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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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

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

Dioxins (TCDD):
- Burning hazardous wastes & plastics
- Bleaching paper
- Production of chlorinated herbicides

Embryonic Mortality and Deformities

Pesticide

Figure 11.7: Concentrations of PCB in eggs of herring gulls from Maggs Island/Leslie Spit colonies, Lake Ontario, 1997. Data supplied by Environment Canada.

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.
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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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Saginaw Bay AOC
Charity Islands
(Outer Bay)

Confined Disposal Facility
(Inner Bay)
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.
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.

<table>
<thead>
<tr>
<th>Location</th>
<th>Relative Risk Ratio (one way exact p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall Nonviability</td>
</tr>
<tr>
<td>All contaminated sites combined</td>
<td>2.48 (0.0006)</td>
</tr>
<tr>
<td>Saginaw Bay AOC</td>
<td></td>
</tr>
<tr>
<td>Both islands combined</td>
<td>2.13 (0.0062)</td>
</tr>
<tr>
<td>SB CDF</td>
<td>2.12 (0.010)</td>
</tr>
<tr>
<td>Little Charity Island</td>
<td>2.16 (0.014)</td>
</tr>
<tr>
<td>River Raisin AOC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.71 (0.0005)</td>
</tr>
<tr>
<td>Grand Traverse Bay</td>
<td></td>
</tr>
<tr>
<td>(Bellow Island)</td>
<td>4.07 (0.0001)</td>
</tr>
</tbody>
</table>

<sup>a</sup> 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

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 immunology
  – 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

<table>
<thead>
<tr>
<th>Site</th>
<th>PHA Stimulation Index (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Is. Twins</td>
<td>147</td>
</tr>
<tr>
<td>SB Little Charity Is.</td>
<td>117</td>
</tr>
<tr>
<td>SB CDF</td>
<td>215</td>
</tr>
<tr>
<td>Monroe</td>
<td>126</td>
</tr>
<tr>
<td>Bellow Is.</td>
<td>196</td>
</tr>
</tbody>
</table>

ANOVA Site: p< 0.0001

B) Caspian Tern

<table>
<thead>
<tr>
<th>Site</th>
<th>PHA Stimulation Index (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tahq. Is.</td>
<td>36</td>
</tr>
<tr>
<td>Two Tree Is.</td>
<td>101</td>
</tr>
<tr>
<td>SB CDF</td>
<td>131</td>
</tr>
<tr>
<td>Charity</td>
<td>104</td>
</tr>
</tbody>
</table>

ANOVA Site: p< 0.0001

C) Black-Crowned Night Heron

<table>
<thead>
<tr>
<th>Site</th>
<th>PHA Stimulation Index (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chantry Is.</td>
<td>12</td>
</tr>
<tr>
<td>SB CDF</td>
<td>21</td>
</tr>
</tbody>
</table>

T-test Site: p<0.05
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

ANOVA Site:
Total p<0.0006
IGG p<0.0001

ANOVA Site:
Total p<0.0002
IGG p<0.02

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)
Discussion

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

• 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.

Great Lakes Caspian Terns
Grasman & Fox 2001 Ecotoxicology 10:101-14

New York Harbor Herring Gulls
Grasman et al. 2013 ETC 32:548-61
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 7 years
• Suppressed T cell-mediated immune response
• Suppressed total antibody and IgG responses
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