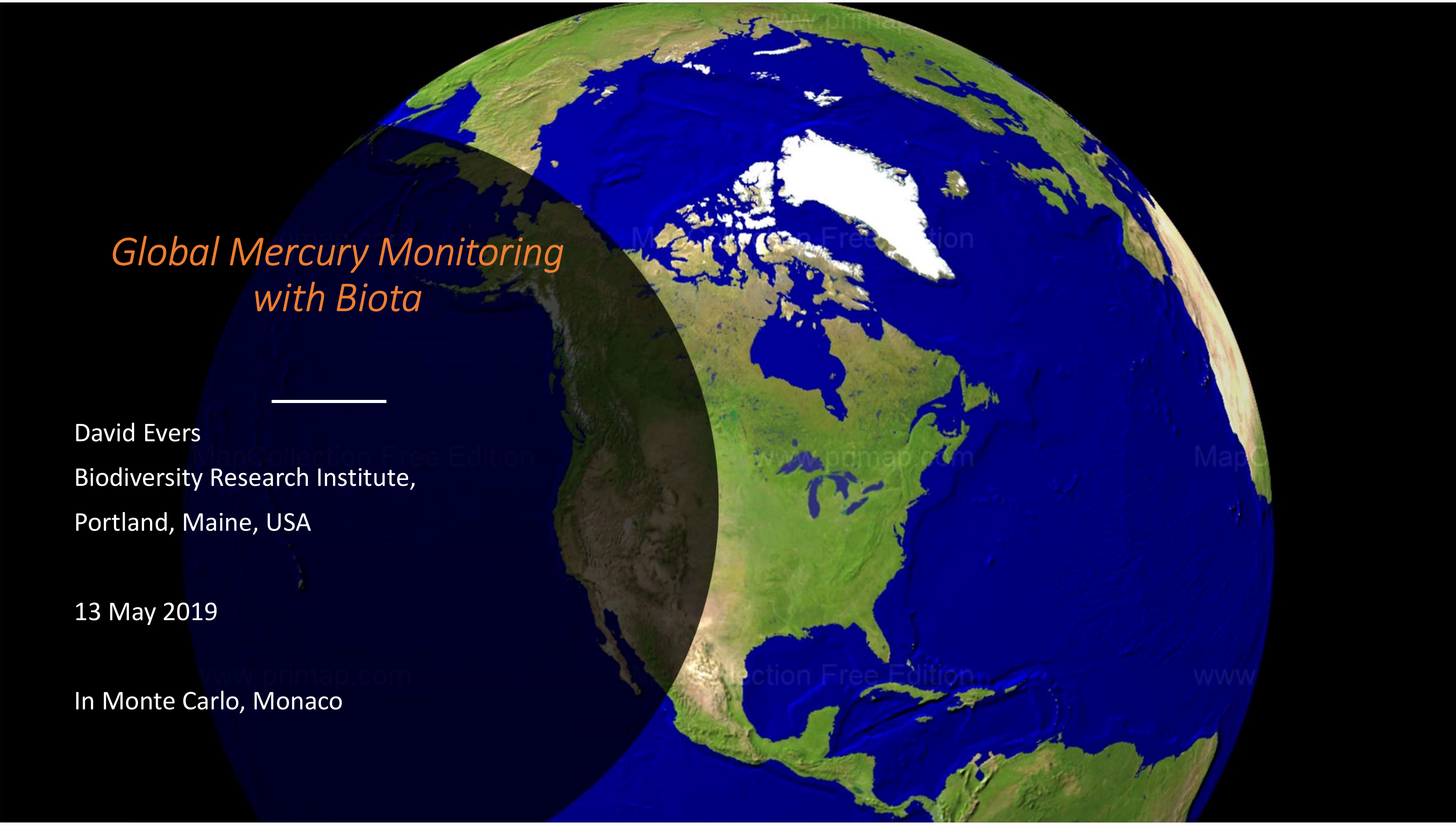


Global Mercury Monitoring with Biota

David Evers
Biodiversity Research Institute,
Portland, Maine, USA

13 May 2019

In Monte Carlo, Monaco

Presentation Outline

1. Global Biotic Mercury Synthesis (GBMS) database	a. Tissue types of interest b. Potential bioindicators by geographic area (e.g., biomes) c. Potential bioindicators for temporal trends
2. Key existing mercury monitoring networks for biota	a. Global – e.g., AMAP b. Regional – e.g., Caribbean MMN c. Local – New York State, USA (NYSERDA)
3. Critical information gaps	a. Biological mercury hotspots b. Mercury source types c. Standardized temporal trend data
4. Key elements of monitoring and analyses for the EE ad hoc Group	a. Why and How b. What and When c. Where

1. Global Biotic Mercury Synthesis (GBMS)

- A database about biotic Hg from the published, peer-reviewed literature (2014-2018 and continuing)
- Over 1,000 references consulted to date (n=1,095)
- More data remain to be collected, but GBMS is exhaustive for some taxa and fairly complete for others
- Used as a basis for the Global Mercury Assessment biota chapter - 2018

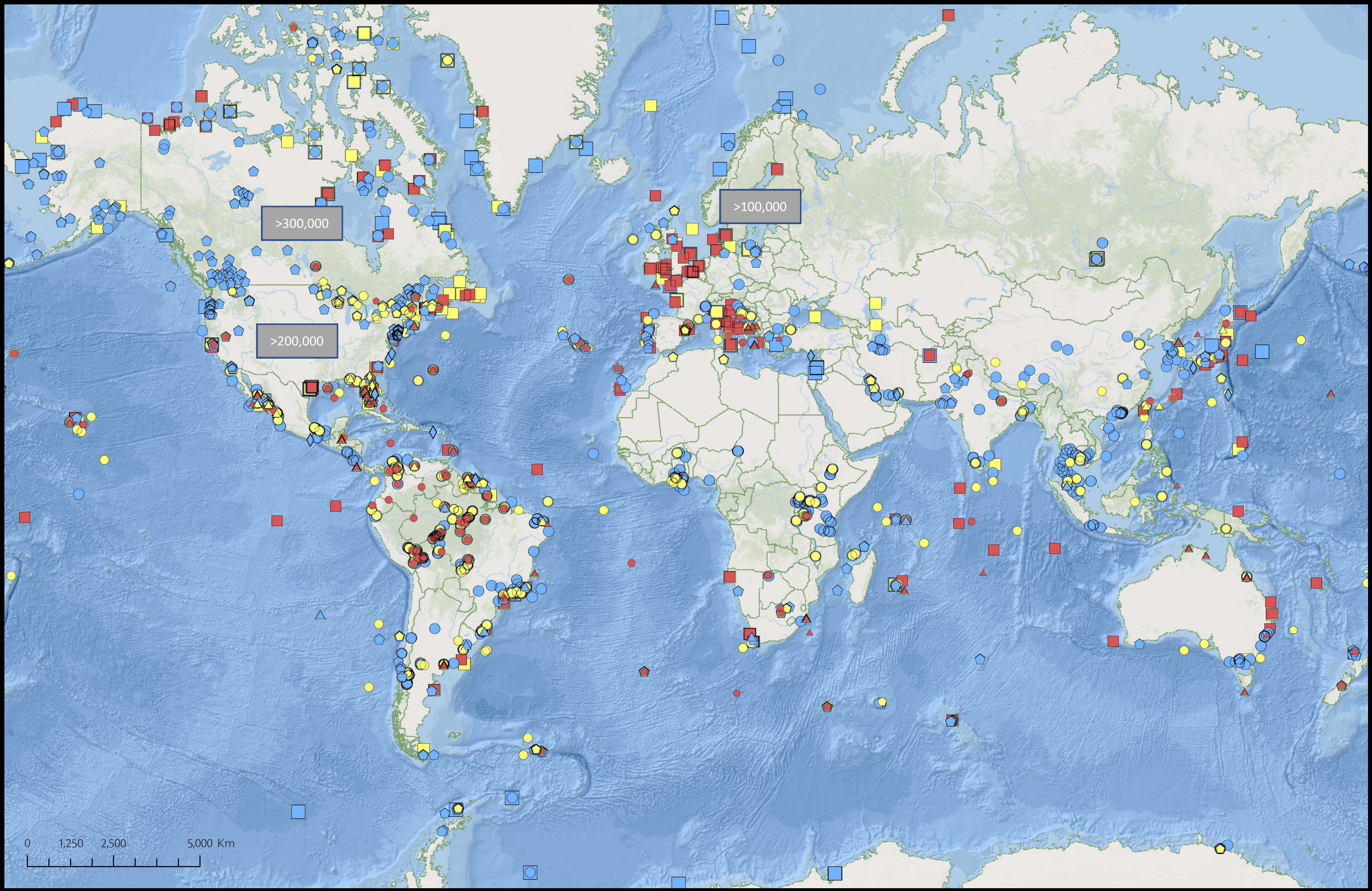
Tissue Types, their meaning and %MeHg

Common tissue types and unit typically used *(ww=wet weight, dw= dry weight, fw= fresh weight)*	***Sampling options***	***Temporal representation***	***% MeHg***
Blood (ww)	Nonlethal	Days to weeks	>95%
Egg (ww or dw)	Nonlethal/lethal	Days to weeks	>95%
Feather (fw)	Nonlethal	Days to years	>95%
Fur (fw)	Nonlethal	Days to years	>95%
Claw tip (fw)	Nonlethal	Weeks	>95%
Brain (ww or dw)	Lethal	Weeks to months	>95%[1]
Muscle (ww)	Nonlethal/lethal	Weeks to years	>90%
Liver (ww or dw)	Nonlethal/lethal	Years	<10%
Kidney (ww or dw)	Lethal	Years	<10%

An overarching Biotic Hg Database

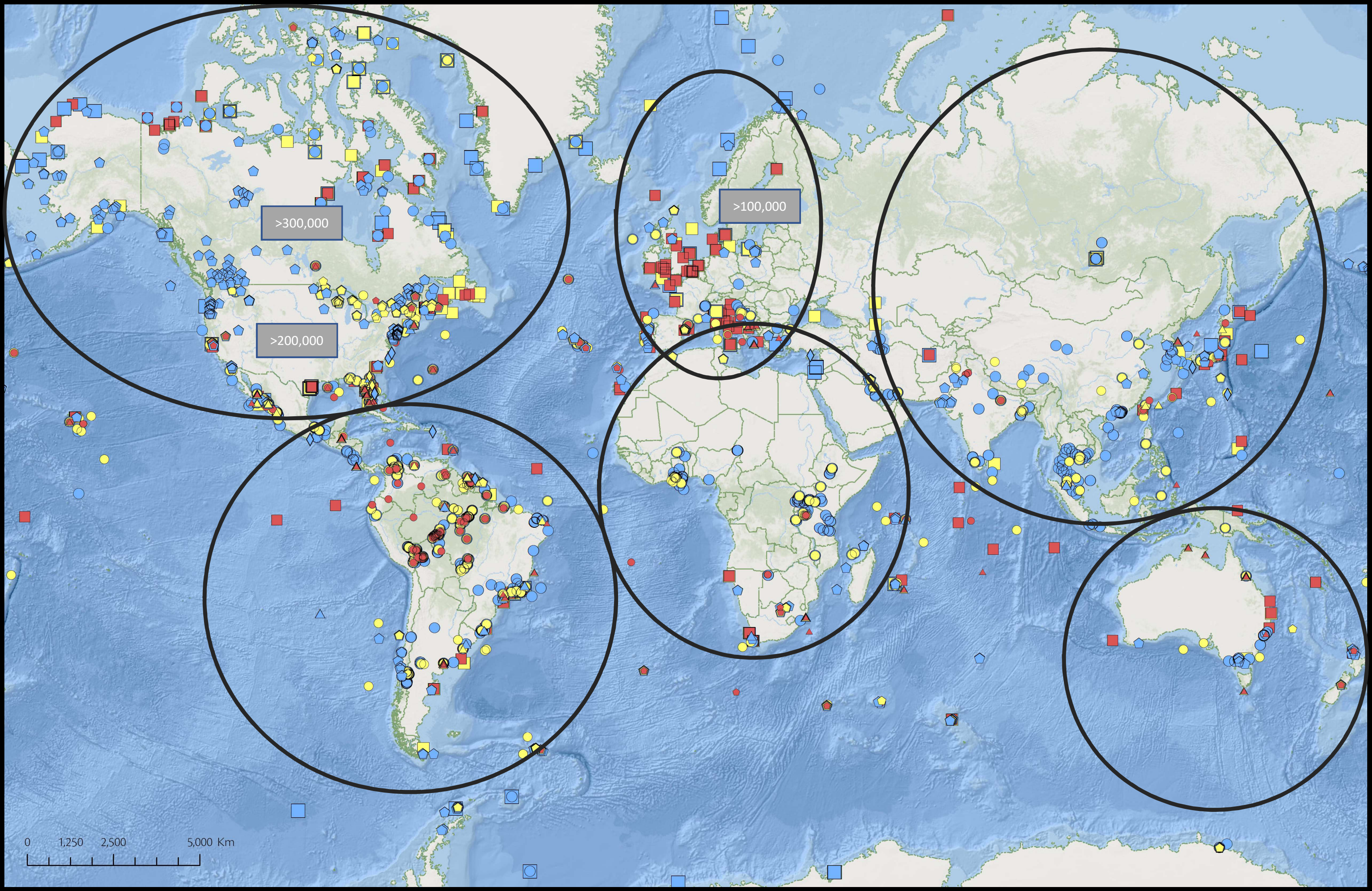
BRI's GBMS Database includes Hg concentrations on shellfish, fish, sea turtles, birds, and marine mammals.

Hg from >515,000 individual organisms are included in the database covering 119 countries and >2,700 unique locations.



Continental Ranking of Existing Biotic Hg data

1. North America: *****
2. South America: *** (one * for ASGM areas)
3. Europe: ****
4. Africa: *
5. Asia: **
6. Australia / South Pacific: *



Biome Structure and Major Biota (and rough coverage)

Target Terrestrial Biome	**Associated Aquatic Ecosystem**			**Ecological Health Bioindicators**				**Human Health Bioindicators**	
		Freshwater and Marine Fish	Sea Turtles	Freshwater and Terrestrial Birds	Marine Birds	Mammals	Freshwater Fish	Marine Fish	Marine Mammal
Polar (Arctic and Antarctic)	Arctic Ocean			X	X	X	X	X	X
Boreal Forest and Taiga	N. Pacific/ Atlantic				X		X	X	
Temperate Forest	N. Pacific/ Atlantic and Med/Car Seas	X		X			X		
Tropical Rainforest	S. Pacific/ Atlantic and Indian Ocean								

Mercury in the Global Environment - Tuna

- Includes most of the published literature on tuna Hg concentrations
- Emphasizes 9 species of tuna
- Tuna Hg concentrations broadly vary according to:
  - species,
  - size class, and
  - ocean basins

Mercury in 9 species of tuna

(n=6,222)

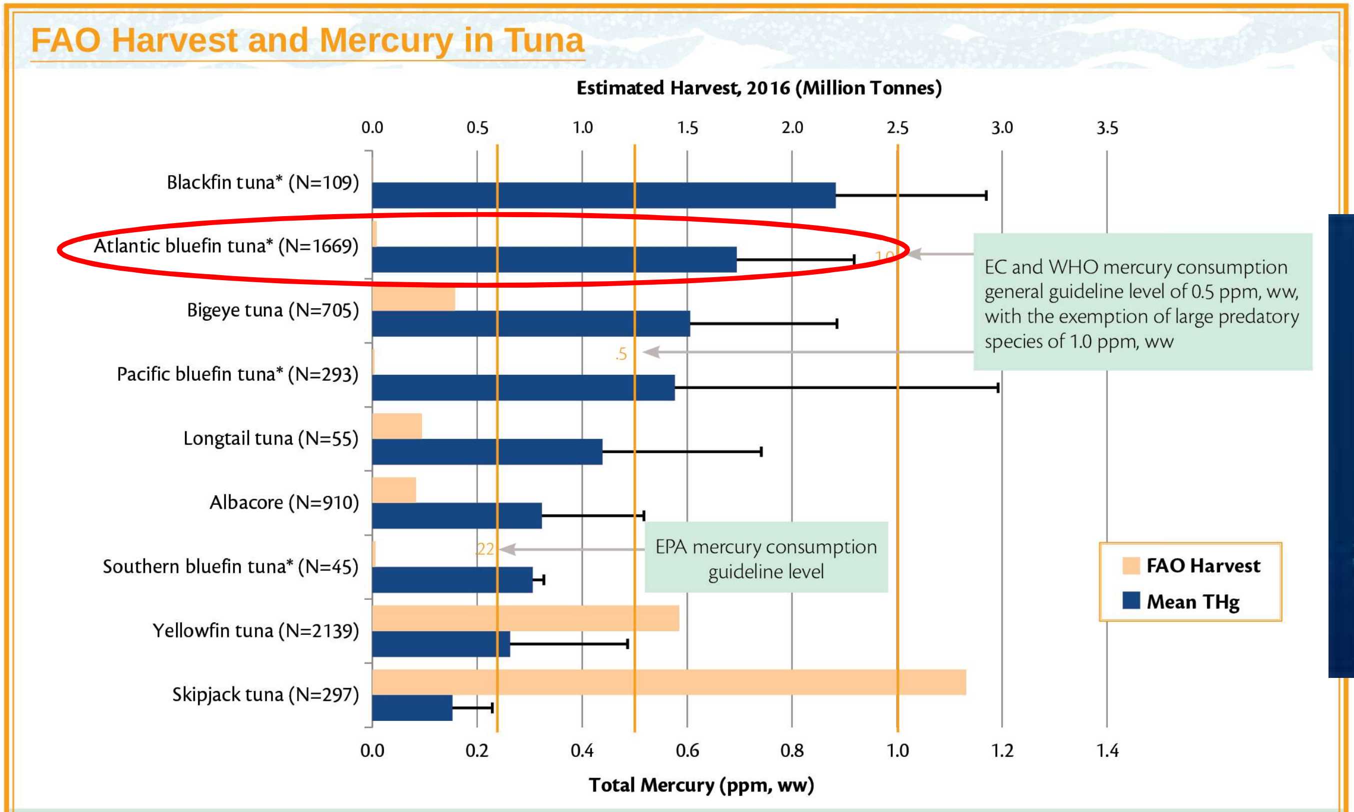
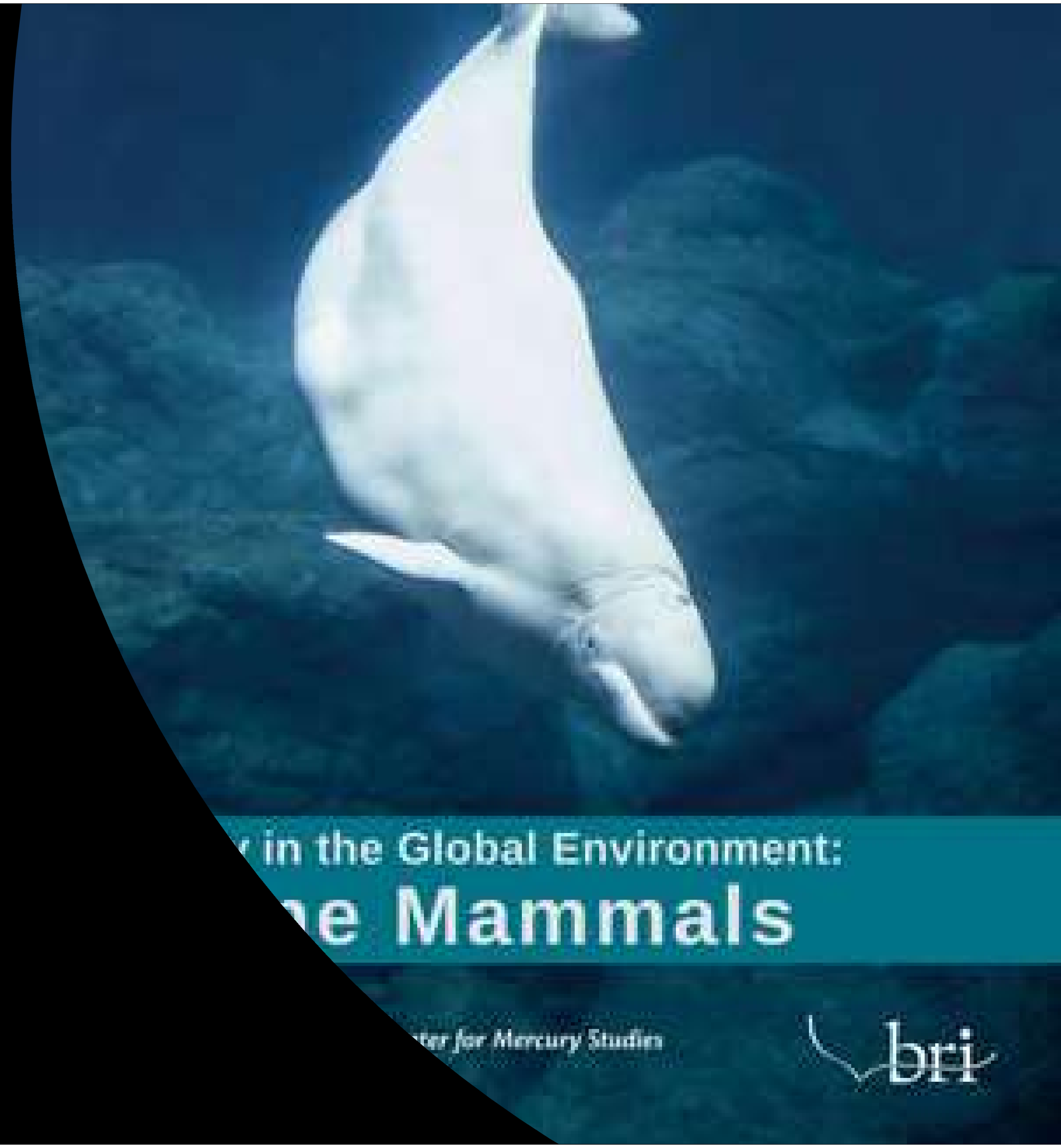


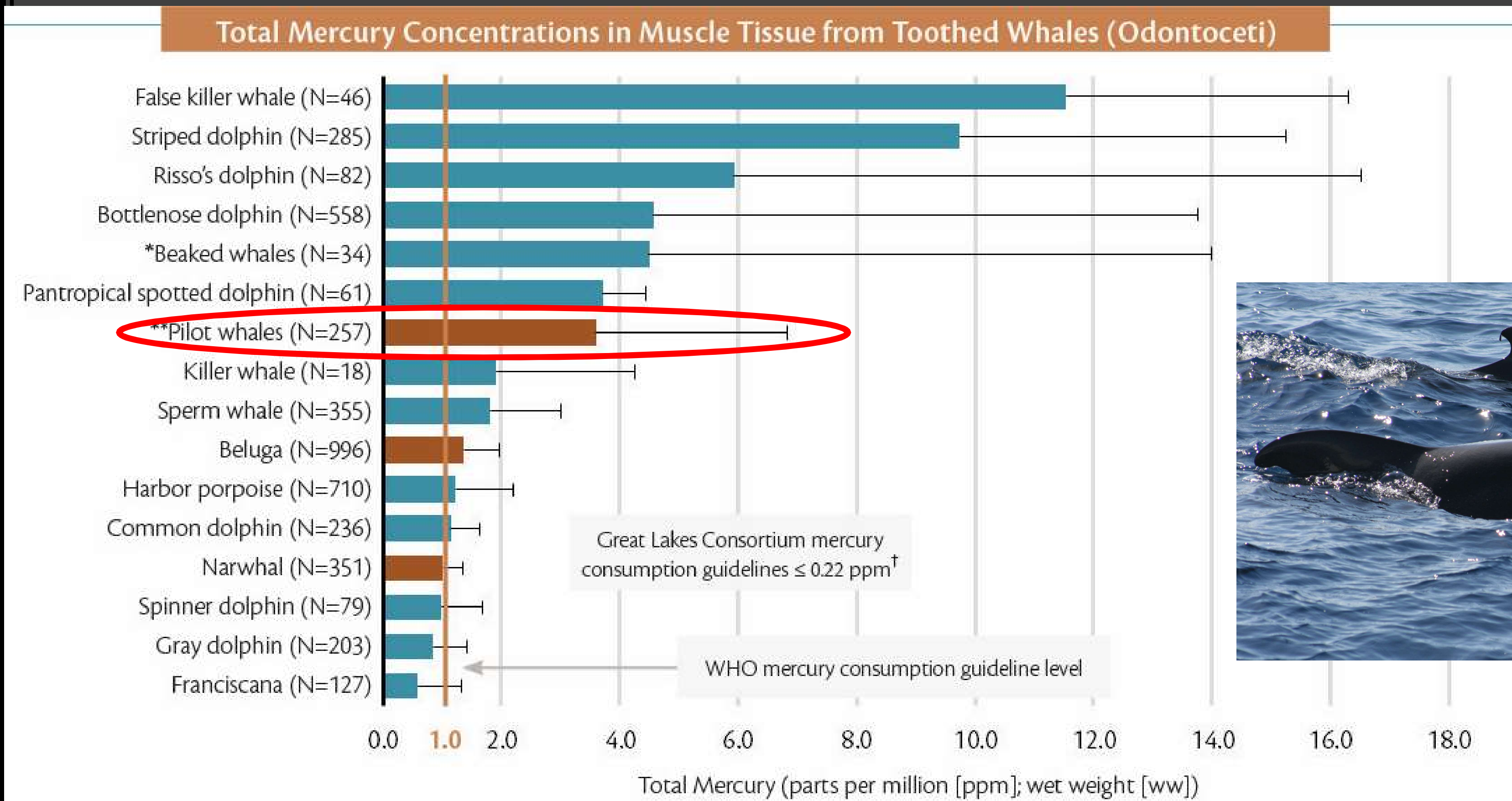
Figure 2. Average (+/– SD; N=sample size) THg concentration in muscle tissue of nine tuna species compared with the FAO harvest estimate in tonnes. See above for mercury consumption guidelines. *FAO harvest is less than 15,000 tonnes.

Mercury in the Global Environment – Marine Mammals

- Includes most of the published literature on marine mammal Hg concentrations
- Emphasizes toothed whales
- Marine mammal Hg concentrations broadly vary according to:
  - species,
  - Foodweb choice,
  - size class, and
  - ocean basins



Mercury in 16 species of toothed whales
(n=4,398)

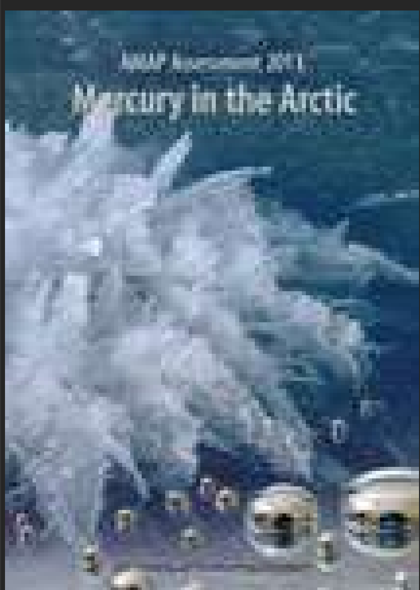


2. Mercury Monitoring Networks for biota

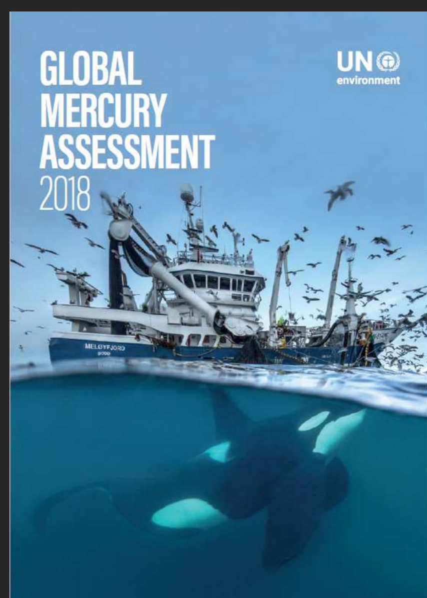
Very few biotic Hg monitoring using standardized methods over time

- Global level biotic Hg monitoring – AMAP is best example
- Regional level – Caribbean Mercury Monitoring Network (NEW)
- Local Level – New York State, USA

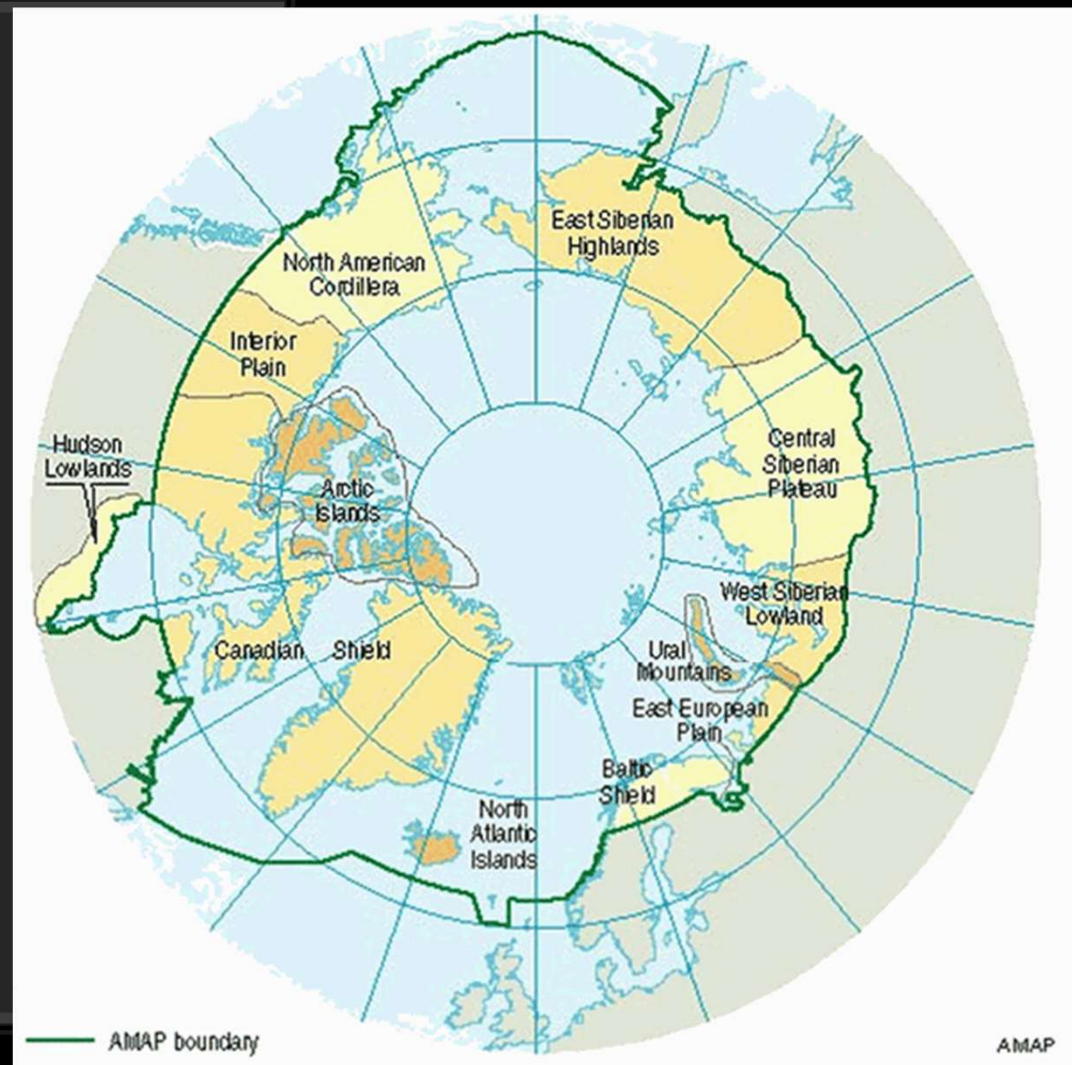
GLOBAL LEVEL:
Arctic Monitoring and Assessment Programme



AMAP ASSESSMENT 2011:
MERCURY IN THE ARCTIC



GLOBAL MERCURY
ASSESSMENT 2018



REGIONAL LEVEL: Caribbean Region Mercury Monitoring Network

Antigua and Barbuda

*

Saint Kitts and Nevis

*

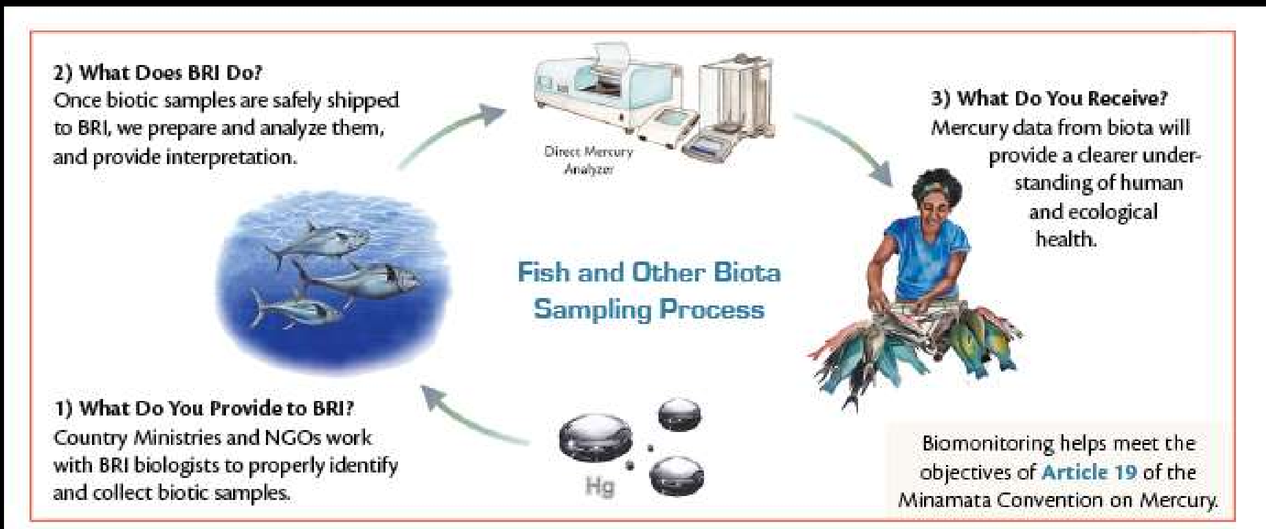
Biodiversity Research Institute

*

Basel Convention Regional Centre – Caribbean

Hg monitoring to date

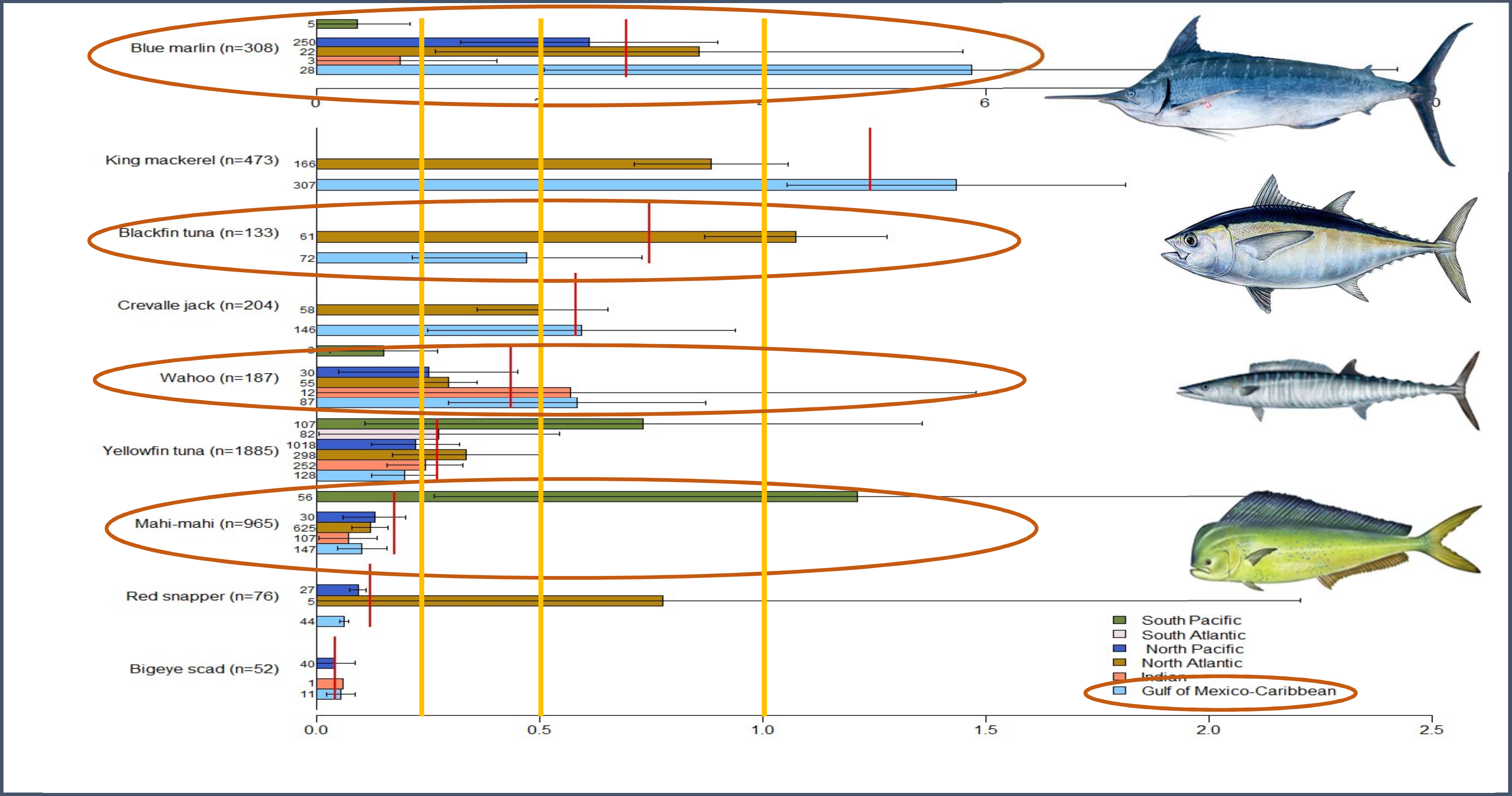
- Air Hg exposure
- Fish / Shellfish Hg exposure (seafood and freshwater)
- Bird Hg exposure
- Human Hg exposure
- Cosmetic Hg exposure (skin-lightening creams)



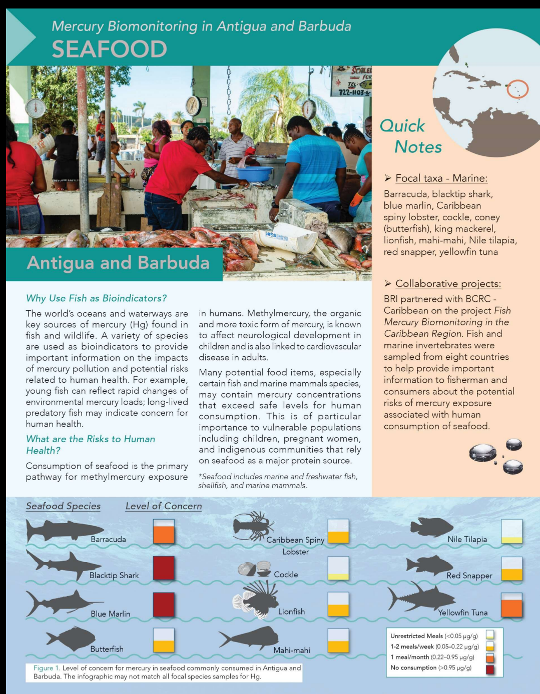
Fish Hg concentrations in the Caribbean: Data generated for over 500 samples

- Fish sampled in 8 Caribbean countries
- Worked with Ministry of Environment and fisheries biologists
- Multiple species selected based on local interests and edible fish of highest concern
- Sample sizes ranged from ~40-100 fish per country
- 9 species are featured for regional comparisons

Mercury concentrations in 9 fish from the Caribbean Sea and comparisons with the 5 major ocean basins



Describing results from seafood mercury analyses in the Caribbean: Antigua and Barbuda



Mercury Biomonitoring in Antigua and Barbuda

SEAFOOD

Antigua and Barbuda

Why Use Fish as Bioindicators?

The world's oceans and waterways are key sources of mercury (Hg) found in fish and wildlife. A variety of species are used as bioindicators to provide important information on the impacts of mercury pollution and potential risks related to human health. For example, young fish can reflect rapid changes of environmental mercury loads; long-lived predatory fish may indicate concern for human health.

What are the Risks to Human Health?

Consumption of seafood is the primary pathway for methylmercury exposure in humans. Methylmercury, the organic and more toxic form of mercury, is known to affect neurological development in children and is also linked to cardiovascular disease in adults.

Many potential food items, especially certain fish and marine mammals species, may contain mercury concentrations that exceed safe levels for human consumption. This is of particular importance to vulnerable populations including children, pregnant women, and indigenous communities that rely on seafood as a major protein source.

**Seafood includes marine and freshwater fish, shellfish, and marine mammals.*

Quick Notes

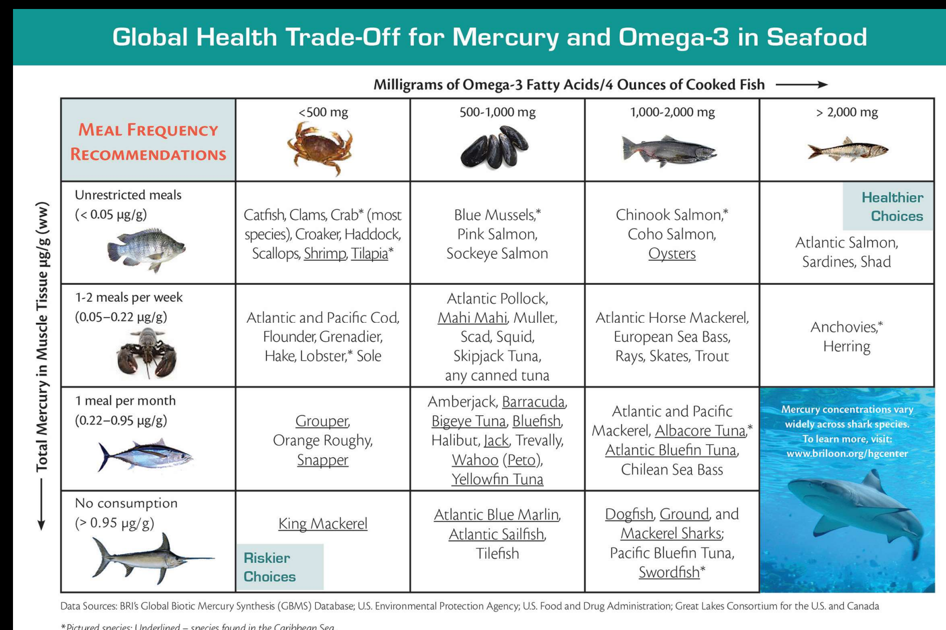
➢ Focal taxa - Marine:

Barracuda, blacktip shark, blue marlin, Caribbean spiny lobster, cockle, coney (butterfish), king mackerel, lionfish, mahi-mahi, Nile tilapia, red snapper, yellowfin tuna

➢ Collaborative projects:

BRI partnered with BCRC - Caribbean on the project *Fish Mercury Biomonitoring in the Caribbean Region*. Fish and marine invertebrates were sampled from eight countries to help provide important information to fisherman and consumers about the potential risks of mercury exposure associated with human consumption of seafood.

Figure 1. Level of concern for mercury in seafood commonly consumed in Antigua and Barbuda. The infographic may not match all focal species samples for Hg.



Global Health Trade-Off for Mercury and Omega-3 in Seafood

Milligrams of Omega-3 Fatty Acids/4 Ounces of Cooked Fish ⟶

Total Mercury in Muscle Tissue μg/g (ww) ⟶

Meal Frequency Recommendations	<500 mg	500-1,000 mg	1,000-2,000 mg	> 2,000 mg
Unrestricted meals (< 0.05 μg/g)	Catfish, Clams, Crab* (most species), Croaker, Haddock, Scallops, Shrimp, Tilapia*	Blue Mussels,* Pink Salmon, Sockeye Salmon	Chinook Salmon,* Coho Salmon, Oysters	Healthier Choices Atlantic Salmon, Sardines, Shad
1-2 meals per week (0.05–0.22 μg/g)	Atlantic and Pacific Cod, Flounder, Grenadier, Hake, Lobster,* Sole	Atlantic Pollock, Mahi Mahi, Mullet, Scad, Squid, Skipjack Tuna, any canned tuna	Atlantic Horse Mackerel, European Sea Bass, Rays, Skates, Trout	Anchovies,* Herring
1 meal per month (0.22–0.95 μg/g)	Grouper, Orange Roughy, Snapper	Amberjack, Barracuda, Bigeye Tuna, Bluefish, Halibut, Jack, Trevally, Wahoo (Peto), Yellowfin Tuna	Atlantic and Pacific Mackerel, Albacore Tuna,* Atlantic Bluefin Tuna, Chilean Sea Bass	Mercury concentrations vary widely across shark species. To learn more, visit: www.briloon.org/hgcenter
No consumption (> 0.95 μg/g)	King Mackerel Riskier Choices	Atlantic Blue Marlin, Atlantic Sailfish, Tilefish	Dogfish, Ground, and Mackerel Sharks; Pacific Bluefin Tuna, Swordfish*	

Data Sources: BRI's Global Biotic Mercury Synthesis (GBMS) Database; U.S. Environmental Protection Agency; U.S. Food and Drug Administration; Great Lakes Consortium for the U.S. and Canada

Pictured species; Underlined – species found in the Caribbean Sea.

Mercury in Tuna: Examples of messaging

- Nearly 5 million tons harvested commercially annually
- Served in cans, sushi and steaks
- Species and their Hg concentrations can be grouped by food item

Eating Tuna - What's Safe?

Lower Concern → Higher Concern

MEAL FREQUENCY RECOMMENDATIONS	White Tuna / Light Tuna		
1-2 meals per week (0.05–0.22 µg/g)	Skipjack (light tuna)	Yellowfin (ahi)	Yellowfin (ahi)
1 meal per month (0.22–0.95 µg/g)	Albacore Yellowfin (ahi) (white tuna)	Bigeye Atlantic Bluefin Southern Bluefin	Albacore Longtail Atlantic Bluefin Southern Bluefin
No consumption (> 0.95 µg/g)		Pacific Bluefin	Blackfin Pacific Bluefin

Safe Catch® brand tests every tuna for low mercury.

Small bluefin: 1 meal/month; large bluefin:"no consumption"

Data Sources: BRI's Global Biotic Mercury Synthesis (GBMS) Database; US EPA; US Food and Drug Administration

TUNA SPECIES[4]	LIFE HISTORY/RANGE	SIZE (common length and max. length)	LIFESPAN (max.)	COMMON FOOD PRODUCT	MERCURY CONCERN LEVEL*
Skipjack (*Katsuwonus pelamis*)	Reproduce early (first year) and often. Found mainly in the tropical areas of the Atlantic, Indian, and Pacific Oceans. Most abundant in equatorial waters. Feed on fish, crustaceans, cephalopods, and molluscs.	80cm. (2.6 ft) 110 cm. (3.6 ft)	~12 years	Canned light tuna	
Blackfin (*Thunnus atlanticus*)	Reproduce early (2 years) and often. Found in the coastal habitats of the western Atlantic from northeastern US to Brazil. Feed on other fish, squid, and crustaceans such as shrimp, crabs, and amphipods.	70 cm (2.3 ft) 110 cm (3.6 ft)	~7 years	Steaks	
Albacore (*Thunnus alalunga*)	Reproduce later (5-6 years). Widely distributed in temperate and tropical waters of all oceans, including the Mediterranean Sea. Feed mostly on deepwater squid and some fish and pelagic crustaceans.	100 cm (3.3 ft) 140 cm (4.6 ft)	~13 years	Canned white tuna and steaks	
Longtail (*Thunnus tonggol*)	Grow more slowly and live longer than similar sized tuna species. Feed on a variety of fish, cephalopods, and crustaceans, particularly prawns.	70 cm (2.3 ft) 145 cm (4.8 ft)	~18 years	Marketed mainly fresh and dried salted, but also smoked, canned, and frozen.	
Yellowfin (*Thunnus albacares*)	Reproduce early (1-2 years) and often. Found in the tropical and subtropical areas of the Atlantic, Indian, and Pacific Oceans. Feed on other fish, pelagic crustaceans, and squid.	150 cm (4.9 ft) 240 cm (7.9 ft)	~9 years	Canned, sushi, sashimi, steaks	
Bigeye (*Thunnus obesus*)	Reproduce later (5 years). Found in the tropical and subtropical areas of the Atlantic (but not the Mediterranean), Indian, and Pacific Oceans. Primarily feed on other fish, crustaceans, and squid.	180 cm (5.9 ft) 250 cm (8.2 ft)	~16 years	Sushi, sashimi	
Southern Bluefin (*Thunnus maccoyii*)	Reproduce later (5 years). Live in the South Pacific. Feed on small fish, crustaceans, and invertebrates such as squid.	160 cm (5.2 ft) 250 cm (8.2 ft)	~40 years	Sushi, steaks	
Pacific Bluefin (*Thunnus orientalis*)	Reproduce later (5 years). Live in the North Pacific. Feed on small fish such as sardines, herring, and mackerel, and invertebrates such as squid.	200 cm (6.6 ft) 300 cm (9.8 ft)	~26 years	Sushi, sashimi, steaks	
Atlantic Bluefin (*Thunnus thynnus*)	Reproduce later (5 years). Live in subtropical and temperate waters of the Atlantic Ocean and Mediterranean Sea. Feed on small fish such as sardines, herring, and mackerel, and invertebrates such as squid.	200 cm (6.6 ft) 458 cm (15 ft)	~50 years	Sushi, steaks	

LOCAL LEVEL:
New York State, USA

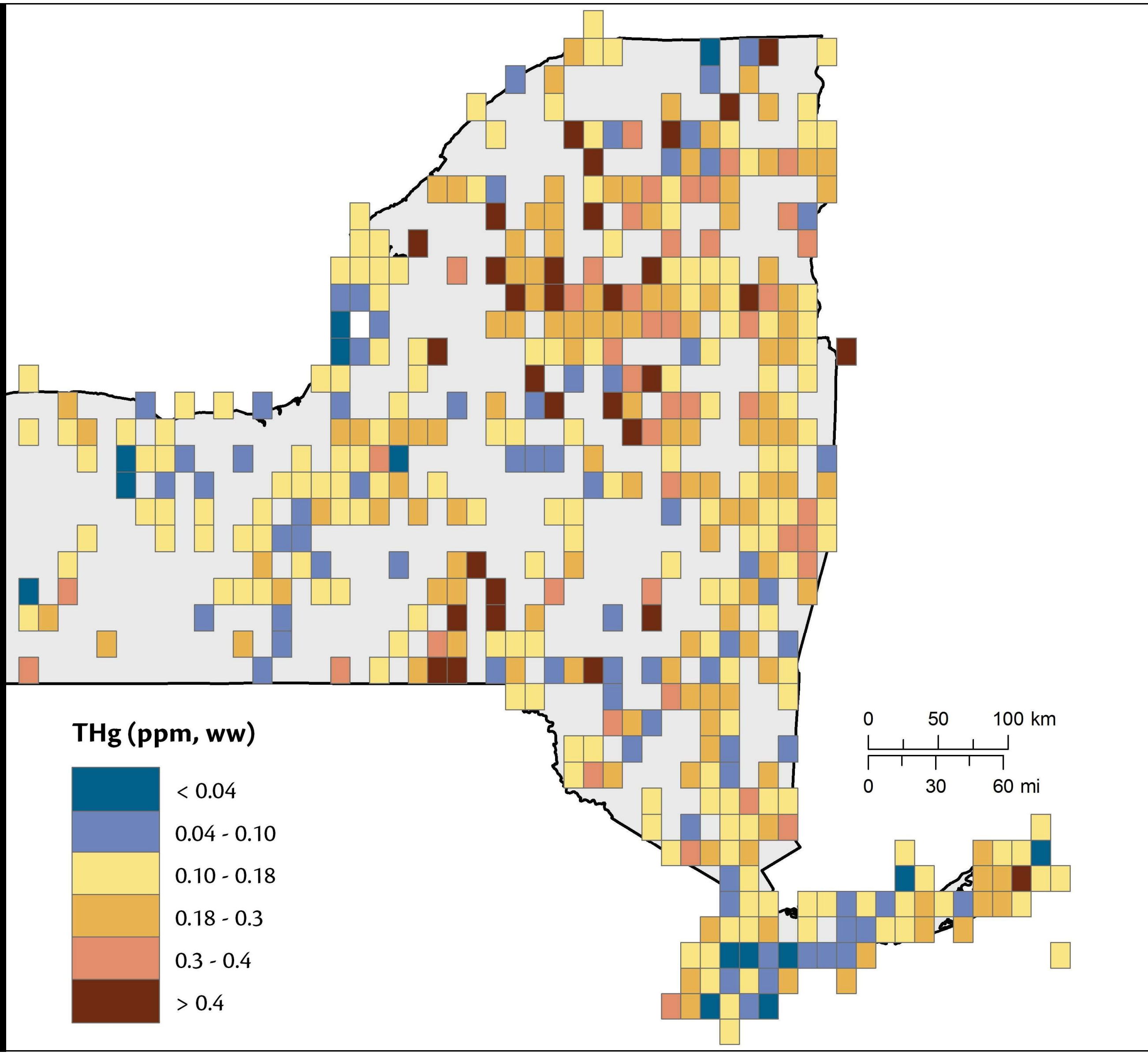
Based on 26 papers submitted for publication in two special journal issues and one synthesis paper submitted to STOTEN

82 scientists contributed data

Project completed in 9 months

Hg data collection

- 47,188 samples (>33,000 fish and >9,000 birds)
- From 1969-2018
- 525 grids represented (>50% of the state) – 1 grid = 250 km^2
- Fish were used as a way to evaluate impacts to fish, fish-eating wildlife and people
- Evaluations based on screening benchmarks from the literature



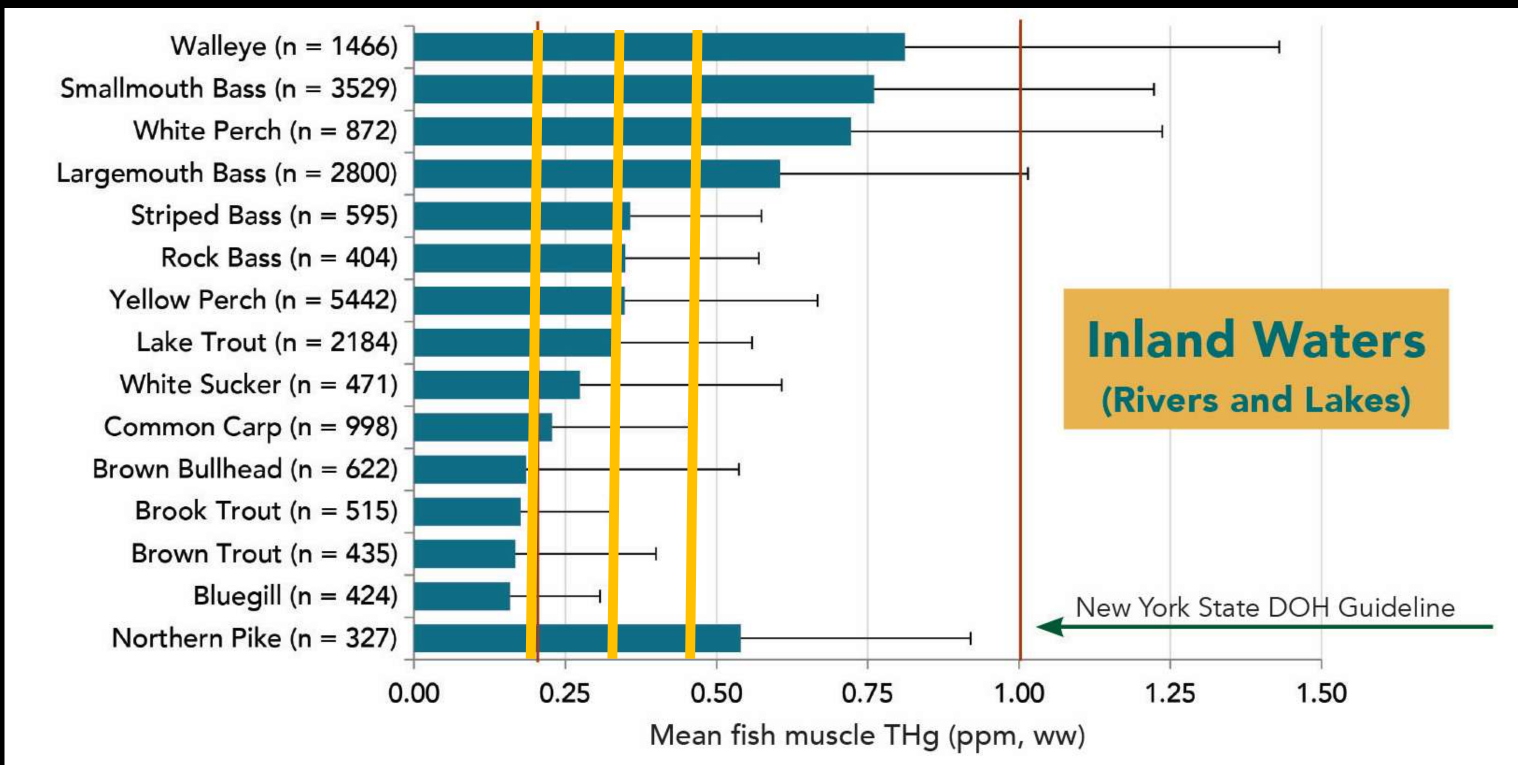
Interpreting Hg exposure in fish and wildlife: Screening Benchmarks

Table 3: Mercury Effects on Taxanomic Groups (Evers 2018)

Taxanomic Group	Tissue Type	Effect	MeHg Exposure	Threshold (ppm)
All Fish	Whole (ppm, ww)	significant reproductive success	diet	0.04
			body burden	0.30
Avian Piscivore Bioindicators: Common Loon; Bald Eagle	Blood (ppm, ww)	fewer fledged young	body burden	1.5 (10%) 2.0 (20%) 2.5 (30%) 3.0 (40%)
Avian Invertivore Bioindicators: Carolina Wren	Blood (ppm, ww)	lowered nesting	body burden	0.7 (10%) 1.2 (20%) 1.7 (30%) 2.2 (40%)
Mammal Piscivore Bioindicators: Mink/River Otter	Fur (ppm, fw)	brain biochemical changes	body burden	35.0
Mammal Invertivore Bioindicators: Bats	Fur (ppm, fw)	brain biochemical changes	body burden	10.0

One of the most useful interpretive endpoints for ecological effects of mercury is reproductive success, as it is meaningful and scalable. For example, in the Common Loon, a 10% reduction in fledged chicks per territorial pair occurs with blood mercury concentrations at 1.5 ppm, 20% at 2.0 ppm, 30% at 2.5 ppm, and a significant population level impact of 40% at 3.0 ppm (Evers 2018). The thresholds to avian invertivores are lower for reproductive loss than avian piscivores. To assess risk to mammals, a LOAEL based on fur is used: for bats (10 ppm, fw), mink (35 ppm, fw) and river otter (45 ppm, fw).

New York State Fish Hg Concentrations (Lakes and Rivers)

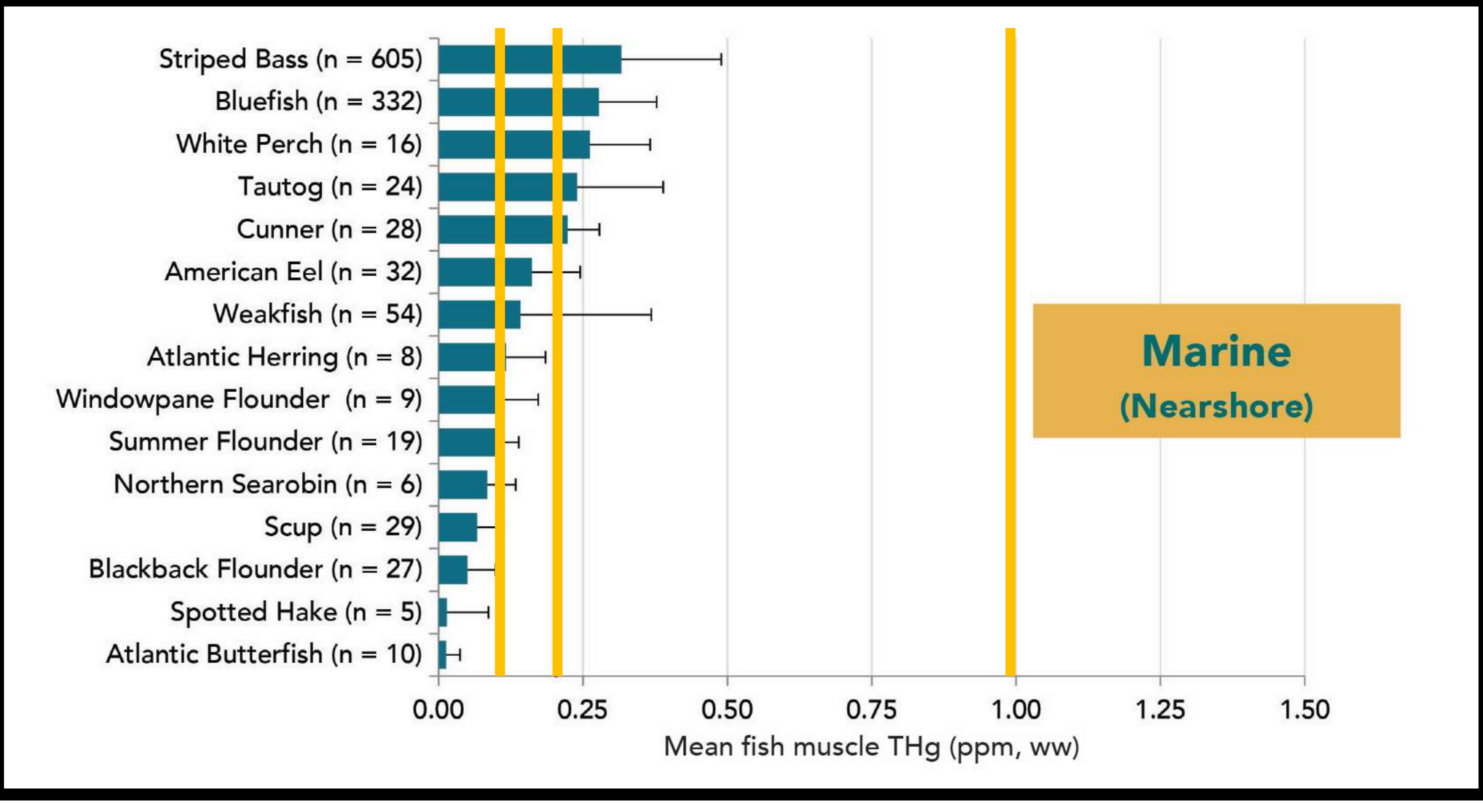


Screening Benchmarks

(whole body fish total Hg in ppm, ww)

- >0.04 ppm in diet of fish (Depew et al. 2012b—effects to fish reproductive success)
- >0.30 ppm in diet of fish (Scheuhammer et al. 2015—reduces reproductive success in fish)
- 0.10–0.18 ppm in diet of birds (Depew et al. 2012a—adverse effects on behavior for avian piscivores)
- 0.18–0.40 ppm in diet of birds (Depew et al. 2012a—significant reproductive impairment for avian piscivores)
- >0.40 ppm in diet of birds (Depew et al. 2012a—reproductive failure for avian piscivores)

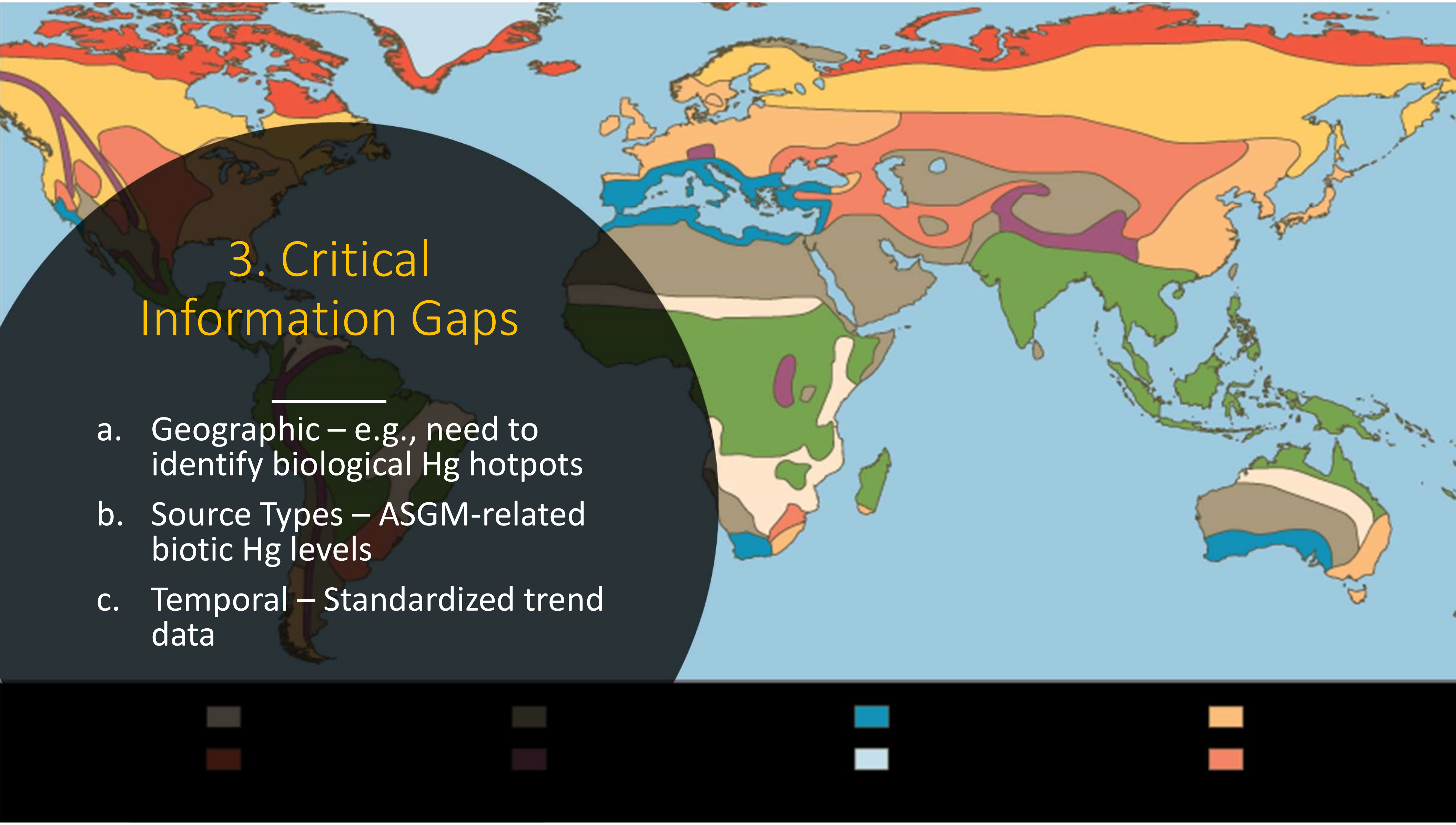
New York State Gamefish Hg Concentrations (Nearshore Marine – does not include pelagic species)



Screening Benchmarks

Mercury in Fish (ppm, ww)	Consumption Guidance
≤ 0.05	unrestricted
0.05-0.11	2 meals per week
0.11-0.22	1 meal per week
0.22-0.95	1 meal per month
> 0.95	no consumption

Source: Great Lakes Consortium

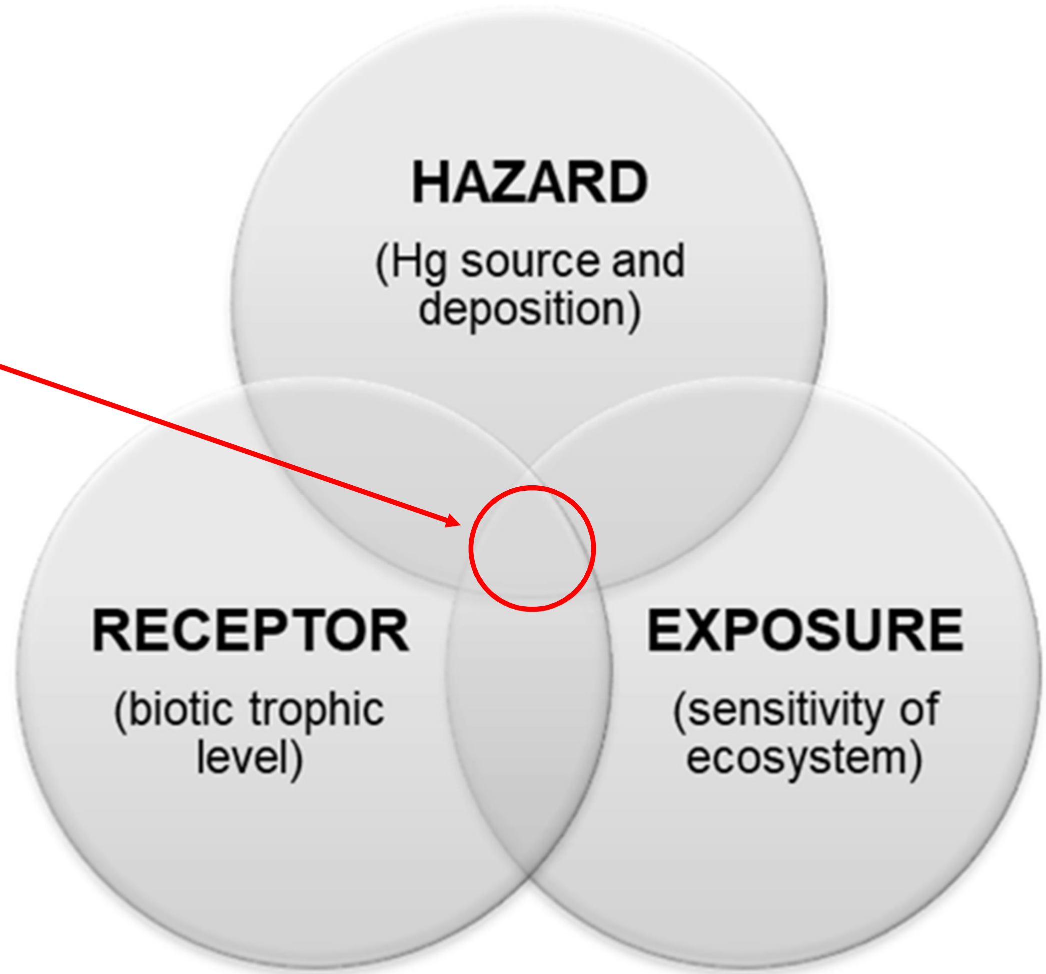


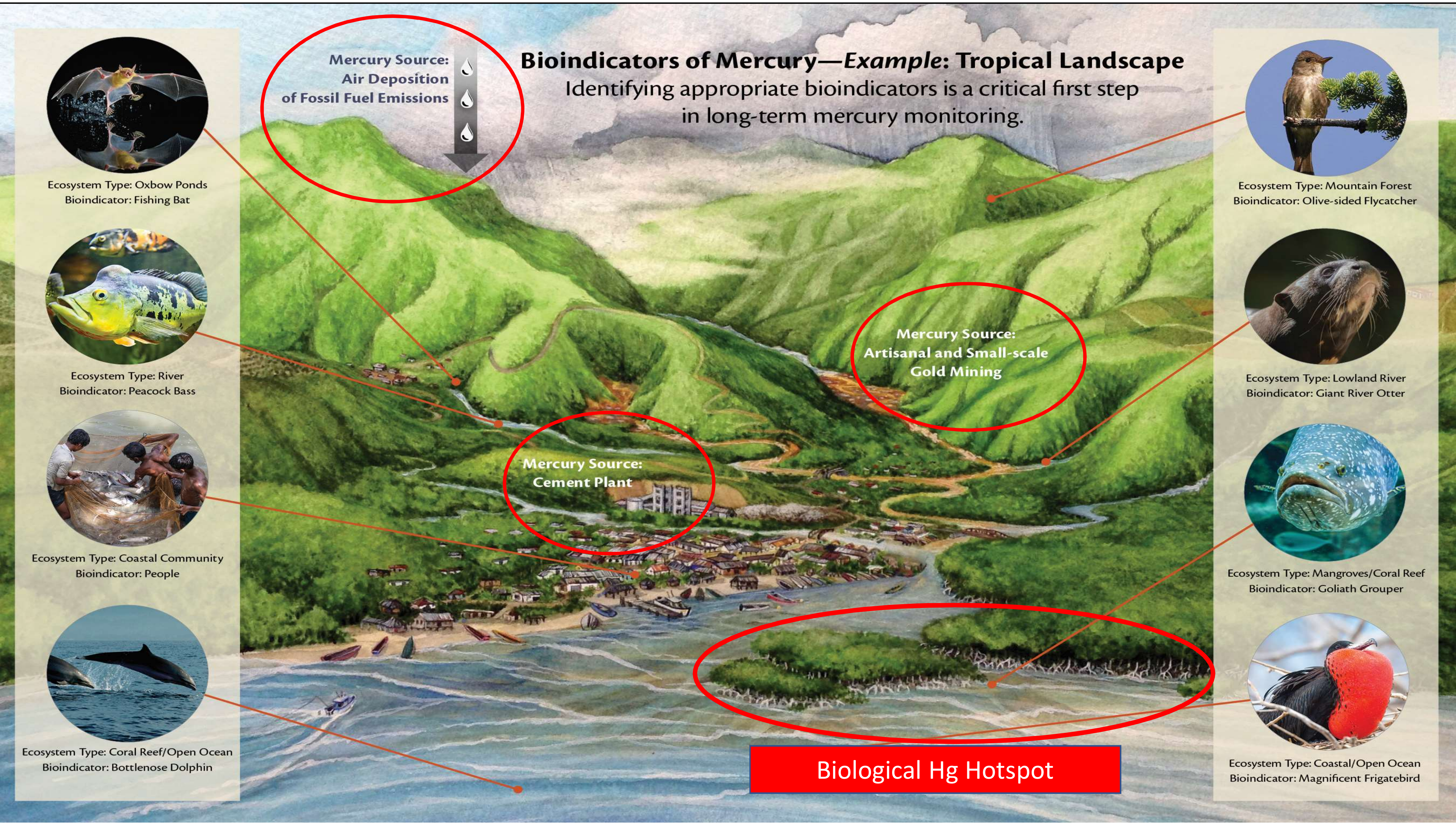
3. Critical Information Gaps

a. Geographic – e.g., need to identify biological Hg hotpots
b. Source Types – ASGM-related biotic Hg levels
c. Temporal – Standardized trend data

Geographic: Biological Hg Hotspot

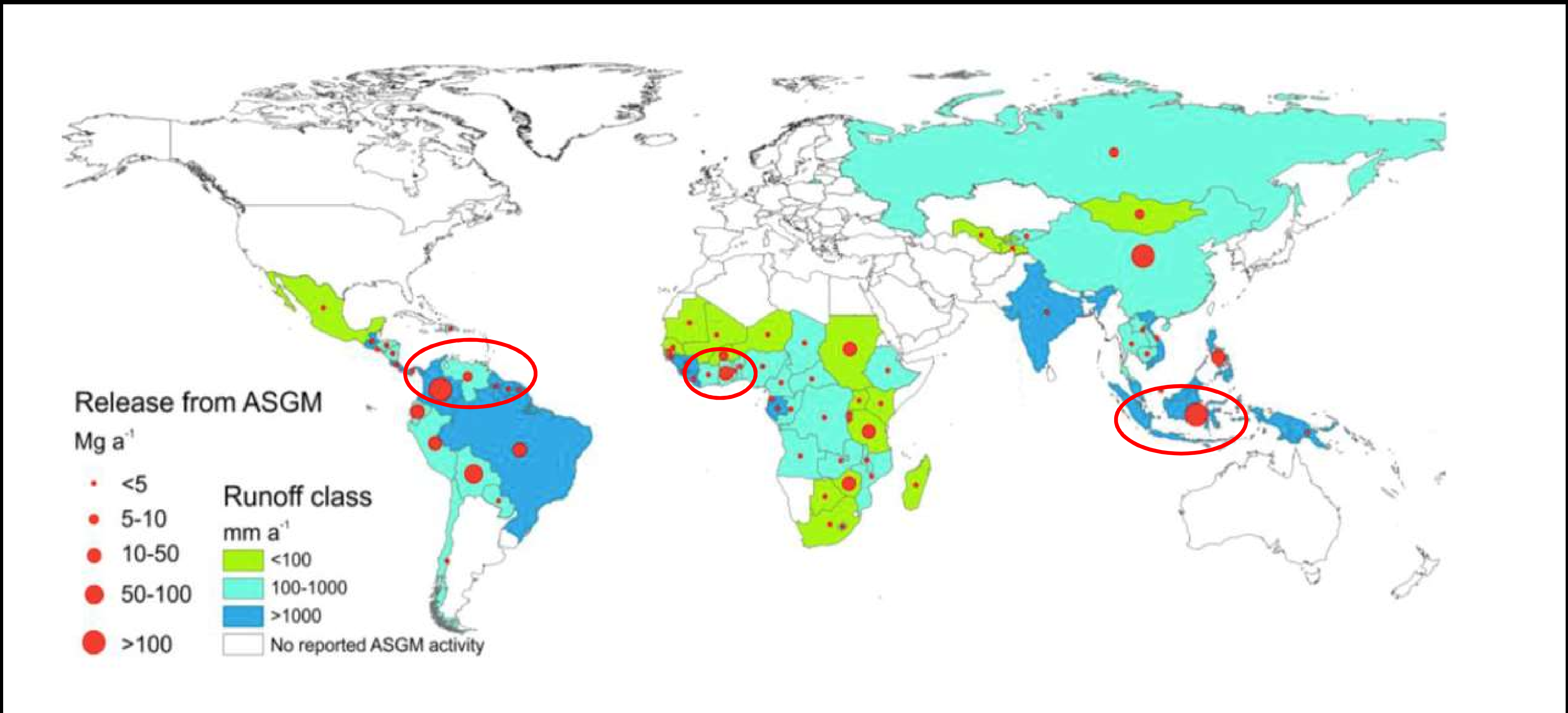
A geographic area where the environmental Hg concentrations are sufficient to be methylated at levels of significant biological concern (e.g., using reproductive endpoints) for biota that are at upper trophic levels.





Biological Hg Hotspot
Mercury Source: Air Deposition of Fossil Fuel Emissions
Biodindicators of Mercury—Example: Tropical Landscape
Identifying appropriate bioindicators is a critical first step in long-term mercury monitoring.
Mercury Source: Artisanal and Small-scale Gold Mining
Mercury Source: Cement Plant
Ecosystem Type: Oxbow Ponds
Bioindicator: Fishing Bat
Ecosystem Type: River
Bioindicator: Peacock Bass
Ecosystem Type: Coastal Community
Bioindicator: People
Ecosystem Type: Coral Reef/Open Ocean
Bioindicator: Bottlenose Dolphin
Ecosystem Type: Mountain Forest
Bioindicator: Olive-sided Flycatcher
Ecosystem Type: Lowland River
Bioindicator: Giant River Otter
Ecosystem Type: Mangroves/Coral Reef
Bioindicator: Goliath Grouper
Ecosystem Type: Coastal/Open Ocean
Bioindicator: Magnificent Frigatebird

Mercury Source Types: ASGM Hg Release Profile



Temporal Trends - Songbirds

- Use museum specimens and recent field sampling to generate a temporal profile for well over a century
- Longer profile provides baseline information
- Shorter temporal profile provides responses to policy changes (e.g., Minamata Convention)

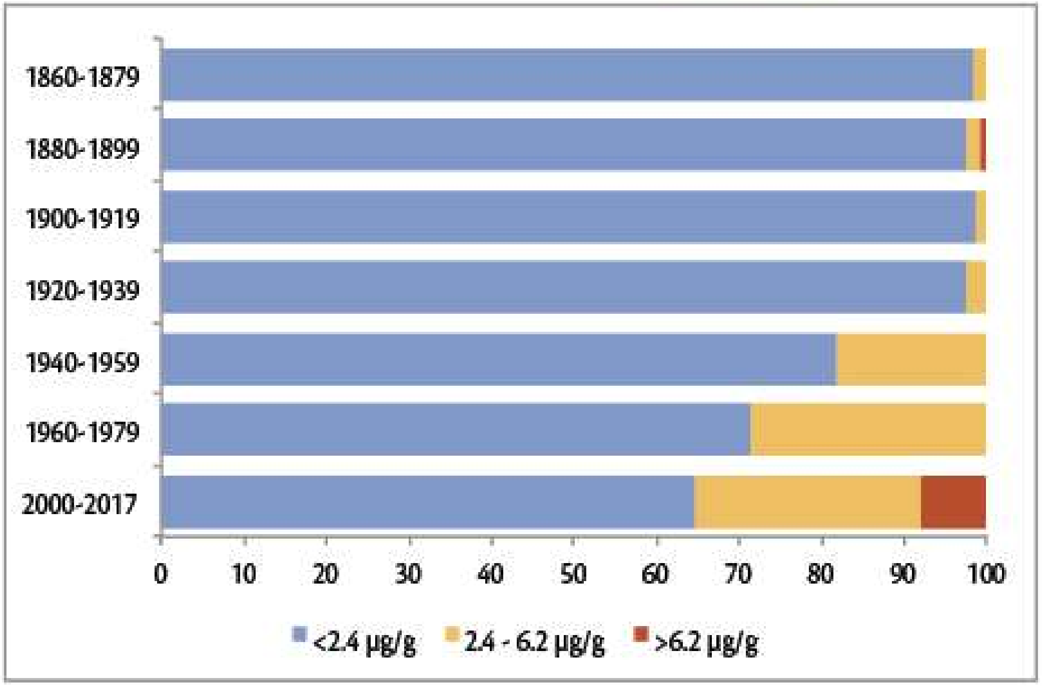


Figure 22. Percentage of individual songbirds from seven species (Northern Waterthrush, Olive-sided Flycatcher, Palm Warbler, Red-eyed Vireo, Rusty Balckbird, Saltmarsh Sparrow, Wood Thrush; n=838) with feather Hg concentrations falling within risk categories for adverse effects of MeHg exposure. Risk categories based on body feather concentrations: 1) <2.4 µg/g, low risk; 2) 2.4 to 6.2 µg/g, moderate risk; 3) >6.2 µg/g, high risk, adapted from (Jackson et al. 2011) .

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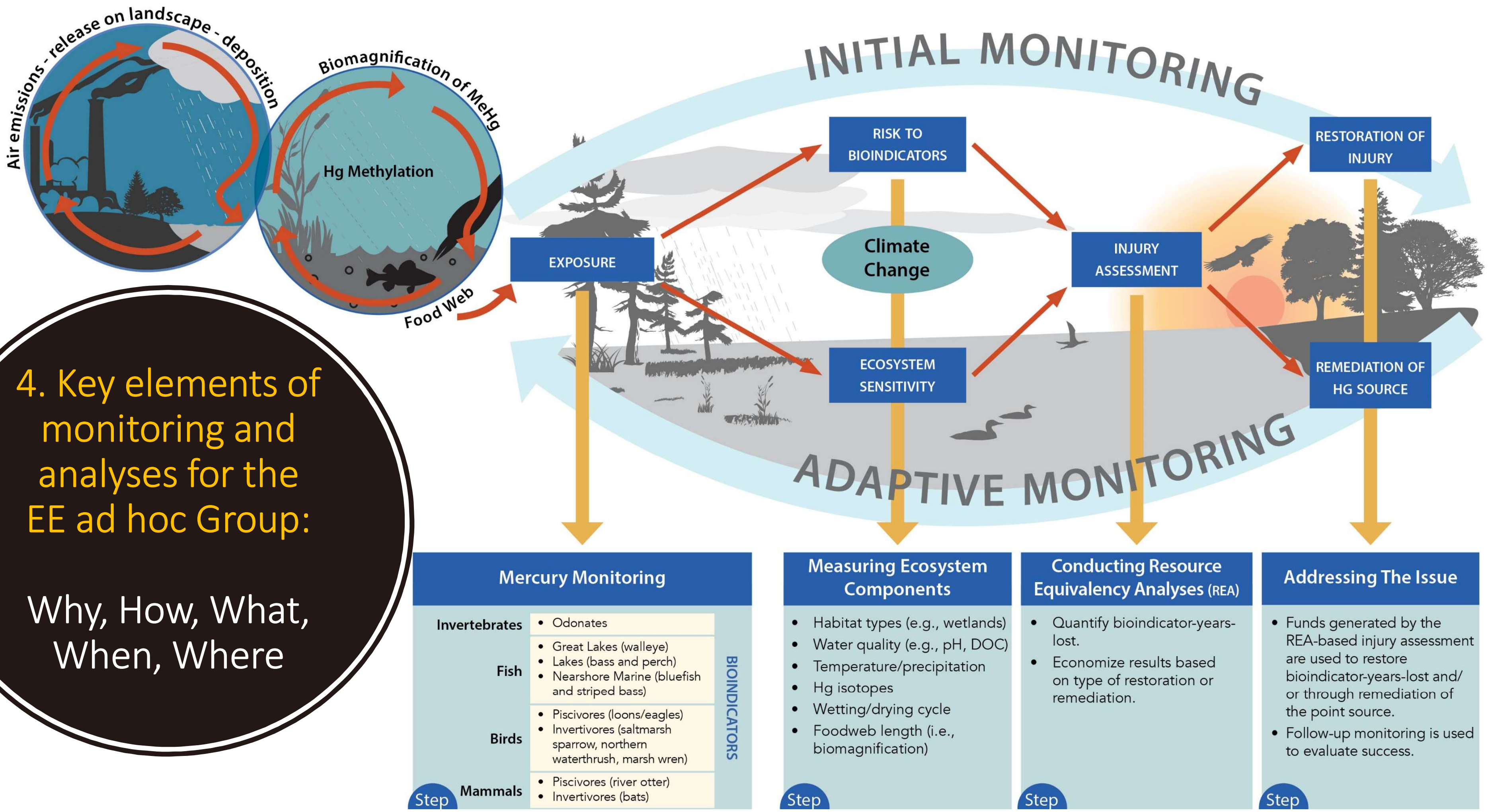
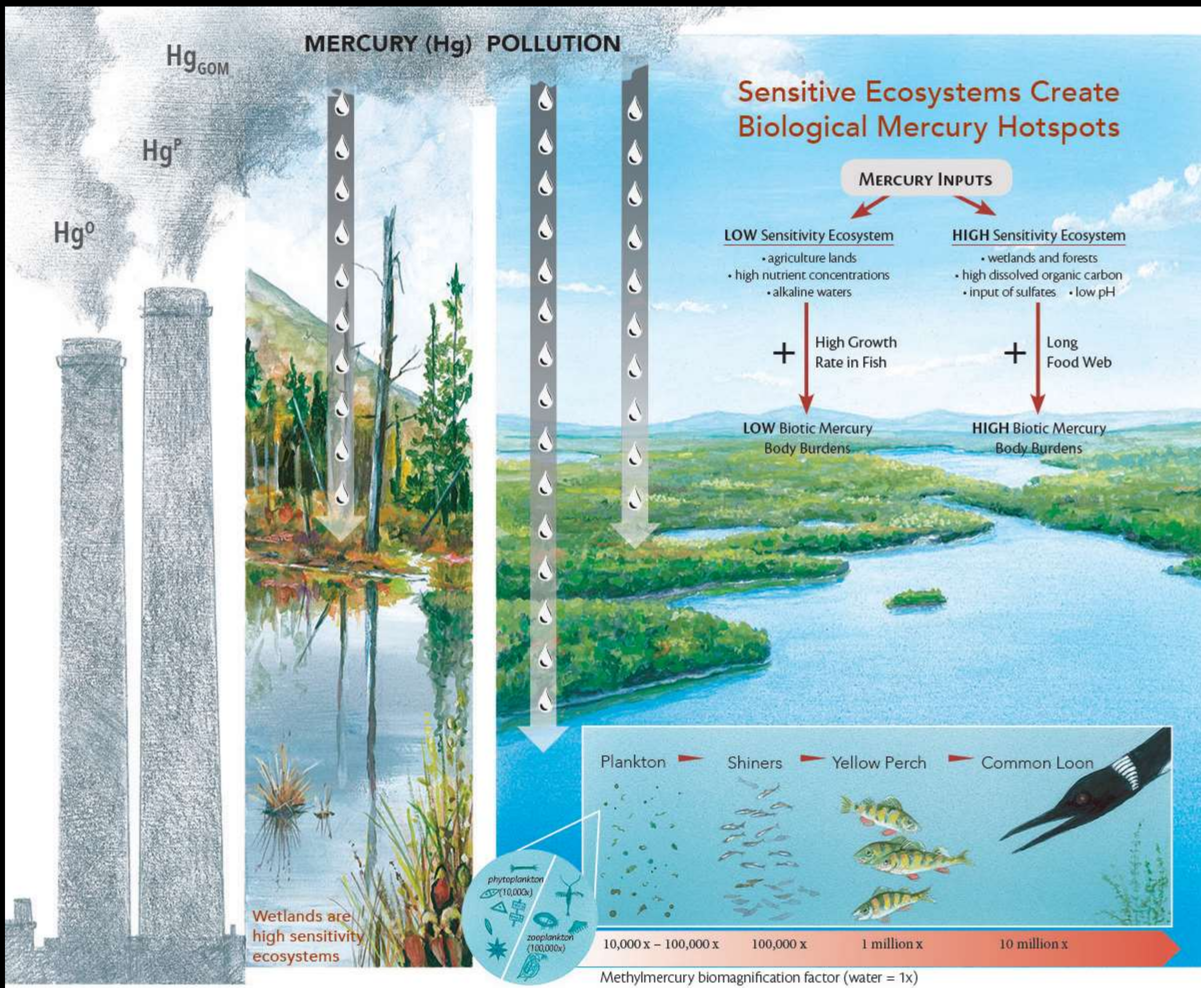
4. Key elements of monitoring and analyses for the EE ad hoc Group:

Why, How, What, When, Where



Why Monitor Mercury in Biota?



Key Elements:

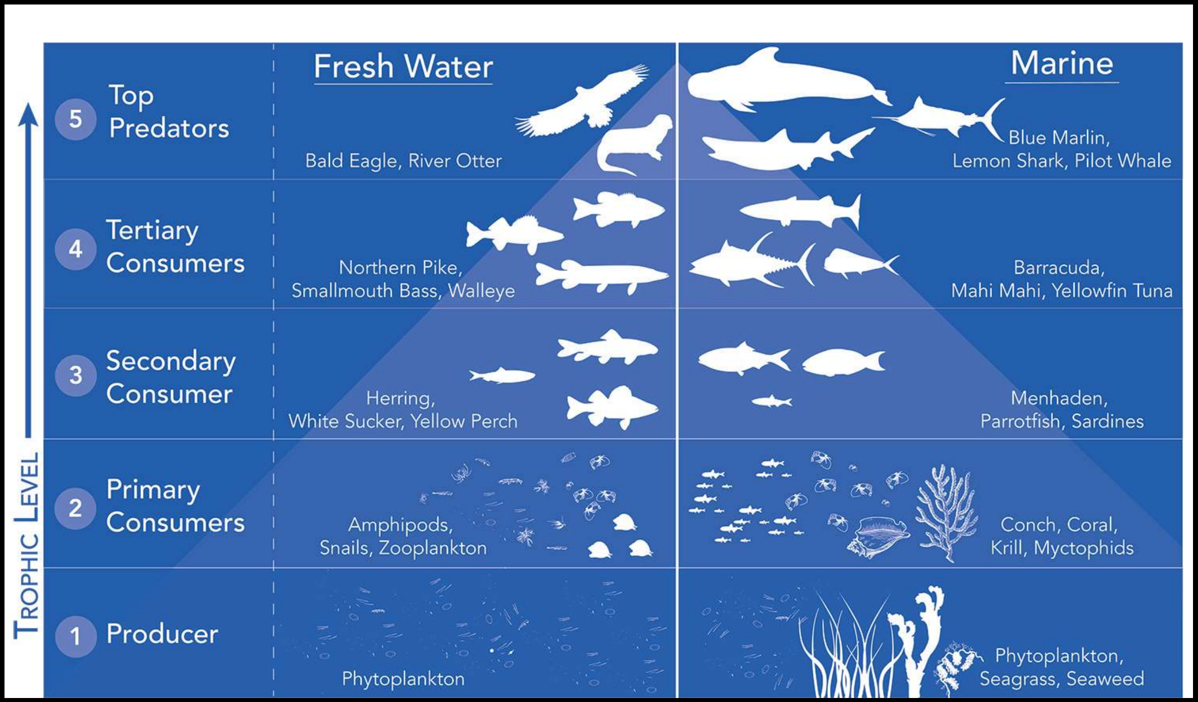
- Article 1 requires protection of Human Health and the Environment
- There is not a linear relationship with Hg in air emissions/ deposition and MeHg body burdens of biota
- Biota Hg exposure is needed to determine both:
  - Human Health concerns
  - Ecological Health concerns (especially for IUCN Red Listed species)

<u>How</u> to Monitor Mercury in Biota?

Key Elements:

- Lots of literature on field sampling to help efficiency
- Lab analytical techniques are well defined and can generally use THg (vs. analyzing MeHg)
- Need to use the proper tissue to best meet the objective. May vary according to:
    - Spatial gradients
    - Ecological health concerns
    - Human health concerns
    - Temporal trends

What Biota should be chosen to Monitor for Mercury?

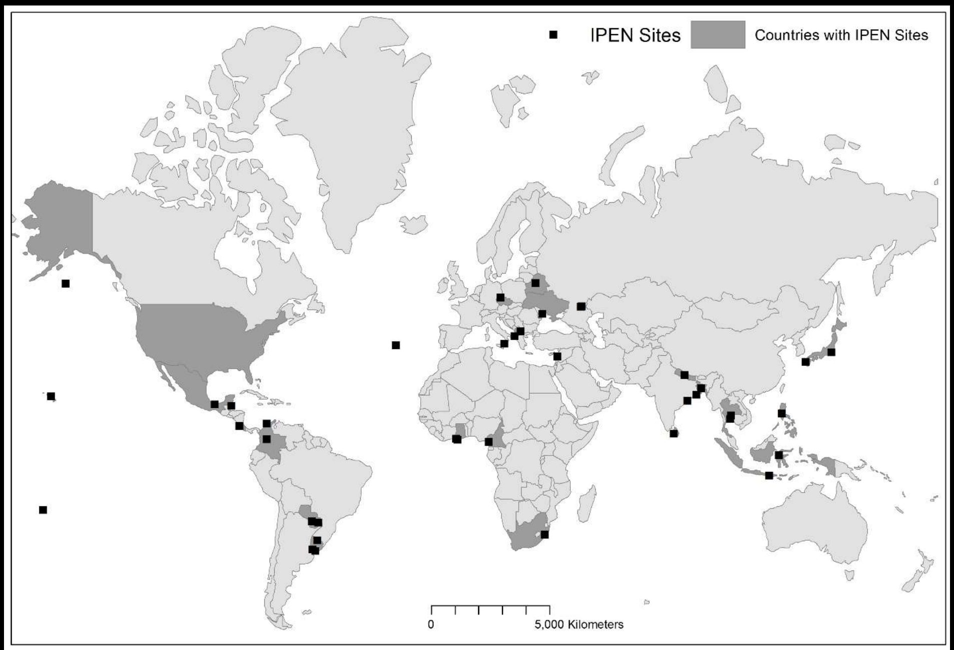


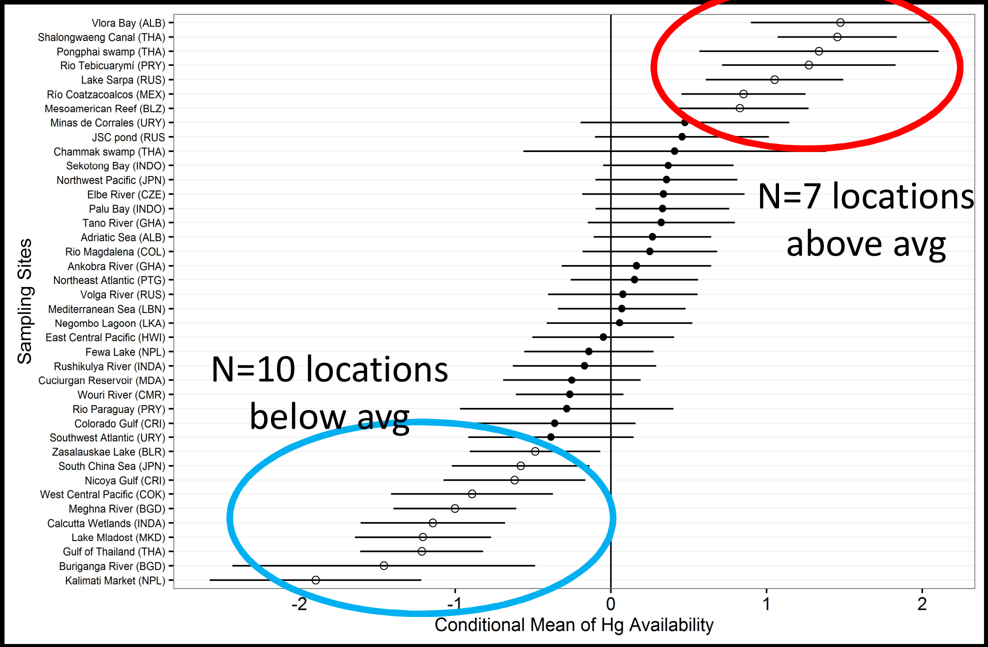
Key Elements:

- Lots of existing information (as summarized in GBMS)
- Choices vary by biome and ecosystem type (e.g., marine, freshwater, terrestrial)
- To protect human health and the environment – generally choose biota that are at greatest risk
- Greatest risk biota are Trophic Level 4 or higher

Rapid assessment of Hg in trophic Level 4 fish

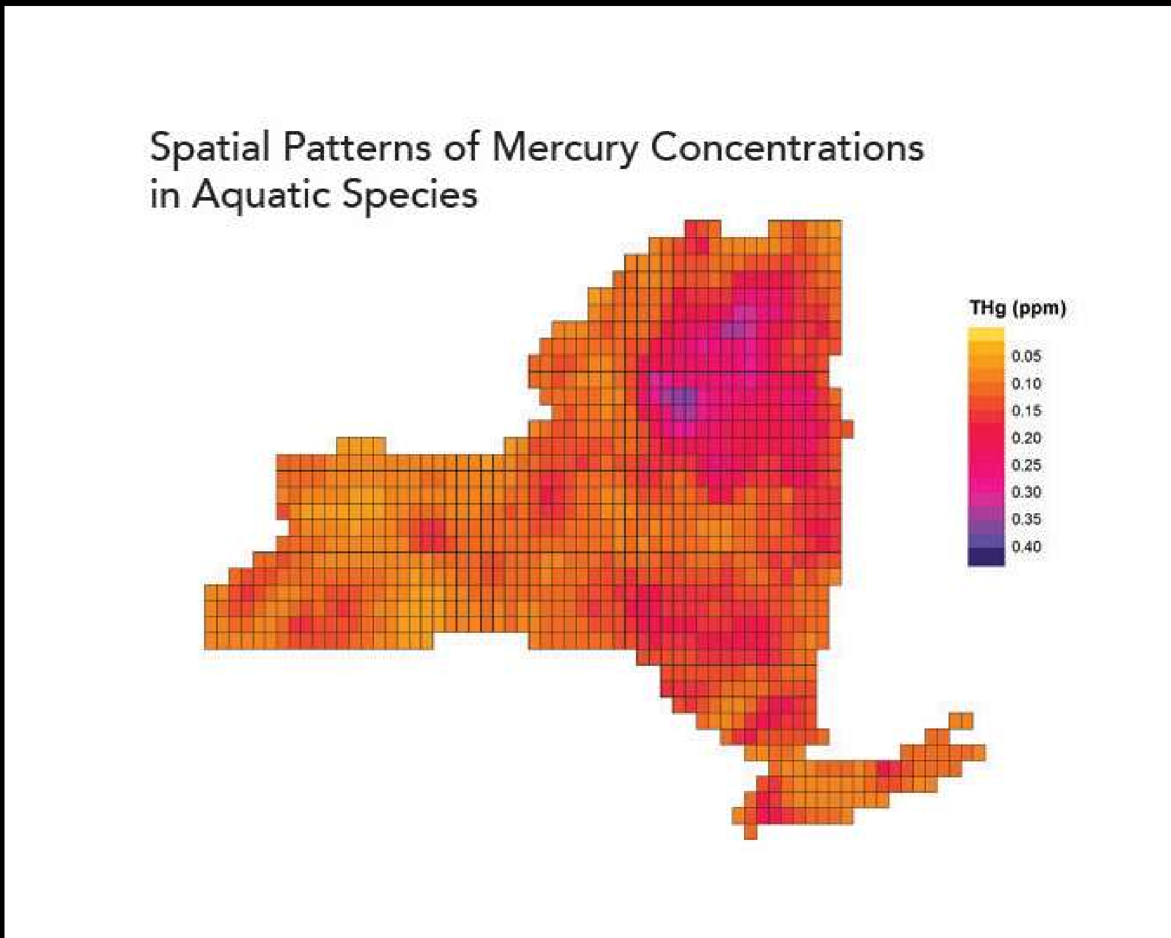
26 countries, 40 locations, 92 species, 451 individuals





Buck, Evers et al. Accepted in 2019. Science of the Total Environment

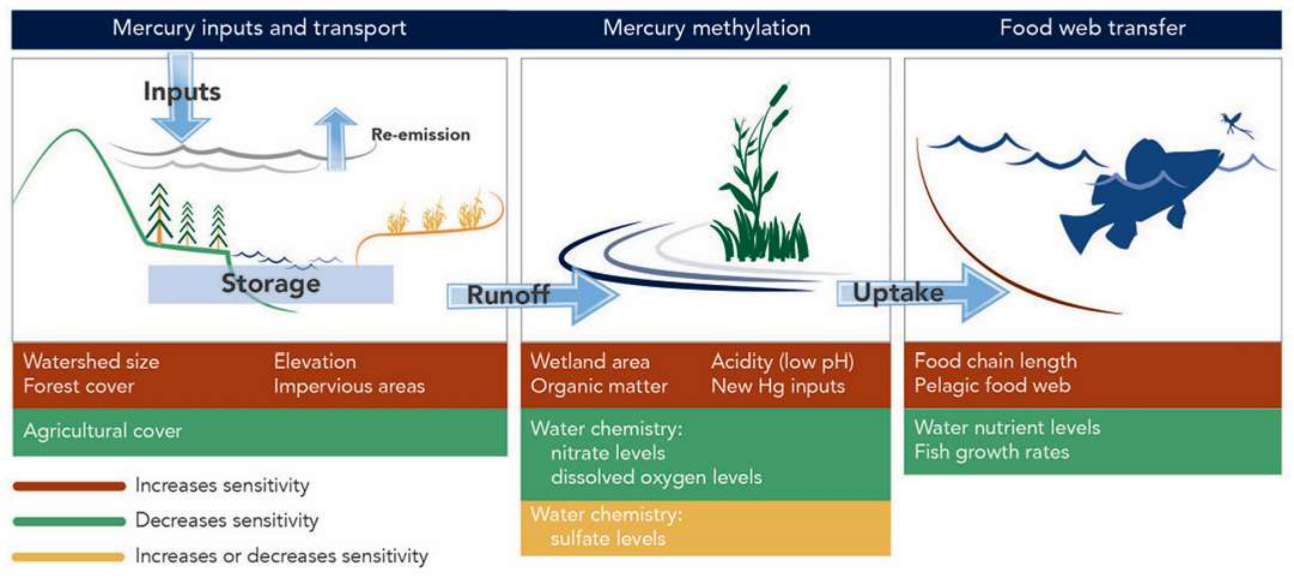
When should biota be chosen to Monitor for Mercury?



Key Elements:

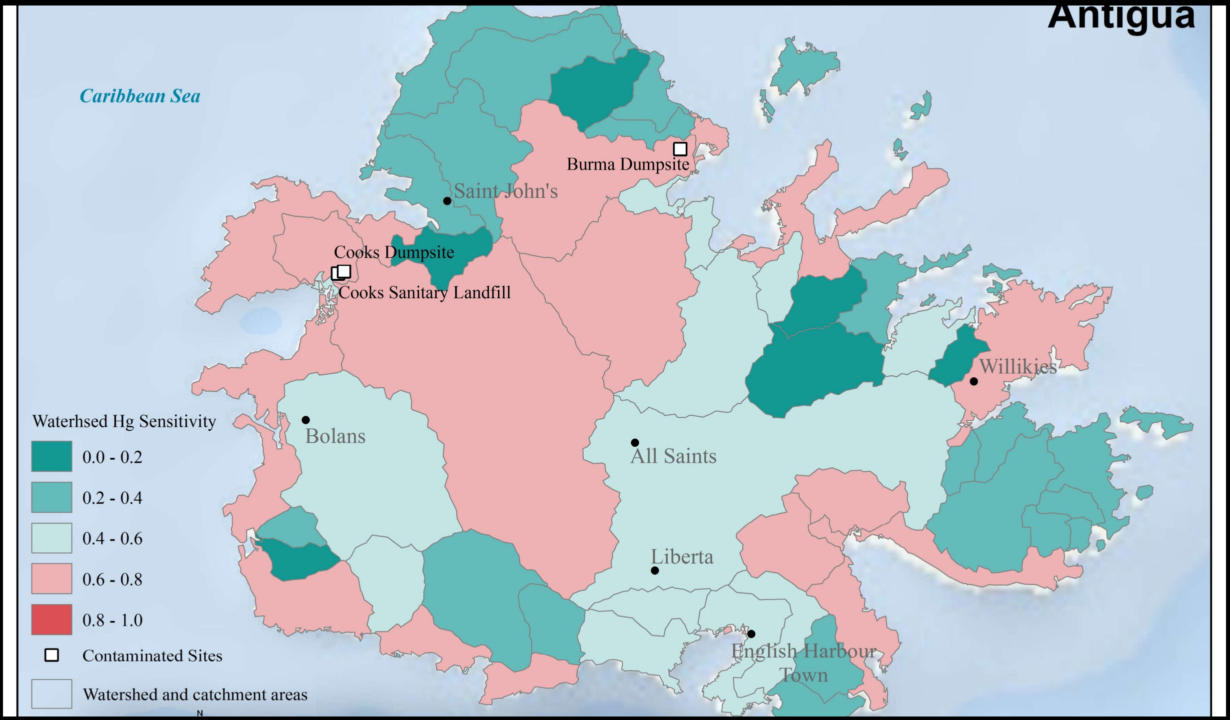
- If people or IUCN Red Listed species are within identified biological Hg hotspots
- If there are limited or no data and there is regular consumption of food items from:
  - A known or modeled biological Hg hotspot
  - Consumption is heavy on trophic level 4 or higher food items
  - Consumption of food items is near a contaminated site

Where should biota be Monitored for Mercury?



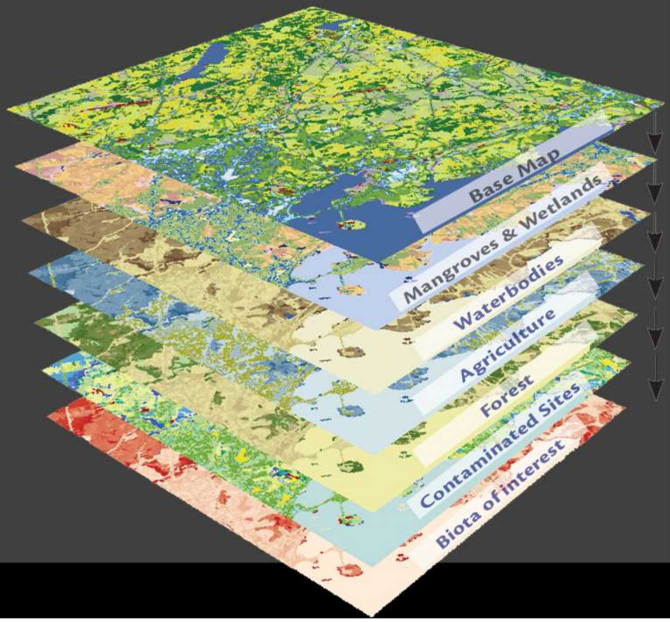
Key Elements:

- Areas that are plentiful with wetlands are prime (such areas include all IUCN Ramsar protected sites)
- Areas that have other features that favor high methylation rates:
  - Wet-dry cycles
  - Forested areas (vs ag lands)
  - Acid conditions
  - Estuaries in general (they have the right balance of dissolved organic carbon and sulfur input)



Mapping biological mercury hotspots: Caribbean example for Antigua and Barbuda

- 7 different variables used
- Wetland extent, type and location are critical – mangrove and estuaries are key
- Association of wetlands with contaminated sites is important



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