# Pilot Assessment of Mercury Exposure in Selected Biota from the Lowlands of Nicaragua

# Evaluación Piloto de Exposición al Mercurio en Biota Selecta de las Tierras Bajas de Nicaragua

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**Abstract.** Methylmercury, a potent neurotoxin, can damage health of humans and wildlife. In 2012, we collected 73 blood and feather samples from birds among diverse foraging guilds to assess mercury exposure in wetland habitats associated with Lakes Managua and Nicaragua. Blood levels (0.72 parts per million) in a piscivorous Neotropic Cormorant *Phalacrocorax brasilianus* from Lake Managua exceeded the United States Environmental Protection Agency recommended screening value for fish consumption of 0.3 ppm. Cormorants should be considered as an upper trophic level bioindicator of aquatic Hg toxicity. Of all the wetland invectivorous birds sampled, Northern Jaçana *Jacana spinosa* had the highest blood mercury concentrations (0.42 ppm) and we consider it as a bioindicator of wetland contaminants. Four of five species exhibiting the highest levels of blood mercury were piscivores and ground foraging invertivores. Several neotropical migrants exceeded feather concentration of >3.0 ppm and are considered at greater risk to reduced reproductive success.

Key words: mercury exposure, bioaccumulation, reproductive loss, wetlands, Nicaragua.

**Resumen**. Los efectos del metilmercurio (MeHg) en seres humanos y vida silvestre a nivel neurológico y reproductivo ha sido poco documentado en el neotrópico. En Febrero de 2012 se colectaron 73 muestras de sangre y plumas en 92 aves de distintos gremios alimenticios (piscívoros, omnívoros, insectívoros). Se encontraron niveles mayores (0.3 partes por millón) a los permitidos por la Agencia para la Protección Ambiental en Norteamérica en *Phalacrocorax brasilianus* (0.72 ppm). Esta ave puede considerarse un buen bioindicador del medio ambiente. De todas las especies muestreadas las concentraciones de mercurio más altas fueron de *Jacana spinosa* (0.42 ppm). Aves paserinas capturadas que registraron niveles de mercurio en los rectrices >3.0 ppm pueden mostrar bajo éxito reproductivo.

Palabras clave: exposición al mercurio, bioacumulación, pérdida reproductiva, humedales, Nicaragua.

## Introduction

A potent neurotoxin, methylmercury (MeHg), even at low concentrations, can cause subtle but permanent damage to the neurological and reproductive systems of wildlife (Wolfe, 1998). Studies of Hg exposure in bird species that eat invertebrates also indicate elevated exposure (Evers *et al.*, 2005; Rimmer *et al.*, 2005; Cristol *et al.*, 2008; Lane *et al.*, 2011; Townsend *et al.*, 2012) and impacts on reproductive success and survival (Schwarzbach *et al.*, 2006; Brasso and Cristol, 2008; Jackson *et al.*, 2011a, Scoville and Lane, 2013). It is introduced into the environment through many pathways, including local point sources and long distance atmospheric deposition, and has the potential to biomagnify up food chains and bioconcentrate in the tissues of higher trophic-level animals, and thus poses a hazard to their health. Through a process known as methylation and subsequent bioaccumulation in living organisms, mercury is stored in the tissues of primary consumers, e.g., herbivorous insects, and increases in secondary consumers, especially predators such as spiders, which tend to exhibit higher levels of mercury. The greatest concentrations of mercury, however, are amassed in tertiary (and upward) consumers such as the higher predators, carnivores and omnivores. Seed- and fruit-eating animals are typically not at risk to mercury exposure.

Elevated mercury in aquatic ecosystems is particularly dangerous because it bioaccumulates in fish and their predators. In fish-eating adult birds such as kingfishers and cormorants the blood effect concentration is 3 parts per million (ppm) and higher (Evers *et al.*, 2008). In adult songbirds the blood Hg levels associated with reduced reproductive success are 0.7 ppm and greater. The higher the Hg concentration, the stronger its impact on the number of nests that successfully fledge at least one young (Jackson *et al.*, 2011a). Recent research in the United States has documented elevated mercury concentrations in songbird blood as far as 130 km downstream from a point source (Jackson *et al.*, 2011b).

In Nicaragua, the extent of mercury contamination and exposure to the human (Hominidae, Linnaeus, 1758) population and wildlife are largely undocumented. Fish from Lake Managua are an important part of the diet of the local population living along the lakeshore, yet there have been high levels of mercury found in native fish species in the Lake (McCrary *et al.*, 2005).

To evaluate mercury bioaccumulation in higher trophic level vertebrates, in February of 2012 we conducted a preliminary assessment of exposure in birds in the lowlands of Nicaragua to (1) identify appropriate indicator species in Nicaragua for further studies, to determine if (2) wetland-inhabiting birds found near Lakes Managua and Nicaragua are at risk to Hg exposure, and (3) if further work is warranted. Other vertebrates, including humans, were sampled opportunistically. We selected the target species because of their omnivorous, piscivorous and insectivorous dietary preferences.

We found almost no information in the literature on mercury exposure in the birds of Central America and very little on other tropical regions (Townsend *et al.*, 2012). Thus, our intent is to provide a baseline mercury concentration database for resident birds and Neotropical migrants wintering in Mesoamerica.

## Materials and Methods

### Study Area

We captured and non-lethally sampled birds and (opportunistically) other vertebrates at five lowland locations in Nicaragua in February of 2012 (11°11’18” - 12°12’12” N and 85°29’25” - 85°55’33” W) 1), Tipitapa on Lake Managua; 2) Guayabo near Granada; 3) Cárdenas at the mouth of río Tirurí on Lake Nicaragua; we sampled two additional coastal sites near the Pacific Ocean as a comparison with the interior lake sites: 4) a tributary of río Escamequita; and 5) San Juan del Sur on the Pacific coast (mangrove habitat) (see Table 1 for elevations). With the exception of a mangrove forest site, which was included to test for potential fresh and saline water differences in mercury levels, all other sites were located in lacustrine or riverine wetland habitat bordering lakes Managua and Nicaragua and their respective drainages (Table 1).

### Field Sampling Techniques

We used four to six, 12 m mist nets with 30 mm mesh to capture birds. We determined sex in dichromatic species and age (adult or hatching year) in all species when able to do so with confidence. We released all birds unharmed within 10 to 25 minutes of capture.

Venipuncture of the cutaneous ulnar vein with a 27-gauge sterile disposable needle allowed collection of 50-70 μl of whole blood into heparinized mylar-wrapped

Table 1. Site names, locations, coordinates and habitats within which mercury samples were collected in Nicaragua (February, 2012).

| Site | Location | Habitat |
|---|---|---|
| La Bocana Bridge, “Highway Norte” (Pan American Highway) | Lake Managua-río Tipitapa<br>12°12’12” N, 86°05’58” W; 46.3 m elev. | Thorn scrub |
| Guayabo, 14 km N of Grenada | Lake Nicaragua-Granada<br>12°01’55” N, 85°55’33” W; 34.4 m elev. | Lacustrine wetland |
| Cárdenas, mouth of río Tirurí | Lake Nicaragua-Cárdenas<br>11°11’18” N, 85°29’25 W; 36 m elev. | Riverine wetland near agricultural plots |
| Tributary of río La Escamequita | Pacific Ocean (0.6 km inland)<br>11°11’32” W, 85°49’04” N; 12.2 m elev. | Riverine wetland bordering riparian woodland |
| Mangrove forest, Pacific Ocean | San Juan del Sur<br>11°15’36” N, 85°52’24” W; 6.4 m elev. | Red (*Rhizophora mangle*) and black (*Avicennia germinans*) mangrove |

tubes for Hg analysis. The capillary tubes were sealed with Critocaps®, stored in plastic vacutainers on ice for up to six hours before freezing at -17 °C. Feathers, mostly the two outer rectrices (4-6, depending on the species) but occasionally body feathers, were pulled and stored in plastic bags until analysis. All capture and sampling were conducted under appropriate Nicaraguan permits. In addition, we sampled hair from five humans (all males).

Mercury concentrations in blood reflect recent dietary uptake. Feather Hg reflects body burden of Hg at the time of molt. Based on Jackson *et al.* (2011a), we use the following three songbird feather thresholds for the estimated percent reduction in nesting success: (1) 10% (3.0 ppm); (2) 20% (4.7 ppm); and (3) 40% (7.7 ppm). To represent mercury concentrations, we use standard abbreviations: Hg (mercury) ppm (parts per million).

## Laboratory Methods

We analysed all blood samples collected but only 43 feathers due to monetary restrictions. Total-mercury was measured in blood and feathers as a proxy for methyl-mercury concentrations as both tissue types contain nearly exclusively methyl-mercury (Rimmer *et al.*, 2005; Edmonds *et al.*, 2010). Mercury in tissues was quantified using gold-amalgamation atomic absorption spectroscopy with a Milestone Direct Mercury Analyzer (DMA-80) following Environmental Protection Agency (EPA) method 7473 (USEPA, 1998), and following Quality Assurance/Quality Control (QA/QC) protocols for initial and continuing calibration, blanks, sample replication, and certified reference materials from the National Research Council Canada, DORM-3 (fish protein) and DOLT-4 (dogfish liver).

## Results

We captured 92 birds and collected 73 blood and feather samples at five banding locations: 18 from Tipitapa on Lake Managua, 12 from Guayabo near Granada, 34 from Cárdenas at the mouth of río Tirurí on Lake Nicaragua, five from the tributary of río Escamequita and four from San Juan del Sur on the Pacific coast.

## Blood Mercury

In general, blood Hg concentrations were low but birds from Cárdenas (río Tirurí) on Lake Nicaragua had the highest Hg concentrations of all the invertivores sampled at all sites (Figure 1, Table 2). The two sites with lowest Hg concentrations were on the Pacific coast: the tributary to río Escamequita and red *Rhizophora mangle* L. and black *Avicennia germinans* (L.) L. mangroves adjacent to Juan del Sur (Figure 1, Table 2).

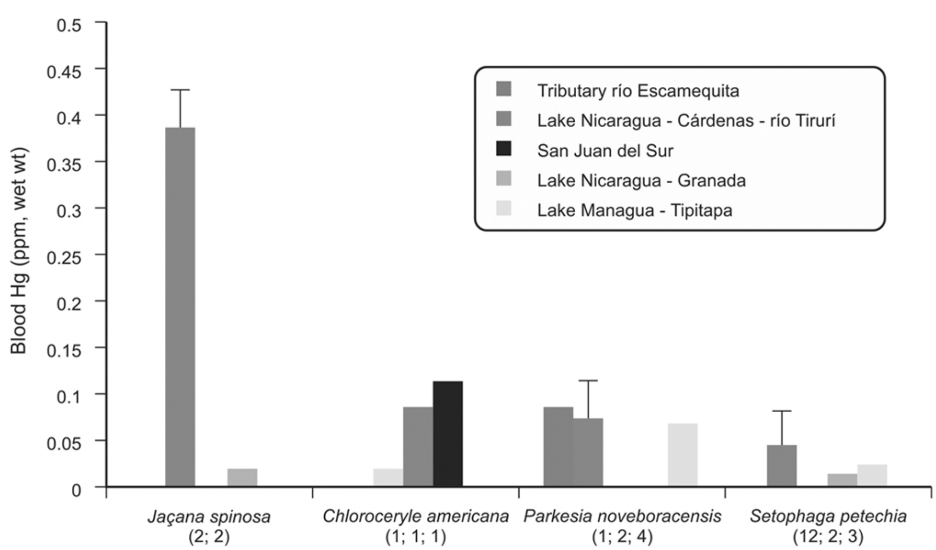


Figure 1. Mean blood mercury concentrations in four species (from left to right: Northern Jaçana, Green Kingfisher, Northern Waterthrush, and Yellow Warbler) sampled in wetland and riverine habitats bordering lakes Managua and Nicaragua and their respective drainages, February 2012 (ppm = parts per million; number in ( ) = sample size of birds).

Table 2. Whole blood total mercury (Hg, ppm wet weight) concentrations in birds sampled in Nicaragua (February, 2012).

| Site | Territory | Common Name Species | Hg |
|---|---|---|---|
| Lk. Managua-Tipitapa | La Bocana Bridge | Neotropic Cormorant | 0.749 |
| Lk. Nicaragua-Cárdenas | Tirurí | Northern Jaçana | 0.417 |
| Lk. Nicaragua-Cárdenas | Tirurí | Northern Jaçana | 0.355 |
| Lk. Nicaragua-Cárdenas | Tirurí | Rufous-and-white Wren | 0.132 |
| Lk. Nicaragua-Cárdenas | Tirurí | Prothonotary Warbler | 0.129 |
| Lk. Nicaragua-Cárdenas | Guayabo | Great-tailed Grackle | 0.114 |
| San Juan del Sur | Mangroves | Green Kingfisher | 0.114 |
| Lk. Nicaragua-Cárdenas | Tirurí | Northern Waterthrush | 0.109 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.096 |
| Lk. Nicaragua-Cárdenas | Tirurí | Rufous-naped Wren | 0.094 |
| Pacific Ocean | Trib. río Escamequita | Spotted Sandpiper | 0.094 |
| Lk. Nicaragua-Cárdenas | Tirurí | Green Kingfisher | 0.086 |
| Lk. Nicaragua-Cárdenas | Tirurí | Northern Waterthrush | 0.086 |
| Lk. Nicaragua-Cárdenas | Tiruri | Common Tody-Flycatcher | 0.081 |
| Lk. Nicaragua-Cárdenas | Tiruri | Rufous-naped Wren | 0.081 |
| Lk. Nicaragua-Cárdenas | Tirurí | Northern Waterthrush | 0.076 |
| Pacific Ocean | Trib. río Escamequita | Northern Waterthrush | 0.074 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Rufous-naped Wren | 0.073 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Northern Waterthrush | 0.071 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Rufous-naped Wren | 0.069 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.069 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Northern Waterthrush | 0.068 |
| San Juan del Sur | Mangroves | Ferruginous Pygmy-Owl | 0.068 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.064 |
| Lk. Nicaragua-Cárdenas | Tirurí | Groove-billed Ani | 0.060 |
| Pacific Ocean | Trib. río Escamequita | Spotted Sandpiper | 0.056 |
| San Juan del Sur | Mangroves | Great-tailed Grackle | 0.046 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.044 |
| Lk. Nicaragua-Cárdenas | Tirurí | Brown-crested Flycatcher | 0.044 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.043 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.043 |
| Lk. Nicaragua-Cárdenas | Tirurí | Prothonotary Warbler | 0.042 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.037 |
| Lk. Nicaragua-Cárdenas | Tirurí | Tropical Kingbird | 0.035 |
| Lk. Nicaragua-Granada | Guayabo | Great-tailed Grackle | 0.031 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.030 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.029 |
| Pacific Ocean | Trib. río Escamequita | Spotted Sandpiper | 0.028 |
| Lk. Nicaragua-Cárdenas | Tirurí | Northern Waterthrush | 0.027 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.026 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Yellow Warbler | 0.025 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Yellow Warbler | 0.024 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.022 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Orchard Oriole | 0.021 |
| Lk. Nicaragua-Cárdenas | Tirurí | Mangrove Swallow | 0.02 |
| Lk. Nicaragua-Cárdenas | Tirurí | Tropical Kingbird | 0.020 |
| Pacific Ocean | Trib. río Escamequita | Green Kingfisher | 0.020 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow Warbler | 0.019 |
| Lk. Nicaragua-Granada | Guayabo | Yellow Warbler | 0.018 |
| Lk. Nicaragua-Granada | Guayabo | Great-tailed Grackle | 0.017 |
| Lk. Nicaragua-Granada | Guayabo | Northern Jaçana | 0.017 |
| Lk. Nicaragua-Granada | Guayabo | Northern Jaçana | 0.017 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Orchard Oriole | 0.015 |

| | | | |
|---|---|---|---|
| Lk. Nicaragua-Granada | Guayabo | Streak-backed Oriole | 0.015 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Orchard Oriole | 0.014 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Yellow Warbler | 0.014 |
| San Juan del Sur | Mangroves | Great Kiskadee | 0.014 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Great Kiskadee | 0.013 |
| Lk. Nicaragua-Granada | Guayabo | Great-tailed Grackle | 0.013 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Blue-black Grassquit | 0.012 |
| Lk. Nicaragua-Cárdenas | Tirurí | Baltimore Oriole | 0.012 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Tennessee Warbler | 0.010 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Great Kiskadee | 0.009 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Tennessee Warbler | 0.009 |
| Lk. Nicaragua-Cárdenas | Tirurí | Streak-backed Oriole | 0.009 |
| Lk. Nicaragua-Granada | Guayabo | Yellow Warbler | 0.009 |
| Lk. Nicaragua-Granada | Guayabo | Great Kiskadee | 0.007 |
| Nicaragua Lk-Granada | Guayabo | Groove-billed Ani | 0.007 |
| Lk. Nicaragua-Tipitapa | La Bocana Bridge | Brown-crested Flycatcher | 0.006 |
| Lk. Nicaragua-Granada | Guayabo | Great Kiskadee | 0.006 |
| Lk. Nicaragua-Cárdenas | Tirurí | Social Flycatcher | 0.005 |
| Lk. Managua-Tipitapa | La Bocana Bridge | Painted Bunting | 0.003 |
| Lk. Nicaragua-Cárdenas | Tirurí | Yellow-bellied Elaenia | 0.003 |

Northern Jaçana *Jacana spinosa* (Linnaeus, 1758) exhibited higher Hg concentrations (0.42 ppm) than other species sampled (Figures 1, 2). Of the species sampled in Cárdenas, Northern Jaçana and the Rufous-and-white Wren *Thryothorus rufalbus* (Lafresnaye, 1845) were the best indicators. Birds from this site had blood Hg levels an order of magnitude higher than those from other sites (Figure 1). The only Neotropic Cormorant *Phalacrocorax olivaceus*

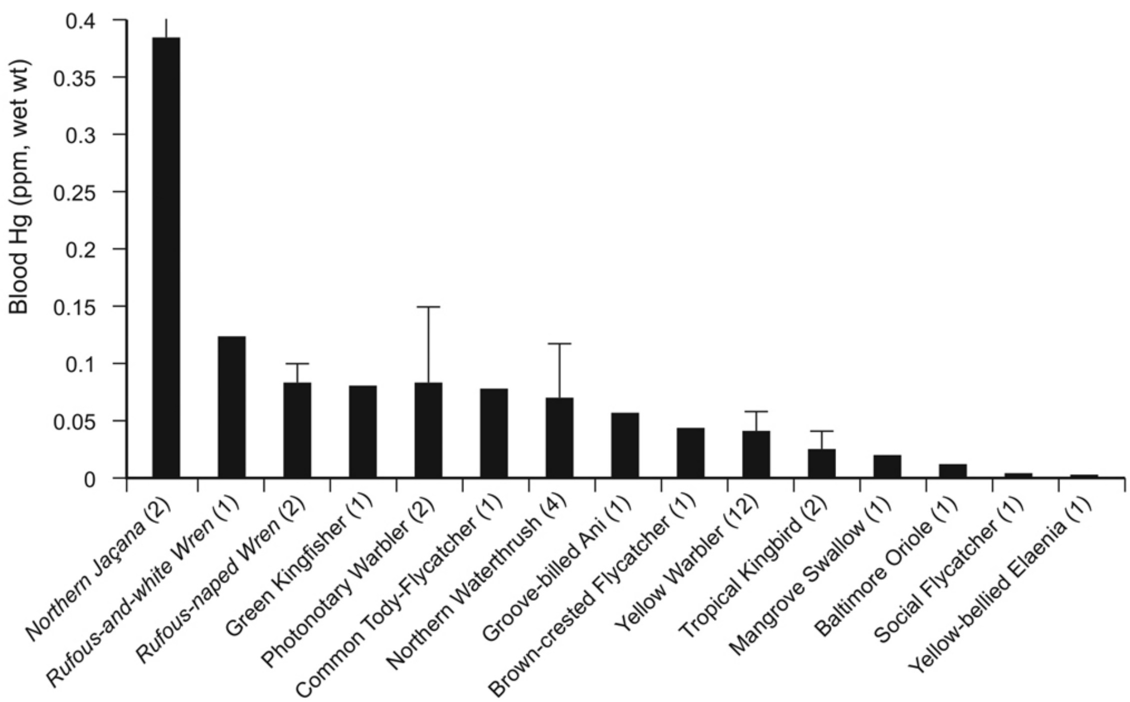


Figure 2. Mean (+SD) blood Hg concentrations in selected species sampled from Cárdenas at the mouth of río Tirurí, Lake Nicaragua, February 2012; number in ( ) represents sample size.

(Gmelin, 1789) sampled in this study (Lake Managua) had blood mercury concentration of 0.72 ppm. This bird had been killed by a local resident to feed his family.

Of the remaining birds, certain species (all piscivores and invertivores) emerged as better indicators of mercury exposure than others, e.g., Great-tailed Grackle *Quiscalus mexicanus* (Gmelin, 1788), Green Kingfisher *Chloroceryle americana* (Gmelin, 1788), Spotted Sandpiper *Actitis macularius* (Linnaeus, 1766), Yellow Warbler *Setophaga petechia* (Linnaeus, 1766), Northern Waterthrush *Parkesia noveboracensis* (Gmelin, 1789), Northern Jaçana and Rufous-naped *Campylorhynchus rufinucha* (Lesson, 1838) and Rufous-and-white wrens (Figure 2). Not all species were present at every site (Table 2).

### Feather Mercury

Feathers from birds sampled near Cárdenas (río Tirurí), had higher mercury concentrations than the same species at other sites (Figure 3). In particular, Yellow Warbler and Northern Waterthrush had elevated feather Hg concentrations (>3 ppm). These species spend the temperate winters in the Neotropics, including Nicaragua, but breed in North America. Plumage characteristics and wing formulae confirmed that all Yellow Warblers sampled were North American migrants.

### Hair Mercury

Mercury concentration in the hair of one of the boys (the 5-yr-old) living on Lake Nicaragua was 1.54 ppm (Table 3), which is considered elevated and is above USEPA effect level of 1.0 ppm.

## Discussion

### Avian Exposure to Hg

As a potent neurotoxin, mercury is a major threat to humans and wildlife populations, adversely affecting the biological systems, reproduction and behaviour of diverse organisms worldwide (Wolfe *et al*., 1998; Seewagen, 2010). In temperate North America, owing to an ample database resulting from numerous contaminant studies spanning several decades (Seewagen, 2010), one can often choose with confidence which species are best selected as target organisms. Conversely, not as many mercury-related studies have been published in Central America and, therefore, it

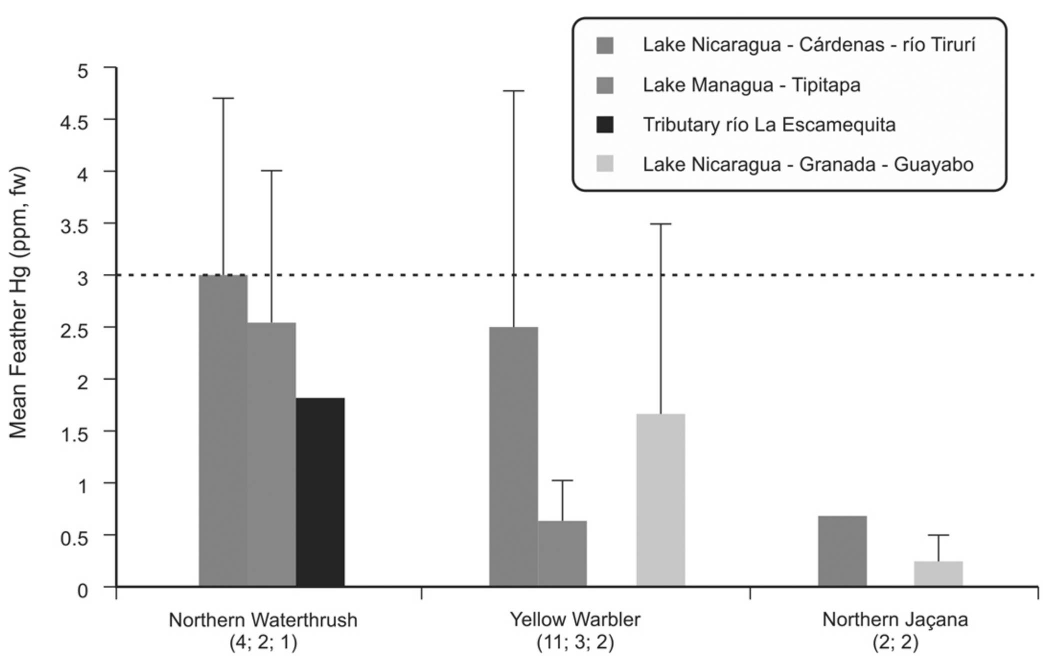


Figure 3. Mean (+SD) feather mercury concentrations from selected species sampled in Nicaragua, February 2012; (dashed line indicates the 3.0 ppm effect level for reduced reproductive success based on Jackson *et al*., 2011a).

Table 3. Hair mercury concentrations (ppm, fresh weight) in males from Tipitapa and Guayabo, Nicaragua, 2012.

| ID | Hg [ppm] | Age (Years) | Location |
|---|---|---|---|
| Adult male No. 1 | 0.618 | 25 | Lake Managua |
| Adult male No. 2 | 0.052 | 35 | Lake Managua |
| Boy No. 1 | 1.535 | 5 | Lake Nicaragua |
| Boy No. 2 | 0.560 | 7 | Lake Nicaragua |
| Boy No. 3 | 0.930 | 12 | Lake Nicaragua |

is not well known which species serve as best indicators of contaminant exposure.

The mercury pollution in Lake Managua is likely a legacy contamination left behind by the Elpesa, Nicaragua's only chlor-alkali plant that came on line in 1968. The plant produced chlorine and caustic soda from salt using the mercury cell process, a technology licensed by the Olin Corporation. As early as 1969, a study traced mercury pollution in Lake Managua to the plant. In the early 1980s, another study revealed that the company had discharged 40 tons of mercury into the lake over a 13-yr period, making it one of the most polluted lakes in the world. In addition, Elpesa may have contaminated nearby Asosasca Lagoon, the drinking water source for much of Managua.

## Blood Mercury

In the tropical lacustrine and riverine wetland habitats we sampled, the permanent resident Northern Jaçana was the prime insectivorous indicator, followed by Great-tailed Grackle, Rufous-naped and Rufous-and-white Wren and Green Kingfisher (see Table 4 for scientific names). Yellow Warbler, Northern Waterthrush and Spotted Sandpiper are Neotropical migrants and, thus, few would be available for sampling year-round.

Being higher on the aquatic food chain, cormorants and kingfishers can bioconcentrate and bioaccumulate mercury at levels harmful to humans and other top predators. Thus, the Neotropic Cormorant and kingfishers can also serve as useful indicators of pollution in aquatic habitats. In one study (Casaux *et al.*, 2009), Neotropic Cormorants from Rosario Lake in Chubut, Argentina foraged on fish that were the most frequent and important prey by number, followed by crustaceans (Crustacea: Brünnich, 1772) and mollusks (Mollusca: Linnaeus, 1758).

Cristol *et al.* (2012) showed that muscle-to-blood Hg concentrations in Mallard *Anas platyrhynchos* (Linnaeus, 1758) from a contaminated site in Virginia was approximately 1:1, and many Mallards in the study area exceeded consumption advisories set for fish by the United States regulatory agencies. If we can apply the same relationship to cormorants, the bird we found to have blood mercury concentration of 0.74 ppm is likely to have a similar concentration in the muscle. Therefore, consuming cormorants from Lake Managua potentially puts humans, especially children, at risk to mercury poisoning.

Whole blood mercury concentrations reflect recent mercury exposure (14 to 21 days). Our blood mercury results suggest that, although generally small, the threat from mercury exposure in some species and local habitats merit further study and continued monitoring. Northern Jaçana tended to accumulate the highest levels of mercury in the blood and can serve as excellent indicator species of tropical wetlands. This wader is an inhabitant of tropical freshwater marshes and streams. It feeds on insects and other small invertebrates such as small mollusks, snails (Mollusca, Gastropoda: Cuvier, 1795), "worms," small "fish" and crabs (Decapoda, Brachyura: Linnaeus, 1758), and occasionally consumes "seeds" (Jenni and Mace, 1999).

Feather Hg reflects body burden at the time of molt when protein-bound methylmercury is depurated in the developing penna. The species with the highest mercury levels, Yellow Warbler and Northern Waterthrush are Neotropical migrants. Consequently, it is not clear where the exposure occurred. However the majority of birds with elevated feather mercury (all but one) were captured at the río Tirurí banding site, bordering agriculture and thus possibly receiving runoff from toxic pesticide residues.

## Human Exposure

Severe neurological damage can result from exposure to high doses of Hg, specifically methylmercury. The main source of human exposure to mercury is the consumption of fish and wildlife contaminated with methylmercury, which may adversely affect early neurodevelopment. Children are especially vulnerable and may be exposed directly by eating contaminated fish. Methylmercury bioaccumulated

Table 4. English and scientific names of birds sampled in Nicaragua.

| Common Name | Scientific Name |
|---|---|
| Baltimore Oriole | *Icterus galbula* |
| Basilisk Lizard | *Basiliscus plumifrons* |
| Blue-black Grassquit | *Volatinia jacarina* |
| Blue-winged Teal | *Anas discors* |
| Brown-crested Flycatcher | *Myiarchus tyrannulus* |
| Common Ground-Dove | *Columbina passerina* |
| Common Tody-Flycatcher | *Todirostrum cinereum* |
| Great Kiskadee | *Pitangus sulphuratus* |
| Great-tailed Grackle | *Quiscalus mexicanus* |
| Green Kingfisher | *Chloroceryle americana* |
| Groove-billed Ani | *Crotophaga sulcirostris* |
| Mangrove Swallow | *Tachycineta albilinea* |
| Neotropic Cormorant | *Phalacrocorax brasilianus* |
| Northern Jaçana | *Jacana spinosa* |
| Northern Waterthrush | *Parkesia noveboracensis* |
| Orchard Oriole | *Icterus spurius* |
| Painted Bunting | *Passerina ciris* |
| Prothonotary Warbler | *Protonotaria citrea* |
| Ruddy-breasted Seedeater | *Sporophila minuta* |
| Rufous-and-white Wren | *Thryophilus rufalbus* |
| Rufous-naped Wren | *Campylorhynchus rufinucha* |
| Social Flycatcher | *Myiozetetes similis* |
| Spotted Sandpiper | *Actitis macularius* |
| Streak-backed Oriole | *Icterus pustulatus* |
| Tennessee Warbler | *Oreothlypis peregrina* |
| Tricolored Munia (or Manikin) | *Lonchura malacca* |
| Tropical Kingbird | *Tyrannus melancholicus* |
| White-collared Seedeater | *Sporophila torqueola* |
| Yellow Warbler | *Setophaga petechia* |
| Yellow-bellied Elaenia | *Elaenia flavogaster* |

in fish and consumed by pregnant women may lead to neurodevelopmental problems in the developing fetus (World Health Organization, 2010). A study of four-year-old children in Spain who consumed fish on a regular basis concluded that hair concentrations of greater or equal to 1 ppm were associated with cognitive developmental delay (Freire *et al*., 2010). The Lowest Observed Adverse Effect Concentration (LOAEC) is 0.3 ppm in hair (World Health Organization, 2010).

Hair mercury concentration in one of the tree boys sampled from Granada was 1.54 ppm, which is higher than the US EPA guideline of 1 ppm. Assuming that his exposure is a result of eating local fish, turtles and iguanas, his hair Hg concentration indicates that his food source is contaminated with mercury and he is at high risk of developing cognitive developmental disorders.

Although cormorants make up an unknown portion of the diet of the local population living on the shores of large lakes in Nicaragua, they and possibly other piscivorous species, if eaten by the locals, could also be adding to the overall detrimental effects of bioaccumulation of mercury in the human population residing in the area.

## Conclusions

Mercury levels in a Neotropic Cormorant were high enough to have negative effects on humans if it is a common source of protein for the local population residing along the shores of Lakes Managua and Nicaragua.

Mercury concentrations in blood were below thresholds known to cause negative effects in birds; however, concentrations were elevated relative to pristine sites and to the background concentration in several species from Lake Managua and Nicaragua.

Mercury concentrations in feathers of several migrants sampled near río Tirurí that spend the temperate winter in the Neotropics, including Nicaragua, were above levels known to cause reduction in reproductive success.

Mercury concentration in the hair of one of five males sampled was higher than the recommended "safe" level.

Based on the results of this pilot study, we are able to predict which of our sampled species serve as better indicators of mercury contamination, and thus we (and others) can design future studies with this information in mind.

In general, our results suggest that invertivores (icterids, warblers, flycatchers, wrens) and piscivores (kingfishers and wading birds-which include invertivores) are appropriate groups to target in mercury assessment studies.

We recommend additional sampling of fish, fish-eating wildlife and humans to better assess mercury exposure in Lakes Managua, Nicaraguan watersheds, and elsewhere in the region, especially at higher elevations in cloud forest, where mercury levels have been shown to be significantly higher than in lowland rain forest (Townsend *et al.*, 2012).

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