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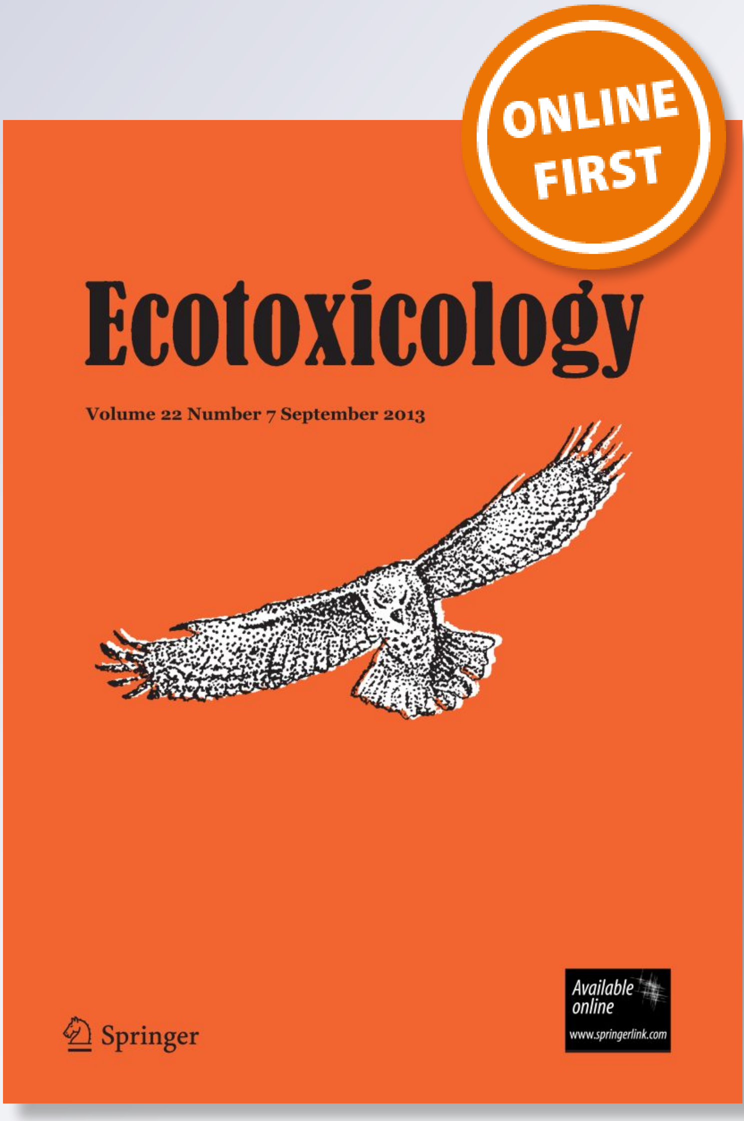

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A case study and a meta-analysis of seasonal variation in fish mercury concentrations

Nathan Mills[1] · Darcy Cashatt[2] · Michael J. Weber[1] · Clay L. Pierce[1,3]

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Abstract
Mercury contamination in aquatic ecosystems is a concern due to health risks of consuming fish. Fish mercury concentrations are highly variable and influenced by a range of environmental factors. However, seasonal variation in mercury levels are typically overlooked when monitoring fish mercury concentrations, establishing consumption advisories, or creating accumulation models. Temporal variation in sampling could bias mercury concentration estimates of accumulation potential. Thus, the objectives of this study were to first evaluate seasonal variation of largemouth bass (*Micropterus salmoides*) axial muscle mercury concentration from two Iowa, USA impoundments. Second, we conducted a meta-analysis to evaluate if seasonal variation in mercury concentration is dependent upon mean mercury concentration, waterbody type, or fish trophic level or mean length. Largemouth bass were collected four times between May and October (24–36 fish per month) from Twelve Mile (2013) and Red Haw (2014) lakes. Largemouth bass axial muscle mercury concentrations were variable within and between lakes, ranging from undetectable (< 0.05 mg/kg) to 0.54 mg/kg. Largemouth bass mercury concentrations were similar across months in Twelve Mile but varied temporally in Red Haw and were highest in July, intermediate in May and September, and lowest during October. Results of the meta-analysis suggest that seasonal variation in mercury concentrations is more likely to occur as mean mercury concentration of the population increases but is unrelated to waterbody type, trophic status, and fish size. Understanding seasonal variation in fish mercury concentrations will aid in the development of standardized sampling programs for long-term monitoring programs and fish consumption advisories.

Keywords Seasonal variation · Midwest · Mercury monitoring · Meta-analysis · Contaminant · Bioaccumulation

Introduction

From smallmouth bass (*Micropterus dolomieu*) in the Shenandoah River, VA, U.S.A. (Murphy et al. 2007) to longtail tuna (*Thunus tonggol*) in the Persian Gulf (Saei-Dehkordi et al. 2010), previous studies evaluating seasonal variation in fish mercury concentrations have covered a large breadth of geographic locations, waterbody types, and fish species across the world. Seasonal variation in fish mercury concentrations is not always present (e.g., Farkas et al. 2000; Foster et al. 2000), but when it has been detected, mercury concentrations tend to be higher during spring compared to summer or fall (e.g., Ward and Neumann 1999; Farkas et al. 2003; Moreno et al. 2015). However, the majority of studies evaluating seasonal variation in fish mercury concentrations have either been conducted in large European lake systems (e.g., Farkas et al. 2000, 2003; Moreno et al. 2015) or coastal regions within the United States (e.g., Ward and Neumann 1999; Foster et al. 2000; Greenfield et al. 2013; Kenney et al. 2014). Thus, limited information regarding seasonal variation in fish mercury concentrations is available in Midwestern U.S. regions.

Despite the occurrence of seasonal variation in fish mercury concentrations in some instances (e.g., Weis et al. 1986; Ward and Neumann 1999; Kenney et al. 2014), it is typically overlooked when designing mercury monitoring

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protocols, establishing consumption advisories, or creating accumulation models. Seasonal variation in mercury concentrations has important implications for mercury monitoring programs. Most monitoring programs sample a large number of waterbodies throughout the course of a year and do not account for potential temporal variation. If seasonal variation occurs, temporally asynchronous sampling regimes could bias mercury concentration comparisons among waterbodies and provide biased estimates of concentrations at regional, local, and individual scales. Furthermore, consumption advisories based on models typically do not include temporal variability and may provide inaccurate predictions of mercury concentrations during certain months (Ward and Neumann 1999; Moreno et al. 2015). Synchronizing sampling protocols for mercury in fishes would reduce the effect of temporal variance in mercury concentrations, but is logistically challenging and unnecessary if seasonal variability does not exist. Thus, understanding seasonal variation in fish mercury levels is an important component of successful monitoring programs.

Large piscivorous fishes tend to have elevated mercury levels compared to other fishes at lower trophic levels (Lange et al. 1993). Largemouth bass (*Micropterus salmoides*) is a common sport fish and can accumulate mercury concentrations in Iowa, USA occasionally surpassing the EPA consumption criterion (0.3mg/kg in edible muscle; IDNR 2014). In Iowa, largemouth bass consumption advisories have been issued for 12 lakes, making it a species of contaminant concern. However, standardized temporal sampling protocols have yet to be developed, making it uncertain whether mercury concentrations measured at different times of the year are comparable for development of consumption advisories. Therefore, the objectives of this study were to (1) evaluate seasonal variation in largemouth bass axial muscle mercury concentrations from two Iowa impoundments and (2) conduct a literature meta-analysis to evaluate whether detection of seasonal variation in fish tissue mercury concentrations is dependent upon average mercury contamination or other environmental factors. Understanding seasonal variation in mercury concentrations will aid the development of standardized sampling for long-term mercury monitoring programs.

Methods

Fish collection and processing

Largemouth bass were collected using pulsed DC electrofishing four times per year between May and October (24–36 fish per month) from Twelve Mile (2013) and Red Haw (2014) lakes, Iowa. Red Haw Lake has a maximum depth of 12.2 m, a mean depth of 4.4 m, a 29 ha surface area, and a 413 ha watershed area. Twelve Mile Lake has a maximum depth of 12.2 m, a mean depth of 4.6 m, a 257 ha surface area, and a 5931 ha watershed area. Largemouth bass were measured for total length (TL mm) and individuals of similar length (Twelve Mile: 311–445 mm TL; Red Haw: 278–370 mm TL) were collected to minimize the effect of length on mercury concentration. In May, fish were euthanized, and up to 10 g of axial muscle tissue was removed using a scalpel. In all other months, fish were not euthanized and two 5 mm diameter biopsy punches were taken to sample the muscle tissue from the same area of the fish where samples were removed during May. Biopsy punches were used to sample tissue from only one fish and then discarded. Other equipment (e.g., scalpel, knife, forceps, etc.) used for obtaining tissue samples was rinsed with water and sanitized with ethanol between samples to prevent contamination among specimens. Tissue samples were stored in a −10 °C freezer until transport for mercury analysis.

Within 90 days, tissue samples were transported on ice to the State Hygienic Lab, Ankeny, Iowa, for mercury analysis. Approximately 1 g of axial muscle tissue was subsampled for mercury analysis (USEPA 2000; USEPA 2003). Mercury concentration was determined from acid-digested tissue samples using Inductively Coupled Plasma—Mass Spectrometry (ICP-MS) using USEPA Method 6020 A (1998) and reported as total wet-weight mercury concentration (mg/kg) and mercury detection threshold was 0.05 mg/kg. Quality assurance and control were done with a standard operating procedure of periodic calibrations and duplicate analyses. Duplicate samples were analyzed approximately every 35 samples and the mean relative percent difference (RPD) was 1.89% (median = 1.22%, range = 0–7.1%, $n = 13$). These analyses were part of a larger mercury analysis across Iowa for which duplicate samples were analyzed approximately every 16 samples where the mean RPD was 3.70% (median = 0.85%, range = 0%–50%, $n = 110$).

Meta-analysis

Three literature searches were conducted to gather published studies evaluating seasonal variation of fish tissue mercury concentrations. For this study, seasonal variation is defined as mean wet-weight muscle tissue mercury concentrations varying within a 1 year period (365 days from initial collection) for a given fish species collected at least twice in 1 year. Presence of seasonal variation was noted if the respective statistical test was significant at $P < 0.05$.

Google Scholar, Web of Science, and EBSCO were searched with the following search phrases: "seasonal variation of fish mercury" and "temporal variation of fish mercury." Additionally, literature cited sections were scanned to identify additional studies evaluating seasonal variation in mercury concentrations that were not identified through internet searches. As a result of these searches, 33 studies evaluating temporal trends of fish tissue mercury concentrations were found. Of the 33 studies found in the literature search, 17 reported dry-weight mercury or methylmercury concentrations or analyzed mercury concentrations with skin-on fillets and were not used as part of the meta-analysis. Additionally, studies that did not follow appropriate data collection or mercury processing methodology or quality control (e.g., spiking samples with known quantity of mercury to estimate recovery rates, running duplicate samples to test for variation) were not included. Species-specific data were extracted from 55 fish populations from 16 studies that fit the study criteria (Appendix Table 2): some studies evaluated seasonal variation of mercury concentrations in multiple species. Extracted data included a binary account of whether or not seasonal variation was detected (i.e., 1 = yes; 0 = no), arithmetic mean mercury concentrations across all seasons, waterbody type (e.g., natural lake, impoundment, river, etc.), a categorical description of trophic level (e.g., piscivore, omnivore, or insectivore), and fish mean total length (mm). If no trophic category was described in the study, diet analyses from Fish Base were used to estimate trophic status (www.fishbase.org; last accessed 1/15/18). In addition to the data extracted from the literature review, information from largemouth bass collected during this study was included in the analyses.

Statistical analyses

For both lakes, seasonal variation of largemouth bass mercury concentration was assessed using Tobit regression (PROC LIFEREG; Statistical Analysis System 9.4; SAS), with the ICP-MS detection threshold of 0.05 as the lower bound, and using Tukey's method for multiple comparisons. Mercury concentrations were $\log_e$-transformed prior to analysis to normalize the residuals. Fish total length was added to each model as a covariate to account for variation due to fish size. A month-length interaction term was initially added to each model to evaluate potential effects of differences in the relationship between fish length and mercury concentration by month. However, these interaction terms were not significant and were therefore omitted from the final analyses. Least squares means was used to obtain estimates of mean mercury concentrations by month. If significant seasonal variation in mercury concentrations existed ($P < 0.05$), differences between months were determined with contrast statements.

For data obtained by the meta-analysis, binary logistic regression was used to evaluate the relationship between overall mean mercury concentrations and whether or not seasonal variation of fish tissue mercury concentrations was detected. Additional explanatory variables, including waterbody type, trophic level, and mean total length, were added to the model individually to test for significance ($\alpha = 0.05$).

Results

Largemouth bass in Iowa lakes

For both lakes, largemouth bass axial muscle mercury concentrations were highly variable, ranging from undetectable (< 0.05 mg/kg) to 0.54 mg/kg. However, largemouth bass mercury concentrations in Twelve Mile Lake were similar among all four months ($P = 0.11$; Table 1; Fig. 1) and unrelated to fish length ($P = 0.15$). All largemouth bass had detectable mercury concentrations during May but percent of bass with undetectable mercury concentrations increased to 27–32% during the summer and fall months (Table 1).

In contrast to Twelve Mile Lake, largemouth bass mercury concentrations varied across months ($P < 0.001$) and increased with fish total length ($P < 0.001$) in Red Haw

Table 1 Largemouth bass sample size (*n*), mean mercury concentration in axial muscle tissue adjusted for mean length (mg/kg; ± 95% confidence interval), percent of largemouth bass sampled with undetectable mercury concentrations (<0.05 mg/kg), and mean bass total length (mm) sampled from Twelve Mile and Red Haw lakes, May–October 2013 and 2014, respectively

Lake	Month	*n*	Mean TL (mm)	Mean Hg (mg/kg; ± 95% C.I.	%<0.05 mg/kg
Twelve Mile Lake	May	31	373	0.19 ± 0.05^a	0
	July	27	374	0.12 ± 0.04^a	33
	August	23	382	0.12 ± 0.04^a	30
	October	33	380	0.14 ± 0.04^a	27
Red Haw Lake	May	30	338	0.17 ± 0.03^a	0
	July	33	310	0.23 ± 0.04^b	3
	September	36	315	0.16 ± 0.03^a	11
	October	30	312	0.11 ± 0.02^c	37

Within each lake, mean Hg concentrations sharing a common superscript are not significantly different ($\alpha = 0.05$)

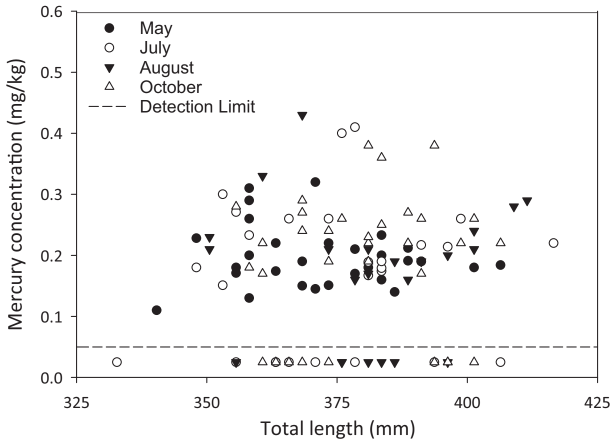

Fig. 1 Relationship between largemouth bass total length (mm) and total mercury concentration (mg/kg) during May (●), July (○), August (▼), and October (Δ) for Twelve Mile Lake, Iowa, 2013. Dashed line represents the detection limit (0.05 mg/kg)

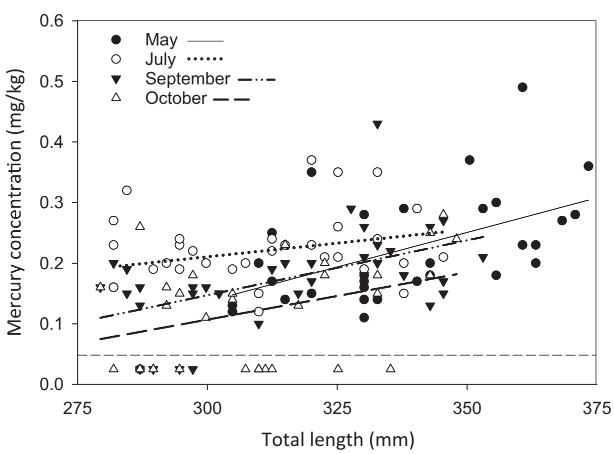

Fig. 2 Relationship between largemouth bass total length (mm) and total mercury concentration (mg/kg) during May (●, solid line), July (○ dotted line), September (▼, dash and dotted line), and October (Δ, dashed line) for Red Haw Lake, Iowa, 2014. Horizontal dashed line represents the detection limit (0.05 mg/kg). Individual month regression equations are as follows, May: Hg = 0.0023*TL – 0.547, P = 0.003; July: Hg = 0.0009*TL – 0.592, P = 0.14; September: Hg = 0.0018*TL – 0.396, P = 0.001; October 0.00156*TL – 0.361, P = 0.047

Lake. Mercury concentrations were highest in July, intermediate in May and September, and lowest during October (Table 1; Fig. 2). Percent of undetectable mercury concentrations increased from 0% of May samples to 37% of October samples (Table 1). Additionally, mercury concentrations increased with largemouth bass total length in Red Haw Lake ($P < 0.01$; Fig. 2).

Meta-analysis

Of the 16 studies identified that evaluated seasonal changes in mercury concentrations in 55 fishes, seasonal variation of

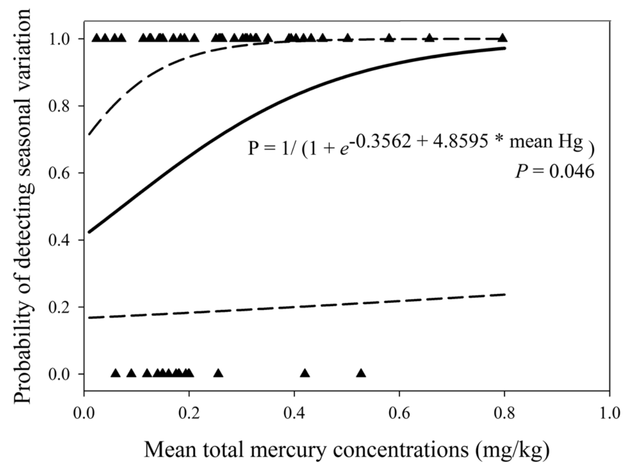

Fig. 3 Binary logistic curve fitted to points evaluating the relationship between mean mercury concentrations in fish muscle tissue and seasonal variation in mercury concentrations. 1 = seasonal variation was detected, 0 = seasonal variation was not detected. Dashed lines represent 95% confidence bands

fish tissue total mercury concentrations occurred in 38 instances (69%), whereas 17 (31%) did not vary seasonally. Logistic regression analysis indicated that the probability of detecting seasonal variation of fish mercury concentration increased with mean mercury concentration of the fishes evaluated ($P = 0.046$; Fig. 3), but was not related to waterbody type ($P = 0.99$), trophic level ($P = 0.99$), or mean total length ($P = 0.71$). Fish populations with an average mercury concentration of < 0.30 mg/kg (EPA consumption advisory threshold) have ≤ 75% probability of detecting seasonal fluctuations, whereas fish populations with an average mercury concentration of > 0.30 mg/kg have over a 75% probability of experiencing seasonal fluctuations in mean mercury concentrations (Fig. 3). Moreover, significant seasonal variation was detected in 90% of studies where mean mercury concentration exceeded 0.30 mg/kg.

Discussion

Although average mercury concentrations were similar in the two study lakes, seasonal variation of largemouth bass mercury concentrations was only detected in one lake. Previous studies have shown fish mercury concentrations tend to peak during the spring and then decline throughout the summer and fall months (e.g., Meili 1991; Ward and Neumann 1999; Bratten et al. 2014; Kenney et al. 2014). Contrary to this phenomenon, largemouth bass mercury concentrations in Red Haw Lake peaked during mid-July, with intermediate levels in September and the lowest levels observed in October. Although there was a statistical difference in largemouth bass mercury concentrations among months in Red Haw Lake, the maximum mean difference between July and October was only 0.12 mg/kg. Thus, fish mercury sampling regimes may not need to be temporally standardized when seasonal concentrations vary minimally. In contrast, of the 38 instances where seasonal mercury concentrations were detected in our meta-analysis, mean maximum seasonal difference in mercury concentrations was 0.24 mg/kg (minimum: 0.04 mg/kg, maximum: 1.24 mg/kg) which is two times larger than we observed for largemouth bass in Iowa.

Mercury concentrations of many fishes in the Midwest tend to be lower than in coastal and marine regions where temporal variation is more common (see Marrugo-Negrete et al. (2010); Saei-Dehkordi et al. 2010; Burger and Gochfeld 2011). Further, largemouth bass mercury concentrations observed in this study were two to four times lower than other studies evaluating seasonal variation in black bass (*Micropterus spp*.) mercury concentrations (e.g., Ward and Neumann 1999; Foster et al. 2000; and Murphy et al. 2007). Thus, based on the results of the meta-analysis, the absence of seasonal variation and the subtle seasonal variation detected in this study may be in part due to a relatively low average mercury concentration in Iowa. Additional seasonal sampling of other lakes throughout the Midwest region with elevated mercury levels may help clarify the extent to which seasonal variation of fish mercury concentrations exists in the Midwestern United States and factors associated with seasonal variation of mercury concentrations.

Several hypotheses have been proposed for why seasonal variation of fish mercury concentrations occurs. First, seasonal warming of water temperature may cause an increase in microbial methylation of mercury, resulting in an increase in bio-available mercury (Weis et al. 1986). Second, a seasonal increase in spring rains may be a source for aerial deposition of mercury (Weis et al. 1986). Third, seasonal variation in fish feeding rates, such as an increased pre-spawn feeding, could result in a pulse of mercury consumption via prey items (Weis et al. 1986), in conjunction with seasonal variation of mercury concentrations in dominant prey items (Ward and Neumann 1999). Finally, growth dilution, where fast tissue growth in summer enabled by warm temperatures effectively dilutes mercury consumed in food compared with slower growth in winter due to cold temperatures, may result in seasonal variation in tissue mercury concentrations (Selch et al. 2007). However, because bioaccumulation of mercury is a time-integrated process, a relatively short pulse of mercury into aquatic systems/organisms, such as spring rains or a brief increase in feeding rate, would not likely immediately increase fish muscle tissue mercury concentrations. Additionally, fish feeding rates are generally high throughout the growing season (Cochran and Adelman 1982) and excretion of mercury is extremely low (Laarman et al. 1976; Van Walleghem et al. 2007; Madenjian et al. 2014). Thus, a brief shift in prey items would probably not result in a decline in fish mercury concentrations throughout the summer and fall months.

An alternative explanation for seasonal variation in fish tissue mercury concentrations is the proximate composition of muscle tissue (composition of moisture, ash, lipids, and proteins; Ward and Neumann 1999). Methylmercury binds to sulfhydryl groups on proteins, and not lipids (Laarman et al. 1976). Thus, fish muscle tissue with low percent lipid composition should have a higher mercury concentrations compared to similar fish muscle tissue with a high-percent lipid composition. Fish muscle lipid composition tends to be lower during the spring months, after lipid stores have been depleted throughout the winter (Leu et al. 1981; Weatherly and Gill 1987; Bae and Lim 2012; Kailasam et al. 2015). Conceptually, the proximate composition of fish muscle tissue is slowly enriched with lipids throughout the growing season (Griffiths and Kirkwood 1995), diluting the protein mass in the muscle tissue and corresponding mercury concentrations per unit wet-weight. Despite these processes, monthly variation of mercury concentrations in horse mackerel (*Trachurus trachurus*) and Atlantic bonito (*Sarda sarda*) was positively related to lipid content and negatively related to protein content (Özden 2010) potentially due to growth dilution. However, mercury concentrations were not adjusted for fish length or age that can have a substantial influence on mercury concentrations and may have confounded these relationships (Wiener and Spry (1996); Tremain and Adams 2012). Further, fat content of roach (*Rutilus rutilus*) and perch (*Perca fluviatilis*) can steadily increase over the growing season that may have implications for protein mass mercury dilution (Griffiths and Kirkwood 1995).

Results of this study indicate that largemouth bass mercury concentrations varied seasonally in one lake but not another lake in close proximity, suggesting localized factors may be important determinants of seasonal variation in mercury concentrations. The incidence of seasonal variation of fish mercury concentrations was related to the overall level of mercury contamination and may be prevalent in populations where the annual mean concentration is >0.30 mg/kg. Thus, seasonal sampling to detect this potentially important source of variation may be warranted to better inform consumption advisories. Seasonal sampling of fishes for mercury monitoring can substantially increase effort and monetary costs (USEPA 2010) but may be necessary in some situations where mercury concentrations vary seasonally.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. This study was performed under the Iowa State University Institutional Animal Care and Use Committee (IACUC) protocol permit 4-14-7780-I and animals were collected under state permit SC1037.

Appendix

Table 2

Table 2 Summary of data used in the meta-analysis

Authors	Year	Common name (*Scientific name*)	*N*	Mean Hg	SV (1/0)	Waterbody type	Trophic level	TL
Bae and Lim	2012	Chub Mackerel (*Scomber japonicus*)	36	0.06	1	Ocean	Piscivore	337
Braaten et al.	2014	Perch (*Perca fluviatilis*)	562	0.26	1	Natural Lake	Piscivore	140
Braaten et al.	2014	Perch (*Perca fluviatilis*)	562	0.31	1	Natural Lake	Piscivore	144
Burger and Gochfeld	2011	Striped Bass (*Morone saxatillis*)	178	0.39	1	Ocean	Piscivore	830
Burger and Gochfeld	2011	Bluefish (*Potamomus saltatrix*)	206	0.35	1	Ocean	Piscivore	470
Burger and Gochfeld	2011	Tautog (*Tautoga onitis*)	47	0.20	0	Ocean	Invertivore	420
Burger and Gochfeld	2011	Windowpane Flounder (*Scophthalmus aquosus*)	48	0.18	0	Ocean	Omnivore	280
Burger and Gochfeld	2011	Weakfish (*Cynoscion regalis*)	60	0.15	0	Ocean	Omnivore	440
Burger and Gochfeld	2011	Northern Kingfish (*Menticirrhus saxatilis*)	72	0.15	1	Ocean	Invertevore	280
Burger and Gochfeld	2011	Summer Flounder (*Paralichthys dentatus*)	260	0.14	0	Ocean	Omnivore	520
Burger and Gochfeld	2011	Atlantic Croaker (*Micropogonias undulatus*)	63	0.12	0	Ocean	Omnivore	310
Burger and Gochfeld	2011	Scup (*Stenotomus chrysops*)	27	0.09	0	Ocean	Invertivore	260
Burger and Gochfeld	2011	Winter Flounder (*Pseudopleuronectes americanus*)	58	0.06	0	Ocean	Invertivore	NR
Burger and Gochfeld	2011	Ling (*Molva molva*)	39	0.04	1	Ocean	Omnivore	260
Costa et al.	2009	Largehead Hairtail (*Trichiurus lepturus*)	104	0.13	1	Ocean	Piscivore	631
Farkas et al.	2000	Bream (*Abramis brama*)	57	0.15	0	Natural Lake	Invertivore	262
Farkas et al.	2000	Pike-Perch (*Stizostedion lucioperca*)	39	0.26	0	Natural Lake	Piscivore	412
Farkas et al.	2000	Eel (*Anguilla anguilla*)	22	0.11	1	Natural Lake	Omnivore	645
Foster et al.	2000	Largemouth Bass (*Micropterus salmoides*)	53	0.42	0	Reservoir	Piscivore	425
Fowlie et al.	2008	Yellow Perch (*Perca flavescens*)	31	0.15	1	River	Piscivore	138
Gochfield et al.	2012	Striped Bass (*Morone saxatillis*)	98	0.39	1	Ocean	Piscivore	833
Hylander et al.	2000	Pintado (*Pseudoplatystoma coruscans*)	23	0.30	1	River	Piscivore	900
Marrugo-Negrete et al.	2010	Bagre Pintado (*Pseudoplatystoma fasciatum*)	24	0.43	1	Marsh	Piscivore	NR
Marrugo-Negrete et al.	2010	Mojarra (*Caquetaia kraussi*)	22	0.40	1	Marsh	Piscivore	NR
Marrugo-Negrete et al.	2010	Moncholo (*Hoplias malabaricus*)	33	0.33	1	Marsh	Piscivore	NR
Marrugo-Negrete et al.	2010	Pacora (*Plagioscion surinamensis*)	33	0.32	1	Marsh	Piscivore	NR
Marrugo-Negrete et al.	2010	Bocachico (*Prochilodos magdalenae*)	33	0.14	1	Marsh	Omnivore	NR
Marrugo-Negrete et al.	2010	Liseta (*Leporinus muyscoruma*)	27	0.26	1	Marsh	Omnivore	NR
Mills et al.	2018	Largemouth Bass (*Micropterus salmoides*)	129	0.18	1	Impoundment	Piscivore	318
Mills et al.	2018	Largemouth Bass (*Micropterus salmoides*)	117	0.19	0	Impoundment	Piscivore	378

Table 2 (continued)

Authors	Year	Common name (*Scientific name*)	*N*	Mean Hg	SV (1/0)	Waterbody type	Trophic level	TL
Moreno et al.	2015	Northern Pike (*Esox lucius*)	49	0.58	1	Natural Lake	Piscivore	514
Moreno et al.	2015	European Whitefish (*Coregonus lavaretus*)	121	0.17	1	Natural Lake	Invertivore	314
Moreno et al.	2015	European Perch (*Perca fluviatilis*)	96	0.42	1	Natural Lake	Piscivore	228
Murphy et al.	2007	Smallmouth Bass (*Micropterus dolomieu*)	45	0.80	1	River	Piscivore	240
Özden	2010	Atlantic Bonito (*Sarda sarda*)	120	0.33	1	Ocean	Piscivore	NR
Özden	2010	Horse Mackerel (*Trachurus trachurus*)	600	0.29	1	Ocean	Piscivore	NR
Saei-Dehkordi et al.	2010	Narrow-Barred Spanish Mackerel (*Scomberomorus commerson*)	12	0.31	1	Ocean	Piscivore	900
Saei-Dehkordi et al.	2010	Dorah Wolf-Herring (*Chirocentrus dorab*)	12	0.16	0	Ocean	Piscivore	690
Saei-Dehkordi et al.	2010	Pickhandle Barracuda (*Sphyraena jello*)	12	0.20	0	Ocean	Piscivore	675
Saei-Dehkordi et al.	2010	Cobia (*Rachycentron canadum*)	12	0.21	1	Ocean	Piscivore	765
Saei-Dehkordi et al.	2010	Longtail Tuna (*Thunus tonggol*)	12	0.53	0	Ocean	Piscivore	565
Saei-Dehkordi et al.	2010	Largehead Hairtail (*Trichiurus lepturus*)	14	0.12	0	Ocean	Piscivore	780
Saei-Dehkordi et al.	2010	Blacktip Tevally (*Caranx sem*)	14	0.25	1	Ocean	Omnivore	440
Saei-Dehkordi et al.	2010	Silver Pomfret (*Pampus argenteus*)	16	0.13	1	Ocean	Omnivore	290
Saei-Dehkordi et al.	2010	Black Pomfret (*Parastromateus niger*)	16	0.18	0	Ocean	Omnivore	280
Saei-Dehkordi et al.	2010	Threadfin Bream (*Nemipterus japonicus*)	10	0.18	0	Ocean	Omnivore	260
Saei-Dehkordi et al.	2010	Orange-Spotted Grouper (*Epinephelus coioides*)	10	0.40	1	Ocean	Piscivore	425
Saei-Dehkordi et al.	2010	Bartail Flathead (*Platycephalus indicus*)	10	0.19	1	Ocean	Piscivore	375
Saei-Dehkordi et al.	2010	Indian Halibut (*Psettodes erumei*)	10	0.45	1	Ocean	Piscivore	405
Saei-Dehkordi et al.	2010	Silver Grunt (*Pomadasys argenteus*)	10	0.26	1	Ocean	Invertivore	490
Saei-Dehkordi et al.	2010	Yellow fin Seabream (*Acanthopagrus latus*)	10	0.39	1	Ocean	Invertivore	400
Tugrul et al.	1980	Red Mullet (*Mullus surmuletus*)	36	0.07	1	Ocean	Invertivore	136
Tugrul et al.	1980	Gray Mullet (*Mugil auratus*)	30	0.02	1	Ocean	Invertivore	307
Ward and Neumann	1999	Largemouth Bass (*Micropterus salmoides*)	75	0.66	1	Impoundment	Piscivore	329
Ward and Neumann	1999	Largemouth Bass (*Micropterus salmoides*)	73	0.50	1	Impoundment	Piscivore	305

Reported here are authors, year of publication, common, and scientific name of fish species, sample size (*N*), mean mercury concentrations (mg/kg; wet-weight measured in axial muscle tissue), binary account of whether or not seasonal variation was detected (SV; 1 = yes, 0 = no), waterbody type, categorical trophic status, and mean total length of fishes evaluated (TL (mm); *NR* not reported).

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