ARTICLE IN PRESS

STOTEN-19470; No of Pages 13

Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Assessing potential health risks to fish and humans using mercury concentrations in inland fish from across western Canada and the United States

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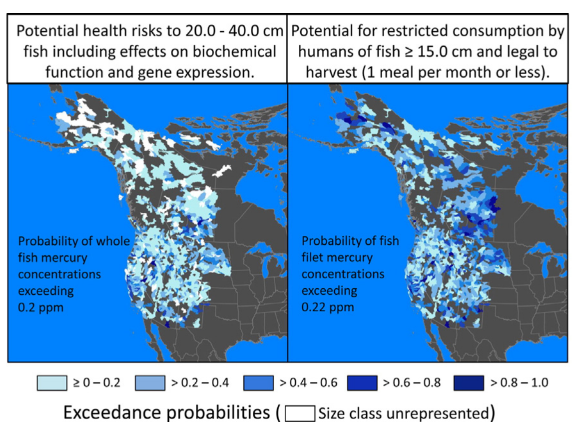
HIGHLIGHTS

- Fish and human health risks from Hg exist in western Canada and the United States.
- We used a hierarchical statistical model characterizing Hg risks and uncertainty.
- Potential health risk was heterogeneous across the region, and higher in some areas.
- Targeted monitoring could improve understanding and mitigation of Hg contamination.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 November 2015
Received in revised form 4 March 2016
Accepted 6 March 2016
Available online xxxx

ABSTRACT

Fish represent high quality protein and nutrient sources, but Hg contamination is ubiquitous in aquatic ecosystems and can pose health risks to fish and their consumers. Potential health risks posed to fish and humans by Hg contamination in fish were assessed in western Canada and the United States. A large compilation of inland fish Hg concentrations was evaluated in terms of potential health risk to the fish themselves, health risk to predatory fish that consume Hg contaminated fish, and to humans that consume Hg contaminated fish. The

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http://dx.doi.org/10.1016/j.scitotenv.2016.03.031

Keywords:
Advisory development
Benchmark
Consumption advice
Hierarchical modeling
Monitoring
Size class
Uncertainty

probability that a fish collected from a given location would exceed a Hg concentration benchmark relevant to a health risk was calculated. These exceedance probabilities and their associated uncertainties were characterized for fish of multiple size classes at multiple health-relevant benchmarks. The approach was novel and allowed for the assessment of the potential for deleterious health effects in fish and humans associated with Hg contamination in fish across this broad study area. Exceedance probabilities were relatively common at low Hg concentration benchmarks, particularly for fish in larger size classes. Specifically, median exceedances for the largest size classes of fish evaluated at the lowest Hg concentration benchmarks were 0.73 (potential health risks to fish themselves), 0.90 (potential health risk to predatory fish that consume Hg contaminated fish), and 0.97 (potential for restricted fish consumption by humans), but diminished to essentially zero at the highest benchmarks and smallest fish size classes. Exceedances of benchmarks are likely to have deleterious health effects on fish and limit recommended amounts of fish humans consume in western Canada and the United States. Results presented here are not intended to subvert or replace local fish Hg data or consumption advice, but provide a basis for identifying areas of potential health risk and developing more focused future research and monitoring efforts.

1. Introduction

Mercury (Hg) is an important contaminant due to its widespread distribution and tendency to bioaccumulate in organisms to levels that impact the health of humans, wildlife, and ecosystems worldwide (Driscoll et al., 2007; Mergler et al., 2007). Hg enters the landscape through a variety of natural and anthropogenic pathways including volcanoes, forest fires, erosion, fossil fuel burning, waste incineration, mining operations, and cement production (Pirrone and Mason, 2009). Inorganic Hg can be converted into methylmercury, the form of Hg that can be taken up in living tissues as the contaminant moves through food webs (Harris et al., 2007; Power et al., 2002; [USEPA] United States Environmental Protection Agency, 2001). Methylmercury is a neurotoxin that can adversely affect fish, humans, and wildlife in a variety of ways, potentially impacting behavior, cognition, growth, reproduction, and survival (Depew et al., 2012; Mergler et al., 2007; Scheuhammer et al., 2007). Despite health concerns related to Hg contamination in fish, the benefits of fish consumption are well documented and have been postulated by some to outweigh the health risks from Hg exposure under certain conditions (Institute of Medicine of the National Academies et al., 2007; Knuth et al., 2003; Mergler et al., 2007).

A variety of Hg exposure benchmarks associated with potential fish and human health effects have been established, but these benchmarks can range widely due to a variety of factors. In fish, factors like species, gender, and age have been considered when determining Hg exposure benchmarks that may have health impacts on individuals and at the population level (see reviews in Depew et al., 2012; Sandheinrich and Wiener, 2011). Further, many different endpoints have been selected to evaluate effects from Hg exposure on fish including, but not limited to, effects on behavior, gene expression, growth, metabolism, gonadal somatic indices, and plasma and blood characteristics (see reviews in Depew et al., 2012; Sandheinrich and Wiener, 2011). In humans, similar to fish, gender and age can impact how Hg exposure affects the health of individuals consuming Hg contaminated fish, primarily affecting children during development and consequently a concern for women who are pregnant or intend to become pregnant (Mergler et al., 2007; [WHO] World Health Organization, 1990). There are also many different endpoints selected to evaluate effects from Hg contamination in humans. Perhaps some of the most important endpoints are those related to intelligence, because fish consumption can positively and negatively affect cognition, meaning that fish consumption is a balance between the advantages and disadvantages it has during human development (Institute of Medicine of the National Academies et al., 2007; Mergler et al., 2007; Oken et al., 2005). An additional complication for evaluating potential health risks from Hg contaminated fish is that their Hg concentrations are inherently variable across species, sizes and locations (e.g., Depew et al., 2013; Evers et al., 2007, 2011). This makes using mean fish Hg concentrations (that often have a log-normal distribution; e.g., Eagles-Smith et al., 2016-in this issue) to assess potential health risks challenging because fish themselves are rarely "average" and piscivorous fish and humans rarely consume "average" fish. Thus, these factors can confound how Hg exposure benchmarks associated with potential fish and human health effects are characterized and how potential health risks are assessed.

Despite these challenges, syntheses of fish Hg datasets in North America have been conducted at a variety of large scales including, but not limited to, the Northeast region (e.g., Evers et al., 2007), the Great Lakes region (e.g., Evers et al., 2011) and the continental United States (e.g., Stahl et al., 2009; Xue et al., 2015). These efforts can be highly useful and provide a basis for presenting and comparing results across broad geographical regions. Data compiled by the Western North America Hg Synthesis Group were used to characterize fish Hg concentrations relevant to fish and human health (see Eagles-Smith et al., 2016-in this issue for further detail about data compilation). The expansive study area includes a variety of different habitats with disparate precipitation regimes across the largest range of elevations found in North America. These characteristics influence the distribution of fish species throughout the area, and ultimately determine the potential for health risks associated with Hg contaminated fish. The overall goal was to identify and characterize potential health risks posed to fish and humans by Hg contamination across the western United States and Canada to inform future monitoring and advisory development efforts. Specific objectives were to develop health risk and fish consumption advice maps for inland fish species; 1) characterizing health risks posed to contaminated fish due to their own Hg concentrations, 2) characterizing health risks posed to fish consuming Hg contaminated prey fish, and 3) characterizing fish consumption advice for humans. These risks were assessed across a range of fish size classes and at various fish Hg concentrations associated with deleterious health effects (fish) and recommended levels of fish consumption (humans; developing children and women who are or intend to become pregnant). This approach was novel in that it characterized potential health risks across a range of fish size classes and at multiple health-relevant Hg concentration benchmarks so results were applicable and interpretable across a variety of fish species and their consumers with differing foraging habits. This method was also particularly relevant to health risk assessment because fish Hg concentration data were presented in terms of probabilities (and importantly their corresponding uncertainties) derived in part from empirical data obtained directly from the fish species and sizes of interest for each sampling location.

2. Materials and methods

2.1. Data description

Empirical total Hg concentration data were used from approximately 150 fish species sampled from 891 hydrologic units (8-digit hydrologic units in the United States and equivalent hydrologic units in Canada) and over 3000 unique sampling locations. Eight-digit hydrologic unit codes were selected because they are delineated by watershed boundaries which are relevant to Hg contamination as water is an important transporter of Hg and can support conditions conducive