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Accumulation and Hazard Assessment of Mercury to Waterbirds at Lake Chapala, Mexico

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Supporting Information

ABSTRACT: Lake Chapala is the largest tropical lake in Mexico. The objectives of this study were to determine bioaccumulation of Hg in fish and to evaluate the potential impacts of Hg in the diet of aquatic birds, particularly the American white pelican (AWPE), in Lake Chapala. Hg concentrations in three fish species ranged from 0.021 to 0.568 μg/g wet weight. Mercury in fish was positively and significantly correlated with total fish length ($R^2 = 0.44$, $P < 0.05$). The $\delta^{15}N$ values in fish were significantly correlated with Hg concentrations in Chapala and the San Antonio Reservoir ($R^2 = 0.69$, $P < 0.001$ and $R^2 = 0.40$, $P < 0.001$, respectively). However, Hg concentrations in bird feathers were not significantly different between years, among locations, or among species. Hg concentrations in fish from Lake Chapala were within values reported in many parts of the world. The Hg (mean range of 2.75 to 4.54 μg/g dw) and δD (mean range of −62‰ to −11‰) values in bird feathers suggested a wide pattern of exposure for highly migratory AWPE and egrets, although birds with lower δD values in feathers appeared to have greater concentrations of Hg than those with higher δD values. Contaminant exposure in aquatic birds in Chapala during the breeding season should be monitored next to better determine the potential effects of Hg on resident aquatic birds.

INTRODUCTION

Mercury (Hg) emissions from anthropogenic sources have contributed to the contamination of aquatic ecosystems all over the world.[1] Anthropogenic sources of Hg include solid waste incineration, coal and oil combustion, pyrometallurgical processes, gold mining, and domestic sewage discharge.[2,3] Natural sources of Hg include primarily volcanic and geothermal activities.[4,5] Mercury occurs in the aquatic environment in inorganic and organic forms; however, the predominant form of Hg is dependent on suspended organic matter.[6] The methylating activity of certain anaerobic bacteria in aquatic environments converts inorganic Hg to methyl mercury (MeHg), which readily bioaccumulates and biomagnifies in the food web.[7] Fish exposed to MeHg could be affected in their behavior, growth, reproduction, development, and survival.[8] Male Nile tilapia (*Oreochromis niloticus*) had a decrease in spermatogenesis and atrophied seminiferous tubules after being experimentally exposed to MeHg in the laboratory for seven months.[9] In female fish, mercury can inhibit steroid hormone synthesis, affect ovarian morphology, and hinder oocyte development.[9] In birds, MeHg has been associated with brain lesions, spinal cord deterioration, and central nervous system dysfunctions.[10−12] Methylmercury in birds also leads to reduced food intake, advanced weakness in wings and legs, trouble flying, walking, and standing, and an inability to coordinate muscle movements.[11,12] Reproductive effects of Hg in birds include reduced hatchability, decreased clutch size, abnormal behavior of juveniles, and possible impaired hearing of juveniles.[12]

The Lerma-Chapala Basin is the home of about 10% of Mexico's human population. Industrial, agricultural, and urban settings along the basin potentially contribute a great variety of contaminants to the Rio Lerma which discharges its waters into Lake Chapala, the largest tropical lake in Mexico (Figure S1, Supporting Information). Lake Chapala represents a major fishery and recreation resource for various communities surrounding the lake, as well as for tourists from many parts of the country.[13] Lake Chapala is the ultimate receptor of a great variety of contaminants from the sub-basin, including

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pesticides, industrial residues, oils, detergents, and heavy metals such as, chromium, lead, zinc, and mercury.[14,15] Local sources of pollution also are visible; Chapala County generates over 95 tons/day of trash which is deposited without treatment in an open pit.[13] Despite concerns for the effects of pollutants on human and ecosystem health, studies addressing contaminant issues in Lake Chapala are few.

The three most commonly harvested and consumed fish species in the Chapala Region include: silverside (*Chirostoma* spp., commonly known as charal), common carp (*Cyprinus carpio*), and tilapia (*Oreochromis spp.*).[16] One recent study has suggested that there has been an increase in the relative abundance of pollution tolerant fish species in Lake Chapala.[17] Contaminant studies in Lake Chapala have focused primarily on metal pollution. Seasonal variability in the accumulation of metals in water, with potential increases during the dry season (likely because of evaporation) and decreases during the rainy season, has been reported.[18] In 1993, elevated concentrations of Cr, Ni, and Cu were reported in sediments.[14] Also, elevated concentrations of Hg were reported previously in silverside (up to 4.9 μg/g dry weight) and common carp (0.87 μg/g wet weight).[15,19,20]

Lake Chapala has been recognized as one of the most important wetlands of Mexico and was designated as a RAMSAR site in 2011.[21] More than 80 species of aquatic birds have been reported for Lake Chapala, and it is one of the largest wintering areas for American white pelicans (*Pelecanus erythrorhynchos*, AWPE) in Mexico (pers. observ. and D.W. Anderson pers. comm.). American white pelicans are fish-eating birds and could be affected by contaminants that accumulate via the food chain, such as MeHg. Mean concentrations of total Hg in eggs of AWPE nesting on Anaho Island, Nevada, ranged from 0.47 μg/g ww in 1988 to 0.39 μg/g ww in 2004, with no apparent negative effects on reproduction.[22] Currently, to our knowledge, there are no studies which have evaluated the impacts of metals and other contaminants on fish-eating birds and other wildlife in Lake Chapala. The American white pelican is a species of special concern in the United States and is protected under the Migratory Bird Treaty Act. The objectives of this study were to determine bioaccumulation of Hg in fish and to evaluate the potential impacts of Hg in the diet of aquatic birds, particularly the American white pelican, in Lake Chapala. We also used stable carbon and nitrogen isotope values (δ^{13}C and δ^{15}N) in fish tissue to determine trophic differences among the three fish species and predict potential Hg movement from water and sediments to fish. Additionally, we analyzed Hg in feathers of AWPE wintering in Chapala to determine Hg exposure in their breeding and molting grounds in the north and to compare with resident aquatic species and one reference colony in North Padre Island, Texas.

METHODS

Study Area. Lake Chapala is located between the boundaries of the states of Jalisco and Michoacan, with more than 80% of the total surface (114,659 Ha) located in Jalisco (Figure S1, Supporting Information).[23] The lake coordinates are 20°07′ N, 102°39′ W, at an altitude of 1524 m above sea level, median length of 14.8 km, maximum length of 75 km, median water volume of 7,653 Mm^3, and median and maximum depth of 4 and 7 m, respectively.[23,24] Annual rainfall is estimated at 730 mm with most rain occurring between May and October.[25] Additional information about the lake is provided in the Supporting Information.

Sample Collection. Water, sediments and fish (common carp, tilapia [*O. aureus*], and silverside) were collected in the winter of 2011 (January 14) and 2012 (January 11) from three locations southeast of Lake Chapala and at a reference location (Figure S1, Supporting Information). All water samples were collected under the best aseptic conditions following EPA clean metals and mercury guidance (EPA Method 1669).[26] Additionally, primary feathers of American white pelicans and egrets (mostly great egrets, *Ardea alba*) were collected from roosting areas along the southeast shore of Lake Chapala during both years. Details about sample preparation and analysis are provided in the Supporting Information.

Chemical Analyses. All the samples were analyzed for Hg at the Trace Element Research Laboratory, College of Veterinary Medicine and Biomedical Sciences, Texas A&M University. Water was analyzed for mercury using EPA method 1631 revision E, with an automated sampling analysis system, Tekran 2600. The sediments, fish, and feather samples were analyzed for total mercury by a Direct Mercury Analyzer (DMA-80) equipped with a 40 position autosampler and a dual cell detector. Mercury concentrations in samples were quantitatively measured by comparing peak absorption with that of known calibration standards. Accuracy was verified by analyzing a certified reference material and spiked samples. Precision was evaluated by analyzing replicate samples. The lowest limit of detection for Hg was 0.0002 ng/g for water, 0.7 ng/g for sediments, 4.4 ng for fish, and 19.4 ng/g for feathers. Additional QA/QC information is provided in Table S2, Supporting Information.

Stable Isotope Analysis of Fish Tissue and Avian Feathers. Stable isotope analysis was performed in the Stable Isotopes for Biosphere Science Laboratory, College of Agriculture and Life Sciences, Texas A&M University. The samples were analyzed for carbon and nitrogen isotope ratios (δ^{13}C and δ^{15}N) using an Elemental Combustion System (EA) (Costech) coupled to a Delta V Advance stable isotope ratio mass spectrometer (Thermo Scientific) and Conflo IV (Thermo Scientific). Carbon and nitrogen isotope results were reported relative to Vienna Pee Dee Belemnite (VPDB) and air, respectively. Hydrogen isotope ratios (δD) of avian feathers were analyzed using a high temperature conversion elemental analyzer (TC/EA) (Thermo Scientific) coupled to a Delta V Advance stable isotope ratio mass spectrometer (Thermo Scientific) and Conflo IV (Thermo Scientific). δD values of lake water samples were analyzed using the same instruments for the feather δD analysis. The δD results are reported relative to Vienna Standard Mean Ocean Water (VSMOW)−Standard Light Antarctic Precipitation (SLAP).

Statistical Analysis. The fish Hg data were log transformed to better fit a normal distribution for comparisons among species, between locations, and between years by GLM ANOVA (SAS 9.3). Stable carbon and nitrogen isotope values in fish also were compared between locations and between years by GLM ANOVA. Linear regression analysis was conducted between log transformed Hg data and total fish length. Hg concentrations in avian feathers from American white pelicans and egrets also were log transformed and compared by the GLM method. Hydrogen isotope values in feathers also were compared by the GLM method and by t tests. A Type I error (α) of 0.05 was used to judge the significance of all statistical tests.

RESULTS

Mean Hg concentrations in water collected in January 2011 from Lake Chapala were 0.015 ± 0.002 ng/mL (n = 6, range of 0.013−0.019 ng/mL). Mean Hg concentrations in sediments collected from the same locations during 2011 and 2012 ranged from 0.4 to 1.0 μg/g dry weight (n = 12, mean = 0.597 ± 0.190 μg/g dw). Mercury concentrations in fish were, for the most part, below 0.2 μg/g wet weight (ww) in the three species collected in Chapala and San Antonio during both years, except during 2011, when common carp from Chapala had mean Hg concentrations of 0.357 μg/g ww. Hg concentrations in common carp collected in 2011 in Chapala were significantly greater ($F_{8,48}$ = 30.1, P < 0.0001) than those in common carp collected in 2012 in Chapala and common carp collected during both years at San Antonio. Hg concentrations in common carp collected in 2011 were also significantly greater than concentrations in silverside and tilapia collected in 2011 and 2012 in Chapala and tilapia collected in San Antonio in 2012 (Table 1). Silverside collected in 2011 in Chapala also had significantly higher concentrations of Hg than those collected in 2012. Similarly, Hg concentrations in silverside during both years were significantly greater than Hg concentrations in tilapia from Chapala and common carp and tilapia from San Antonio. Common carp collected in 2012 in Chapala also had significantly higher concentrations of Hg than in tilapia collected both years in Chapala as well as in tilapia collected in San Antonio in 2012. Overall, concentrations of Hg in common carp and silverside were significantly greater than those in tilapia. Mercury in fish was positively and significantly correlated with total fish length (R^2 = 0.44, P < 0.05, Figure 1), as expected.[27]

Table 1. Total Mercury Levels (Geometric Mean and Range, μg/g Wet Weight) in Fish Collected from Lake Chapala and San Antonio Reservoir in 2011 and 2012[a]

year	location	species	n	Hg (μg/g ww)
2011	Chapala	common carp	8	0.357 A (0.265−0.568)
		tilapia	10	0.035 E (0.021−0.108)
		silverside	8[b]	0.150 B (0.126−0.172)
	San Antonio	common carp	5	0.073 CD (0.042−0.134)
2012	Chapala	common carp	6	0.101 BC (0.056−0.215)
		tilapia	6	0.036 DE (0.024−0.064)
		silverside	8[b]	0.076 C (0.067−0.091)
	San Antonio	common carp	3	0.072 BCDE (0.033−0.11)
		tilapia	3	0.031 DE (0.027−0.033)

[a]Mean values not sharing the same letter are significantly different. [b]Composite samples (8 individuals each).

Stable carbon and nitrogen isotope ratios (δ^{13}C, δ^{15}N) of fish tissue varied among species, primarily between common carp and tilapia from Lake Chapala with those in the San Antonio Reservoir (Table 2). Silverside which grows to an average of 90 mm, approximately one-third the total length of common carp, had δ^{15}N values very similar to those of common carp (Table 2, Figure 2). The δ^{15}N values in these two species were nearly one trophic level above (difference in δ^{15}N of 2.69‰ for common carp and 2.48‰ for silverside) the level observed for tilapia in Chapala. Also, δ^{15}N values in common carp and tilapia from Chapala were nearly 2 trophic levels higher (difference in δ^{15}N of 5.46‰ and 5.07‰, respectively) than those in common carp and tilapia from the San Antonio Reservoir (Table 2, Figure 2). We consider that there is an enrichment of δ^{15}N of about 3‰ from one trophic level to the next.[28] δ^{15}N was a very good predictor of Hg concentrations both in Chapala and in the San Antonio Reservoir (Figure 3); the coefficient of determination was highly significant for the fish in Chapala (R^2 = 0.69, P < 0.001) and also for the San Antonio reservoir (R^2 = 0.40, P < 0.001). The predictive equation for Hg based on δ^{15}N values in fish from Chapala was:

$$\log \text{Hg} = -4.3 + 0.19\ (\delta^{15}\text{N})$$

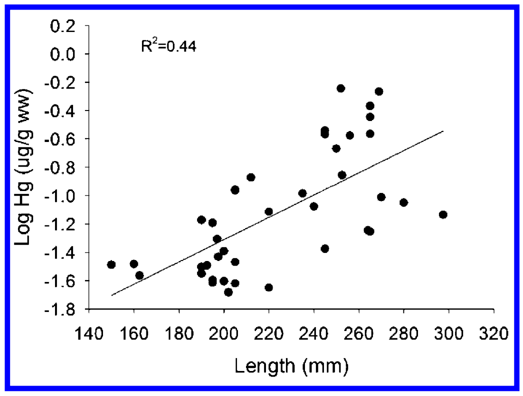

Figure 1. Relationship between total fish length and Hg concentration (silverside fish not included).

The δ^{13}C values were somewhat broader in common carp from San Antonio (range of −20.2‰ to −30.93‰) than in common carp from Chapala (−25.06‰ to −27.26‰). The three fish species from Chapala had much narrower δ^{13}C values than the fish from San Antonio (Table 2, Figure 2).

Mercury concentrations in bird feathers were not significantly different ($F_{4,45}$ = 2.1, P = 0.09) among locations or among species; however, they were slightly higher in egrets from Chapala and were much lower in AWPE from Padre Island National Seashore than in AWPE from Lake Chapala (Table 3). The δD values in the same feathers analyzed for Hg from the three species were quite variable and ranged from −11‰ to −161‰ suggesting many locations of feather growth (Table 3, Figure 4). Only a few δD values in feathers were close to the δD values in water from Lake Chapala (mean = −25.9 ± 0.5‰). There was not a significant relationship between Hg in feathers and δD.

DISCUSSION

Total Hg values in water from Lake Chapala were somewhat high compared with results from other freshwater lakes; however, the highest Hg values (18.8 ppt) were lower than those measured in the Jose Antonio Alzate Reservoir, Mexico in 1995 (104 ppt), which is formed by the Lerma river upstream of Lake Chapala.[29] However, the method for Hg analysis was not described in this study; thus, their results may not be comparable with ours.[29] Notwithstanding, Hg levels in water from Lake Chapala were higher than those observed in Lake

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Table 2. Stable Isotope Ratios (Means ± SD) of Carbon ($\delta^{13}C$) and Nitrogen ($\delta^{15}N$) in Fish from Lake Chapala, Jalisco, and San Antonio Reservoir, Michoacán, Mexico

location	species	*n*	total length (mm)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Lake Chapala	common carp	14	263 ± 14	−26.11 ± 0.65	18.03 ± 1.41
	tilapia	16	199 ± 8	−26.86 ± 1.73	15.34 ± 0.98
	silverside	16[a]	90 ± 0	−26.65 ± 0.20	17.82 ± 1.20
San Antonio	common carp	8	244 ± 40	−25.79 ± 3.87	12.57 ± 1.10
	tilapia	3	158 ± 7	−30.77 ± 0.78	10.27 ± 0.53

[a]Composite samples.

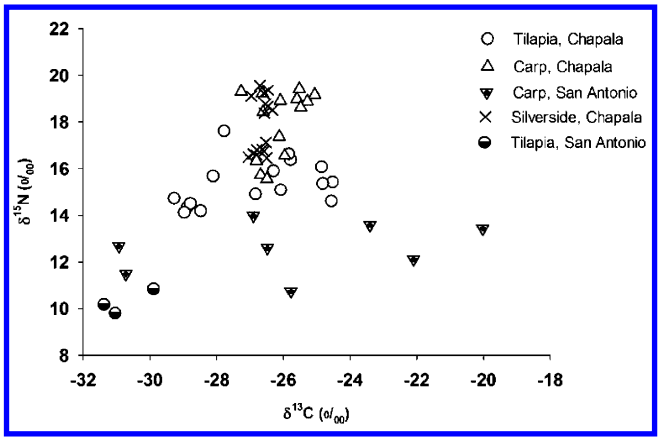

Figure 2. Relationship between $\delta^{13}C$ and $\delta^{15}N$ values in fish from Lake Chapala and San Antonio Reservoir.

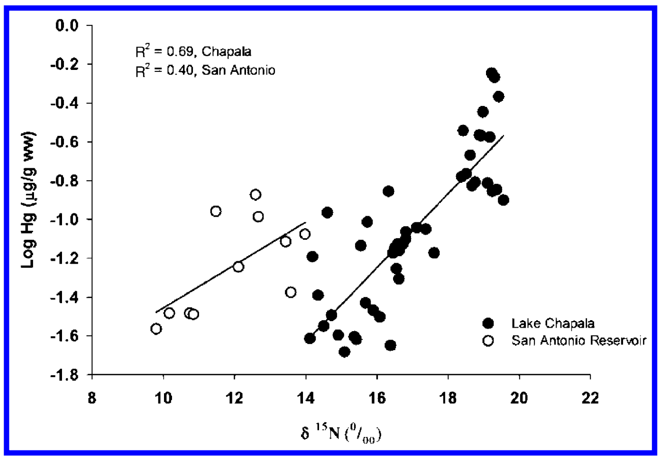

Figure 3. Relationship between Hg concentration (μg/g ww) and $\delta^{15}N$ values (‰) in fish muscle from Lake Chapala and San Antonio Reservoir.

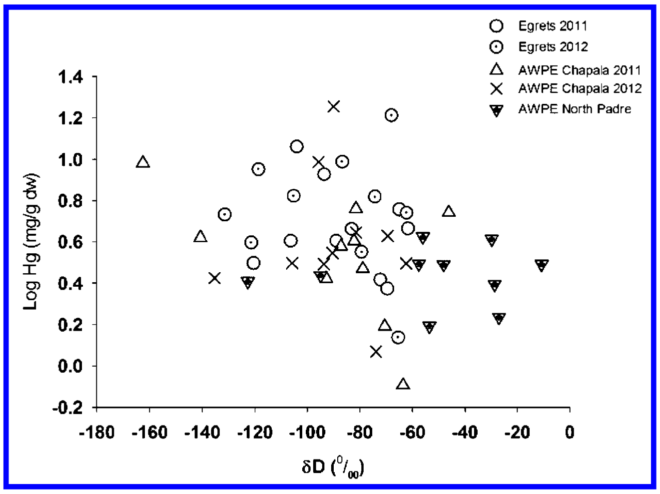

Figure 4. Relationship between Hg concentration (μg/g ww) and δD values (‰) in feathers of egrets and American white pelicans from Lake Chapala, Mexico, and North Padre Island National Seashore, Texas.

Zapotlan, Jalisco, Mexico, as well as in Minnesota, Nova Scotia, eastern Massachusetts, Lake Michigan, and south Brazil.[30−35] Chapala is a highly alkaline lake with a high pH (pH = 9.6, our measurement) which likely influenced the Hg concentrations in water. Accordingly, in alkaline lakes, there is less assimilation or methylation of Hg by bacteria than in more acidic lakes.[36]

Sediment Hg concentrations in Lake Chapala were similar to those reported in previous studies; however, sediment samples collected from deeper sites showed higher Hg concentrations (up to 1.28 ppm).[14,20] Hg concentrations in sediments from Lake Chapala were much greater than those observed in some Mississippi lakes and in Lake Ontario.[37,38]

Mercury concentrations in fish from Lake Chapala were within values reported in many parts of the world but were much greater than those reported for the reference reservoir San Antonio Guaracha in Michoacan and a nearby lake in Jalisco, Lake Zapotlan.[30] Hg concentrations in silverside were

Table 3. Total Mercury Levels (Geometric Mean and Range, μg/g Dry Weight) and δD Range Values (‰) in Feathers of American White Pelicans from Lake Chapala, Mexico, and North Padre Island National Seashore, Texas, and Egrets from Lake Chapala[a]

		2011			2012		
species	location of feather collection	*n*	Hg (μg/g dw)	δD range (‰)	*n*	Hg (μg/g dw)	δD range (‰)
American white pelican	Lake Chapala	10	3.37 (0.81−9.57)	−46 to −163	10	4.02 (1.17−18.0)	−62 to −135
	North Padre Island National Seashore	10	2.75 (1.56−4.21)	−11 to −123			
egrets	Lake Chapala	10	4.537 (2.36−11.5)	−62 to −120	10	5.69 (1.37−16.3)	−62 to −131

[a]Mean Hg concentrations were not significantly different among species or between years.

higher in previous years (0.704−4.937 μg/g dw) than what we observed (0.257−0.626 μg/g dw) in 2011−2012.[19,20] Higher Hg values also were reported for common carp in previous years (0.87 μg/g ww) relatively to what we observed in 2011−2012.[20] Previous studies indicate that most Hg in fish is actually MeHg, which is highly toxic to aquatic and terrestrial organisms.[39] Common carp was the only species with mean Hg values above the fish tissue residue criterion for freshwater and estuarine fish of 0.3 mg methyl Hg/kg fish ww recommended by the U.S. EPA but only during 2011.[40] In all cases, total Hg geometric mean values were well below the FDA action level of 1 mg/kg ww of methyl mercury in fish (http://www.fda.gov). The high pH value of Lake Chapala could also help explain the lower than expected Hg concentrations in fish.[32,41] However, the fish fillets analyzed included scales; thus, it is possible that the inclusion of scales contributed to lower than expected values in axial muscle tissue or skin on fillets.

Stable nitrogen isotopes (δ^{15}N) of fish tissue were useful to establish trophic differences among the three fish species in the two reservoirs and also to establish differences in Hg accumulation based on δ^{15}N levels. There were noticeable differences in trophic position particularly for common carp and tilapia from Lake Chapala and the San Antonio Reservoir. Within reservoirs, the fish species' diet was very similar in the two years of sampling (Table 2). Common carp and silverside from Chapala appeared to be feeding almost at the same trophic level or close to one trophic level above (δ^{15}N difference of 2.72‰ and 2.27‰, respectively) the level observed in tilapia in Chapala. The trophic level differences between reservoirs were remarkable. δ^{15}N values in common carp and tilapia in Chapala were 5.7‰ and 5.3‰ higher, respectively, than δ^{15}N values in common carp and tilapia in the San Antonio Reservoir. Also, it was clear that silverside and common carp in Chapala were feeding at a much higher trophic level than common carp in San Antonio. These feeding differences help explain differences in Hg accumulation between the species in Chapala and those from San Antonio. The most surprising finding was that silverside, a small fish growing to a total length of no more than 90 mm, seemed to be feeding almost at the same level as common carp, which can grow up to three times longer or more. In Lake Chapala, silversides feed primarily on cladocerans and copepods;[42] thus, this may explain the higher than expected Hg concentrations in silverside tissues.

The high accumulation of Hg in common carp and silverside in Chapala has implications for the accumulation and impacts of Hg on fish-eating birds, such as the AWPE, and aquatic birds such as egrets. The AWPE in Chapala feeds primarily on scraps from tilapia provided by fisherman; however, they also feed on common carp or other available fish. The silversides are probably too small for the AWPE to pursue as part of their diet. Great and snowy egrets are more likely to feed on smaller fish, such as silverside, suggesting that the Hg intake from eating this smaller fish species is quite high. This intake is probably reflected in the observed higher levels of Hg in egrets' feathers. Ardeid species are also more likely to represent resident species than AWPE. The highly positive significant relationship between δ^{15}N and log Hg (Figure 3) suggests that nitrogen isotope values could be good predictors of Hg concentration in fish in Lake Chapala. This is particularly important for tropical lakes such as Chapala to allow for more continuing monitoring of pollutants, such as Hg, with the use of less expensive analyses such as stable isotopes.

The highest Hg concentrations in feathers were from egrets; however, the δD values in water from Lake Chapala were much more enriched (−25.9 ± 0.5) than the δD values observed in egrets' feathers, suggesting that perhaps the egrets wintering in Chapala were not resident species but migrants that molted elsewhere in the north. However, there is fractionation between δD in water and δD in feathers; thus, we cannot rule out that the birds developed their feathers while drinking water from the lake.[43] Feathers of AWPE wintering in Lake Chapala had intermediate levels of Hg, whereas feathers of AWPE nesting in North Padre Island, Texas, had the lowest. This could be explained because birds that feed primarily on freshwater lakes tend to have higher concentrations of Hg than those that feed in marine or brackish environments.[44−46] The Hg in feathers suggests a wide pattern of exposure for AWPE from many inland locations relative to the North Padre Island colony. We analyzed δD values of feathers with the overall purpose of deducing potential breeding or molting areas for AWPE and egrets. Unfortunately, the δD values were too broad and inconclusive.

δD values in egret feathers were not different from those in feathers of AWPE wintering in Chapala. Feathers of AWPE from North Padre were the most enriched in agreement with other studies which have shown that feathers from birds feeding in coastal or marine environments have higher δD values than those feeding in terrestrial environments.[44−46] The δD values in feathers of AWPE and egrets collected in Lake Chapala suggest that between 50% and 70% of the feathers molted in more northern regions (δD_f range of −80‰ to −163‰), more likely at western breeding colonies in the north.[47] Recent studies have pointed out that the use of δD values to infer the origin of molting and breeding bird location should be taken with caution given that there are interspecific differences which may influence the transfer of hydrogen from a source to a consumer tissue.[43] Although not significant, Hg values tended to be higher in feathers with δD values between −70‰ and −120‰ more representative of midlatitude or northern regions.[44] Hg concentrations in feathers of AWPE wintering in Lake Chapala were within the lower range of those reported previously for AWPE from various regions of Nevada, Idaho, and Oregon (3.7−20 μg/g dw).[22] Similarly, Hg values in common carp from Chapala were within the ranges observed in fish regurgitated from various AWPE colonies in Nevada and Oregon in 1996.[22]

Lewis and Furness (1991) estimated that primary feathers of black-headed gulls (*Larus ridibundus*) accumulated between 1.33 and 4.67 μg/g dw MeHg when chicks were dosed with 20 and 100 μg MeHg, respectively.[48] There was a progressive reduction in the concentration of Hg in the primary feathers as successive primary feathers were grown. American white pelicans consume an average of 1.8 kg fish/da or 20−40% of their body mass.[49] If pelicans in Chapala were feeding exclusively on common carp, the Hg intake would have been on average 0.182 and 0.642 mg Hg/da for 2012 and 2011, respectively. This estimate indicates that Hg intake by AWPE could lead to much higher residues in feathers. However, AWPE are often seen in large flocks near commercial fisherman who discard tilapia and common carp remains after collecting fillets. American white pelicans feeding on tilapia would be expected to ingest lower concentrations of Hg. Exposure of AWPE to Hg in their diet while wintering in Lake Chapala could be of concern depending on the variability of Hg in fish. Lake Chapala is a very shallow lake, and the total volume of water in the lake could oscillate significantly based on drought

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and the amount of water withdrawn by different municipalities and the city of Guadalajara. Thus, it is expected that Hg concentrations in water and biota undergo considerable annual variations. The bird species found to be most sensitive to MeHg in the diet are common loons, and levels of 0.1, 0.18, and 0.4 μg/g MeHg ww in fish prey have been associated with thresholds for behavioral impacts, reproductive impairment, and reproductive failure, respectively.[50] Diets of about 1 μg/g ww in birds can result in Hg concentrations in feathers near 20 μg/g dw.[51] In raptorial birds, normal Hg concentrations in feathers are around 1−5 μg/g dw.[51] Clearly, there is considerable variability in Hg accumulation in bird feathers. Contaminant exposure in aquatic birds in Chapala during the breeding season should be monitored to better determine the potential effects of Hg on aquatic birds.

■ ASSOCIATED CONTENT

Supporting Information

One figure of Lake Chapala and reference sampling location, plus detailed information about sampling procedure and sample chemical analyses. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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