Sub-Indicator: Toxic Chemicals in Herring Gull Eggs

Note: There have been factors that have resulted in limited updates for the 2022 State of the Great Lakes Report. Between 2020 and 2022, data collection was greatly impacted by suspended operations throughout the COVID-19 pandemic. Since 2022, a more routine collection scheduled has resumed. As noted below, there is a gap in data from 2020 to 2022 and in some cases, the trend assessments may be impacted and need to be longer or shorter, as noted.

Overall Assessment

Status: Good

Trends:

10-Year Trend: (2013 – 2023): Unchanging

Long-term Trend (1974 – 2023): Improving

Rationale: The long-term trends (1974 to present) of virtually all legacy contaminants (Polychlorinated Biphenyls-PCBs, dioxins and furans, organochlorine pesticides-OCs) have declined substantially since the 1970s, mostly as exponential declines. Using the Wildlife Environmental Quality Index (WEQI) based solely upon legacy organics, contaminant concentrations in most colonies of Herring Gulls have also improved in this time frame. Using a WEQI based solely upon legacy organics (e.g. PCBs, sum dichlorodiphenyltrichloroethane [DDT], Dieldrin, Mirex, sum chlordane, heptachlor epoxide [HE], and octachlorostyrene [OCS]), contaminant concentrations in most colonies of Herring Gulls have generally improved from 2002 to 2023, with a few exceptions. The 10-year, shorter-term trends of legacy contaminants (PCBs, OCs, mercury) over the last decade are a mixture of a few significant declines and no significant changes. From 2013-2023, eleven colonies were unchanged, only two colonies improved, and the condition of one colony declined. Most of the WEQI scores were driven by PCBs in all lakes, with a smaller contribution from Dichlorodiphenyltrichloroethane (DDT).

Although a few select compounds did decrease in gull eggs in the Great Lakes from 2013-2023, generally the overall status was one of stasis, with only the St. Lawrence River indicating an overall reduction in contamination and improved environmental quality. Although long-term trends have indicated a first-order decline for legacy compounds, recent trends indicate that the observed concentrations are higher than predicted concentrations, suggesting a reduction in elimination rates. Given the missing data for most colonies in 2020 to 2022, 2013 to 2023 was used, despite representing an 11 year period, for the assessment of recent contaminant trends. Polybrominated diphenyl ethers (PBDEs) have generally not changed in the last decade, and have decreased at only one colony (Granite Island) from 2013 to 2023. Concentrations of the flame retardants Dechlorane Plus (DDC-CO) and Hexabromocyclododecane (HBCDD) have also declined in two and one colony, respectively, whereas polybrominated biphenyl (PBB) 101 increased at one colony. Perfluoroalkyl acids (PFAAs) are the class of chemicals that has shown the most declines since 2013, with 4 out of 11 colonies showing a reduction in concentrations.

From 2002 to 2023, the WEQI improved in 9 out of 14 colonies. On a watershed basis, the WEQI of all lakes except for Lake Erie and Niagara River improved during this time. Conversely, from 2013 to 2023, the WEQI improved for only 2 colonies; Snake Island (Lake Ontario) and Strachan (St. Lawrence River). The WEQI declined for one colony in Lake Michigan, albeit from 2013-2018, as no data post-2018 was available for that colony. Although some individual colonies improved from 2013-2023, no lake watershed improved during that period.

More specifically, since 2013, most legacy compounds were not declining as an exponential decay, but instead better fit with linear relationships, and with a few exceptions, most were not declining at all; out of 126 temporal

trends, only 19 (15.0%) had significant declines, and one increased. Hence, these were predominantly Unchanging trends. Hexachlorobenzene (HCB) had the most declines, with 5 out of 14 colonies with reductions in HCB concentrations. Dieldrin did not decline at any colony. Most of the declines were localized, with the St. Lawrence River (7 declines) and Lake Ontario (5 declines) with the most declines, thus representing 55% of all the significant relationships throughout the Great Lakes.

For halogenated flame retardants (HFRs); Dechlorane Plus (DDC-CO), HBCDD, polybrominated biphenyl (PBB) 101, and sum PBDEs), from 2008 to 2023, there were virtually no significant changes in concentrations, with two exceptions; DDC-CO decreased in Hamilton Harbour and PBB 101 increased in Toronto Harbour.

For PFAS (Perfluoroalkyl carboxylic acids [PFCAs], Perfluorosulfonic acids [PFSAs], and total PFAAs), from 2009 to 2023, PFAAs declined in 6 out of 14 comparisons, which mirrored PFSAs. PFCAs declined in 9 of 14 comparisons.

Lake-by-Lake Assessment

Lake Superior

Status: Good

10-Year Trend (2013 – 2023): Unchanging

Long-term Trend (1974 – 2023): Improving

Rationale: The traditional legacy contaminants (organochlorine pesticides, Sum PCBs, Hg and TCDD) have declined significantly in the long term (1974-2023), but the majority of the declines were in the 1990s and earlier. From 2013-2023, no legacy contaminants (PCBs, OC pesticides, Hg) changed in either colony in Lake Superior. PFAS declined in gull eggs from Agawa Rocks but not Granite Island. From 2013 to 2023, PBDEs and DDC-CO declined at one colony (Granite), but not at the other colony, whereas concentrations of PBB 101 and HBCDD did not change at any colony. The Wildlife Environmental Quality Index indicated no change from 2013 to 2023, regardless of colony in Lake Superior.

Lake Michigan

Status: Good

10-Year Trend (2013 – 2023): Unchanging

Long-term Trend (1974 – 2023): Improving

Rationale: The traditional legacy contaminants (organochlorine pesticides, Sum PCBs, Hg and TCDD) have declined significantly in the long term (1974-2023), but the majority of the declines were in the 1990s and earlier. From 2013-2023, no legacy contaminants (PCBs, OC pesticides, Hg) changed in either colony in Lake Michigan. PFAS did not decline in gull eggs from Gull Island, but due to the shorter timeline (since covid), no comparisons were done for Big Sister. DDC-CO declined at one colony (Big Sister) but not at the other colony, whereas concentrations of PBB 101, PBDEs and HBCDD did not change at either colony in Lake Michigan. The Wildlife Environmental Quality Index indicated no change from 2013 to 2019 for Gull Island, but did decrease for Big Sister Island.

Lake Huron

Status: Good

10-Year Trend (2013 – 2023): Unchanging

Long-term Trend (1974 – 2023): Improving

Rationale: The traditional legacy contaminants (organochlorine pesticides, Sum PCBs, Hg and TCDD) have declined significantly in the long-term (1974-2023), but the majority of the declines were in the 1990s and earlier. From 2013-2023, no legacy contaminants (PCBs, OC pesticides, Hg) changed in Lake Huron, except for a decline in HE and chlordane in eggs from Chantry Island. PFAS did not decline in gull eggs from any of the three colonies in Lake Huron. Concentrations of DDC-CO, PBB 101, PBDEs and HBCDD did not change at any colony in Lake Huron from 2013 to 2023. The Wildlife Environmental Quality Index indicated no change from 2013 to 2023, regardless of colony in Lake Huron.

Lake Erie

Status: Good

10-Year Trend (2013 – 2023): Unchanging

Long-term Trend (1974 – 2023): Improving

Rationale: The traditional legacy contaminants (organochlorine pesticides, Sum PCBs, Hg and TCDD) have declined significantly in the long term (1974-2023), but the majority of the declines were in the 1990s and earlier. From 2013-2023, HCB declined at both Middle and Port Colborne colonies, whereas OCS and PCBs declined as well at Port Colborne. PFAAs declined in gull eggs from Port Colborne but not Middle Island in Lake Erie. Concentrations of DDC-CO, PBB 101, PBDEs and HBCDD did not change at either colony in Lake Erie from 2013 to 2023. The Wildlife Environmental Quality Index indicated no change from 2013 to 2023, regardless of the colony in Lake Erie.

Lake Ontario (including the International Section of the St. Lawrence River)

Status: Good

10-Year Trend (2013 – 2023): Unchanging

Long-term Trend (1974 – 2023): Improving

Rationale: The traditional legacy contaminants (organochlorine pesticides, Sum PCBs, Hg and TCDD) have declined significantly in the long term (1974-2023), but the majority of the declines were in the 1990s and earlier. From 2013-2023, HCB, chlordane, OCS and PCBs declined at both Strachan Island and Snake Island, but not Toronto or Hamilton harbours, whereas mercury declined at only at Snake Island and HE and Mirex declined only at Strachan Island. PFAAs declined in gull eggs from Strachan and Snake islands, but no changes at Toronto or Hamilton harbours from 2013-2023. Few flame retardants changed over that time period; concentrations HBCDD declined at Snake Island, but PBB 101 increased at Toronto. While the Wildlife Environmental Quality Index indicated that Strachan and Snake islands improved from 2013 to 2023, it did not improve at either Toronto or Hamilton harbours.

Status Assessment Definitions

Good: The metrics show that the contaminant levels in fish-eating waterbirds eggs are meeting the ecosystem objectives/guidelines or they are otherwise in an acceptable condition.

Fair: The metrics show that the contaminant levels in fish-eating waterbirds eggs are not meeting the ecosystem objectives/guidelines, but they are exhibiting minimally acceptable conditions.

Poor: The metrics show that the contaminant levels in fish-eating waterbirds eggs are not displaying minimally

acceptable conditions and are severely impacted.

Undetermined: Data are not available or are insufficient to assess condition of the ecosystem components.

Trend Assessment Definitions

Improving: Statistically significant decreases in the concentrations of the plurality of contaminants (legacy and PFAS and HFRs).

Unchanging: No significant changes in the concentrations of the plurality of contaminants (legacy and PFAS and HFRs).

No Trend: Data are available for a 10-year or longer period but the trend is not statistically Improving or Deteriorating due to high variability in the data. No Trend is different from Unchanging (which would be used when the trend is not statistically significant and has low variability (i.e., stable)) and Undetermined (which would be reserved for cases where data availability is limited).

Deteriorating: Statistically significant increases in the concentrations of the plurality of contaminants (legacy and PFAS and HFRs).

Undetermined: Data are not available or are insufficient to assess the trend of contaminant levels in fish-eating waterbirds at this time.

Endpoints and/or Targets

Chemical levels and biological measures in colonial nesting waterbirds are not different from those from reference sites in Atlantic Canada or from the Prairies. The target is to see decreasing contaminant trends in the monitored chemicals.

Sub-Indicator Purpose

This sub-indicator will assess the current toxic chemical concentrations and trends in representative colonial waterbirds (gulls, terns, cormorants and/or herons) on the Great Lakes; infer and measure the impact of contaminants on the health (i.e. the physiology and breeding characteristics) of the waterbird populations; and assess ecological and physiological endpoints in representative colonial waterbirds on the Great Lakes. It can be used to describe temporal and spatial trends of bioavailable contaminants in representative biota throughout the Great Lakes; to infer the effectiveness of remedial actions related to the management of critical pollutants; and to document and describe the trends of chemicals of emerging concern.

Ecosystem Objective

Tracking progress of fish-eating colonial waterbirds on the Great Lakes toward an environmental condition in which there is no difference in contaminant levels and related biological endpoints between birds on and off the Great Lakes. As part of this sub-indicator, contaminant levels are also measured in Herring Gull eggs to ensure that levels continue to decline.

This sub-indicator best supports work towards General Objective #4 of the 2012 Great Lakes Water Quality

Agreement which states that the Waters of the Great Lakes should "be free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain."

Methods

This sub-indicator will report on annual concentrations of Polychlorinated Biphenyls (PCBs), organochlorine pesticides such as Dichlorodiphenyltrichloroethane (DDT) and related metabolites, other organic contaminants, and total mercury in Herring Gull (*Larus argentatus*) eggs, and were selected from 15 Environment and Climate Change Canada's Great Lakes Herring Gull Monitoring Program (GLHGMP) sites throughout the Great Lakes (U.S. and Canada). Niagara River was not used this time as there were fewer egg collections, due to difficulty in landing at the colony because water levels were too high to land on the island, followed by Covid-19 restrictions. The Niagara colony is expected to appear in subsequent reports.

The Wildlife Environmental Quality Index (WEQI) is developed to integrate multiple contaminants into a single index; currently only legacy compounds are included (see Table 1), but plans are to incorporate other chemicals of emerging concern (CECs), such as PFAS and PBDEs. WEQI is the same as index as the index formerly known as Wildlife Quality Index (WCQ) in the 2022 SOGL report, but in the peer-review process the name was changed (c.f. Hammond et al. 2024). The WEQI integrates the exceedance of guidelines in a biological sample by multiple contaminants *i*. This integration yields a single value, ranging from 0 to 100:

$$\mathrm{WEQI} = 100 - \frac{\sqrt{\mathrm{Scope}^2 + \mathrm{Amplitude}^2}}{1.414} \quad \ldots(1)$$

where 1.414 is a scaling constant that ensures the index value ranges between 0 and 100 when combining scope and amplitude components that also range from 0 to 100 (see Marvin et al., 2004; CCME, 2017 for details). The WEQI incorporates both Scope (proportion of contaminants that exceeded (N_{failed}) the number of measured contaminants (N_i)),

$$\mathrm{Scope} = 100 \times \frac{\mathrm{N_{failed}}}{\mathrm{N_i}} \quad \ldots(2)$$

and Amplitude (average size of contaminant exceedances),

$$\mathrm{Amplitude} = \frac{\overline{\mathrm{NC}}}{0.01\overline{\mathrm{NC}} + 0.01} \quad \ldots(3)$$

$\overline{NC}$ is the mean degree of non-compliance based on ratios of a contaminant's observed concentration with its guideline concentration

$$\overline{\mathrm{NC}} = \frac{\sum_i \frac{\text{Failed test value}_i}{\text{Guideline value}_i} - 1}{\mathrm{N_i}} \quad \ldots(4)$$

The WEQI, scope and amplitude were calculated for each colony in each study. The tissue residue concentrations from the New York Fish Flesh Criteria (Newell et al. 1987) were used as guideline values, which correspond to the

NOEL values for mortality, reproductive impairment, and organ damage for piscivorous wildlife (Table 1).

Discussion

Although there are Great Lakes wildlife species that are more sensitive to contaminants than Herring Gulls and colonial nesting waterbird species in general, there is no other species with a long-term dataset like the Herring Gull program. The Herring Gull egg contaminants dataset is the longest running continuous (annual) contaminants dataset for wildlife in the world. As contaminant levels continue to decline, the usefulness of the Herring Gull as a biological indicator species may lessen (due to its reduced sensitivity to low levels of contamination) but its value as a chemical indicator will remain and probably increase - as levels become harder and harder to measure in other media. It is an excellent accumulator tracker since many of the biological measures (e.g. immune function, thyroid status, P450 induction, etc.) are correlated with contaminant levels in their eggs. In other colonial waterbirds, there are similar correlations between contaminant levels in eggs and various biological measures. Contaminant levels in eggs of other colonial waterbirds are usually correlated with those in Herring Gulls. Adult Herring Gulls nest on all the Great Lakes and the connecting channels and remain on the Great Lakes year-round. Because their diet is primarily fish, they are an excellent terrestrially-nesting indicator of the aquatic community. The chemical related sub-indicators showing long-term trends of contaminants in biota provide valuable insight into the relative abundance of contaminants in the vicinity of fish and waterbird populations. They represent not just contaminants in water, but offer insight into how chemicals enter and move throughout the food web.

Status of Chemicals of Mutual Concern (CMCs)

The Parties to the GLWQA designated the first set of Chemicals of Mutual Concern in May 2016. For State of the Great Lakes reporting in 2025 and moving forward, the toxic chemical sub-indicators will support reporting on Chemicals of Mutual Concern (CMCs) in a more fulsome, consistent and transparent way. Information on additional chemicals of interest for the Great Lakes (not CMCs) is valuable for inclusion in the report and will be included in a separate section, as appropriate. For the 2025 report, the assessment is not based solely on CMCs but PCBs are a driver of the WEQI scores. PCBs are a designated Chemical of Mutual Concern and are a deleterious class of contaminant in the Great Lakes and can have negative effects on fish, wildlife and humans.

The following chemicals were identified as the first set of CMCs:

- Hexabromocyclododecane (HBCDD/HBCD)
- Long-Chain Perfluorinated carboxylic acids (LC-PFCAs)
- Mercury (Hg)
- Perfluorooctanoic acid (PFOA)
- Perfluorooctane sulfonate (PFOS)
- Polybrominated Diphenyl Ethers (PBDEs)
- Polychlorinated Biphenyls (PCBs)
- Short-Chain Chlorinated Paraffins (SCCPs)

Contaminant Burdens

Annual concentrations of legacy compounds, such as organochlorine pesticides, PCBs, PCDFs/PCDDs (annual analyses ceased in 2014), polybrominated diphenyl ethers and other brominated flame retardants and other

organic contaminants, and mercury and other metals are measured in Herring Gull eggs from 15 sites from the Great Lakes Herring Gull Monitoring Program (Figure 1). On a less routine basis, measurements perfluorinated sulfonates (PFSAs) and perfluorinated carboxylic acids (PFCAs) are also analyzed.

At all colonies of Herring Gulls monitored in the Great Lakes Herring Gull Monitoring Program (Environment and Climate Change Canada), concentrations of PCBs, PCDD/Fs and organochlorine pesticides have fallen dramatically since the 1970s (de Solla et al., 2016). The range in concentrations of PCBs (sum of 33 PCB congeners) in colonies monitored in both 1980 was between 17.4 and 69.6 µg/g, whereas by 2023 the concentrations ranged between 2.1 to 16.4 µg/g (Table 2). In general, trends in contaminant burdens followed an exponential decline from the 1970s to 2013, i.e., the rate of decline is proportional to concentrations (de Solla et al. 2016). Although generally the declines were consistent with a first order exponential decay model, the rates of decline in Persistent Organic Pollutants (POPs) in Herring Gull eggs were generally lower in later years, and for many colonies, concentrations have stabilized in the last few years. When all colonies were pooled, the mean half-lives for organochlorine pesticides ranged from 5.6 to 13.1 years with HCB having the shortest half-life and chlordane with the longest (Table 3). For PCBs, the half-lives ranged from 5.45 years (Chantry Island) to 17.1 years (Middle Island) with an average of 8.6 years across colonies (Table 4). However, there appears to be some deviation from an exponential decay, with concentrations in gull eggs generally higher than predicted in more recent years, suggesting the half-lives are longer than estimated (de Solla, per obs). Overall, lakes Erie and Huron, and St. Lawrence River had the longest half-lives for PCBs, whereas Niagara River and lakes Superior and Ontario had the shortest.

In terms of halogenated flame retardants (HFRs), PBDEs remain the dominant class, between 10 to 100 × higher than Dechlorane Plus, Polybrominated Biphenyl (101), or HBCDD (Table 5). Generally, concentrations of PBDEs in 2023 or 2019 were similar to those in 2008 (Table 6). The year 2019 was included as for some colonies (especially American colonies) where no data were available post covid. Concentrations of perfluorinated alkyl acids (PFAAs) in gull eggs were dominated by PFOS, which constituted ~ 98% of PFSAs, and were ~ 80% of the sum of PFAAs (Table 6). Overall, concentrations of the various contaminant classes in gull eggs throughout the Great Lakes were PCBs >> PBDEs ≈ PFAAs > DDE > Hg > non DDE organochlorine pesticides (Tables 2, 5, 6). Generally, contaminant burdens varied among the 15 GLHGMP colonies, with concentrations generally highest in colonies with substantial urban or industrial influences nearby or upstream. Overall, Herring Gull eggs from western Lake Erie (Middle Island), Toronto Harbour and Hamilton Harbour (Lake Ontario), and Green Bay (Channel Shelter Island) were the most contaminated for legacy POPs. Conversely, the colonies from northern Lake Huron and Lake Superior tended to be the least contaminated (Table 2).

Using the procedures initially developed for the derivation of the Canadian Water Quality Index (WQI) and then used for development of the Sediment Quality Index (SQI) as a means of summarizing data (Canadian Council of Ministers of the Environment, 2001; Grapentine et al., 2002), a wildlife environmental quality (WEQI) was calculated to examine temporal trends in overall contaminant exposure as an indicator of protection to piscivorous wildlife (Figure 2). This site-specific method combines individual contaminant data and calculates an integrated numerical score by incorporating counts of guideline exceedances (scope) and the magnitude of those exceedances (amplitude) for compounds of interest in a study area. Fish flesh criteria were selected as guidelines developed by Newell et al. (1987) which were designed to protect animals eating contaminated fish from adverse effects such as mortality, reproductive impairment, and organ damage. Using contaminant levels in eggs at each colony for each study year, an index was calculated using eight compounds for which guidelines are available and for which there was at least one exceedance. These compounds, with corresponding fish flesh criteria guidelines shown in brackets, are as follows: Sum PCBs (110 ng/g), total DDT (200 ng/g), dieldrin (120 ng/g), mirex (330 ng/g), sum chlordane (500 ng/g), heptachlor epoxide (200 ng/g), octachlorostyrene (20 ng/g), and TEQs based on concentrations of dioxins and furans (3 pg/g). Unlike the applicable uses of the WQI and SQI which provide an assessment of water and sediment quality as these relate to protection of aquatic life, the value of the WEQI

examines changes in exceedances of guidelines over time and thus assess temporal changes in the protection of piscivorous wildlife at a colony or Great Lake. Note that higher WEQI scores are associated with better conditions versus lower scores for where there are more and/or larger exceedances.

The WEQI generally improved at most colonies from 2002 to 2023, with a few exceptions. However, since 2013, WEQI did not improve at most colonies, and increased only at Snake Island (Lake Ontario) and Strachan Island (St. Lawrence River), and even declined at Big Sister (up to 2019; Lake Michigan; Table 7; Figure 2). Most of the WEQI was driven by PCBs in all lakes, with a smaller but roughly equal contribution of DDT.

These declines in legacy POPs are consistent with compounds whose production ceased in the 1970s; however, temporal trends for other compounds whose production continued in the 2000s or later show different trajectories. For example, PBDEs in Herring Gull eggs from 6 colonies generally showed rapid increases from 1982 to 2000 and then no further increasing trend from 2000 to 2006 (Gauthier et al. 2008). Using breakpoint analysis, levels of PBDEs and other HFRs appeared to increase and then decrease at some colonies from 2008-2023 (Vanderlipp et al., in prep.) When compared to those years that HFRs were added to the Annex A of the Stockholm Convention (penta- and octa- PBDEs 2009; Deca-BDE 2017; HBCDD 2013; Dechlorane Plus 2023; Figure 3), levels of these substances did decline at some colonies, but were not closely associated with the year of being added to the Annex (Vanderlipp et al., in prep). Despite decades of regulation under SC-POP, herring gulls continue to be exposed to HFRs, from ongoing sources such as stockpiles, discarded products, and/or re-release from environmental reservoirs. When trends of PBDEs and HBCDD in gull eggs from Snake Island (Lake Ontario) were compared to those in lake trout, precipitation and air, for some compounds trends were similar (e.g. PBDE 47, PBDE 99), but had opposite trends for others (e.g. HBCDD; Li et al. 2023; Figure 4).

Assessment of Health of Colonial Waterbirds

The health of colonial waterbirds, particularly in relation to contaminant burdens or exposure, has been assessed at a number of colonies, primarily in Areas of Concern (AOCs). Contaminant burdens were examined in eggs of Herring Gulls and Double-Crested Cormorants (*Phalacrocorax auritius*) collected from colonies in the vicinity of the Spanish Harbour AOC in Recovery (Lake Huron) and compared to reference colonies in 2011 and 2012. Concentrations of TCDD, PCBs, and mercury, were low in eggs and were not notably elevated in the Area in Recovery (AiR) relative to the reference colonies, and were considered to be below those associated with adverse effects on reproduction. Recent egg burdens appeared to be markedly lower relative to concentrations measured in earlier time periods (Hughes et al. 2014a). Similarly, reproduction and development were examined in Herring Gulls and Common Terns (*Sterna hirundo*) breeding within the St. Marys River Area of Concern (Lake Huron) in 2011 and 2012. Freshly-laid eggs were collected from colonies within the AOC and from reference sites were artificially incubated in the laboratory and assessed for embryonic viability, incidence of embryonic deformities, contaminant burdens and other biochemical endpoints. Overall, embryonic viability of Herring Gulls and Common Terns was high at AOC colonies. Frequencies of embryonic deformities were comparable between AOC colonies and reference colonies for both species, were not associated with exposure to dioxin-like PCBs and dioxins, which did not differ between AOC and reference sites. Contaminants were not sufficiently elevated in embryos to adversely impact the reproductive success and development of Herring Gulls and Common Terns foraging in the St. Marys River AOC (Hughes et al. 2014b).

Breeding success of the Black-crowned Night-Heron (*Nycticorax nycticorax*) was examined at a colony on Turkey Island in the Detroit River Area of Concern (AOC) and an upstream non-AOC reference colony on Georgian Bay in 2009 and 2011. Breeding success was lower in Night-Herons from the AOC compared to the reference colony in both study years; at the AOC colony in 2009, productivity was below a range of thresholds considered to be typical for a stable population. Despite higher concentrations found overall at the AOC colony, concentrations of PCBs, other organochlorines and PBDEs in eggs and liver of nestlings were below concentrations associated with

adverse reproductive effects. Mercury concentrations in eggs and livers of nestlings from the AOC colony were comparable to concentrations at the reference colony and were below those associated with adverse reproductive effects. Reduced breeding success in 2009 was likely not due to elevated concentrations of contaminants historically associated with the AOC, but likely to other stressors, such as predation, weather and disturbance. At both colonies, concentrations of DDT, PCBs and mercury in eggs and nestling livers exceeded tissue residue guidelines (Hughes et al. 2013).

Concentrations of PFOS were generally higher (Figure 5) than those associated with the Lowest Observed Adverse Effects Level (LOAEL) of PFOS for reduced hatchability in white leghorn chicken embryos (100 ng/g; Molina et al. 2006), although that threshold should be viewed with significant caution. Most concentrations in eggs were below the draft Canadian Federal Environmental Quality Guideline (1900 ng/g) for PFOS; only a single year did the average PFOS levels exceed this threshold (Hamilton Harbour, Lake Ontario, 2016; Figure 5).

Other Chemicals of Interest

Variable DNA microsatellites were used to screen for mutations in Double-Crested Cormorants (*Phalacrocorax auritus*) families from two colonies in Hamilton Harbour AOC (Lake Ontario) and Mohawk Island (Lake Erie). Microsatellite mutation rates were 6 times higher at the Hamilton Harbour site closest to the industrial sources of Polycyclic Aromatic Hydrocarbons (PAHs) than the other Hamilton Harbour site, and both were higher than the reference colony (King et al. 2014). A Phase I metabolite of the PAH benzo[a]pyrene was identified in bile and liver from Hamilton Harbour cormorant chicks suggesting that these cormorants are exposed to and metabolizing PAHs, highlighting their potential to have caused the observed mutations (King et al. 2014).

The health of Herring Gulls is also being assessed at Thunder Bay (Lake Superior) and Hamilton Harbour AOCs. Periodic measurements are made of biological features of gulls and other colonial waterbirds known to be directly or indirectly impacted by contaminants and other stressors. These include (but are not limited to): clutch size, eggshell thickness, hatching and fledging success, size and trends in breeding population, various physiological biomarkers including vitamin A, immune and thyroid function, stress (corticosterone) and growth hormone levels, liver enzyme induction, PAH levels in bile and porphyrins and genetic and chromosomal abnormalities. Additional monitoring considerations include: tracking porphyria, vitamin A deficiencies, and the evaluation of avian immune systems. Chemical burdens in eggs of colonial nesting waterbirds are assessed for temporal trends, and are compared to suitable reference sites.

Linkages

There are many linkages between the Toxic Chemicals in Great Lakes Herring Gull Eggs sub-indicator and many other sub-indicators within the Great Lakes reporting suite. There is a link between Fish-Eating and Colonial Nesting Waterbirds and Toxic Chemicals in Whole Fish. Fish and gull eggs have shown similar trends in mercury both among lakes and within basins within each lake (McGoldrick et al., 2018; Blukacz-Richards et al, 2017).

There are also links to the Lake Sturgeon, Lake Trout and Native Preyfish Diversity sub-indicators. Changes in fish productivity of the Great Lakes have been reflected in fish-eating birds (Paterson et al. 2014); temporal changes in the energy density of forage fish eggs are reflected in those of both top predator fish (Lake Trout) and a fish-eating bird (Herring Gulls).

A link has also been shown by Dr. Craig Hebert between contaminant levels in Herring Gull eggs and winter severity. Hebert et al (2020) demonstrated that energy density in gull eggs, determined as lipid content, not only varies among colonies, but is declining at some colonies in the Great Lakes. Alterations in lipid content in the eggs may influence the concentrations of contaminants in the eggs. Some of the changes in energy density was

correlated with winter severity (Hebert et al. 2020); further, in more northernly colonies, colder winters was correlated with higher contaminant burdens in gull eggs (Hebert, 1998). Inferences on the effects of long term changes in environmental conditions (e.g., air temperature, water temperature, precipitation) on the accumulation of contaminants in aquatic biota are beyond the scope of this sub-indicator as they would have to include changing food webs and energy cycling though them.

There is a direct link between Herring Gull contaminants and endocrine disruption.

In terms of the health of Great Lakes fish-eating birds, there is also a link between Herring Gulls and both botulism outbreaks and the occurrence of fish diseases.

Assessing Data Quality

Data Characteristics	Agree	Neutral or Unknown	Disagree	Not Applicable
Data are documented, validated, or quality-assured by a recognized agency or organization	X			
Data are from a known, reliable and respected generator of data and are traceable to original sources	X			
Geographic coverage and scale of data are appropriate to the Great Lakes Basin	X			
Data obtained from sources within the U.S. are comparable to those from Canada	X			
Uncertainty and variability in the data are documented and within acceptable limits for this sub-indicator report	X			
Data used in assessment are openly available and accessible	No			

Data Limitations

Herring Gull eggs have been collected annually on all 5 lakes and connecting channels since 1974 (de Solla et al. 2016) and are highly tolerant of persistent contamination and may underestimate biological effects occurring in other less monitored, more sensitive species.

Some adult Herring Gulls from the upper Lakes, especially Lake Superior, move to the lower Lakes, especially Lake Michigan, during harsh winters. This has the potential to confound the contaminant profile of a bird from the upper lakes. Most of the gull's time is still spent on its home lake and this has not been noted as a serious limitation up to this point. Using contaminant accumulation by young, flightless gulls would eliminate this problem, but their contaminant levels and effects would be less due to lower contaminant exposure/intake.

It is difficult to show consistent differences in biological effects among colony sites within the Great Lakes. This is probably due to the great overall reduction in contaminant levels as well as the lessening in differences among

Great Lakes sites. The comparisons which show the greatest differences for biological effects of contaminants are between sites on and off the Great Lakes.

At one GLHGMP site (Detroit River), Herring Gulls no longer breed. The only colonial waterbird at that site is currently Double-Crested Cormorants. Two other colonies – Toronto and Niagara River, are precariously small, but Cormorants are present at those colonies as well. Currently at those and other sites, Cormorant eggs are being collected to allow for continual monitoring of contaminants. At some sites, there may be a switch to Cormorants for long term monitoring (i.e. Detroit River), and for others the Cormorants will be assessed only for short term to aid in inter species comparisons. Having both species as long-term monitors may be prohibitively expensive, so the use of Cormorants will be limited in the long term. Currently the differences in PCB accumulation are being evaluated on gulls and cormorants at the same colonies (Hammond et al, in review), which will aid in the interpretation of these two species; a migratory obligate piscivore (Cormorant) vs a nonmigratory facultative piscivore (Gull).

Additional Information

Historical data on levels of chemical contamination in gull eggs are available, on an annual basis, for most sites in both the Canadian and U.S. Great Lakes dating back to the early 1970s. An immense database of chemical levels and biological measures from the Great Lakes, as well as many off-lake sites, is available from the Wildlife and Landscape Science Directorate at Environment and Climate Change Canada. Data on temporal trends, portrayed as annual contaminant levels over time, for 1974-present in most instances, are available for each site and each chemical compound. For example, DDE, from 1974-2023, is available for Toronto Harbour and could be displayed graphically. Geographical patterns in contaminant levels, showing all sites relative to one another, are also available for most years from 1974-present and for most chemical compounds.

The bioavailability of POPs, and thus exposure to wildlife is not simply a function of the concentrations found in environmental matrices such as water, soil or sediment, but varies considerably with the myriad of factors that control the transport and fate of contaminants. Measurements of body burdens in waterbirds integrate the net effect of factors such as bioavailability, temperature, growth rates, food chain dynamics, and chemical partitioning behaviour. One of the advantages of using colonial waterbirds as indicators is that their rates of elimination of body burdens for POPs are generally much faster than the rates of environmental degradation; hence changes in body burdens reflect changes in the bioavailability of POPs.

Degradation half-lives in sediment of the PCB congeners typically found in Herring Gull eggs range between 10 to 19 years in sediment (Sinkkonen and Paasivirta 2000). Conversely, the half-life of *p*,*p*'-DDE in Herring Gulls was estimated to be 264 days (Norstrom et al. 1986), with half-lives for PCBs likely to be similar. The half-lives of PCBs fed to ring doves ranged from 7 to 53 days (Drouillard and Norstrom 2001). Hence, Herring Gulls respond faster to inputs of POPs through their diet than the degradation rate of POPs in the general environment. Although there were dramatic declines in contaminant burdens of legacy POPs in Herring Gull eggs from the 1970s to 2013, not all of the changes in egg burdens were due solely to the elimination of the contaminants in the environment. Changes in food web components affect dietary exposure and hence body burdens of POPs in wildlife. By using ecological tracers, Hebert and Weseloh (2006) found that not only did Herring Gull diets and trophic level change at many Great Lakes colonies between 1974 and 2003, but when the effect of changing trophic level was removed, the rates of contaminant declines were reduced. Hence, a proportion of the declines were due to reductions in dietary exposure from feeding at lower trophic levels.

Also, contaminant concentrations in most colonially-nesting, fish-eating birds are at levels where gross ecological effects, such as eggshell thinning, reduced hatching and fledging success, and population declines, are no longer apparent. Greater reliance for detecting biological effects of contaminants is being put upon physiological and

genetic biomarkers.

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References

Blukacz-Richards, EA, Visha A, Graham ML, McGoldrick DL, de Solla SR, Moore DJ, Arhonditsis GB. 2017. Mercury levels in herring gulls and fish: 43 years of spatio-temporal trends in the Great Lakes. Chemosphere 172: 476-487.

CCME (Canadian Council of Ministers for the Environment), 2001. Canadian water quality guidelines for the protection of aquatic life: Canadian water quality index 1.0 technical report. In: Canadian Environmental Quality Guidelines. Winnipeg, Manitoba.

de Solla SR, Weseloh DVC, Hughes KD, Moore DJ. 2016. 40 year decline of organic contaminants in eggs of herring gulls (*Larus argentatus*) from the great lakes, 1974 to 2013. Waterbirds 39: 171-180.

Drouillard KG ,Norstrom RJ. 2001. Quantifying maternal and dietary sources of 2,2',4,4',5,5'-hexachlorobiphenyl deposited in eggs of the ring dove. Environ. Toxicol. Chem. 20: 561-567.

Environment and Climate Change Canada, unpublished data.

Gauthier LT, Hebert CE, Weseloh DVC, Letcher RJ. 2008. Dramatic changes in the temporal trends of polybrominated diphenyl ethers (PBDEs) in herring gull eggs from the Laurentian Great Lakes: 1982–2006. Environ. Sci. Technol. 42(5): 1524-1530.

Grapentine L, Marvin C, Painter S. 2002. Initial development and evaluation of a sediment quality index for the Great Lakes region. Human & Ecological Risk Assessment 8(7): 1549–1567.

Hammond MP, de Solla SR, Hughes KD, Bohannon MEB, Drouillard KG, Barrett GC, Bowerman WW. 2024. Legacy contaminant trends in the Great Lakes uncovered by the wildlife environmental quality index. Environ. Pollut. 343: 123119

Hebert CE. 1998. Winter severity affects migration and contaminant accumulation in northern Great Lakes herring gulls. Ecol. Appl. 8: 669–679.

Hebert CE, Weseloh DVC. 2006. Adjusting for temporal change in trophic position results in reduced rates of

contaminant decline. Environ. Sci. Technol. 40: 5624-5628.

Hebert CE, Weseloh DVC, Arts MT, de Solla SR, Moore DJ, Paterson G, Pekarik C. 2020. Trends in herring gull egg quality over four decades reflect ecosystem state. J. Great Lakes Res. 46: 538-548

Hughes KD, Crump D, Williams K, Martin PA. 2014a. Contaminants in Colonial Waterbirds Breeding near the Spanish Harbour Area in Recovery. Environment Canada, Ecotoxicology and Wildlife Health Division, Ottawa, Canada. 15 pp.

Hughes KD, Crump D, Williams K, Martin PA. 2014b. Assessment of the Wildlife Reproduction and Deformities Beneficial Use Impairment in the St. Marys River Area of Concern (Ontario). Environment Canada, Ecotoxicology and Wildlife Health Division, Ottawa, Canada. 36 pp.

Hughes KD, Weseloh DV, Martin PA, Moore D, de Solla SR. 2013. An Assessment of Breeding Success of Black-crowned Night-Herons (*Nycticorax nycticorax*) in the Detroit River Area of Concern (Ontario). Environment Canada, Ecotoxicology and Wildlife Health Division, Ottawa, Canada. 18 pp.

King LE, de Solla SR, Small, JM, Sverko, E, Quinn, JS. 2014. Microsatellite DNA mutations in Double-crested Cormorants (*Phalacrocorax auritus*) associated with exposure to PAH-containing industrial air pollution. Environ. Sci. Technol. 48: 11637-11645.

Li WL, McDaniel TV, de Solla SR, Bradley L, Dove A, McGoldrick D, Helm P, Hung H. 2023. Temporal trends of legacy and current-use halogenated flame retardants in Lake Ontario in relation to atmospheric loadings, sources, and environmental fate. Environ. Sci. Technol. 57: 14396-14406.

McGoldrick DJ, Pelletier M, de Solla SR, Martin PA. 2018. Legacy of legacies: Chlorinated naphthalenes in Lake Trout, Walleye, Herring gull eggs and sediments from the Laurentian Great Lakes indicate possible resuspension during contaminated sediment remediation. Sci. Total Environ. 634: 1424-1434.

Molina ED, Balander R, Fitzgerald SD, Giesy JP, Kannan K, Mitchell R, Bursian SJ. 2006. Effects of air cell injection of perfluorooctane sulfonate before incubation on development of the white leghorn chicken (*Gallus domesticus*) embryo. Environ. Toxicol. Chem. 25: 227-32.

Newell, AJ, Johnson DW, Allen LK. 1987. Niagara River Biota Contamination Project: Fish Flesh Criteria for Piscivorous Wildlife. New York State Department of Environmental Protection, Buffalo, New York. *Bureau of Environmental Protection Technical Report 87*.

Norstrom RJ, Clark TP, Jeffrey DA, Won HT, Gilman AP. 1986. Dynamics of organochlorine compounds in Herring Gulls (*Larus argentatus*): I. Distribution and clearance of [^{14}C]DDE in free-living herring gulls (*Larus argentatus*). Environ. Toxicol. Chem. 5: 41-48.

Paterson G, Hebert CE, Drouillard KG, Haffner DG. 2014. Congruent energy density trends of fish and birds reflect ecosystem change. Limnology and Oceanography. 59: 1171-1180.

Sinkkonen S, Paasivirta J. 2000. Degradation half-life times of PCDDs, PCDFs and PCBs for environmental fate modeling. Chemosphere 40: 943-949.

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Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

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Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

Figure 2. Wildlife Environmental Quality Indices for herring gull eggs from 14 Great Lakes colonies, based on legacy contaminants (PCBs, organochlorine pesticides), 2013-2023; i) Lake Superior, ii) Lake Michigan, iii) Lake Huron, iv) Lake Ontario, v) Lake Erie, vi) St. Lawrence River, v) Niagara River.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

Figure 3. Trends and breakpoints for concentrations (log ng/g) of $\sum_{11}$PBDE corresponding to the penta- and octa-commercial mixtures in herring gull eggs from 17 colonies in Canada from 2008–2023. The year of addition of penta- and octa-BDE to Annex A of the Stockholm Convention (2009) is shown as a solid vertical line. Models that are statistically significant are denoted by an asterisk (*) beside the colony name. From VanderLipp, in prep).

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

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Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

Figure 5. Mean PFOS concentrations (ng/g, wet weight) in individual samples of eggs of gulls in the Great Lakes from 2008–2023. The draft Canadian Federal Environmental Quality Guideline (FEQC; 1900 ng/g) for PFOS and the

Lowest Observed Adverse Effect Level (LOAEL) for reduced hatchability in white leghorn chicken embryos (100 ng/g) are shown.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

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Table 1. Contaminants Indexed by the Wildlife Environmental Quality Index (WEQI) and their Exposure Guidelines. No Observable Effect Levels in fish flesh were used from Newell et al. (1987) for mortality, reproductive impairment, and organ damage in piscivorous wildlife.

Contaminant	No Effect Concentration
∑PCBs	110 ng/g
Total DDT	200 ng/g
Dieldrin	120 ng/g
Mirex	330 ng/g
∑Chlordane	500 ng/g
Heptachlor epoxide	200 ng/g
Octachlorostyrene	20 ng/g
Dioxin	3 pg/g

Table 2. Concentrations of PCBs (as Aroclor 1:1 1254:1260 equivalents), select organochlorine pesticides and mercury (µg/g, wet weight) in Herring Gulls eggs from the Great Lakes in four time periods, from 1980 to 2023.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

Lake	Colony	Year	PCB1:1	DDE	ΣChlordane	HCB	Dieldrin	Mirex	HE	OCS	Hg
Erie	**Middle**	1980	54.29	2.60	0.20	0.088	0.16	0.093	0.14		
		2009	28.42	0.59	0.059	0.022	0.045	0.014	0.020	0.010	0.25
		2013	14.79	0.69	0.060	0.021	0.040	0.008	0.015	0.007	0.15
		2019	16.41	0.94	0.047	0.013	0.027	0.016	0.014	0.006	0.16
		2023	10.97	0.41	0.008	0.006	0.019	0.005	0.006	0.002	0.13
	Port Colborne	1980	37.59	3.40	0.23	0.085	0.27	0.28	0.13		
		2009	8.09	0.34	0.039	0.012	0.000	0.022	0.011	0.002	0.10
		2013	5.82	0.42	0.051	0.018	0.039	0.017	0.010	0.003	0.14
		2019	4.33	0.46	0.036	0.011	0.030	0.024	0.010	0.003	0.14
		2023	4.11	0.33	0.004	0.004	0.005	0.012	0.004	0.0001	0.09
Huron	**Channel Shelter**	1980	69.55	8.90		0.19		0.20			
		2009	13.88	0.50	0.035	0.016	0.026	0.008	0.009	0.013	0.12
		2013	10.64	1.04	0.044	0.083	0.023	0.020	0.008	0.064	0.14
		2019	6.38	0.69	0.027	0.021	0.017	0.014	0.008	0.028	0.13
	Double	1980	17.41	2.60	0.15	0.055	0.24	0.058	0.11		
		2009	3.49	0.22	0.027	0.011	0.013	0.016	0.008	0.001	0.11
		2013	4.14	0.47	0.167	0.020	0.021	0.028	0.036	0.002	0.16
		2019	2.91	0.44	0.026	0.011	0.012	0.036	0.009	0.003	0.07

Lake	Colony	Year	PCB1:1	DDE	ΣChlordane	HCB	Dieldrin	Mirex	HE	OCS	Hg
		2023	6.61	0.52	0.006	0.010	0.009	0.025	0.005	0.002	0.10
	Chantry	1980	23.41	2.83	0.18	0.075	0.23	0.16	0.11		
		2009	3.22	0.25	0.021	0.010	0.000	0.012	0.009	0.002	0.06
		2013	2.84	0.42	0.053	0.017	0.020	0.044	0.009	0.002	0.11
		2019	2.14	0.37	0.022	0.008	0.010	0.041	0.006	0.002	0.07
		2023	2.31	0.29	0.004	0.006	0.005	0.024	0.003	0.001	0.07
Michigan	**Big Sister**	1980	56.95	11.38	0.74	0.084	0.65	0.068	0.36		
		2009	4.08	0.72	0.045	0.014	0.040	0.012	0.014	0.001	0.11
		2013	4.15	0.69	0.050	0.019	0.037	0.008	0.013	0.001	0.08
	Gull	1980	58.70	12.95	0.78	0.100	0.75	0.14	0.332		
		2009	6.77	0.58	0.072	0.021	0.058	0.009	0.022	0.001	0.10
		2013	7.49	1.00	0.13	0.031	0.062	0.023	0.020	0.002	0.13
		2019	4.16	0.52	0.052	0.024	0.027	0.016	0.015	0.002	0.14
Niagara	**Weseloh Rocks**	2009	6.43	0.34	0.028	0.016	0.012	0.033	0.007	0.002	0.12
		2013	5.90	0.52	0.053	0.030	0.039	0.036	0.010	0.005	0.13
		2019	6.31	0.45	0.031	0.009	0.013	0.018	0.006	0.001	0.18
Ontario	**Hamilton Harbour**	2009	13.36	0.57	0.031	0.016	0.0001	0.102	0.008	0.002	0.11
		2013	7.05	0.83	0.062	0.017	0.034	0.103	0.009	0.004	0.12
		2019	12.09	1.33	0.033	0.011	0.015	0.122	0.007	0.003	0.08
		2023	8.63	0.98	0.008	0.009	0.011	0.094	0.005	0.002	0.08
	Snake	1980	53.49	7.12	0.24	0.15	0.20	1.58	0.089		
		2009	8.09	0.60	0.039	0.015	0.000	0.154	0.010	0.003	0.23
		2013	7.01	0.79	0.060	0.029	0.031	0.150	0.010	0.004	0.24
		2019	4.01	0.83	0.033	0.012	0.017	0.122	0.008	0.003	0.14
		2023	3.26	0.50	0.005	0.007	0.010	0.069	0.003	0.001	0.12
	Toronto	1980	59.69	8.17	0.35	0.20	0.18	1.72	0.090		
		2009	9.94	0.96	0.054	0.023	0.062	0.190	0.012	0.003	0.14
		2013	8.78	1.48	0.13	0.033	0.075	0.196	0.017	0.007	0.14
		2019	8.28	1.82	0.052	0.018	0.030	0.223	0.012	0.004	0.15
	Strachan	2009	8.48	0.38	0.025	0.010	0.008	0.12	0.006	0.002	0.20
		2013	5.33	0.65	0.033	0.012	0.020	0.12	0.006	0.002	0.21

Lake	Colony	Year	PCB1:1	DDE	ΣChlordane	HCB	Dieldrin	Mirex	HE	OCS	Hg
		2019	4.72	0.63	0.024	0.009	0.008	0.11	0.005	0.002	0.20
		2023	2.45	0.21	0.003	0.004	0.004	0.040	0.001	0.000	0.20
Superior	**Agawa Rocks**	1980	23.68	3.70	0.31	0.080	0.35	0.17	0.12		
		2009	2.85	0.29	0.04	0.013	0.022	0.015	0.014	0.001	0.11
		2013	3.38	0.34	0.07	0.021	0.032	0.017	0.020	0.002	0.18
		2019	2.27	0.33	0.05	0.014	0.019	0.023	0.013	0.003	0.25
		2023	2.15	0.24	0.01	0.011	0.013	0.009	0.010	0.003	0.19
	Granite	1980	27.48	3.65	0.30	0.08	0.33	0.091	0.16		
		2009	3.27	0.36	0.035	0.012	0.020	0.013	0.011	0.001	0.12
		2013	3.15	0.40	0.060	0.018	0.028	0.020	0.013	0.002	0.14
		2019	2.57	0.29	0.035	0.013	0.015	0.011	0.010	0.002	0.16
		2023	2.59	0.30	0.009	0.010	0.018	0.007	0.009	0.001	0.18

Table 3. Mean and standard deviation of decay constants and half-lives of organochlorine pesticides from first-order decay models from Great Lakes Herring Gull eggs, 1974-2023.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

Compound	Decay constant *K*	SD *K*	$t_{½}$	SD $t_{½}$
Chlordane	0.057	0.019	13.08	3.15
DDE	0.12	0.057	6.92	3.17
Dieldrin	0.076	0.016	9.51	1.77
HCB	0.14	0.046	5.56	1.88
HE	0.064	0.018	11.55	2.84
Mirex	0.24	0.34	6.04	3.10
PCBs	0.089	0.025	8.57	3.27

Table 4. Mean and standard deviation of decay constants and half-lives of PCBs from first-order decay models from Great Lakes Herring Gull eggs, 1974-2023.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

Colony	Decay constant *K*	$t_{½}$
Middle	0.041	17.11
Channel Shelter	0.048	14.56
Hamilton Harbour	0.066	10.53
Port Colborne	0.077	8.97
Strachan	0.08	8.95
Overall Average	**0.089**	**8.57**
Gull	0.083	8.36
Fighting	0.093	7.48
Big Sister	0.095	7.33
Granite	0.095	7.32
Agawa Rocks	0.10	7.08
Weseloh Rocks	0.10	6.97
Double	0.10	6.83
Toronto	0.12	6.00
Snake	0.12	5.63
Chantry	0.13	5.45

Table 5. Concentrations of brominated flame retardants (ng/g, wet weight) in Herring Gulls eggs from the Great Lakes in 2008, 2019 and 2023.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

Lake	Colony	Year	Sum 13 PBDEs	Total DDC-CO	PBB101	HBCDD
Erie	Middle Is.	2008	185.6	1.69	0.32	2.70
		2019	219.8	6.81	0.71	3.53
		2023	210.8	0.08	0.27	3.23
	Port Colborne	2008	136.1	0.72	0.22	1.41
		2019	387.4	2.06	0.18	4.53
		2023	152.0	1.77	0.092	6.38
Huron	Channel-Shelter Is.	2008	361.0	1.73	0.88	2.61
		2019	428.9	6.19	0.62	5.62

Lake	Colony	Year	Sum 13 PBDEs	Total DDC-CO	PBB101	HBCDD
Huron	Chantry Is.	2008	153.4	2.28	0.10	6.78
		2019	199.8	1.21	0.12	5.69
		2023	242.5	1.84	0.24	5.53
Huron	Double Is.	2008	236.5	1.28	0.09	7.30
		2019	417.4	1.87	0.18	7.17
		2023	346.8	1.77	0.25	8.57
Michigan	Big Sister Is.	2008	264.4	5.47	0.13	10.23
	Gull Is.	2008	421.0	1.01	0.28	9.97
		2019	372.2	2.57	0.25	8.25
Niagara R.	Niagara R.	2008	254.1	3.37	0.08	2.60
		2019	299.3	4.32	0.30	3.44
Ontario	Hamilton Harbour	2008	296.2	2.06	0.13	2.77
		2019	364.0	1.20	0.22	4.69
		2023	273.6	3.08	0.15	10.70
	Snake Is.	2008	230.7	0.50	0.082	2.01
		2019	202.9	1.00	0.16	3.61
		2023	166.2	0.067	0.086	2.35
	Toronto	2008	396.6	3.24	0.082	6.96
		2019	400.7	3.98	0.34	6.42
	Strachan Is.	2008	245.3	1.09	0.068	7.04
		2019	193.3	1.23	0.016	5.06
		2023	216.6	3.18	0.029	4.24
Superior	Agawa Rocks	2008	199.5	4.40	0.35	7.53
		2019	239.4	2.26	0.13	11.30
		2023	212.2	4.20	0.049	4.70
	Granite Is.	2008	346.6	3.22	0.078	7.31
		2019	401.6	1.95	0.14	12.80
		2023	350.2	1.13	0.049	22.90

Table 6. Concentrations of PFOS, sum PFSAs, PFCAs, and sum PFAAs (PFSAs +PFCAs) (ng/g, wet weight) in Herring Gulls eggs from the Great Lakes in 2009, 2017 and 2023.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

Lake	Colony	Year	PFOS	∑PFSA	∑PFCA	Sum PFAAs
Erie	**Middle I.**	2009	676.5	695.6	118.8	814.4
		2017	194.4	200.4	29.7	230.0
		2023	181.7	186.9	31.0	217.9
	Port Colborne	2009	155.0	158.9	34.5	193.4
		2017	157.5	160.8	30.3	191.1
		2023	95.4	96.7	14.8	111.6
Huron	**Channel-Shelter Is.**	2009	126.5	136.4	31.3	167.7
		2017	125.9	131.3	28.2	159.5
	Chantry I.	2009	114.2	118.0	26.3	144.3
		2017	86.7	89.1	18.1	107.2
		2023	51.9	52.9	13.1	66.0
	Double I.	2009	148.6	150.8	82.9	233.7
		2017	105.5	107.1	36.1	143.2
		2023	142.7	144.3	61.1	205.4
Michigan	**Big Sister Is.**	2009	191.6	195.6	34.8	230.4
		2017	152.9	154.8	24.6	179.4
	Gull Is.	2009	199.3	202.1	24.3	226.4
		2017	298.5	302.0	45.7	347.6
Ontario	**Hamilton Harbour**	2009	651.8	668.9	69.3	738.2
		2017	374.8	383.5	38.8	422.3
		2023	595.8	603.2	46.3	649.5
	Snake I.	2009	354.0	359.8	66.2	426.0
		2017	231.4	233.7	31.2	264.9
		2023	112.1	114.1	19.9	134.0
	Toronto Harbour	2009	469.7	480.5	65.1	545.6
		2017	414.5	420.4	43.4	463.8

Lake	Colony	Year	PFOS	∑PFSA	∑PFCA	Sum PFAAs
Niagara	**Weseloh Rocks**	2009	361.4	365.3	64.6	429.9
St. Lawrence River	**Strachan I.**	2009	485.5	494.0	72.4	566.4
		2017	255.2	257.9	31.8	289.7
		2023	240.4	243.4	31.9	275.3
Superior	**Agawa Rocks**	2009	102.8	105.3	51.3	156.6
		2017	61.7	62.8	67.0	129.8
		2023	45.8	46.4	44.3	90.7
	Granite I.	2009	97.5	100.1	30.4	130.5
		2017	84.1	85.1	44.4	129.5
		2023	53.6	54.5	30.9	85.4

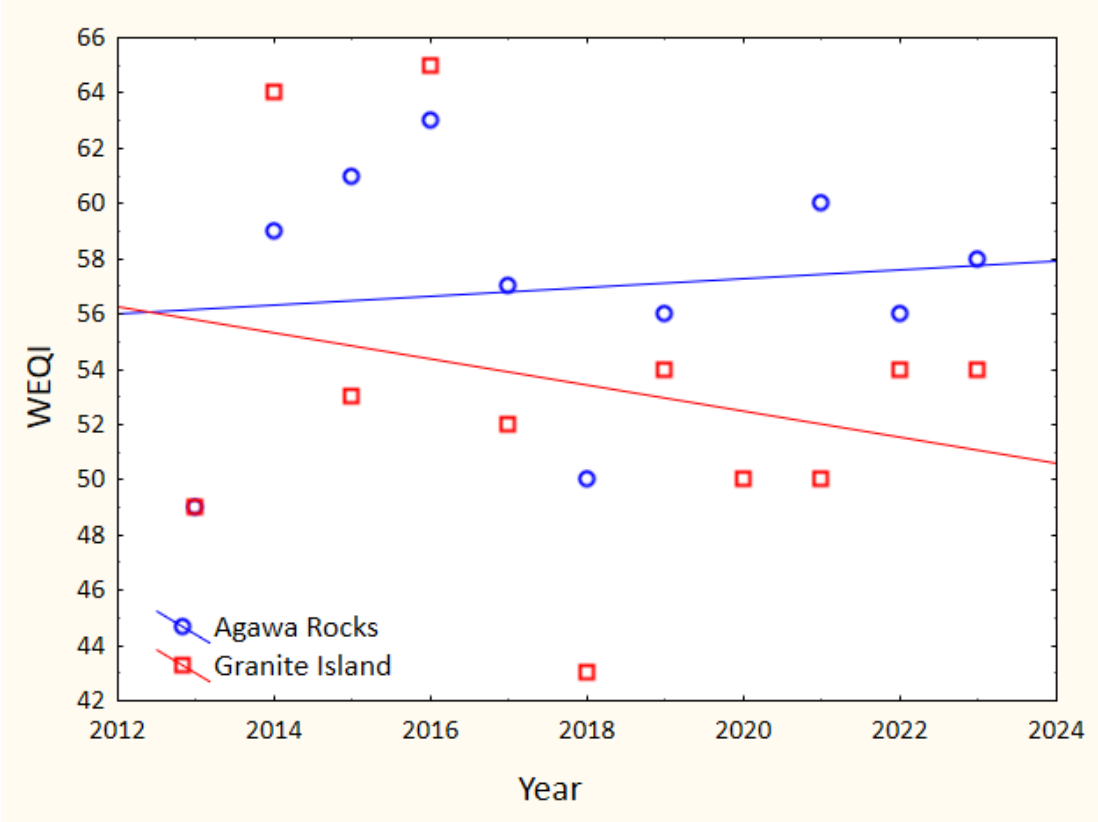
Table 7. Regression coefficients of regressions between Wildlife Environmental Quality Index values and year (2013-2023) for herring gulls from Great Lakes. Significant regressions are in red, which positive trends indicating improving conditions, whereas negative trends are deteriorating trends.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

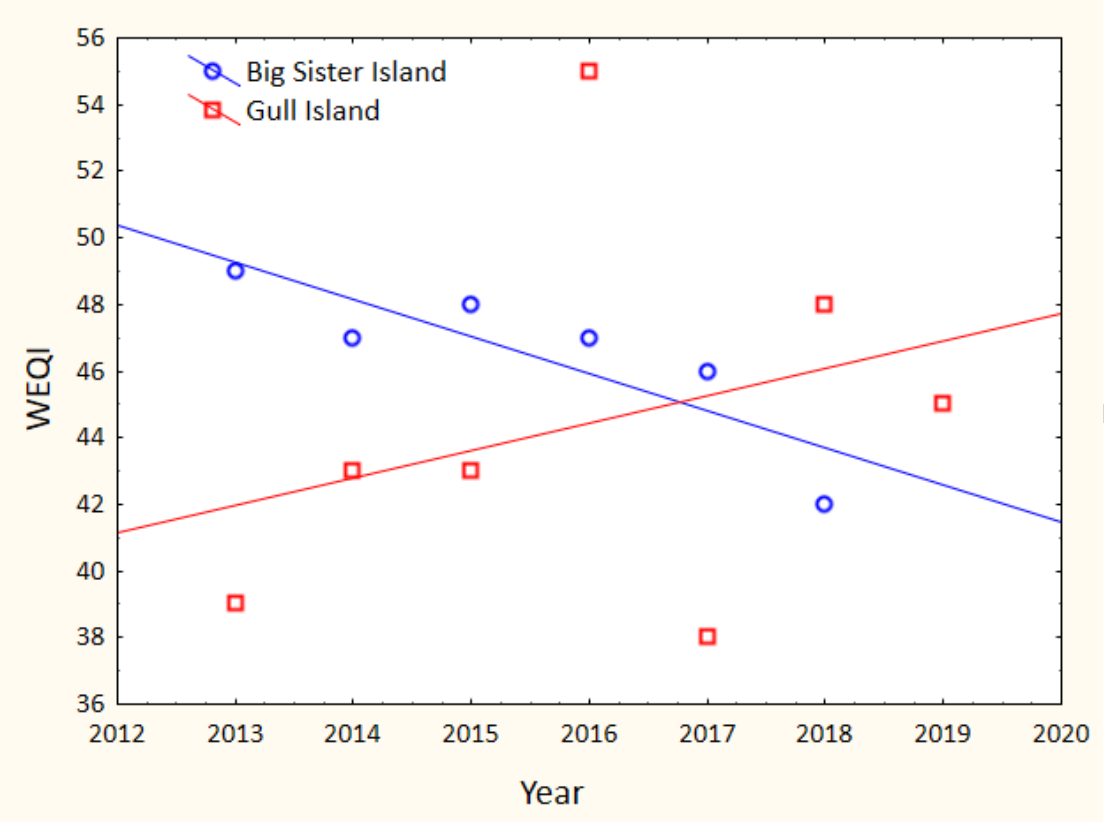
Lake	Colony	Ceofficient	t	P-value	Beta
Erie	Middle Is.	0.22	1.57	0.1560	0.48
Erie	Port Colborne	0.52	1.60	0.1535	0.52
Huron	Chantry Is.	1.02	1.36	0.2164	0.46
Huron	Channel-Shelter Is.	0.79	0.70	0.5205	0.33
Huron	Double Is.	-1.35	-2.03	0.0816	-0.61
Michigan	Big Sister Is.	-1.11	-3.34	0.0287	-0.86
Michigan	Gull Is.	0.82	0.72	0.5022	0.31
Niagara	Weseloh Rocks	-1.25	-1.64	0.1999	-0.69
Ontario	Hamilton Harbour	-0.41	-2.25	0.0595	-0.65
Ontario	Leslie St. Spit	-0.48	-0.94	0.3836	-0.36
Ontario	Snake Is.	0.80	3.28	0.0111	0.76
Ontario	Strachan Is.	0.96	2.77	0.0276	0.72
Superior	Agawa Rock	0.16	0.35	0.7380	0.12
Superior	Granite Is.	-0.47	-0.77	0.4628	-0.25

Figure 1. Locations of Great Lakes Herring Gull Monitoring Program collection sites.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]



Lake Superior



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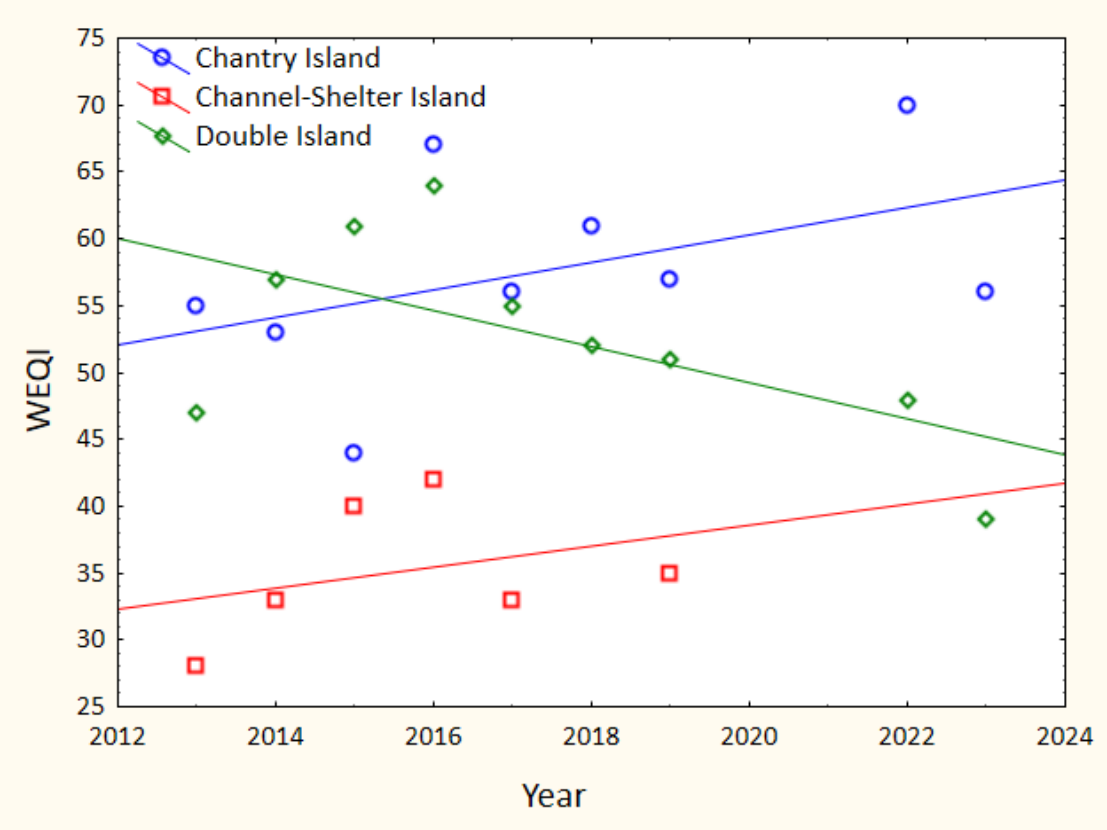
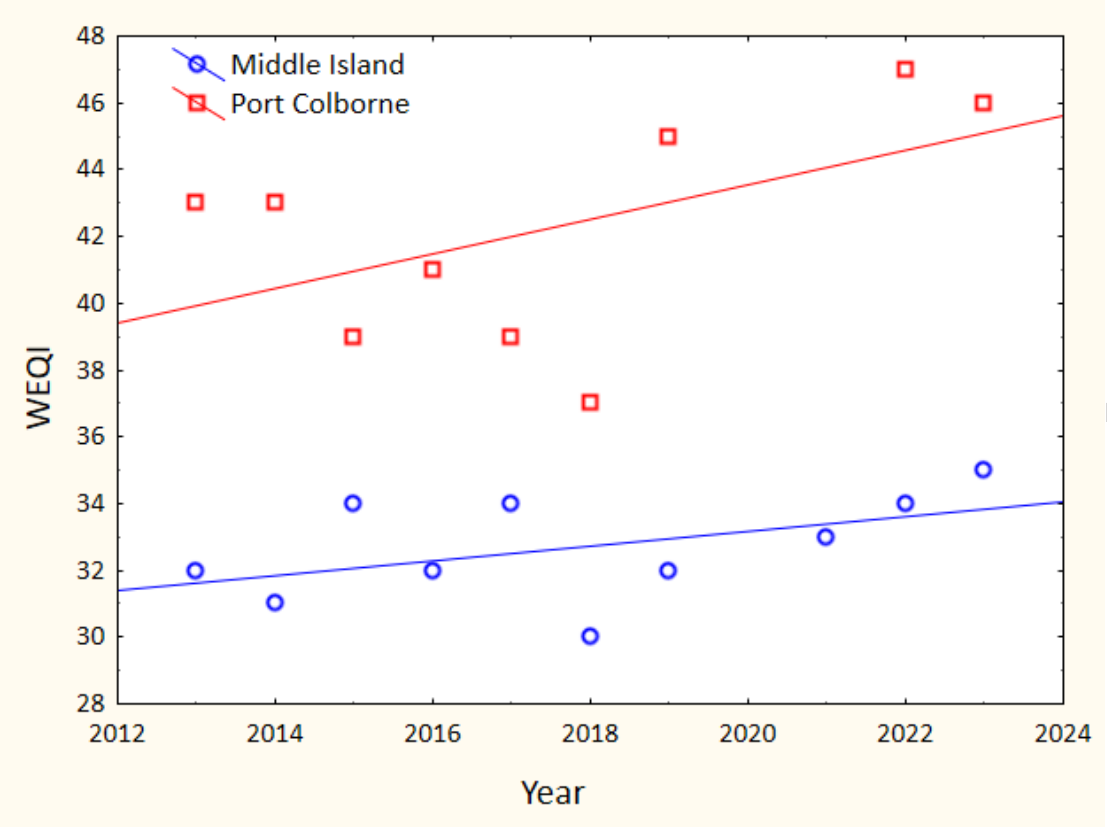
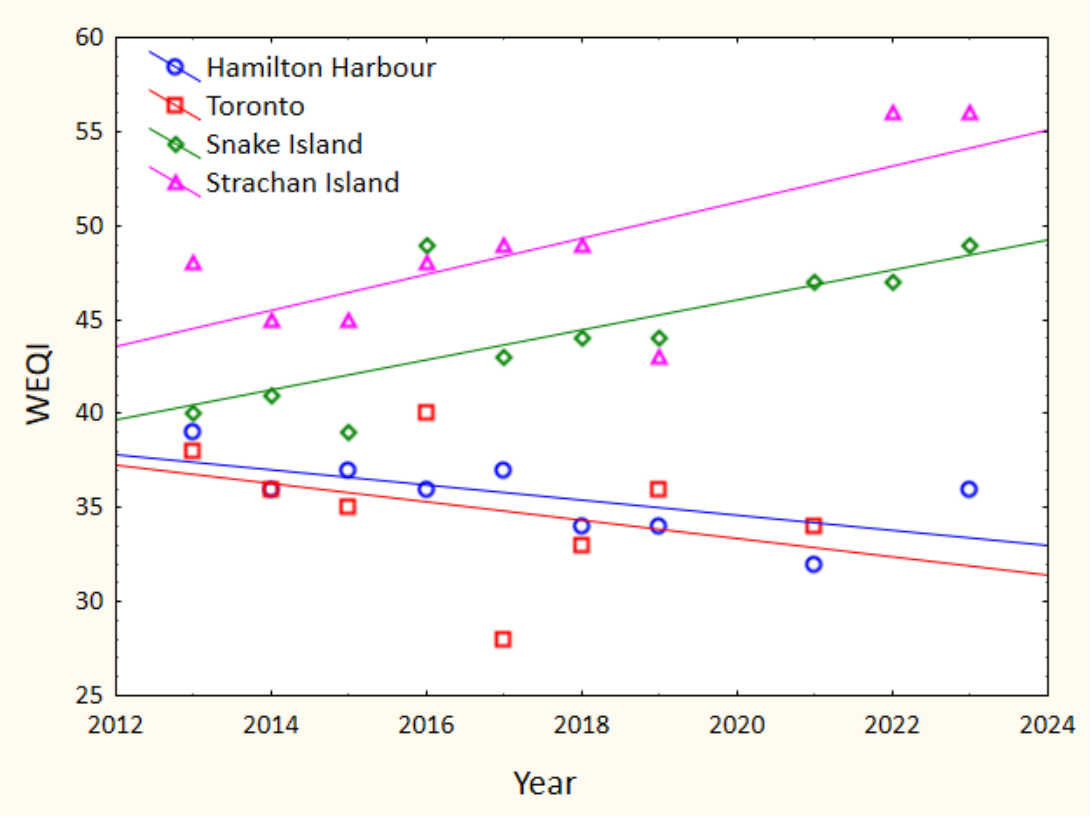


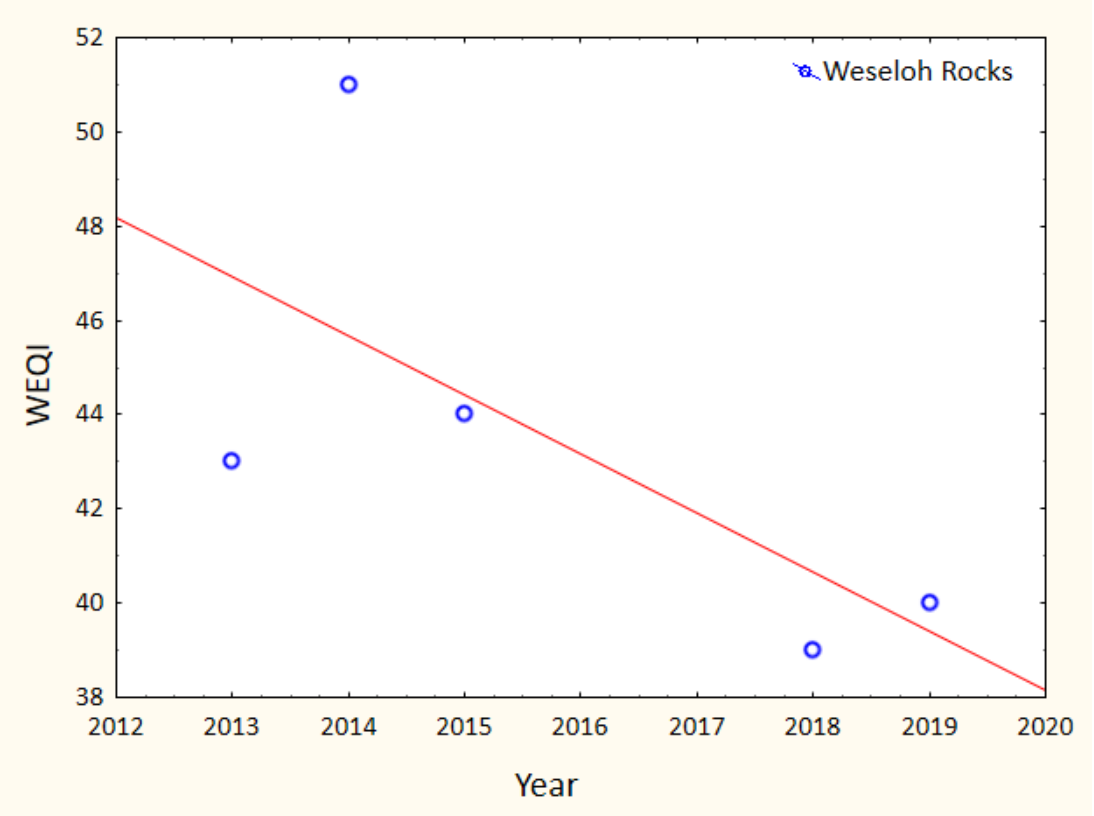
Lake Huron



Lake Erie



Lake Ontario



Niagara River

Figure 2. Wildlife Environmental Quality Indices for herring gull eggs from 14 Great Lakes colonies, based on legacy contaminants (PCBs, organochlorine pesticides), 2013-2023; i) Lake Superior, ii) Lake Michigan, iii) Lake Huron, iv) Lake Erie, v) Lake Ontario, vi) St. Lawrence River, v) Niagara River. Positive slopes indicate improving conditions.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

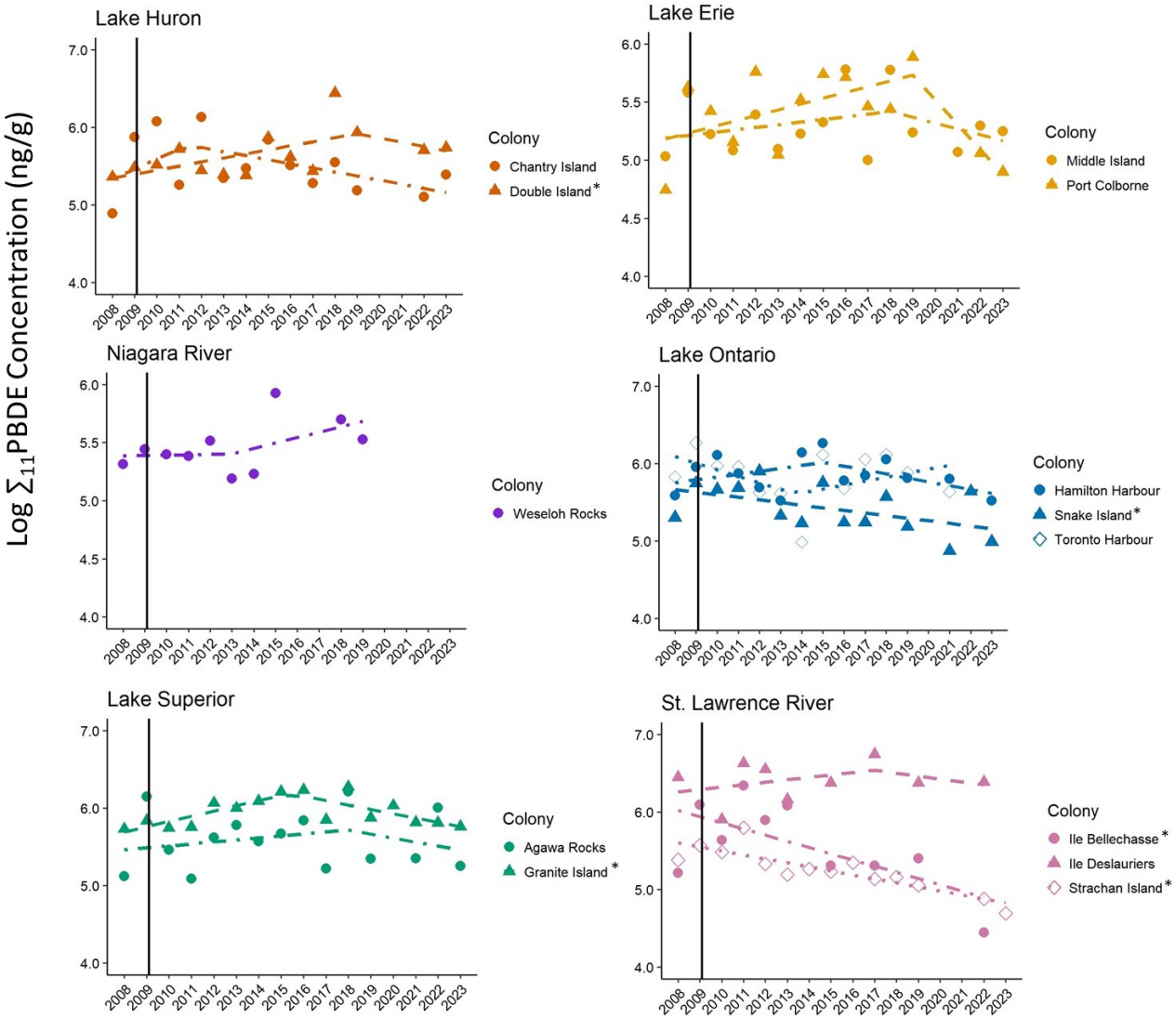


Figure 3. Trends and breakpoints for concentrations (log ng/g) of $\sum_{11}$PBDE corresponding to the penta- and octa-commercial mixtures in herring gull eggs from 17 colonies in Canada from 2008–2023. The year of addition of penta- and octa-BDE to Annex A of the Stockholm Convention (2009) is shown as a solid vertical line. Models that are statistically significant are denoted by an asterisk (*) beside the colony name. From VanderLipp, in prep).

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

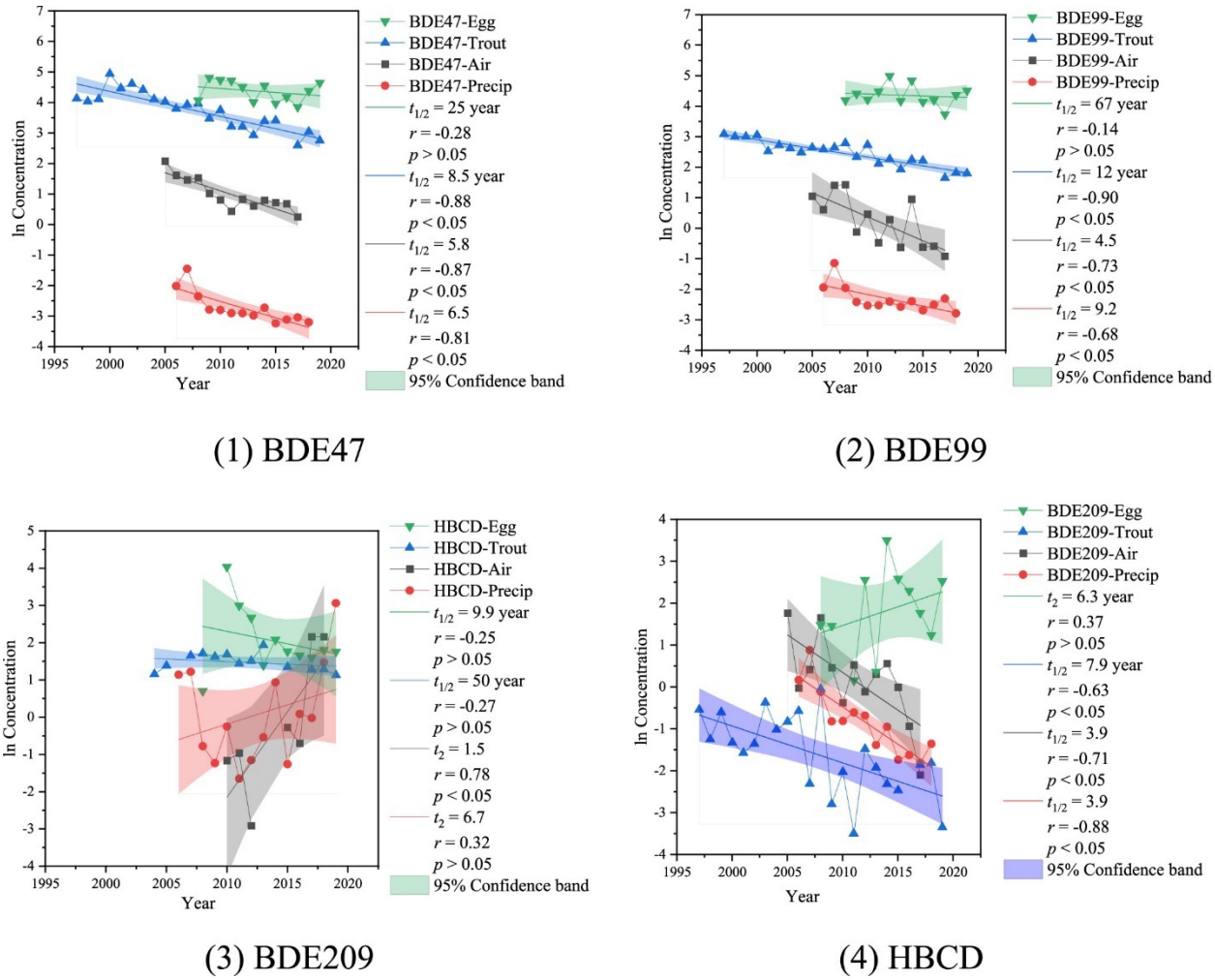


Figure 4. Comparisons on the natural logarithm of annual concentrations of PBDEs in the air (pg/m^3; black), precipitation (ng/L; red), lake trout (ng/g; blue), and herring gull eggs (ng/g; green) in Lake Ontario (from Li *et al.* 2023).

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]

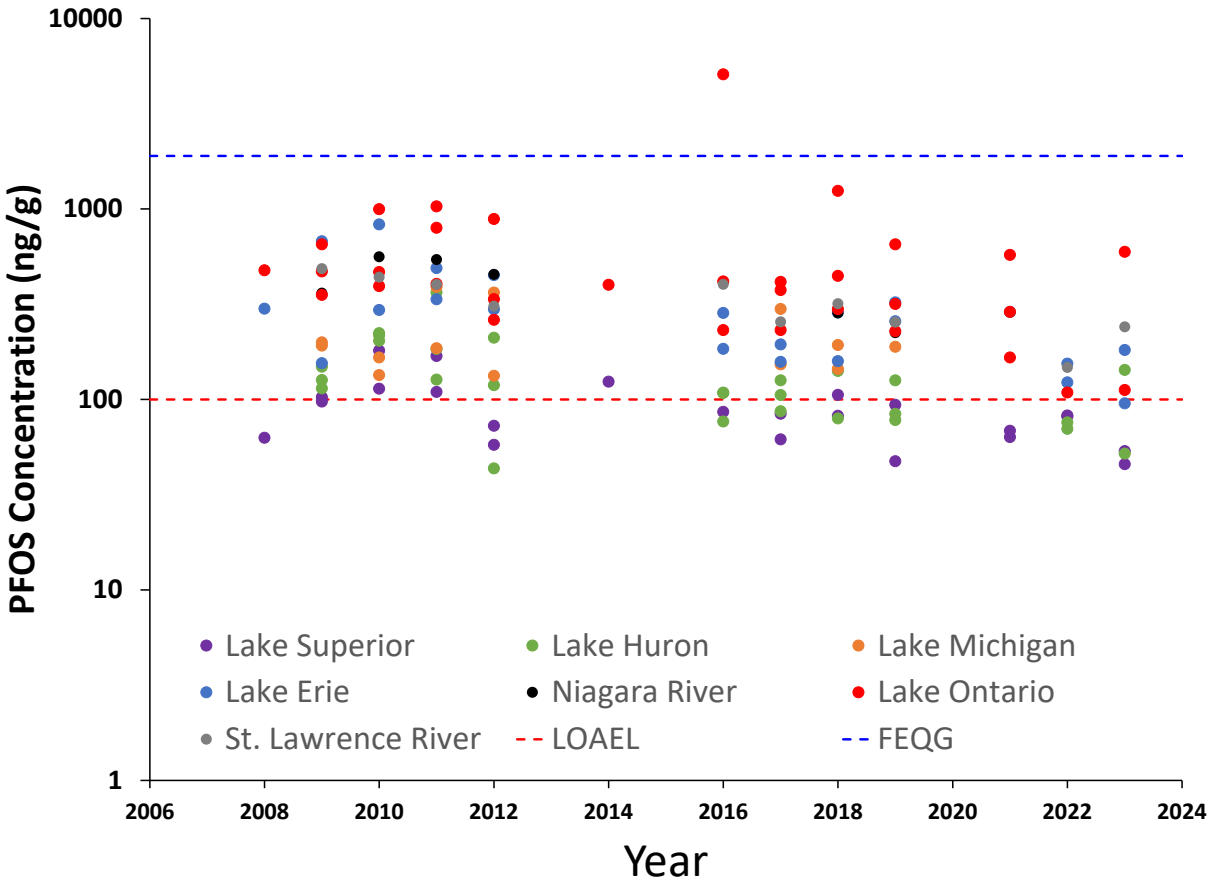


Figure 5. Mean PFOS concentrations (ng/g, wet weight) in individual samples of eggs of gulls in the Great Lakes from 2008–2023. The draft Canadian Federal Environmental Quality Guideline (FEQC; 1900 ng/g) for PFOS and the Lowest Observed Adverse Effect Level (LOAEL) for reduced hatchability in white leghorn chicken embryos (100 ng/g) are shown.

Source: Great Lakes Herring Gull Monitoring Program [Environment and Climate Change Canada]