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Potential Health Risks of Methylmercury Contamination to Largemouth Bass in the Southeastern United States

Ryan D. Seymour, Ray W. Drenner, and Matthew M. Chumchal*

Biology Department, Texas Christian University, Fort Worth, Texas, USA

Abstract: Widespread mercury (Hg) contamination of freshwater systems, due primarily to deposition of atmospheric inorganic Hg (IHg), poses a potential threat to recreational fisheries. In aquatic ecosystems, IHg is converted by bacteria to methylmercury (MeHg), a potent toxin that bioaccumulates in consumers and biomagnifies through the food web, reaching elevated concentrations in fish. Methylmercury has concentration-dependent sublethal effects on fish, including reductions in reproductive output. In the present study, we conducted the first analysis of the potential health risks of MeHg contamination to largemouth bass (*Micropterus salmoides*), a popular game fish, in the southeastern United States. To assess the potential health risk posed by MeHg to largemouth bass, we compared MeHg concentrations in three sizes of adult largemouth bass to benchmarks associated with the onset of adverse health effects in fish. We also determined how the risk posed by MeHg to largemouth bass varied spatially throughout the southeastern United States. Our study suggests that in the southeastern United States MeHg poses a potential risk to largemouth bass health and that MeHg contamination may be detrimental to the fisheries of this economically important species of game fish. *Environ Toxicol Chem* 2023;42:1755–1762. © 2023 The Authors. *Environmental Toxicology and Chemistry* published by Wiley Periodicals LLC on behalf of SETAC.

Keywords: Methylmercury; Largemouth bass; Ecoregions; Southeastern United States; Health risks

INTRODUCTION

Game fish in all freshwater ecosystems are contaminated with toxic methylmercury (MeHg), due primarily to widespread deposition of atmospheric inorganic mercury (IHg); but MeHg concentrations in fish differ between water bodies. In freshwater ecosystems, IHg deposited from the atmosphere is converted by bacteria into MeHg that concentrates in algae and bacteria at the base of the food chain (Miles et al., 2001) and then biomagnifies as it moves up the food web (Chumchal et al., 2011). Consumers such as game fish are exposed to MeHg through their diet, and the concentration of MeHg increases with both age (due to bioaccumulation) and trophic position (due to biomagnification) of the game fish (Chumchal & Hambright, 2009; Lavoie et al., 2013; Lepak et al., 2016). Thus, within water bodies, MeHg reaches its highest concentrations in large (i.e., older and higher trophic position) game fish relative to small (i.e., younger and lower trophic position) game fish (Chumchal & Hambright, 2009; Lavoie et al., 2013; Lepak et al., 2016).

Concentrations of MeHg in game fish of a given size and trophic position differ between water bodies in part because of variance in landscape sensitivity to atmospheric deposition of IHg (Driscoll et al., 2013). Mercury-sensitive landscapes are those in which relatively small inputs of IHg can cause significant contamination of fish in upper trophic levels (Drenner et al., 2011, 2022; Driscoll et al., 2007; Evers et al., 2007). Methylmercury contamination of game fish tends to be highest in regions with land cover such as forests and wetlands, which increase the deposition and methylation of IHg, respectively (Drenner et al., 2022; Driscoll et al., 2013; Eagles-Smith, Herring et al., 2016; Evers et al., 2007).

Methylmercury poses a potential health risk to fish (Lepak et al., 2016; Sandheinrich et al., 2011; Sandheinrich & Wiener, 2011; Scheuhammer et al., 2007). Laboratory studies demonstrate that MeHg has concentration-dependent sublethal effects on fish, including reductions in reproductive output, and that adverse health effects occur at concentrations commonly observed in wild fish (Crump & Trudeau, 2009; Sandheinrich & Wiener, 2011). To characterize the potential health risk posed to fish from elevated Hg concentrations within their own

* Address correspondence to m.m.chumchal@tcu.edu
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bodies, Lepak et al. (2016) used laboratory studies (Beckvar et al., 2005; Sandheinrich & Wiener, 2011) to identify three whole-body Hg concentration benchmarks associated with the onset of adverse effects on fish health. The Hg concentration benchmarks (and potential effects) were >200 ng/g (potential effects on biochemical function and gene expression), >300 ng/g (potential effects on behavior, reproduction, and histology), and >1000 ng/g (potential effects on growth and other deleterious effects). Lepak et al. (2016) noted that little or no effect on fish health was observed at concentrations <200 ng/g. These Hg concentration benchmarks create four ranges of Hg concentrations associated with potential health risks in fish (Figure 1).

The potential risks to game fish from elevated MeHg concentrations within their own bodies have been investigated within North America (e.g., the western United States and Canada [Depew et al., 2013; Eagles-Smith, Herring et al., 2016; Eagles-Smith et al., 2014; Lepak et al., 2016], the Great Lakes area [Sandheinrich et al., 2011; Wiener et al., 2012], the northeastern United States and Canada [Batchelar et al., 2013; Gandhi et al., 2015; Willacker et al., 2020], and the circumpolar Arctic [Barst et al., 2022]), but no studies have been conducted across the southeastern United States. In the present study, we examined the potential health risks of MeHg contamination to game fish in the southeastern United States. To assess the potential health risk posed by MeHg to game fish, we compared MeHg concentrations in three sizes of adult largemouth bass (*Micropterus salmoides*) to benchmarks associated with the onset of adverse health effects in fish. We also determined how the health risk posed by MeHg to largemouth bass varied spatially throughout the southeastern United States.

MATERIALS AND METHODS

Study site

The present study focused on a 15-state area of the southeastern United States spanning from Texas and Oklahoma in the west to Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida in the east (Figure 2A). This region accounts for 33% of the land area of the United States (US Census Bureau, 2010). The region contains 24 US Environmental Protection Agency (USEPA) Level III ecoregions (Figure 2B). Ecoregions are areas where ecosystems as well as the type, quality, and quantity of environmental resources are generally similar (USEPA, 2022). Ecoregions are designed to serve as spatial frameworks for the research, assessment, and monitoring of ecosystems and ecosystem components (McMahon et al., 2001; Omernik & Griffith, 2014). These regions have been used for structuring and implementing ecosystem management strategies across federal agencies, state agencies, and nongovernmental organizations that are responsible for different types of resources within the same geographic areas (McMahon et al., 2001; Omernik & Griffith, 2014). In a previous study characterizing the risk of MeHg in game fish to human consumers, Drenner et al. (2022) found that average MeHg concentration in skinless fillets of largemouth bass varied between the Level III ecoregions of the southeastern United States.

Focal species

We focused on MeHg contamination of largemouth bass because, as adults, largemouth bass are representative of high–trophic position game fish with high levels of MeHg contamination (Chumchal & Hambright, 2009; Depew et al., 2013; Eagles-Smith, Ackerman, et al., 2016; Fry & Chumchal, 2012). Largemouth bass are a popular species of freshwater game fish that are highly sought after by anglers (US Fish and Wildlife Service, 2018) and naturally distributed and/or stocked throughout the southeastern United States (Fuller et al., 2023).

Estimation of MeHg in fish

We used the National Descriptive Model of Mercury in Fish (NDMMF; Wente, 2004) to estimate Hg concentrations in

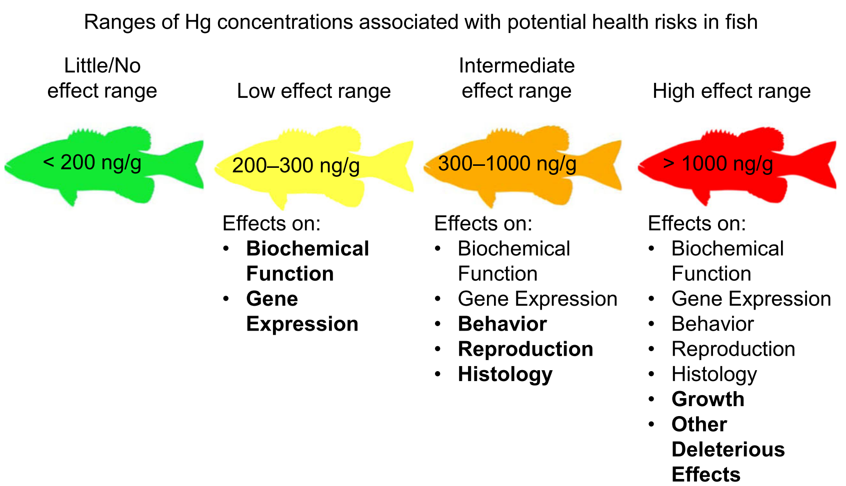

FIGURE 1: Four ranges of whole-body mercury concentrations in fish and their potential adverse effects on fish health (reviewed in Lepak et al., 2016). Novel effects associated with a given concentration range appear in bold.

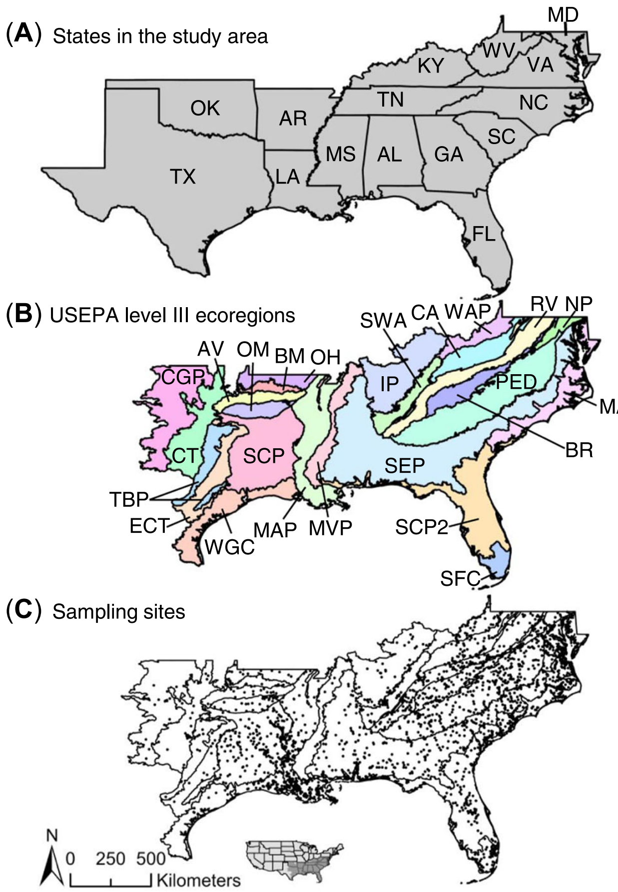

FIGURE 2: The present study focused on (**A**) a 15-state area that contains (**B**) 24 US Environmental Protection Agency Level III ecoregions. (**C**) Locations of 2233 sampling sites in the present study. AV = Arkansas Valley; BM = Boston Mountains; BR = Blue Ridge; CA = Central Appalachian; CGP = Central Great Plains; CT = Cross Timbers; ECT = East Central Texas Plains; IP = Interior Plateau; MAC = Middle Atlantic Coastal Plain; MAP = Mississippi Alluvial Plain; MVP = Mississippi Valley Loess Plains; NP = Northern Piedmont; OH = Ozark Highlands; OM = Ouachita Mountains; PED = Piedmont; RV = Ridge and Valley; SCP = South Central Plains; SCP2 = Southern Coastal Plain; SEP = Southeastern Plains; SFC = South Florida Coastal Plain; SWA = Southwestern Appalachian; TBP = Texas Blackland Prairies; USEPA = US Environmental Protection Agency; WAP = Western Alleghany Plateau; WGC = Western Gulf Coastal Plain. Copyright 2022 Wiley. Used with permission from Drenner et al. (2022).

whole-body largemouth bass equivalents (hereafter *largemouth bass*). Because it is impractical to collect fish of the same size and species from different water bodies over large regions (Wente, 2004), the NDMMF has been widely used to estimate Hg concentrations in common sizes and species of fish from water bodies that have been previously sampled (Adams et al., 2016; Depew et al., 2013; Drenner et al., 2011, 2013, 2022; Gerstle et al., 2019).

The data set in the present study was compiled by the USGS for use with the NDMMF (Drenner et al., 2022). After excluding sites with coordinates that we could not verify, the final data set consisted of 4970 fish sampling events collected over the period 1969–2010 (92% of the fish samples were collected between 1990 and 2010) from 2233 lentic (e.g., oxbow lakes, reservoirs, human-made ponds) and lotic (e.g., creeks, rivers, streams, bayous) sites (Figure 2C; Drenner et al., 2022). If lentic sites had multiple sampling events (were sampled at different times or at multiple locations in the same lentic water body), the sampling events were merged by calculating the mean of the estimated concentrations of Hg (Drenner et al., 2022). If multiple sampling events (sampling times or locations) occurred in the same lotic water body and were within 1 km of each other, they were merged in the same manner (Drenner et al., 2022). After merging sampling events, ecoregions contained from nine to 347 sites, with an average of 93 sites per ecoregion (Drenner et al., 2022).

For each site, we used the NDMMF to estimate whole-body total Hg for the minimum total lengths of largemouth bass associated with three fishery size designations proposed by Gabelhouse (1984): *stock* (20.3 cm total length), *preferred* (38.0 cm total length), and *trophy* (63.5 cm total length). These size designations span the sizes of fish caught by anglers and were proposed by Gabelhouse (1984) to facilitate communication between fisheries professionals. Bloom (1992) found that 99% of the total Hg in largemouth bass is MeHg, and the USEPA (2000) recommends analyzing the concentration of total Hg in fish tissues as a proxy for the concentration of MeHg (Drenner et al., 2022). Therefore, we assumed that 100% of total Hg in largemouth bass was MeHg (Drenner et al., 2022). We assessed the potential level of risk posed by MeHg to largemouth bass by comparing whole-body MeHg concentrations in largemouth bass from each site to Hg concentration benchmarks for adverse effects on fish health developed by Lepak et al. (2016).

Approach

The present study had two objectives. Our first objective was to examine the potential health risk posed by MeHg to adult largemouth bass in the southeastern United States. To accomplish our first objective, we computed the proportion of sites that fell within the four Hg concentration ranges developed by Lepak et al. (2016; Figure 1) for three sizes of adult largemouth bass from 2233 sites across the southeastern United States. Our second objective was to examine how the potential health risk posed by MeHg to largemouth bass varies spatially throughout the southeastern United States. To accomplish our second objective, we computed the proportion of sites that fell within the four Hg concentration ranges for three sizes of adult largemouth bass within each of the 24 ecoregions in the southeastern United States.

RESULTS

Potential health risk of MeHg to adult largemouth bass in the southeastern United States

Mean whole-body MeHg concentrations of largemouth bass increased with fish size (stock, preferred, and trophy sizes with whole-body mean (±SE) MeHg concentrations = 157 ± 2.9 ng/g, 337 ± 6.3 ng/g, and 641 ± 11 ng/g, respectively). For stock-size largemouth bass (Figure 3A), most sites (73%) had MeHg concentrations within the no/little-effects range (<200 ng/g). Thirteen percent of sites had stock-size largemouth bass with concentrations of MeHg within the low-effects range (200–300 ng/g), and 14% were within the intermediate-effects range (300–1000 ng/g). Very few sites (0.2%) had stock-size largemouth bass with concentrations of MeHg in the high-effects range (>1000 ng/g). For preferred-size largemouth bass (Figure 3B), 41% of sites had MeHg concentrations within the no/little-effects range (<200 ng/g). Seventeen percent of sites had preferred-size largemouth bass with concentrations of MeHg within the low-effects range (200–300 ng/g), and 39% of sites were within the intermediate-effects range (300–1000 ng/g). Only 3% of sites had preferred-size largemouth bass with concentrations of MeHg within the high-effects range (>1000 ng/g). For trophy-size largemouth bass (Figure 3C), only 17% of sites had MeHg concentrations within the no/little-effects range (<200 ng/g). Fourteen percent of sites had trophy-size largemouth bass with concentrations of MeHg within the low-effects range (200–300 ng/g), and 49% were within the intermediate-effects range (300–1000 ng/g). Twenty percent of the sites had trophy-size largemouth bass with concentrations of MeHg within the high-effects range (>1000 ng/g). These results suggest that while stock-size fish experience adverse effects from MeHg contamination at relatively few sites, trophy-size fish may experience adverse effects at the majority of sites across the southeastern United States.

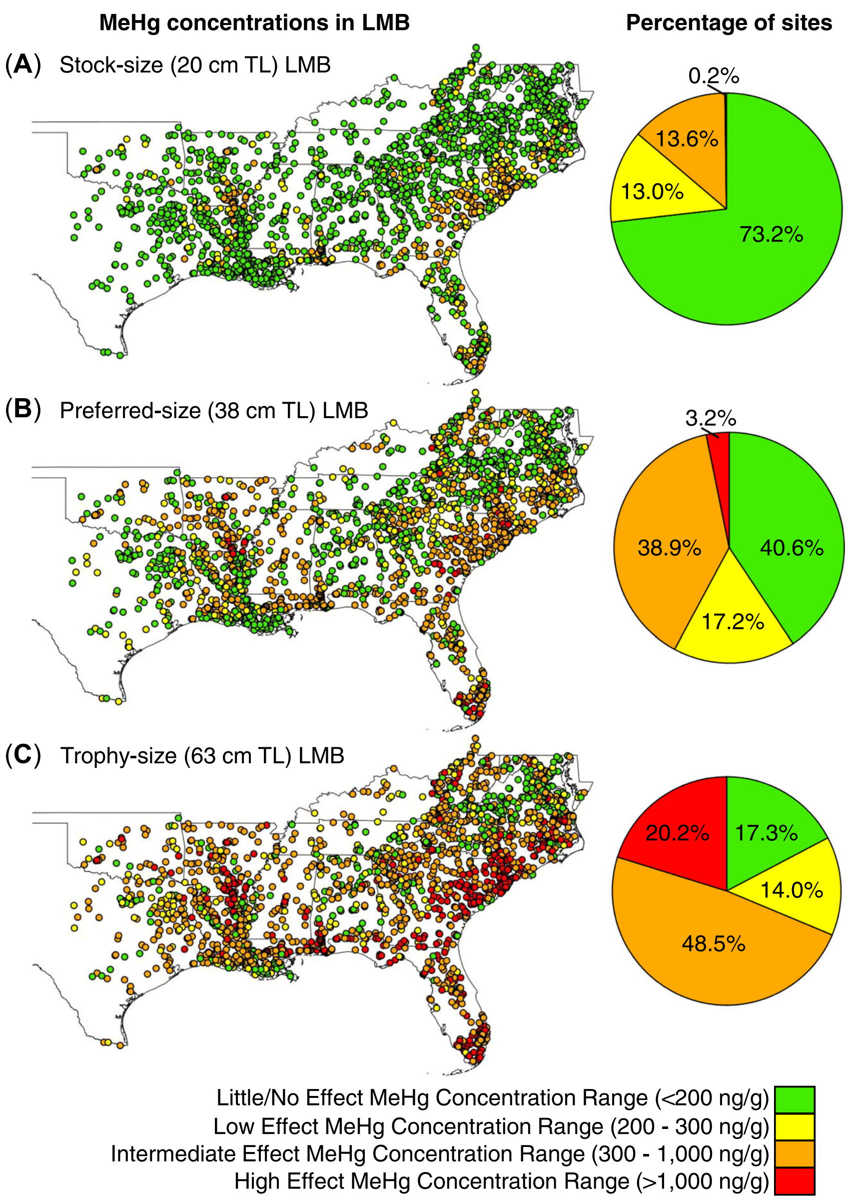

FIGURE 3: Whole-body methylmercury (MeHg) concentrations in largemouth bass estimated using the National Descriptive Model of Mercury in Fish for 2233 sites in the southeastern United States and the percentage of sites within risk effect ranges (defined in Figure 1) for three sizes of largemouth bass: (**A**) stock size (20 cm total length [TL]), (**B**) preferred size (38 cm TL), and (**C**) trophy size (63 cm TL). LMB = largemouth bass.

Spatial variation in potential risk posed by MeHg contamination to adult largemouth bass in the southeastern United States

The MeHg concentrations in largemouth bass and the potential risk of adverse effects were highly variable within and between ecoregions (Figure 4). For stock-size largemouth bass (Figure 4A), the majority of sites in most ecoregions contained largemouth bass with MeHg concentrations within the no/little-effects range (<200 ng/g). However, in highly contaminated ecoregions, some sites had stock-size largemouth bass with MeHg concentrations that fell within the low- and intermediate-effects range. Almost no sites had stock-size largemouth bass with MeHg concentrations in the high-effects range. For preferred-size largemouth bass (Figure 4B), the majority of sites contained largemouth bass with MeHg concentrations in the low- and intermediate-effects range, but a few ecoregions had sites where largemouth bass had MeHg concentrations in the high-effects range. For trophy-size largemouth bass (Figure 4C), most ecoregions had a low percentage of sites where the concentrations of MeHg in largemouth bass were within the no/little-effects range. Within most ecoregions, a majority of sites contained trophy-size largemouth bass with MeHg concentrations within the intermediate-effects range, and sites with trophy-size largemouth with MeHg concentrations within the high-effects range were much more prevalent than for the two smaller sizes of largemouth bass.

DISCUSSION

Although previous studies have demonstrated that largemouth bass in the southeastern United States have concentrations of MeHg in fillets of dorsal muscle tissue that are high

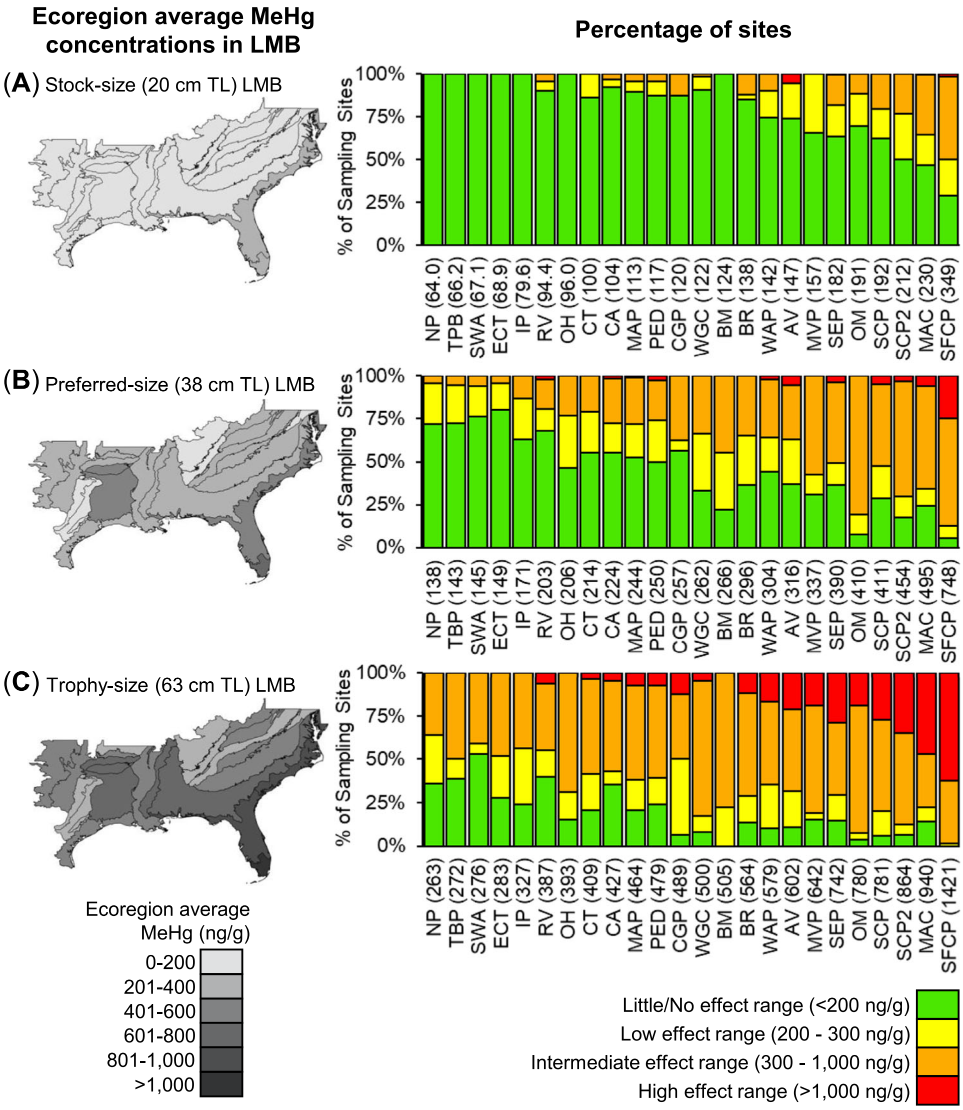

FIGURE 4: Average concentrations of whole-body methylmercury (MeHg) in largemouth bass from ecoregions of the southeastern United States and the percentage of sites within risk effect ranges in each ecoregion for three sizes of largemouth bass: (**A**) stock size (20 cm total length [TL]), (**B**) preferred size (38 cm TL), and (**C**) trophy size (63 cm TL). We used the estimated concentrations of MeHg in largemouth bass generated by the National Descriptive Model of Mercury in Fish for each site within an ecoregion (Figure 2C) to calculate ecoregion-level average MeHg concentrations in largemouth bass for each of the 24 ecoregions (shown in shaded maps and in the histograms [parenthetically adjacent to ecoregion abbreviations]). Ecoregion abbreviations are defined in the legend of Figure 2. LMB = largemouth bass.

enough to pose a threat to human consumers (see Drenner et al., 2022), the present study is the first to examine the potential risk of MeHg to the health of largemouth bass of the southeastern United States. Largemouth bass size is an important variable affecting MeHg concentrations and potential risk because MeHg increases in largemouth bass as they age and grow (Chumchal et al., 2008), and the concentration of MeHg determines the types of adverse health effects that largemouth bass may experience (Figure 1). In most ecoregions, stock-size largemouth bass would be predicted to experience little or no effect from MeHg contamination, whereas in the most contaminated ecoregions, trophy-size fish have such high concentrations of MeHg that they may experience an array of negative health effects including impacts on biochemical function, gene expression, behavior, reproduction, histology, and growth (Figure 1).

We found considerable spatial variability in the risk posed by MeHg to largemouth bass in different ecoregions in the southeastern United States. Ecoregions differ in the level of MeHg contamination of fish, in part because of the differences in land-cover variables that affect the MeHg cycle (Drenner et al., 2022). Drenner et al. (2022) found that ecoregions in the southeastern United States with high coverage by evergreen forests and emergent herbaceous wetlands had high levels of MeHg contamination of largemouth bass. The results of the present study suggest that largemouth bass in these same ecoregions with high coverage by evergreen forests and emergent herbaceous wetlands may be most at risk from the negative health effects from Hg. Ecoregions with high coverage by evergreen forests and emergent herbaceous wetlands are Hg-sensitive because these land cover types enhance atmospheric Hg deposition and are conducive to Hg methylation, respectively (Driscoll et al., 2013; Evers et al., 2007).

The MeHg contamination of trophy-size largemouth bass may have important implications for the quality of recreational largemouth bass fisheries. Trophy-size largemouth bass have higher reproductive output (relative to smaller individuals) and are thought to be important in enhancing the genetic makeup of largemouth bass populations (see Texas Freshwater Fisheries Center, n.d.); thus, the loss of these large-sized individuals (or a reduction in their reproductive output) could have negative impacts on the population. States have hatchery-based breeding and stocking programs to augment the genetic contributions of trophy-size largemouth bass to lakes (see Texas Freshwater Fisheries Center, n.d.), which may ameliorate these negative impacts of MeHg on trophy-size bass. We are unaware of field studies that have examined the potential health effects of MeHg on populations of trophy-size largemouth bass, but such studies are needed given the economic importance of this game fish. The paucity of studies may be in part because trophy-size largemouth bass usually occur at very low densities and are rarely collected by state agencies. Even if trophy-size largemouth bass are captured by state agencies during field surveys, agencies may be hesitant to destructively sample these rare and valuable individuals (personal observation, R. W. Drenner).

Laboratory and field studies of MeHg effects on fish

Our estimates of potential risk of MeHg to largemouth bass are based on benchmarks developed from laboratory studies (Lepak et al., 2016), but findings on individual organisms in the laboratory may not necessarily translate to population-level effects in the field (Fuchsman et al., 2016). A disconnect between lab and field toxicology studies could be due to factors such as long-term adaptation and tolerance of the toxicant by the fish, confounding interactions with other toxicants also present in the environment, or ecological factors (e.g., predator–prey interactions, migration, and emigration; Fuchsman et al., 2016). Although there is empirical evidence that MeHg exposure can have toxicological effects on wild largemouth bass (Adams et al., 1999; Baldigo et al., 2006; Friedmann et al., 2002; Gehringer et al., 2013; Hinck et al., 2008; Martinez-Durazo et al., 2023; Richter et al., 2014; Schlenk et al., 1995; Sugg et al., 1995), there has been little study of the effects of MeHg on largemouth bass populations and fisheries. We are aware of only one study of Hg effects on the abundance of largemouth bass (in Clear Lake, California, USA), the results of which were inconclusive (Suchanek et al., 2008).

CONCLUSION

Given the widespread MeHg contamination of freshwater systems and its potential effects on fish health and fisheries, it is important that future studies examine the effects of MeHg contamination on freshwater fisheries. It will be challenging to determine the effects of MeHg contamination on freshwater fisheries because fish recruitment and populations are highly variable from year to year (see Ludsin & DeVries, 1997; Post et al., 1998; Suchanek et al., 2008). Population-level responses of fish integrate the cumulative effects of MeHg and other chemical stressors on individuals as those individuals interact with and are affected by their conspecifics, competitors, predators, prey, habitat, and other biotic and abiotic factors (Kramer et al., 2011). The present study suggests that the concentrations of MeHg in largemouth bass in the southeastern United States are high enough to have negative effects on largemouth bass populations and that MeHg contamination should be considered in future studies of largemouth bass growth, reproduction, and recruitment. Thus, the effects of MeHg contamination on largemouth bass fisheries will only be understood if government agencies begin to routinely include assessment of MeHg concentration in fish tissues in their long-term field monitoring programs of largemouth bass fisheries.

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Writing—original draft; Visualization; Writing—review & editing. **Ray W. Drenner:** Conceptualization; Writing—original draft; Writing—review & editing. **Matthew M. Chumchal:** Conceptualization; Writing—original draft; Visualization; Writing—review & editing.

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