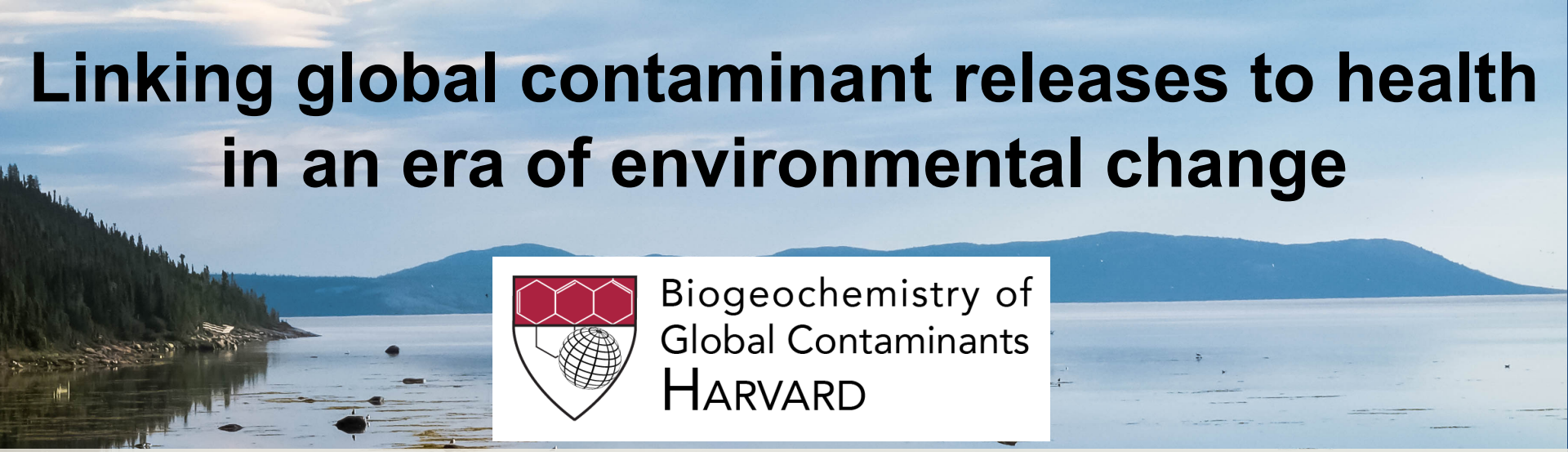
Linking global contaminant releases to health in an era of environmental change



Biogeochemistry of Global Contaminants
HARVARD

- Elsie M Sunderland (ems@seas.harvard.edu)

HARVARD T.H. CHAN
SCHOOL OF PUBLIC HEALTH
Powerful ideas for a healthier world

HARVARD
John A. Paulson School of Engineering and Applied Sciences

Human activities are transforming the global environment

1-in-6 children suffer from a neurodevelopmental abnormality, mostly of unknown causes.

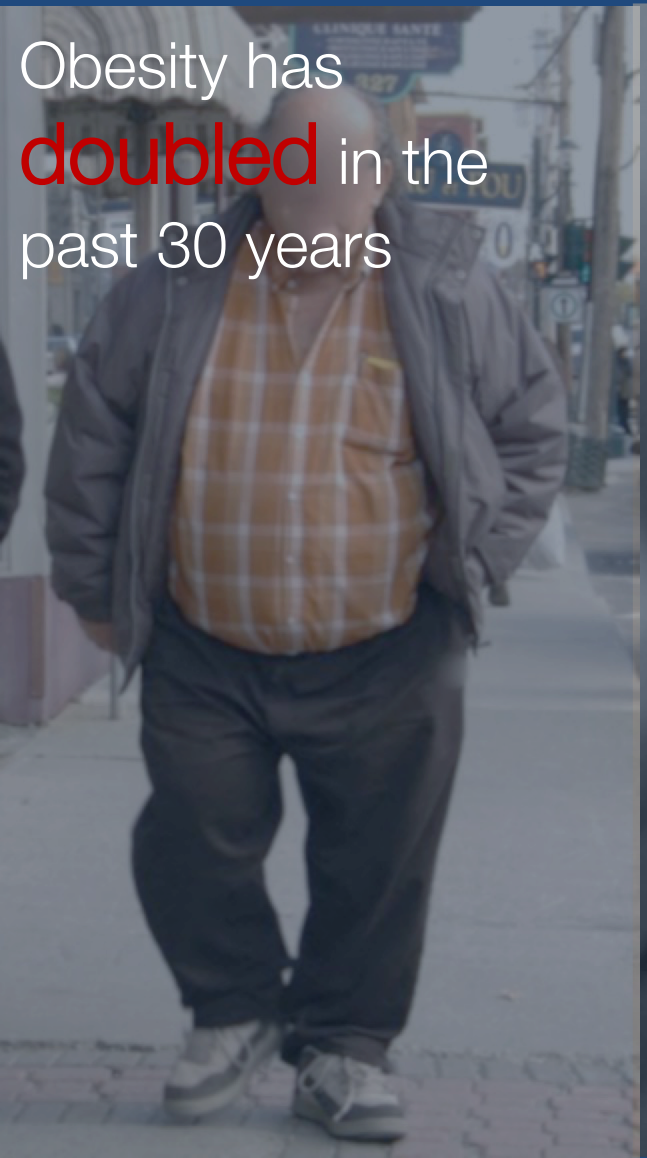
10 million U.S. children below age 17 diagnosed with asthma (14% population) and 12% suffer from skin allergies.

http://braindrain.dk

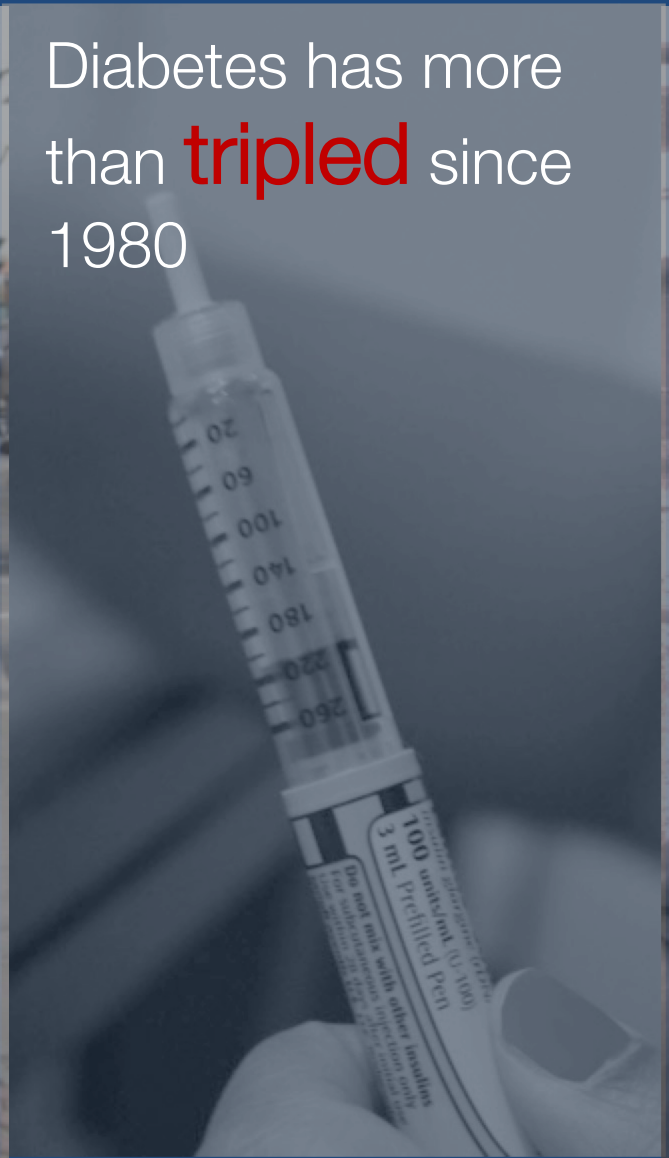
Environmental Releases

More than carbon

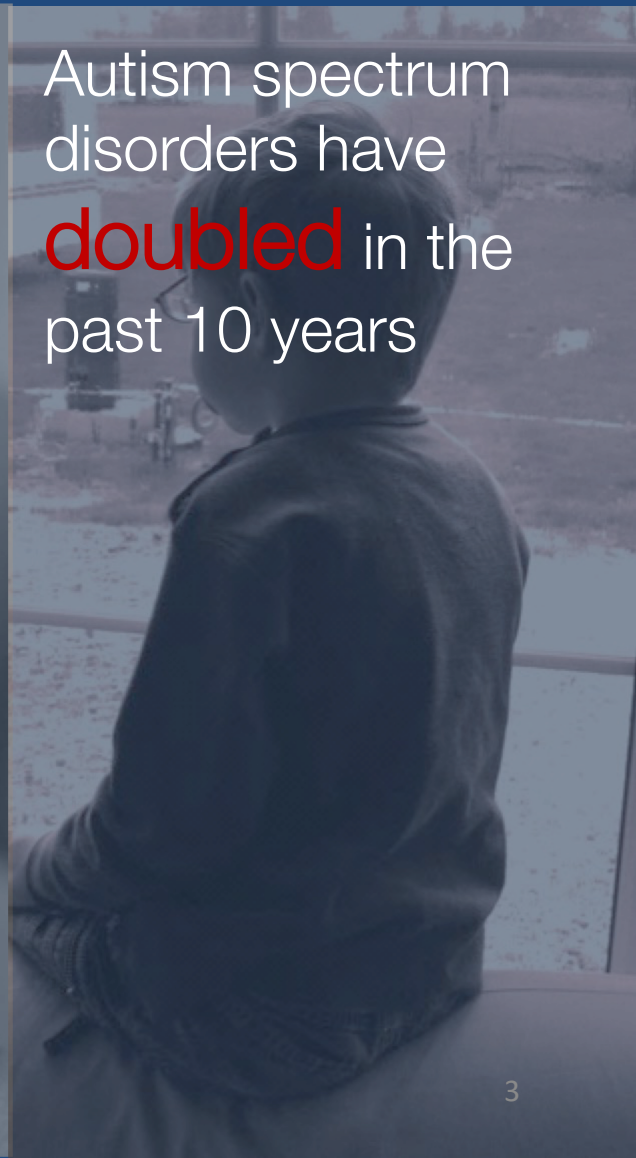
Environmental factors suspected as a primary cause of rise in chronic disease



Obesity has **doubled** in the past 30 years

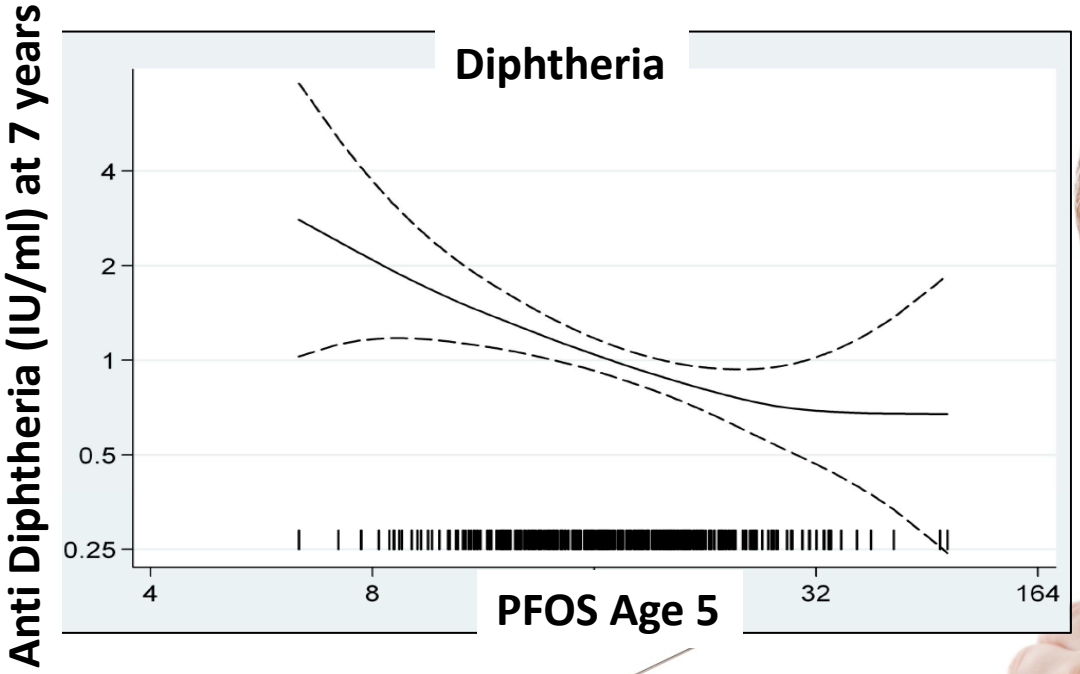


Diabetes has more than **tripled** since 1980

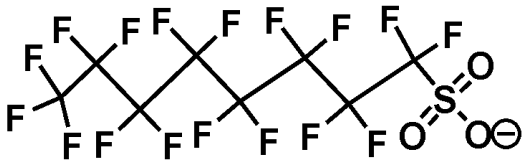


Autism spectrum disorders have **doubled** in the past 10 years

Epidemiology associates *human biomarkers* (blood, hair, nails) with health outcomes, so *how do we identify the exposure source?*



50% Reduction in antibody concentrations for each doubling of PFOS



Grandjean et al., 2012

Also linked to:
Cancer
Obesity
Developmental Disorders
Elevated Cholesterol
Endocrine Disruption

Question: What is the exposure source?

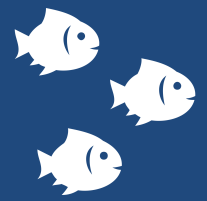
Answer: Direct for air pollution.

Complex pathways for aquatic toxicants.

1. Emissions

7. Humans

2. Deposition



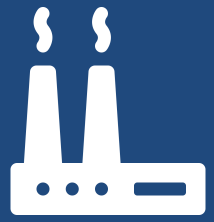
6. Food webs

3. Land

4. Ocean

5. Bioavailability

Linking global contaminant releases to health in an era of environmental change



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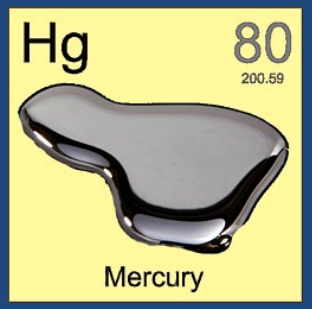

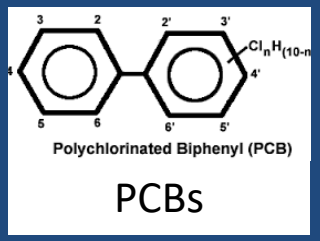

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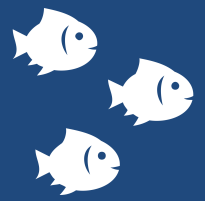
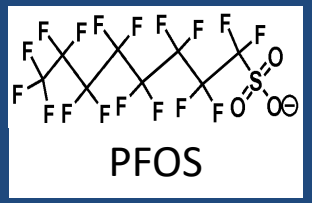


6. Food webs



3. Land

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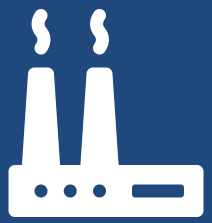
Biogeochemistry of Global Contaminants
HARVARD

Three Examples

1. Hydroelectric power expansion and indigenous health in Canada

2. Exposures pathways for PFAS from drinking water, seafood, and consumer products

3. Impacts of climate change on methylmercury in Atlantic bluefin tuna



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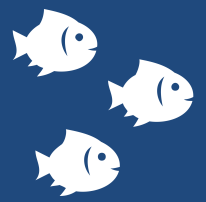
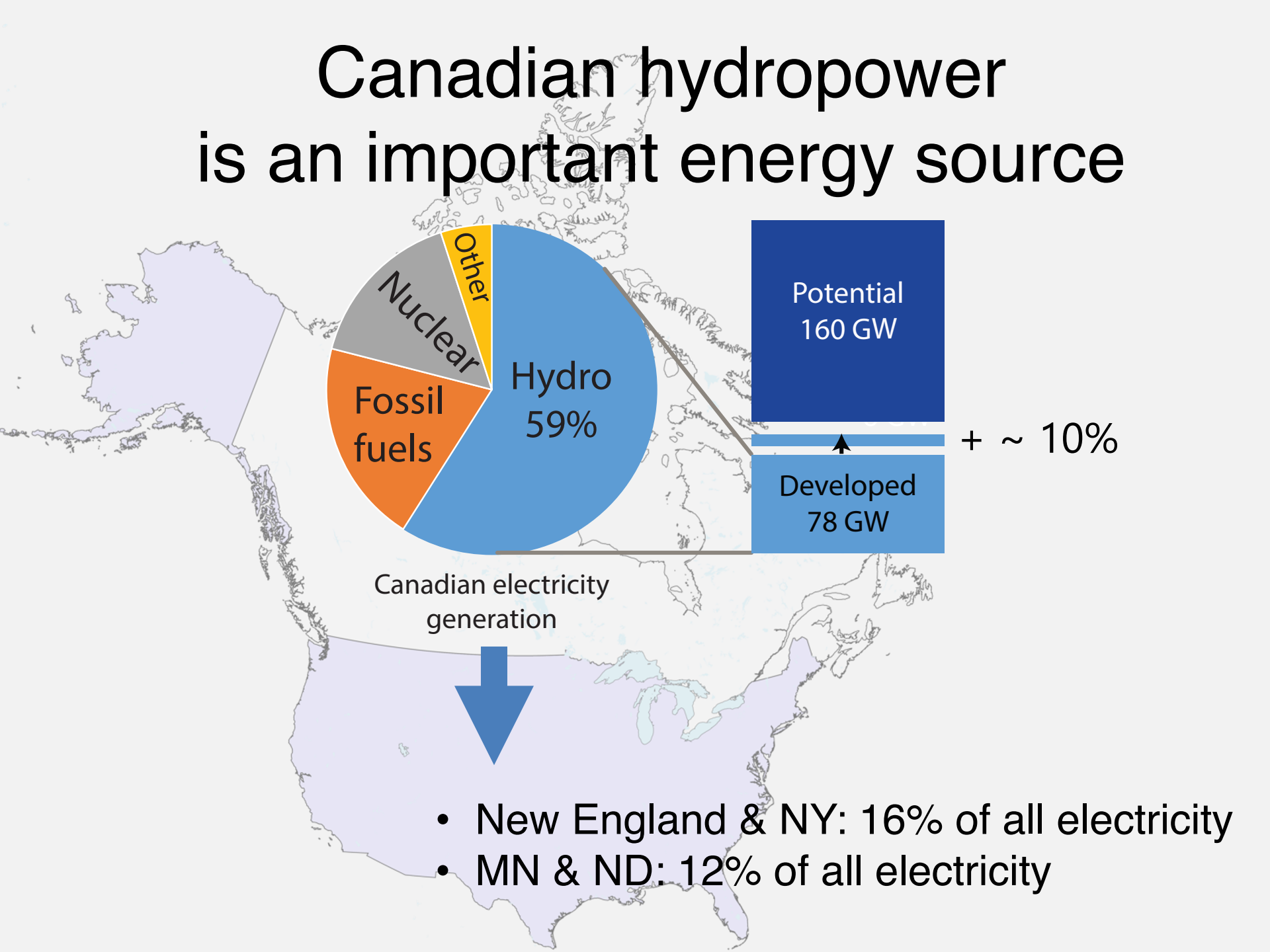


6. Food webs

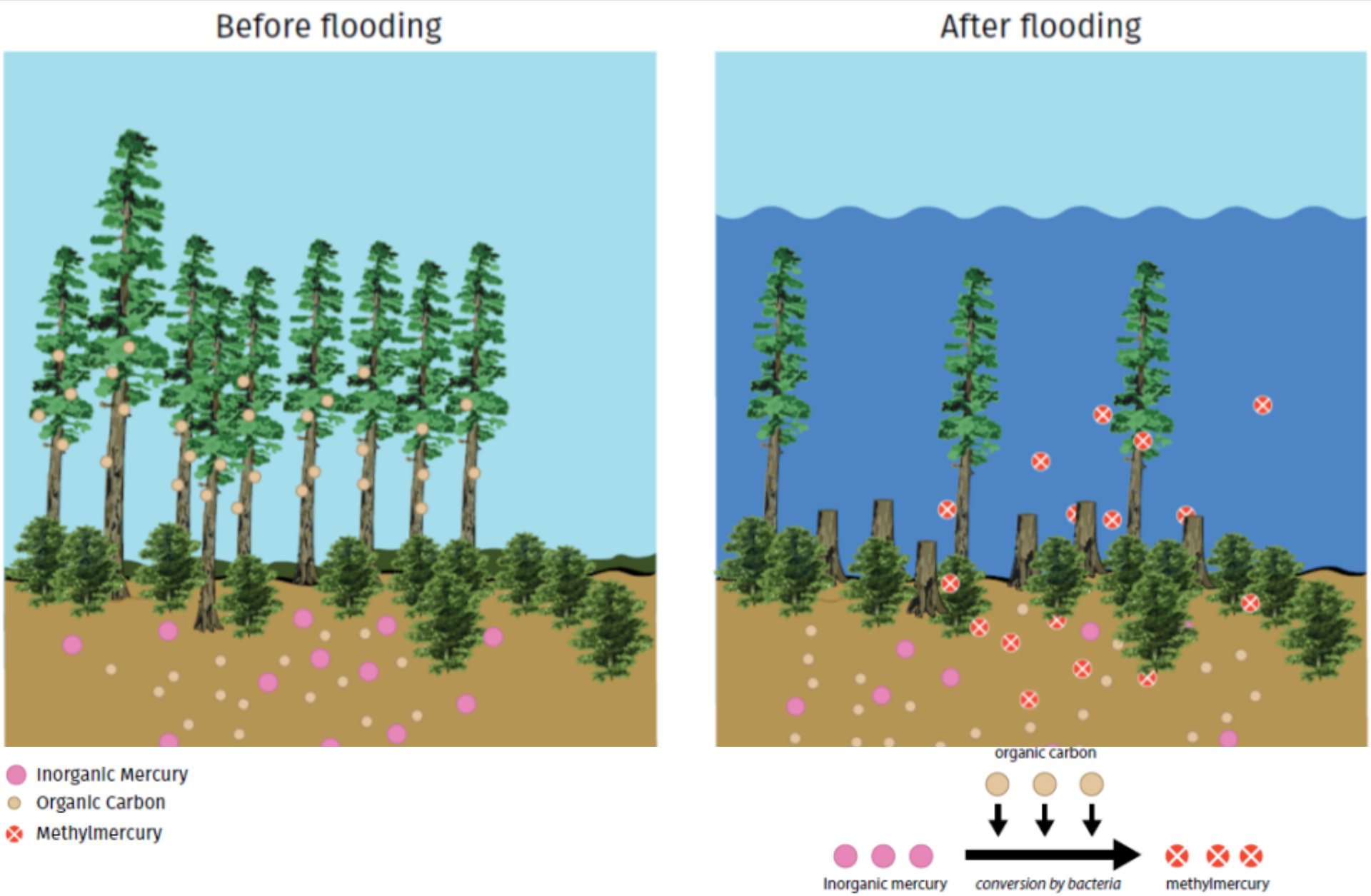
7. Humans

Canadian hydropower is an important energy source



- New England & NY: 16% of all electricity
- MN & ND: 12% of all electricity

Hydro dams and methylmercury

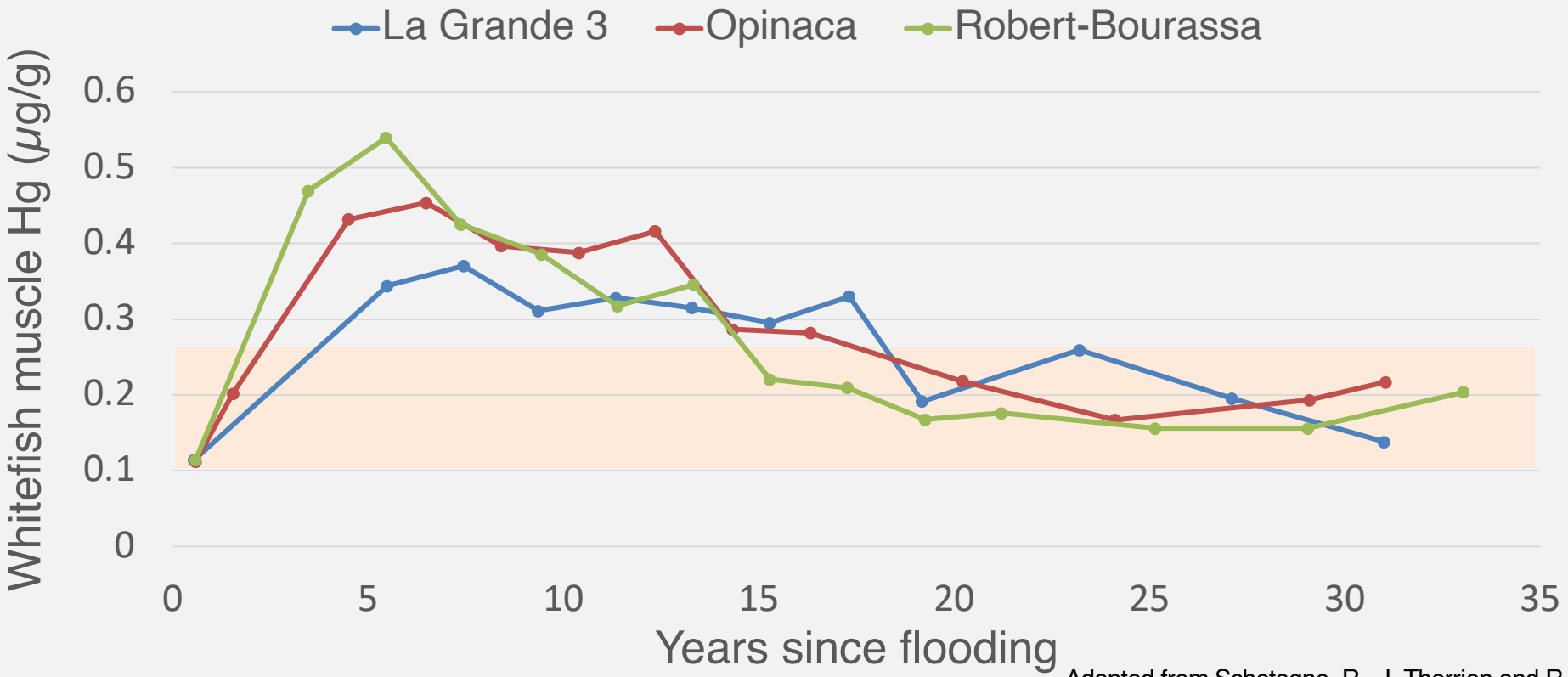


The form of mercury determines its health impact

- Inorganic mercury
  (i.e., quicksilver and Hg^{II})
  - Low absorption (0.01 – 7% avg)

- Methylmercury
  - High absorption (>90%)
  - Primarily a central nervous system toxin
  - Half-life of 50-70 days
  - Chelation not effective

Flooding soils causes a pulse in methylmercury

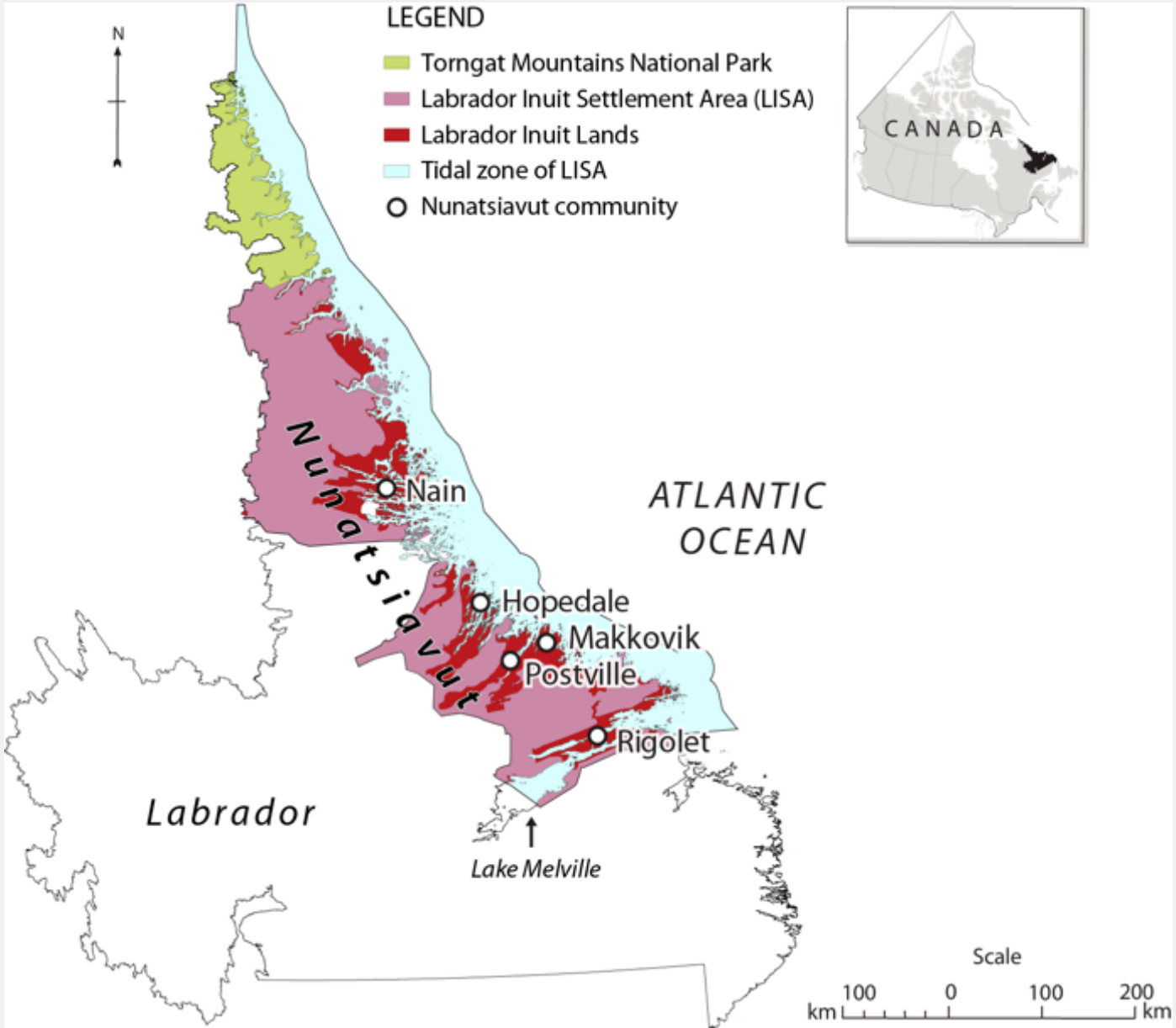


Adapted from Schetagne, R., J. Therrien and R. Lalumière (2003). "Environmental monitoring at the La Grande Complex: evolution of fish mercury levels: summary report 1978-2000."

This has been known for half a century!!

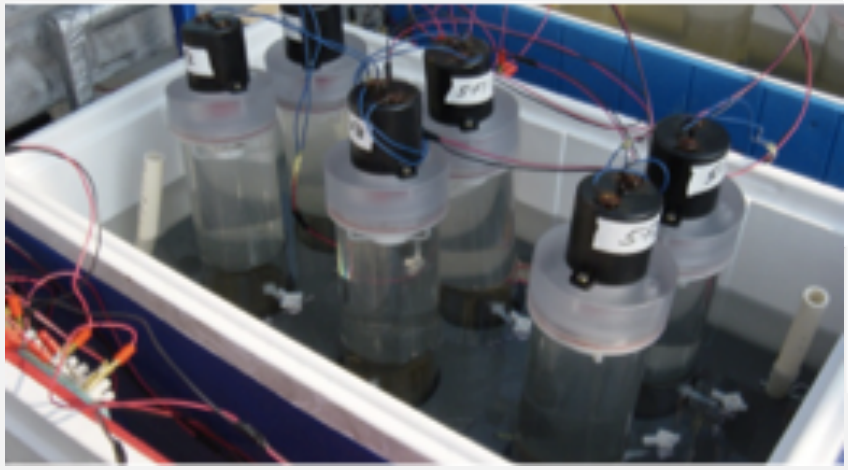
Northern communities are especially vulnerable to climate change and environmental pollutants

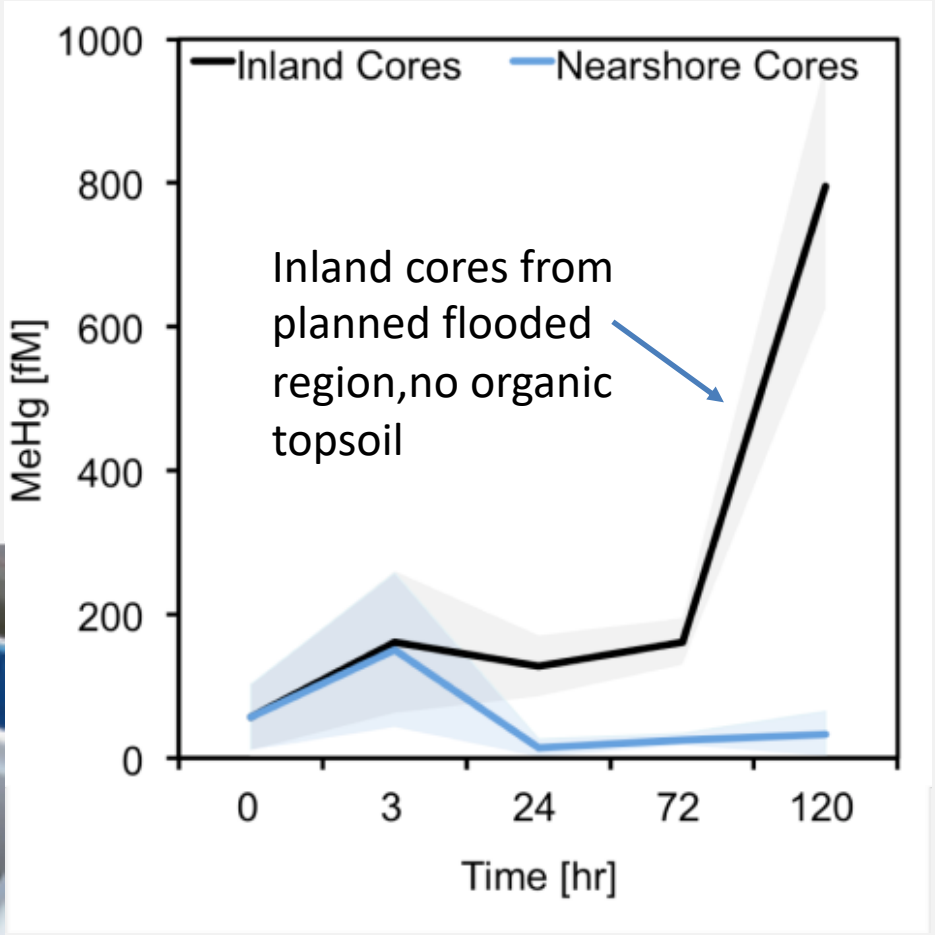
Nunatsiavut, the Labrador Inuit homeland



MeHg in Flooded Reservoir Increases Rapidly

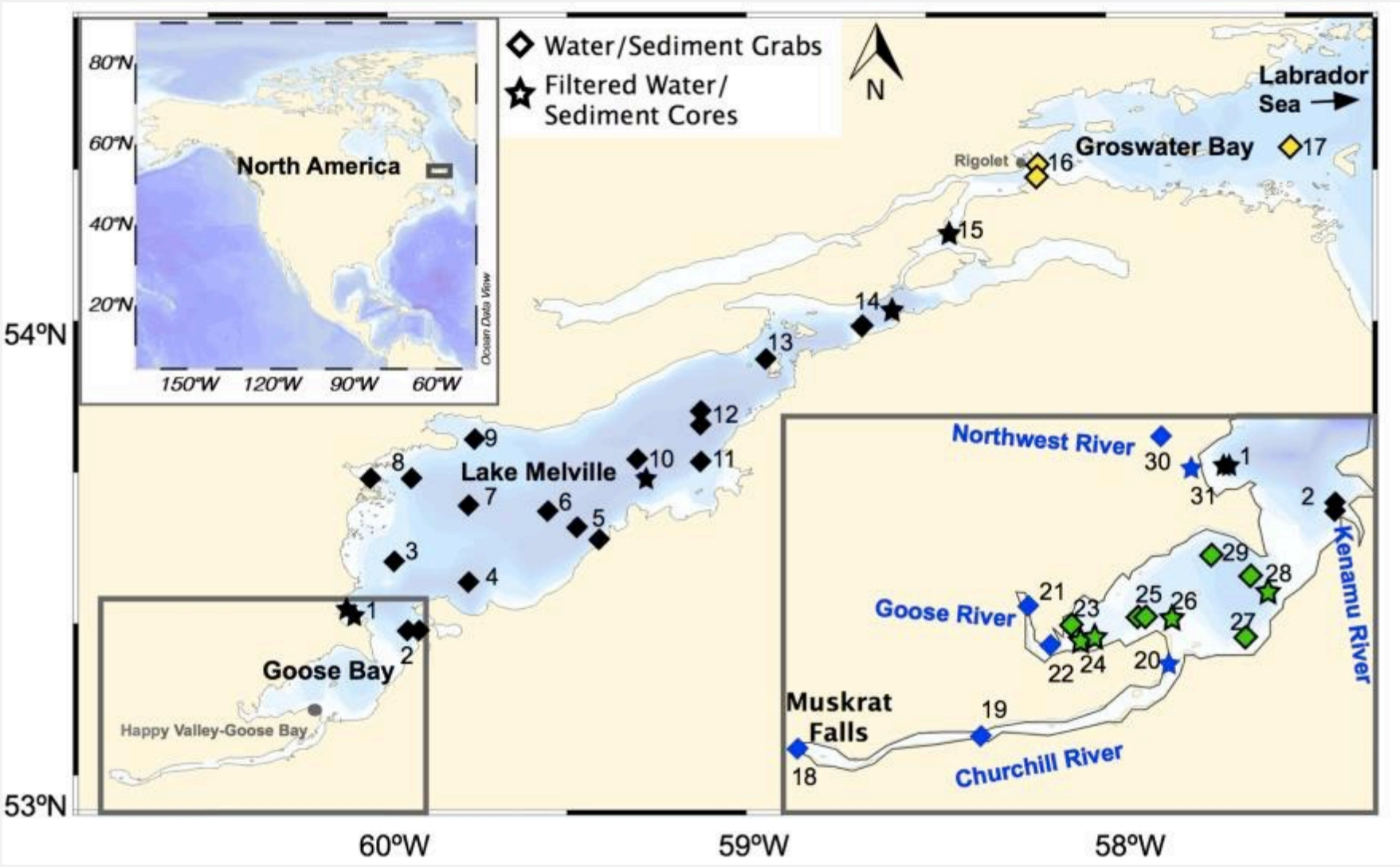
Rapid increase in methylmercury in river water above saturated soils 3-days after flooding



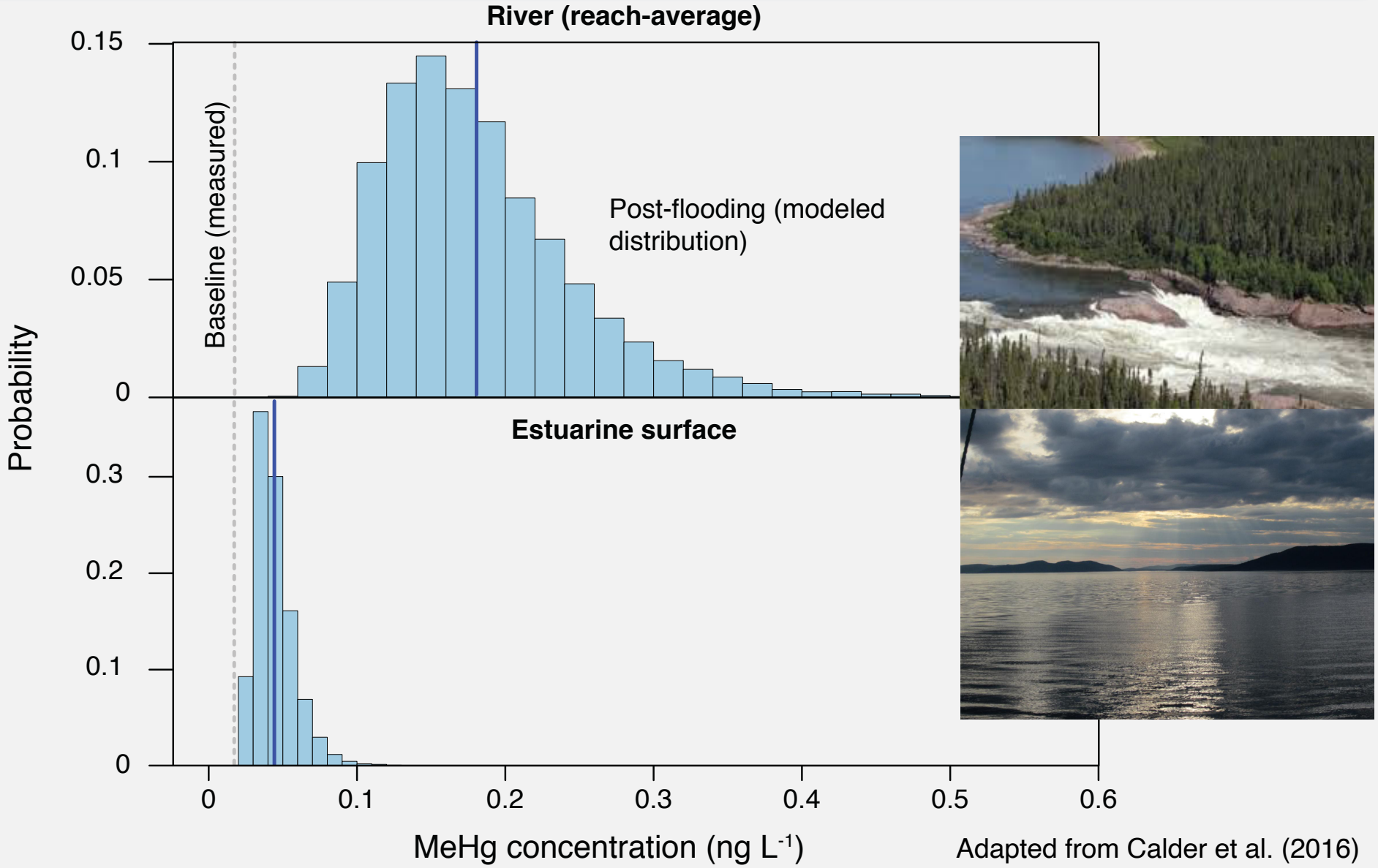


Schartup et al., 2015

Field sampling downstream of Planned Hydro Facility Prior to Flooding



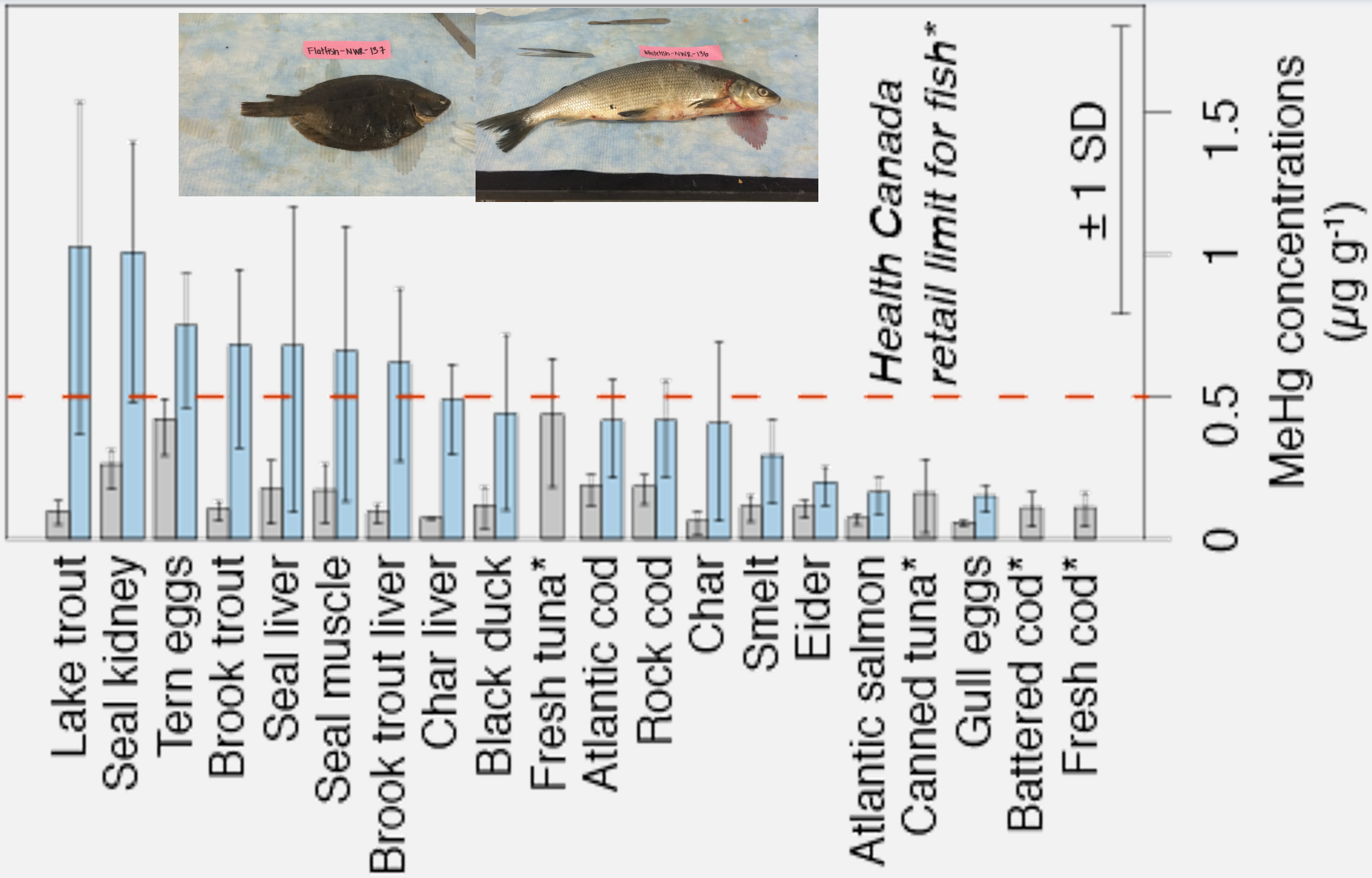
Methylmercury concentrations projected to increase by 10-fold (river) and 2.6 fold (estuary)



Adapted from Calder et al. (2016)

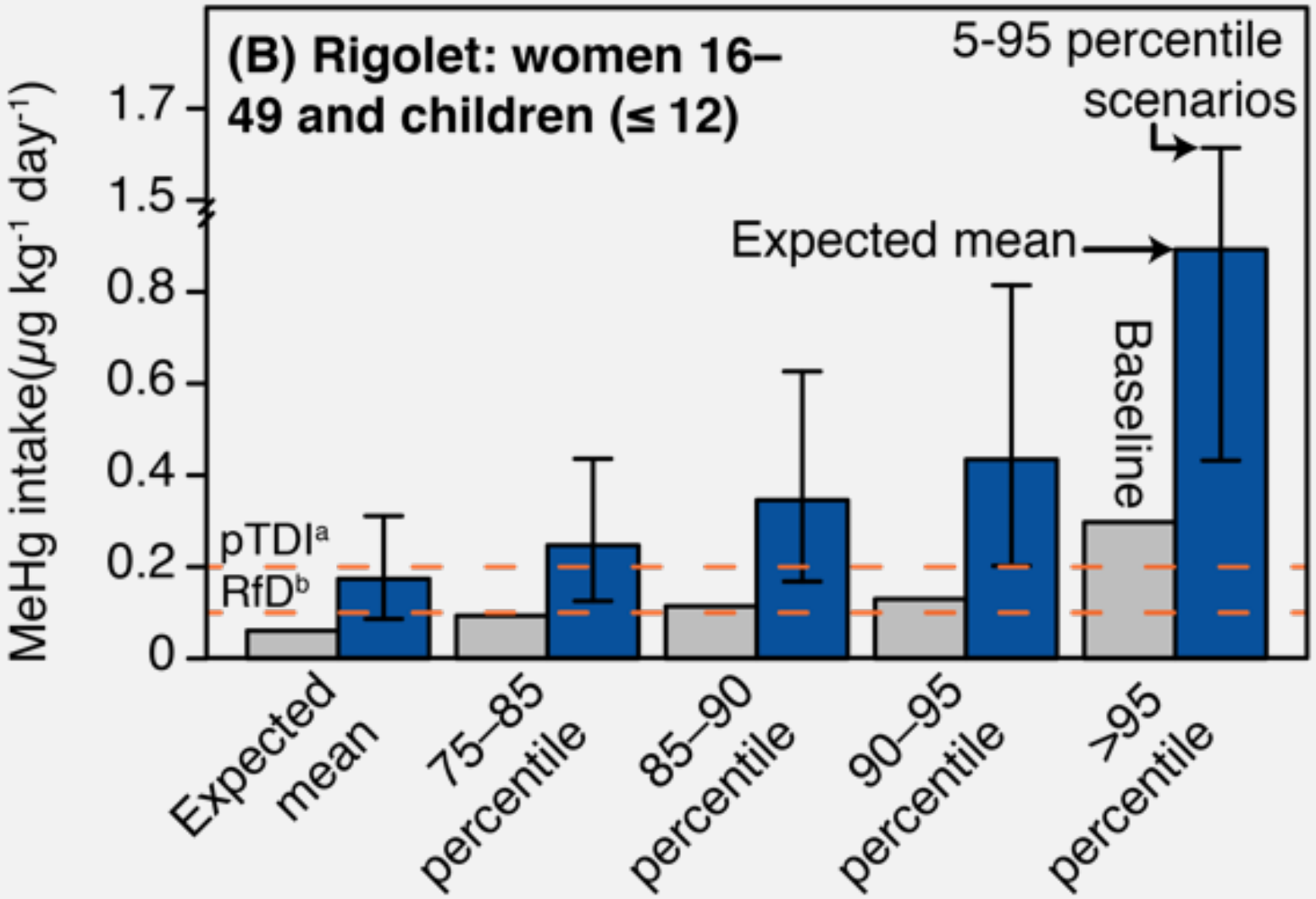
Angsar Walk 2002

Mean Inuit exposure forecasted to double



Adapted from Calder et al. (2016)

Exposure of sensitive groups greatest concern

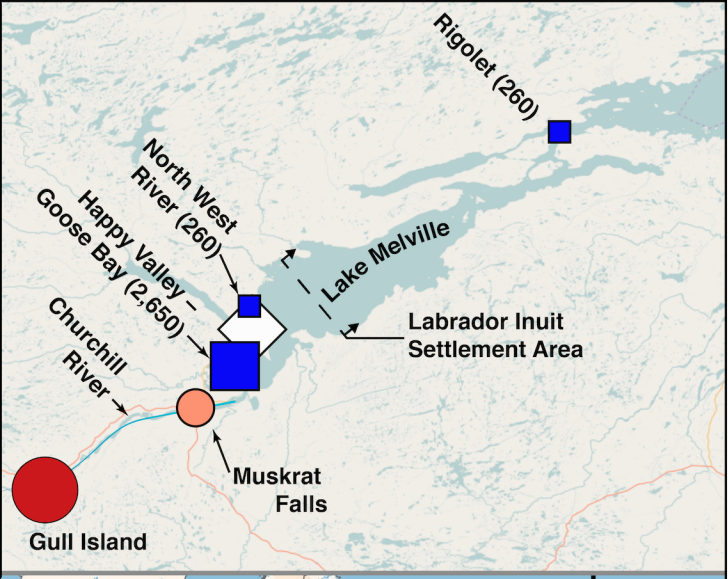


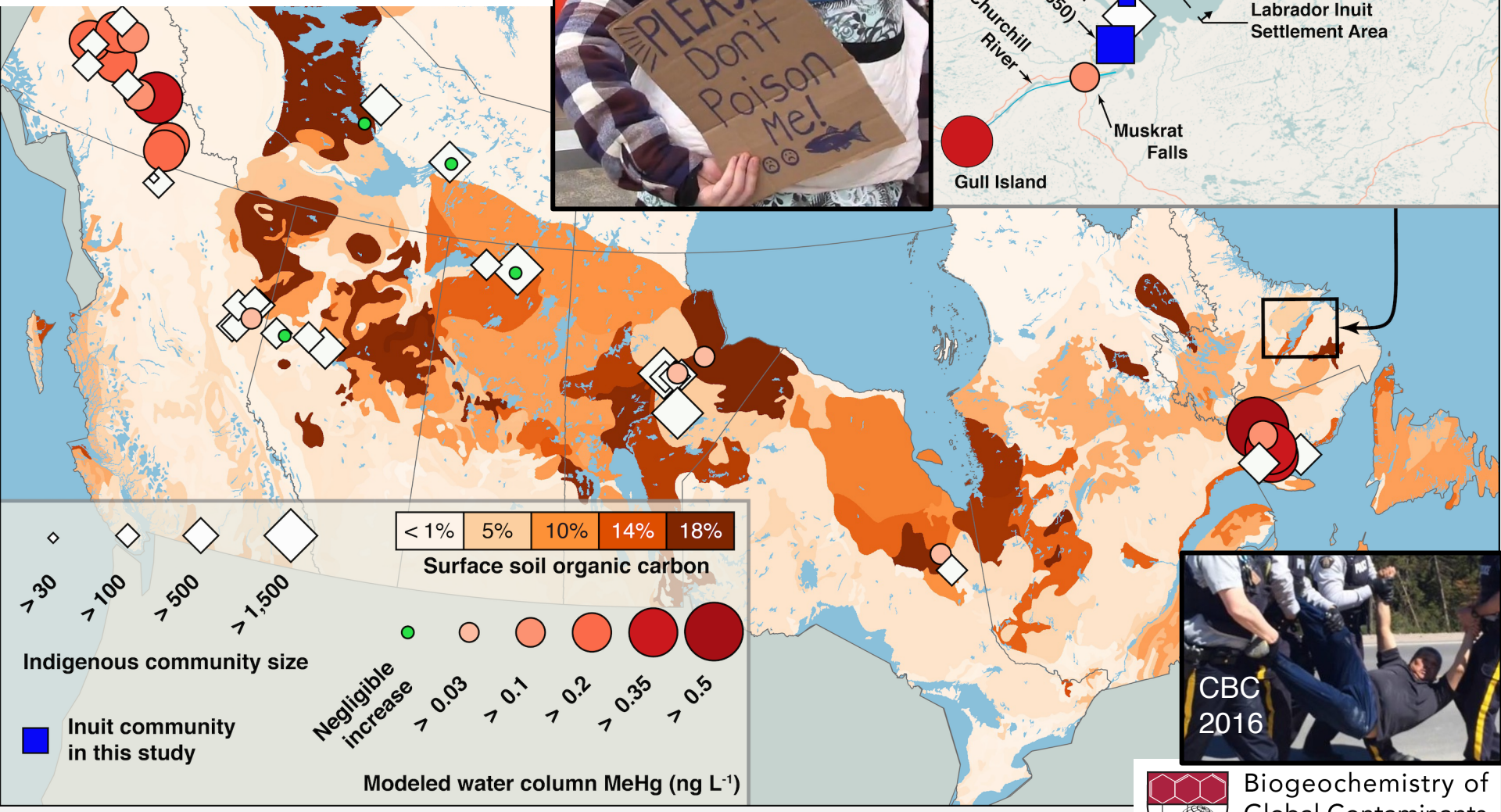
Calder et al., 2016

Canada's Big Dams Produce Clean Energy, and High Levels of Mercury

By IAN AUSTEN NOV. 10, 2016

The New York Times





Calder et al., 2016

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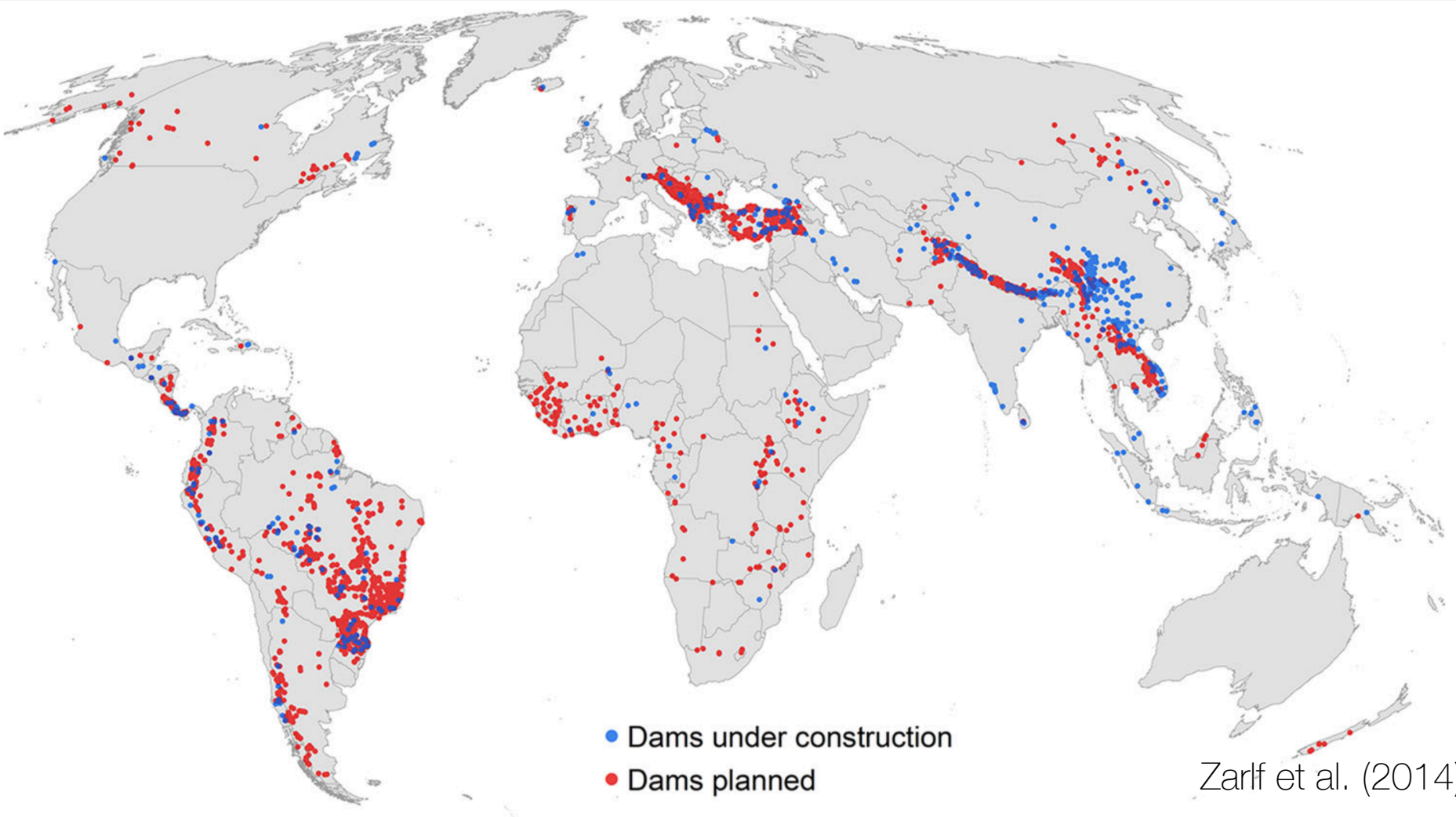
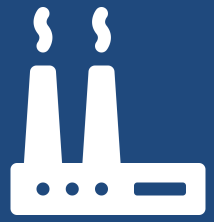
These dams would increase global hydropower capacity by 73%



Zarlf et al. (2014)


There's a high cost in doing
Muskrat Falls wrong.
There's power in
doing it right.
#makemuskratright

Three Examples



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2. Exposures pathways for PFAS from drinking water, seafood, and consumer products

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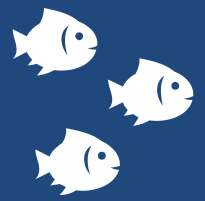

6. Food webs

7. Humans

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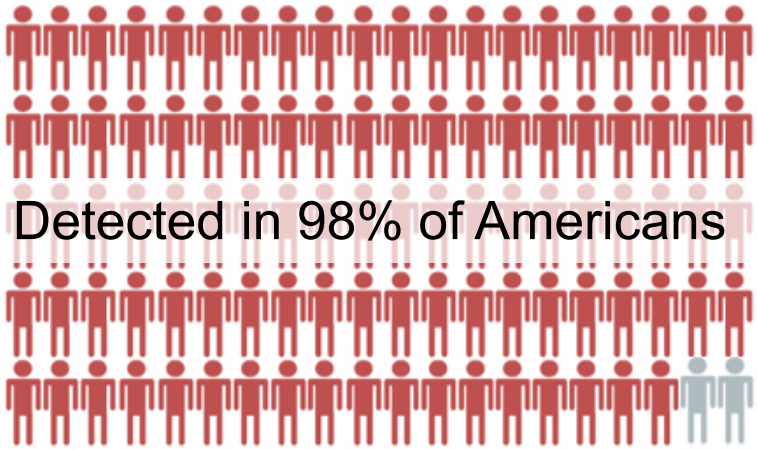
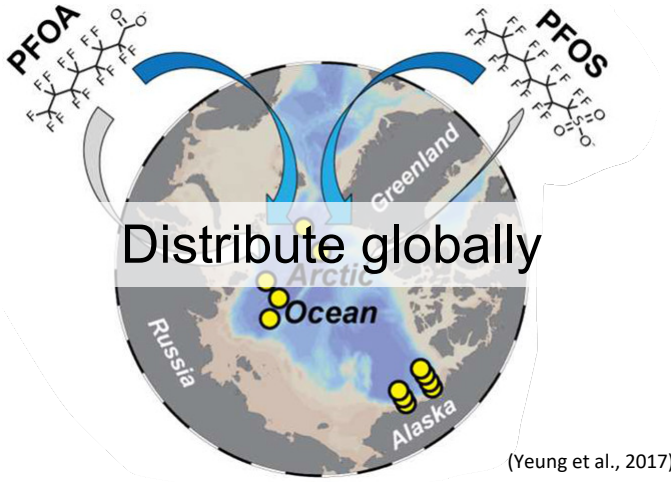
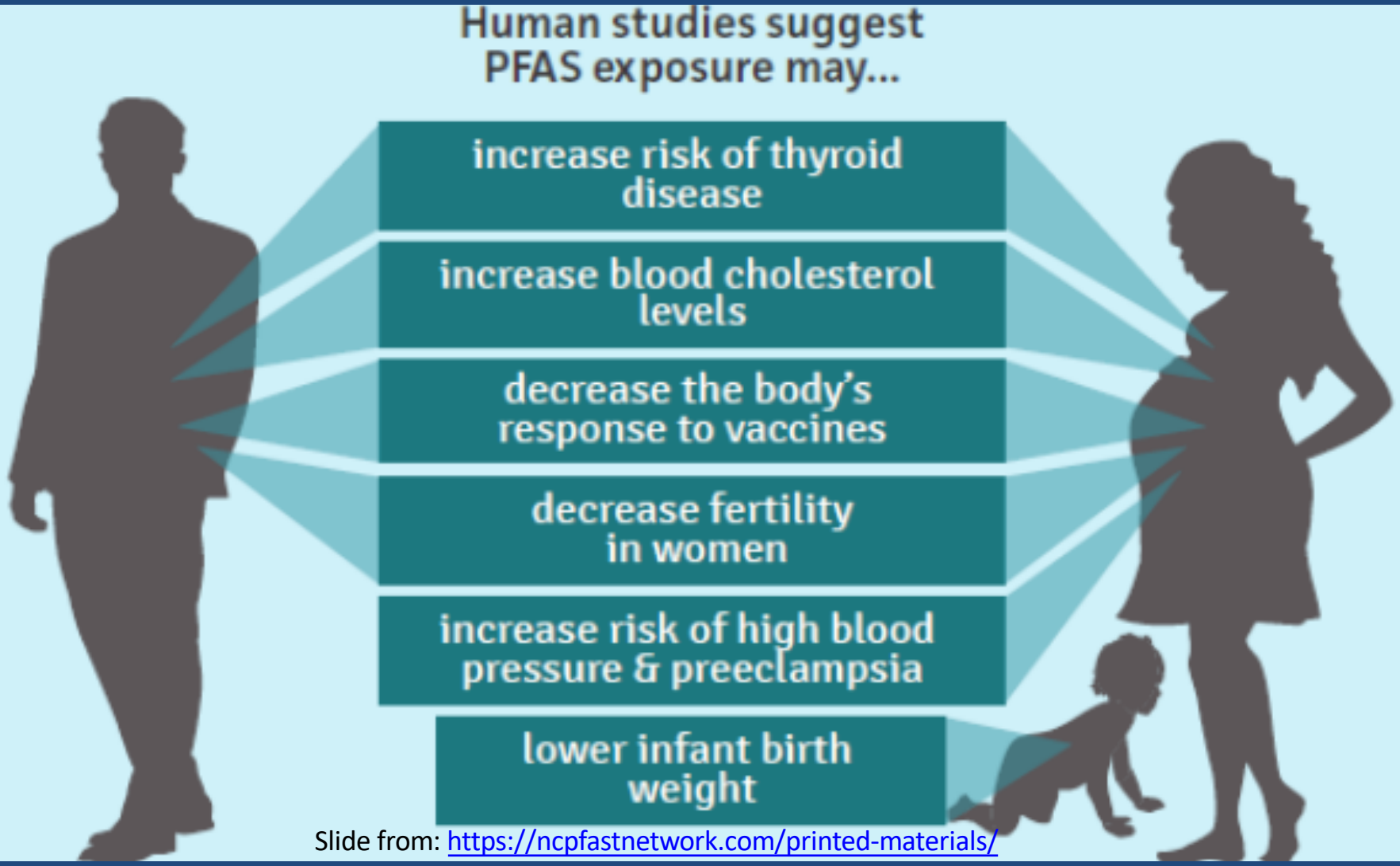
What are poly- and perfluoroalkyl substances (PFAS)?





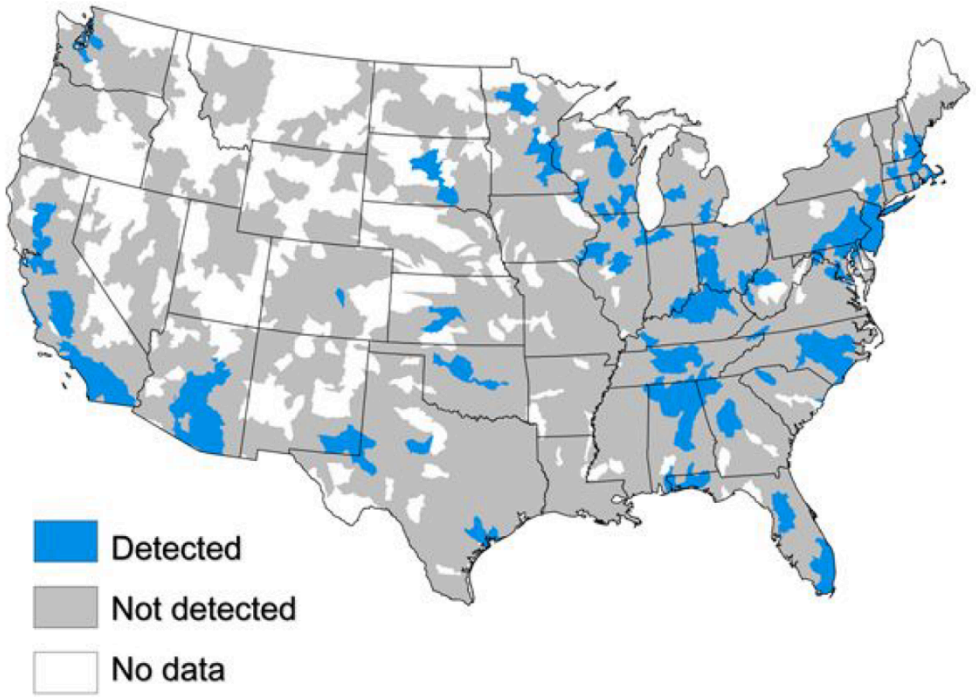
(Yeung et al., 2017)



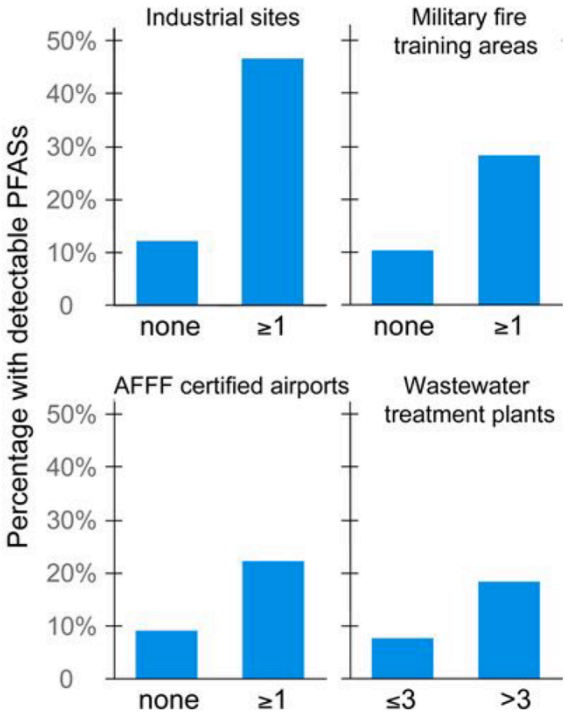
Slide from: https://ncpfastnetwork.com/printed-materials/

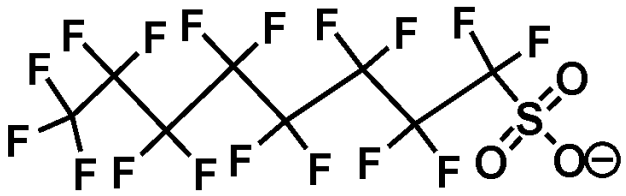
Drinking water supplies for 6 million Americans above provisional guidelines for PFASs

Hydrological units with detectable PFASs



Point sources

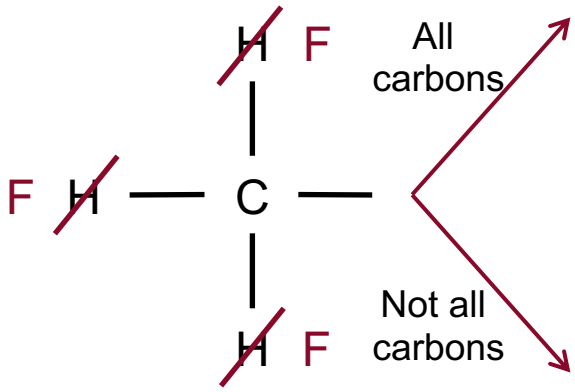




Hu et al., 2016

PFAS are "Forever-Chemicals"
F-C backbone does not degrade in nature

>4700 Compounds



All carbons

Not all carbons

Perfluoroalkyl substances
(C_nF_{2n+1}-R)

Polyfluoroalkyl substances
(C_nF_m-R)

PFCAs
(C_nF_{2n+1}-COOH) → C4 – C14:
buta-, penta-, hexa-, hepta-, ***octa- (PFOA),*** *nona-, deca-, etc.*

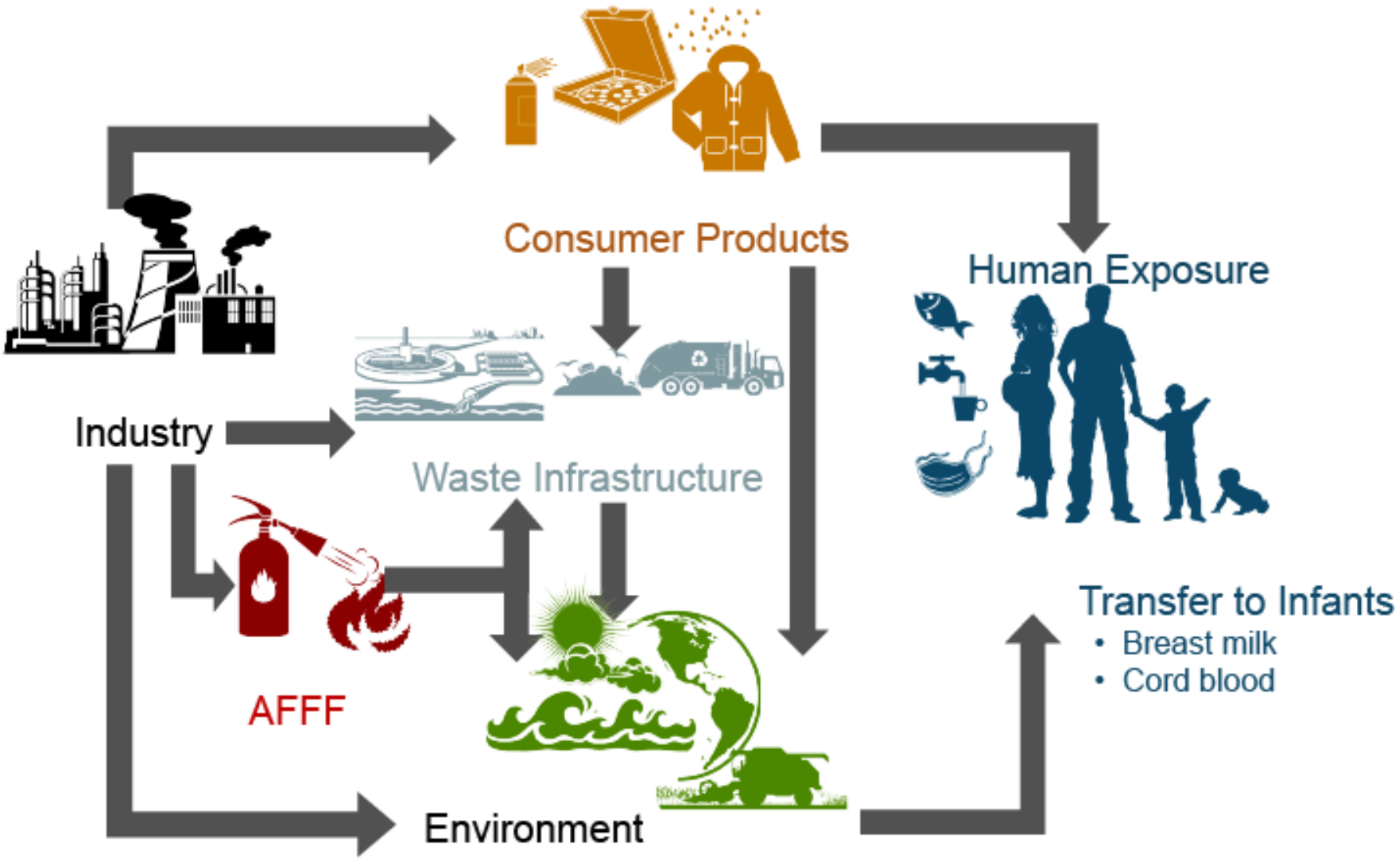
PFSAs
(C_nF_{2n+1}-SO_3H) → C4 – C10:
buta-, hexa-, ***octa- (PFOS),*** *deca-*

Long-chain PFASs:
PFCAs, n ≥ 7
PFSAs, n ≥ 6

More bioaccumulative, more persistent

(Buck et al. 2011; Wang et al. 2017)

Pathways of Human Exposure to PFAS

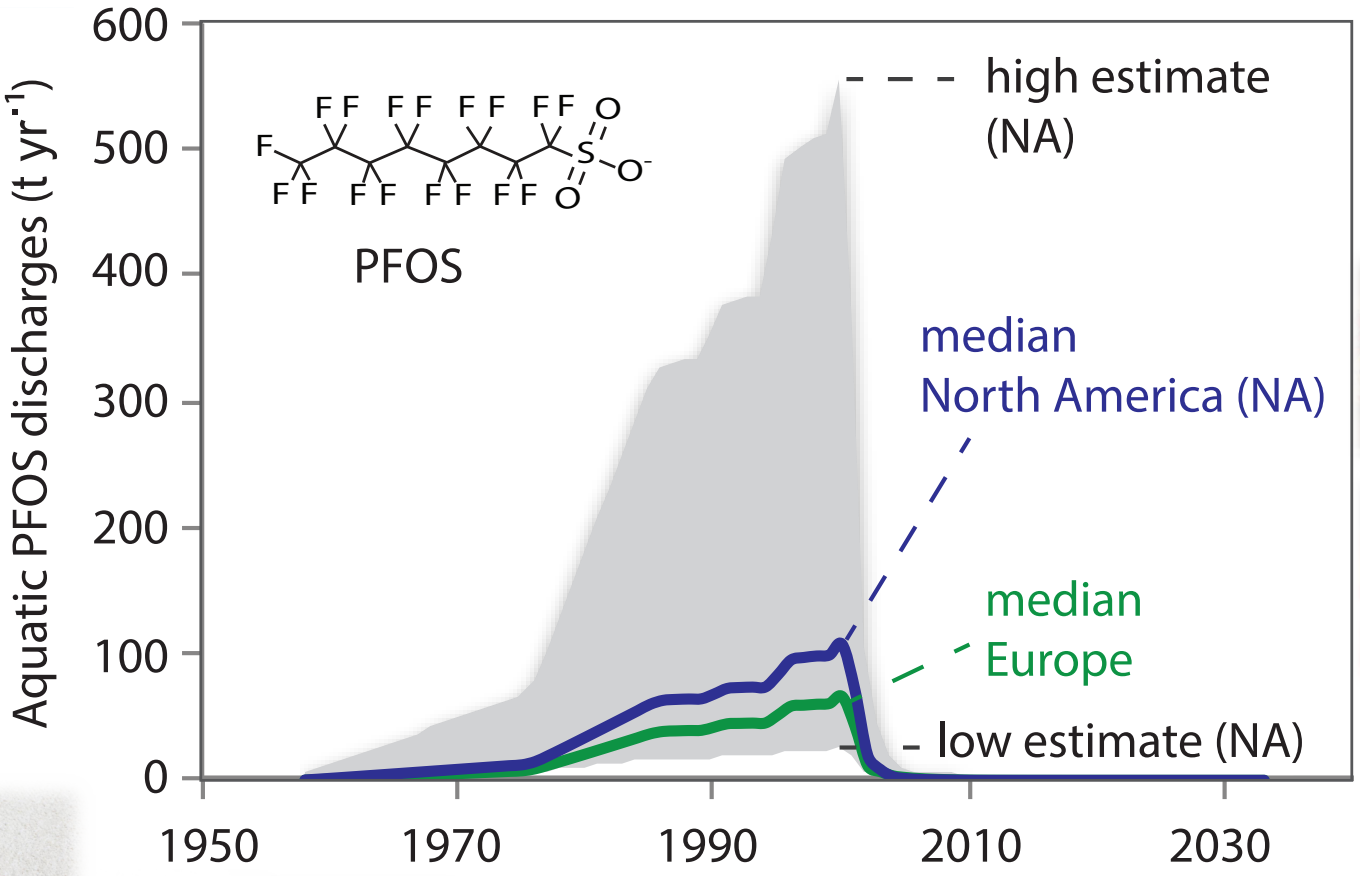


Sunderland et al., 2019

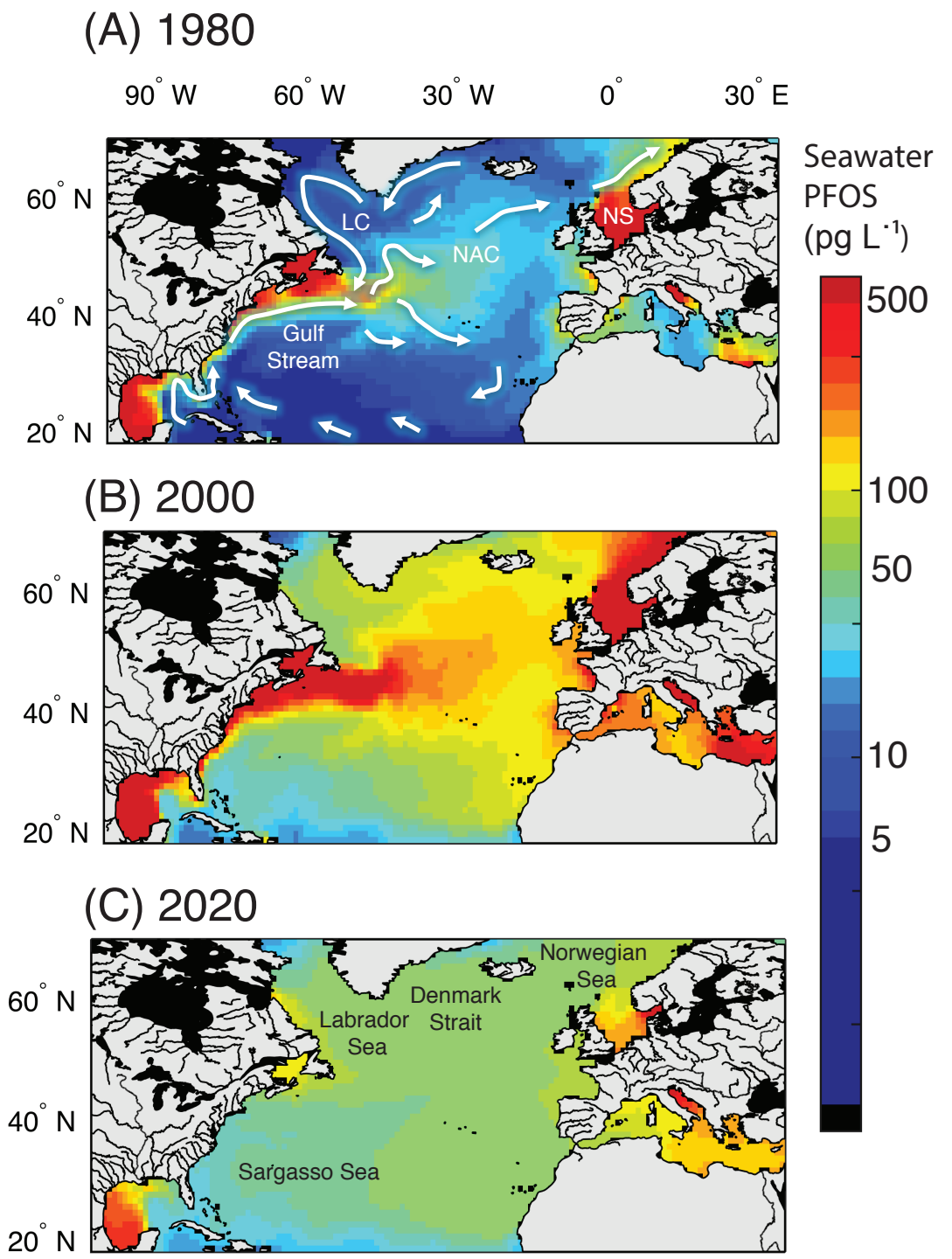
How quickly will toxicants in ocean food webs decline after global regulations?

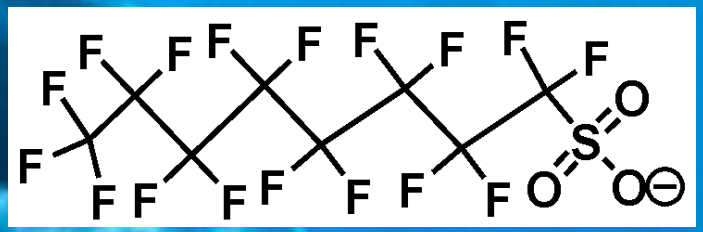
Parent chemical to perfluorooctane sulfonate (PFOS) phased out by 3M between 2000-2002

Riverine discharges to the North Atlantic Ocean



X. Zhang et al., 2017

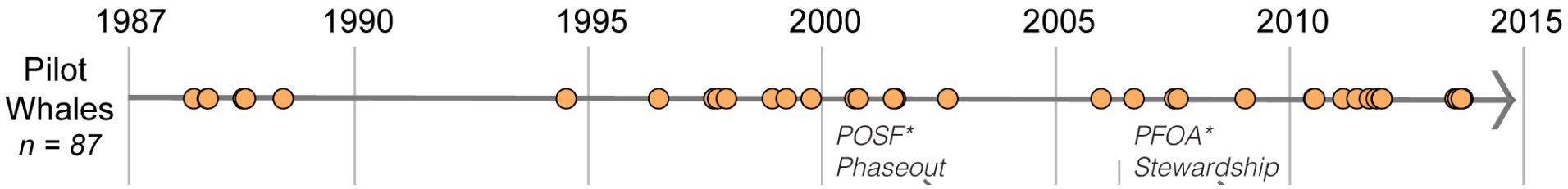




Modeled PFOS in North Atlantic seawater (10 m)

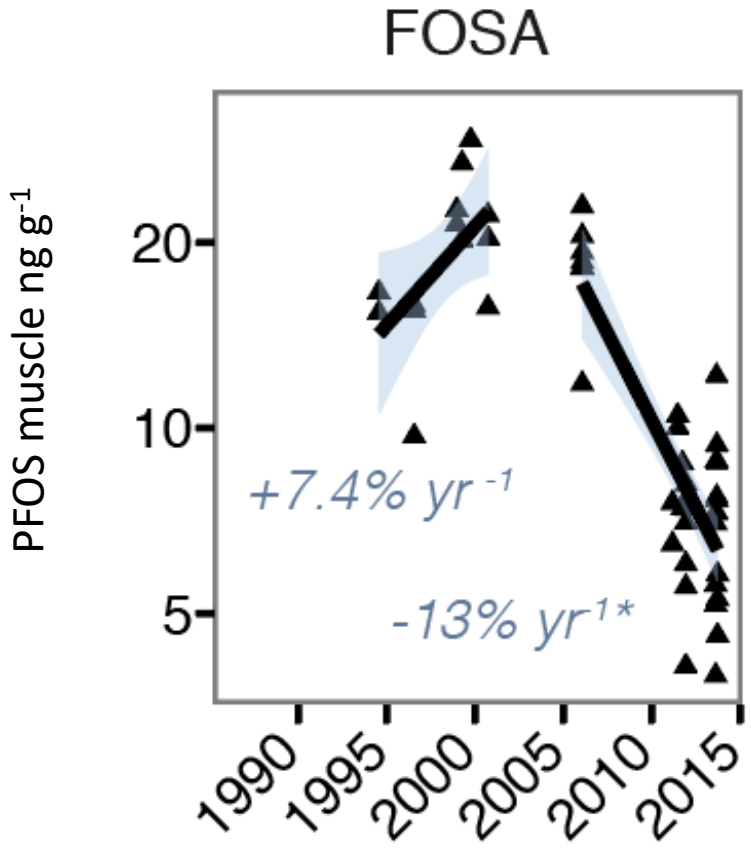
X. Zhang et al., 2017

Large decline in FOSA in Pilot Whales

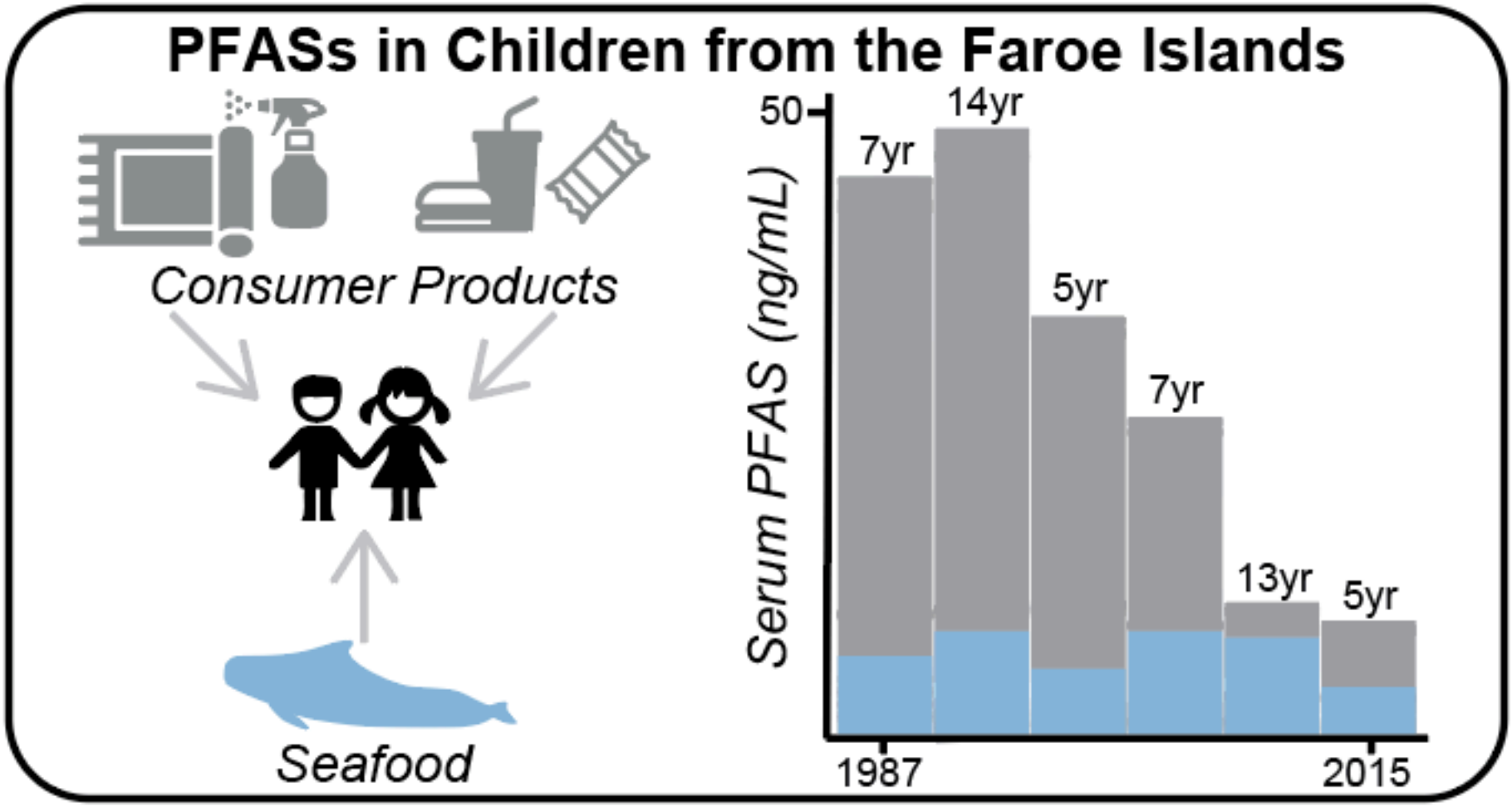


Dassuncao et al., 2017, ES&T

Juvenile males 9-12 years



Decline in legacy PFAS in children likely driven by changes in consumer products



Dassuncao et al., 2018, ES&T

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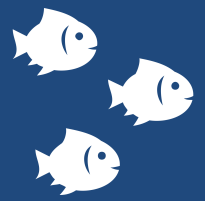

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Methylmercury is a bioaccumulative neurotoxin

Concentrations are x10^6-10^7 water

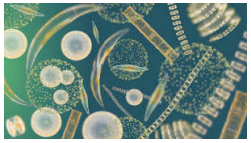
top predators

- Neurotoxin
- Impaired cardiovascular health
- Endocrine disruptor
- Immunotoxin

big fish

small fish

10^4 - 10^5



plankton

water

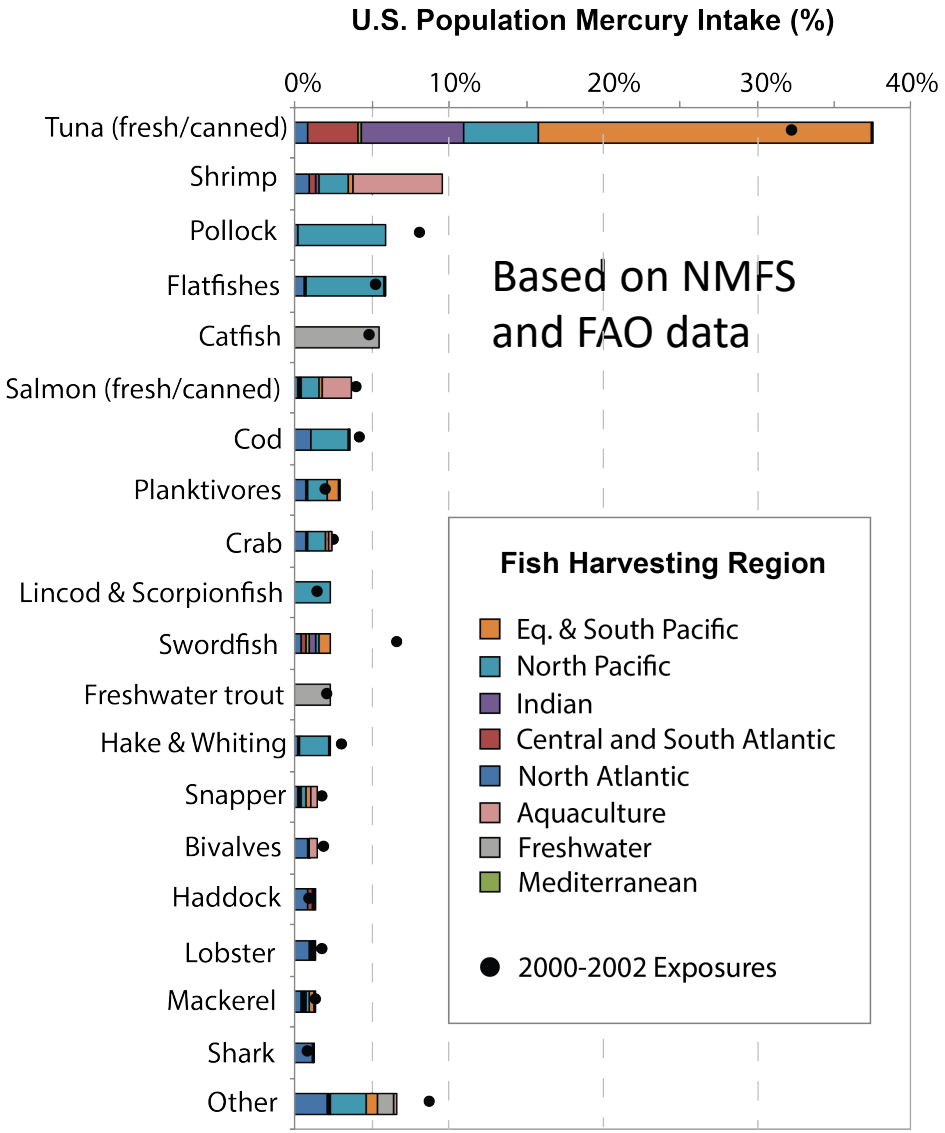
$CH_3Hg(I)$

methylmercury concentration

Societal Costs of methymercury exposure in US & Europe > $15 B

(Bellanger et al., 2013; Grandjean et al., 2012)

Tuna accounts for almost 40% of US population-wide methylmercury exposure



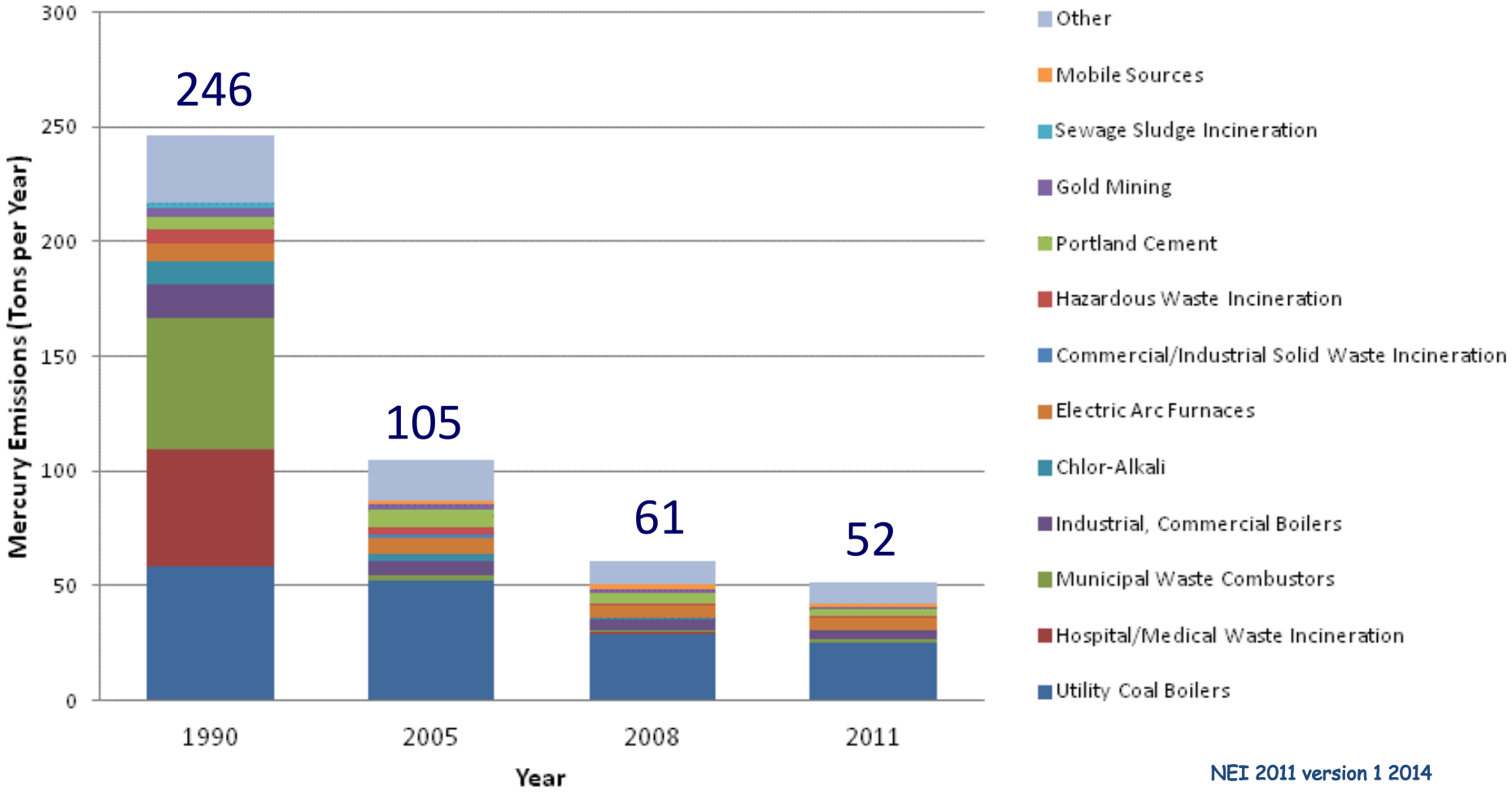
Decadal differences
2000 – 2010

U.S. Department of Commerce
Dolphin Safe

Sunderland et al., 2018

Biogeochemistry of Global Contaminants
HARVARD

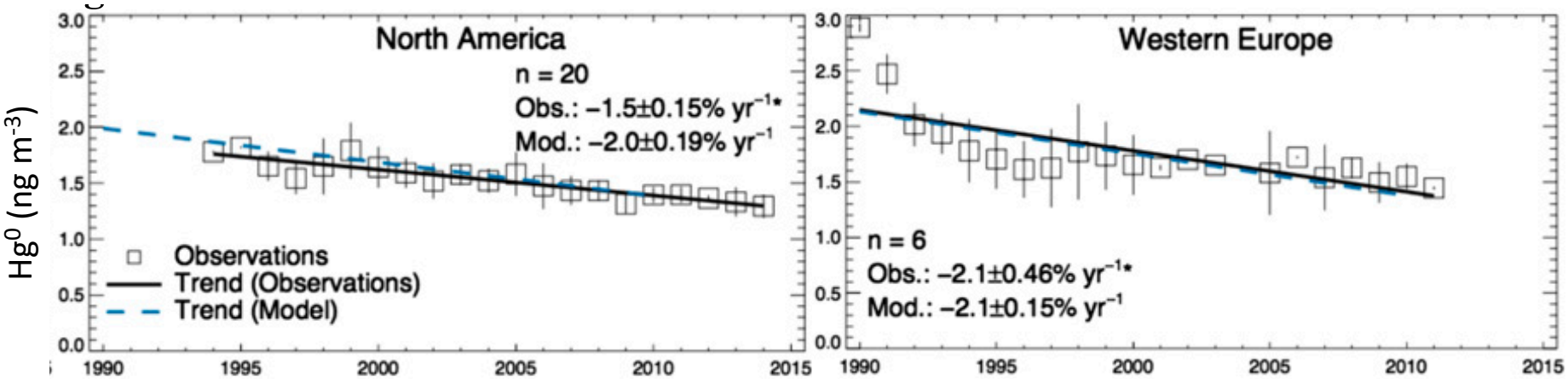
U.S. mercury emissions, major sources 1990, 2005, 2008, 2011



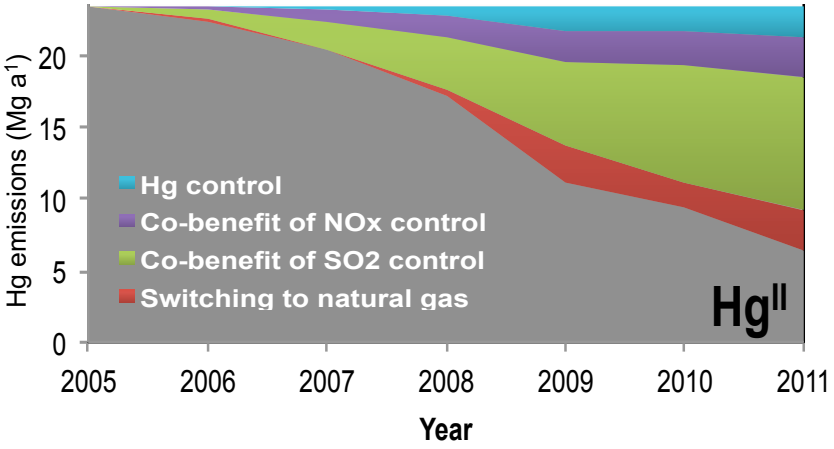
NEI 2011 version 1 2014

Controls on US utilities and products help explain 30% declines in atmospheric Hg concentrations

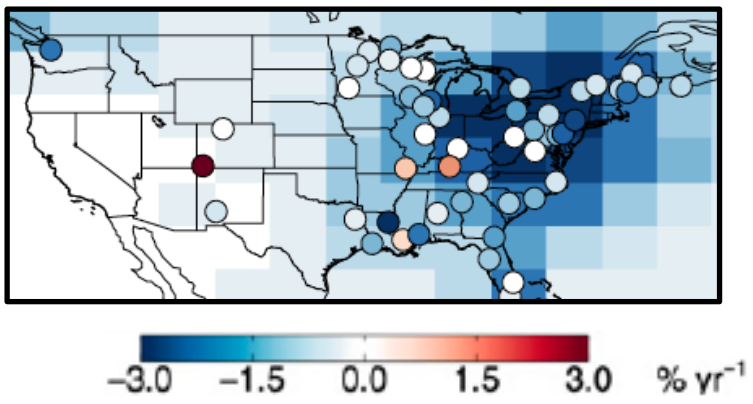
Observed Trends atmospheric Hg^0 (1990-2010)



US utilities Hg^{II} emissions

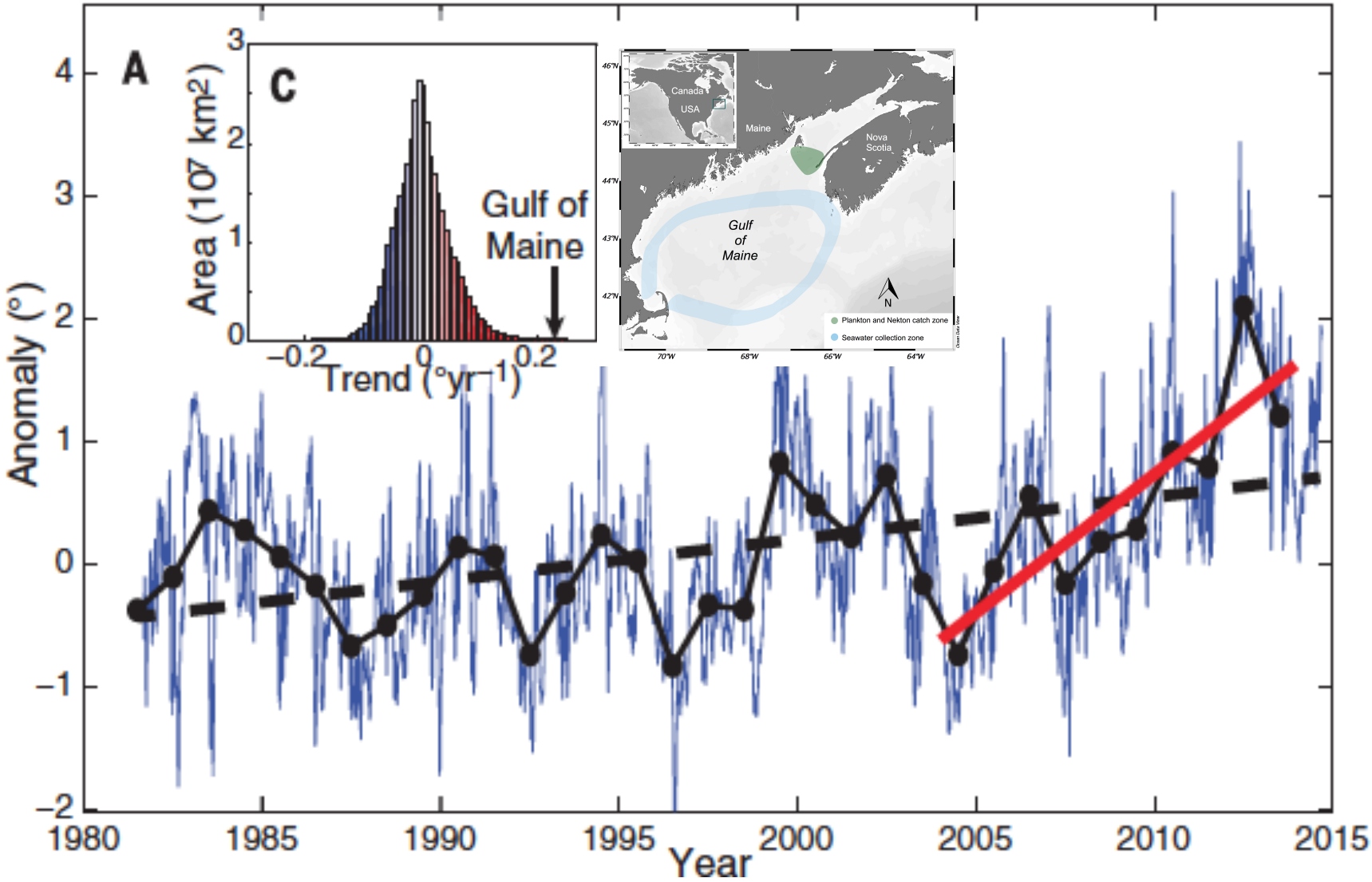


US wet deposition trend, 1990-2010

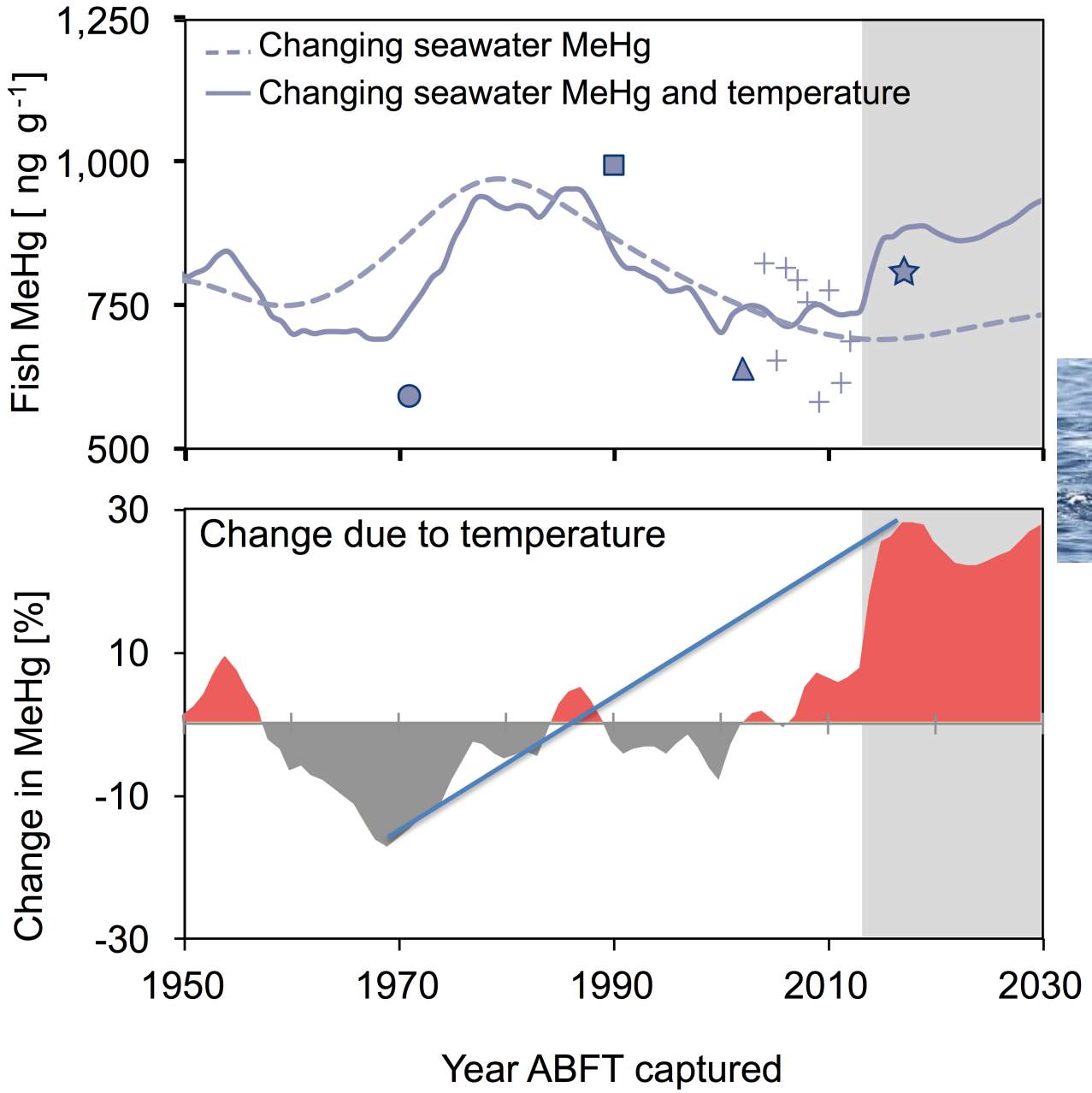


Y. Zhang et al., 2016

Warming affects fish metabolism and growth, MeHg elimination, prey availability, and species habitat



Pershing et al., 2015

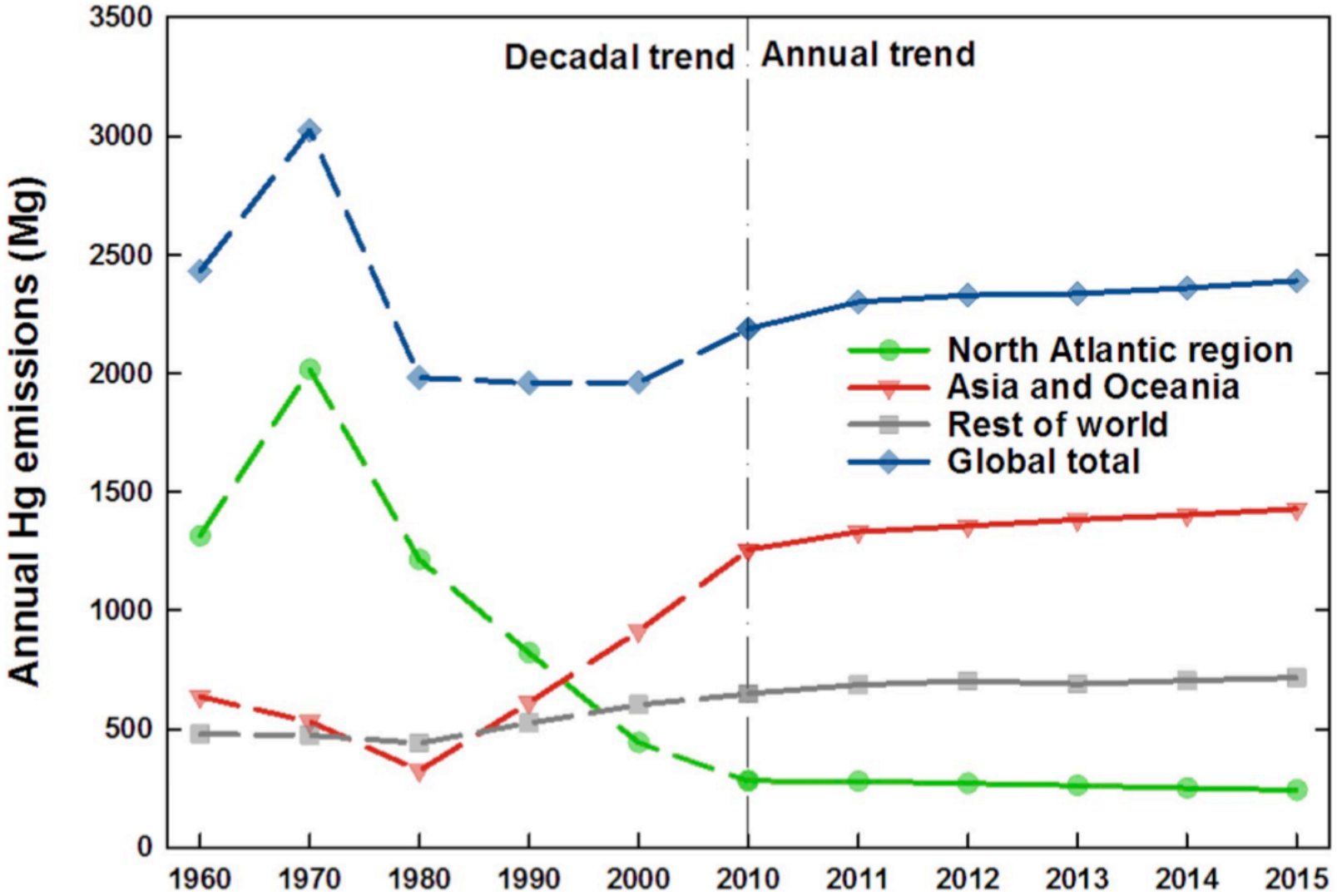


>20% decrease between 1990-2010

~50% Increase between 1970-2015

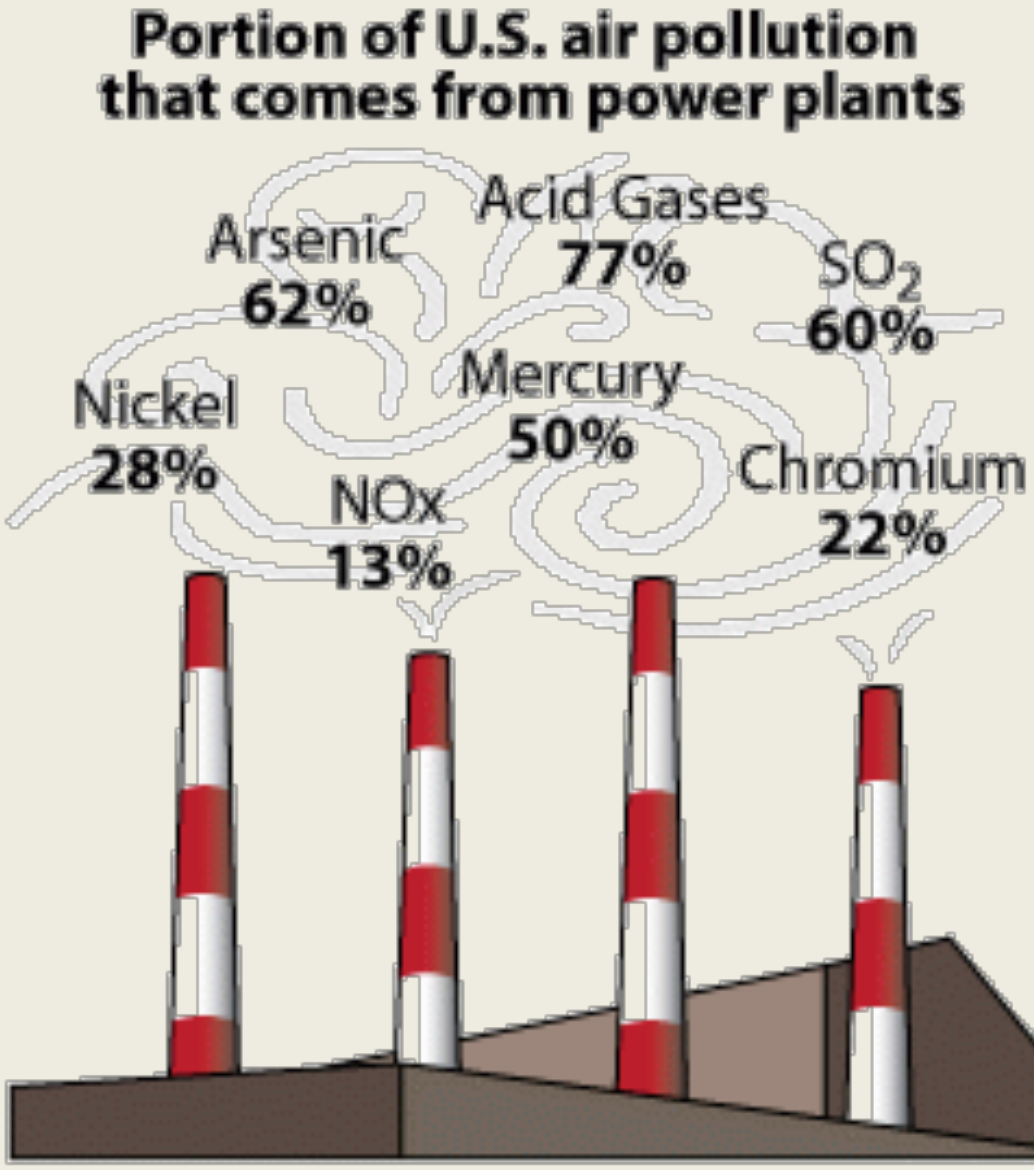
Schartup et al., 2019, Nature

Current plateau in global Hg emissions means seawater warming will be important factor for methylmercury in marine fish



Streets et al., 2019, Atm Environ

Societal costs of different energy choices have not been fully evaluated; unquantified costs are LARGE



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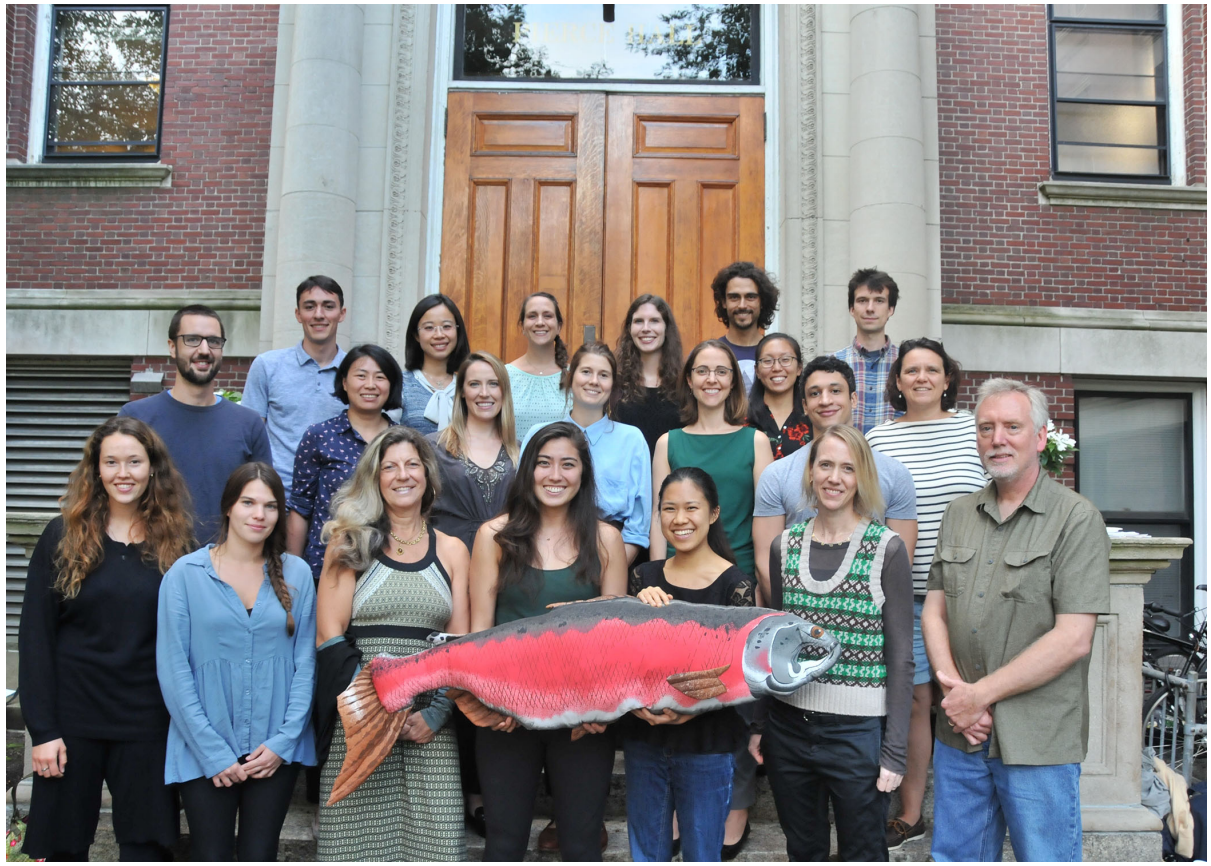
Summary

- Hydroelectric power expansion warrants careful consideration. Design that minimizes environmental impacts is possible but rarely discussed.
- PFAS is consumer products is likely the main exposure pathway for the general population outside of contaminated communities where drinking water dominates.
- Global regulations can be extremely effective at reducing exposures as illustrated for PFOS.
- Regulations on carbon and mercury emissions from coal-fired utilities are both needed to prevent further methylmercury accumulation in fish

Acknowledgements



NIEHS National Institute of Environmental Health Sciences

NUNATSIAVUT kavamanga Government

Gulf of Maine Council on the Marine Environment
Canada and the United States working together for a healthy environment

EPRI ELECTRIC POWER RESEARCH INSTITUTE

NEREUS PROGRAM Predicting Future Oceans

THE NIPPON FOUNDATION

VE RI TAS

VE RI TAS

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