

# An Evaluation of Stressor Interactions in the Great Lakes

A Report of the International Joint Commission's  
Science Advisory Board - Science Priority Committee  
September 22, 2020

*Welcome to the Webinar*

# Welcoming Remarks

- This webinar will present results from a recent IJC Science Advisory Board project
- 45 minute presentation followed by 45 minutes of Q+A
- Please enter questions for panelists in the Q+A panel
- Welcoming remarks from:

Dr. Carol Miller

U.S. Co-Chair, IJC Science Advisory Board-Science Priority Committee  
& Wayne State University



# Presenters



**Dr. J. David Allan, Work Group Chair**  
**University of Michigan & IJC Science Advisory Board member**  
**Primary author of report**

Dr. John Bratton, Project Contractor  
LimnoTech

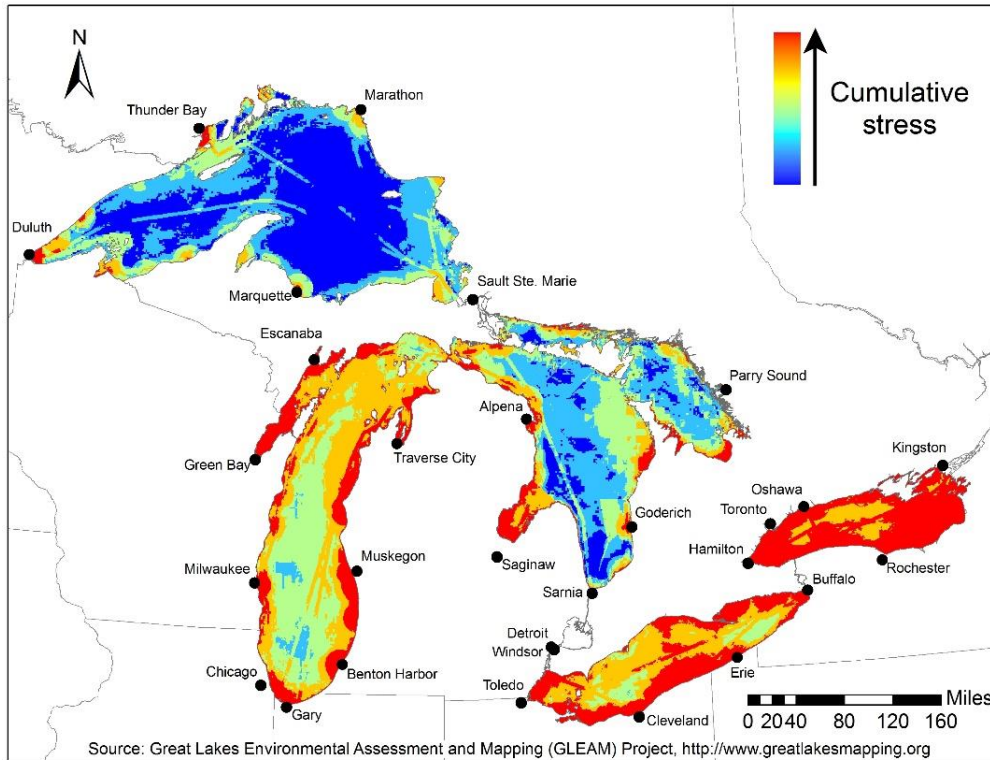


Dr. Karen Kidd, Work Group Member  
McMaster University  
& IJC Science Advisory Board member

Dr. Michael W. Murray, Work Group Member  
National Wildlife Federation  
& IJC Science Advisory Board member



# Environmental Stressors of the Great Lakes



***“there is an urgent need to understand whether the ecosystem response to multiple stressors is simply additive, or involves synergistic or antagonistic effects”***  
(Sturner et al. 2017).

Bails et al. 2005. Prescription for Great Lakes ecosystem protection and restoration, December 2005.

Danz et al. 2007. Integrated measures of anthropogenic stress in the U.S. Great Lakes Basin. *Environmental Management* 39:631-647

Allan JD et al. 2013. Joint analysis of stressors and ecosystem services to enhance restoration effectiveness. *Proc Natl Acad Sci USA* **110**: 372–77.

Smith et al. 2019. Evidence for interactions among environmental stressors in the Laurentian Great Lakes. *Ecol. Indic.* 101, 203–211.

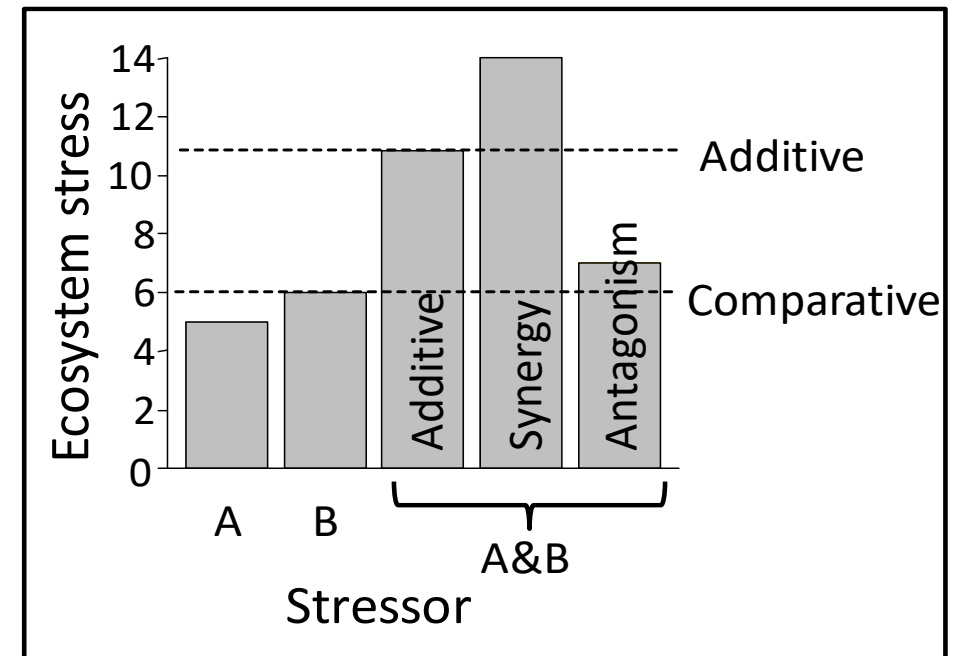
Sturner et al. 2017. Grand challenges for research in the Laurentian Great Lakes. *Limnol. Oceanogr.* 62(6), 2510–2523.

# Cumulative Stress (CS)

- Presence of multiple environmental stressors implies that populations and ecosystems experience cumulative stress
- However, without knowledge of how stressor interactions occur, CS is largely unknown
- A growing literature explores stressor interactions, using terms such as additive, multiplicative, synergistic and antagonistic
- A deeper understanding of interactions between pairs of stressors is an important first step to better understand CS and determine whether such information can inform management actions

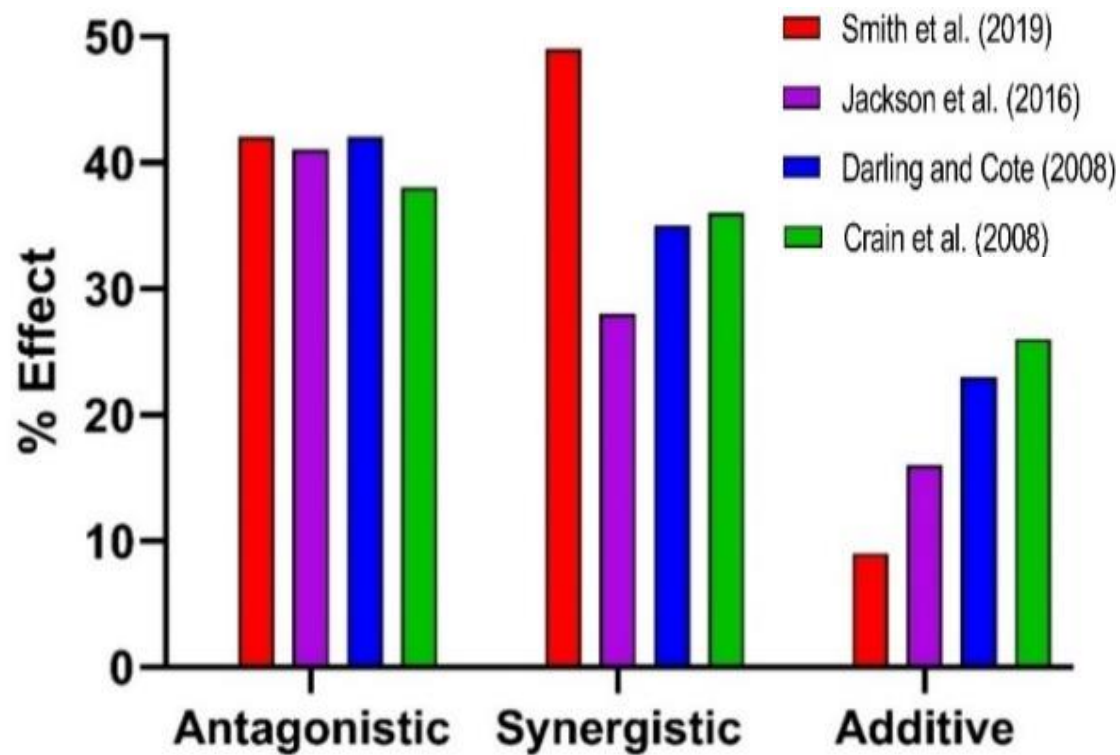
# Definitions

Definition of Terms	
<b>Additive</b>	Combined stressor impacts that are equal to the sum of the individual impacts
<b>Antagonism</b>	Combined stressor impacts that are less than the sum of the individual impacts
<b>Cumulative</b>	The influence of all stressors together, often estimated as an additive summation
<b>Multiplicative</b>	Stressor impacts are synergistic or antagonistic rather than additive
<b>Synergy</b>	Combined stressor impacts that are greater than the sum of the individual impacts



Conceptualization of interactions among stressors (from Smith et al. 2019, based on Folt et al. 1999).

# Evidence from other studies



*Antagonistic and synergistic outcomes both were common in these four analyses of many studies. In contrast, a large body of European work found mainly additive effects*

Crain et al. 2008. Interactive and cumulative effects of multiple human stressors in marine systems. *Ecol. Lett.* 11(12), 1304–1315.

Darling and Côté 2008. Quantifying the evidence for ecological synergies. *Ecol. Lett.* 11(12), 1278–1286.

Jackson et al. 2016. Net effects of multiple stressors in freshwater ecosystems: a meta-analysis. *Glob. Chang. Biol.* 22(1), 180–189.

Smith et al. 2019. Evidence for interactions among environmental stressors in the Laurentian Great Lakes. *Ecol. Indic.* 101, 203–211.

Hering et al. 2015. Managing aquatic ecosystems and water resources under multiple stress—an introduction to the MARS project. *Sci. Total Environ.* 503-504(2015), 10–21.

# An Evaluation of Stressor Interactions in the Great Lakes

- A project of the Science Advisory Board – Science Priority Committee of the International Joint Commission
- Involved a working group, facilitated workshop, and literature synthesis by LimnoTech
- Goals
  - Identify a subset of priority stressors affecting Great lakes ecosystems
  - Evaluate likelihood of interactions between pairs of stressors
  - Consider likely mechanisms of stressor interaction, and the potential for such interaction to result in enhanced or reduced harm as a consequence of each interaction
  - Explore implications for management response



# Project Team

## IJC Advisory Board Members

Dave Allan(Chair), University of Michigan  
Lucinda Johnson, University of Minnesota-Duluth  
Karen Kidd, McMaster University  
Michael Murray, National Wildlife Federation  
Joe DePinto, Independent Consultant  
Bob Hecky, University of Minnesota-Duluth  
Carol Miller, Wayne State University  
Christina Semeniuk, University of Windsor  
Scott Sowa, The Nature Conservancy  
John Jackson, Citizen Activist  
Kathy McKague, Ontario Ministry of Env., Cons. & Parks  
Debbie Lee, National Oceanic & Atmos. Admin.

## Contractor

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Bob Sterner, University of Minnesota  
Craig Stow, NOAA-GLERL  
Don Uzarski, Central Michigan University

# Priority stressors

- Seven stressors were selected for their importance in the Great Lakes
  - Invasive species (mussels, lampreys, gobies, Asian carp, *Phragmites*)
  - Toxic chemicals (persistent organic pollutants (PCB, DDT, PFAS), mercury, pharmaceuticals and personal care products)
  - Nutrients (phosphorus, also nitrogen, silica)
  - Climate change (warming, precipitation changes)
  - Habitat loss (wetlands)
  - Fish harvest (commercial)
  - Pathogens (VHS, other viruses, fecal indicator bacteria)
- Interacting effects were categorized for eleven pairs of stressors
  - To evaluate likelihood of additive, synergistic, or antagonistic outcomes
  - Evaluations were based on scientific literature, and are largely qualitative

The seven priority stressors result in 21 possible pair-wise combinations, of which eleven were considered in detail

Code: additive or synergistic, +/++ ; antagonistic, - ; both antagonistic and additive/synergistic outcomes are likely, -/+; not considered, N/C. Cells shaded in grey are redundant.

	Invasive species	Toxic chemicals	Climate change	Nutrients	Habitat loss	Fish harvest	Pathogens
Invasive species							
Toxic chemicals	N/C						
Climate change	+/++	-/+					
Nutrients	+/++	-	+/++				
Habitat loss	+/++	-/+	+/++	+/++			
Fish harvest	+/++	N/C	N/C	N/C	N/C		
Pathogens	N/C	-/+	N/C	N/C	N/C	N/C	

# Spatial and temporal considerations

- Spatial and temporal variation in stressor occurrence determines
  - The possibility for stressors to interact
  - The intensity of their interactions
- Many stressors are most prevalent in nearshore areas, near river mouths and urban areas, and in embayments
- But:
  - Invasive species often have specific distributions and habitat requirements
  - Different aspects of a stressor can differ in the location of their greatest impact. Warming trends vary across the lakes separately from precipitation intensity and runoff, and these two climate variables have different seasonal effects
- How stressor interactions vary with location and across scale merits further study

## - Case Studies -

1. Precipitation and Phosphorus Loading: A Synergistic Interaction (John Bratton)
2. PCBs and Phosphorus: An Antagonistic Interaction (Karen Kidd)
3. Mercury and Wetland Loss: Both Types of Interactions (Mike Murray)

# Increased precipitation/warming and phosphorus loading: An example of additive or synergistic interactions

- Climate Change: impacts Great Lakes with more rainfall overall and more intense storms, high river flows; warmer summers start earlier and end later
- Algal blooms: produced by excess nutrients
- Hypoxia: oxygen depleted in bottom water by decaying algae and reduced mixing of lakes during summer
- Nuisance macroalgae: grow well in clear, warm, nutrient-rich water

Sources: Stow et al. 2015; Lake Erie Binational Phosphorus Reduction Strategy, 2019; LimnoTech 2020

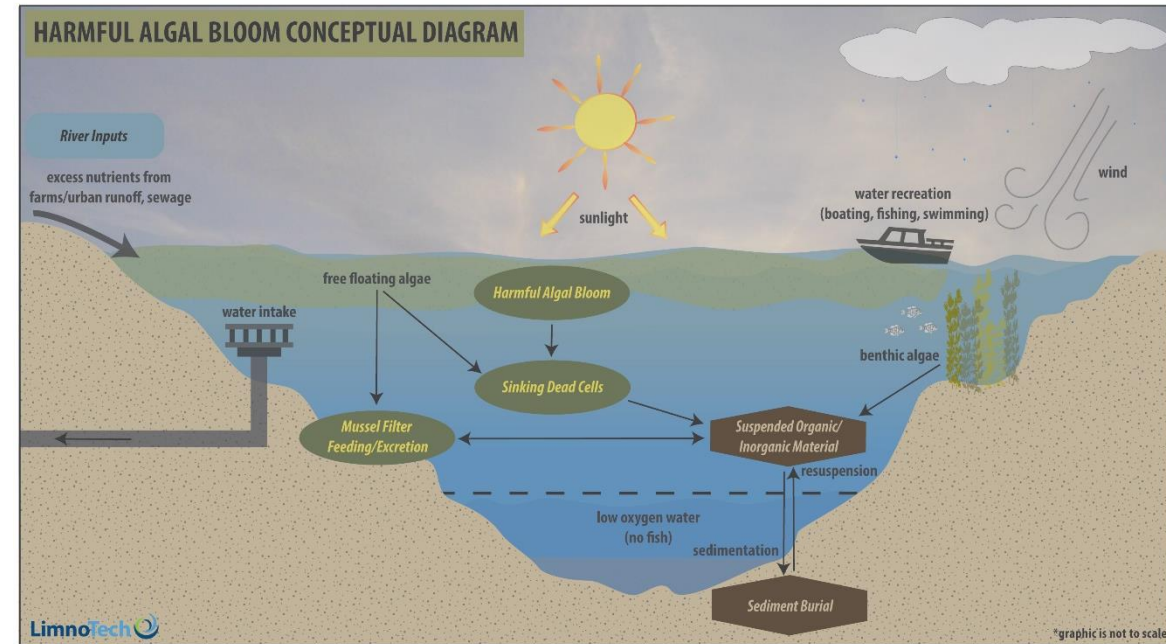


Landsat 8 image of W. L. Erie, Sept. 2017, NASA/USGS



# Precipitation/warming and P loading: Mechanisms

- Rain, heat, and nutrients:
  - More nutrients can grow more algal cells.
  - Toxic algal species grow better when hotter.
- Synergism/additivity: More rain yields more soil erosion and fertilizer loss from fields; more nutrients and warmer lake water produce larger toxic blooms and “dead zones”; low oxygen releases sediment P
- Antagonism? Less snow so less spring runoff? Warmer wet springs and early algal blooms could “burn through” nutrient supply and reduce late summer blooms (possibly seen in 2018, not typical)



# Precipitation/warming and P loading: Management, research implications

- P load reductions from changing agricultural practices (conservation tillage, cover crops, 4Rs, etc.) may be offset by climate change impacts
- Ongoing questions on how legacy P and new P get from fields to lakes, and the most effective ways to reduce this
- Enhancing ecosystem services by wetland restoration, riparian buffers, two-stage ditches, etc. can improve system resilience to climate change
- Long-term monitoring of farm practices, rivers, and lake conditions is necessary to detect trends, focus actions



Manure injection:

<https://www.manuremanager.com/manure-injection-can-benefit-farm-neighbors-30501/>

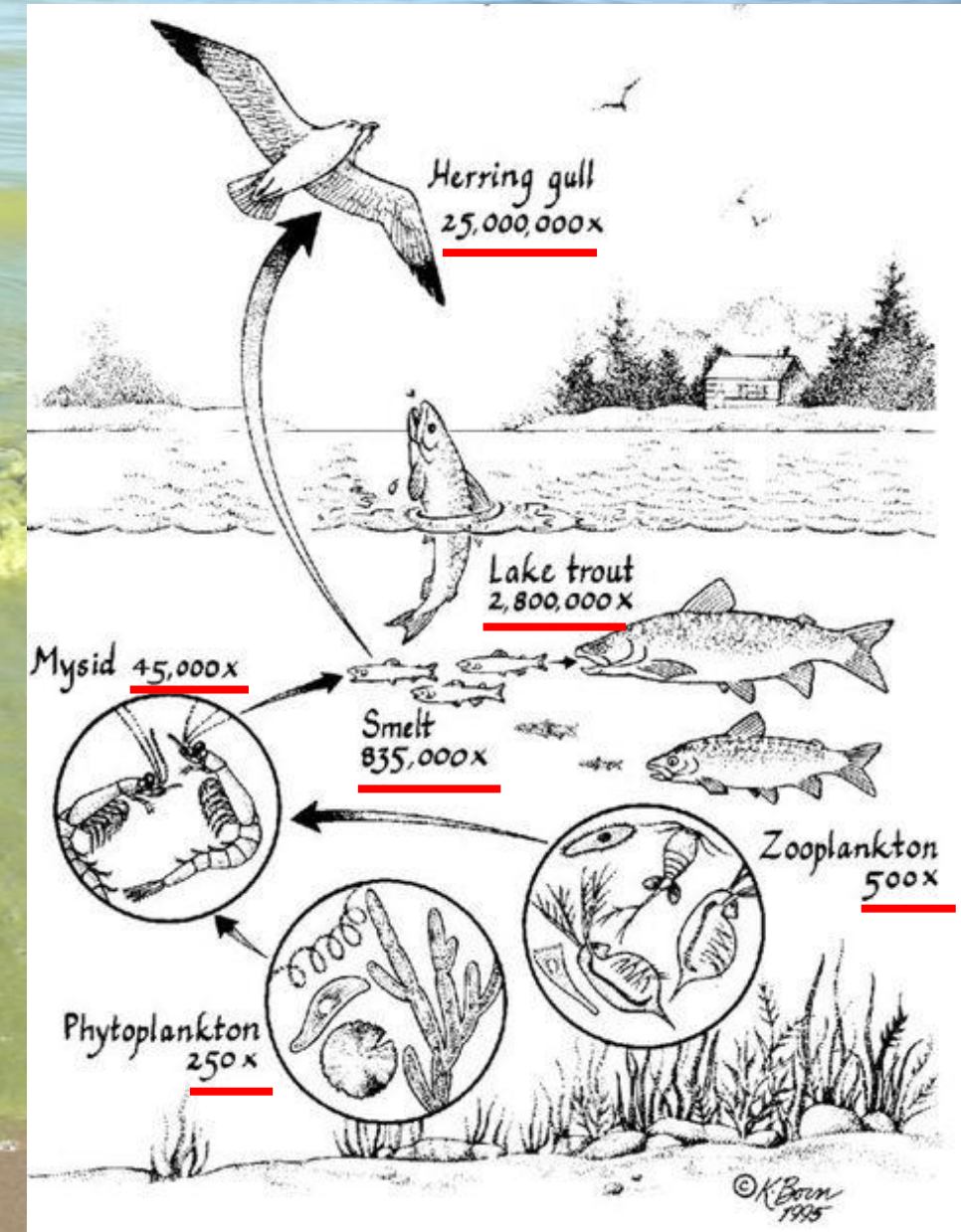
Sources: Bosch et al., 2014; LimnoTech, 2020



# Toxic chemicals and nutrients: An example of antagonism

## Introduction

- PCBs: Widely used, banned late '70s, accumulate in food webs, risks to human health, fish, wildlife
- PCBs in fish: affected by loadings to environment, diet, growth rates, age
- Phosphorus: Excess nutrient inputs ↑ algal blooms
- Phosphorus in ecosystems: ↑ increased productivity and growth of organisms, including fish





# Toxic chemicals and nutrients: Mechanisms for antagonism

- PCBs and phosphorus are antagonistic:
  - Increased nutrients decrease PCBs in fish
    - higher dilution at base of food web
    - higher growth of fish
    - greater burial of PCBs in sediments
  - Spatial considerations, strong linkages in
    - shallow embayments, e.g. western Lake Erie
- Antagonism also occurs with other toxic chemicals

Source: LimnoTech, 2020

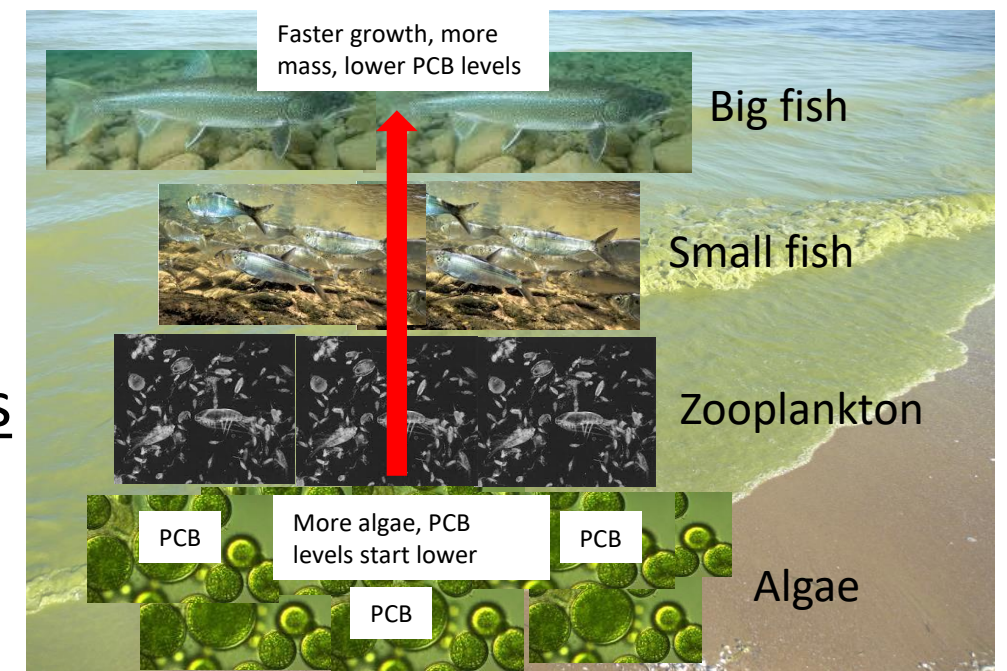
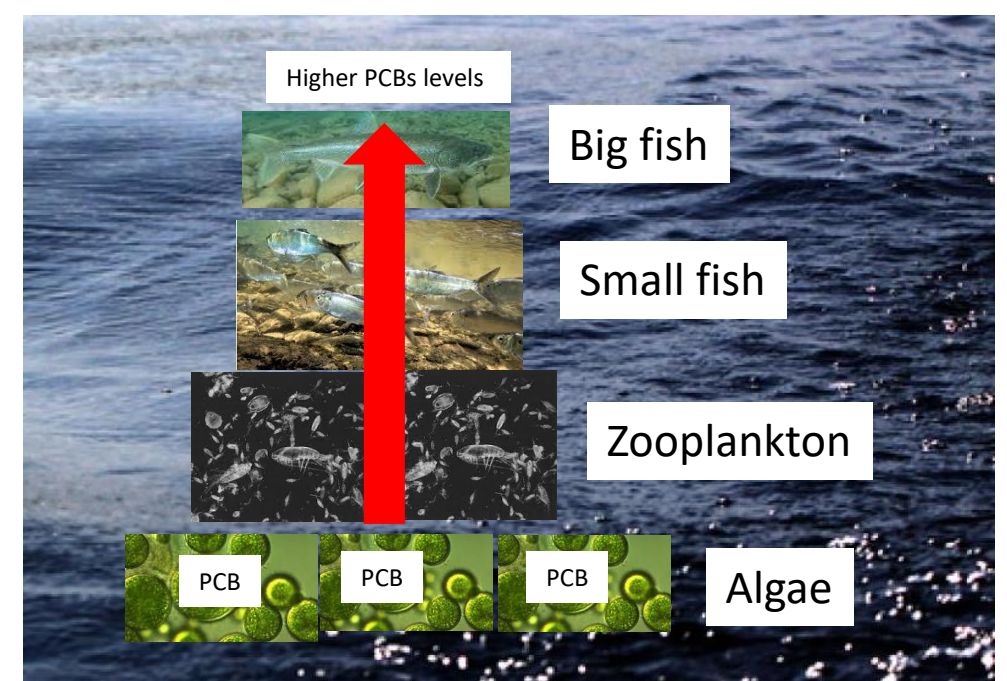


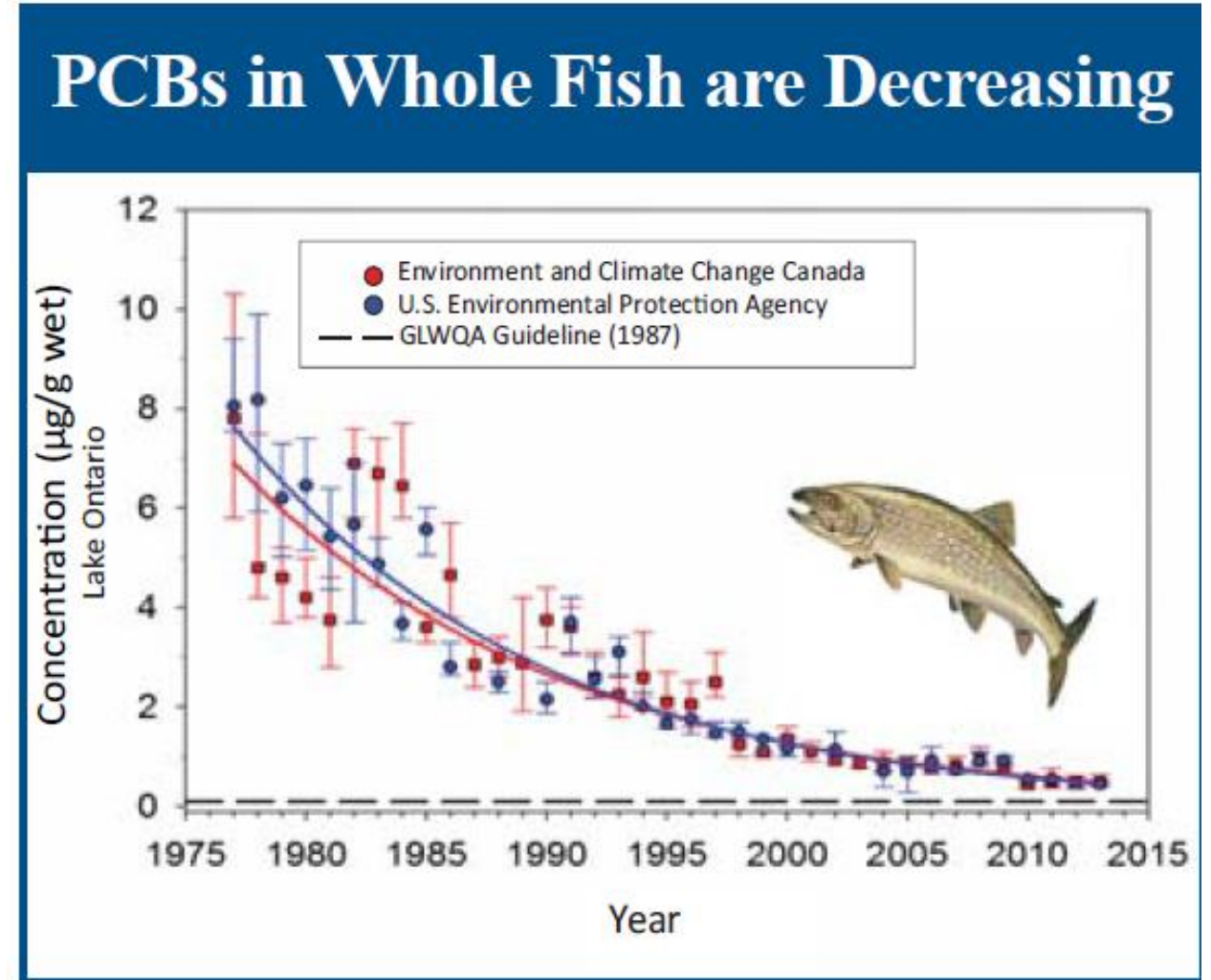
Photo credits: IJC, Tom Archer/Michigan Sea Grant 18

# Toxics and nutrients:

## Management, research implications

- Reduction of one stressor (P), may increase another (PCBs)
- Or slow PCB trends in fish over time (see graph)
- Despite antagonisms, continued reductions of phosphorus, e.g. in Lake Erie, are encouraged
- Awareness of such antagonisms needed

Source: LimnoTech, 2020



# Mercury and wetlands loss:

## An example of both types of interactions

- Mercury (Hg): Risks to human health, fish, wildlife
- Methylmercury (MeHg): Bioaccumulates, biomagnifies to greater extent
- Hg concentrations in biota: Affected by many factors, including loads and Hg methylation
- Wetlands and loss: Wetlands have multiple ecosystem functions; significant losses historically in Great Lakes

Sources: Wiener et al., 2012; LimnoTech 2020

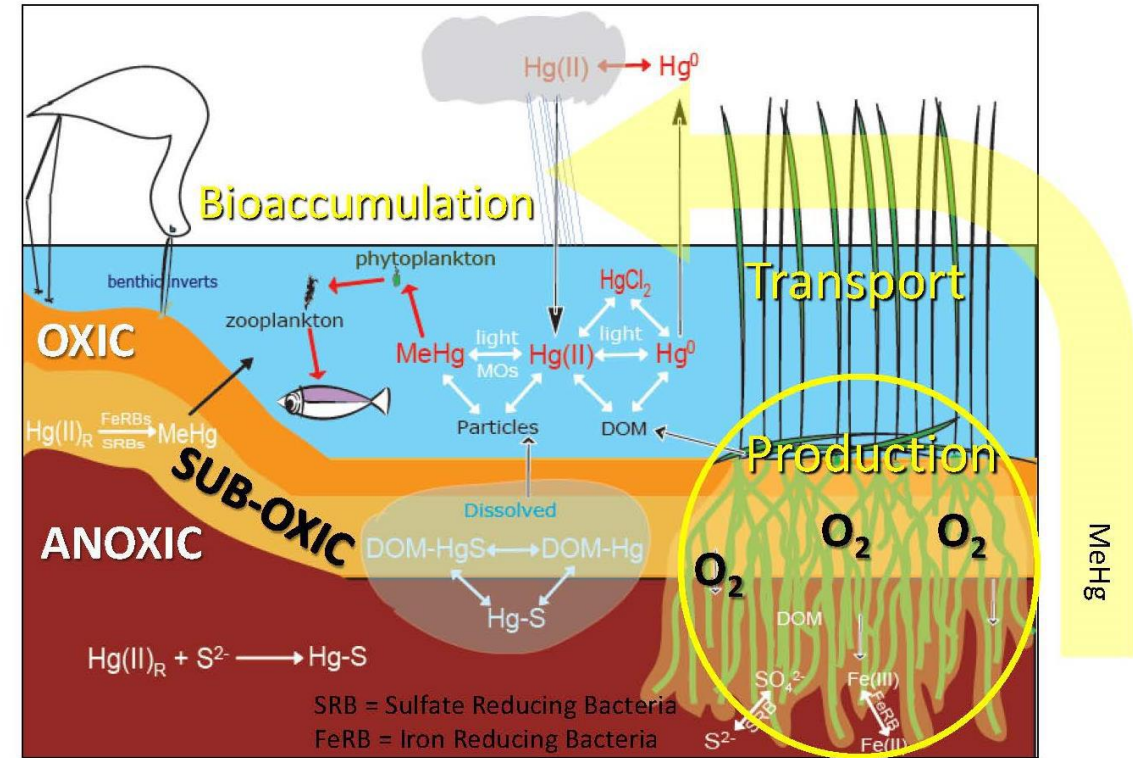


Ottawa NWR (M. Murray)



# Mercury and wetlands loss: Mechanisms

- Wetlands & Hg:
  - Sites of MeHg production; but can be sink for inorganic Hg
  - Multiple factors involved – e.g. oxygen levels, water level changes, microorganism activity
- Synergism/additivity: Wetlands loss can mobilize Hg export
- Antagonism: Wetlands loss means decreased MeHg production



Widham-Myers, L. 2016 (USGS)

# Mercury and wetlands loss: Management, research implications

- Wetlands - multiple ecosystem functions and services, including providing habitat, sequestering contaminants
- Challenge to generalize toxic chemical/wetland loss interaction (Hg/MeHg vs. other contaminants); ongoing research questions
- Management may be context-dependent – e.g. contaminated industrial site vs. more pristine site

Sources: Trebitz et al., 2009; Watras et al., 2019; LimnoTech, 2020



Little Rock Lake, WI (J. Gaeta)

# Finding & Recommendation #1

- Stressor interactions in the Great Lakes are important to consider and are likely to result in an overall increase in cumulative ecosystem stress.
- There is a need for continued attention to this issue, using the infrastructure, organizations and governance systems that already exist in the Great Lakes basin.
- At this point in our understanding of stressor interactions in the Great Lakes, there is no clear resolution to the question of whether to continue traditional stressor-by-stressor management, or to adopt more holistic, integrated management of stressors within an explicit framework of interacting stressors.

**Recommendation 1:** That the Parties (U.S. and Canadian governments) and other stakeholders that support Great Lakes monitoring and research programs investigate the gaps in understanding of stressor interactions described in this report, with an emphasis on those stressor interactions that are both most likely to impact natural environments across a range of environmental conditions and be amenable to management intervention at appropriate scales.

# Finding & Recommendation #2

- Quantitative syntheses find that stressor interactions are common in freshwater ecosystems, although they are often limited to controlled laboratory settings or mesocosms and single species or life stages.
- Ecosystem responses to both individual stressors and interacting stressors may be nonlinear, whereby cumulative stress may push ecosystems beyond tipping points that often cannot be anticipated.
- There are existing Great Lakes management programs that consider stressor interactions (e.g., Areas of Concern, Great Lakes fishery management) and those programs may hold promise for improved understanding of the management of stressor interactions, and for development of management approaches that explicitly consider interactions.

**Recommendation 2:** That any management actions in the Great Lakes by the Parties, state and provincial governments, and Tribes, First Nations and Métis governments should be targeted toward interactions that are best understood. Current management approaches that consider multiple stressors should be incorporated into approaches for addressing the interactions of other combinations of multiple stressors.



# Finding & Recommendation #3

- Spatial and temporal variability in the occurrence of individual stressors and long-term trends in their intensity are important contextual considerations in the evaluation of stressor interactions.
- Because the majority of stressors originate on land where agricultural and urban activities are most pronounced, the intensity of many stressors is likely to be greatest in nearshore waters and decrease with distance from shore.
- Stressors can vary with weather extremes, ecosystem conditions and drivers of human activity. In some cases, the analysis of interactions may be required at a relatively fine spatial and temporal scale.

**Recommendation 3: Lessons learned from science and management efforts that identify important stressor interactions should include spatial, temporal and other contextual information that is critical to the transferability of information.**

# Finding & Recommendation #4

- Climate change is the most pervasive stressor that merits further consideration in terms of its interaction with other stressors – particularly toxic chemicals, invasive species, habitat loss, nutrients and pathogens.

**Recommendation 4: That the Parties tailor their Great Lakes science and management programs to explicitly consider how the multiple facets of climate change may interact with other stressors, and manage wherever possible toward enhancing resilience.**

# Questions & Discussion

- Please enter questions into Q+A -

## Contact:

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## Report Download:

Report at <https://ijc.org/en/sab/evaluation-stressor-interactions-great-lakes>

# Thank you

## Contact:

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