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Assessment of nonlethal methods for predicting muscle tissue mercury concentrations in coastal marine fishes

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Abstract

Caudal fin clips and dorsolateral scales were analyzed in this study as a potential nonlethal approach for predicting muscle tissue mercury (Hg) concentrations in marine fishes. Target fishes were collected from the Narragansett Bay (RI, USA), and included black sea bass *Centropomus striata* ($n = 54$, 14–55 cm total length, TL), bluefish *Pomatomus saltatrix* ($n = 113$, 31–73 cm TL), striped bass *Morone saxatilis* ($n = 40$, 34–102 cm TL), summer flounder *Paralichthys dentatus* ($n = 64$, 18–55 cm TL), and tautog *Tautoga onitis* ($n = 102$, 27–61 cm TL). For all fish species, Hg concentrations were greatest in muscle tissue (mean muscle Hg = 0.47–1.18 mg/kg dry weight), followed by fin clips (0.03–0.09 mg/kg dry weight) and scales (0.01–0.07 mg/kg dry weight). The coefficient of determination (R^2) derived from power regressions of intra-species muscle Hg against fin and scale Hg ranged between 0.35–0.78 (mean $R^2 = 0.57$) and 0.14–0.37 (mean $R^2 = 0.30$), respectively. The inclusion of fish body size interaction effects in the regression models improved the predictive ability of fins ($R^2 = 0.63$ –0.80; mean = 0.71) and scales ($R^2 = 0.33$ –0.71; mean = 0.53). According to the high level of uncertainty within the regression models (R^2 values) and confidence interval widths, scale analysis was deemed an ineffective tool for estimating muscle tissue Hg concentrations in the target species. In contrast, the examination of fin clips as predictors of muscle Hg had value as a cursory screening tool, but this method should not be the foundation for developing human consumption advisories. It is also noteworthy that the efficacy of these nonlethal techniques was highly variable across fishes, and likely depends on species-specific life history characteristics.

Keywords

Caudal fin; Mercury; Muscle; Nonlethal; Scale

Methylmercury (MeHg) is a pervasive environmental toxicant that poses considerable risk to biotic receptors, including humans (US EPA 1997). Humans are exposed to MeHg mainly through the consumption of fish (Hightower and Moore 2003), and MeHg typically constitutes > 95% of the total mercury (Hg) in fish muscle tissue (Bloom 1992). Further, MeHg bioaccumulates in fish tissue at concentrations that often exceed recommended human consumption thresholds (US EPA 1997). Accordingly, monitoring mercury concentrations in commercially- and recreationally-valuable fisheries is needed to properly assess risks to human health resulting from dietary MeHg exposure.

Federal and state monitoring programs evaluate fish Hg concentrations to develop consumption advisories, which in turn inform the public of potential health risks associated with eating fish. These programs collect a representative sample from target populations and

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subsequently sacrifice the fish to remove muscle tissue for analysis. However, frequent and large-scale sampling efforts may be cost prohibitive and potentially detrimental to the ecosystem, e.g., removal of upper trophic level fish may alter food web structure. The implementation of nonlethal analysis techniques provides several advantages relative to traditional methods, including increasing the sample size, e.g., collecting specimens from angling tournaments and scientific surveys, and expanding the spatial distribution of collection sites by including protected areas with threatened fish populations (Osmundson et al. 2000; Hamilton et al. 2002; Baker et al. 2004). Moreover, nonlethal techniques allow multiple samples to be removed from a single fish, and thus, Hg accumulation may be analyzed across sequential life history stages (Hamilton et al. 2002).

Nonlethal sampling techniques as predictors of muscle tissue Hg concentration have been examined in freshwater fishes, including the analysis of muscle biopsies (Baker et al. 2004; Schmitt and Brumbaugh 2007), blood (Schmitt and Brumbaugh 2007), anal, caudal, and pelvic fin clips (Gremillion et al. 2005; Rolfhus et al. 2008) and scales (Lake et al. 2006). The use of muscle tissue biopsies and blood samples of freshwater fishes provided a reliable alternative to traditional whole-fish methods; however, these sampling techniques may be invasive and potentially more difficult, expensive, and time-consuming to collect (Baker et al. 2004; Schmitt and Brumbaugh 2007). Conversely, the use of fins and scales to predict muscle Hg concentrations are simple and non-invasive, but may be variable and less reliable as independent methods of Hg analysis for the issuance of fish advisories (Lake et al. 2006; Rolfhus et al. 2008). It is also noteworthy that the implementation of these alternative methods has been limited in estuarine and marine fishes, despite the importance of these species as a dietary resource for the human population (US EPA 2002).

The Narragansett Bay estuary (RI, USA) has been the subject of recent Hg research, including the bioaccumulation and trophic transfer of Hg in recreationally- and commercially-important fishes (Piraino and Taylor 2009; Payne and Taylor 2010; Szczebak and Taylor 2011). The products of this research effort have provided meaningful assessments of fish Hg contamination that potentially threatens environmental and human health. This report is an extension of the ongoing research in Narragansett Bay and specifically evaluates the utility of nonlethal sampling techniques as predictors of muscle tissue Hg concentrations in coastal marine fishes. Fish caudal fin clips and dorsolateral scales were used in this analysis because of the ease and non-invasive manner in which they are collected (Smith and Buckley 2003; Wells et al. 2003; Tringali et al. 2008). The fish species targeted in this study include black sea bass *Centropristis striata*, bluefish *Pomatomus saltatrix*, striped bass *Morone saxatilis*, summer flounder *Paralichthys dentatus*, and tautog *Tautoga onitis*: five unique species that support lucrative commercial and recreational fisheries in the northeastern United States.

Materials and Methods

Target species (black sea bass, bluefish, striped bass, summer flounder, and tautog) were collected from Narragansett Bay from May to September 2006 to 2010 using bottom-trawls and hook and line (Fig. 1). Fish captured in the field were immediately placed on ice for transportation and frozen at -20°C after returning to the laboratory. Upon further processing, fish were partially thawed and measured for total length (TL; cm) and whole-body wet weight (Wt; g). Additional samples of recreationally-caught striped bass and tautog were collected at local marinas, whereby only filleted racks (i.e., fish with fillets removed) were available. These specimens were preserved and processed identically to whole-body fish; however, body size was only measured as TL. For all samples, a white muscle tissue sample (~ 0.6 g dry weight with skin and scales removed) was extracted from the dorsal region above the operculum on each side of the fish using stainless-steel surgical

blades. This axial muscle tissue is accessible in all fishes, including filleted racks, and its Hg concentration is indicative of the whole-body fillet (Piraino and Taylor 2009; Payne and Taylor 2010; Szczebak and Taylor 2011). For individual fish, two fin clips (~ 0.04 g dry weight) were removed from the upper and lower lobes of the caudal fin using stainless-steel scissors. The caudal fin clip extended from the base of several fin rays to the distal tip of the fin, hence minimizing the potential biases associated with the differential apportionment of Hg in the proximal and distal areas of the fin (Rolfhus et al. 2008). Multiple scales (~ 0.04 g dry weight) were also removed from the dorsolateral region of both sides of the fish using a stainless-steel scalpel and forceps. After removal, fin clips and scales were rinsed with deionized water to remove surface debris. Cleaning procedures were implemented between fish dissections to avoid potential cross-contamination, which consisted of thoroughly scrubbing instruments and surfaces (i.e., blades, scissors, forceps, and trays) with polyethylene brushes and Liquinox® liquid detergent, followed by rinsing with warm water (~ 50 °C). After dissections, all tissue samples were freeze-dried for 48 hr (Labconco FreeZone 4.5-L Benchtop Freeze-Dry System). Dried samples were then weighed (g dry weight), homogenized with a clean stainless-steel spatula (muscle only), and stored at room temperature in borosilicate vials.

The concentration of Hg in fish muscle tissue, fin clips, and scales were measured using a direct mercury analyzer (DMA-80, Milestone, Shelton, Connecticut) following the protocols outlined in EPA Method 7473 (US EPA 1998). The DMA-80 has a detection limit of 0.01 ng Hg (typical working range = 0.05–600 ng), and the Hg content of all samples in this study were above the instrument's detection limit. Certified reference materials (CRMs) of known Hg content, including TORT-1 (lobster hepatopancreas) and DORM-2 (dogfish muscle), prepared by the National Research Council Canada Institute of Environmental Chemistry (Ottawa, Canada) were used to calibrate the mercury analyzer. Calibration curves were highly linear (range $R^2 = 0.99$ – 1.00 ; $p < 0.0001$), and the recovery of independently analyzed samples of TORT-1, DORM-2, and PACS-2 (marine sediment) CRMs ranged from 91.1% to 108.3% (mean = 96.8%). Two concurrent investigations also determined that the DMA-80 used in this study produced statistically equivalent results to isotope dilution gas chromatography-inductively coupled plasma mass spectrometry, with R^2 values of 0.902–0.946 between the two methods (Piraino and Taylor 2009; Payne and Taylor 2010). All muscle, fin clip, and scale samples were analyzed as duplicates and values were averaged for statistical analysis. The mean absolute difference in Hg concentrations between duplicates was 4.2%, 14.5%, and 16.2% for muscle, fin clips, and scales, respectively. For additional quality control, blanks were analyzed every 10 samples in the DMA-80 to assess instrument accuracy and potential drift.

Prior to parametric statistical analyses, data were $\log_{10}$ -transformed to meet assumptions of normality and homogeneity of variance, as determined from Shapiro-Wilk and Levene's tests. Intra-species differences in the muscle, fin clip, and scale Hg concentrations were analyzed with one-way analysis of variance (ANOVA) models using tissue-type as a fixed factor. Mean differences in Hg concentrations across the 3 levels of tissue were contrasted with Ryan-Einot-Gabriel-Welsch (Ryan's Q) multiple comparison tests. Least-squares power regression models (log-log transformed) were used to analyze the relationship between the Hg concentrations (mg/kg dry weight) of muscle tissue and their respective fin clips and scales. Stepwise multivariate regression models were also used to examine the additional effect of fish body size and spatio-temporal conditions on muscle Hg concentrations. Variables included in the stepwise regression model were fin or scale Hg content, whole-body wet weight [g; black sea bass, bluefish (scales), striped bass, and summer flounder], total length [cm; bluefish (fins) and tautog], fin or scale Hg–body size interaction effects, year (2006–2010), date of capture (day of year), and place of capture (latitude and longitude; decimal degrees). For a given explanatory variable, the significance

level for entry and retention into the regression model was set at $p < 0.05$. To further evaluate the predictive ability of regression models, 95% confidence intervals (CI) and CI widths were calculated from individual predicted values. Confidence interval widths (CIW; %) were determined for defined muscle Hg concentrations ranging between 1.3 and 1.4 mg/kg dry weight [CIW = ((Upper 95% CI – Lower 95% CI) / Predicted value) × 100]. The muscle Hg concentrations of 1.3 to 1.4 mg/kg dry weight represents the US Environmental Protection Agency action level (0.3 mg/kg wet weight), converted to dry weight using species-specific wet/dry ratios (77.2–78.6%; Piraino and Taylor 2009; Payne and Taylor 2010; Szczebak and Taylor 2011).

Results and Discussion

The relationships between Hg concentration in dorsal muscle tissue and both caudal fin clips and dorsolateral scales were analyzed for five fish species collected from the Narragansett Bay estuary ($n = 373$ total fish). Among all fish species, Hg concentrations were significantly greater in muscle tissue (mean muscle Hg = 0.47–1.18 mg/kg dry weight), followed by fin clips (0.03–0.09 mg/kg dry weight) and scales (0.01–0.07 mg/kg dry weight) (1-way ANOVA: $p < 0.0001$; Ryan's Q multiple comparison test) (Table 1). There was also a significant positive relationship between Hg concentrations in fish muscle tissue and their corresponding fins and scales (Table 2; Fig. 2). Specifically, the coefficient of determination (R^2) derived from power regressions (log-log transformed) of muscle Hg against fin and scale Hg ranged between 0.35–0.78 (mean $R^2 = 0.57$) and 0.14–0.37 (mean $R^2 = 0.30$), respectively (Table 2). These results indicate that fin clips, relative to scales, have more utility in predicting muscle Hg concentrations of marine fishes, as was reported previously for freshwater fish (Ryba et al. 2008). Further, the inclusion of fish body size interaction effects (fin or scale Hg × Wt or TL) in the stepwise regressions improved the predictive ability of the models, such that cumulative R^2 -values ranged from 0.63–0.80 (mean = 0.71) and 0.33–0.71 (mean = 0.53) for fins and scales, respectively (Table 2). With the exception of bluefish and the effects of TL (fins) and Wt (scales), no other variables were significant in the regression models.

Univariate and multivariate regression models were used to evaluate the ability of caudal fins and dorsolateral scales to predict a muscle tissue Hg concentration equivalent to the US EPA threshold (1.3–1.4 mg/kg dry weight). According to univariate regression analyses, the estimates of muscle Hg concentration from fin and scale data produced a mean CIW of 155.2% (range = 84.7–212.6%) and 208.9% (range = 116.3–291.3%), respectively (Table 2). Further, the inclusion of body size interaction effects in the multivariate analyses reduced the uncertainty in muscle Hg estimates, such that CIWs were 129.0% (range = 85.2–218.6%) for fins and 153.1% (range = 115.8–204.9%) for scales (Table 2). These uncertainty measurements are comparable to estimates of largemouth bass *Micropterus salmoides* muscle Hg concentrations that were derived from scale Hg relationships (CIW = 131%; Lake et al. 2006). In contrast, relative to this study, CIWs were narrower for 13 species of freshwater fish, which were based on the ability of muscle tissue biopsies to predict fish whole-body Hg burdens (CIW = 84.0%; Peterson et al. 2005).

Variability in muscle Hg concentrations explained by caudal fin clip and dorsolateral scale Hg differed among target fishes. The strongest relationship between the Hg concentration of muscle tissue and fins and scales was observed in tautog ($R^2 = 0.78$ and 0.37; Table 2). This observation is attributed to the elevated Hg content of these tissues (Table 1), which enables the fins and scales to be a more robust estimate of the muscle Hg concentration (Ryba et al. 2008). Moreover, variability in the utility of these nonlethal sampling techniques appears to be related to species-specific life history characteristics. For example, a strong relationship between Hg concentrations of muscle tissue and fins was also observed for black sea bass

when the effect of fish size was incorporated into the model ($R^2 = 0.76$; Table 2). Both tautog and black sea bass exhibit high site fidelity with distinct habitat associations (Steimle and Shaheen 1999; Steimle et al. 1999), which may improve the Hg signature of fins relative to muscle tissue. Fish Hg burdens often vary over relatively small spatial scales (Ryba et al. 2008; Piraino and Taylor 2009; Payne and Taylor 2010; Szczebak and Taylor 2011), which in turn is attributed to site-specific differences in biogeochemical and ecological conditions that affect the production, mobilization, and trophic transfer of Hg in aquatic ecosystems (Chen et al. 2008). Accordingly, fishes with strong site fidelity are expected to have a greater correlation between their respective muscle and fin Hg concentrations.

The deposition and accumulation rate of Hg differs among fish tissue, including muscle, fins, and scales (Rolfhus et al. 2008; Ryba et al. 2008). Therefore, assessing Hg relationships among diverse tissues in fish can be problematic for species that demonstrate seasonal migrations and ontogenetic shifts in habitat use and diet, as reported for several species examined in this study (Packer et al. 1999; Collette and Klein-MacPhee 2002; Drohan et al. 2006; Shepherd and Packer 2006). For example, striped bass and bluefish are migratory species and exhibit both seasonal and ontogenetic shifts in movement patterns. More specifically, striped bass are estuarine-dependent and participate in a range of migration patterns from local movements within estuaries to large oceanic migrations (Secor and Piccoli 2007). Bluefish are also highly migratory, with adults spawning on the inner continental shelf and juveniles/adults foraging opportunistically in estuaries and coastal waters (Collette and Klein-MacPhee 2002; Shepherd and Packer 2006). Presumably this migratory behavior was reflected by weaker and more variable relationships between muscle and fin Hg concentrations for striped bass and bluefish ($R^2 = 0.59$ and 0.69 ; Table 2), as compared to tautog and black sea bass.

The weakest relationship between muscle tissue and fin and scale Hg concentrations was observed in summer flounder ($R^2 = 0.35$ and 0.32 ; Table 2), which has a benthic lifestyle and prefers soft-bottom, muddy-sand substrates (Packer et al. 1999). Estuarine sediments are repositories for Hg and have substantially higher contaminant concentrations relative to the overlying water column (Kannan et al. 1998; Balcom et al. 2004). Therefore, one might expect benthic fishes to have a disproportionate amount of Hg in fins and scales, relative to the sub-dermal muscle tissue, owing to their direct contact with the substrate and surficial contamination. Yet, data from this study do not support that supposition, considering that fin and scale Hg concentrations were relatively low for summer flounder (Table 1). Moreover, there was no significant difference in the mean Hg concentration of scales taken from the sighted versus blind side of summer flounder, noting that the blind side has proximate contact with the substrate (mean Hg concentration of sighted and blind scales = 0.012 and 0.014 mg/kg dry weight; standard t -test: $p = 0.259$).

Previous studies that evaluated nonlethal methods for assessing fish tissue Hg concentrations reported significant positive relationships between muscle tissue and scale and fin Hg concentrations (Table 3). Lake et al. (2006) observed a stronger positive relationship ($R^2 = 0.90$) between Hg concentration in scales and muscle tissue of largemouth bass than observed for all species analyzed in the current study (mean $R^2 = 0.30$ and 0.53 for univariate and multivariate regressions; Table 2). The higher R^2 -value reported in Lake et al. (2006) is attributed to a rigorous scale cleaning protocol, which has been verified in other investigations to improve the predictive ability of scale analysis (Iversen et al. 2011). Nevertheless, Lake et al. (2006) also reported considerable variation in the muscle-scale Hg relationship, and therefore suggested that scales be used only as a first level screening tool to assess general trends in muscle tissue Hg concentrations. Other investigators did not detect significant relationships between total Hg concentrations in fish muscle tissue and (unwashed) scales for individual freshwater species, including chub *Squalis cephalus*, bream

Abramis brama, perch *Perca fluviatilis*, and roach *Rutilus rutilus* (Števenka et al. 2011; Valová et al. 2013) (Table 3). In the present study, the relatively high level of uncertainty within the regression models indicates that scales were an ineffective tool for estimating muscle tissue Hg concentrations in marine fishes. While multivariate analysis improved the predictive ability of scales, the inherently low Hg concentration of scales may prove problematic for instrument sensitivity and Hg quantitation.

The relationships between fin and muscle tissue Hg concentration in the present study, as determined from R^2 -values, are similar to those previously reported (Baker et al. 2002; Gremillion et al. 2005; Lake et al. 2006; Rolffhus et al. 2008; Ryba et al. 2008). Previous studies that examined the fin clips of freshwater fishes as a surrogate measurement for muscle tissue Hg yielded R^2 -values between 0.62 and 0.85 (mean = 0.74) (Table 3). Those values are comparable to the R^2 -values observed in the current study when body size was included in the regressions (mean R^2 -values for multivariate regressions = 0.71). Accordingly, based on our investigation, the practical application of caudal fin clips as nonlethal predictors of muscle tissue Hg concentrations in marine fishes is essentially equivalent to its utility in freshwater species. Importantly, however, the variability in muscle Hg explained by caudal fin Hg differed significantly among target fishes, and thus, the efficacy of this nonlethal approach is highly species-specific. Further, given the level of uncertainty in all regression models, the examination of fin clips as predictors of muscle Hg content in marine fishes should be limited to a cursory screening tool and should not be the foundation for developing human consumption advisories.

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Fig. 1.

Fig. 2.

Table 1

Comparison of mean ($\pm$ standard error) total length (cm), whole-body wet weight (g), total mercury concentration (Hg, mg/kg dry weight) of fish dorsal muscle tissue (Muscle Hg), caudal fin clips (Fin Hg), and dorsolateral scales (Scale Hg)

Source	Length	Weight ^a	Muscle Hg	Fin Hg	Scale Hg
Black sea bass (<i>n</i> = 54)	33.8 $\pm$ 1.3	619.5 $\pm$ 62.7	0.706 $\pm$ 0.045	0.037 $\pm$ 0.002	0.012 $\pm$ 0.001
Bluefish (<i>n</i> = 113)	51.8 $\pm$ 1.1	1426.1 $\pm$ 66.7	1.080 $\pm$ 0.034	0.082 $\pm$ 0.003	0.035 $\pm$ 0.002
Striped bass (<i>n</i> = 40)	66.2 $\pm$ 3.0	2645.0 $\pm$ 474.8	1.176 $\pm$ 0.119	0.042 $\pm$ 0.003	0.007 $\pm$ 0.001
Summer flounder (<i>n</i> = 64)	41.5 $\pm$ 0.9	799.3 $\pm$ 46.0	0.466 $\pm$ 0.029	0.028 $\pm$ 0.002	0.012 $\pm$ 0.001
Tautog (<i>n</i> = 102)	43.1 $\pm$ 0.6	2181.0 $\pm$ 271.9	0.822 $\pm$ 0.062	0.093 $\pm$ 0.007	0.067 $\pm$ 0.005

^aSample sizes for striped bass, summer flounder, and tautog weight measurements = 30, 49, and 14, respectively

Table 2

Parameter estimates and summary statistics for univariate and stepwise multivariate regression models used to analyze the relationships among total mercury (Hg) concentration (mg/kg dry weight) of fish dorsal muscle tissue (M_{Hg}), caudal fin Hg (F_{Hg}), dorsolateral scales (S_{Hg}), whole-body wet weight (W ; g), and total length (TL ; cm). Confidence interval widths (CIW; %) based on individual predicted values are also presented for defined muscle Hg concentrations ranging from 1.3 to 1.4 mg/kg dry weight [CIW = ((Upper 95% CI–Lower 95% CI) / Predicted value) $\times$ 100]

Relationship	Model	F (df)	p	R ²	CIW
Univariate regression					
Black sea bass					
Fin	$\log(M_{Hg}) = 0.823 \times \log(F_{Hg}) + 1.003$	36.65 (1, 53)	<0.0001	0.413	171.3
Scale	$\log(M_{Hg}) = 0.435 \times \log(S_{Hg}) + 0.656$	8.44 (1, 53)	<0.01	0.140	219.2
Bluefish					
Fin	$\log(M_{Hg}) = 0.766 \times \log(F_{Hg}) + 0.889$	254.11 (1, 112)	<0.0001	0.688	84.7
Scale	$\log(M_{Hg}) = 0.377 \times \log(S_{Hg}) + 0.578$	51.76 (1, 112)	<0.0001	0.318	116.3
Striped bass					
Fin	$\log(M_{Hg}) = 1.003 \times \log(F_{Hg}) + 1.418$	52.46 (1, 39)	<0.0001	0.593	212.6
Scale	$\log(M_{Hg}) = 0.858 \times \log(S_{Hg}) + 1.868$	19.22 (1, 39)	<0.0001	0.348	291.3
Summer flounder					
Fin	$\log(M_{Hg}) = 0.635 \times \log(F_{Hg}) + 0.679$	33.42 (1, 63)	<0.0001	0.354	175.3
Scale	$\log(M_{Hg}) = 0.498 \times \log(S_{Hg}) + 0.635$	28.34 (1, 63)	<0.0001	0.317	187.5
Tautog					
Fin	$\log(M_{Hg}) = 0.899 \times \log(F_{Hg}) + 0.841$	355.26 (1, 101)	<0.0001	0.777	132.2
Scale	$\log(M_{Hg}) = 0.543 \times \log(S_{Hg}) + 0.490$	57.24 (1, 101)	<0.0001	0.374	220.0
Multivariate regression					
Black sea bass					
Fin	$\log(M_{Hg}) = 0.400 \times \log(F_{Hg}) \times W\eta - 0.679$	167.75 (1, 53)	<0.0001	0.763	101.7
Scale	$\log(M_{Hg}) = 0.402 \times \log(S_{Hg}) \times W\eta - 0.477$	117.28 (1, 53)	<0.0001	0.693	117.5
Bluefish					
Fin	$\log(M_{Hg}) = 0.766 \times \log(F_{Hg}) + 0.077 \times \log(TL) + 0.758$	127.59 (2, 112)	<0.0001	0.691	85.2
Scale	$\log(M_{Hg}) = 0.398 \times \log(S_{Hg}) + 0.057 \times \log(W\eta) + 0.434$	26.95 (2, 112)	<0.0001	0.329	115.8
Striped bass					
Fin	$\log(M_{Hg}) = 0.465 \times \log(F_{Hg}) \times W\eta - 0.929$	48.56 (1, 29)	<0.0001	0.634	218.6

Relationship	Model	F (df)	p	R ²	CIW
Scale	$\log(M_{Hg}) = 0.572 \times \log(S_{Hg}) \times W\bar{h} - 0.704$	70.02 (1, 29)	<0.0001	0.714	186.8
Summer flounder					
Fin	$\log(M_{Hg}) = 0.448 \times \log(F_{Hg}) \times W\bar{h} - 0.933$	82.93 (1, 48)	<0.0001	0.643	113.8
Scale	$\log(M_{Hg}) = 0.354 \times \log(S_{Hg}) \times W\bar{h} - 0.688$	44.27 (1, 48)	<0.0001	0.490	140.7
Tautog					
Fin	$\log(M_{Hg}) = 0.821 \times \log(F_{Hg}) \times TL - 0.587$	400.21 (1, 101)	<0.0001	0.800	125.5
Scale	$\log(M_{Hg}) = 0.515 \times \log(S_{Hg}) \times TL - 0.380$	73.13 (1, 101)	<0.0001	0.438	204.9

Literature review of reported relationships between fish muscle mercury concentrations and the mercury content of corresponding scales and fin clips. For each source document, the following information is provided: fish species and general habitat, tissue-type and mercury form analyzed (Hg: total mercury; MeHg: methylmercury), sample size (n), and R^2 values from linear regression models (muscle mercury vs. scale or fin mercury)

Table 3

Habitat and Species	Conditions		Statistics		Source
	Tissue	Mercury	n	R ²	
Freshwater					
Chub (<i>Squalis cephalus</i>)	Scale	Hg	48	0.002	Valová et al. (2013) ^b
Largemouth bass (<i>Micropterus salmoides</i>)	Scale	Hg	14	0.90 ^a	Lakee t al. (2006) ^b
Largemouth bass (<i>M. salmoides</i>)	Caudal fin	Hg	169	0.85	Rybae t al. (2008) ^b
Northern pike (<i>Esox lucius</i>)	Caudal fin	Hg	12	0.78	Gremillion et al. (2005) ^b
Northern pike (<i>E. lucius</i>)	Caudal fin	Hg	319	0.72	Rolfhus et al. (2008) ^c
Northern pike (<i>E. lucius</i>)	Pelvific in	Hg	311	0.62	Rolfhus et al. (2008) ^c
Walleye (<i>Sander vitreus</i>)	Caudal fin	Hg	17	0.83	Gremillion et al. (2005) ^b
Walleye (<i>S. vitreus</i>)	Caudal fin	Hg	88	0.73	Rolfhus et al. (2008) ^c
Walleye (<i>S. vitreus</i>)	Pelvific in	Hg	79	0.63	Rolfhus et al. (2008) ^c
Arctic grayling (<i>Thymallus arcticus</i>)	Adiposef in	MeHg	8	0.84	Rolfhus et al. (2008) ^c
Arctic grayling (<i>T. arcticus</i>)	Dorsal fin	MeHg	12	0.65	Rolfhus et al. (2008) ^c
Marine					
Winter flounder (<i>Pseudopleuronectes americanus</i>)	Anal fin	MeHg	14	0.94	Rolfhus et al. (2008) ^c

^a R^2 -value is for scales cleaned with mild soap solution. R^2 -value for untreated scales = 0.69–0.74 ($n = 14–76$)

^b Hg analyzed using combustion atomic absorption spectroscopy (Direct Mercury Analyzer, Milestone, Inc. or Leko AMA-254, ALTEC, Inc.)

^c Hg measured using cold-vapor atomic absorption spectrophotometry

^d MeHg measured using cold-vapor atomic fluorescence spectrophotometry