

Biogeochemistry of
Global Contaminants
HARVARD

Global Contaminants in an Era of Environmental Change

Elsie M. Sunderland (ems@seas.harvard.edu)
May 20, 2021



HARVARD
T.H. CHAN

SCHOOL OF PUBLIC HEALTH



HARVARD
John A. Paulson
School of Engineering
and Applied Sciences

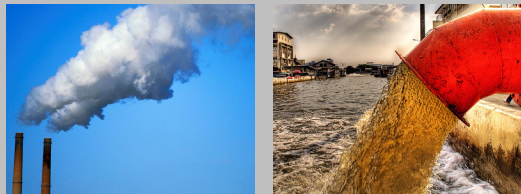
We are conducting a global chemical experiment on our health

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 diseases

A photograph of a person with significant obesity standing on a sidewalk. They are wearing a brown jacket over a plaid shirt and dark pants. The image is slightly faded to serve as a background for the text.

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

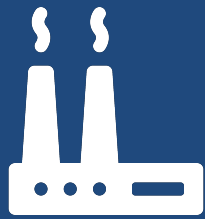
A close-up photograph of a medical syringe, specifically a 3 mL prefilled pen. The syringe is held in a hand, and the needle is visible. The image is slightly faded to serve as a background for the text.

Diabetes has more than **tripled** since 1980

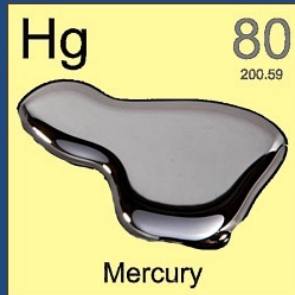
A photograph of a person with autism spectrum disorder sitting on a bench. They are wearing a dark jacket and glasses. The image is slightly faded to serve as a background for the text.

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

Little quantitative information relating large scale environmental releases of aquatic pollutants & health



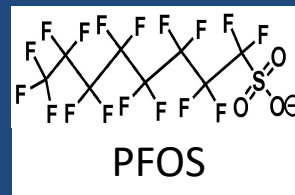
1. Emissions



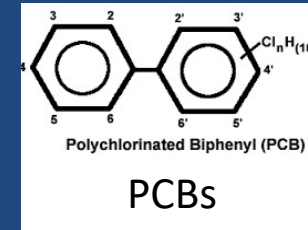
2. Deposition



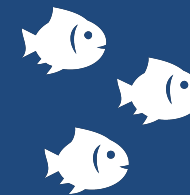
3. Land



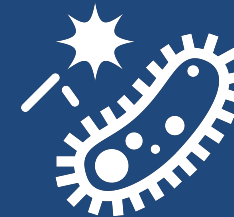
4. Ocean



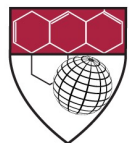
7. Humans



6. Food webs

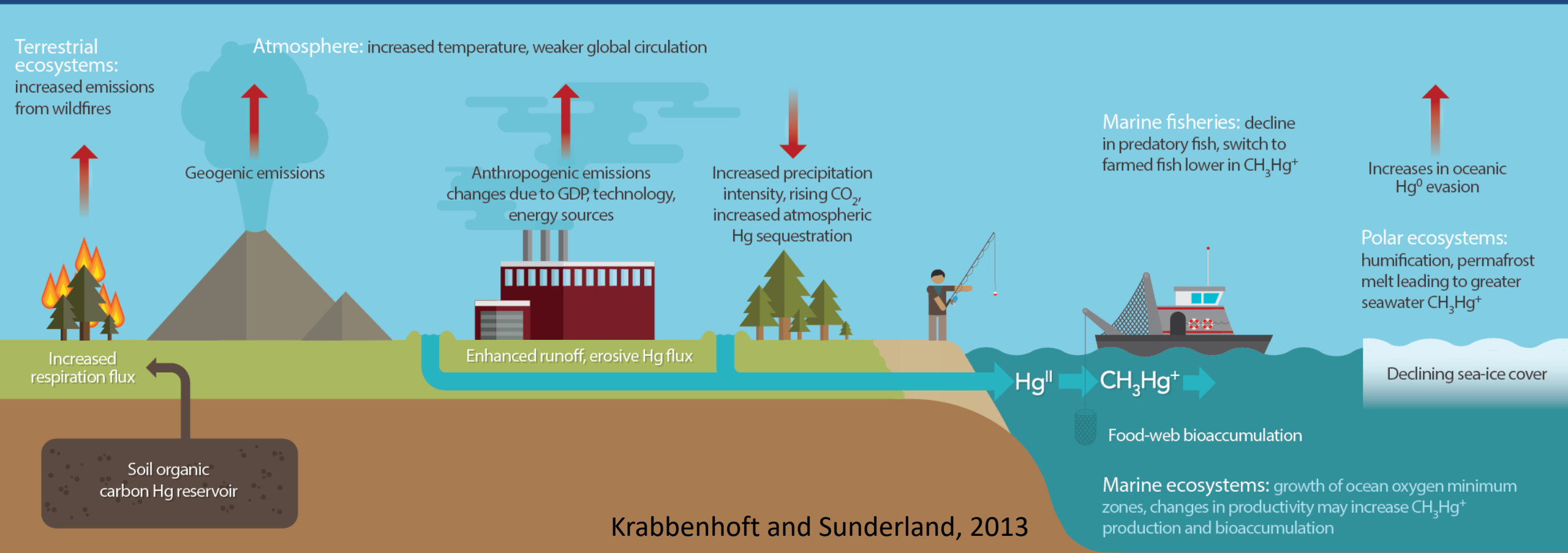


5. Bioavailability

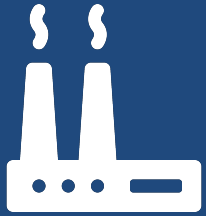


Impacts of Global Change on Contaminants

- Seawater Temperature
- Ocean circulation
- Freshwater discharges
- Sea-ice melt



Three Examples



1. Emissions



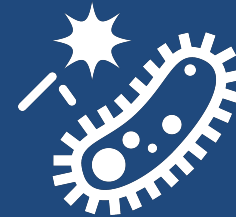
2. Deposition



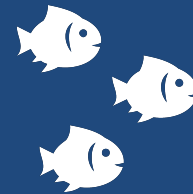
3. Land



4. Ocean



5. Bioavailability



6. Food webs

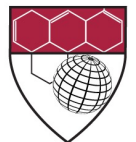


7. Humans

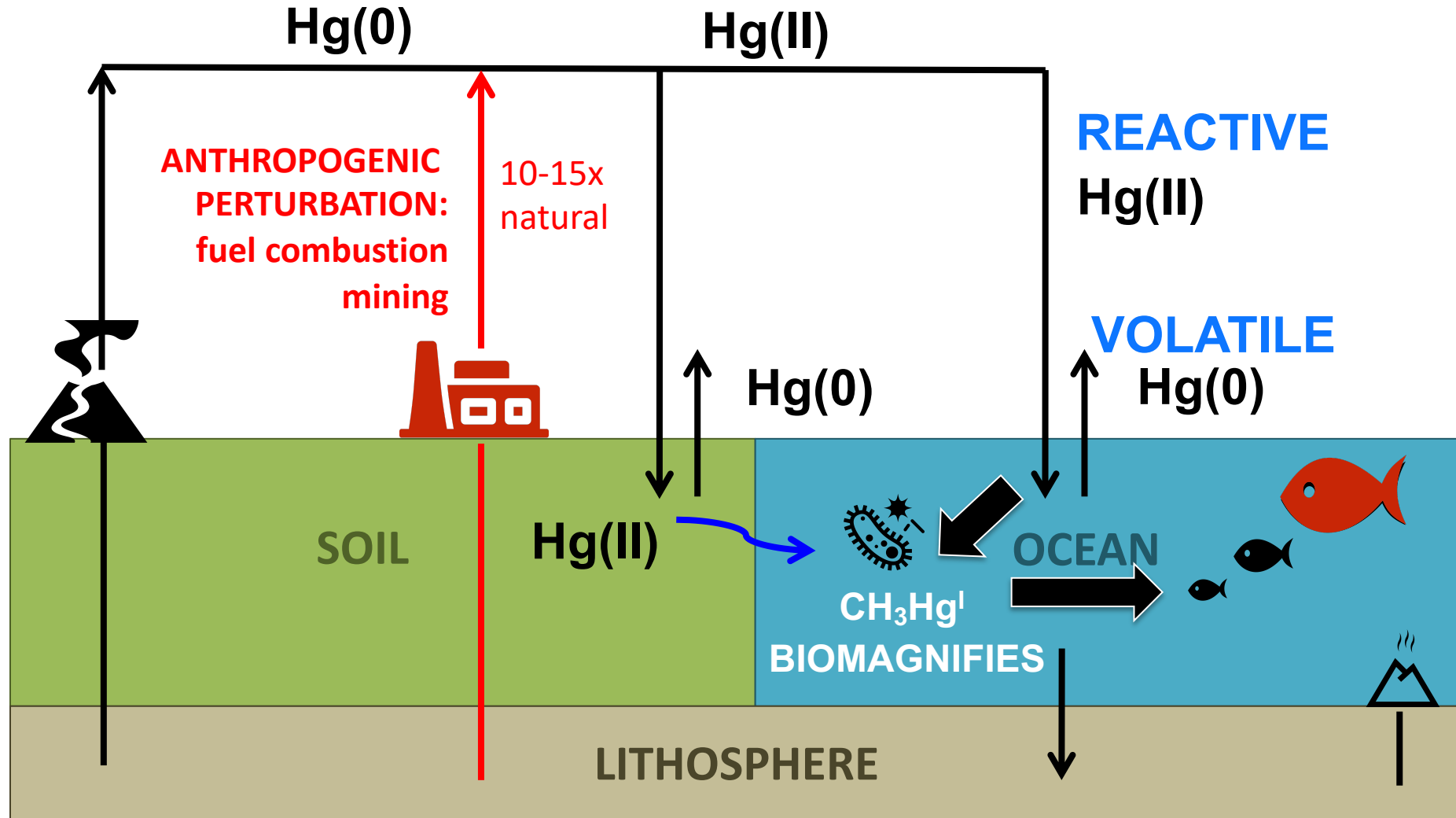
1. How is climate change affecting Hg in fish?

2. How is climate change affecting PCBs in the Arctic?

3. What about PFOS in the North Atlantic?



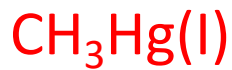
Global biogeochemical Hg cycle



Methylmercury is a bioaccumulative neurotoxin

Concentrations are $\times 10^6$ - 10^7 water

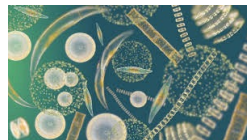
- Neurotoxin
- Impaired cardiovascular health
- Endocrine disruptor
- Immunotoxin



water



$10^4 - 10^5$



plankton



small fish



big fish



top predators



methylmercury concentration

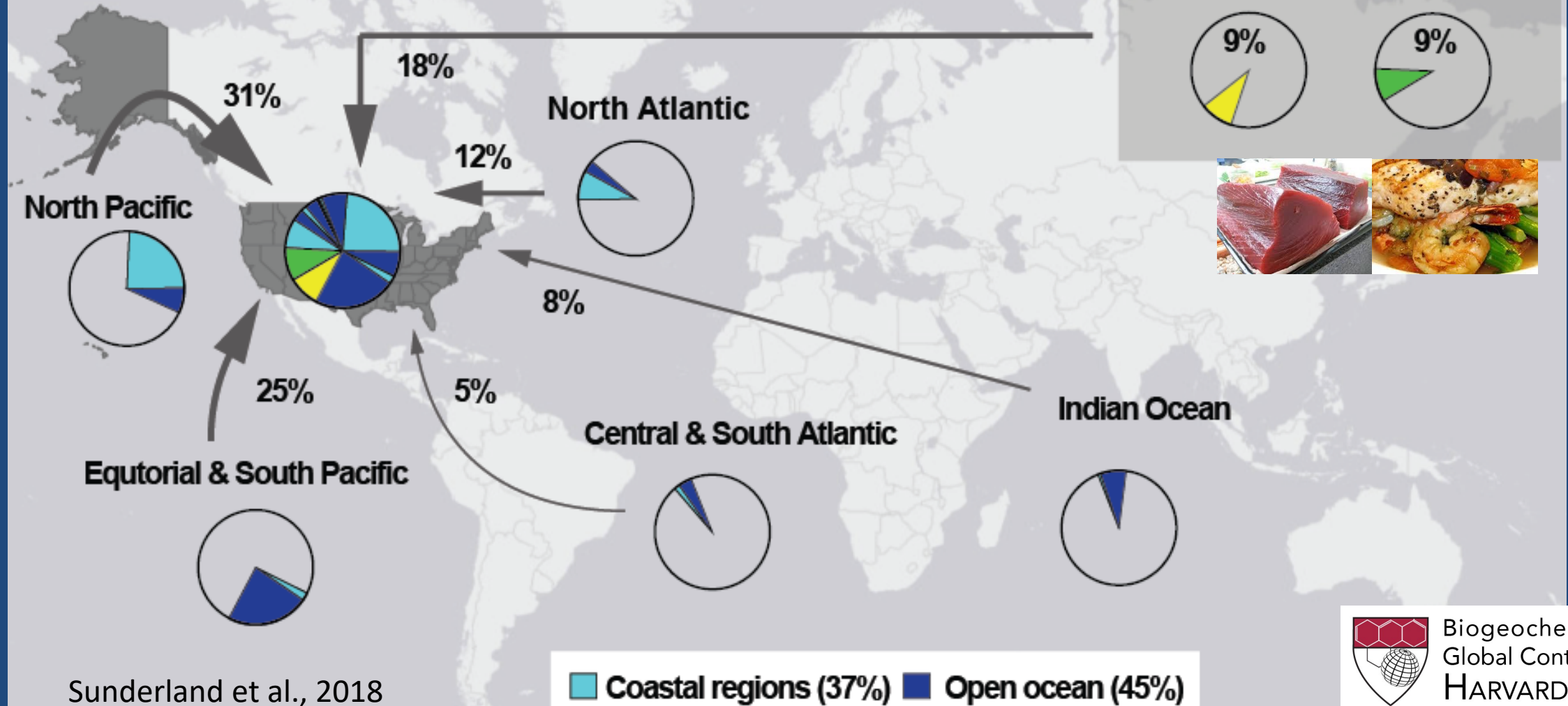


Societal Costs of methylmercury exposure in US & Europe > \$15 B

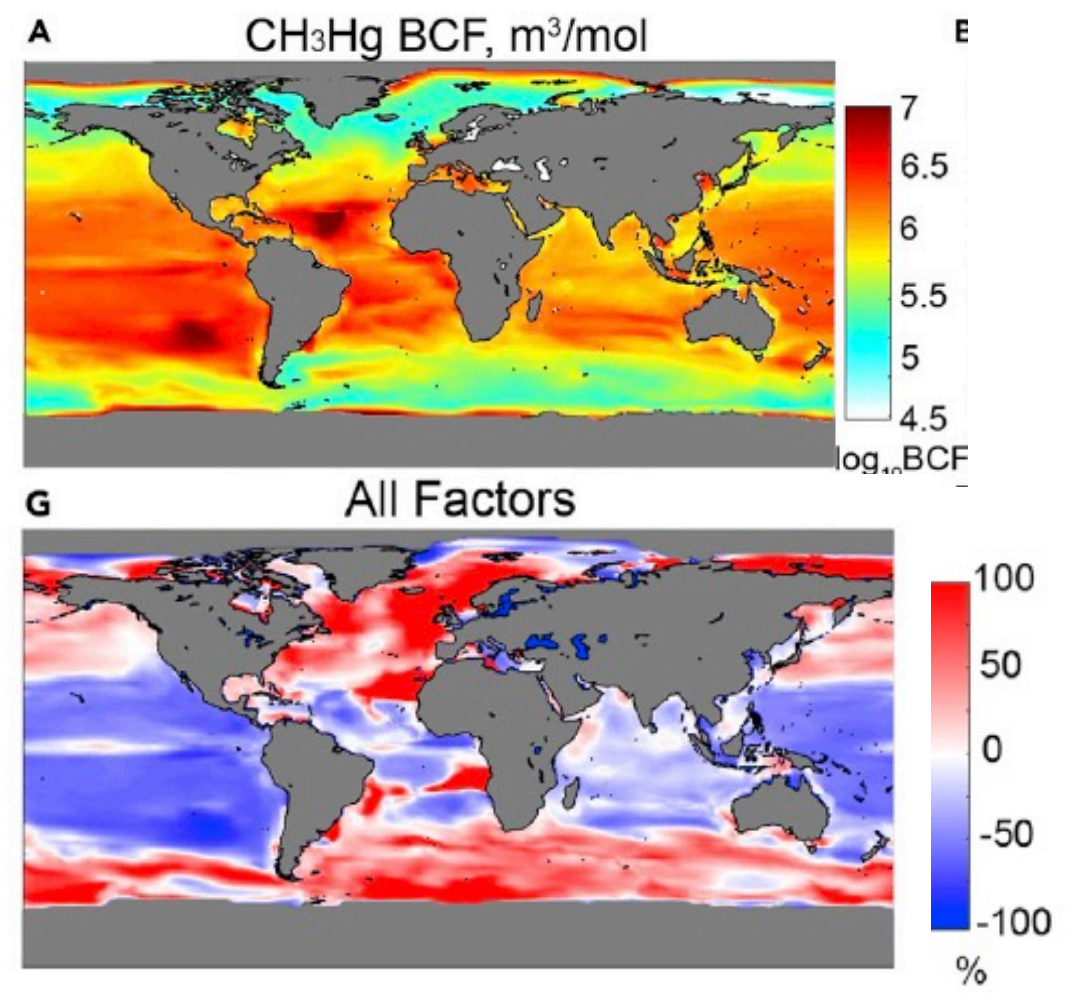
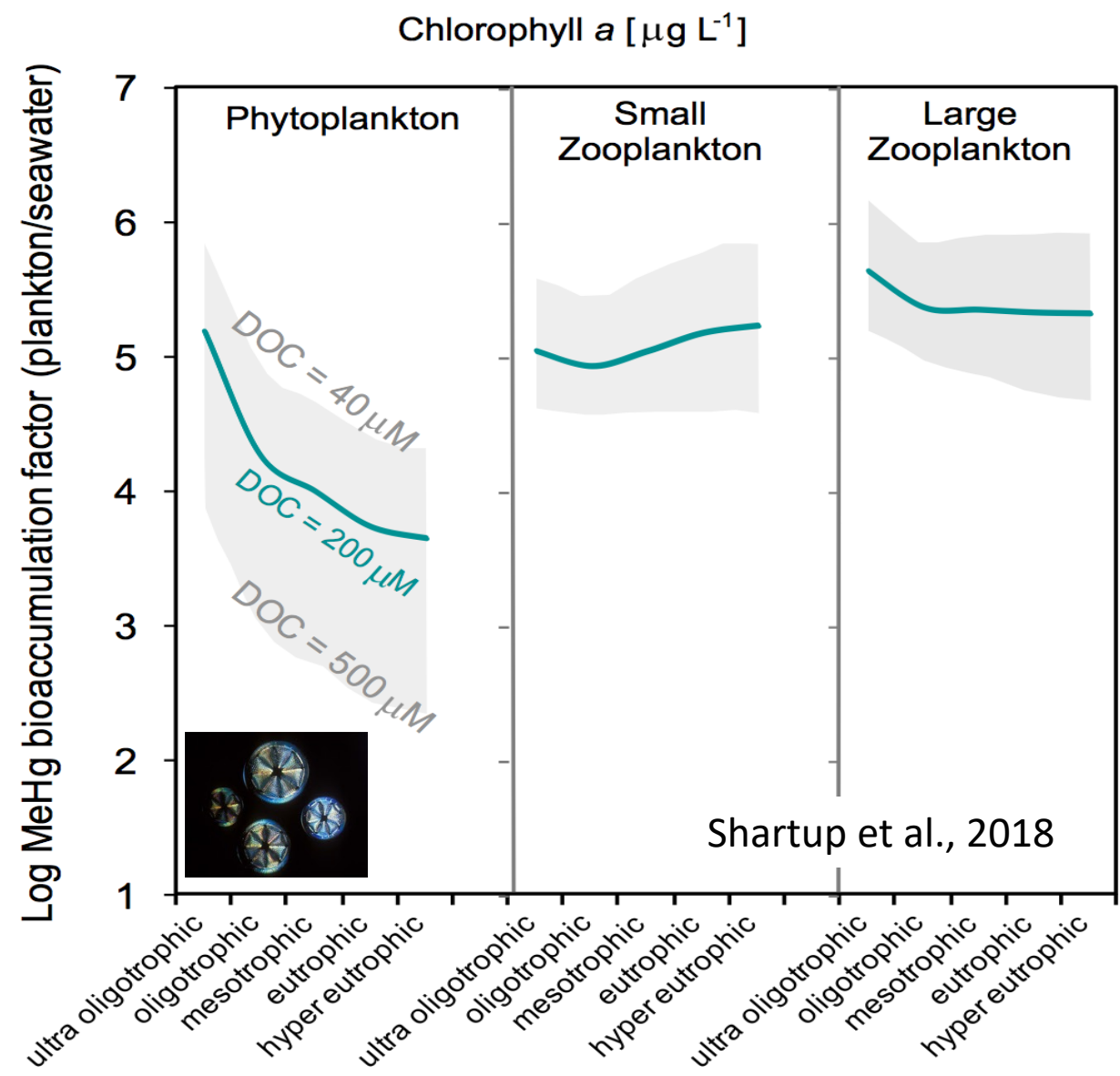
(Bellanger et al., 2013; Grandjean et al., 2012)

Global environmental quality affects chemical exposures from seafood

U.S. population **methylmercury** exposure (2010-2012)

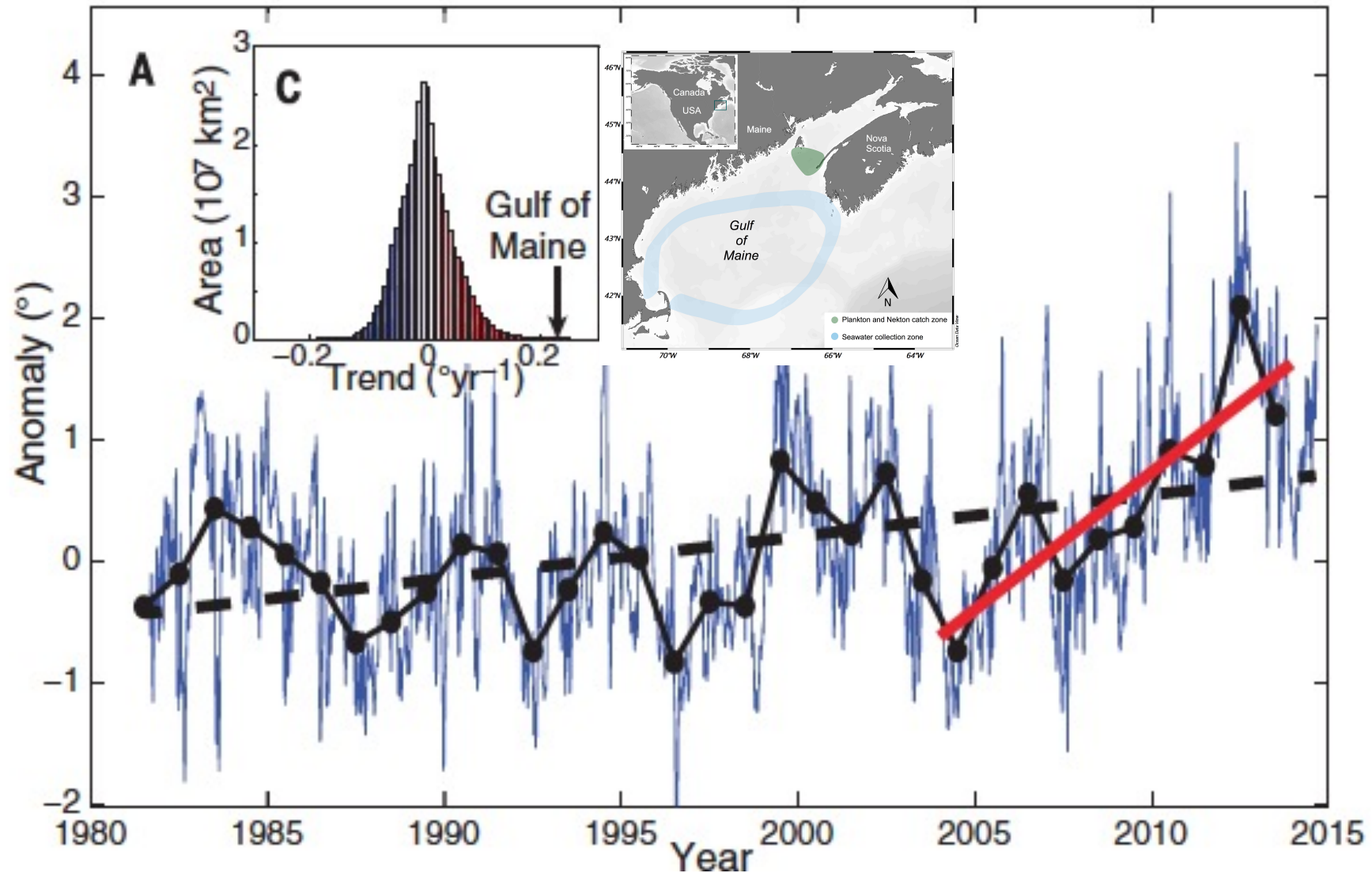


Impacts of acidification, circulation, and temperature small compared to variability in DOC and ecosystem productivity at base of food web

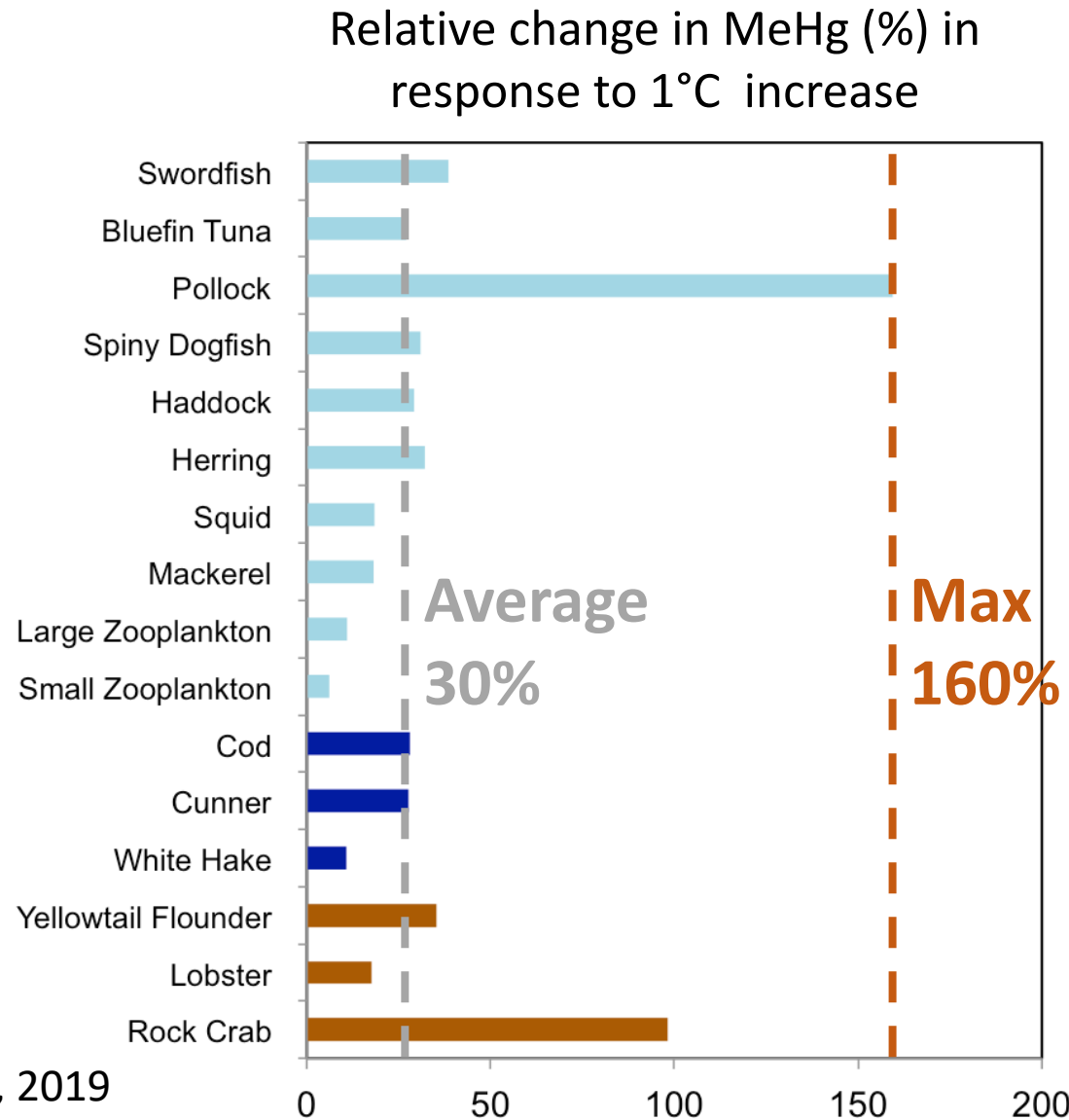


Zhang et al., 2021

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



Species respond differently to temperature increase

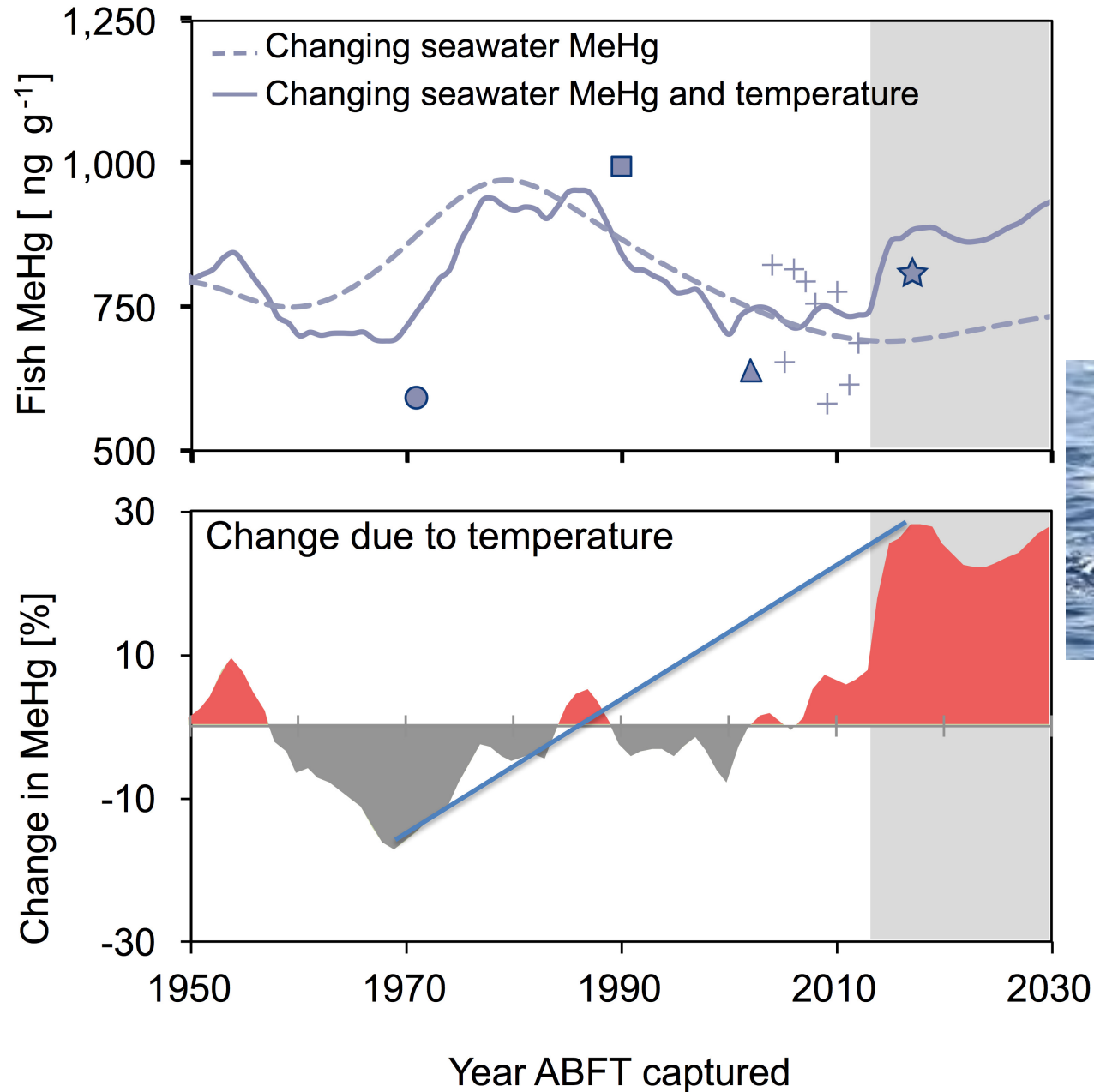


Schartup et al., 2019



Copyright: Andy Murch / Elasmodiver.com

Atlantic Bluefin Tuna (ABFT): Age 14 Years



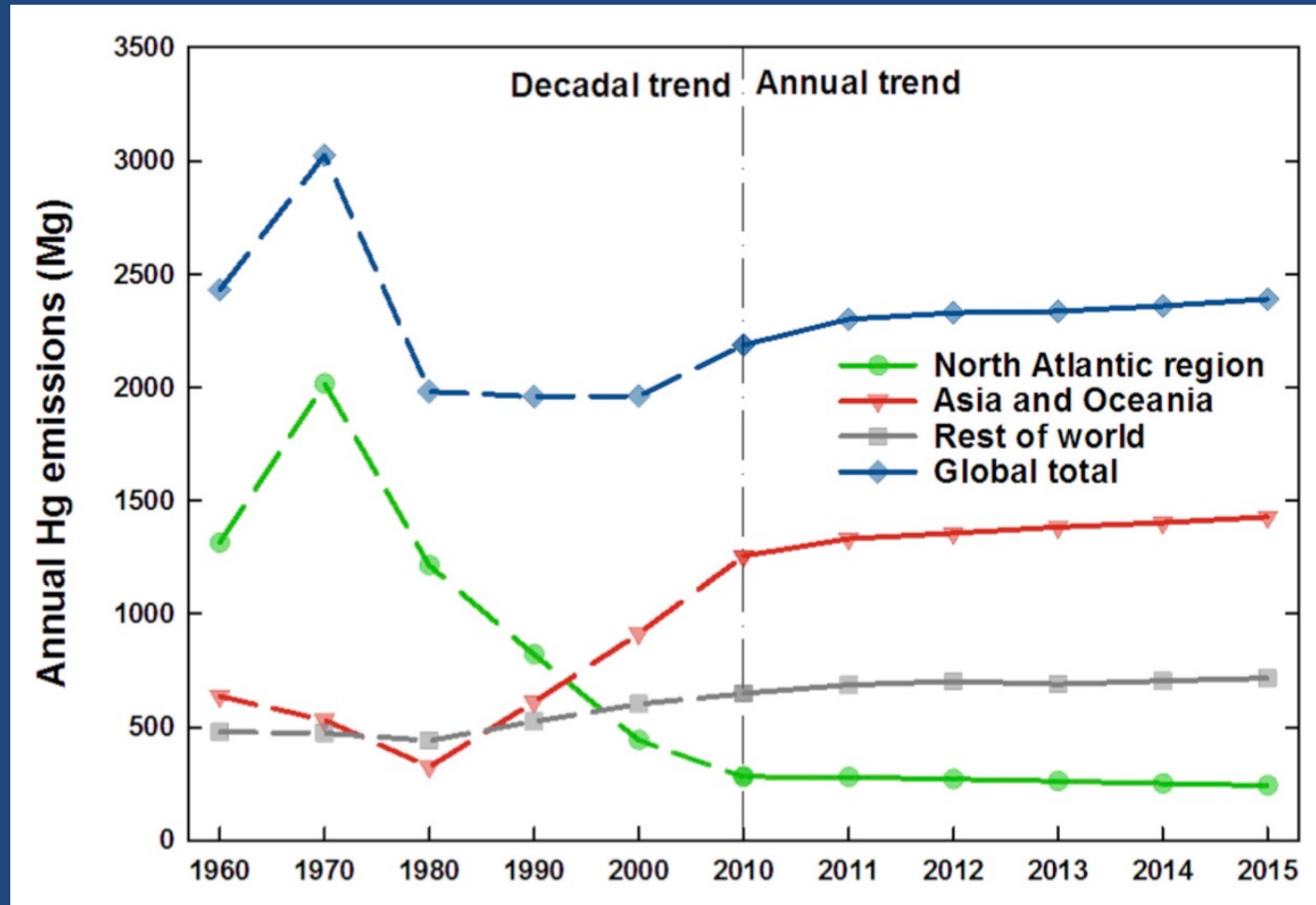
>20% decrease
between
1990-2010



~50% Increase
between
1970-2015

Schartup et al., 2019,
Nature

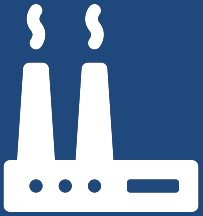
Current plateau in global Hg emissions means seawater warming will be important factor for marine fish MeHg



Streets et al., 2019, Atm Environ



Three Examples



1. Emissions



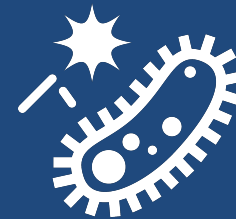
2. Deposition



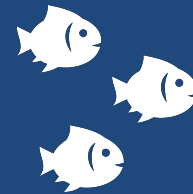
3. Land



4. Ocean



5. Bioavailability



6. Food webs

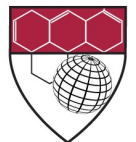


7. Humans

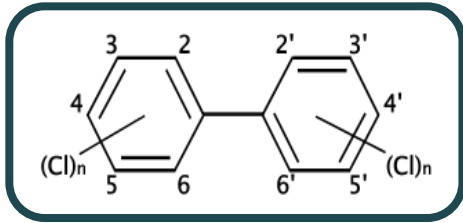
1. How is climate change affecting methylmercury in fish?

2. How is climate change affecting PCBs in the Arctic?

3. What about PFOS in the North Atlantic?

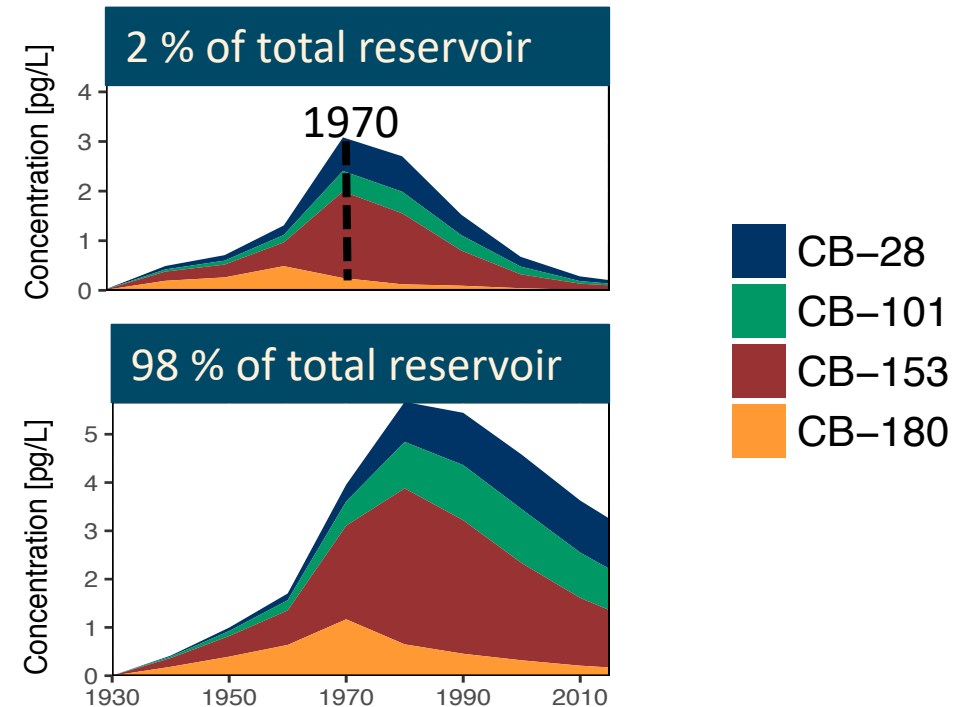
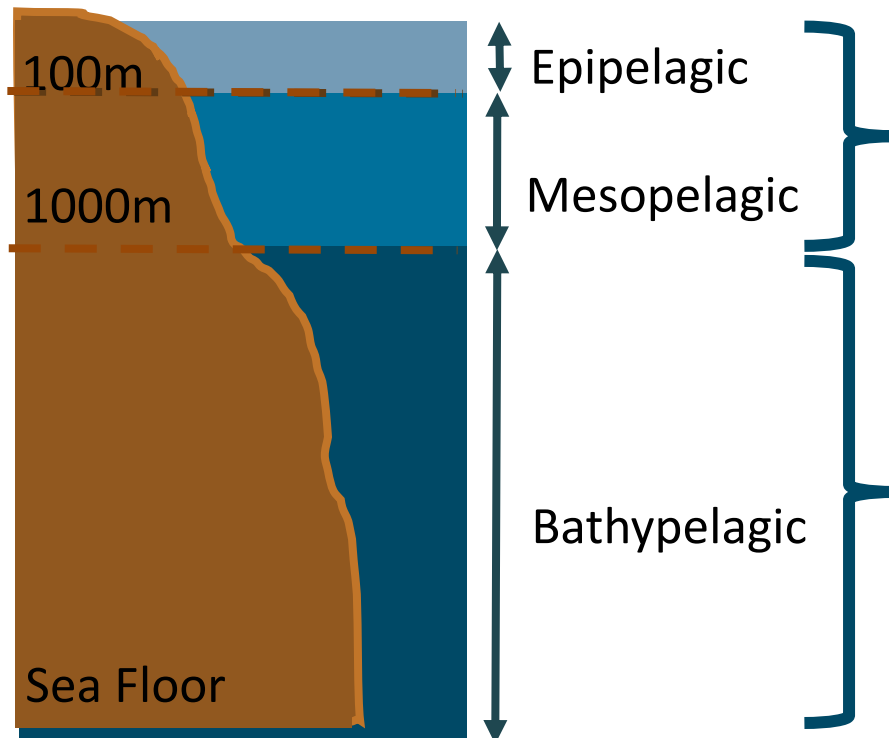


Stronger affinity of PCBs for particles leads to more rapid accumulation in the deep ocean



- 209 congeners; carcinogenic, neurotoxic
- Extremely hydrophobic
- Strong affinity for particles
- Variable volatility depending on MW

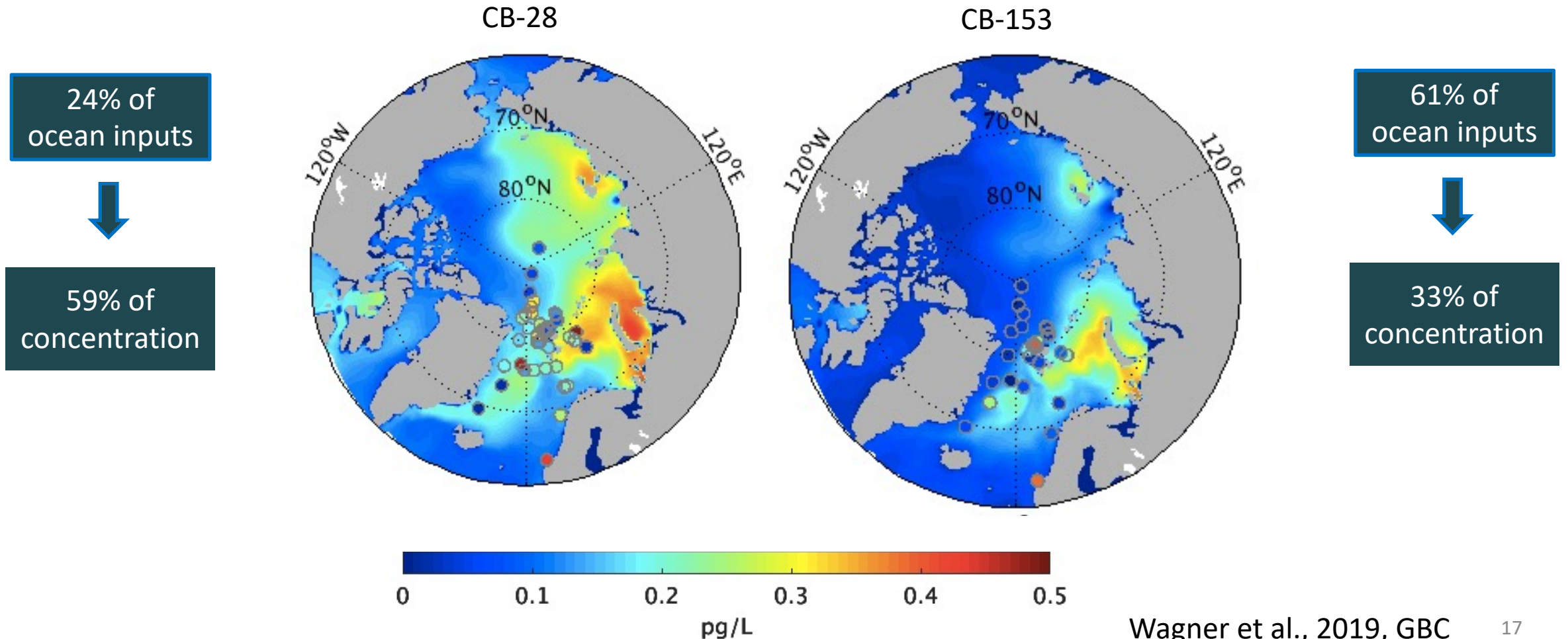
Ocean water column



Relative enrichment of volatile congeners in the Arctic sustaining biological concentrations 30 years after ban

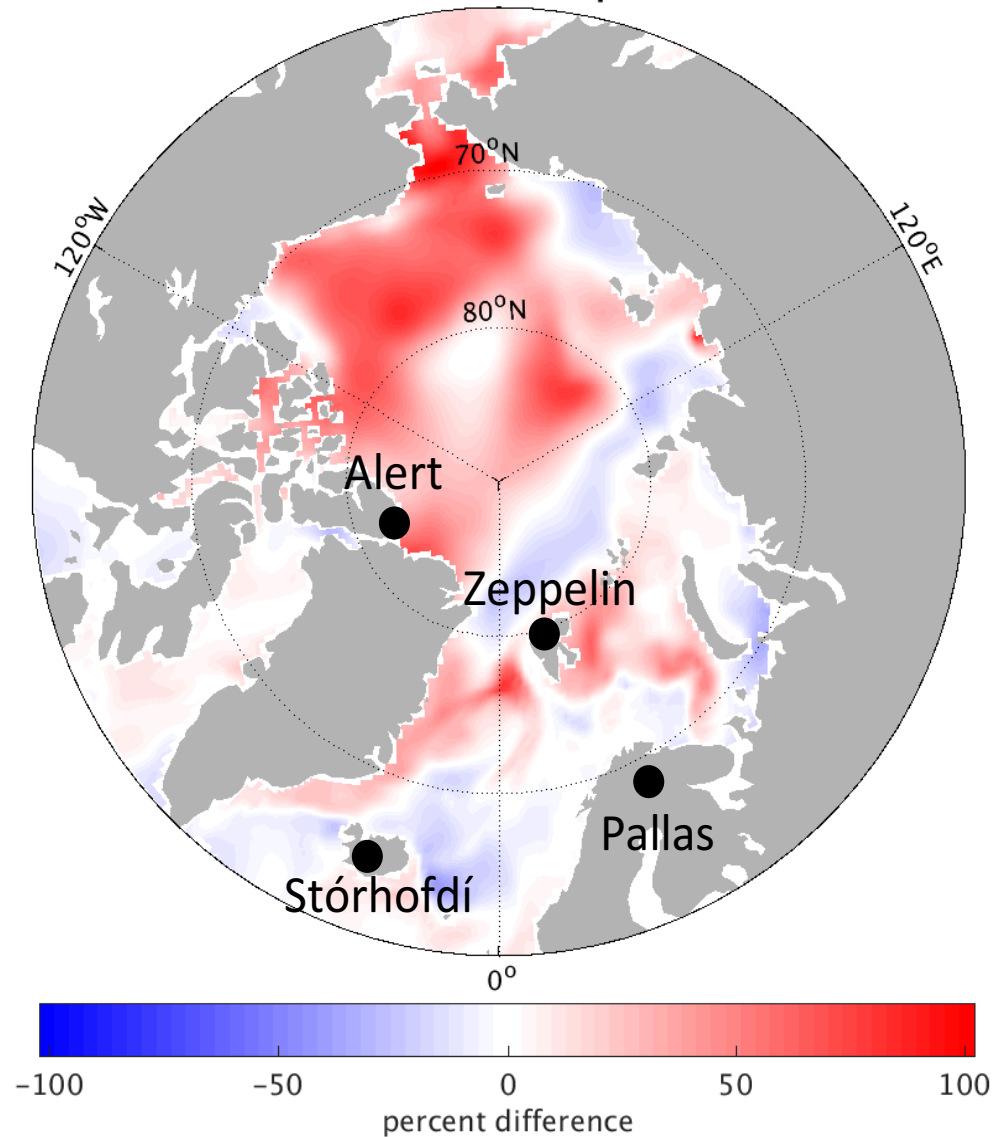
Surface Seawater Concentrations (10 m depth)

Observations (2000-2016) shown as circles



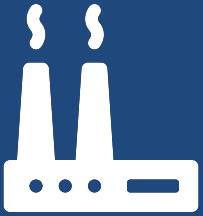
Sea-ice melt enhancing concentrations of PCBs in some regions of the Arctic

Difference between simulated
concentrations of chlorinated
biphenyl 153 (CB-153) with
constant 1992-1996
meteorology and 1992 to 2015
meteorology



Wagner et al., 2019

Three Examples



1. Emissions



2. Deposition



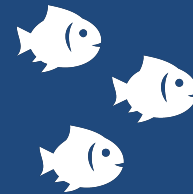
3. Land



4. Ocean



5. Bioavailability



6. Food webs

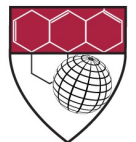


7. Humans

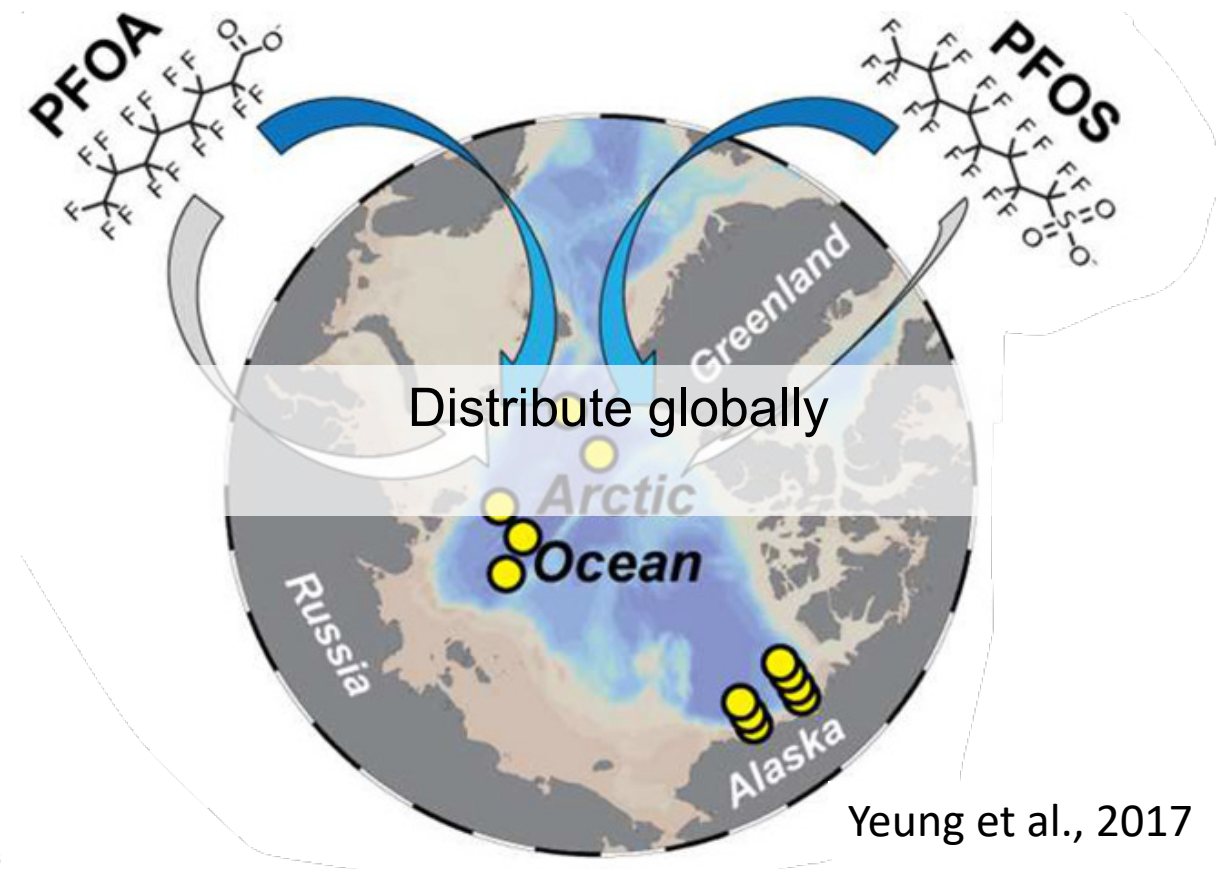
1. How is climate change affecting methylmercury in fish?

2. How is climate change affecting PCBs in the Arctic?

3. What about PFOS in the North Atlantic?



Poly- and perfluoroalkyl substances (PFAS) are both local and global contaminants



Human studies suggest PFAS exposure may...

increase risk of thyroid
disease

increase blood cholesterol
levels

decrease the body's
response to vaccines

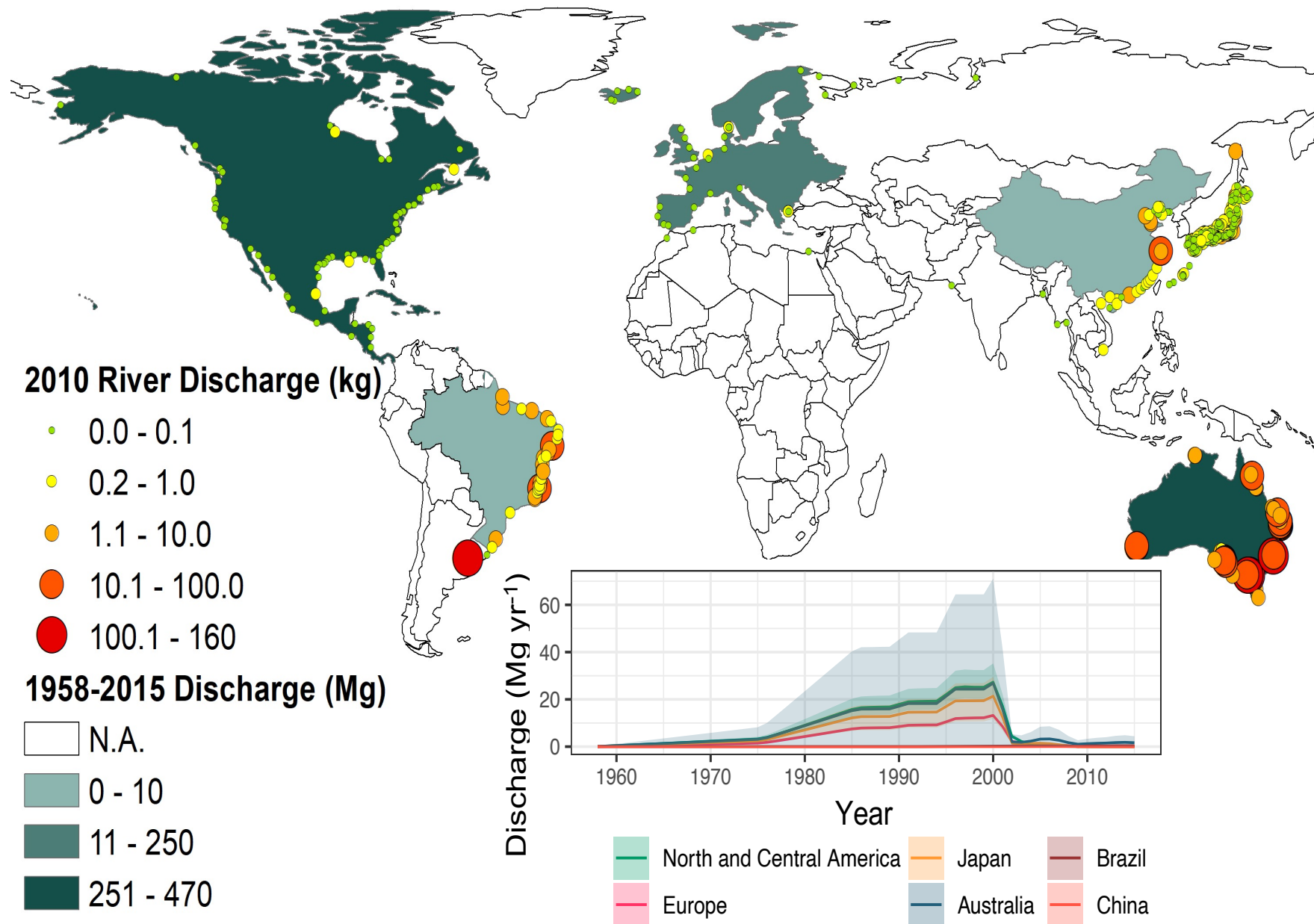
decrease fertility
in women

increase risk of high blood
pressure & preeclampsia

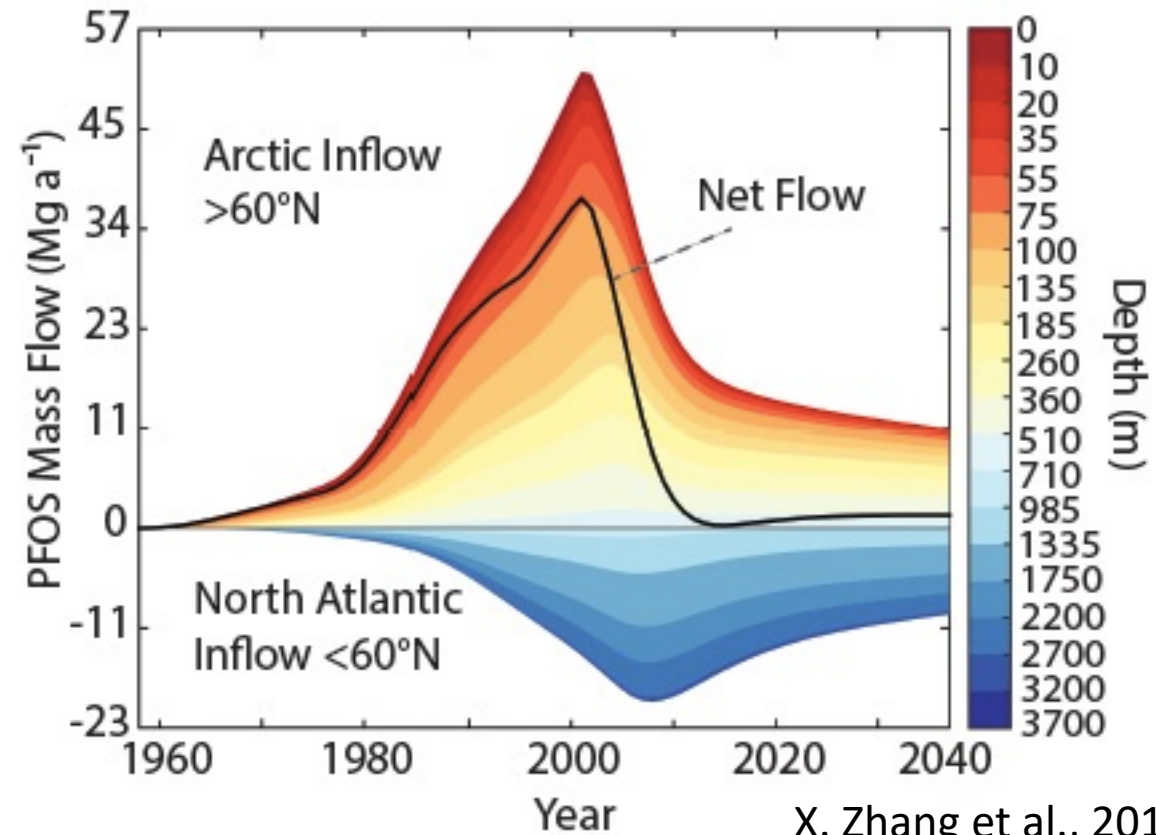
lower infant birth
weight



Modeled
global
PFOS
discharges
from rivers
to the
oceans ca.
2010



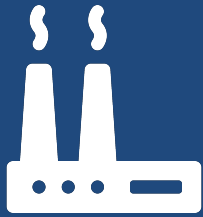
Weakened AMOC = Greater inputs of bioaccumulative contaminants to the Arctic



X. Zhang et al., 2017

Simplified global overturning circulation

Summary



1. Emissions



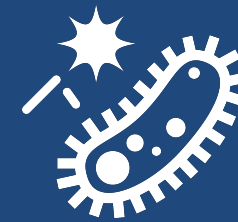
2. Deposition



3. Land



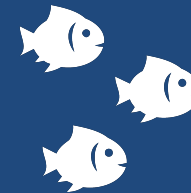
4. Ocean



5. Bioavailability



7. Humans



6. Food webs

1. Climate warming likely to increase methylmercury in fish – especially migratory pelagic species due to shifts in bioenergetics
2. Enrichment of some POPs in ice-free Arctic waters
3. AMOC creates a large sink in the deep North Atlantic for aqueous pollutants like PFOS from NA and Europe

Sunderland Group Photo: 2019



Sunderland Group Photo: 2020-2021

