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Sexual difference in mercury concentrations of lake trout (*Salvelinus namaycush*) from Lake Ontario

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ABSTRACT

We determined total mercury (Hg) concentrations in 50 female lake trout (*Salvelinus namaycush*) and 69 male lake trout from Lake Ontario (Ontario, Canada and New York, United States). Results showed that, on average, males were 8% higher in Hg concentration than females in Lake Ontario. We also used bioenergetics modeling to determine whether a sexual difference in gross growth efficiency (GGE) could explain the observed sexual difference in Hg concentrations. According to the bioenergetics modeling results, male GGE was about 3% higher than female GGE, on average. Although the bioenergetics modeling could not explain the higher Hg concentrations exhibited by the males, a sexual difference in GGE remained a plausible explanation for the sexual difference in Hg concentrations of the lake trout. In an earlier study, male lake trout from Lake Ontario were found to be 22% higher in polychlorinated biphenyl (PCB) concentration than females from Lake Ontario. Thus, although males were higher in both Hg and PCB concentrations, the degree of the sexual difference in concentration varied between the two contaminants. Further research on sexual differences in Hg excretion rates and Hg direct uptake rates may be needed to resolve the disparity in results between the two contaminants.

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1. Introduction

Fish accumulate mercury (Hg) primarily from the food that they eat (Trudel et al., 2000). Mercury can also enter a fish's body via direct uptake from the water through the gills, although this direct uptake pathway is less important than the dietary pathway (Post et al., 1996; Trudel and Rasmussen, 2001). Fish are capable of eliminating or excreting Hg from their bodies, although this excretion process is slow (Trudel and Rasmussen, 1997; Van Walleghem et al., 2007).

Sexual differences in Hg concentrations of fish have been attributed to: (1) shedding of eggs causing a substantial decrease in Hg concentrations of females immediately after spawning and (2) a sexual difference in gross growth efficiencies (GGEs). Walker (1976) and Phillips (1980) proposed that Hg concentrations in female fish are reduced immediately after spawning, because Hg is transferred to the eggs. However, Niimi (1983) showed that Hg concentration in females of five different fish species, including rainbow trout (*Oncorhynchus mykiss*), white sucker (*Catostomus commersoni*), white bass (*Morone chrysops*), smallmouth bass (*Micropterus dolomeui*), and yellow perch (*Perca flavescens*), actually increase between 5.5% and 22.4% immediately after spawning. This increase in Hg concentration immediately after spawning was attributable to the Hg concentration in the eggs being lower than the Hg concentration in the somatic tissue of the females. Thus, for most fishes, the mechanism of egg release is not a plausible explanation for higher Hg concentration in males compared with females.

Higher Hg concentrations in males of northern pike (*Esox lucius*) and several species of sharks have been attributed to faster growth by females (Olsson, 1976; Walker, 1976; Macrovecchio et al., 1986; Endo et al., 2009). Typically, a sexual difference in growth rates would indicate a sexual difference in GGE, because GGE is usually well correlated with growth rate (Madenjian et al., 1994). Here, GGE is defined as the amount of growth divided by the amount of food eaten to attain that growth. In addition, Nicoletto and Hendricks (1988) proposed that the higher Hg concentrations observed in females of four centrarchid fishes were due to greater energy expenditure by females during spawning. Because the females were believed to be expending energy at a higher rate than males, they would consume more food and consequently more mercury than males to attain the same size of the males, and thereby have a higher Hg concentration than males. In essence,

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Nicoletto and Hendricks (1988) were attributing the sexual differences in Hg concentrations to a greater GGE of males.

To the best of our knowledge, no attempt has been made to study sexual differences in Hg concentrations of fish by determining whole-fish Hg concentrations. In all previous studies of sexual differences of Hg concentrations in fish, Hg concentration was determined in the muscle tissue only. Although Hg concentration in muscle has often been assumed to be equal to whole-fish Hg concentration (Trudel et al., 2000; Rennie et al., 2008), the validity of this assumption has rarely been evaluated. When using polychlorinated biphenyl (PCB) concentrations in fish fillets to infer sexual differences in whole-fish PCB concentrations, the results of such studies are valid only if the ratio of whole-fish PCB concentration to fillet PCB concentration is identical between the sexes (Madenjian, 2011). For fishes like coho salmon (*Oncorhynchus kisutch*) and walleye (*Sander vitreus*), this assumption appears to be valid, whereas this assumption appears invalid for lake trout (*Salvelinus namaycush*) (Madenjian, 2011). Analogously, the inference of sexual differences in whole-fish Hg concentrations based on determinations of muscle Hg concentrations critically depends on the assumption that the ratio of whole-fish Hg concentration to muscle Hg concentration is identical between the sexes. Given the PCB findings, this assumption likely does not hold for all fish species and all fish populations.

All other factors being equal, the degree of the sexual difference in Hg concentration should be equal to the degree of the sexual difference in PCB concentrations for a given fish population. Both Hg and PCBs have been identified as tracers for food consumption by fish (Madenjian et al., 2000; Trudel et al., 2000). A sexual difference in GGE appeared to be the most prevalent mechanism driving sexual differences in PCB concentrations of fish (Madenjian, 2011). Therefore, we may expect a similar degree of sexual difference in both Hg and PCB concentrations from the same fish population. Nevertheless, because Hg and PCBs are very different with respect to the tissues that they are associated with in the fish's body, the importance of direct uptake and excretion in the fish's contaminant budget may vary between these two contaminants. Whereas PCBs are lipophilic and found in fatty tissues (Eisler, 2000b), Hg is primarily stored in protein and thiol groups in the muscle tissue (Eisler, 2000a).

A better understanding of the underlying causes for sexual differences in contaminant concentrations can contribute toward a more efficient sampling design for monitoring contaminant concentrations in fish, and can be used to forecast changes in contaminant concentrations under various environmental scenarios (Sheffy, 1980; Masnado, 1987; Madenjian et al., 1998b; Rypel et al., 2007). In addition, higher rates of energy expenditure by males has been proposed as a mechanism for higher natural mortality rates in male fishes compared with female fishes (Henderson et al., 2003). Therefore, documentation of higher rates of energy expenditure (and consequently food consumption) by males, via food consumption tracers, may provide better insights into fish population dynamics. To date, sexual differences in whole-fish Hg concentrations of lake trout have not been investigated. Lake trout populations in North America support valuable recreational and commercial fisheries (Martin and Olver, 1980).

The objectives of this study were to: (1) determine whether Hg concentrations differed between the sexes of lake trout from Lake Ontario, (2) ascertain whether bioenergetics modeling could explain a sexual difference in Hg concentrations of lake trout, and (3) compare the sexual difference in Hg concentrations with the findings of Madenjian et al. (2010) on the sexual difference in PCB concentrations of lake trout from Lake Ontario.

2. Methods

2.1. Field methods

At offshore sites in Canadian waters of Lake Ontario, lake trout were caught in gill nets during August and September of 1986 (Borgmann and Whittle, 1991). If the adipose fin was clipped, the snout of the lake trout was removed and frozen. If the adipose fin was unclipped, then a scale sample was obtained for aging purposes. According to hatchery practices, a lake trout has its adipose fin clipped if and only if the lake trout also receives a coded-wire tag (CWT) prior to stocking into the lake. Each fish was then wrapped in solvent-rinsed aluminum foil and placed on ice. The fish were later transported to a freezer, where they were stored at −25 °C, at the Canada Centre for Inland Waters (CCIW). Please refer to Borgmann and Whittle (1991) for more details on the field methodology.

2.2. Laboratory processing of lake trout

At the CCIW, lake trout were thawed, total lengths were determined to the nearest mm, each fish was weighed to the nearest g, and the sex of each fish was determined. Each whole lake trout was then homogenized in a commercial blender, and 50 g of the homogenate was placed in a contaminant-free glass jar, sealed with a lid, and then stored at −25 °C until time of extraction. If the snout of the lake trout was removed for aging purposes, then the CWT was extracted from the snout and decoded. Before homogenization in the blender, the snout was then combined with the lake trout from which the snout was removed. Enumeration of annual growth rings on the scales in conjunction with fin clip information was used to age the lake trout lacking an adipose fin clip and CWT (Borgmann and Whittle, 1991). Each lake trout was assigned an age based on either the decoding of the CWT or the scale aging procedure. Please refer to Borgmann and Whittle (1991) for more details.

Total Hg concentrations in the homogenized fish tissue samples were determined using the methods in the Canadian Department of Environment Analytical Methods Manual, which involved use of the cold vapor atomic absorption spectrometry (CVAAS) procedure (Environment Canada, 1990). Each sample was digested in sulfuric acid, further oxidized with potassium permanganate and persulfate, clarified with a hydroxylamine sulfate/sodium chloride solution, and measured by CVAAS after mercury reduction and vaporization by stannous sulfate. Please refer to Environment Canada (1990) for more details. Appropriate quality control measures were taken, including blanks, duplicates, and spikes. The detection limit was 2 ng g^{-1}. Acceptable levels of recovery from the spiked samples ranged from 79% to 121%. Duplicate samples were considered acceptable if their relative percent difference was less than 25%. On average, the relative percent difference between duplicate samples was 8%. In addition, a standard reference material (lobster tomalley [TORT-2] or dogfish liver tissue [DOLT-2], Certified Reference Materials, National Measurement Standards, National Research Council of Canada, Ottawa, Canada) was used as part of the quality assurance procedure. All Hg determinations were completed within 9 months following capture of fish. All Hg concentrations were reported on a wet weight basis. Although all of our determinations were for total Hg, we expected that all or nearly all of the mercury contained in the lake trout was in the form of methylmercury. Raymond and Rossmann (2009) showed that all of the mercury found in Lake Michigan lake trout was in the methylmercury form.

2.3. Data analyses for Hg

To determine whether the Hg concentration of male lake trout was significantly different from the Hg concentration of female