Assessment of Population, Reproductive, and Health Impairments in Great Lakes Colonial Waterbirds Breeding in Contaminated Sites in Michigan

Saginaw Bay and River Raisin Areas of Concern and Grand Traverse Bay, 2010-2017

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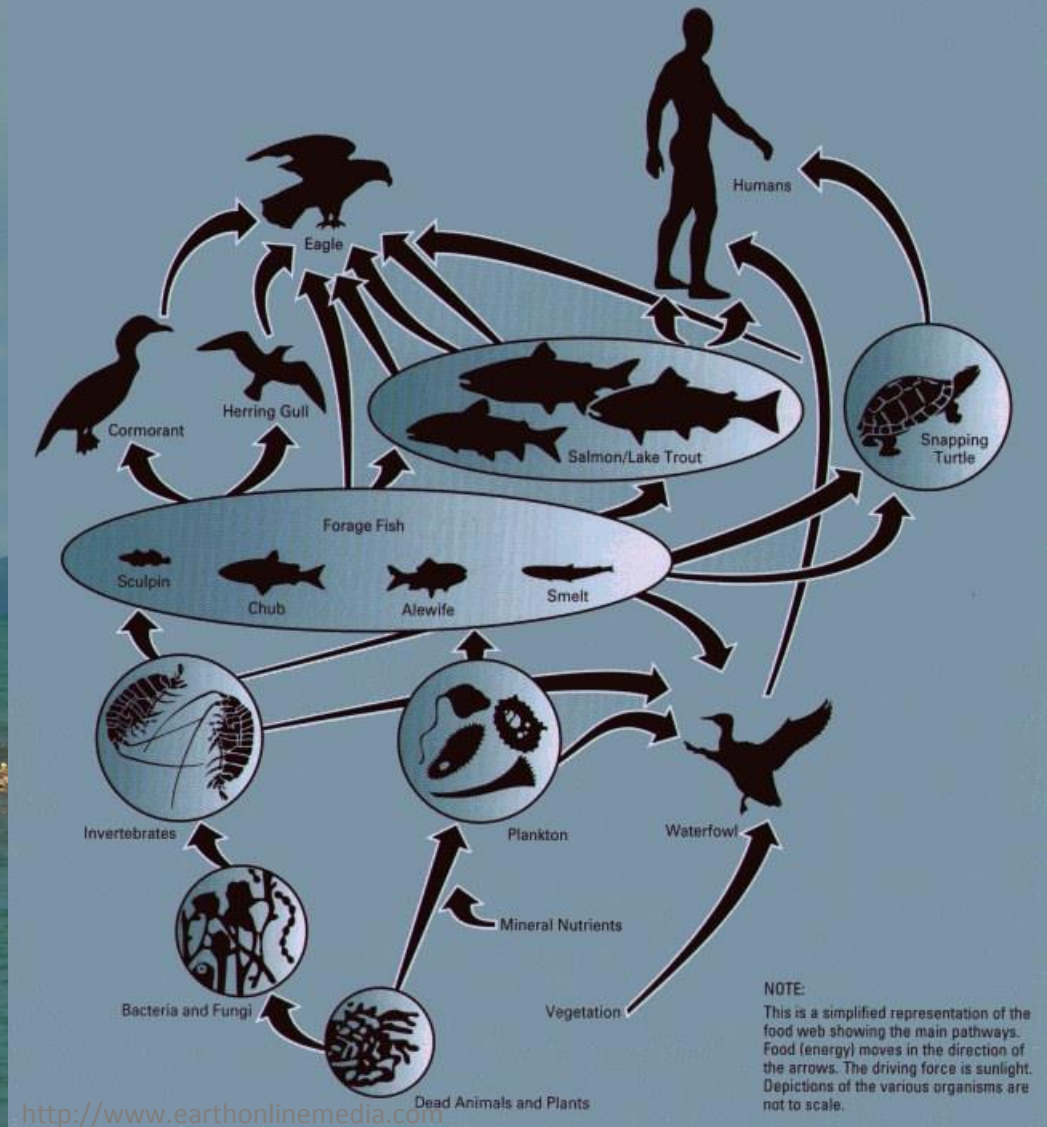
USFWS—Areas of Concern and Remediation and Restoration of Contaminated Sediments

Calvin College, Science Division

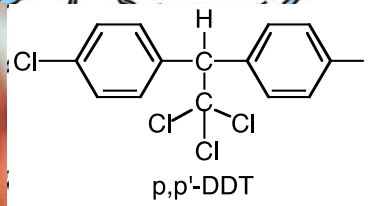
Fish-eating birds are excellent sentinel species for assessing and monitoring ecosystem health

- K-selected species
  - Long-lived
  - Low reproductive rates
  - Specialized niches
  - Slow population growth and recovery
- Top of food web makes them susceptible to ecosystem stressors
  - Disrupted energy flow
  - Natural toxins
  - Environmental contaminants

bioaccumulation & biomagnification



Eggshell Thinning



p,p'-DDT

Pesticide

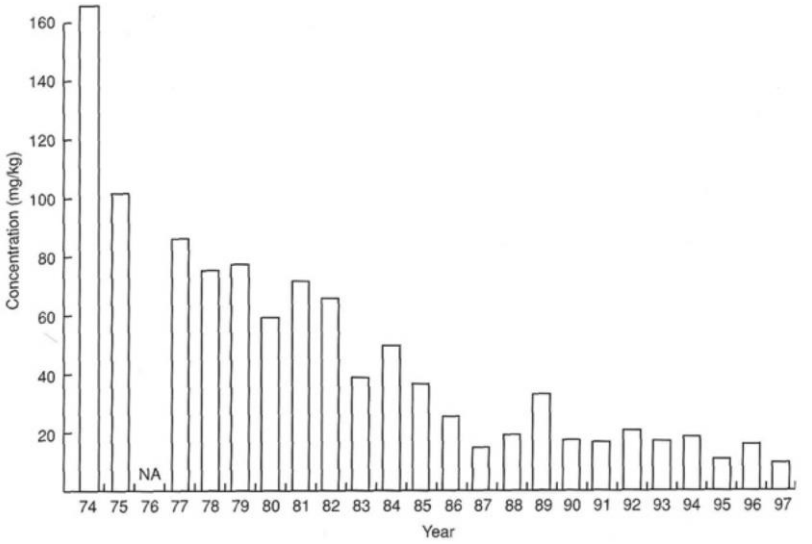
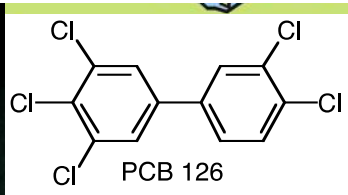


FIGURE 11.7 *Concentrations of PCB in eggs of herring gulls from Muggs Island/Leslie Spit colonies, Lake Ontario, 1974–97. Data supplied by Environment Canada.*

Embryonic Mortality and Deformities

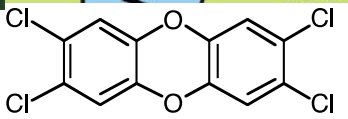


PCB 126

3,3',4,4',5-pentachlorobiphenyl

PCBs:

Electrical transformers
Industrial and hydraulic oils
Flame retardants (paints)
Microscope immersion oil



2,3,7,8-tetrachlorodibenzo-*p*-dioxin

Dioxins (TCDD):

Burning hazardous wastes & plastics
Bleaching paper
Production of chlorinated herbicides

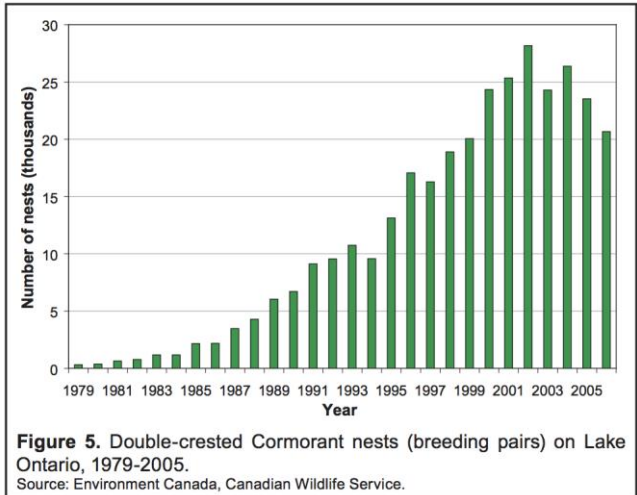


Figure 5. Double-crested Cormorant nests (breeding pairs) on Lake Ontario, 1979-2005.
Source: Environment Canada, Canadian Wildlife Service.

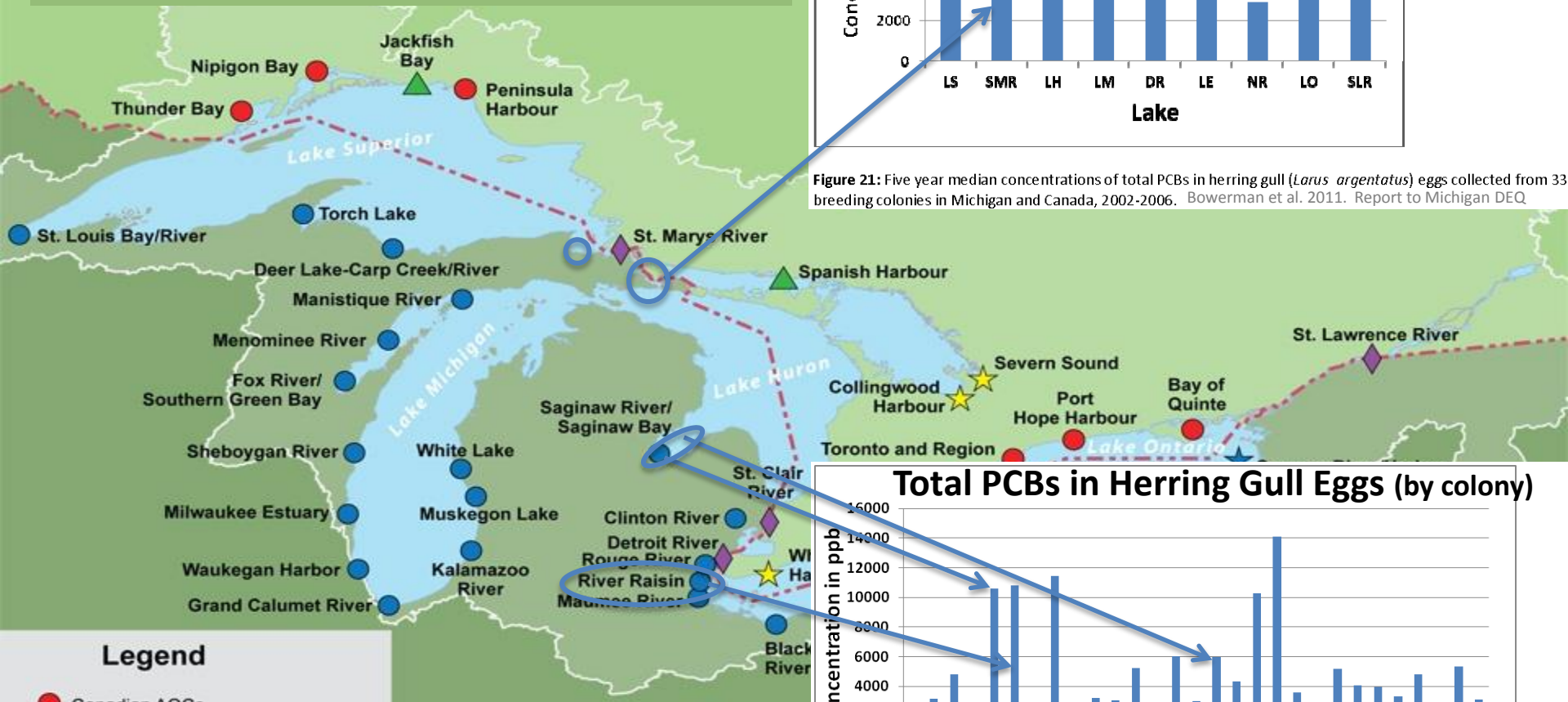
The Great Lakes Water Quality Agreement Defines Beneficial Use Impairments (BUIs) for AOCs and Lakes:

- Wildlife Populations
- Bird and Animal Reproduction and Deformities

This project is reassessing wildlife-related BUIs in colonial waterbirds in the Saginaw Bay and the River Raisin AOCs

Canadian and U.S.
in the Great Lakes–St.

This project is reassessing wildlife-related BUIs in colonial waterbirds in the Saginaw Bay and the River Raisin AOCs



Legend

- Canadian AOCs
- Delisted Canadian AOCs
- Canadian Areas in Recovery
- Binational AOCs
- U.S. AOCs
- Delisted U.S. AOC
- U.S. Area in Recovery

Total PCBs in Herring Gull Eggs (by lake)

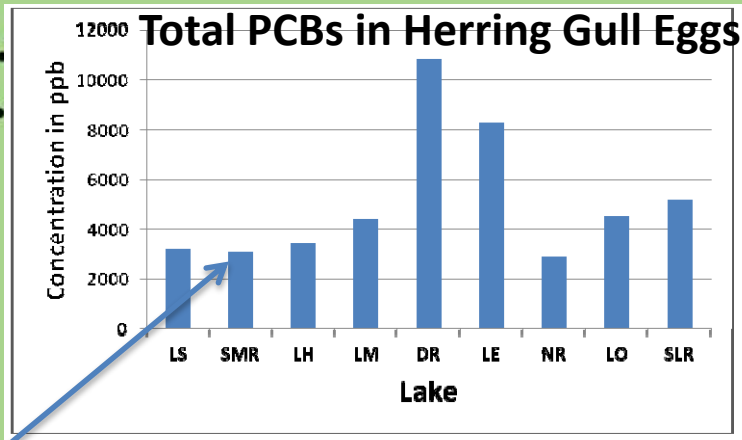


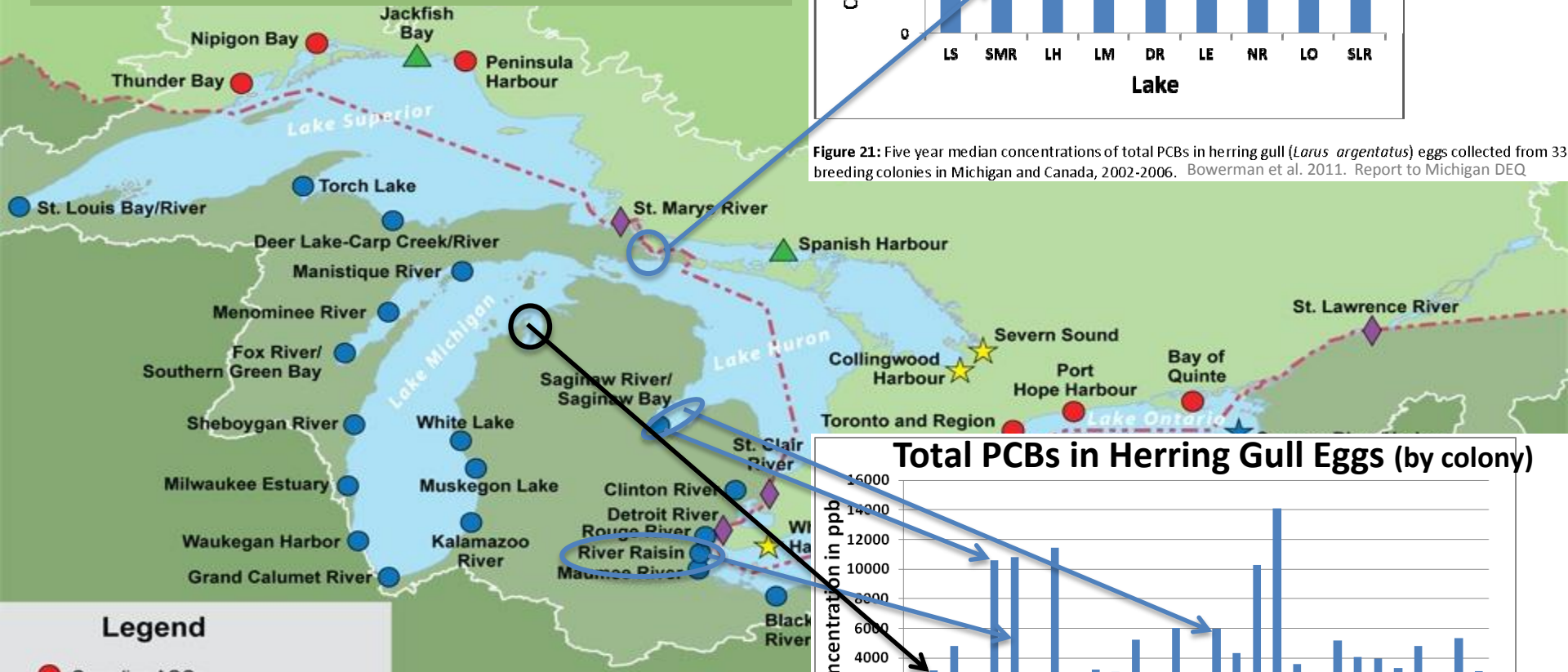
Figure 21: Five year median concentrations of total PCBs in herring gull (*Larus argentatus*) eggs collected from 33 breeding colonies in Michigan and Canada, 2002-2006. Bowerman et al. 2011. Report to Michigan DEQ

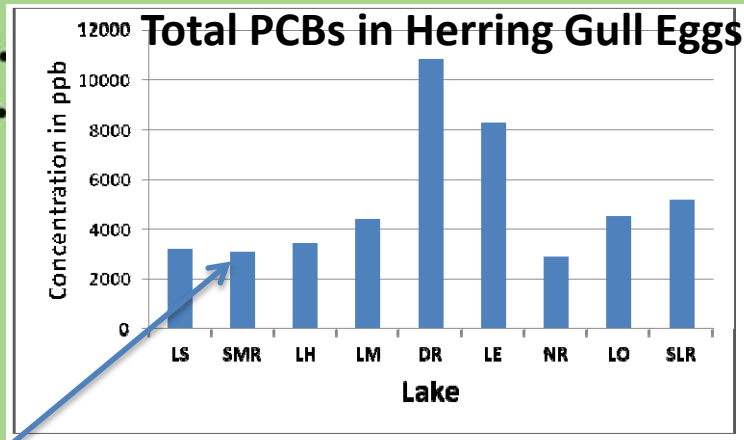
Total PCBs in Herring Gull Eggs (by colony)

Figure 16: Median concentrations of total PCBs in herring gull (*Larus argentatus*) eggs collected from 29 breeding colonies in Michigan and Canada, 2002-2006. Bowerman et al. 2011. Report to Michigan DEQ

Canadian and U.S. in the Great Lakes–St.

This project is assessing wildlife-related impairments in colonial waterbirds Grand Traverse Bay, which has a unique mixture of legacy contaminants





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Canadian and U.
in the Great Lakes–S

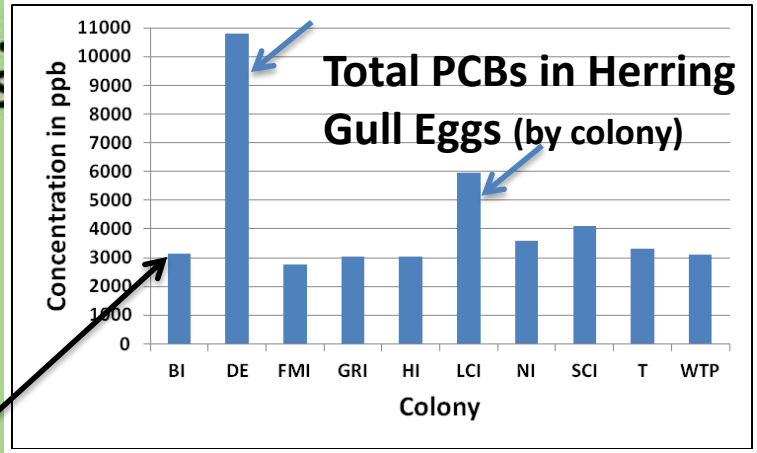


Figure 2: Five year median concentrations of total PCBs in herring gull (*Larus argentatus*) eggs collected from 10 breeding colonies in Michigan, 2002-2006. Bowerman et al. 2011. Report to Michigan DEQ

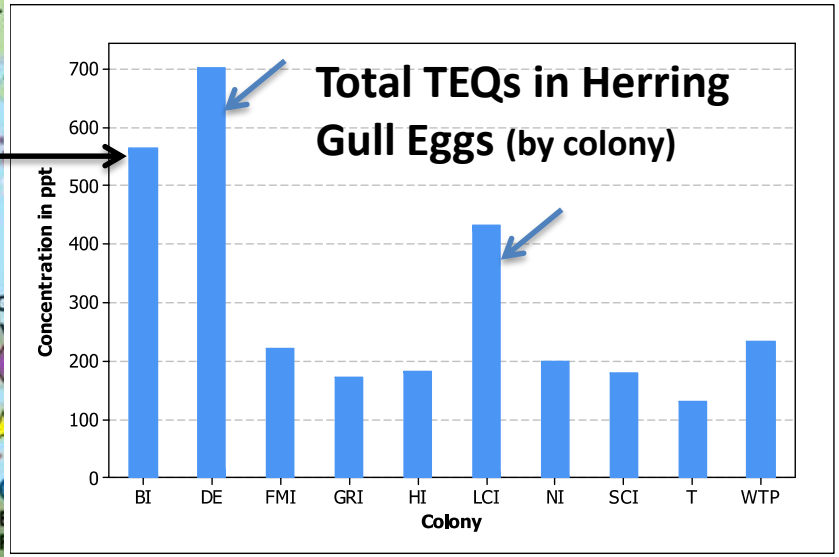
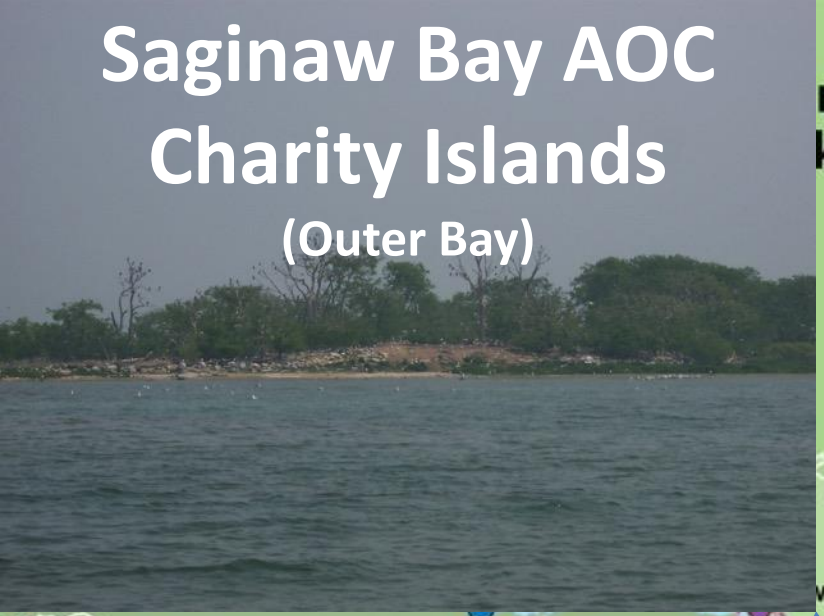


Figure 3: Five year median concentrations of TEQ in herring gull (*Larus argentatus*) eggs collected from 10 breeding colonies in Michigan, 2002-2006. Bowerman et al. 2011. Report to Michigan DEQ

This project is assessing wildlife-related impairments in colonial waterbirds Grand Traverse Bay, which has a unique mixture of legacy contaminants

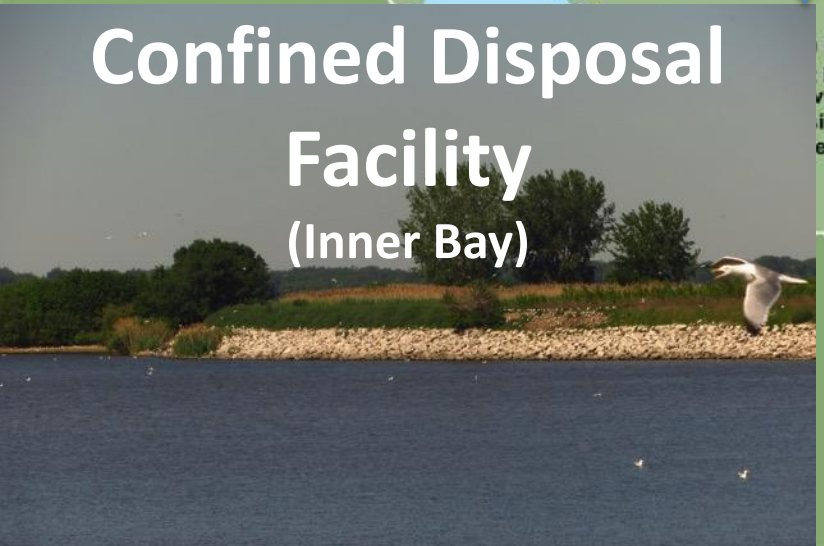
Saginaw Bay AOC Charity Islands

(Outer Bay)



Confined Disposal Facility

(Inner Bay)



River Raisin AOC
Monroe Power Plant

Canadian and U.S. Area in the Great Lakes–St. Law

Nipigon Bay
Jackfish Bay
Thunder Bay
Peninsula Harbour
Lake Superior
Torch Lake
St. Louis Bay/River
St. Marys River
Deer Lake-Carp Creek/River
Spanish Harbour
Manistique River
Menominee River
Lake Michigan
Fox River/ Southern Green Bay
Lake Huron
Saginaw River/ Saginaw Bay
Severn Sound
Collingwood Harbour
Port Hope Harbour
Bay of Quinte
St. Lawrence River
Sheboygan River
White Lake
Toronto a
St. Clair River
Milwaukee Estuary
Muskegon Lake
Clinton River
Detroit River
Rouge River
Wheatley Harbour
Waukegan Harbor
Kalamazoo River
River Raisin
Grand Calumet River
Cuyaho
Black River

U.S.

Legend

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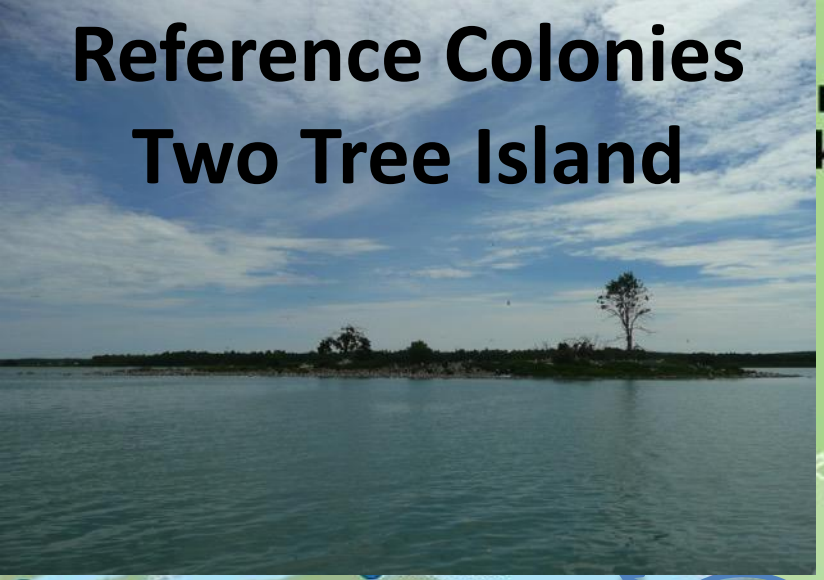
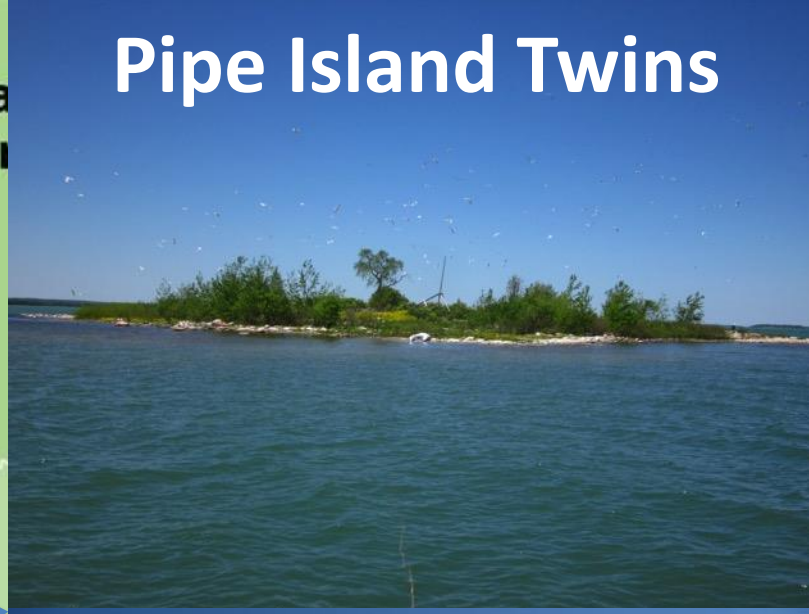
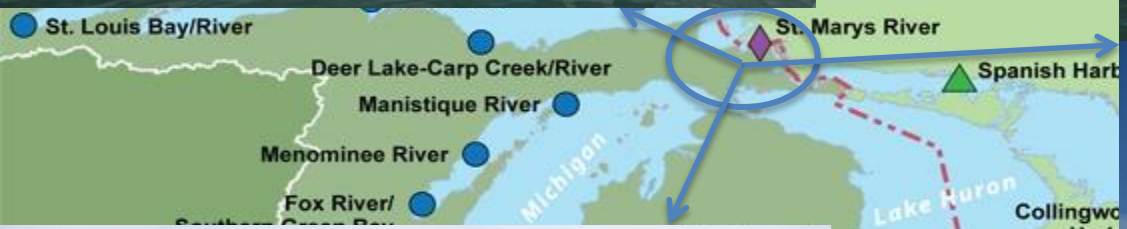
Reference Colonies
Two Tree Island



Pipe Island Twins





Tahquamenon Island

Grand Traverse Bay Bellow Island

nd U.S. Areas of Concern
kes–St. Lawrence River Basin

CANADA

Marys River
Spanish Harbour
Deer Lake-Carp Creek River
Manistique River
Menominee River
Fox River/
Southern Green Bay
Lake Michigan
Lake Huron
Saginaw River/
Saginaw Bay
Severn Sound
Collingwood
Harbour
Port
Hope Harbour
Bay of
Quinte
St. Lawrence River
Sheboygan River
White Lake
Toronto and Region
Lake Ontario
EighteenMile
Creek
Oswego River/Harbor
Rochester Embayment
St. Clair
River
Hamilton
Harbour
Milwaukee Estuary
Muskegon Lake
Clinton River
Niagara River
Detroit River
Rouge River
River Raisin
Maumee River
Wheatley
Harbour
Lake Erie
Buffalo River
Presque Isle Bay
Ashtabula River
Waukegan Harbor
Kalamazoo
River
Grand Calumet River
Cuyahoga River
Black
River

U.S.A.

0 200 400 Kilometres

Legend

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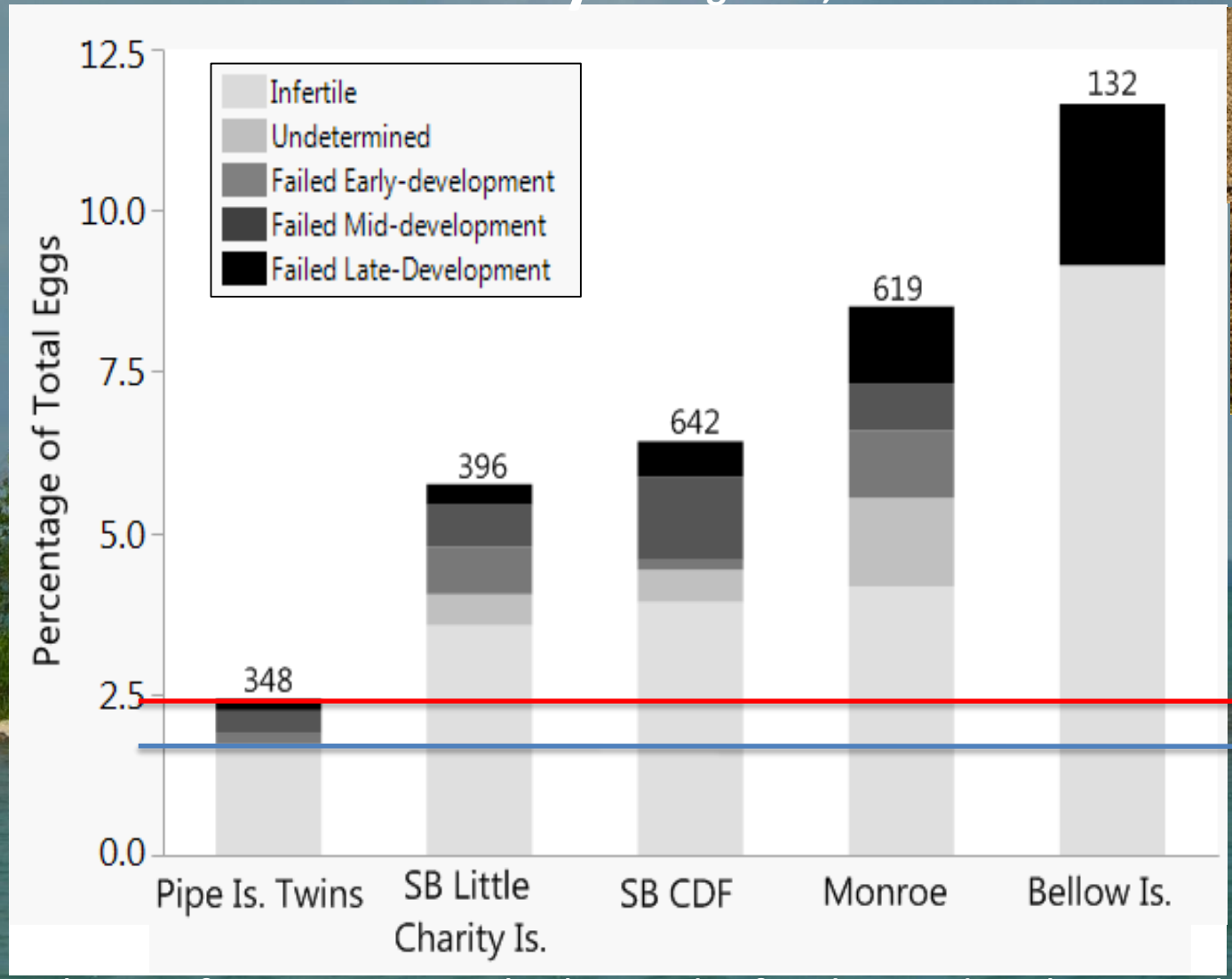
Study Objectives

- To investigate population-level effects associated with contaminants in Great Lake fish-eating birds by assessing breeding numbers and reproductive rates (e.g., embryonic mortality, deformities, productivity)
- To investigate immunological functions associated with potential population-level effects
- To investigate these endpoints in certain species (e.g., Caspian terns) whose conservation status is of special concern
- To compare effects endpoints measured in this study with contaminant concentrations in bird eggs

Embryonic Viability in Herring Gulls

- Herring gull nests marked during laying (1-2 of 3 eggs)
- Viability assessed at mid-late incubation (20-22 days later)
- Nonviable eggs opened to determine fertility, stage of failed development, and deformities

Embryonic Non-viability is Elevated in Herring Gulls at the Saginaw Bay and River Raisin AOCs and Grand Traverse Bay during 2010, 2012-17



Mostly infertile at reference site, with elevated infertility and embryonic death at AOCs

Embryonic Non-viability is Elevated in Herring Gulls at the Saginaw Bay and River Raisin AOCs and Grand Traverse Bay during 2010, 2012-17

Table 1. Relative risk ratios for incidence rates of embryonic nonviability, fertility, and failed development in herring gulls in the Saginaw Bay and River Raisin AOCs and Grand Traverse Bay compared to the reference site (Pipe Island Twins) during 2010-17.

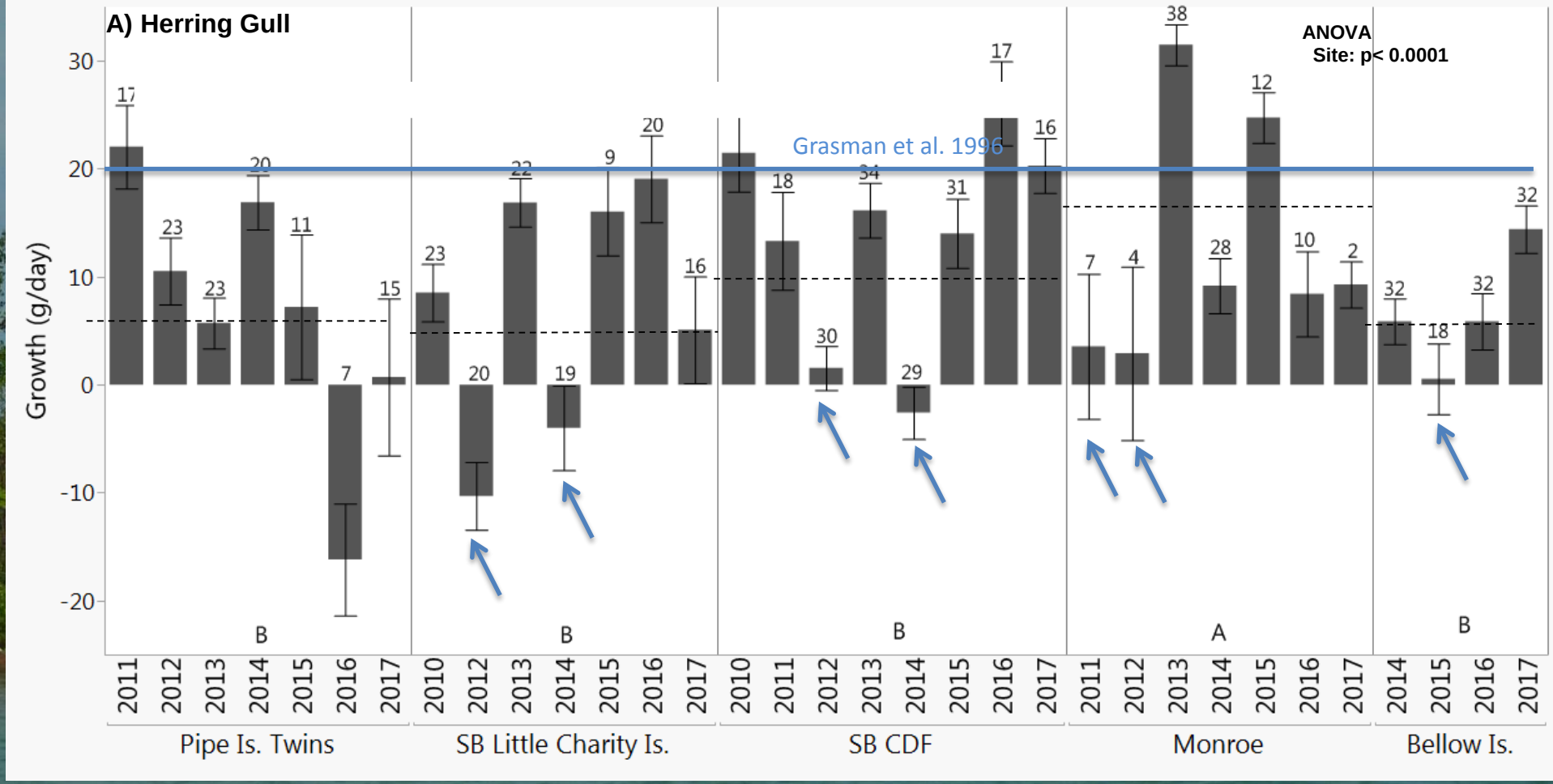
Location	**Relative Risk Ratio** (one way exact p-value)		
	Overall Nonviability	**Infertile**[a]	**Failed Development**[a]
All contaminated sites combined	**2.48 (0.0006)**	**2.47 (0.0053)**	**2.82 (0.012)**
Saginaw Bay AOC Both islands combined	**2.13 (0.0062)**	**2.25 (0.016)**	*2.26 (0.055)*
SB CDF	**2.12 (0.010)**	**2.09 (0.036)**	**2.44 (0.047)**
Little Charity Island	**2.16 (0.014)**	**2.51 (0.015)**	1.98 (0.13)
River Raisin AOC	**2.71 (0.0005)**	**2.41 (0.013)**	**3.67 (0.0034)**
Grand Traverse Bay (Bellow Island)	**4.07 (0.0001)**	**4.52 (0.0007)**	**3.30 (0.044)**

[a] includes undetermined eggs that were either infertile or early failed

Deformities Continue at AOCs

Cross-billed colonial waterbird chicks and embryos observed at AOCs during this study: herring gulls at Monroe in 2012 (A), 2013 (B), and 2016 (C); a Caspian tern on L. Charity Is. in 2016 (D); herring gull embryos on the SB CDF in 2016 (D) and L. Charity Is. in 2017 (E); and a cormorant on L. Charity Is. in 2017 (G).

Growth is Variable but Often Low in Herring Gull Chicks at AOCs and Grand Traverse Bay

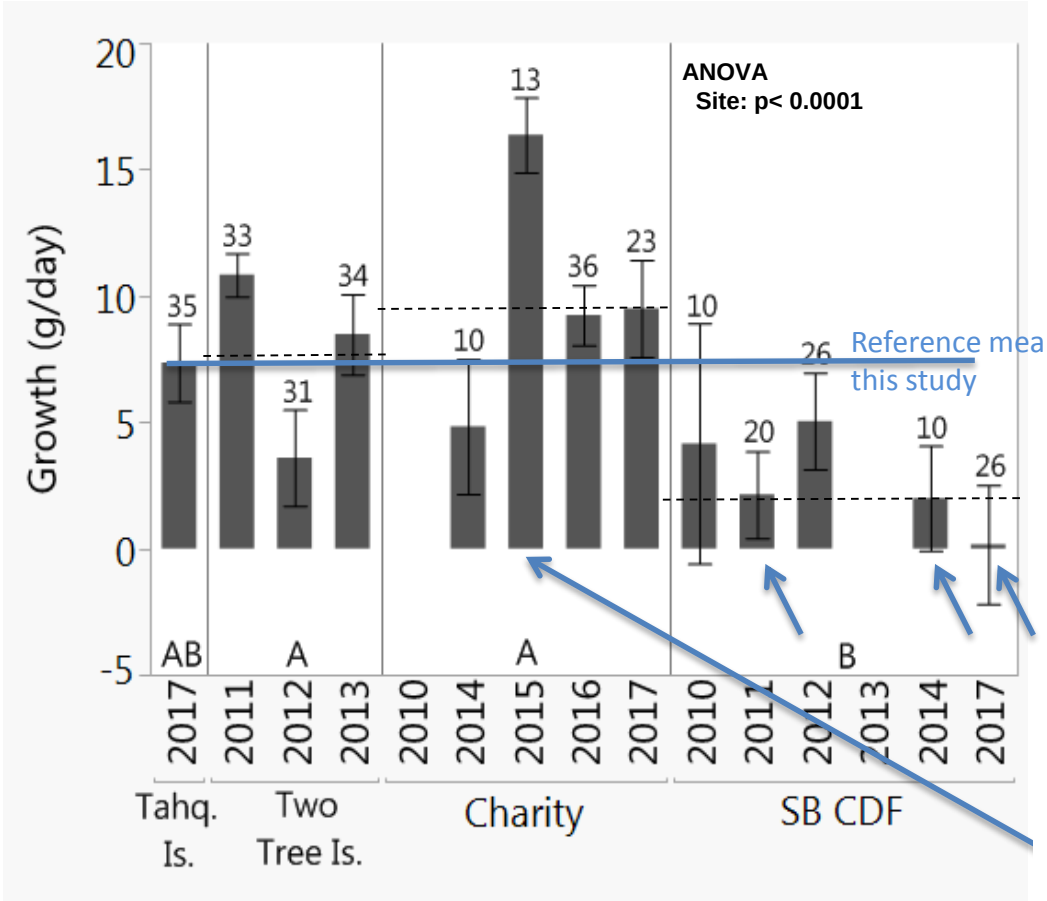


Black dotted lines indicate site means across years

Food supply is generally abundant in AOCs, possibly declining at St. Marys reference

(Saginaw Bay and western Lake Erie are highly productive ecosystems)

Growth is Variable but Often Low in Caspian Tern Chicks in SB AOC

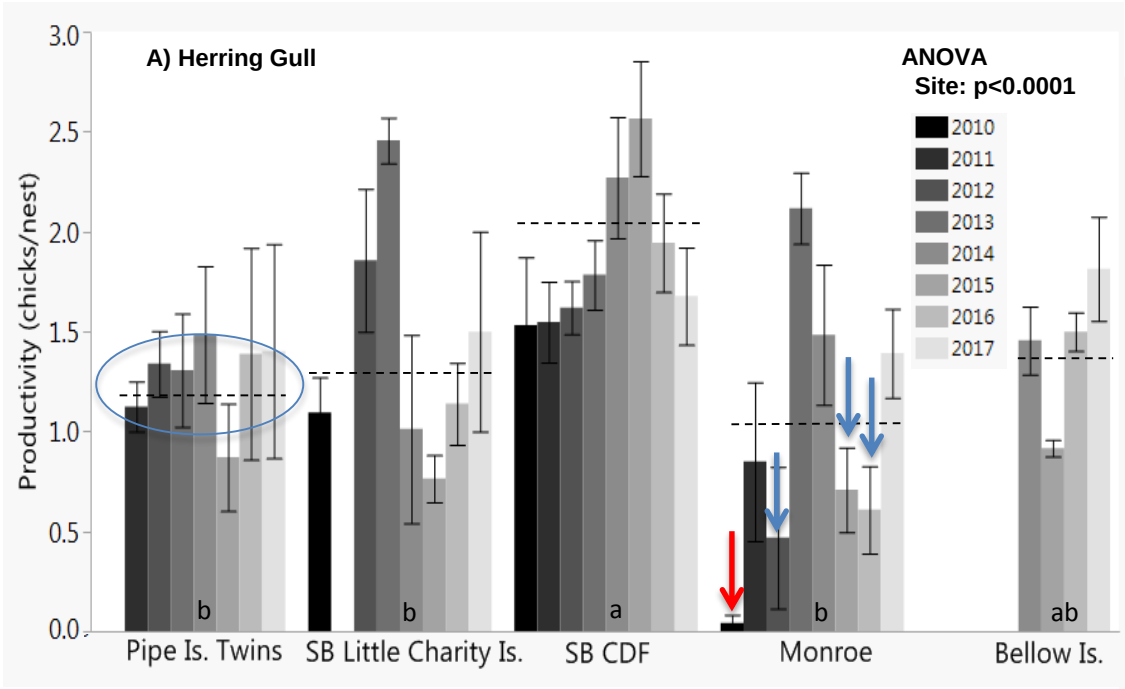


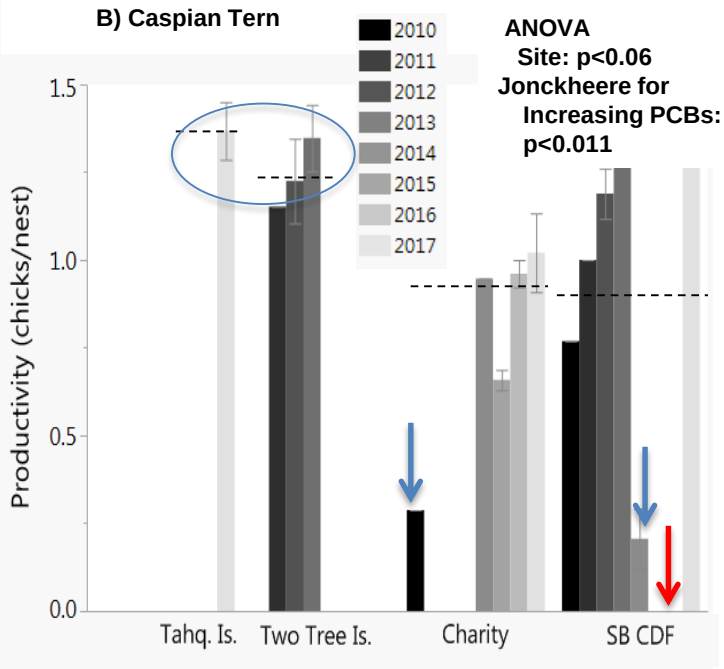
Interpret with caution (younger chicks than other groups because of re-nesting)

Black dotted lines indicate site means across years

Food supply is generally abundant in Saginaw Bay AOC

Overall Reproductive Success is Variable but Sometimes Very Low at AOCs





Indicates complete reproductive failure for the year

Black dotted lines indicate site means across years

Immunotoxicity of PCBs and Dioxins

- Many mechanisms of immunotoxicity
  - Thymic atrophy and suppressed T cell function
    - Acute, chronic, and developmental exposure
  - Altered antibody responses (often acute exposure)
  - Decreased/increased lymphocyte proliferation *in vitro*
  - The developing immune system is particularly sensitive

- Associated with increased infections:
  - Mallard ducklings challenged with duck hepatitis virus
  - Marine mammals--cetaceans and pinnipeds
  - Norwegian glaucous gulls--intestinal nematodes
  - Inuit children in northern Quebec--ear infections

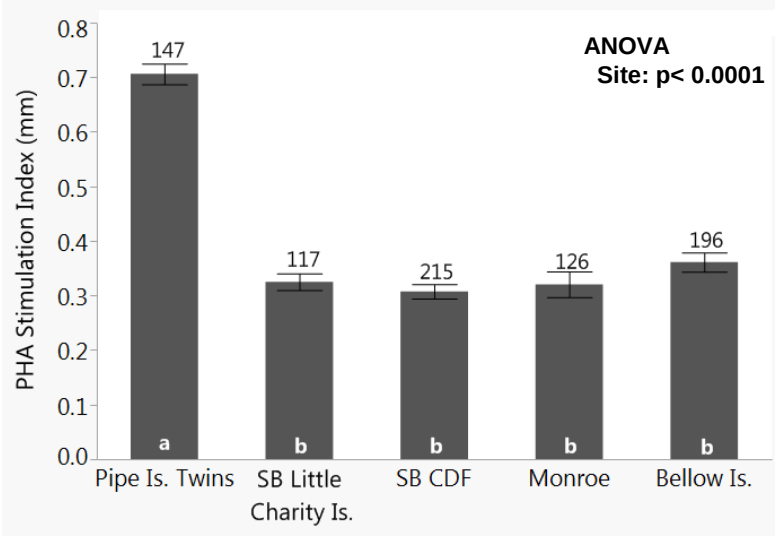
Phytohemagglutinin Skin Response

- Intradermal PHA causes a T cell-dependent inflammation in 12-48 h
- Integrates multiple T cell functions:
  - Proliferation, differentiation, cytokine, WBC infiltration
- Elimination of T cells with drugs or irradiation reduces the response by 50-60% in captive birds
- Similar to human tuberculin skin test
- One of the most common immune assays in avian immunotoxicology and immuno-ecology
  - Low response = low survival in wild birds

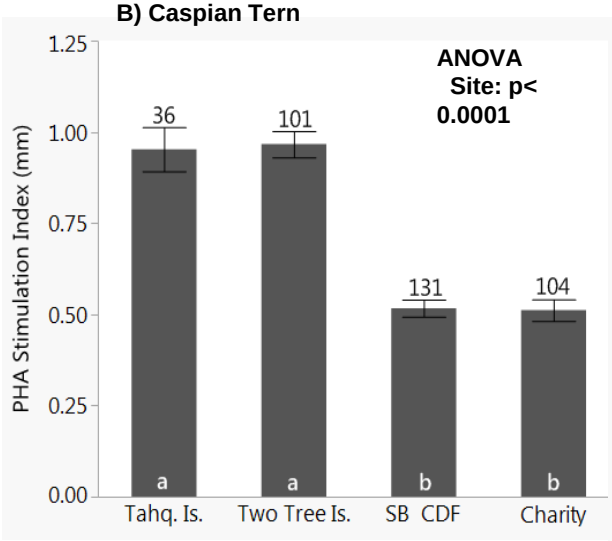
T Cell-Mediated Immunity is Severely Suppressed at both AOCs and in Grand Traverse Bay

including three species in Saginaw Bay

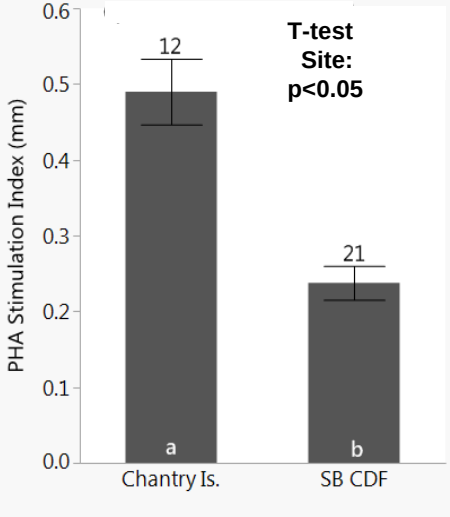
A) Herring Gull



B) Caspian Tern



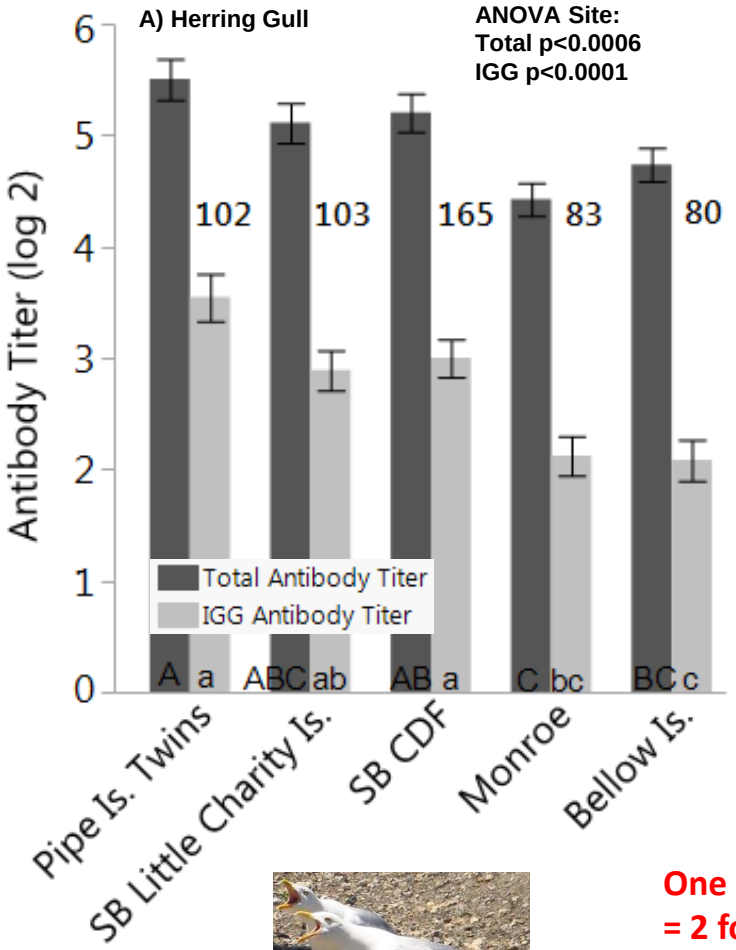
C) Black-Crowned Night Heron

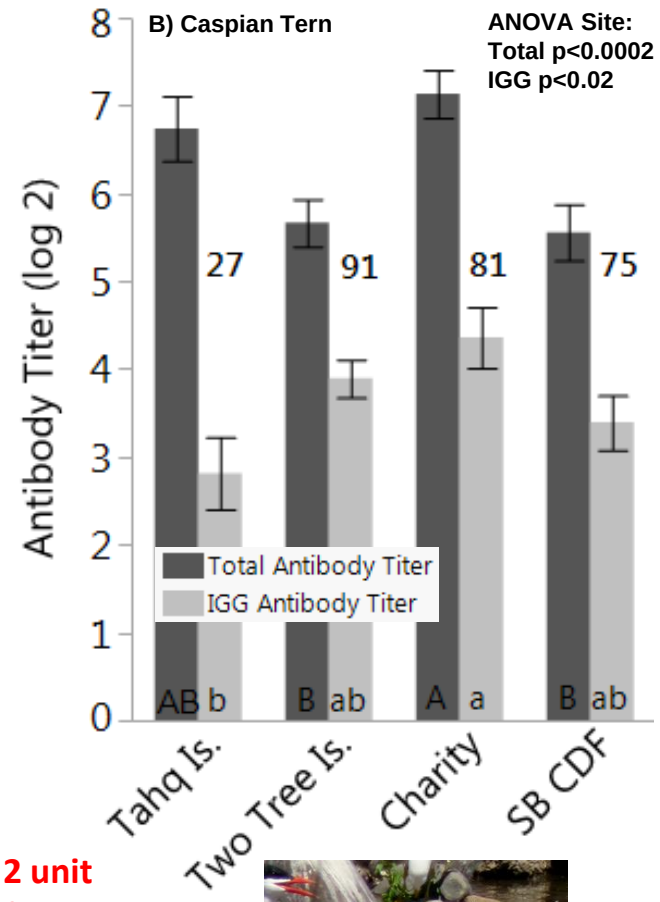


Anti-SRBC Antibody Response

- Immunization stimulates antibody titer measurable 6-7 days later
  - Similar to a flu vaccine
- Integrates multiple immune cell functions:
  - B lymphocytes, helper T lymphocytes, macrophages
- Easily adapted to wild species
- In laboratory rodents, the anti-SRBC antibody assay is one of several preferred screening assays for immunotoxicity
  - Sensitivity, integrative nature, & correspondence with other immune measures
- One of the most common immune assays in avian immunotoxicology

Anti-SRBC Antibody Response is Suppressed in Herring Gulls in the River Raisin AOC and Grand Traverse Bay





One Log 2 unit
= 2 fold change

Ecological Significance of a Suppressed Immune Response in Wild Birds

- 12 studies on immune response and subsequent survivorship (9 PHA)
  - "The relationship between immune response and survival accounted for 18.4% of the variance, while three other studies of potential predictors of survival (secondary sex characteristics and symmetry) only accounted for 1.4, 1.5 and 6% … Thus, immune response is by far the best predictor identified so far."
    (Moeller & Saino 2004, Oikos 104:299-344)

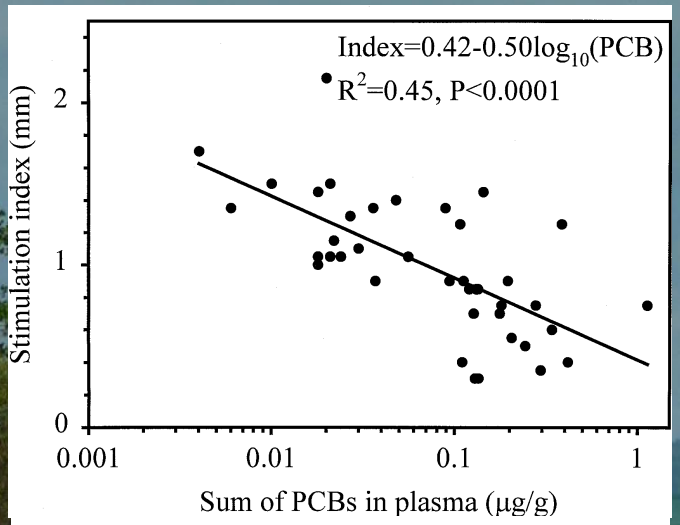
- Another meta-analysis concluded that higher PHA responses in nestlings increased the probability of establishing a new local population, presumably because a strong immune system helped fight novel diseases (Moeller & Cassey 2004, J Animal Ecol 73:1035-42)

Fixed effect	Parameter estimate	Standard error	*t* statistic
Life history			
Log_{10}(Body mass)	0·40	0·69	0·59
Log_{10}(Annual fecundity)	1·55	1·77	0·88
Ecology			
Habitat generalism	1·11	0·25	4·39**
Migratory habit	−0·40	0·33	−1·21
Sexual monochromatism	0·30	0·59	0·51
Introduction event			
Log_{10}(no. of propagules)	0·73	0·18	4·15**
Immune response			
Nestling T-cell response	0·75	0·40	1·88*
Adult T-cell response	2·96	4·35	0·68

*$P < 0·05$, **$P < 0·01$.

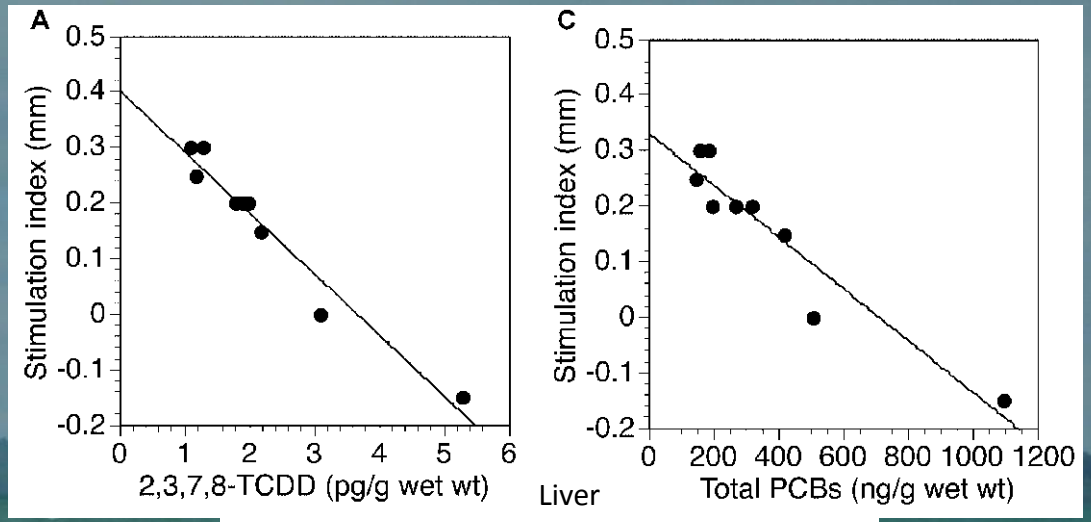
Discussion

- The observed reproductive and immune impairments are consistent with past studies showing associations with legacy pollutants (PCBs and dioxins)



Great Lakes Caspian Terns

Grasman &Fox 2001 Ecotoxicology 10:101-14



New York Harbor Herring Gulls

Grasman et al. 2013 ETC 32:548-61

- Another component of this study is examining contaminants of emerging concern (CECs) at these sites
- This study provides a set of assessment tools for work at other AOCs or contaminated sites with colonial waterbird colonies

Summary

Grand Traverse Bay

Herring gulls at Grand Traverse Bay, a site with high PCDDs and DDE, showed impairments in immunity and reproduction

- Elevated embryonic nonviability, including both infertility and failed development, in gulls
- Low growth rates
- Suppressed T cell-mediated immune response
- Suppressed total antibody and IgG responses

Saginaw Bay AOC

Herring gulls, Caspian terns, and black-crowned night herons exhibited health and reproductive impairments, consistent with past studies

- Embryonic nonviability, primarily infertility but also failed development, was elevated in gulls
- Terns had lower overall productivity in the AOC when compared to reference sites
- Growth of tern chicks was significantly lower on the SB CDF than the reference site
- Suppressed T cell-mediated immunity was demonstrated by herring gulls, Caspian terns, and black-crowned night herons

River Raisin AOC

Herring gulls exhibited health and reproductive impairments, consistent with past studies

- Embryonic nonviability, including both infertility and failed development, was elevated in gulls in the River Raisin AOC
- Complete reproductive failure in one year, and low chick productivity in three other years
- Low growth rates in gull chicks in 5 out of 7years
- Suppressed T cell-mediated immune response
- Suppressed total antibody and IgG responses

Acknowledgments

- Dave and Therese Best
  - USFWS (retired/volunteer)
  - Logistical support in field
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- Annette Trowbridge
  - USFWS Region 3
- Becky Hill, Emily Douglas, Yarrow Brown, and Jenee Rowe
  - Leelanau Conservancy (Bellow Is.)
- Kayla Maas, Lisa Haggerty, Atira Mabin
  - DTE Energy (Monroe Power Plant)
- Calvin Students
  - Rachel Abma
  - David Bouma
  - Sylvia Fuhrman
  - Amanda Harris
  - Stacy Hooker
  - Sarah Hughes
  - Monica Langeland
  - Dorthea Leisman
  - Alaina Mahn
  - Meagan Mc Rae
  - Alyssa Moore
  - Joe Singer
  - Will VanDenHeuvel
  - Jenna Van Bruggen
  - Rachel Warners