# Establishing a Surveillance System to Track and Link Louisiana's Blood Mercury and Fish-Tissue Mercury Levels: Issues and Results


## ABSTRACT

The purpose of this study is to evaluate the feasibility and applications of a surveillance system which tracks blood mercury and fish-tissue mercury. Issues encountered in setting up a novel surveillance system to track and evaluate Louisiana's residential blood mercury levels and fish-tissue mercury levels are presented here along with the results of a preliminary review of these data. The quality and scope of existing health and environmental databases were evaluated and assessed. Parish-level proportions of above background blood mercury cases were calculated and mapped. Species- and size-specific fish-tissue sampling sites were mapped and mercury levels were interpolated. Fish-tissue mercury interpolations were overlaid with parish-level proportions of above background blood mercury cases to identify areas where consumption of local fish may be contributing to high blood mercury case rates. Based on these results, recommendations for an outcome-based public health action plan were developed. Limitations and issues encountered during the development of this novel surveillance system are discussed. The system presented holds promise for identifying areas where fish consumption may potentially play a part in elevated blood mercury levels, and areas where biomonitoring may be necessary. Once limitations are addressed, this surveillance system will enable identification, ranking, and prioritization of geographic areas of potential concern; targeted outreach and biomonitoring to communities of potential concern; and more efficient use of available resources allocated for prevention and intervention efforts. Use of this tool, in the long-term, may ultimately reduce mercury exposures, and subsequently, adverse mercury-related health effects.


## INTRODUCTION

The Louisiana Department of Health and Hospitals (LDHH), Office of Public Health (OPH), Section of Environmental Epidemiology and Toxicology (SEET) was awarded funds by the Association of State and Territorial Health Officials (ASTHO) to conduct a demonstration project tracking blood mercury and fish-tissue mercury levels. There exists ample evidence that fish consumption is the primary mode of non-occupational mercury exposure. This building evidence has prompted public concern, as mercury is one of the top ten causes of waterbody impairment in Louisiana (LA) (EPA, 2002), and fishing and seafood consumption are important economic and recreational activities to LA residents.

This tracking project was proposed in response to this building public concern; but also in response to the results of a fish consumption survey conducted by SEET in 1998 and 2003. To determine if regional fish-tissue mercury levels and fish consumption patterns presented a public health concern, in 1998 fish consumption survey responses and blood samples were obtained from 313 individuals residing near mercury advisory areas. Significantly high blood mercury levels were found in individuals associated with commercial fishing and those reporting increased fish consumption. Of the residents participating, 7% had a blood mercury level >10 ug/L, which is the US Centers for Disease Control and Prevention's (CDC) clinical case definition for mercury poisoning. In 2003, follow-up testing was conducted in a three parish area of concern on 77 residents. Roughly 30% of 2003 survey participants had a blood mercury level > 10 ug/L, the majority of whom reported eating locally caught fish on a regular basis (≥ 1 meal/week).

While a correlation had been demonstrated confirming the potential relationship between local fish consumption and blood mercury levels, the geographic scope of this public health issue was unknown. Although fish-tissue mercury samples had been collected throughout the state, very few blood mercury samples were reported. In order to identify areas of potential concern across the state it would be necessary to collect blood mercury data from a larger population and develop a statewide environmental public health surveillance system to track both blood and fish-tissue mercury levels. To address the need for statewide blood mercury data, changes in disease reporting requirements were made in June of 2006 to require the reporting of all laboratory results for cases of heavy metal exposure (arsenic, cadmium, lead, and mercury) to SEET.

With recently acquired blood mercury reports, SEET is in a position to initiate development of a public health environmental surveillance system which will enable identification of areas of potential concern. SEET proposed to ASTHO to develop and evaluate an initial statewide surveillance system to track and link fish-tissue and blood mercury data. Environmental public health surveillance systems should ideally encompass measures of hazard, exposure and health impact.

Yet even with these indices it should be noted that most surveillance systems can serve only descriptive functions for ecological analyses. If it is the goal of the surveillance system to determine causality, etiologic studies must be conducted which require indices of exposure and other disease risk factors (e.g., confounders or effect modifiers). Given the cost of blood testing, scarcity of test results, lack of health care access in rural areas, other indices will be mapped for future analyses. It is anticipated that hazard, exposure, health outcome and confounder data will be added when available to improve this surveillance system. For instance, SEET has collected information regarding the number of fishing permits allocated by zip code and parish to identify areas with a high number of fishers who may be underrepresented in the blood mercury database. Other information which can be tracked include: advisory locations, fishing permit counts, popular fishing locations/recreational areas, boat launches and marinas, and commercial fishing employment and demographic factors. None of these indicators are by themselves ideal. For example, while there is utility in exploring the proximity of people with elevated mercury levels to fish sampling areas, account needs to be taken for mobility and variety in fishing locations. As blood mercury levels represent total mercury from all exposures (e.g., occupational, accidents, fish, etc.), and no speciated blood mercury data exist to estimate blood methyl mercury levels (indicating exposures more likely due to fish consumption), other data to be mapped in future investigations may include: industries locations, air and water releases, and mercury spills. As total mercury represents all sources of mercury exposure it is important to account for other potential sources. The lack of speciated blood mercury samples complicates linkage and evaluation of these data in terms of identifying exposures due to fish consumption.

As the relationship between fish consumption, blood mercury levels and adverse health outcomes have been appropriately established in the literature, the primary goal of this surveillance system is to geographically target interventions such as fish advisories and expanded fish tissue sampling in “hot spot” areas of predicted high mercury fish tissue levels to reduce exposures and minimize population risk. Other applications include policy (e.g., evaluating the scope and magnitude of the problem to decide whether a statewide fish consumption advisory be issued), and public transparency or access to information. Further refining of this surveillance system will be necessary to identifying other potential risk factors.

The specific project objectives are to: 1) assess the quality and scope of existing blood and fish-tissue mercury databases; 2) utilize a Geographic Information System (GIS) to link patient-specific blood mercury data to site-specific fish-tissue mercury data); 3) identify high-risk groups (populations) and / or geographical areas; and 4) make recommendations for an outcome-based public health action plan to address the issue of mercury exposure from local fish consumption.

## METHODS

*Blood Mercury Data Analysis.* Data were compiled in Microsoft Excel, proofread, edited and queried via Microsoft Access to eliminate outliers of questionable data quality and ensure data consistency. Cases with other known sources of mercury exposure (accidental spills, suicide attempts and occupational exposures) were removed from the blood mercury databases analyzed here. Cases with urine samples, which are known to be occupationally-related, were linked to the blood mercury database using personal identifiers to remove occupationally-related blood mercury samples. Limitations to data applications were noted. Summary statistics were calculated using R (version 2.8.1) and SAS (version 9.1). Summary statistics (minimum and maximum; arithmetic and weighted means; 50$^{th}$, 75$^{th}$, 80$^{th}$, 95$^{th}$, and 99$^{th}$ percentiles; and variance and standard deviation) were calculated. Summary statistics, box plots, bar plots, pairwise plots, histograms, stripcharts and distributions were used to analyze the data where appropriate.

In order to derive parish-specific above background proportions, above background and clinical cases of blood mercury poisoning in adults (≥ 15 years of age) and children (< 15 years of age), had to be identified. SEET compared blood mercury test results to the clinical case definition for mercury poisoning developed by the CDC, (blood mercury level > 10 µg/L). In order to differentiate clinical cases from cases above background, SEET compared blood mercury test results to the national background blood mercury levels established by the CDC through its National Health and Nutrition Examination Survey (NHANES). NHANES tests a random sample of the U.S. population for a number of substances including mercury. NHANES found that the 95th percentile of blood mercury levels are 1.9 µg/L in children 1 to 5 years of age (1.4 - 2.9 µg/L Confidence Interval (CI)), and 4.6 µg/L in women 16 to 49 years of age (3.7 - 5.9 µg/L CI)). NHANES does not present background blood mercury levels for men. The upper confidence limit was used to identify individuals with blood mercury levels exceeding the national background (≥3 µg/L for children <15 years; ≥6 µg/L for adults ≥15 years). Based on these comparison values, cases were classified according to blood mercury test results as presented in **Table 1**. Age- and parish-specific proportions of above background blood mercury cases (over tested) were calculated.

**Table 1.** Guidance Values for Blood Mercury Cases

| | **Children <15 yrs** | **Adults ≥ 15 yrs** |
|---|---|---|
| **Background** | <3 | <6 |
| **Above Background** | 3-10 | 6-10 |
| **Clinical Case** | >10 µg/L | >10 µg/L |

*Fish-tissue mercury data analysis.* Louisiana has set the screening value for fish-tissue mercury concentrations at 0.24 ppm for sensitive populations (children and women of child-bearing age or nursing), and at 0.72 ppm for the general public. This value is based on the EPA's Reference Dose for methylmercury and the assumption that 30 grams / day of fish is consumed. The screening values are used to aid in the identification of areas where more intensive site-specific monitoring and / or evaluation should be conducted, and do not always indicate a health risk. Other factors such as fish length, consumption rate and general availability should also be considered. The frequency of exceedance of the screening values was used to categorize levels of concern for different species: species with greater than or equal to 50% of samples exceeding the screening value for the general public and for sensitive populations were identified as "of concern". These categories have no regulatory significance, but are merely used for descriptive purposes.

*GIS Mapping.* Data were mapped using ESRI's Arc GIS Desktop 9.3.1. Blood mercury cases were geocoded with the most specific locational data available in this order: patient address, patient zipcode, patient city, patient parish, hospital address. After geocoding, patients were associated with their respective parishes and parish-level blood mercury case proportions were derived for those parishes with ≥ 30 tests reported (count of parish level cases above background / count of parish level people tested), based on the Central Limit Theorem. Data for parishes with < 30 blood mercury reports were suppressed due to low sample count. Parishes with at least 30 tests were retained to enable presentation of the potential linkage procedures even though above background proportions presented may not represent actual parish-level population proportion. Only 10 out of 64 parishes are represented with blood mercury case proportions due to small sample size.

Fish-tissue mercury concentrations were mapped using sample-specific geographic coordinates. Given the geographic gaps in sampled sites, it was decided to map an interpolation of fish-tissue mercury levels. 'Natural neighbor' interpolation was used to estimate fish-tissue mercury levels in unsampled areas. Natural neighbor interpolation is a method of constructing new data points via approximation based on a discrete set of known data points, and is the most general and robust method of interpolation available to date. Interpolation enables the user to present the data as isopleth instead of choropleth which is prone to areal bias. Attributing average mercury concentrations to management units such as parishes or basins may conceal specific waterbodies with high and low fish-tissue mercury levels and this can impact interpretation. As almost 20 percent or 8,277 square miles of the states' 43,566 square miles of land area is covered by water, interpolation may be useful for estimating fish-tissue mercury concentrations related to non-point source mercury.

Due to the high sample number, it was possible to restrict data to one species of defined length to reduce sample variability. To identify a good indicator species for evaluating spatial variability, it is important to identify a higher trophic level that typically bioaccumulate greater mercury levels. Indicators should also have high sample counts, a large percentage of mercury detections, widespread spatial representation, low migration (resident), and a strong length-mercury relationship that varies based on where samples are collected. Based on the species-specific summary statistics, the predator fish largemouth bass (*micropterus salmoides*) has a high percentage of mercury detects (>0.001 ppm); the highest sample count; and the greatest number of sites from which samples were taken. Largemouth also displays a strong length-mercury relationship that varies by waterbody. Largemouth bass is also piscivorous, pelagic and resident- groups that have relatively higher fish-tissue mercury levels. Largemouth bass is a primary target species at all sites as they are known for their propensity to accumulate mercury, and are widespread and abundant.

Largemouth bass (29-43 cm) was selected for mapping as this species are the most frequently sampled, have a large percentage of mercury detections, widespread spatial representation, low migration (resident), and a strong length-mercury relationship. Sites with at least ten samples of largemouth bass ranging in length from 29 to 43 cm were mapped to determine if geographic coverage for this stratified group is adequate for trend identification. Spatial coverage was deemed adequate with 1,508 samples of 5,697 individual largemouth bass (29-43 cm) collected from 217 sampling stations in 89 different waterbodies located within all river basins. Interpolations were conducted using EPA's Spatial Analysis and Decision Assistance software Version 4.1.50 (SADA) and ESRI Spatial Analyst Extension for Arc GIS Desktop 9.3.1

Fish-tissue mercury interpolations were overlayed with parish-specific proportions of above background cases to total tested to identify areas where fish-tissue hotspots coincided with high blood mercury proportions.

## RESULTS

### Database Assessment

*Assessment of Resident Blood Mercury Database*

In June of 2006, changes in disease reporting requirements mandated that healthcare providers report all laboratory results for cases of heavy metal exposure (arsenic, cadmium, lead, and mercury) to SEET. SEET receives an average of 17 lab reports for mercury weekly. Since mandatory reporting was initiated, over 2000 mercury-related laboratory records have been received to date (n=2,062). Due to the lack of long-term laboratory reports, an accurate assessment of temporal trends is not yet possible. Variables reported include: provider name and address, lab results and sample collection date, patient date of birth, age and sex. Name of employer, patient address and telephone number, and exposure details are available for some cases. Cases with blood mercury levels > 10 ug/L are investigated. Investigations include review of medical records and interviews with health care providers and patients to determine source of exposure and signs and symptoms. For mercury poisoning cases where fish consumption is the reported source of exposure, detailed information on frequently consumed species, amount consumed, and location if caught recreationally, is collected and added to the database. Most of those interviewed were exposed to mercury via fish consumption though not all fish consumed were locally caught.

*Assessment of Fish-Tissue Mercury Database*

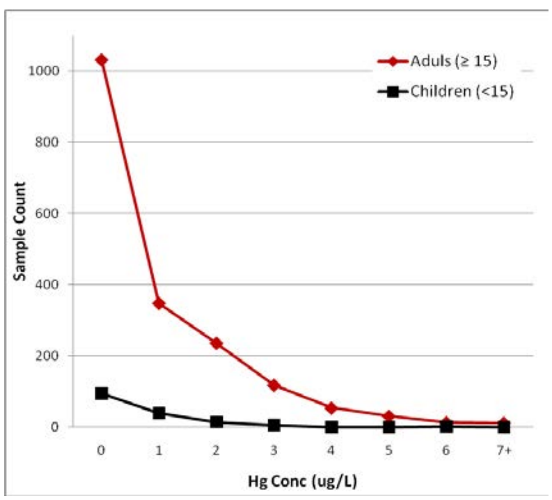
SEET, in collaboration with the Louisiana Department of Environmental Quality (LDEQ), has been tracking mercury levels in fish, a core environmental public health indicator, since 1994 when the state legislature allocated funding for a statewide mercury program. The LDEQ has collected 14,246 fish-tissue samples composited from 40,778 fish and 71 species of fish and shellfish. Samples were collected at 652 sampling stations in 371 waterbodies and all twelve major river basins in the state for the purpose of determining the nature and extent of fish-tissue mercury contamination within Louisiana's waterways. Fish/shellfish tissue samples are primarily collected in areas where contamination is suspected or known, and popular fishing spots. Information collected for each fish tissue sample includes: date of collection, species, length, weight, mercury concentration, and sample locations (latitude/longitude coordinates). Variable coverage for all samples (n=>14,000) is 100%. Approximately 1,000 samples are collected every year, and results are maintained in a comprehensive database. Composite samples are made from two or more fish of the same species, age and weight class in cases where fish tissue collected from one fish was not enough for accurate mercury detection. The variance in fish-tissue mercury levels within composites averaged six percent.

**Data Summary**

*Summary of Louisiana's Blood Mercury Levels*

This review evaluated 2,062 blood mercury test results reported to SEET between 1/1/2007 and 7/2/2009. **Figure 1** presents the distribution of blood mercury concentrations for individuals tested. Approximately 4% of individuals tested were above the national background levels (≥3 µg/L for children and ≥6 µg/L for adults). Adults have higher blood mercury concentrations in general possibly due to the effects of bioaccumulation.

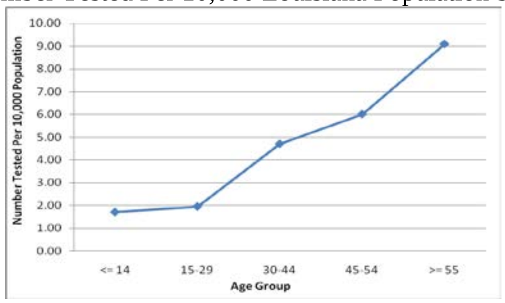
**Figure 1.** Distribution of Blood Mercury Concentrations for Louisiana Individuals Tested




Blood mercury levels were reported for approximately 5 out of 10,000 people in Louisiana. Individuals with blood mercury levels within NHANES background ranges (<3 µg/L for children and <6 µg/L for adults) comprised approximately 96% of the tested population.

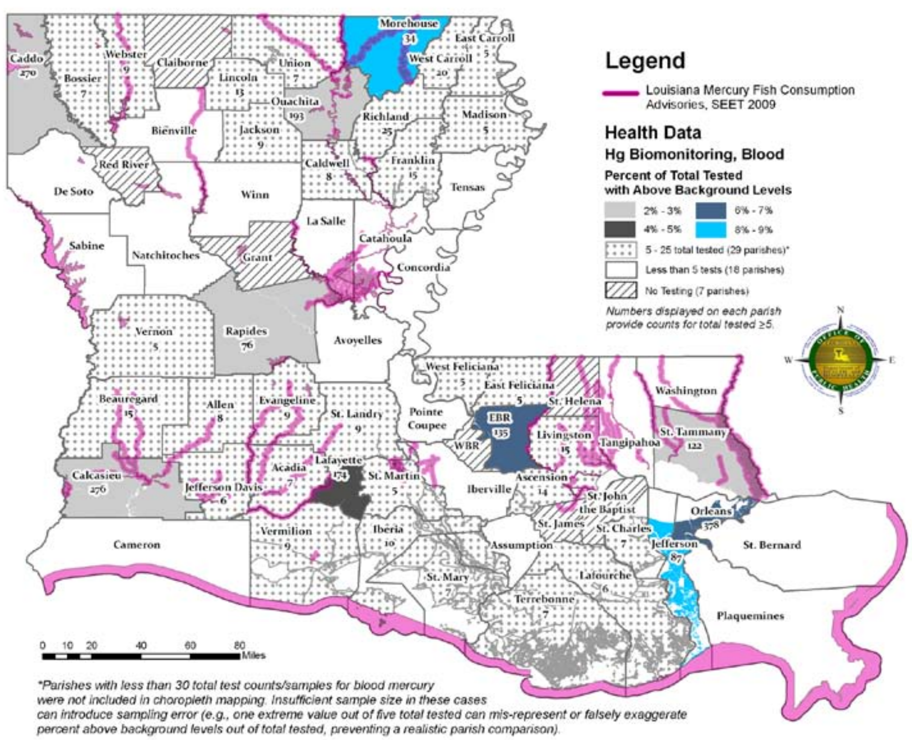
**Figure 2** shows how the tested population differed from the state population in terms of age. Testing was biased towards older individuals with 9 out of 10,000 individuals aged 55 and older being tested compared to 2 out of every 10,000 individuals 14 years or younger tested. Given the skewed nature of testing individuals suspected of exposure, the bioaccumulative nature of mercury, and the high proportion of elderly tested, the tested population is likely to have higher levels than the general population. Thus results presented here for tested individuals are not representative of the general population.

**Figure 2.** Number Tested Per 10,000 Louisiana Population by Age Group




In an effort to determine parishes of potential concern, Louisiana parishes with a high proportion of above background cases over tested (where background is ≥3 μg/L for children and ≥6 μg/L for adults) were identified among the parishes reporting. Parishes with above background proportions of ≥5% above background blood mercury cases out of total tested were mapped, and may represent a starting point for identifying areas of potential concern. These include: Morehouse, Jefferson and East Baton Rouge. Among the reporting parishes, Morehouse (with proportion of 9% above background of total tested) has been identified in previous studies as an area of potential concern with respect to mercury (**Figure 3**). Jefferson Parish (9%), East Baton Rouge (7%), Orleans (6%) and Lafayette (5%) follow (**Figure 3**). These parishes are all bordered by fish advisory areas where commercial or recreational fish are likely to be consumed (**Figure 3**).

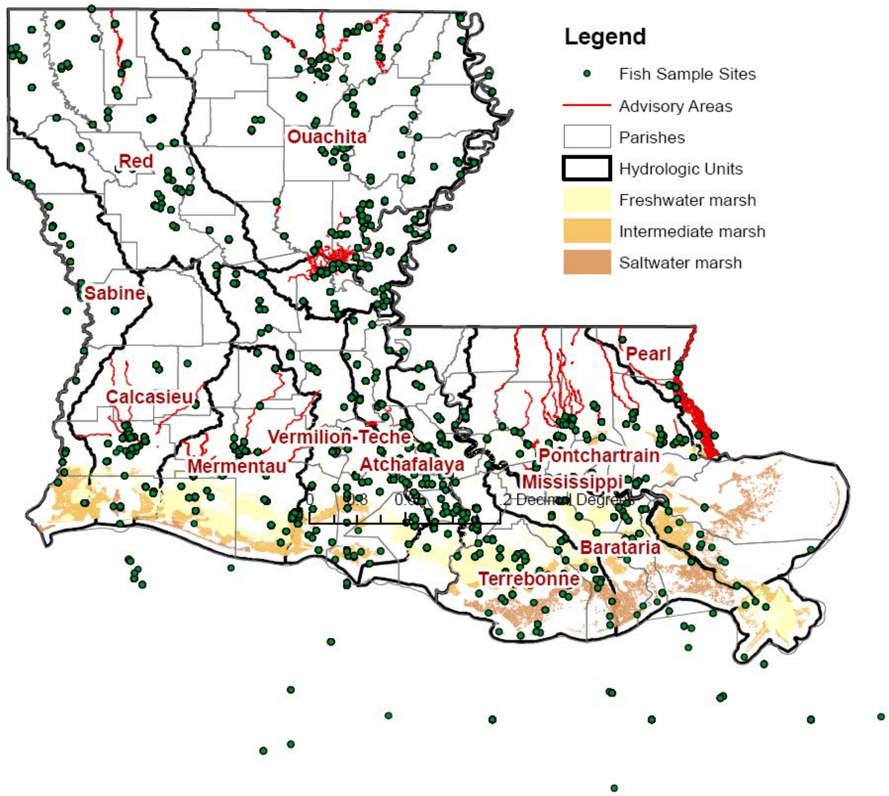
**Figure 3.** Proportion of Above Background Cases of Total Tested by Parish




*Summary of Louisiana's Fish-Tissue Mercury Levels*

A preliminary assessment of fifteen years of fish-tissue mercury data revealed significant spatial variation, but no significant temporal variation- which supports aggregation of sample values over the period of collection (1994-2008). **Figure 4** presents sites from which fish samples were collected between 1994 and 2008.

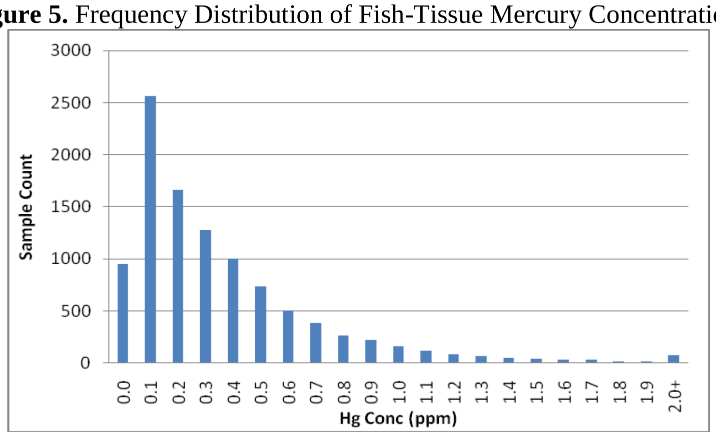
**Figure 4.** Fish-Tissue Sample Stations and River Basin Locations: 1994-2008




**Note:** Estuarine area data from the LA Department of Wildlife and Fisheries.

Mercury was detectable in approximately 98.8% of the fish samples collected after 1996. The frequency distribution for mercury concentrations is skewed to the right (or positively skewed) (**Figure 5**).

**Figure 5.** Frequency Distribution of Fish-Tissue Mercury Concentrations




Four fish species comprised 59% of all fish samples taken up to the end of 2008: (1) largemouth bass, (2) bowfin, (3) freshwater drum and (4) black crappie. These species also had the highest mean fish-tissue mercury levels among the inland species sampled. **Table 2** presents sample counts and mean mercury levels for these species. Largemouth bass comprised 29% of all samples collected; while bowfin, freshwater drum and black crappie comprised 11%, 10%, and 9% respectively.

**Table 2.** Sample Counts and Mean Mercury Concentrations in the Most Frequently Sampled Species (1994-2008)

| Species | % of Samples | % Detect | Sample Number | Site Count | Fish Count | Arithmetic Mean Hg (ppm) | Weighted Mean Hg (ppm) | Max Hg (ppm) | Standard Deviation Hg | Variance Hg |
|---|---|---|---|---|---|---|---|---|---|---|
| Largemouth Bass | 29 | 100 | 4121 | 4121 | 13630 | 0.43 | 0.39 | 2.44 | 0.32 | 0.10 |
| Bowfin | 11 | 100 | 1561 | 1561 | 2887 | 0.58 | 0.54 | 3.98 | 0.51 | 0.26 |
| Freshwater Drum | 10 | 99 | 1416 | 1416 | 2823 | 0.42 | 0.39 | 1.90 | 0.33 | 0.11 |
| Black Crappie | 9 | 99 | 1270 | 1270 | 4857 | 0.28 | 0.26 | 1.45 | 0.22 | 0.05 |
| White Crappie | 8 | 99 | 1106 | 1106 | 4160 | 0.27 | 0.24 | 4.37 | 0.25 | 0.06 |
| Blue Catfish | 7 | 98 | 1003 | 1003 | 2281 | 0.15 | 0.14 | 1.59 | 0.15 | 0.02 |

**Note:** Minimum fish-tissue mercury levels in all basins is 0.001 (the detection limit).

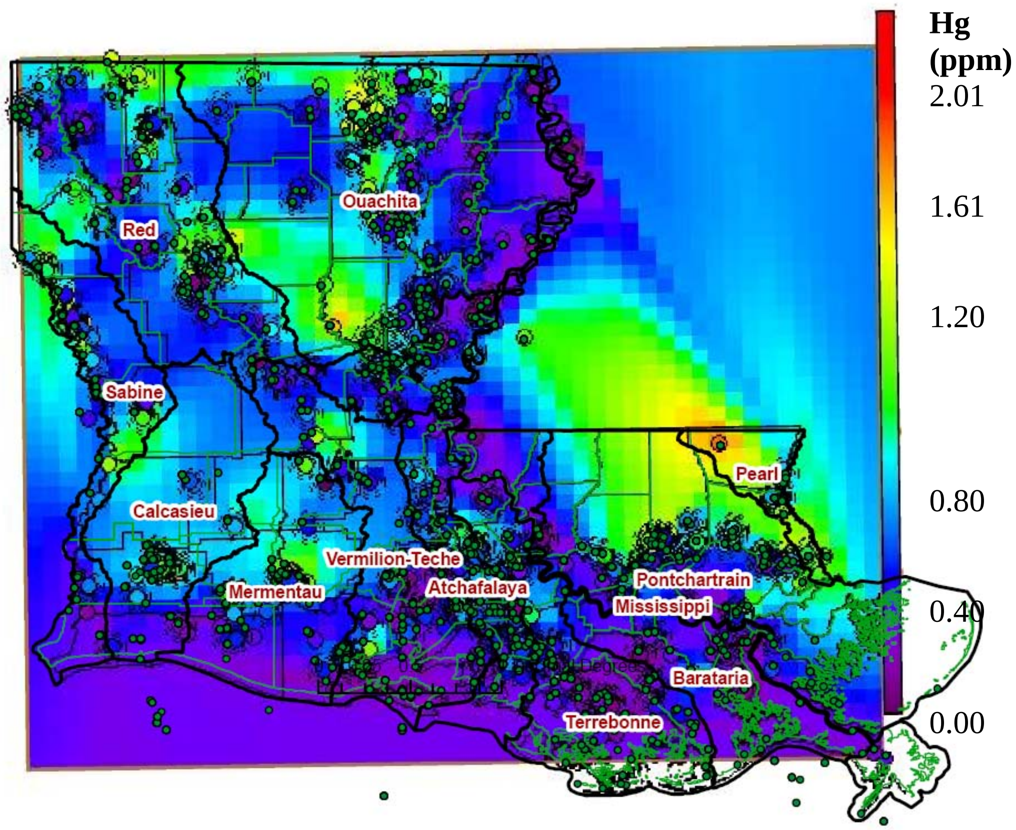
Twelve percent of fish-tissue samples collected between 1994 and 2008 equaled or exceeded the screening value for the general public (n=1,728); while 52% of samples equaled or exceeded the screening value for sensitive populations (n=7,457). Higher fish-tissue mercury levels were observed in species categorized as resident, pelagic, freshwater, and predatory.

Upon review of summary statistics for mercury concentrations in species with more than ten samples, species with ≥50% of samples exceeding the screening value for the general public were identified. These species included: king mackerel (70% exceeded the general public screening value, n=86) and blackfin tuna (69%, n=26). King mackerel and blackfin tuna are currently under a Louisiana advisory, along with cobia and greater amberjack. King mackerel is also listed on EPA's nationwide fish advisory. All other sampled species had a majority below the general public screening value.

Species with more than ten samples and with≥50% of samples exceeding the screening value for the sensitive populations were also identified. King mackerel (98% exceeded the sensitive population screening value, n=86), blackfin tuna (92%, n=26), greater amberjack (92%, n=36), cobia (84%, n=43), warsaw grouper (83%, n=12), spotted bass (80%, n=275), bowfin (77%, n=1561), largemouth bass (70%, n=4121), freshwater drum (65%, n=1416), white bass (57%, n=225), warmouth (53%, n=51) and bigmouth buffalo (51%,n=266).

**Figure 6** presents an interpolation of fish-tissue mercury levels for largemouth bass (29-43 cm) from areas where more than ten samples were collected. Presented here are areas of high (red / orange) and low (purple / blue) average fish-tissue mercury levels. Based on this analysis, hotspot areas exist in Pearl and Ouachita basins. Contamination in the Pearl River prompted the legislature to fund a fish advisory program in 1994. As with Pearl, many of the sampled sites in Ouachita are under advisory. Ouachita was also identified as a hotspot in the 1998 survey. An accurate assessment of areas of potential concern near estuarine and coastal waters could not be conducted given the need to restrict data in this analysis to a freshwater species.

**Figure 6.** 'Natural Neighbor' Interpolation of Average Fish-Tissue Mercury Concentrations at Sites with >10 Samples of Largemouth Bass (29-43 cm)



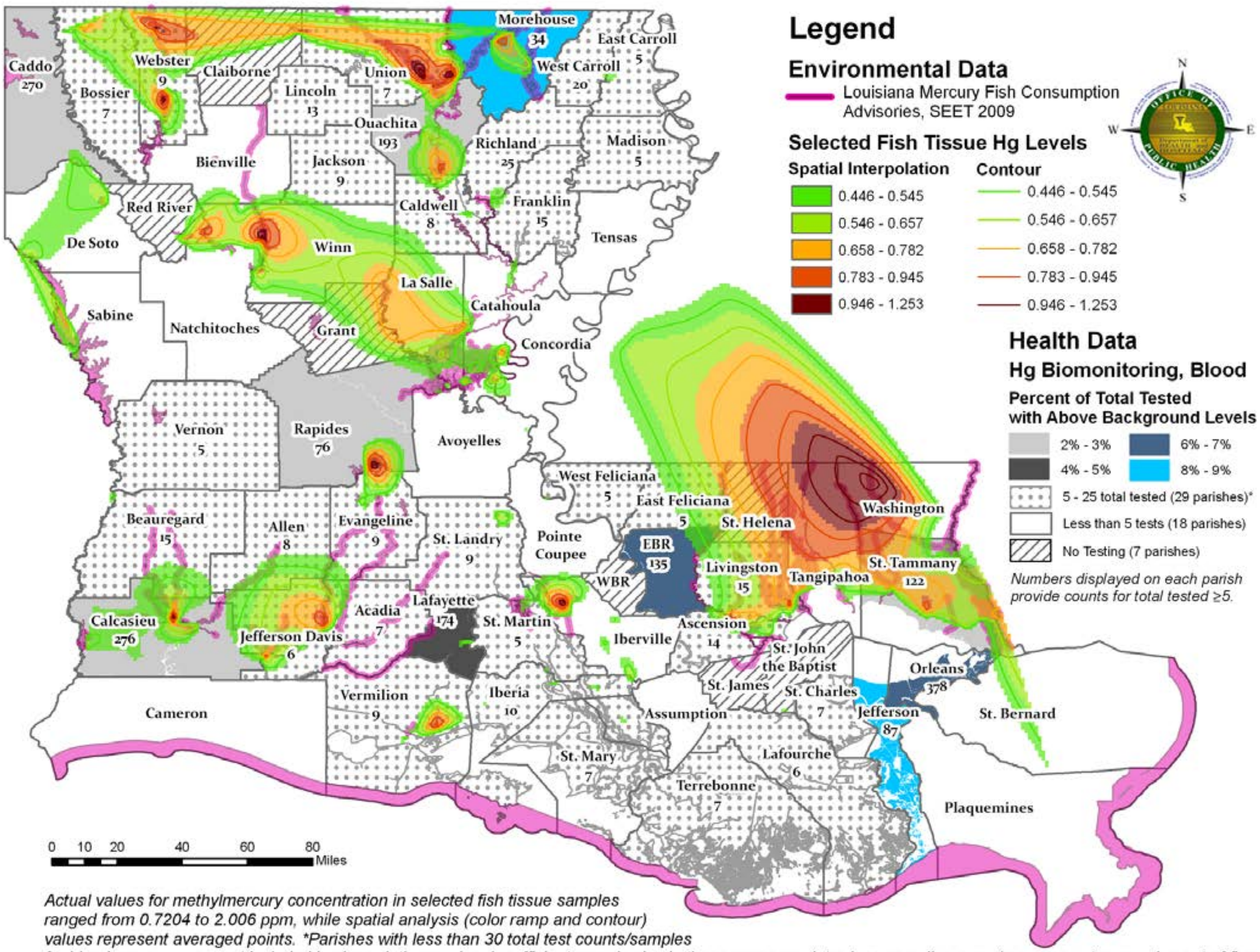

*Areas Where High Blood Mercury may be Attributable to High Fish-Tissue Mercury*

To identify areas where high blood mercury may be attributable to consumption of fish with high mercury levels, parish-level proportions of above background blood mercury cases were mapped and overlaid with an interpolation of fish-tissue mercury concentrations of size-limited largemouth bass (29-43 cm) (see **Figure 7**).

The map overlay of environmental and health surveillance data generates a number of research questions for further study. Areas where fish consumption of local contaminated fish may contribute to high proportions of above background cases may be identified as those with 1) high proportions of above background cases and 2) high fish-tissue mercury levels. Only Morehouse meets these criteria.

Additionally, areas in need of blood mercury testing may be identified as those parishes with no or low reported blood mercury tests but high fish-tissue mercury concentrations. These parishes include: Bossier, Webster, Union, Claiborne, Red River, Natchitoches, Winn, La Salle, Evangeline, Jefferson Davis, Vermilion, Iberville, St. Helena, Tangipahoa, Grant, Washington and Livingston. Increased surveillance of these areas may be warranted.

**Figure 7.** Proportion of Above Background Blood Mercury Cases of Total Tested and Real and Interpolated Fish-Tissue Mercury Levels for Species-Specific Size-Restricted Fish (LmB, 29-43 cm)




*Actual values for methylmercury concentration in selected fish tissue samples ranged from 0.7204 to 2.006 ppm, while spatial analysis (color ramp and contour) values represent averaged points. *Parishes with less than 30 total test counts/samples for blood mercury were not included in choropleth mapping. Insufficient sample size in these cases can introduce sampling error (e.g., one extreme value out of five total tested can mis-represent or falsely exaggerate percent above background levels out of total tested, preventing a realistic parish comparison).*

## DISCUSSION

### Limitations

*Blood Mercury Data*

As testing for mercury is not part of routine clinical assessments and is conducted more often in areas and populations with accessible healthcare, surveillance results may be biased towards individuals who may have been exposed to mercury, who have symptoms consistent with mercury toxicity, or who live in areas where more blood mercury testing is conducted. The timing of testing is also an issue as blood levels change with regard to the time of exposure. Due to the indirect and delayed method of obtaining exposure information, some exposure information may be incorrect, thus leading to non-differential misclassification bias and recall bias. Such bias may result in a decreased likelihood of detecting an association even if it exists. Bias may also be introduced from surrogate interviews, in which exposure information is obtained from second hand parties (e.g., the health care provider or spouse). Finally, given the recent implementation of this surveillance system, case numbers are small, thus reducing the potential significance of results as counts will change with more comprehensive surveillance. An accurate ranking of parishes in terms of exposure to mercury cannot be made as some parishes under-tested and / or under-reported.

One issue encountered was how to represent the blood mercury data geographically. Due to the lack of patient-specific addresses some cases can only be mapped to health care provider locations, which can result in incorrect area estimates biased towards urban areas. Parishes with higher testing and reporting are likely to have higher counts above background. Also due to the potential for increased mercury bioaccumulation with age, a map of blood mercury levels would be biased in areas where testing favors a specific age group out of proportion with the parish's actual age stratified population. Small sample size prevents population stratification that would reduce sample variability. It is anticipated that maps will alter considerably once more comprehensive data obtained over a longer period is considered. A list of these and other limitations is presented in **Table 4**. These limitations prevent an accurate representation of the true distribution of blood mercury levels.

*Fish-Tissue Mercury Data*

Only 31% of the samples were analyzed on an individual fish basis (n=4,384) instead of as a composite sample. This may limit conclusions which can be made regarding spatial variability or factors influencing mercury concentrations. Thus, the results of this survey will not be a statistically rigorous assessment of fish-tissue mercury levels in Louisiana fish. As with blood mercury data, surveillance results may be biased towards areas with mercury contamination, or areas more popular with fishers as these areas are targeted during sampling. And while the fish-tissue database is extensive, areas do exist where no sampling was conducted thus limiting the ability to provide an accurate representation of the spatial distribution of fish-tissue mercury levels.

Problems with how to represent the fish-tissue mercury data geographically were also encountered due to the same issue of bioaccumulation of mercury with age, and differential bioaccumulation of mercury by trophic group (diet). Older (longer) fish will have more mercury than younger (smaller) fish of the same species; and species in higher trophic positions (e.g., predators) will have more mercury than those in lower trophic positions (e.g., herbivores). This problem was overcome by using data from largemouth bass of a select size and interpolating fish-tissue mercury concentrations to fill in areas with no sample values. The biggest limitation in using largemouth bass as an indicator to evaluate fish-tissue mercury trends is that they are a freshwater species, thus, they cannot be used to evaluate mercury levels or trends in estuarine or marine systems. Another limitation in this method is that interpolation is a statistical model that does not consider source location and output or water flow, thus is prone to error. Natural neighbor interpolation is the most general and robust method of interpolation available to date, however the representation accuracy depends on the density of the data. The more data available across sampling locations, the more reliable this method is. Thus results may change with more data. A list of these and other limitations is presented in **Table 3**.These limitations prevent a comprehensive statewide representation of fish-tissue mercury levels.

**Table 3.** Some Limitations of Data and Data Interpretation

| **Limitations** |
|---|
| Only total blood mercury available which represents all potential mercury exposures not just methyl mercury which is most likely due to from fish consumption |
| Low reporting- 7 parishes had no reports and 39 parishes had ≤10 samples. Only 17 parishes had >10 reports. Reduces significance of results. Small sample size also prevents population stratification that would reduce sample variability |
| Lack of patient addresses resulted in mapping to provider location which can result in incorrect area estimates biased towards urban areas where hospitals are located |
| Unknown delay between exposure and testing. |
| Unknown reason for sampling- sampling bias towards people suspected of mercury poisoning or exposure, and populations / areas with accessible healthcare |

| |
|---|
| Unknown source of exposure due to no follow-up survey or incorrect exposure information due to delayed follow-up or surrogate surveys |
| Due to the potential for increased mercury bioaccumulation with age, a map of blood mercury levels would be biased in areas where testing favors a specific age group out of proportion with the parish's actual age stratified population. |
| Most fish-tissue data analyzed as composites of multiple fish thus limiting conclusions |
| Fish-tissue mercury surveillance results may be biased towards areas with mercury contamination, or areas more popular with fishers as these areas are targeted during sampling |
| While the fish-tissue database is extensive, areas do exist where no sampling was conducted thus limiting the ability to provide an accurate representation of spatial distribution |
| Limitation of analysis of spatial trends in fish-tissue mercury to largemouth bass prohibits evaluation of estuarine and marine areas |
| Interpolation is a statistical model that does not consider source location and output or water flow, thus is prone to error |
| Representation accuracy of interpolated results depends on the density of the data |
| Spatial health data has unique characteristics which make them prone to misrepresentation and misinterpretation – e.g., [1]spatial autocorrelation and variance instability |
| Clustering does not necessarily illuminate etiology- especially when scant information is available on exposure history |
| Spatial and temporal mismatches where information on cases and exposures do not align in space or time. Particularly problematic for diseases with long latencies and where population mobility (such as migration to diverse fishing areas) is expected |
| [2]Ecologic Fallacy is inherent in most spatial analyses of grouped health data |

**Notes:** 1. Spatial autocorrelation is the tendency for proximal samples to have correlated attribute values. Variance instability is a visual bias towards sparsely or densely populated areas. 2. Ecologic fallacy is the chance that associations observed at the aggregate level are inconsistent with associations observed at the individual level.

*Summary of Limitations*

The scarcity of exposure data (i.e., blood mercury data) is not acceptable for simple descriptive analyses, let alone complex linkages which require even more and better data. It is difficult to design a map that is not biased toward either sparsely or densely populated areas. Insufficient blood mercury data prevents a conclusive and comprehensive identification of all areas of concern. Such challenges will require more complex statistical analyses to reduce misrepresentation and misinterpretation.

The primary issues encountered in setting up this environmental public heath tracking system were how to standardize and represent data geographically; identifying potential bias in data systems; and utilizing as much as possible the available data while interpreting results in a meaningful way, given low sample counts in the blood mercury database. The lack of speciated blood mercury samples hinders linkage of these data to fish-tissue mercury hotspots and prevents interpretation of results. Conclusions derived here are expected to change when more blood mercury lab reports are obtained.

It should be emphasized that this surveillance system can only identify limited areas of potential concern with regards to mercury exposure. In particular, the system can identify areas where fish consumption may potentially play a part in elevated blood mercury levels, based on geographic overlap of areas with high blood and fish-tissue mercury levels. Other potential areas of mercury exposure may be derived with information about other mercury sources (e.g., leaking manometers, industrial mercury emissions, accidental spills, occupational sources, etc.).

Based on these results, recommendations for an outcome-based public health action plan were developed. A proposed plan involves supplementation of this surveillance system with other data sources to enable more comprehensive and thorough mercury tracking; and development of a spatial multi-criteria approach which considers and quantifies other factors of influence.

**Public Health Action Plan Recommendations**

The fundamental components of this action plan are to: 1) procure and process new data; 2) develop a multi-criteria approach which considers and quantifies factors of influence useful in assessing potential risk and ranking parishes or other geographical units; and 3) to design an effective media outreach plan targeted to at-risk populations.

*Data Procurement and Processing*
It will be useful to obtain exposure information on all cases (below background as well) to enable source identification. This may be useful for providing a denominator among those tested to determine how many were exposed only by eating fish. In LA, some health and environmental surveillance systems are located in disparate systems across state departments and have yet to be associated. Data to be procured, evaluated and standardized for geographic projections include: parish-level recreational and commercial fishing permit counts, fish consumption advisory areas, industrial emissions, and boat launch and marina locations. The scientific literature will be reviewed to identify other potential at-risk groups that may have been underrepresented in survey (e.g., Vietnamese and Native Americans). Census demographics will be used to locate areas where these populations are concentrated. Results from the survey on fishing (favorite fishing spots, take home counts, etc) and fish consumption habits (most frequently consumed species, consumption frequency, etc) discussed in the introduction of this report will be used to guide hot spot identification. Such data include but are not limited to prefered fishing areas and distance traveled from boat launch areas.

*Spatial Multi-Criteria Decision Making*
A GIS-based weighted quantitative risk ranking and hotspot mapping method may be developed based on previously published methods and expert assessment of influential factors. Data will be reviewed and evaluated by experts for determination of suitability and strength of variable influence. Data to be considered include environmental (i.e., chemical emissions and contamination), physical (i.e., conditions favoring mercury methylation), topographical, demographic, socio-economic and health. Under expert guidance influential factors will be selected and appropriate methods of geographic representation will be proposed. Uncertainties and other influencing factors can be included. An analytical hierarchy process will be used by experts to decompose all relevant decision criteria into a hierarchial structure. Pairwise comparison will then be conducted to create a ratio matrix to produce relative weights as outputs. Standardized criteria will be mapped and processed via weighted risk algorithms. Multiple criteria will be aggregated into a single evaluation score according to weighted linear combination rules (i.e., weighted averages or simple additive weighting). GIS-based decision support systems will be used to test different standardization and aggregation procedures to explore differences in results and to address different objectives. Quantitative measures of area-specific risk will be used to rank and prioritize areas of potential concern in support of future decision-making.

*Outreach*
A successful public health action plan depends on a targeted outreach plan. Once at-risk populations are identified geographically, demographically and quantitatively from the steps above, public stakeholders such as the State Department of Wildlife and Fisheries and other which can facilitate community outreach will be identified. Communication outreach strategies will be targeted to internal and external partners, community stakeholders, and the public. Surveillance and survey results will be used to guide outreach activities including. Outreach will be conducted prior to times of peak exposure, such as fishing seasons. The literature will be reviewed to identify successful outreach methods and to avoid common errors in public health communication (e.g., using language that scares the public from eating fish). Promotional and factual information will be translated in commonly used languages and disseminated via mass media, public presentations and partnerships.

## CONCLUSION

This project evaluated the potential processes, limitations and potential applications of a GIS-based surveillance system which links mercury exposure (blood mercury) to a specific mercury source (fish-tissue mercury). Simple mapping and overlay of data can assist in targeting geographic areas of potential concern, where biomonitoring or outreach may be necessary. While results derived from linking hazard and health outcome data are susceptible to ecologic bias and misinterpretation, this system does hold promise for identifying areas where fish consumption may potentially play a part in elevated blood mercury levels. As more blood mercury data become available, geographic areas with relatively higher blood mercury levels may become more apparent. This system will also enable identification of areas with high fish-tissue mercury levels and low blood mercury testing, - areas which can be targeted for biomonitoring. Once limitations are addressed, this surveillance system will enable identification, ranking, and prioritization of geographic areas of potential concern; targeted outreach and biomonitoring to communities of potential concern; and more efficient use of available resources allocated for prevention and intervention efforts. In the long-term, use of this tool may ultimately reduce mercury exposures, and subsequently, adverse mercury-related health effects.