Characterization of Potential Health Risks Associated with Consumption of Fish from

Caddo Lake

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INTRODUCTION

Caddo Lake, a 26,810- surface-acre water body located on the Texas-Louisiana border in Marion and Harrison counties, is the largest naturally formed lake in the southern United States. Two theories address the formation of Caddo Lake. According to an old Caddo Indian legend, strong earthquakes recorded over the Madrid Fault in 1811 and 1812 were instrumental in forming the lake. However, scientists have found no evidence of earthquakes in sediment core samples from around and beneath Caddo Lake. A second hypothesis is that a mass of fallen logs in the Red River – known as the Great Raft – caused the lake to form. The Great Raft, discovered long before the earthquakes of 1811-1812, reportedly obstructed the Red River in 1806 causing major flooding. [1]. Whatever the lake's origin, Caddo Lake, known for its dense stands of bald cypress, lush vegetation, and its marshy shoreline, affords excellent fishing to a diverse population that may include subsistence fishers [2].

Public health issues relating to mercury in fish from Caddo Lake originated in 1992 when Louisiana and Arkansas responded to a discovery of mercury in largemouth bass from the Ouachita River by issuing consumption advice for several rivers and lakes in south Arkansas and north Louisiana. Researchers – unable to identify point sources for mercury – surmised that mercury in these fish arose from bioaccumulation and bio-magnification of mercury deposited from the atmosphere [3]. Caddo Lake, like other east Texas reservoirs, attains aquatic conditions that encourage formation of organic (methyl) mercury from inorganic mercury. Therefore, the Texas Department of State Health Services (DSHS, formerly the Texas Department of Health, TDH) has long examined fish from reservoirs near the Texas-Louisiana border for mercury or other contaminants of interest to public health risk managers. Caddo Lake has historically been among those lakes evaluated.

During one such evaluation of Caddo Lake in the summer of 1994, the DSHS collected 18 largemouth bass and two freshwater drum for assessment. The DSHS laboratory analyzed the 20 fish for mercury and also analyzed four of the 20 for other metallic contaminants such as arsenic, cadmium, copper, lead, and zinc. In those samples, total mercury in largemouth bass reportedly increased with increased body size. None of the four fish analyzed for metallic contaminants other than mercury contained any metal at levels of concern for public health. In fact, most such chemicals were near the laboratory reporting limits [3].

In January 1995, consequent to the 1994 finding of mercury in fish from Caddo Lake, the DSHS issued a fish consumption advisory (ADV-11) for Caddo Lake [4]. ADV-11 recommended that people refrain from consuming freshwater drum or largemouth bass that were over eighteen (18) inches in length. ADV-11 also suggested that women of childbearing age and children under the age of six years limit consumption of largemouth bass under 14 inches in length to one meal (eight ounces-women; four ounces-children) per month. The Texas Parks and Wildlife Department (TPWD) has an established slot length limit for largemouth bass at Caddo Lake, making it illegal to possess largemouth bass that are between 14 and 18 inches in length [5].

The investigation of mercury in fish from Caddo Lake continued in April 1995, when the DSHS surveyed several east Texas area reservoirs, including Caddo Lake in the survey. The 34 fish collected in 1995 from Caddo Lake expanded the species represented in the Caddo sample to include crappie, white bass, channel catfish, spotted suckers, chain pickerel, sunfish, and yellow bullhead. In all, 54 fish were collected from Caddo Lake between the summer of 1994 and January 1995. Of those, DSHS evaluated mercury in six largemouth bass that were larger than 14 inches but less than 18 inches in length to determine relationships between size of the largemouth bass and mercury concentrations. However, because of the extant slot length limit imposed by the TPWD, the DSHS did not use those six fish to make public health-related decisions about the advisability of consuming largemouth bass from Caddo Lake.

In November 1995, subsequent of its evaluation of the samples from April 1994, the DSHS issued a fish consumption advisory (ADV-12) for mercury in fish taken from several east Texas reservoirs: B.A. Steinhagen Reservoir, Sam Rayburn Reservoir, Toledo Bend Reservoir, Caddo Lake, and Big Cypress Creek [6]. ADV-12, which superceded earlier advice for Caddo Lake fish [4], recommended that adults eat no more than two fish meals, not to exceed eight ounces per meal per month, of largemouth bass and freshwater drum combined. Children were to consume no more than two meals of fish per month, not to exceed four ounces of fish per meal, of largemouth bass and freshwater drum, combined, from Caddo Lake. ADV-12 remains in effect as of this writing.

Mercury, an element, is found in the earth's crust, in air, water, soil, aquatic sediments, and in plants and animals. Because mercury is an element, it is neither created nor destroyed in nature. Thus, mercury cycles through various environmental media naturally and through human activity. Anthropogenic production of mercury is about equal to that of natural sources. Combustion of fossil fuels, especially coal, contributes significantly to environmental mercury loads, emitting elemental mercury or inorganic salts of mercury into the environment. Although mercury can exist as an element in the environment, it is a relatively reactive element, forming salts rather easily. The most important inorganic salts (those containing no carbon) include mercury monochloride (calomel-still used in topical medications), mercuric chloride (a corrosive salt that sublimates and is a violent poison), and mercuric sulfide (cinnabar ore from which mercury is mined; also known as vermilion, a red pigment used in paints). Aquatic microorganisms use inorganic mercury to produce organic mercury, the most prominent compound of which is methylmercury. In water, certain conditions conducive to formation of methylmercury include low water pH, high concentrations of organic matter in surface water or sediment, the presence of microorganisms capable of converting inorganic mercury to organic mercury, and low dissolved oxygen concentrations – methylation of mercury is primarily an anaerobic process.

Some aquatic organisms easily absorb methylmercury from water, concentrating the substance in their body tissues. Those tissues may achieve higher concentrations than the concentrations of mercury in the surrounding water, a process called bioconcentration. Some fish have no mechanisms for removing methylmercury from their bodies. Continued absorption of methylmercury without concomitant excretion results in accumulation of the substance in tissues, a process called bioaccumulation [7]. It follows that older, larger fish may contain higher levels of methylmercury than younger, smaller fish. Predatory fish that eat smaller mercury-contaminated fish will further accumulate methylmercury. Thus, predators occupying niches near the top of the food chain attain even higher levels of methylmercury, a process called biomagnification. People are exposed to the toxicant through consumption of contaminated fish. Although humans can excrete methylmercury, the process is relatively slow. People who eat older, larger fish or who eat predator fish are exposed to higher levels of methylmercury than those who eat fish dwelling near the bottom of the food chain (e.g. sunfish, channel catfish, blue catfish, common carp, etc) or those who eat fewer fish meals. Certain vulnerable people –women of child-bearing potential or pregnant women, for instance – may consume enough methylmercury to damage the fetal brain, thought to be the organ primarily damaged by methylmercury [8]. Although it is impossible to eliminate human exposure to mercury, exposure to methylmercury occurs principally through consumption of contaminated fish. People who do not eat fish thus avoid most exposure to methylmercury. Consequently, methylmercury exposure is controllable. Knowledge of the whereabouts of methylmercury-contaminated fish or shellfish and concentrations in those foodstuffs allows people to limit their exposure to this toxicant.

Despite – or perhaps, because of the extant consumption advisory for Caddo Lake, the Environmental and Injury Epidemiology and Toxicology Branch (EIETB) at the DSHS sporadically receives anecdotal reports and complaints of people continuing to eat unlimited quantities of largemouth bass and freshwater drum from Caddo Lake [9]. In May 2004, the EIETB, intending to examine consumption patterns and blood mercury levels in people who eat fish and bullfrogs from Caddo Lake, administered a survey to seventy-one (71) volunteer participants. Survey respondents answered questions about the types of fish they eat, quantities consumed, and intervals between meals of fish from Caddo Lake [10]. The survey instrument also documented sources – including locations in Caddo Lake – from which study participants obtained fish and bullfrogs for consumption. At the time of the survey, each participant donated a blood sample for mercury analysis. To correlate consumption patterns and blood mercury levels with mercury concentrations in fish eaten by respondents, the EIETB provided funds for the DSHS Seafood and Aquatic Life Group (SALG) to examine mercury levels in fish and bullfrogs from Caddo Lake. The present report addressing the public health implications of mercury in fish and bullfrogs from Caddo Lake is the result of the collaboration between the EIETB and the SALG.

METHODS

Fish Tissue Collection and Analysis

The DSHS collects and analyzes edible fish and shellfish from the state's public waters to evaluate potential risks to the health of people consuming contaminated fish or shellfish. Fish and shellfish tissue sampling follows standard operating procedures from the DSHS *Seafood and Aquatic Life Group Survey Branch Standard Operating Procedures and Quality Control/Assurance Manual* [11]. The SALG bases its sampling and analysis protocols, in part, on procedures established by the United States Environmental Protection Agency (EPA) in *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1* [12] and on direction from the legislatively-mandated State of Texas Toxic Substances Coordinating Committee (TSCC) Fish Sampling Advisory Subcommittee (FSAS) [13]. Samples usually represent species, trophic levels, and legal-sized specimens available for consumption from a water body. When practical, the DSHS collects samples from two or more sites within a water body to characterize the geographical distribution of contaminants. The DSHS laboratory, using established EPA methodology, analyzes fillets (skin off) of fish and edible meats of shellfish (crab and oyster) for common contaminants. Seven metals – arsenic, cadmium, copper, lead, total mercury[1], selenium, and zinc – are typically analyzed, as are panels of volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), pesticides, and polychlorinated biphenyls (Aroclor® 1016, 1221, 1224, 1232, 1248, 1254, and 1260). For the present evaluation, the DSHS laboratory analyzed fish and bullfrog tissues for mercury only.

Description of Sample Sets

1994-95 Data Set ("Historical Data")

The SALG accessed historical data from databases maintained by the group to compare mercury levels in fish collected from Caddo Lake during 1994 and 1995 [14] with those collected in 2004.

2004 Caddo Lake Sample Set

The SALG analyzed the surveys completed by people living near Caddo Lake to determine target species and sample sites for this project. Survey responses revealed specific locations from which people harvested fish from Caddo Lake as well as species of fish consumed. Local residents reported eating (listed in order of preference as measured by number of respondents naming that species) crappie, sunfish, catfish, largemouth bass, bullfrogs (an amphibian species), freshwater drum, buffalo, alligator gar, white bass, chain pickerel, turtle (a reptile), and yellow bass. The SALG thus targeted nekton for collection based upon species reportedly consumed by local residents.

In late May of 2004, SALG personnel collected 63 fish and 7 bullfrogs from six sites around Caddo Lake (map Appendix 1). Fish samples consisted of 15 black crappie, 14 largemouth bass, 12 sunfish (four bluegill, four redear sunfish, and four warmouth), 10 channel catfish, 6 freshwater drum, 2 white bass, 2 chain pickerel, 1 flathead catfish, and one spotted gar. The number of samples collected at each site was variable, ranging from six fish at Site 4 up to 20 fish at Site 3. Not all species were collected from all sites. Most samples collected for this study conformed to the TPWD guidelines for legal possession [7]. However, the group collected seven largemouth bass between 14 and 18 inches in length to further elucidate the relationship between the length of largemouth bass from Caddo Lake and mercury concentration.

Data Analysis

The SALG toxicologist used SPSS® statistical software, versions 10.01 and 13.0 [15, 16] installed on IBM-compatible microcomputers to generate descriptive statistics (mean, standard deviation, median, range, and minimum and maximum concentrations) on total mercury concentrations in bullfrogs and in each species of fish. The SALG utilized SPSS® software for hypothesis testing and to generate graphs [15, 16]. DSHS also employed Microsoft Excel® [17] spreadsheets to generate a health-based assessment comparison value (HAC_{nonca}) for mercury and to calculate hazard quotients (HQ) and meal consumption limits for fish and bullfrog

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[1] Nearly all mercury identified in upper trophic-level fish over three years of age is methylmercury [25]. Total mercury is a surrogate for methylmercury concentration in fish and shellfish. Because methylmercury analyses cost much more than total mercury analyses, EPA recommends that states determine total mercury concentrations in fish and that – to protect human health – states assume that all mercury in fish or shellfish is methylmercury. TDH analyzes fish and shellfish tissues for total mercury. In its risk characterizations, TDH compares total mercury concentrations in tissues to a comparison value derived from the ATSDR's minimal risk level for methylmercury [26]. TDH may utilize the terms "mercury" and "methylmercury" interchangeably to refer to methylmercury in fish.

samples collected in 2004 from Caddo Lake. Statistical analyses and comparison matrices included all samples.

Derivation and Application of Health-Based Assessment Comparison Values (HACs)

People who regularly consume contaminated fish or shellfish likely get repeated exposures to low concentrations of contaminants over an extended time. Such exposures seldom result in acute toxicity but may increase risk of subtle, chronic, and/or delayed adverse health effects, including cancer, benign tumors, birth defects, infertility, blood disorders, brain damage, peripheral nerve damage, lung disease, and kidney disease, to name but a few [18]. Presuming people to eat a variety of fish and/or shellfish, the DSHS routinely collapses data across species and sampling sites to evaluate average contaminant concentrations in samples from a specific water body because such an approach likely reflects consumers' exposure to contaminants in seafood over time. However, when relevant to the case, the agency also examines risks associated with ingestion of individual species of fish or shellfish from separate collection sites or at higher concentrations (e.g., the upper 95^{th} percentile of average concentrations).

The DSHS evaluates contaminants in fish by comparing the average measured concentration of a contaminant to its health-based assessment comparison (HAC) value (in mg contaminant per kg edible tissue or mg/kg) derived for non-cancer and cancer endpoints. To derive HAC values for systemic (HAC_{nonca}) effects, the department assumes a standard adult weighs 70 kilograms and that adults consume 30 grams of fish per day (about one 8-ounce meal per week). The DSHS uses EPA's oral reference doses (RfDs) [8] or the Agency for Toxic Substances and Disease Registry's (ATSDR) chronic oral minimal risk levels (MRLs) [19] to generate HAC values used to evaluate systemic (noncancerous) adverse health effects. The RfD, as defined by the EPA, is *"An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.* The EPA also states, "RfDs may be derived from a NOAEL[2], a LOAEL[3], or a benchmark dose, and that uncertainty factors are applied to reflect limitations of the data used" and "RfDs are generally reserved for health effects thought to have a threshold or a low dose limit for producing effects [20]." ATSDR derives minimal risk levels (MRLs) similarly [21]. The DSHS compares the estimated daily dose (mg/kg/day) – derived from the average measured concentration of a contaminant – to the contaminant's RfD or MRL by way of a hazard quotient (HQ). The HQ is "the ratio of the estimated exposure dose of a contaminant (in mg/kg/day) to the contaminant's RfD or MRL" [22]. For risk management, the DSHS assumes that consumption of fish with a toxicant-to RfD ratio (the HQ) of less than 1.0 is unlikely to result in adverse health effects.

The constants (RfDs, MRLs) the DSHS employs to calculate HAC_{nonca} values incorporate built-in margins of safety called "uncertainty factors," as mentioned in EPA reference materials [8]. In developing RfDs and MRLs, scientists utilize uncertainty factors to minimize the potential for systemic adverse health effects in people who eat contaminated fish or shellfish, including vulnerable groups such as women who are pregnant or lactating, women who may become

2 NOAEL: No Observed Adverse Effect Level
3 LOAEL: Lowest Observed Adverse Effect Level

pregnant, the elderly, infants, children, people with chronic illnesses, or those who consume exceptionally large servings of fish or shellfish [8].

The DSHS calculates cancer-risk comparison values (HAC_{ca}) from the EPA's chemical-specific cancer slope factors (SFs), derived through mathematical modeling [8]. For carcinogenic outcomes of exposure, the DSHS calculates a theoretical lifetime excess risk of cancer using a standard 70-kg body weight and assumes an adult eats 30 grams edible tissue per day. Two additional factors are used to determine theoretical lifetime excess cancer risk: (1) an acceptable lifetime risk level (ARL) of one excess cancer case in 10,000 persons equally exposed daily, and (2) an exposure period of 30 years. Comparison values used to assess the probability of cancer, thus, do not contain "uncertainty" factors as such. However, conclusions drawn from those probability determinations represent substantial safety margins for all people by virtue of the models utilized to derive SFs.

Because the calculated comparison values (HAC_{nonca} and $HAC_{ca)}$ are conservative, adverse systemic or carcinogenic health effects are unlikely, even if exposures are higher than calculated comparison values. Moreover, comparison values for adverse health effects (systemic or carcinogenic) do not represent sharp dividing lines between safe and unsafe exposures. The perceived strict demarcation between acceptable and unacceptable exposures or risks is primarily a tool to assist risk managers to make decisions that ensure protection of public health. For instance, the DSHS finds it unacceptable when consumption of four or fewer meals per month of contaminated fish or shellfish would result in *exposure* to contaminant(s) in excess of a HAC value or other measure of risk *even* when such exposure is unlikely to result in adverse health effects. The department further advises that people who wish to minimize exposure to contaminants in fish or shellfish eat a variety of fish and/or shellfish and that they limit consumption of those species most likely to contain toxic contaminants. DSHS aims to protect vulnerable subpopulations with its consumption advice. The DSHS assumes advice that is protective of vulnerable subgroups will also minimize the impact on the general population of consuming contaminated fish or shellfish.

Children's Health Considerations

The DSHS recognizes that fetuses, infants, and children may be uniquely susceptible to the effects of toxic chemicals and that exceptional susceptibility, if any, demand special attention [23, 24]. Windows of vulnerability (i.e., critical periods) exist during development, particularly during early gestation, but may appear at any point during pregnancy, infancy, childhood, or adolescence – indeed, at any time during development – times when toxicants can impair or alter the structure or function of vulnerable systems [25]. Unique early vulnerabilities may occur because, at birth, organs and body systems are structurally or functionally immature, continuing to develop throughout infancy, childhood and adolescence. These developmental variables may influence the mechanisms or rates of absorption, metabolism, storage, and excretion of toxicants, any of which factors could alter concentration of biologically effective toxicant at the target organ(s) or modulate the system's response to the toxicant. Children's exposures to toxicants may be more extensive than adults' exposures because, in proportion to their body weights, children consume more food and liquids than do adults, another factor that might alter the concentration of toxicant at the target [23]. Infants can ingest small amounts of toxicants through breast milk – an exposure pathway that could go unrecognized [26]. Nevertheless, the advantages of breastfeeding outweigh the probability of significant exposure to infants through this medium; women are encouraged to continue breastfeeding and to limit exposure by limiting intake of contaminated food [26]. It is possible that children could experience effects at a lower exposure dose than adults because children's organs may be more sensitive to the effects of toxicants. Stated differently, children's systems could respond more violently to a given dose than would adults' organs exposed to an equivalent exposure dose. Children could be more prone to developing certain cancers from chemical exposures than are adults [27, 28]. Nonetheless, if a chemical – or a class of chemicals –is observed to be – or is thought to be – more toxic to the fetus, infants, or children than to adults, the constants (e.g., RfD, MRL, or CPF) are usually lower to assure protection of the immature system's potentially greater susceptibility [8]. Additionally, in accordance with the ATSDR's *Child Health Initiative* [29] and the EPA's *National Agenda to Protect Children's Health from Environmental Threats* [30], the DSHS seeks to further protect children from the potential effects of toxicants in fish and shellfish and suggests that this potentially sensitive subgroup consume smaller quantities of contaminated fish or shellfish than adults consume. DSHS therefore recommends that children weighing 35 kg or less and/or who are 11 years of age or younger limit exposure to contaminated fish or shellfish by consuming smaller meals (no more than four ounces of fish or shellfish per meal). The DSHS also recommends that consumers spread these meals out over time. For instance, if consumption advice recommends eating no more than two meals per month, children consuming affected fish or shellfish should consume no more than 24 meals per year and, ideally, should not eat such fish or shellfish more than twice per month.

RESULTS

Analytical and Statistical Results

The following paragraphs summarize the mercury data from fish and bullfrog tissue data and the statistical comparisons among species and collection years. Tables 1 and 2 present laboratory analytical results of mercury in fish and bullfrogs collected from Caddo Lake in 1994, 1995, and 2004. Figures 1 and 2 illustrate the influence of body length and body mass on mercury concentrations in fish.

Statistical Analysis: Mercury in Fish from Caddo Lake, 1994-95 or 2004

The DSHS laboratory analyzed all samples collected in 1994, 1995 (historical data), and in 2004. To the authors' knowledge, the DSHS laboratory made no substantive changes between 1994 and 2004 to analytical procedures for assessing mercury in fish tissues. Thus, alterations to laboratory procedures should not confound any statistically significant differences in mercury concentrations among different sample groups. Neither have sampling, tissue handling or submission practices been changed in the intervening years.

Risk assessors evaluating mercury in fish from Caddo Lake in 1994 and 1995 had previously combined the data collected in 1994 and 1995 from Caddo Lake to assess risk and to suggest regulatory/advisory actions. In the present analysis, risk assessors re-analyzed data collected in 1995 and those collected in 1994 to ascertain that data from those two collection dates were not statistically different. Statistical analyses uncovered no significant differences in mercury from samples collected in 1994 and those collected in 1995. Therefore, the SALG collapsed the 1994 and 1995 data to increase sample sizes for comparison with 2004 samples. In the discussion of statistical results, the SALG refers to historical data as the "1994-95" samples.

Risk assessors generated summary statistics for recorded length (mm) and weight (g) (data not shown) and mercury concentrations (mg/kg; Table 1) in fish and bullfrogs collected from Caddo Lake during 1994-95 or 2004. The DSHS reviewed mercury concentrations in largemouth bass from both 1994-94 and 2004 according to length: length categories utilized were as follows: (a) less than (<14) inches; (b) equal to or greater than fourteen (≥14) inches but less than eighteen (<18) inches; and (c) equal to or greater than eighteen (≥ 18) inches. The rationale for categorizing largemouth bass into length categories was the TPWD slot length limit for this species at Caddo Lake. The 14"-18" slot length limit disallows harvest of largemouth bass between 14 and 18 inches in length. Thirteen largemouth bass were ≤ 14", 13 were between 14" and 18", and 11 samples were ≥ 18" in length.

The DSHS examined data from Caddo Lake fish for relationships among length, weight, and mercury concentrations, for time-delimited trends, and for differences in mercury among species (for statistical analyses, SALG analysts analyzed bullfrogs – an amphibian species first collected in 2004 – separately from fish species). The DSHS also examined mercury concentrations in largemouth bass across collection year and length. All samples from 1994-95 contained measurable levels of mercury. However, four samples from 2004 (one bullfrog and three fish) contained "unquantifiable" levels of mercury. To avoid underestimating mercury concentrations, analysts replaced "non-detects" with a value equal to one-half the reporting limit before conducting statistics, as suggested by the EPA [12].

<u>Bullfrogs</u>

Bullfrogs contained mercury at levels ranging from "undetectable" to 0.157 mg/kg, with an average concentration of 0.11±0.03 mg/kg (Table 1). Further, bullfrogs' body weight did not significantly correlate with tissue mercury concentration (Pearson's r = 0.311, N=7; P=0.249). Data on length were not available for bullfrogs.

<u>Fish</u>

Mercury was present in 114 of 117 fish collected from Caddo Lake between 1994 and 2004. Concentrations ranged from undetectable levels to 1.77 mg/kg (Table 1). One black crappie and two channel catfish contained no detectable mercury. The highest concentration of mercury in fish from Caddo Lake was in a largemouth bass (CDL67) collected in 2004 from Site 5 (Caddo Lake State Park/Hwy 43). Average mercury concentrations in fish ranged from 0.169 mg/kg (channel catfish) to 1.274 mg/kg (freshwater drum), and varied by species, length, and weight. Mercury concentration correlated with fish body weight (r=+0.731) and with total length (r=+0.615; Figures 1 and 2). Two-step cluster analysis – an exploratory tool designed to explore natural groupings within a data set that might not otherwise be apparent – correctly classified fish species according to whether mercury concentration exceeded the HACnonca for methylmercury. Cluster 1 contained all catfish, crappie, white bass, spotted sucker, sunfish, and chain pickerel while the second Cluster contained freshwater drum, largemouth bass, and spotted gar.

Largemouth Bass (LMB):

Mercury concentrations in largemouth bass ranged from 0.169 mg/kg to 1.77 mg/kg (Tables 1 and 2). Mercury in largemouth bass collected in 1995 did not differ from mercury in largemouth bass collected in 1994, so the SALG toxicologist combined samples from 1994 and 1995 for all further analyses. Mercury in largemouth bass correlated with body length and body weight in both 1994-95 and 2004 (Figures 3 and 4). Average mercury concentration in largemouth bass from the 1994-95 year were 0.509, 0.669, and 1.114 mg/kg for bass <14", 14"-18", or ≥ 18", respectively. In largemouth bass collected in 2004, average mercury concentration by length category was 0.371, 0.627, and 1.405 mg/kg (Table 2). Multivariate analysis of variance (MANOVA) revealed no differences in length, weight, or mercury in LMB collected in different years. On the other hand, body length category was significantly associated with body weight and mercury concentration in LMB. Two-step cluster analysis using length category and mercury correctly assigned individual LMB to one of three previously assigned length categories based on mercury concentration. Post hoc contrasts (Bonferroni) showed the shortest LMB group to have the lowest body weights, followed by LMB in the intermediate length group and then by those in the group over 18", indicating that the pre-assigned length categories adequately differentiated LMB by size. Other researchers have previously concluded that, in largemouth bass, body length predicts tissue mercury concentration – explaining between 34% and 77% of the variance in mercury concentrations in this fish species [31]. Both *a priori* and *post hoc* (Bonferroni) contrasts on mercury in LMB groups from different length categories showed the two smaller length categories to have similar mercury levels, while the longest LMB group had significantly higher mercury concentrations. Temporal changes in the ecosystem also reportedly influence mercury concentrations in largemouth bass [31]. The facts that collection year did not influence weight or mercury concentration in largemouth bass and that the interaction term for collection year and length category was not significant on either body weight or mercury concentration in LMB suggest that temporal ecosystem changes were not responsible for differences in mercury in largemouth bass categorized according to length.

White Bass

ADV-12 recommended that people restrict consumption of white bass from B.A. Steinhagen Reservoir. The 1994-95 samples included seven white bass. In 2004, the SALG collected two white bass from Caddo Lake. Mercury in white bass ranged from 0.090 to 0.780 mg/kg and correlated with body length ($r = +0.622$). White bass from 2004 appeared smaller than samples collected in 1995 and mercury levels were commensurately lower. Nonetheless, nonparametric analysis (Mann-Whitney U test) revealed no significant differences in mercury concentrations between white bass collected in 1994-95 and those collected in 2004.

Freshwater drum

Freshwater drum are included in the extant advisory for Caddo Lake. Therefore, the SALG collected six freshwater drums for the present study. Mean mercury concentrations in freshwater drum collected in 1994-95 (Table 1) correlated with freshwater drum body length ($r = +0.421$) and weight ($r = +0.453$). Neither correlation was significant, however. Mercury in freshwater drum did not differ between 1994-95 and 2004.

Channel catfish, flathead catfish, yellow bullhead catfish

DSHS investigators collected one flathead catfish and one yellow bullhead in 1994-95. Both contained mercury. Researchers collected 5 channel catfish in 1994-95 and 10 in 2004. Thirteen of the 15 channel catfish contained mercury. In the present analysis, all catfish, including the flathead and the yellow bullhead were analyzed as "catfish." Mercury concentrations in catfish ranged from undetectable levels to 0.533 mg/kg with an average concentration of 0.207 mg/kg. Mercury concentration in catfish was not significantly associated with collection year. In catfish, neither body weight nor length correlated significantly with mercury concentration.

Chain pickerel

DSHS staff collected two chain pickerels in 1994-95; two pickerels were collected in 2004. Average weight, length, and mercury concentrations of samples from 2004 appeared lower in samples from 1994-95. Exact tests of significance applied to weight, length, and mercury in these small groups (Mann-Whitney U, Wilcoxin) revealed no significant differences in length, weight, or mercury between sampling years.

Crappie

Crappie species from 2004 were approximately the same length and weight as those collected in 1994-95. Mercury levels in crappie did not correlate significantly with weight or with length. Mercury concentrations in crappie species were significantly lower in 2004 than in 1994-95. The significance of this observation is unknown but is possibly be related to temporal differences in ecosystem parameters [31].

Spotted gar, spotted sucker, yellow bullhead

A single large spotted gar collected in 2004 contained mercury at 1.160 mg/kg. Spotted gar were not collected during the 1994-95 sampling excursion. Spotted suckers collected in 1994-95 contained an average of 0.520 mg/kg mercury.

Sunfish (bream)

One sunfish was collected in 1994-95. Mercury in this sample was 0.390 mg/kg. Average mercury in 12 sunfish collected during 2004 was 0.271 mg/kg (±0.099 mg/kg), with concentrations in individual samples ranging from 0.158 mg/kg to 0.423 mg/kg. Mercury in sunfish did not correlate with length or weight.

DISCUSSION

Conclusions and Public Health Implications

Comparisons of Mercury Concentrations in Bullfrogs and Fish from Caddo Lake

DSHS compared average mercury concentrations in fish or bullfrogs from Caddo Lake to the HAC_{nonca} value for mercury derived from the ATSDR's MRL for methylmercury. Those comparisons revealed

- That mercury in bullfrogs did not exceed the HAC_{nonca} for methylmercury.
- That mercury in catfish did not exceed the HAC_{nonca} for methylmercury.
- That mercury in crappie species did not exceed the HAC_{nonca} for methylmercury.
- That mercury in sunfish species did not exceed the HAC_{nonca} for methylmercury.
- That mercury in chain pickerel from 1994-95 exceeded the HAC_{nonca} for methylmercury but that mercury in chain pickerel collected in 2004 did not exceed the HAC_{nonca} for methylmercury, possibly because those chain pickerels collected in 2004 were smaller than chain pickerel collected in the 1994-95 year.
- That mercury in freshwater drum from both collection years exceeded the HAC_{nonca} for methylmercury.
- That mercury in largemouth bass generally exceeded the HAC_{nonca} for methylmercury.
- That mercury in largemouth bass was dependent upon the size of the fish:
    - Largemouth bass ≥18 inches contained mercury at concentrations that clearly exceeded the HAC_{nonca} for methylmercury.
    - Mercury in largemouth bass from other length categories did not exceed the HAC_{nonca} for methylmercury. Nonetheless, mercury concentrations in largemouth bass from the two categories containing smaller fish contained mercury at levels approaching the HACnonca for methylmercury.
    - Mercury in largemouth bass as a species, combined across length categories and collection years exceeded the HAC_{nonca} for methylmercury.

Characterization of Lifetime Risk of Cancer from Consumption of Caddo Lake Fish Containing Mercury

The EPA classifies methylmercury as a possible human carcinogen (Group C). However, the EPA has not published a chemical-specific cancer slope factor for methylmercury. Therefore, the

Texas Department of State Health Services was unable to assess the risk of cancer from consumption of mercury-contaminated fish from Caddo Lake.

Characterization of Risk of Adverse Systemic Health Effects from Consumption of Caddo Lake Fish Containing Mercury

DSHS toxicologists characterize the likelihood that public health will be adversely impacted by consumption of contaminated fish and shellfish harvested from Texas water bodies by recreational or subsistence fishers. The DSHS concludes from the results of the present risk characterization

1. That routine consumption of largemouth bass ≥18 inches from Caddo Lake could result in systemic adverse health effects due to the presence of mercury in largemouth bass of this and smaller sizes. Consumption of largemouth bass ≥18 inches in length from Caddo Lake **poses an apparent human health hazard**.

2. That regular or frequent consumption of freshwater drum from Caddo Lake could result in systemic adverse health effects due to the presence of mercury in these fish. Consumption of freshwater drum from Caddo Lake **poses an apparent human health hazard**

3. That consumption of spotted gar from Caddo Lake could result in adverse health effects, but the presence of only one spotted gar in samples collected from Caddo Lake limits conclusions about risk to human health. Therefore, consumption of spotted gar Caddo Lake **poses an indeterminate human health hazard.**

4. That mercury in chain pickerel and in spotted sucker could cause systemic adverse health effects if these species are regularly consumed, but that, once again, small sample sizes and variable results between years or lack of samples from both years render conclusions difficult regarding risk to human health from consumption of these species from Caddo Lake. Thus, consumption of chain pickerel and spotted sucker from Caddo Lake **poses an indeterminate human health hazard.**

5. That consumption of bullfrogs, channel catfish, crappie, sunfish, and white bass from Caddo Lake containing mercury at levels similar to those observed in this study is unlikely to result in systemic adverse health effects. Therefore, consumption of bullfrogs ("frog legs"), channel catfish, crappie, sunfish, and white bass from Caddo Lake **poses no apparent human health hazard**.

Recommendations

Risk assessors at the DSHS may suggest risk management strategies to DSHS risk managers. Risk assessors base suggestions solely on the risk characteristics generated by methodical analysis of laboratory results of toxic contaminants in fish and shellfish using pre-chosen assumptions about population behaviors. As such, the suggestions do not encompass the complex regulatory issues addressed by risk management professionals. Risk managers at the DSHS, on the other hand, have established criteria for issuing fish consumption advisories based on approaches suggested by the EPA [32] and on regulatory powers given this public health agency by the legislature of the state of Texas. For instance, confirmation that four or fewer meals per month (adults: eight ounces per meal; children: four ounces per meal) might be expected to result in toxic exposures at levels exceeding DSHS health guidelines, risk managers could issue consumption advice for fish from the water body in question. Risk managers also have the option to ban possession of the affected fish or shellfish. Possession bans are enforceable under subchapter D of the Texas Health and Safety Code, part 436.061(a) [33]. Consumption advisories are not enforceable by law and carry no penalties for noncompliance. Nonetheless, DSHS consumption advisories tell the public of potential health hazards from consuming contaminated fish or shellfish so that members of the public can make informed decisions about eating contaminated fish or shellfish. The SALG and the EIETB of DSHS conclude from the data in this risk characterization that spotted gar, freshwater drum and largemouth bass from Caddo Lake contain mercury at concentrations that, if consumed regularly or over time, could pose a risk to health. Therefore, the SALG and the EIETB recommend

1. That the DSHS retains ADV-12, presently in place, to address consumption of largemouth bass and freshwater drum from Caddo Lake.

Pursuant to the extant advisory, risk assessors recommend

2. That the DSHS advises people to eat no more than two meals per month of any combination of largemouth bass, spotted gar, and/or freshwater drum from Caddo Lake because regular consumption of large quantities of these fish species from Caddo Lake poses an apparent hazard to health.

3. That the DSHS advises that people may freely consume bullfrogs, catfish, crappie, sunfish, and white bass from Caddo Lake.

4. That the DSHS re-visits Caddo Lake to collect samples for examination for all routinely monitored chemical toxicants, with emphasis on mercury in all species of fish from Caddo Lake.

Communication of Health Risks from Consumption of Contaminated Fish or Shellfish

The DSHS publishes fish consumption advisories and bans in a booklet available to the public through the SALG: (512-719-0215) [34]. The SALG also posts this information on the Internet at URL: http://www.tdh.state.tx.us/bfds/ssd. Risk characterizations for water bodies surveyed by DSHS are available through the SALG: (512-719-0215); some may also be available from the ATSDR (http://www.atsdr.cdc.gov/HAC/PHA/region6.html). The DSHS provides the EPA (URL: http://fish.rti.org), the TCEQ (URL: http://www.tceq.state.tx.us), and the TPWD (URL: http://www.tpwd.state.tx.us) with information on all consumption advisories and possession bans. Each year, the TPWD informs the fishing and hunting public of fish consumption advisories and bans in an official hunting and fishing regulations booklet [5], available at some state parks and at establishments that sell fishing licenses.

Readers may direct questions about the scientific information or recommendations in this risk characterization to the SALG (512-719-0215) or the EIETB (512-458-7269) at the DSHS. Toxicological information on a variety of contaminants in seafood and other environmental media may also be obtained from the ATSDR Division of Toxicology by telephoning ATSDR at the toll free number (800-447-1544) or from the ATSDR website (URL: http://www.atsdr.cdc.gov).

TABLES and FIGURES

Table 1. Mercury (mg/kg) in fish collected from Caddo Lake in 1994-95 or 2004 and in bullfrogs collected in 2004.					
Species/Collection Year	**#Detected/# Collected**	**Average Concentration ± S.D.**	**Median Concentration (Min-Max)**	**Health Assessment Comparison (HAC) Value (mg/kg)**	**Basis for HAC Value**
Bullfrogs				0.7	ATSDR) Minimal Risk Level (MRL) for long-term exposure: 0.0003 mg/kg -day
1994-95	Not Collected				
2004	6/7	0.106±0.032	0.107 (nd-0.157)		
All Bullfrogs	6/7	0.106±0.032	0.107 (nd-0.157)		
Chain Pickerel					
1994-95	2/2	0.955±0.289	0.955 (0.750-1.610)		
2004	2/2	0.339±0.379	0.339 (0.071-0.610)		
All Chain Pickerel	4/4	0.647±0.450	0.679 (0.071-1.160)		
Channel Catfish					
1994-95	5/5	0.212±0.105	0.190 (0.099-0.360)		
2004	8/10	0.169±0.149	0.140 (nd-0.533)		
All Channel Catfish	13/15	0.183±0.134	0.144 (nd-0.533)		
Crappie					
1994-95	5/5	0.472±0.246	0.430 (0.110-0.760)		
2004	14/15	0.248±0.165	0.212 (nd-0.630)		
All Crappie	19/20	0.304±0.206	0.300 (nd-0.760)		
Flathead Catfish					
1994-95	Not Collected				
2004	1/1	0.332	0.332		
All Flathead Catfish	1/1	0.332	0.332		

Table 1. Mercury (mg/kg) in fish collected from Caddo Lake in 1994-95 or 2004 and in bullfrogs collected in 2004.					
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Crappie					
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All Crappie	19/20	0.304±0.206	0.300 (nd-0.760)		
Flathead Catfish					
1994-95	Not Collected				
2004	1/1	0.332	0.332		
All Flathead Catfish	1/1	0.332	0.332		
Freshwater Drum					
1994-95	8/8	1.274±0.205	1.298 (0.920-1.530)		
2004	6/6	0.913±0.500	0.716 (0.302-1.620)		
All Freshwater Drum	14/14	1.119±0.392	1.233 (0.302-1.620)		
Largemouth Bass					
1994-95	23/23	0.788±0.370	0.680 (0.208-1.630)		
2004	14/14	0.647±0.412	0.586 (0.169-1.770)		
All Largemouth Bass	37/37	0.734±0.387	0.640 (0.169-1.770)		
Spotted Gar					
1994-95	Not Collected				
2004	1/1	1.160	1.160		
All Spotted Gar	1/1	1.160	1.160		
Spotted Sucker					
1994-95	2/2	0.520±0.085	0.520 (0.460, 0.580)		
2004	Not Collected				
All Spotted Sucker	2/2	0.520±0.085	0.520 (0.460, 0.580)		

Table 1. Mercury (mg/kg) in fish collected from Caddo Lake in 1994-95 or 2004 and in bullfrogs collected in 2004.					
Species/Collection Year	**#Detected/# Collected**	**Average Concentration ± S.D.**	**Median Concentration (Min-Max)**	**Health Assessment Comparison (HAC) Value (mg/kg)**	**Basis for HAC Value**
Sunfish Sp					
1994-95	1/1	0.390	0.390		
2004	12/12	0.271±0.099	0.283 (0.158-0.423)		
All Sunfish species	13/13	0.280±0.100	0.246 (0.158-0.423)		
White Bass					
1994-95	7/7	0.444±0.217	0.430 (0.150, 0.780)		
2004	2/2	0.184±0.133	0.184 (0.090, 0.278)		
All White Bass	9/9	0.386±0.225	0.360 (0.090-0.780)		
Yellow Bullhead					
1994-95	1/1	0.430	0.430		
2004	Not Collected				
All Yellow Bullhead	1/1	0.430	0.430		
All Species 1994-95	54/54	0.715±0.413	0.636 (0.099-1.630)		
All Species 2004	66/70	0.378±0.363	0.259 (nd-1.770)		
All Species, All Years	120/124	0.525±0.419	0.416 (nd-1.770)		

Table 2. Mercury (mg/kg) in Largemouth Bass of Different Lengths, 1994-95 and 2004

Length Category (Inches)	Year Collected	#Detected/ #Collected	Mercury Concentration ± Std Deviation	Health Assessment Comparison Value	Basis for HAC Value
≤14”	1994-95	8/8	0.509±0.251	0.7 mg/kg	ATSDR MRL for Methylmercury 0.0003 mg/kg/day
	2004	5/5	0.371±0.146		
>14” and <18”	1994-95	6/6	0.669±0.130		
	2004	7/7	0.627±0.233		
≥ 18”	1994-95	9/9	1.114±0.322		
	2004	2/2	1.405±0.516		
All Lengths	1994-95	23/23	0.788±0.370		
All Lengths	2004	14/14	0.647±0.412		
TOTAL		37/37	0.734±0.387		

Table 3. Hazard quotients (HQ) and recommended weekly meal consumption rates for mercury-containing fish collected from Caddo Lake in 1994-95 or 2004.

Species	Collection Year	Hazard Quotient (HQ)	Recommended Consumption (Meals/Week)
Bullfrogs	1994-95	Not Collected	
	2004	0.15	6.1
Largemouth bass	1994-95	**1.13**	**0.8**
	2004	0.92	1.0
Freshwater drum	1994-95	**1.82**	**0.5**
	2004	**1.30**	**0.7**
Spotted gar	1994-95	Not Collected	
	2004	**1.66**	**0.6**
Channel catfish	1994-95	0.30	3.1
	2004	0.24	3.8
Crappie sp.	1994-95	0.67	1.4
	2004	0.36	2.6
Sunfish sp.	1994-95	0.56	1.7
	2004	0.37	2.5

***Emboldened numbers suggest that consumption may be limited.** *A person (70-kg adult: 8 ounces per meal; 35-kg child: 4 ounces per meal) should be able to eat four or more meals each month of fish or shellfish from a water body. DSHS considers it unacceptable, depending upon individual water body characteristics, if a person cannot consume a minimum of four fish or shellfish meals per month (one meal per week) from a given water body.*

Table 4. Theoretical risk of adverse health effects (developmental) from consumption of mercury-containing largemouth bass of different sizes collected in 1994-95 or 2004 from Caddo Lake along with recommended consumption rates for a 70-kg person

Size Category	Collection Year	HAZARD QUOTIENT	Recommended Consumption (Meals/Week)
≤14”	1994-95	0.73	1.3
	2004	0.53	1.7
>14” and <18”	1994-95	0.96	1.0
	2004	0.90	1.0
≥ 18”	1994-95	**1.59**	**0.6**
	2004	**2.00**	**0.5**

Figure 1. Influence of Body Length on Mercury Concentration in Fish collected from Caddo Lake in 1994-95 or 2004

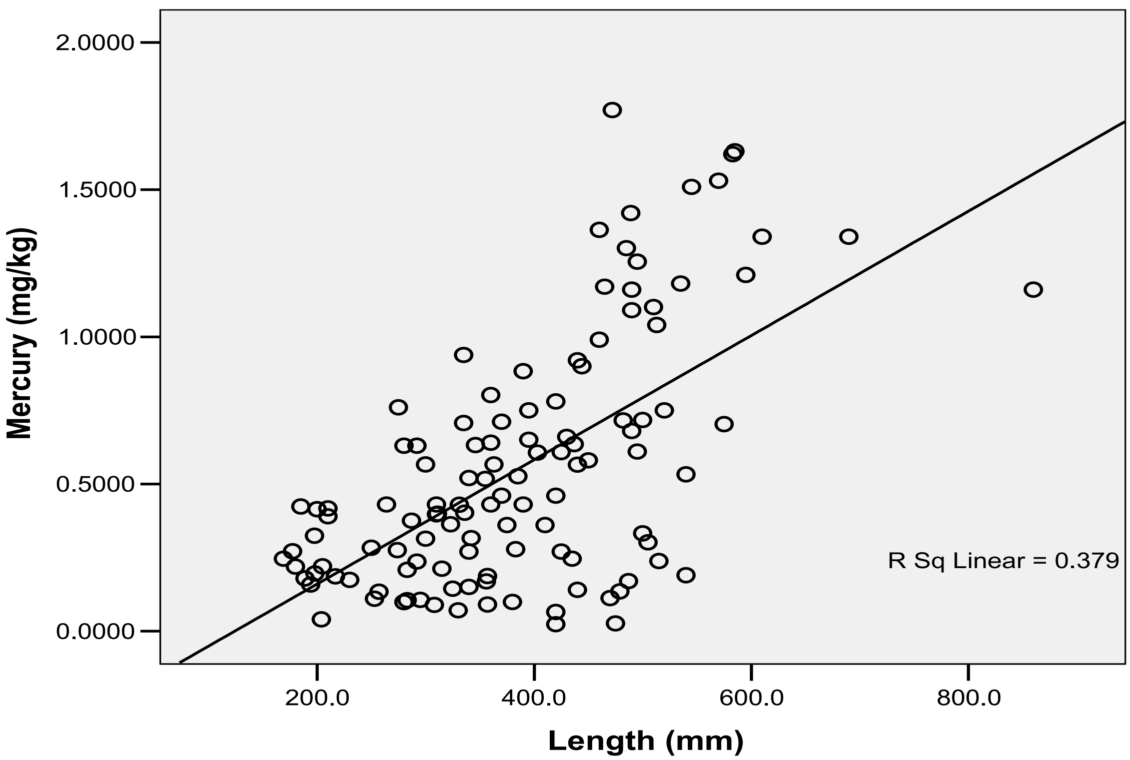


Figure 2. Influence of Body Weight on Mercury in Fish collected from Caddo Lake in 1994-95 or 2004

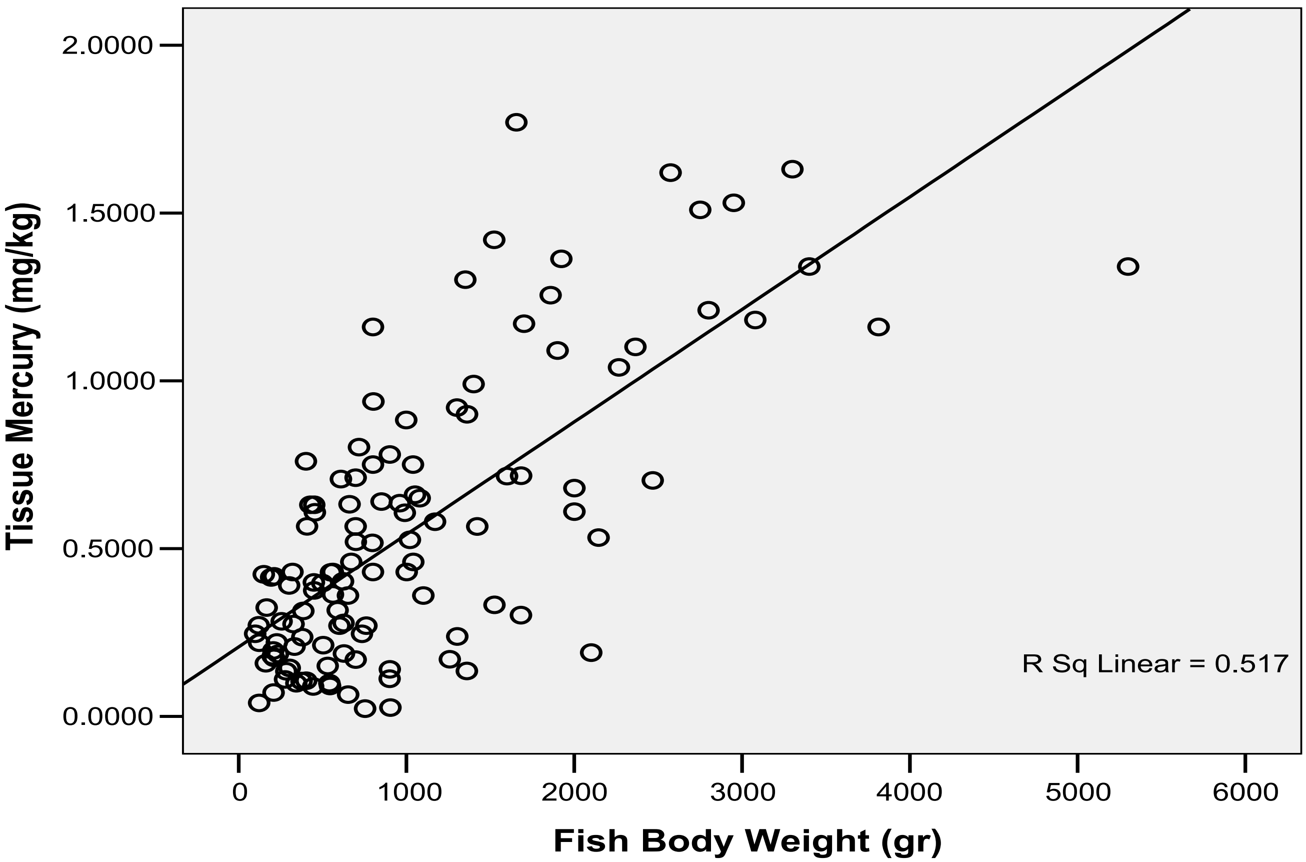


Figure 3. Influence of Body Length on Mercury in Largemouth Bass(LMB) Collected from Caddo Lake in 1994-95 or 2004.

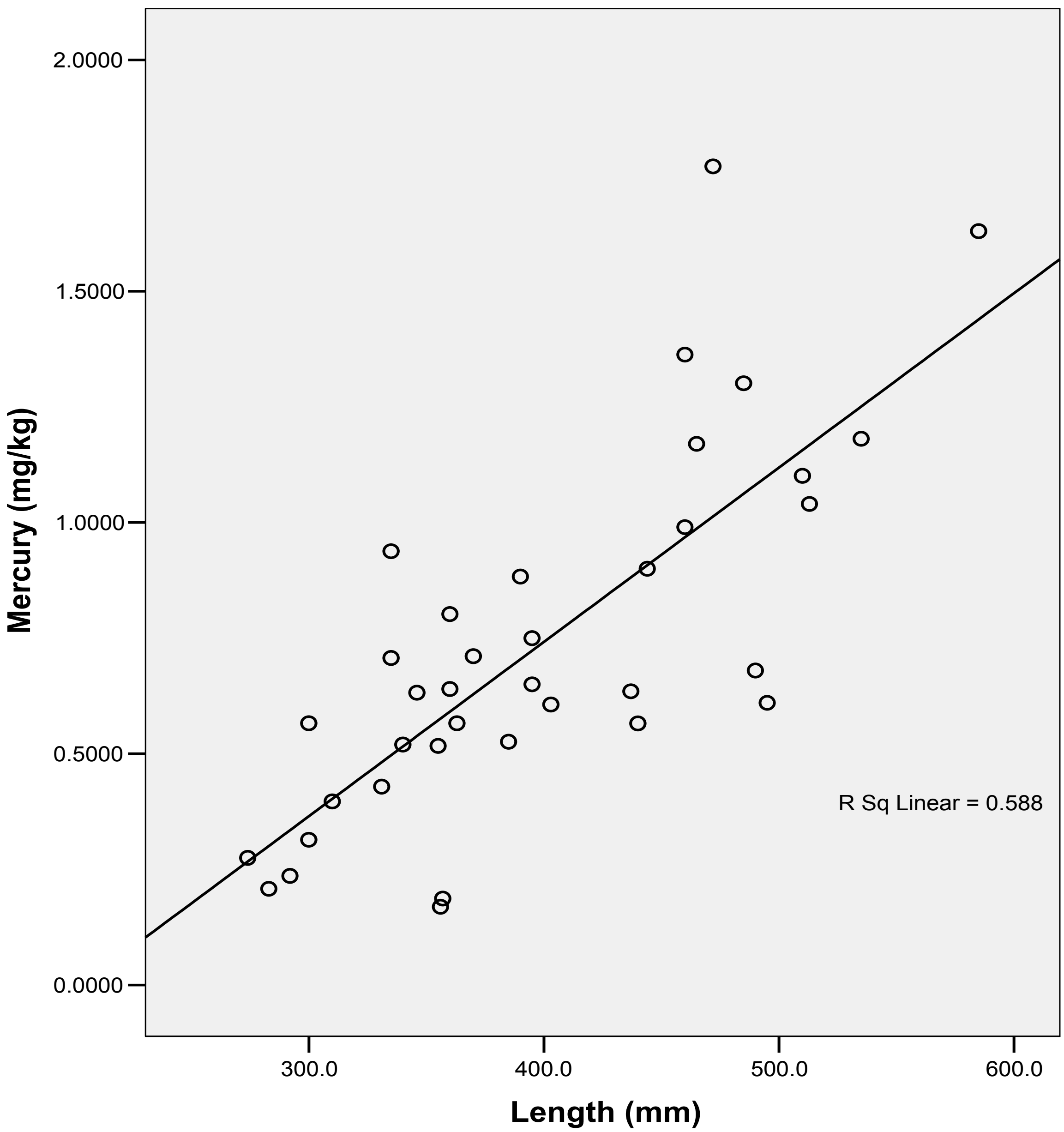
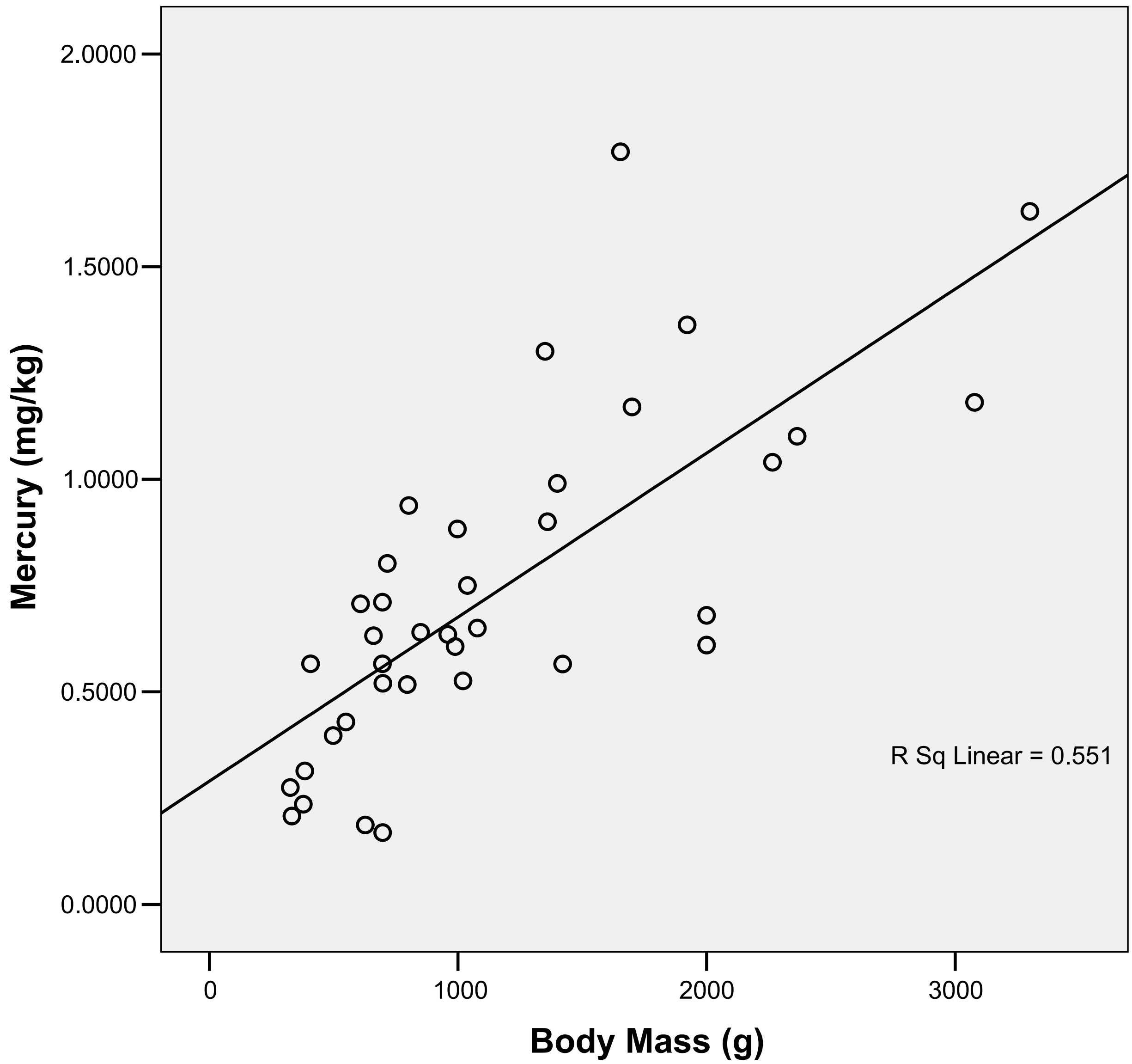


Figure 4. Influence of Body Mass on Mercury in Largemouth Bass Collected in 1994-95 or 2004 from Caddo Lake



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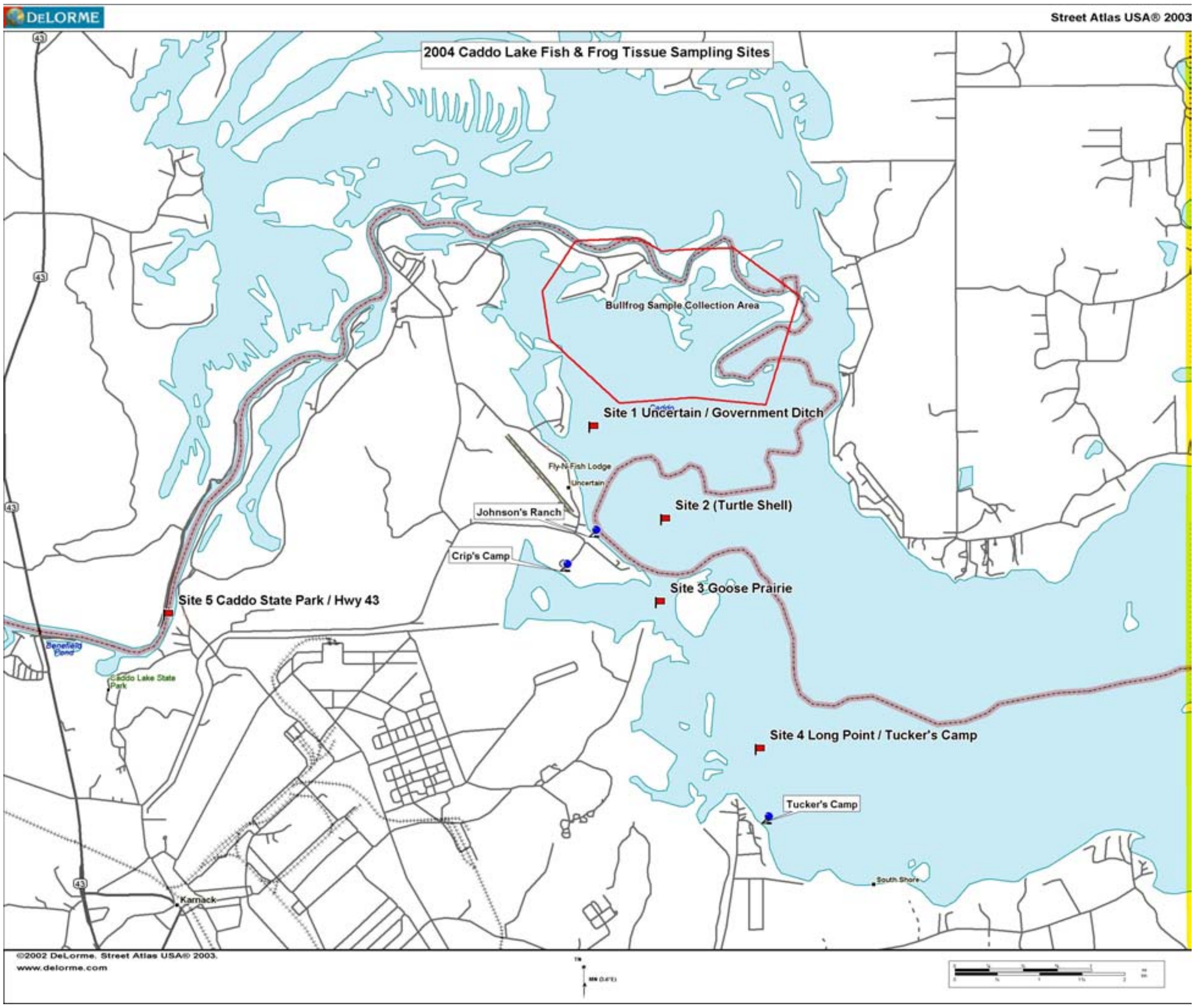
APPENDIX: Sampling Site Map, Caddo Lake, 2004



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