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Total mercury accumulation and spatial distribution in Beachland Park Pond, West Hartford, CT and Keney Park Pond, Hartford, CT

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TOTAL MERCURY ACCUMULATION AND SPATIAL DISTRIBUTION IN BEACHLAND PARK POND, WEST HARTFORD, CT AND KENEY PARK POND, HARTFORD, CT

BY

SHANE MCLAUGHLIN

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ABSTRACT

Ponds are ecologically important as centers for biodiversity, and those within urbanized watersheds typically have altered hydrology, morphology, and water chemistry. The accumulation of heavy metals, such as mercury (Hg), in subaqueous pond sediments has the potential to harm pond ecosystems, but the behavior of Hg in urban ponds is poorly understood. I investigated spatial variability of mercury accumulation within the sediments of two urban ponds: Beachland Park Pond in West Hartford, CT, USA, and Keney Park Pond, in Hartford, CT, USA. I collected 5 samples from 14 distinct sites around each pond's perimeter. I analyzed the fine (<63 μm) fractions of each sediment sample directly for total Hg. In Beachland Park Pond, mean Hg concentration exceeded the Threshold Effect Concentration (TEC) at four sample sites, and the Probable Effect Concentration (PEC) at a site on the northeastern shore of the pond. An analysis of variance (ANOVA) and post hoc Tukey test revealed that mean mercury concentration at this site differed significantly from all other sites ($F = 4.635$, $df = 13, 56$, $p < 0.0001$). In Keney Park Pond, mean Hg concentration exceeded TEC at one site in the southwestern corner of the pond. The statistical analysis revealed that this site differed significantly from most others ($F = 42.4$, $df = 13, 56$, $p < 2 \times 10^{-16}$). The relative lack of variability among most sample sites was to be expected due to ubiquitous atmospheric deposition of mercury, and additional mercury sources must be considered for the sites which exceed the TEC. More research is needed to investigate sources of Hg in areas of high concentration, as well as temporal variation in mercury concentration.

INTRODUCTION

Ponds are ecologically important and can provide a vast number of ecosystem services (Moore and Hunt 2012, Céréghino et al. 2014). They influence hydrologic regulation by reducing flooding and increasing groundwater recharge (de Groot 2006, Moore and Hunt 2012). Additional services provided by ponds include carbon sequestration, increased biodiversity, and cultural services (Moore and Hunt 2012). Ponds act as potential refuges for wildlife and chemically active sites for nutrient and water cycling within a watershed (Williams et al. 2004, Hamer et al. 2012, Le Viol et al. 2012, Moore and Hunt 2012, Céréghino et al. 2014). The role of ponds as possible centers of biodiversity is especially important, because research has shown that ponds frequently have more species present than other lentic bodies of water (Williams et al. 2004, Céréghino et al. 2014). Ponds have the potential to supply a wide variety of food resources and habitats for wildlife, as well as to provide opportunities for productive interaction between aquatic and terrestrial biota (Moreno-Opo et al. 2011, Céréghino et al. 2014).

Naturally occurring ponds which exist within highly urbanized watersheds are typically impacted by land-use change, and constructed ponds also have altered hydrology based on their intended purposes (Mason and Sullivan 1998, Persson et al. 1999). One of the predominant effects of urbanization is increased pollution from runoff as a result of increased impervious surface cover (Arnold Jr. and Gibbons 1996, Mason and Sullivan 1998, Brabec et al. 2002). Urbanization and human industrial activities also contribute to increased pollution of urban watersheds through atmospheric deposition of contaminants, which can occur extremely far from the source of contamination (Mason and Sullivan 1998, Balcom et al. 2004). Ponds are dynamic systems within watersheds, but they also provide opportunities for contaminants to settle and accumulate in their sediments, due to the relative absence of flow (Lee et al. 1997, Karlsson et al. 2010). The degree of contamination within urban pond sediments can be highly variable, depending on local and non-local sources of pollution, as well as watershed morphology and hydrology (Axtmann and Luoma 1991, Balcom et al. 2004, Bergeron et al. 2010).

One problematic environmental pollutant is mercury, which is most commonly found in its elemental form (Hg^0 and Hg(II)) and in the significantly more toxic organic compound methylmercury (CH_3Hg; Figure 1; Burbacher et al. 1990, Balcom et al. 2004, Estrade et al. 2010, Shao et al. 2011, Cheng et al. 2011, Chumchal and Drenner 2015). Mercury is toxic, volatile, and readily transported long distances, especially within the atmosphere (Balcom et al. 2004, Zahir et al. 2005, Estrade et al. 2010). Clinical studies have shown that mercury toxicity causes a variety of neurological disorders, as well as pulmonary and nephrological diseases (Ratcliffe et al. 1996, Tchounwou et al. 2003, Zahir et al. 2005, Mergler et al. 2007, Carvalho et al. 2008). In aquatic systems, it has been shown that some bacteria anaerobically convert mercury to methylmercury (Gilmour and Henry 1991, Boening 2000, Strickman and Mitchell 2017). In this form, mercury is a strong toxin that is more easily retained by organisms and bioaccumulated throughout ecosystems (Morel et al. 1998, Mason and Sullivan 1998, Mergler et al. 2007). Once mercury has entered an ecosystem and begins undergoing methylation by bacteria, the process of bioaccumulation and biomagnification begins, as it is retained in organisms and passed up the food chain to their predators (Morel et al. 1998). This bioavailability allows for accumulation of methylmercury in fish, which can directly impact any humans who consume the contaminated fish (Clarkson 1990, Mozaffarian and Rimm 2006). Methylmercury is also easily transferred between aquatic and terrestrial ecosystems by emergent aquatic insects (Chumchal and Drenner 2015).

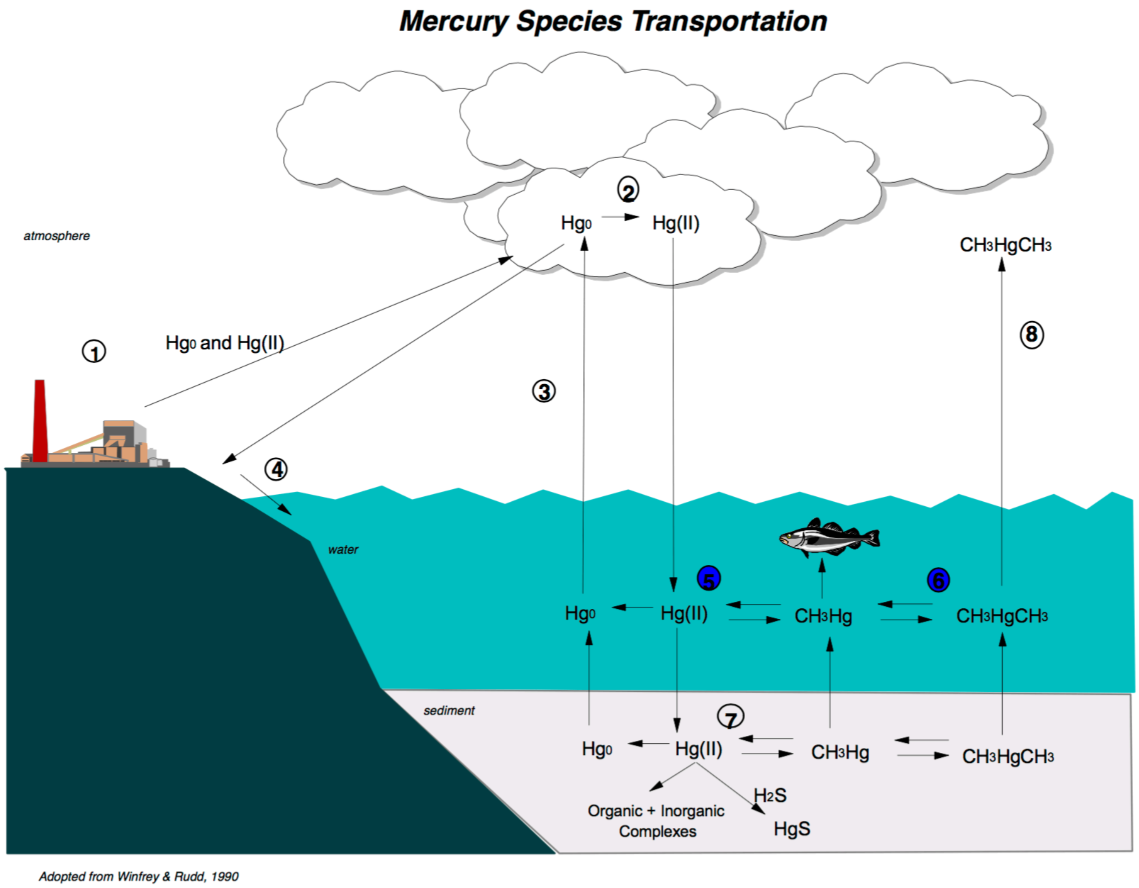

Figure 1. Mercury (Hg) transport and bioaccumulation through human activity (Huber 1997).

Atmospheric deposition of mercury accounts for a large percentage of overall environmental mercury contamination, with coal burning power plants being one of the main sources of atmospheric mercury (Driscoll et al. 2007, Evers et al. 2007). A 1994 study determined that 181 million kilograms of mercury had been deposited on soils from the atmosphere since 1890 (Schroeder and Munthe 1998). Evers et al. (2007) found that the northeastern United States receives mercury contamination from the coal burning power plants found in the Midwest of the country, due to prevailing eastward wind patterns which transport atmospheric mercury. Mercury can also enter the environment from anthropogenic point sources in an area, such as insecticides, fungicides, phosphate fertilizers, paint, plastics, cosmetics, batteries, and fireworks (Sutherland 2000).

There is not a very large body of research concerning mercury contamination levels within the sediments of ponds in urbanized watersheds, but one study found a relatively uniform distribution of mercury in the bottom sediments of ponds, lakes, streams, and rivers in the Polish city of Poznán (Boszke and Kowalski 2006). Another study assessed urban ponds in northern England to have overall poor ecological quality (Noble and Hassall 2015). Urban ponds within green spaces are likely to be used by people for recreational activities, such as fishing, which may be problematic if there are harmful levels of mercury in the ecosystem (Moore and Hunt 2012).

This study was designed to evaluate the spatial distribution of mercury concentrations around the perimeter of two urban ponds in the greater metropolitan area of Hartford, CT, USA. I hypothesized that mercury would be present in all samples and have a generally uniform distribution due to widespread atmospheric deposition. I also hypothesized that the most likely locations in which mercury concentrations might stray from this uniform distribution would be nearest to each pond's main inflow and outflow.

MATERIALS AND METHODS

Study Sites

In order to assess the spatial distribution of mercury accumulation in urban recreational ponds, two study ponds were selected within the greater metropolitan area centered around Hartford, CT. Hartford has a long history of commerce and manufacturing due to its location close to the Connecticut River, and this resulted in a rapid increase in impervious surface cover, as well as the disposal of toxic industrial wastes into water bodies (Walsh et al. 2005, Sterner 2012). The area was surveyed for potential ponds using Google Earth (Google, Mountain View, California, USA) with three main criteria that the study ponds should be located in green spaces, should not be adjacent to agriculture and should not have have large inflows and/or outflows. The ponds selected for sediment sampling were Beachland Park Pond in West Hartford, CT (Figure 2), and Keney Park Pond (Figure 3) in Hartford, CT due to their fulfillment of these criteria and logistically manageable sizes.

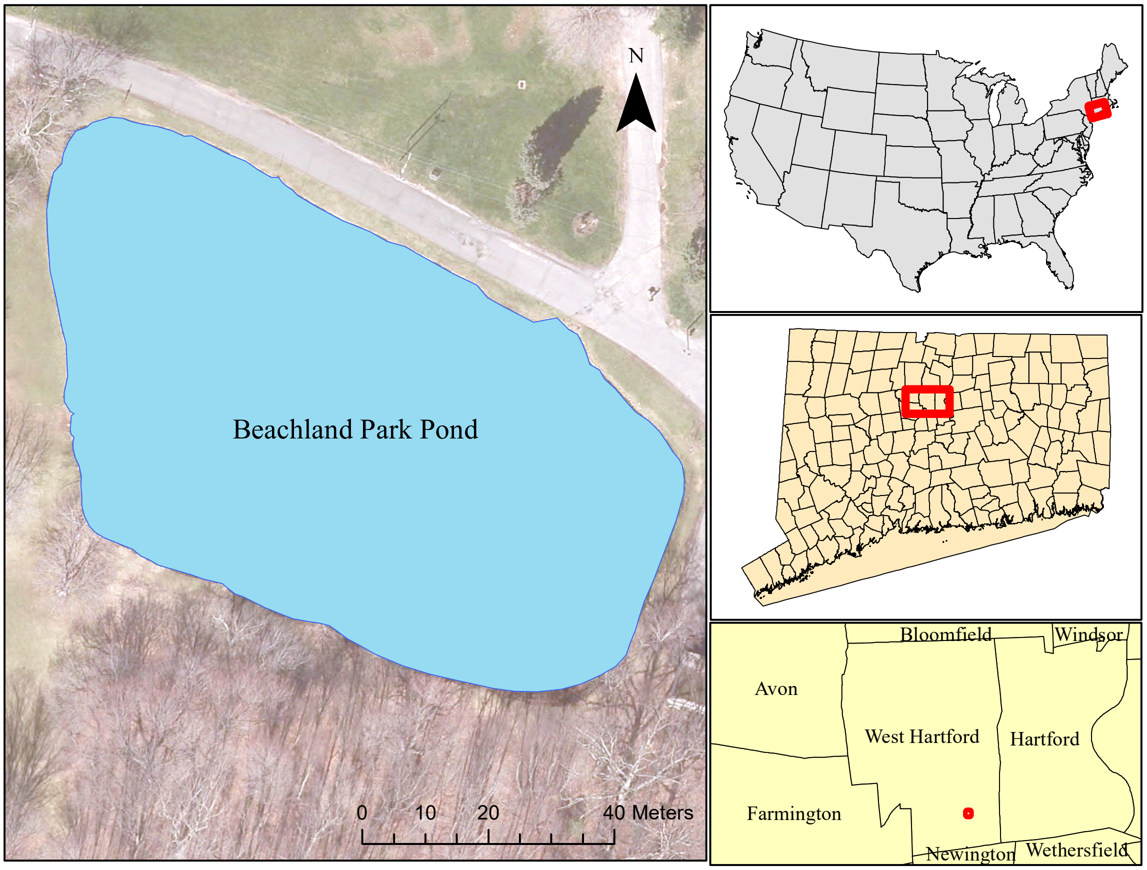

Figure 2. Map of Beachland Park Pond, showing its location within West Hartford, CT, United States (CT DEEP and USGS 2005, CT DEEP 2016, Price 2018).

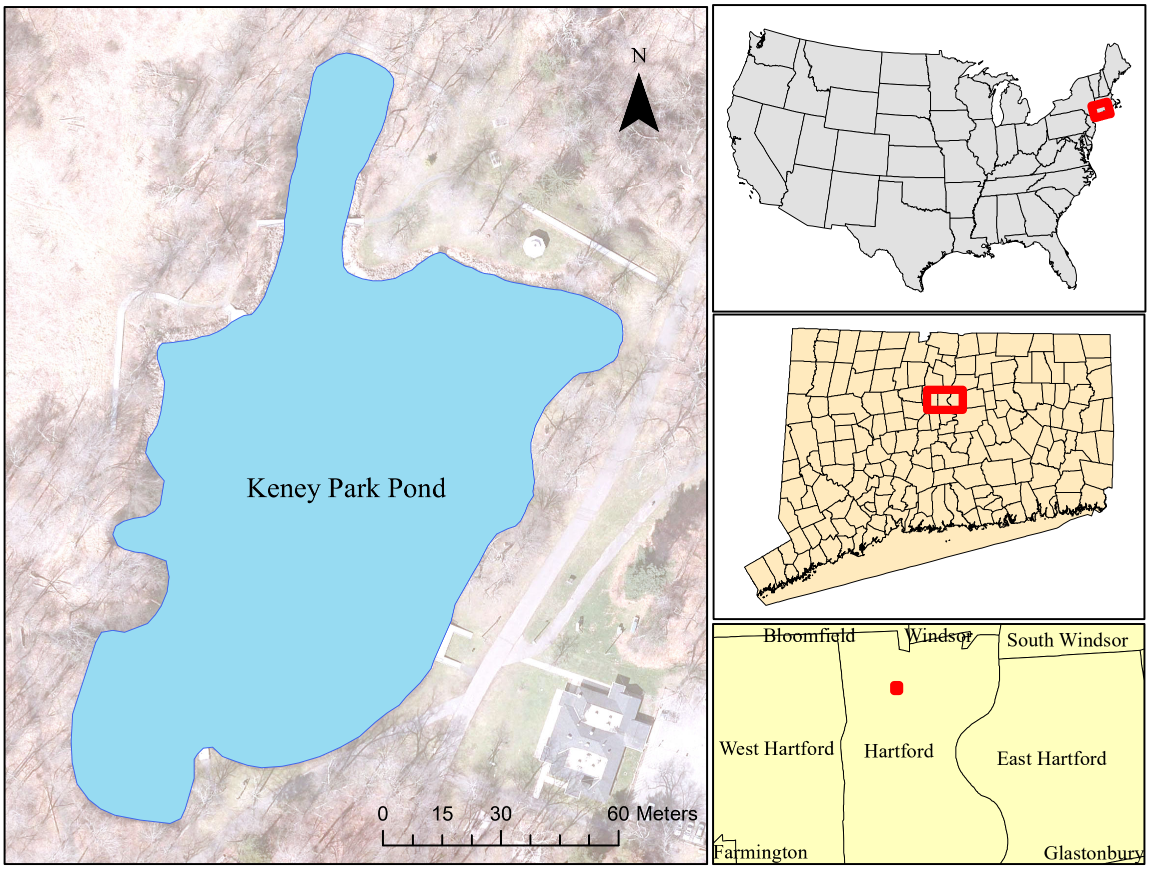

Figure 3. Map of Keney Park Pond, showing its location within Hartford, CT, United States (CT DEEP and USGS 2005, CT DEEP 2016, Price 2018).

Beachland Park covers an area of approximately 100,000 m^2, and the pond itself covers approximately 6,025 m^2. The periphery of the pond is approximately 30% forested land and 70% manicured lawn, with a paved park road directly adjacent to a thin strip of manicured lawn on about 50% of the perimeter. Beachland Park Pond was formerly part of the Vine Hill Dairy farm, where it was used to power a mill and for ice harvesting during the winter months, until 1932, when the area became a public park (ElmwoodCT 2014). The pond is adjacent to major roads and drains into the highly impacted Trout Brook by an overflow structure and connected subterranean channel. The pond has visibly murky water, and due to its proximity to and downward sloping direction from major roads, Beachland Park Pond is likely heavily impacted by stormwater runoff and urban pollutants.

Keney Park covers an area of approximately 2.9×10^6 m^2, and the pond itself covers approximately 14,800 m^2. The periphery of the pond is about 30% manicured lawn or constructed viewing platforms and 70% forested land or undeveloped meadow. Keney Park Pond is relatively isolated from major roads within a large park system. The pond is fed by a natural spring beside a low dam on its southern end, drains into the open meadow to its west, and has visibly clear water. The CT Department of Energy and Environmental Protection stocks the pond with fish each year for recreational fishing (Alexopolous 1983, Morrison and Pelletier 2014).

Perimeter surveys have revealed the presence of the American bullfrog (*Lithobates catesbeianus*) and the green frog (*Lithobates clamitans*) at Beachland Park Pond. The same survey found the American bullfrog, eastern painted turtle (*Chrysemys picta picta*), red-eared slider (*Trachemys scripta elegans*), bluegill (*Lepomus macrochirus*), and largemouth bass (*Micropterus salmoides*) in Keney Park Pond (Pitt and McLaughlin 2018). This could indicate that both ponds are used as wildlife refuges, with Keney Park Pond being potentially more biodiverse.

Sediment Sampling Methods

Sample collection took place over the course of two weeks in September 2018 at Beachland Park Pond, and in October 2018 at Keney Park Pond. The methodology was designed in order to map a high-resolution distribution of mercury in the pond sediments. Beginning at an arbitrary point on each pond's perimeter, 5 grab samples of sediment were collected in Whirl-Pak sterile sampling bags (Nasco) from less than 1 m away from the bank. This process was repeated approximately every 20 meters, for a total of 14 sample sites and 70 individual sediment samples per pond. Sample site spacing was sometimes inconsistent due to obstacles such as large outgrowths of common cattail (*Typha latifolia*), and constructed features (e.g., viewing platforms). When an obstacle prevented consistent site spacing, the closest possible site beyond 20 m was sampled. The samples were stored at 4 °C until laboratory analysis.

Sample Preparation

Each sediment sample was filtered through a 63-μm nylon sieve into a new 1-L #2 high-density polyethylene (HDPE) Nalgene bottle (Nalge Nunc International Corporation, Rochester, New York, USA). The wet-sieving ensured a small and uniform grain size of sediments for analysis and was done because smaller grains have more surface area relative to their volume, and therefore can potentially adsorb more mercury (John and Leventhal 1995). Bottles of filtered sediment were allowed to settle in a refrigerator for 24 hours, then the slurries were transferred into 50 mL digiTUBEs (SCP Science). After another 24-hour settling period, excess water was removed from the digiTUBEs using plastic pipets, and the samples were frozen for 24 hours. All samples were then freeze-dried using a Labconco Freezone 6 Liter Benchtop Freeze Dryer (Labconco, Kansas City, Missouri, USA).

Sample Analysis

All freeze-dried sediment samples were analyzed for total mercury concentration using a Milestone Direct Mercury Analyzer (DMA-80; Milestone S.r.L., Sorisole, Italy). The instrument analyzed a 100 ppb mercury standard solution and reported within 10% error. For each sediment sample, between 0.001 g and 0.01 g was loaded in each nickel boat. Each distinct sample was run three times. A maximum of two out of three runs were performed within a single day to account for possible instrument drift, and the results were averaged.

Statistical Analysis

Analysis of variance (ANOVA) tests were performed using R (R Core Team, Vienna, Austria) to test for differences among the 14 sample sites at Beachland Pond, and among the 14 sample sites at Keney Pond. Mean Hg concentrations were compared to the consensus-based Threshold Effect Concentration (TEC) and Probable Effect Concentration (PEC) to assess environmental hazard. The TEC is the concentration below which a contaminant is unlikely to cause harmful effects, and the PEC is the concentration above which a contaminant is likely to cause harmful effects, in a freshwater ecosystem. For mercury, the TEC and PEC, respectively, are 180 ppb and 1,060 ppb (MacDonald et al. 2000).

RESULTS

Beachland Park Pond

Out of the 70 sediment samples analyzed, 21 exceeded the Consensus-based Threshold Effect Concentration (TEC) of 180 ppb, below which harmful effects are unlikely to be caused by mercury (MacDonald et al. 2000). Of those 21 samples, 6 also exceeded the Consensus-based Probable Effect Concentration (PEC) of 1,060 ppb, indicating that their mercury concentrations are likely to cause harmful effects (Table 1; MacDonald et al. 2000).

Mean (± SD) mercury concentration for Site 1 (261.5 ± 89 ppb), Site 3 (630.8 ± 383 ppb), Site 4 (2270.3 ± 2237 ppb), and Site 14 (808.1 ± 474 ppb) exceeded the TEC (Figure 4). Site 4 was the only site to also exceed the PEC of 1,060 ppb, with a mean concentration of almost double that value. A closer analysis of Site 4 (Figure 2) revealed that Sample 4_3 (6213.6 ppb) disproportionately affected the mean and standard deviation for the site overall, and the mean (± SD) of the remaining 4 samples was thus calculated for comparison (1284.5 ± 441 ppb). This value still exceeded the PEC.

There was a significant variation in mean mercury concentration among sampling sites, with Site 4 having significantly greater mercury concentrations than all other sites ($F = 4.635$, $df = 13, 56$, $p < 0.0001$). No other pairs of sites differed significantly from one another.

The mean mercury concentrations for each site were mapped onto their geographic coordinates, revealing that the 4 sites which exceed the TEC are approximately clustered in the northeast corner of the pond (Figure 6).

Table 1. Mean mercury concentration and standard deviation based on three mercury analysis runs per sample in 70 samples of subaqueous sediment in Beachland Park Pond, West Hartford, CT.

Sample	Mean Hg Concentration, ppb	SD	Sample	Mean Hg Concentration, ppb	SD
1_1*	218.8	35.6	8_1	142.3	32.1
1_2	179.5	11.9	8_2	83.4	5.3
1_3*	342.2	98.0	8_3	124.8	1.9
1_4*	371.8	107.7	8_4	86.9	11.3
1_5*	195.0	15.4	8_5	101.4	12.0
2_1	102.0	3.3	9_1	108.3	93.6
2_2*	254.0	109.3	9_2	107.2	21.1
2_3	149.6	44.4	9_3	41.8	10.7
2_4	176.4	74.6	9_4	49.6	4.6
2_5	162.2	35.9	9_5	72.3	27.3
3_1*	363.1	26.7	10_1	32.2	1.6
3_2*	368.1	29.5	10_2	28.7	1.7
3_3*	796.5	47.3	10_3	29.2	1.2
3_4*	395.0	20.9	10_4	37.9	12.3
3_5***	1231.6	57.4	10_5	40.4	2.5
4_1***	1774.3	242.1	11_1	57.0	3.8
4_2*	864.3	5.4	11_2	54.5	5.0
4_3***	6213.6	1490.9	11_3	82.0	8.1
4_4*	962.7	487.5	11_4	59.1	5.9
4_5***	1536.6	585.1	11_5	63.2	12.0
5_1*	290.4	14.5	12_1	97.3	1.8
5_2	156.6	26.5	12_2	104.7	13.5
5_3	162.7	7.3	12_3	128.2	24.4
5_4	64.2	9.1	12_4	107.2	7.3
5_5	178.8	11.0	12_5	151.1	14.3
6_1	64.2	5.9	13_1	140.5	69.5
6_2	73.5	9.8	13_2	87.2	9.3
6_3	43.4	8.6	13_3	106.6	20.7
6_4	68.3	2.2	13_4	113.7	9.6
6_5	73.7	14.9	13_5	125.1	16.7
7_1	74.4	8.1	14_1***	1217.9	197.6
7_2	50.4	13.1	14_2*	536.8	45.6
7_3	37.5	8.4	14_3*	538.8	68.2
7_4	48.8	21.4	14_4***	1411.2	275.7
7_5	41.2	27.7	14_5*	335.7	13.5

* Exceeds TEC, *** Exceeds PEC

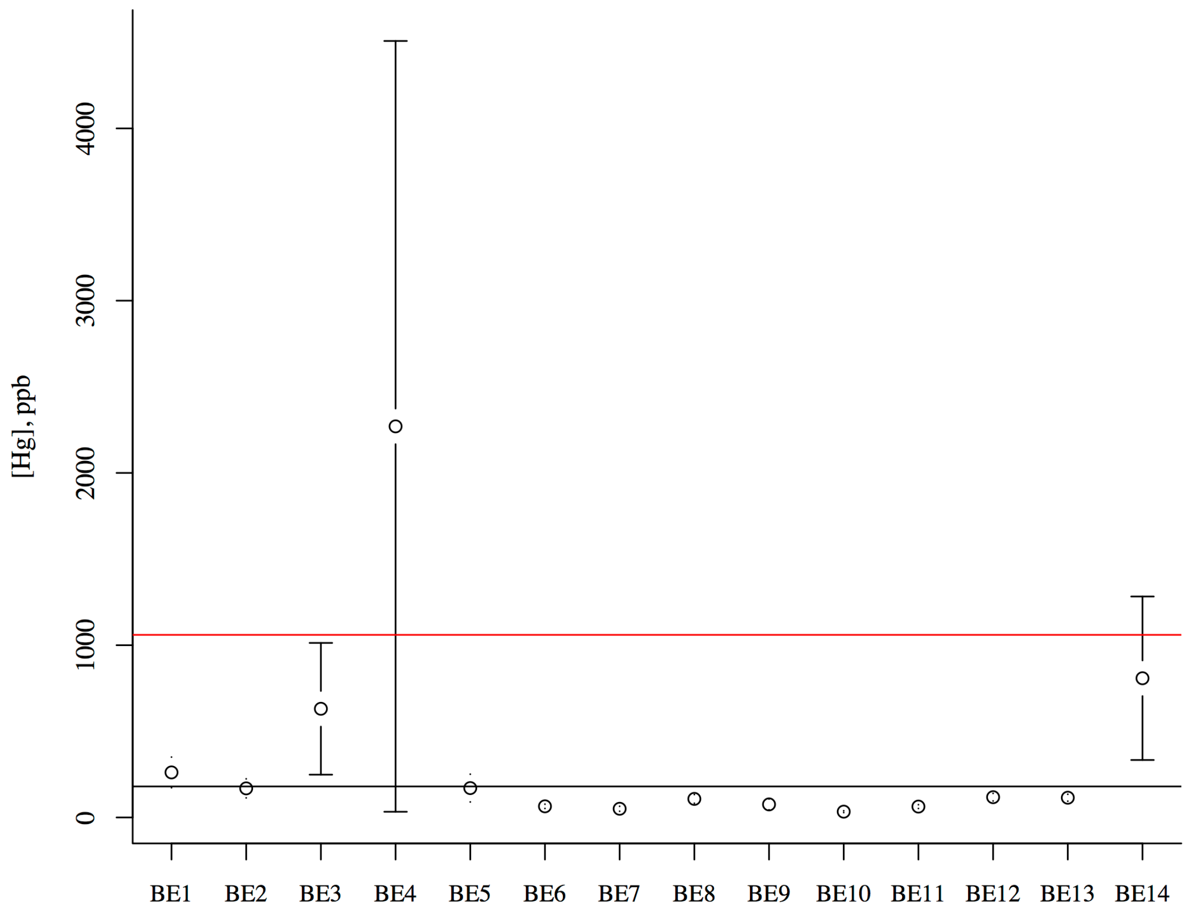

Figure 4. Mean (± SD) mercury concentration in subaqueous sediment at 14 sample sites (5 samples per site) in Beachland Park Pond. The Threshold Effect Concentration (TEC), below which [Hg] is unlikely to cause harmful effects, is marked as a horizontal black line. The Probable Effect Concentration (PEC), above which [Hg] is likely to cause harmful effects, is marked as a horizontal red line.

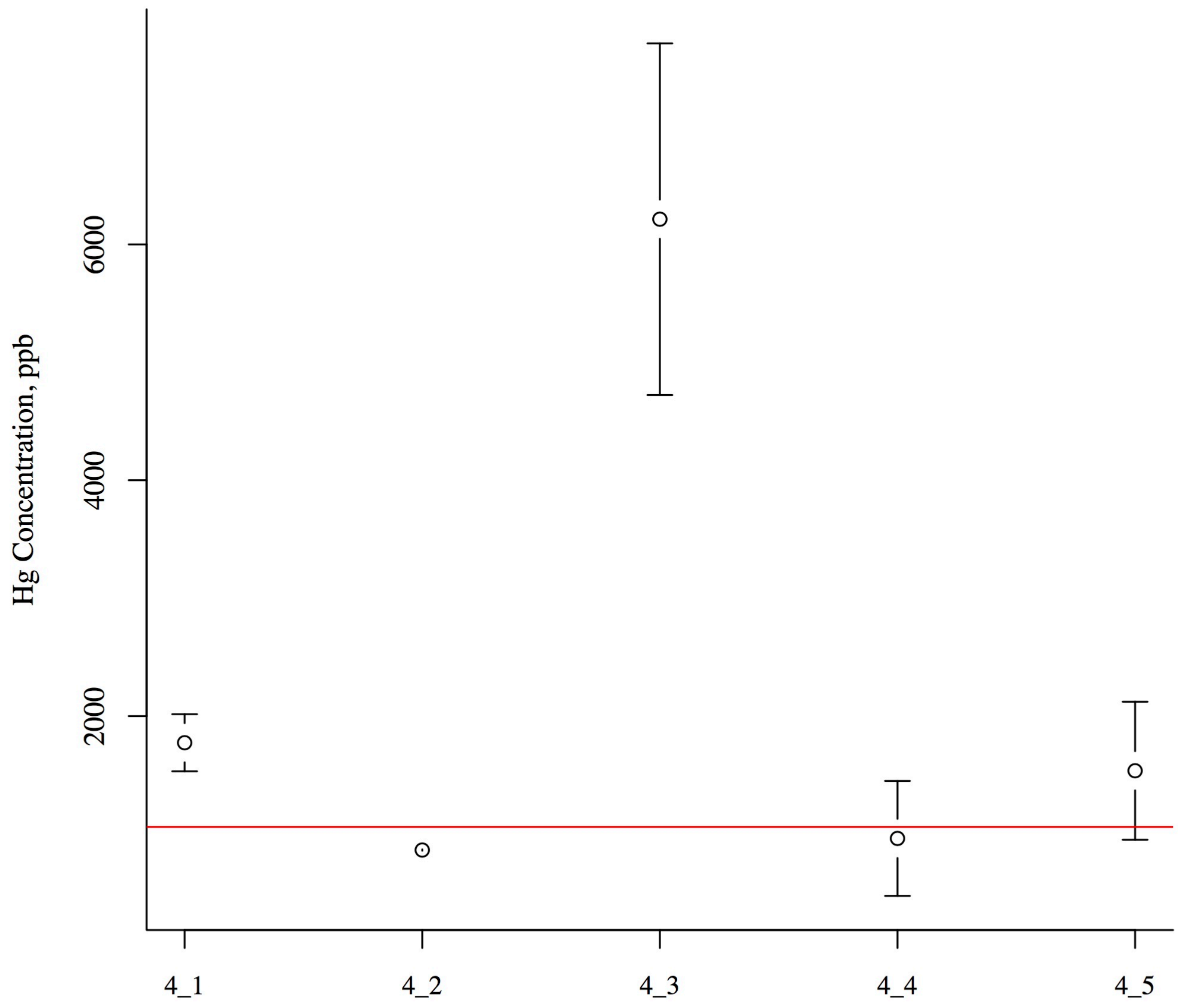

Figure 5. Mean (± SD) mercury concentration in subaqueous sediment in each of 5 samples (3 mercury analysis runs per sample) at Site 4 in Beachland Park Pond. The Probable Effect Concentration (PEC), above which [Hg] is likely to cause harmful effects, is marked as a horizontal red line.

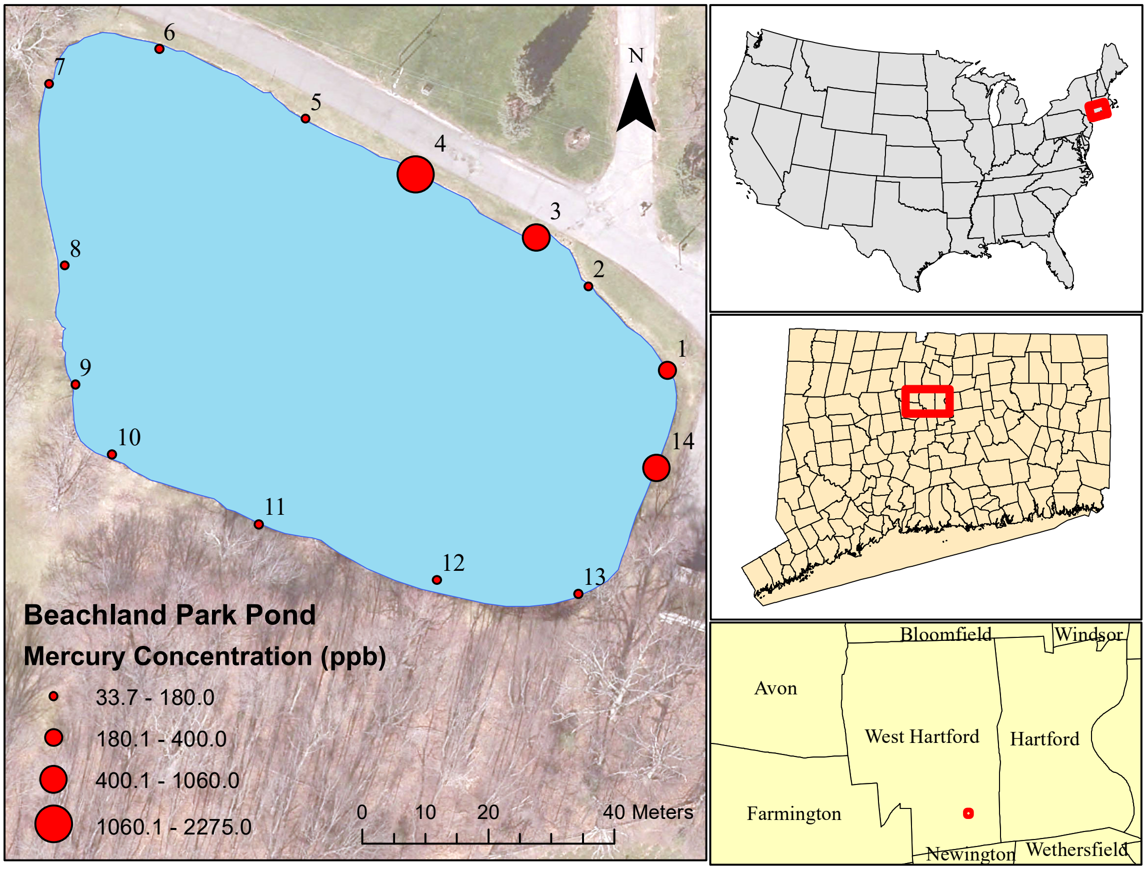

Figure 6. Map of mean mercury concentration in subaqueous sediment at 14 sample sites (spaced approximately 20 m apart) in Beachland Park Pond, classified by the TEC, PEC, and a point between them (CT DEEP and USGS 2005, CT DEEP 2016, Price 2018).

Keney Park Pond

Out of the 70 sediment samples analyzed, 5 exceeded the Consensus-based Threshold Effect Concentration (TEC), below which harmful effects are unlikely to be caused by mercury (MacDonald et al. 2000). None of them exceeded the Consensus-based Probable Effect Concentration (PEC; Table 2).

Mean (± SD) mercury concentration exceeded the TEC at Site 11 only (244.5 ± 28 ppb; Figure 7). None of the sample sites exceeded the PEC. A closer analysis of Site 11 (Table 2) reveals that the five samples have relatively uniform mercury concentrations, all of which exceed the TEC.

There was a significant variation in mean mercury concentration among sampling sites, with Site 11 having significantly greater mercury concentrations than all other sites except Site 10, and Site 10 having significantly greater mercury concentrations than Sites 1, 2, 4, 6, and 12-14. ($F = 42.4$, $df = 13, 56$, $p < 2E{-16}$).

The mean mercury concentrations for each site were mapped onto their geographic coordinates, revealing that Site 11, which exceeds the TEC, is in the southwest corner of the pond, as well as the site with the second-highest mercury concentration, Site 10 (124.9 ± 8.0 ppb; Figure 8).

Table 2. Mean mercury concentration and standard deviation based on three mercury analysis runs per sample in 70 samples of subaqueous sediment in Keney Park Pond, Hartford, CT.

Sample	Mean Hg Concentration, ppb	SD	Sample	Mean Hg Concentration, ppb	SD
1_1	71.5	18.5	8_1	51.3	6.3
1_2	52.1	6.9	8_2	91.6	18.7
1_3	67.7	4.2	8_3	70.1	12.3
1_4	61.3	4.9	8_4	64.2	8.4
1_5	60.5	2.7	8_5	161.5	31.6
2_1	56.7	5.6	9_1	89.0	9.7
2_2	60.4	4.4	9_2	72.7	9.1
2_3	25.1	5.1	9_3	89.9	29.7
2_4	59.2	11.5	9_4	86.8	22.6
2_5	44.6	5.1	9_5	79.4	24.4
3_1	67.8	16.5	10_1	126.7	30.8
3_2	109.3	74.4	10_2	116.4	29.9
3_3	60.3	37.7	10_3	137.6	15.1
3_4	98.8	47.8	10_4	121.3	13.7
3_5	96.4	35.4	10_5	122.5	5.3
4_1	22.8	9.0	11_1*	280.9	63.0
4_2	30.7	2.5	11_2*	265.8	18.2
4_3	35.4	15.2	11_3*	210.7	35.2
4_4	31.8	11.6	11_4*	230.2	16.5
4_5	36.5	22.4	11_5*	234.7	7.8
5_1	72.7	19.6	12_1	57.1	12.9
5_2	64.7	8.2	12_2	35.8	17.1
5_3	109.4	34.1	12_3	31.0	9.2
5_4	110.8	22.3	12_4	45.1	18.1
5_5	107.0	20.4	12_5	36.9	12.4
6_1	37.9	6.5	13_1	92.3	41.4
6_2	36.5	3.7	13_2	29.6	1.1
6_3	24.5	1.3	13_3	44.2	3.7
6_4	59.2	28.4	13_4	46.2	4.6
6_5	56.2	6.6	13_5	31.9	2.8
7_1	82.9	3.6	14_1	32.8	9.2
7_2	87.8	16.4	14_2	21.4	3.1
7_3	109.4	26.1	14_3	21.4	4.3
7_4	107.8	12.6	14_4	30.4	10.1
7_5	90.7	3.7	14_5	24.1	2.7

* Exceeds TEC

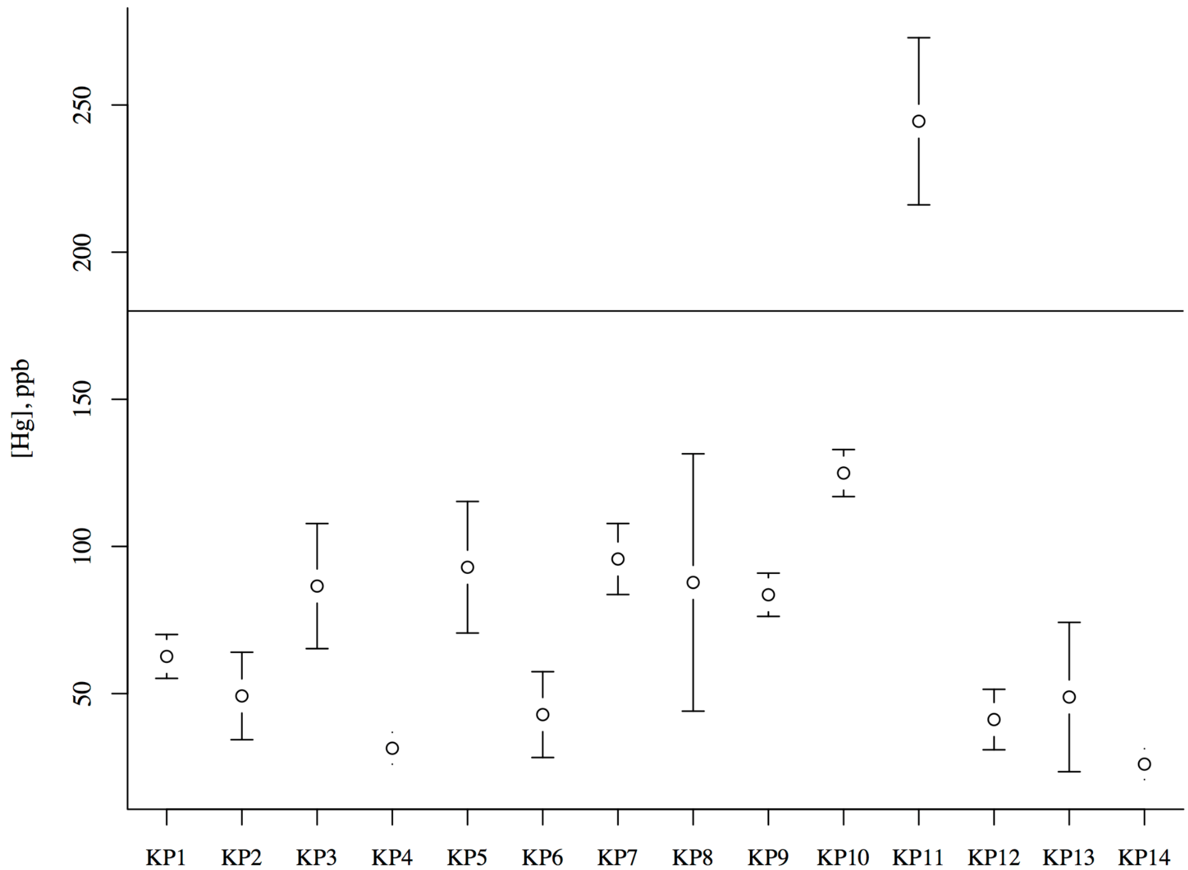

Figure 7. Mean (± SD) mercury concentration in subaqueous sediment at 14 sample sites (5 samples per site) in Keney Park Pond. The TEC is marked as a horizontal black line.

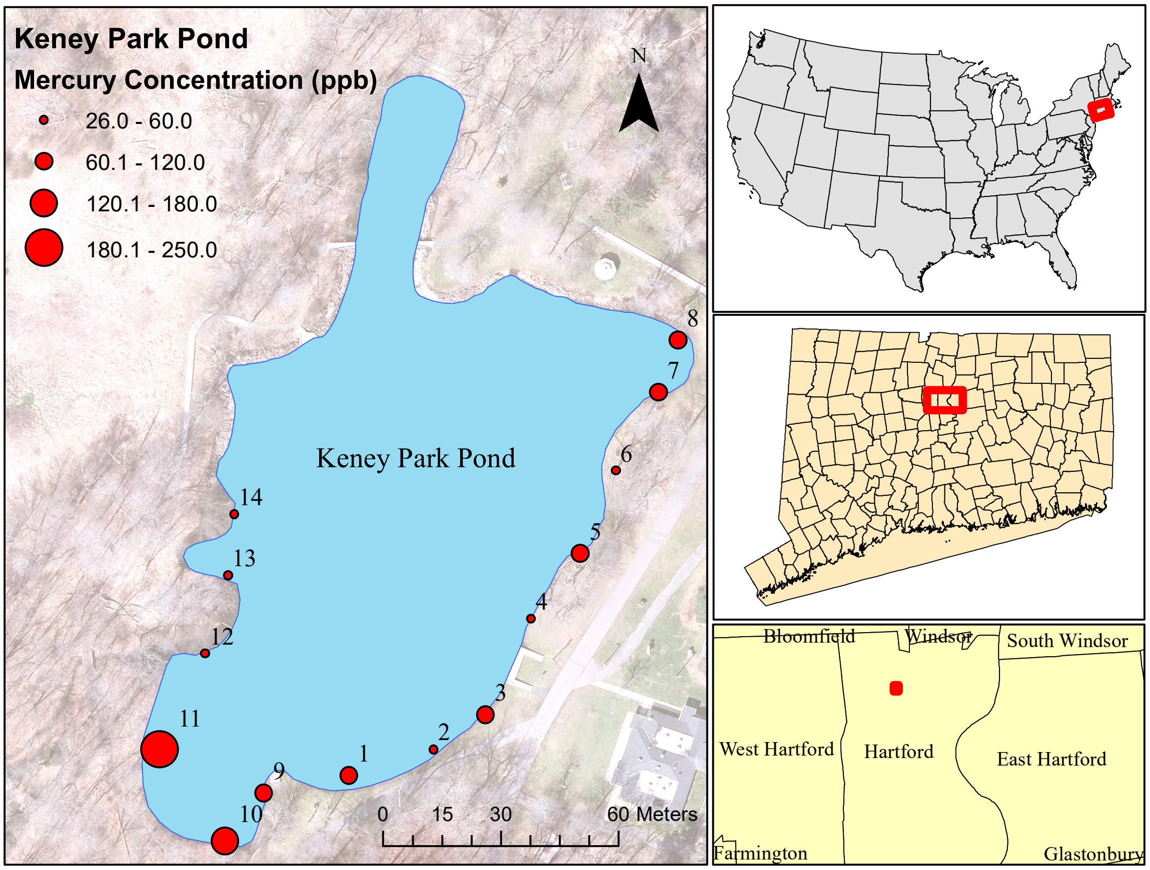

Figure 8. Map of mean mercury concentration in subaqueous sediment at 14 sample sites (spaced approximately 20 m apart) in Keney Park Pond, classified by the TEC and two points below it (TEC/3 and 2TEC/3; CT DEEP and USGS 2005, CT DEEP 2016, Price 2018).

DISCUSSION

The data collected in this study for Beachland Park Pond reveals that 13 out of a possible 91 pairs of sample sites showed significant variation, with Site 14 differing significantly from all other sites. In Keney Park Pond, 39 out of a possible 91 pairs of samples sites showed significant variation. The majority of this data supports previous findings and the hypothesis that mercury concentrations would be approximately consistent around the pond's perimeter. The most significant pathway for environmental mercury contamination in the northeastern United States is atmospheric deposition, and due to prevailing wind patterns and mercury's ability to travel long distances, much of this atmospheric mercury can be traced to coal burning power plants in the Midwest (Balcom et al. 2004, Driscoll et al. 2007, Evers et al. 2007). Due to the nonselective nature of atmospheric deposition as a source of mercury, it could be expected to find no significant variation in mercury concentration among sites within a single pond (Jeffries and Snyder 1981). In fact, research has found evidence of this lack of spatial variation (Wopereis et al. 1988, Boszke and Kowalski 2006, Strickman and Mitchell 2017).

Beachland Park Pond's one visible outfall exists approximately halfway between Site 8 and Site 9 (Figure 5), and the lack of significant variation in mercury concentration between either of those two sites and others further from the outfall supports previous research (Phillips et al. 1997). For example, Phillips et al. (1997) found no variation in mercury concentrations between Barred sand bass (*Paralabrax nebulifer*) near an outfall and elsewhere.

Site 4, with a mean ± SD of 2270.3 ± 2237.2 ppb, may not be explained by atmospheric deposition alone. The northeastern corner of Beachland Park Pond is the location of a covered drain, where water drains downward out of the pond and into a subterranean channel that feeds into the nearby heavily impacted, urban stream, Trout Brook. This drain structure itself could be a potential source of mercury, which is supported by the fact that Site 3, about 2 meters from the drain, exceeded the TEC (Figure 5). However, by far the highest mercury concentration was found at Site 4, which is further from the drain than both Site 2 and Site 3.

Sites 1-4 and 14 seem to show a gradient in mercury concentration, with the lowest concentration occurring at the center point, Site 2, and the highest concentrations occurring at the two points furthest from the center, Sites 4 and 14 (Figure 5). This cluster of sites is approximately centered on the large drain structure in the pond. Trout Brook, a partially-channelized urban stream, exhibits a flashy hydrograph following precipitation events and often has significant flooding (Walsh et al. 2005). Therefore, it is possible that when the stream is high enough, water could flow back through the channel and into Beachland Park Pond. This back-flooding could transport contaminants, including mercury, into the pond from the stream, and it is possible that the mercury concentration gradient in the northeastern area of the pond represents the extent to which mercury enters the pond from the stream during a flooding event before settling into the sediment. The very high concentrations on the edges of this region could be explained by the rapid influx of water when a flooding event starts, which can transport particles further than slower-moving water (Puig et al. 2003). This initial wave of input would be followed by mercury-contaminated particles beginning to settle around the farthest reaches into the pond of the floodwater, and as the flood recedes back towards the drain, mercury-contaminated particles would continue to settle, resulting in the shown concentration gradient (Figure 5).

Anecdotal evidence from a private citizen provides a third hypothesis for Beachland Park Pond. The citizen shared that the pond is sometimes treated for algae growth, and in the past some algicides and pesticides were organic mercury-containing compounds, until these were banned by the Environmental Protection Agency in 1976 (Fitzgerald and DerVartanian 1969, United Press

International 1976, Weiss-Magasic et al. 1997). Mercury has a tendency to remain in sediments for an extended period of time, so it is possible that historical use of these chemicals continues to impact the ecosystem (Saniewska et al. 2014). The proximity of roads to the northeastern corner of the pond make this a logistically good place from which to do the algicide treatment, and this may result in the elevated mercury concentrations from samples in that area. Additionally, the proximity of this part of the pond to roads, an example of an impervious surface, indicates there would be increased runoff into the pond near the sampling sites of concern (Semrod and Gourley 2014).

Due to prevailing wind patterns and mercury's ability to travel long distances, much of the atmospheric mercury in the northeastern United States can be traced to coal burning power plants in the Midwest (Balcom et al. 2004, Driscoll et al. 2007, Evers et al. 2007). It is possible that these common wind patterns are also contributing to the accumulation of mercury in the pond's northeastern shore (Klink 1999). Atmospheric mercury deposited on the pond surface by these wind currents would be likely to accumulate on the northeastern shore as particles are driven against the sediment, whereas the opposite shore is protected from deposition by a barrier of forested land (visible in Figure 2), and therefore has lower mercury concentrations.

Keney Park Pond seems to be more easily explained by the initial hypotheses of the study. In general, the sampling sites in this pond have a relatively uniform distribution of mercury concentrations, which supports previous research and the mechanism of atmospheric deposition (Jeffries and Snyder 1981, Wopereis et al. 1988, Boszke and Kowalski 2006, Strickman and Mitchell 2017). Site 11, the only sampling site to exceed the TEC, is found in the southwestern corner of the pond (Figure 8). This does not support the hypothesis of wind patterns causing high accumulation in the northeastern part of ponds, as was proposed for Beachland Park Pond.

However, the data support the initial hypothesis of mercury concentrations being highest near the pond's inflow and/or outflow. Site 11 is located directly in front of a low dam and corrugated metal tube which is the main entry point of water into the pond. Water enters here at a very low flow rate, and any mercury which may be present in the water is likely to settle quickly near this location (Lee et al. 1997, Karlsson et al. 2010).

Further research is needed to investigate sources of mercury in areas of high concentration, as well as temporal variation in mercury concentration. An investigation of mercury concentrations in subaqueous sediments in the central area of the ponds could reveal more about the overall distribution, and a similar investigation of terrestrial sediments surrounding the ponds could also reveal more about mercury's mechanism of transportation and accumulation in these urban pond systems. Expanding this study to more ponds in the region could allow for the development of a generalized predictive model of where mercury accumulates in urban pond ecosystems.

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