater contains new and phased out PFAS

The chemicals were found in rural and urban rainwater

by *Katherine Bourzac*

April 6, 2021

ELSEVIER

Water Research

Volume 190, 15 February 2021, 116685

Correlation Analysis of Perfluoroalkyl Substances in Regional U.S. Precipitation Events

Kyndal A. Pike [a, b, 1], Paul L. Edmiston [a], Jillian J. Morrison [b], Jennifer A. Faust [a]

Concentration (ng L^{-1})[a] at Location

PFAS	Shaker Heights, OH	Willoughby, OH	Wooster, OH	Ashland, OH	Rockford, OH	Whitestown, IN	Jackson Hole, WY
PFOA	2	1	8	1	0.6	0.5	2
	0.3-8	0.4-3	1-30	0.5-3	0.2-1	0.03-0.9	1-3

What Can be Done?

For new and current persistent chemicals, learning more about their toxic impacts on a substance-by-substance basis will take too long in the face of ongoing and irreversible exposures.

Policy strategies are needed **that can address multiple uses and multiple chemicals (or chemical classes!).**

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The Essential Use Concept

Environmental Science
Processes & Impacts

CRITICAL REVIEW

View Article Online
View Journal

Cite this: DOI: 10.1039/c9em00163h

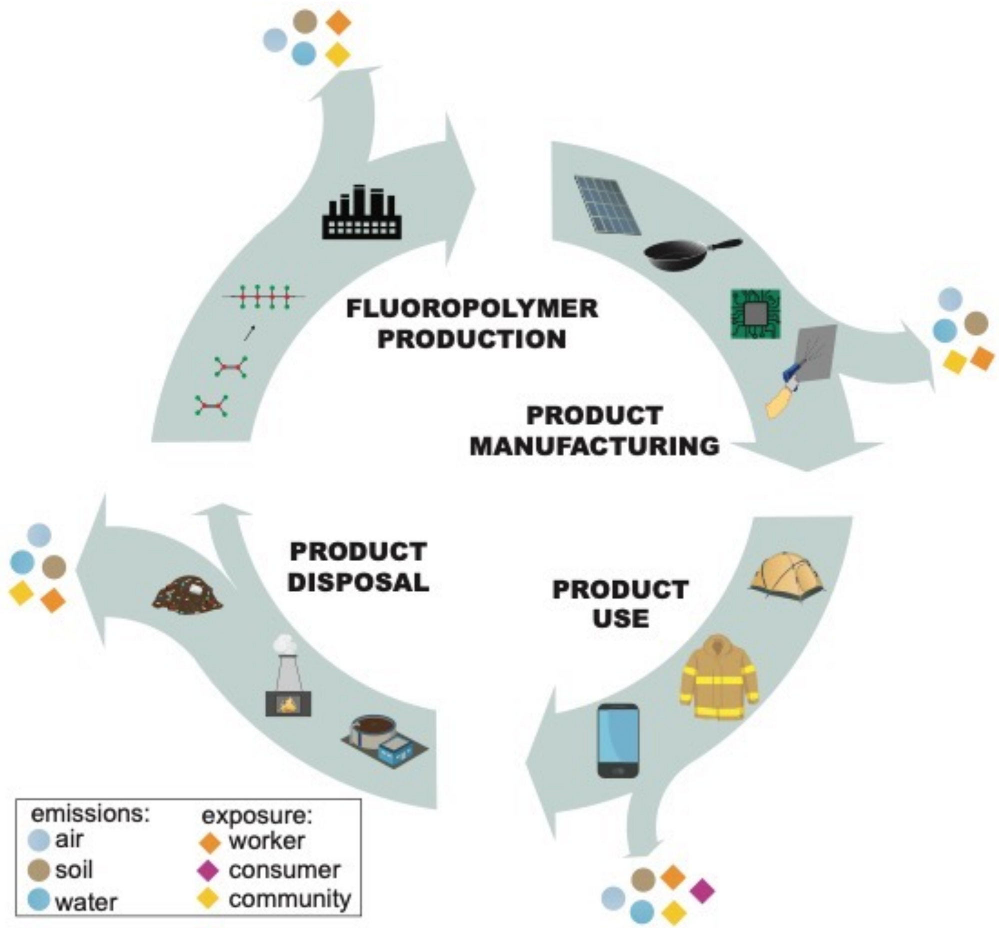
The concept of essential use for determining when uses of PFASs can be phased out

Ian T. Cousins, †*[a] Gretta Goldenman,[b] Dorte Herzke,[c] Rainer Lohmann,[d] Mark Miller,[e] Carla A. Ng,[f] Sharyle Patton,[g] Martin Scheringer,[h] Xenia Trier,[i] Lena Vierke,[j] Zhanyun Wang[k] and Jamie C. DeWitt[l]

University of Pittsburgh

GLOBAL PFAS SCIENCE PANEL

The Life Cycle Approach to PFAS (and all chemicals)



University of Pittsburgh

Lohmann et al. 2020 ES&T

Questions?