A Methylmercury Risk Screening Assessment to Identify Fish Species and Populations of Potential Concern

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***Abstract*- State fish consumption advisories provide meal limit recommendations for recreationally-caught fish. In Louisiana, these recommendations are based on species-specific fish tissue contaminant concentrations, and default assumptions about fish consumption. This approach can lead to advisories for infrequently eaten species, and inappropriately targeted monitoring and outreach activities. The goal of this study is to identify and prioritize species, populations and areas of potential concern based on a screen of mercury intake. Mercury doses were estimated based on species-specific fish consumption data from a population-based survey of Louisiana's recreational fishers (n=1774), and regional fish tissue mercury concentration data (n=15,030). Estimates of species-specific mercury doses were derived for each survey respondent based on mean and 90th percentile fish tissue mercury levels. Mercury exposure distributions for various species and sub-populations were compared to the U.S. Environmental Protection Agency's health-based standard for methyl-mercury. As children and commercial and subsistence fishers were not surveyed, conclusions presented here are only applicable to adult recreational fishers, who are expected to eat less fish than commercial and subsistence fishers. Species with the largest number of at-risk fishers were drum (primarily red drum), speckled trout, catfish, crappie, bass and bream. Populations of potential concern included women of childbearing age; African- and Native-Americans; fishers from northern Louisiana; and fishers with Hook and Line and Basic licenses. Results were used to make recommendations to optimize monitoring, advisory development and outreach activities. This study demonstrates the importance of collecting fish consumption data for ensuring adequate public health protection.**

***Keywords* - Mercury; Fish; Advisory; Risk; Louisiana**

I. INTRODUCTION

The primary source of human exposure to environmental mercury (Hg) is through seafood consumption. Most fish advisory programs throughout the country monitor local fish to evaluate methylmercury (mHg) levels, the bioaccumulative toxic form of Hg. When warranted, states develop meal limit recommendations or advisories for local fish. Methylmercury exposure is a particular concern, as it has been associated with impaired neurological development in developing fetuses, infants, and children [1]. The severity of adverse health effects attributable to mHg varies depending on the dose; which in turn depends in part on fish consumption rates and fish tissue mHg levels. It is expected that mHg exposures are higher in coastal areas such as Louisiana (LA), for which seafood is economically or culturally important. A recent study evaluating data from the National Health and Nutrition Examination Survey (NHANES) reported that elevated blood Hg levels occurred more frequently in individuals living in coastal areas of the U.S. [2].

Fish consumption is also healthful for the developing fetus as it is one of the primary dietary sources of polyunsaturated fatty acids (PUFA), which play an essential role in the normal development and functioning of the brain and central nervous system. For the purpose of reducing the risk of contaminant exposure and maximizing the nutritional benefits of fish consumption, Louisiana issues species- and waterbody-specific advisories for the sensitive population (children and women of child-bearing age) and the general public. Louisiana's Fish Advisory Program is responsible for monitoring regional fish, developing fish consumption advisories, and educating populations at risk.

The state bases mHg-related advisories for the sensitive population of women of child-bearing age and children on the U.S. Environmental Protection Agency's (US EPA) mHg Reference Dose (RfD) of 0.1μg/kg body weight-day, which was developed to protect the health of a developing fetus [1]. In Louisiana (LA) as in most states, average species-specific Hg concentrations are used with default fish consumption rates, portion size, and bodyweight values to derive meal limit recommendations. Louisiana's advisories are based on the assumption that a 70 kg adult eats no more than four 227-gram meals per month (an average of 30 grams per day (g/d)) of species-specific sportfish from a particular waterbody for 30 years. This value (30 g/d) is the US EPA's estimate of the 50th percentile of consumption of all fish and shellfish from marine,

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estuarine and fresh waters for recreational fishers [3]. The ratio of meal size to body weight for a child is assumed to be the same as for an adult. These default values are used in lieu of actual data, and therefore may differ considerably from the actual rates and values for the population of concern.

As exposure assumptions are essentially the same for all species, monitoring and advisory decisions are primarily based on fish tissue Hg concentrations. This can lead to situations in which advisories are developed for species with the highest fish tissue Hg levels, regardless of how frequently they are consumed. For example, fish such as bowfin, which are infrequently eaten by LA fishers [4], are the species most frequently monitored. These higher trophic level species typically have the highest fish tissue Hg levels, thus are good indicators of environmental Hg contamination for screening purposes [5]. As a consequence, bowfin is also the species most commonly listed in LA advisories. Up to date it is listed on 91 waterbody-specific fish consumption advisories. However, results from a recent study of LA's coastal recreational fishers indicated that bowfin was not a major contributor to Hg dose [6]. Instead, the Lincoln study indicates that high consumption of fish with low-to-moderate Hg levels drove intake in this study. If bowfin consumption frequency were considered during the advisory process, 15% of LA's mercury-based fish advisories or those based on bowfin alone (n=48), may be found unnecessary, if information about the generally high Hg levels in bowfin is communicated. The opposite case could also be found, in which waterbodies without advisories on frequently eaten fish with low-to-moderate Hg levels may require re-evaluation.

This study aims to identify species and populations of potential concern by conducting a screen of mHg dose estimates from survey-obtained species-specific fish consumption data and regional fish tissue Hg concentration data. Results were used to evaluate the impact that consideration of fish consumption rates may have on monitoring and advisory decisions; and to make recommendations to optimize monitoring, advisory development and outreach activities.

II. METHODS

The Louisiana Recreational Fisherman and Health Advisory Survey was mailed out to a random sample (n=6,064) of residents throughout the state who purchased recreational fishing licenses from the LA Department of Wildlife and Fisheries (LDWF) in the 2008 license year (i.e., June 1, 2007 to May 31, 2008). Questions used in the survey were based on USEPA guidelines for conducting fish consumption surveys [3]. An informal pre-test with colleagues was used to ensure that the questionnaire was understood by respondents as the authors intended. More information about the survey design, survey population and data analysis is described in Katner *et al.*, 2011 [4]. To minimize sampling error and ensure representative responses, resident fishers from the LDWF database (n=503,336) were stratified by license type and resident location, and selected using population–based proportional sampling with the "surveyselect" procedure in SAS (v 9.1; SAS Institute, Cary, NC). Survey responses were collected between September of 2008 and January 2009 (n=1774). Data on fishing habits, fish consumption patterns and advisory awareness were analyzed as described in Katner *et al.* 2011 [4]. Samples were adjusted for non-deliverable surveys before response rates were derived. The overall response rate of 33% (1,774 respondents) is comparable to past LDWF surveys.

An analysis of fishers responding to the second mail request (n=812) was conducted in an attempt to characterize "non-respondents". No significant differences were observed between the first (n=962) and second (n=812) wave of respondents with respect to license, location, education, ethnicity, age, income and gender ($\chi 2$, $p>0.05$). Socio-demographics of respondents are summarized in Katner *et al*, 2011 [4]. Most respondents were Caucasian males between the age of 40 and 59. Almost half of our population came from the southeast (47%). Forty-percent of our survey population is comprised of individuals with a saltwater fishing license (with both freshwater and saltwater fishing rights). Over one third of our population had only a high school education (36%). Twelve percent of respondents were females of childbearing age (between 18 and 45 years of age); and 20% had a child less than 8 years in the household within the 12 months preceding this survey. Twenty percent of all respondents were seniors (> 60 years); and 14% of all respondents were reported being retired (n=1726). Most Southern respondents hold a Saltwater license (in addition to a Basic license); and most Northern respondents hold a Basic license.

Consumption of the three most frequently eaten sportfish was reported by survey respondents (n=1218) as a frequency (<1 meal per month (assumed ate 0.5 meals per month), 1-2 meals per month (assumed ate 1.5 meals per month), 3-4 meals per month (assumed ate 3.5 meals per month), >4 meals per month (assumed ate 7 meals per month based on the mean consumption rate for people eating >4 meals per month), can't remember or don't know (assumed ate 0.5 meals per month). Monthly meal frequencies were converted into an equivalent number of meals per day (m/d) (0.02 m/d, 0.05, 0.08, 0.17, 0.23).

Fish tissue Hg data were obtained from the LA Department of Environmental Quality (LDEQ) [7], which has been collecting fish samples since 1992 for the purpose of determining the nature and extent of fish tissue Hg contamination within LA's waterways. These data were evaluated and described in Katner *et al*, 2010 [5].

Dose estimates (μg Hg per kg body weight per day) were based on the respondent's species-specific fish consumption frequency (meals per month), and a mean and upper 90th percentile species-specific total fish tissue Hg concentration (mg of contaminant per kg of fish). Total fish tissue Hg levels were used to estimate mHg dose due to cost restrictions. This is a common method of estimating mHg as an estimated 90-100% of total Hg is mHg- the toxic form of Hg upon which the U.S. EPA's RfD is based [8]. However, there is still uncertainty and variability in the fraction of total Hg present as mHg. For each respondent, species-specific Hg doses were estimated for each of their three most frequently consumed sportfish species, and

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summed to get an individual dose estimate (consumption rates for only the three most frequently consumed finfish were requested to keep the survey short). Default body weights of 60 and 70 kg were used for women and men, respectively; and a default meal size was set at 227 grams per meal [3]. Intake was assumed to continue for 30 years over a lifetime (70 years), 12 months a year based on guidelines presented in the LA's "Protocol for issuing public health advisories for chemical contaminants in recreationally caught fish and shellfish" [9]. The following formula was used to estimate the Hg dose for each recreationally-caught finfish species consumed:

Dspecies= (IRspecies* Cspecies) / BW * L [Eqn. 1]

Where:

Dspecies = Lifetime average species-specific daily Hg dose (µgof Hg per kg of body weight/day)

IRspecies = Species-specific intake rate [(227 grams of fish per meal) * (meals per day *30 years)]

Cspecies = Species-specific average fish tissue Hg concentration (µg of Hg per gram of fish)

BW = Default Body Weight (60 or 70 kg body weight)

L = Lifetime (70 years)

The following formula was used to estimate the total Hg dose from the top three most frequently eaten recreationally-caught finfish species for each respondent.

Dtotal= Σ (Dspecies) [Eqn. 2]

Where:

Dtotal = Lifetime average total daily Hg dose for each respondent from recreationally-caught finfish (µg of Hg per kg of body weight per day)

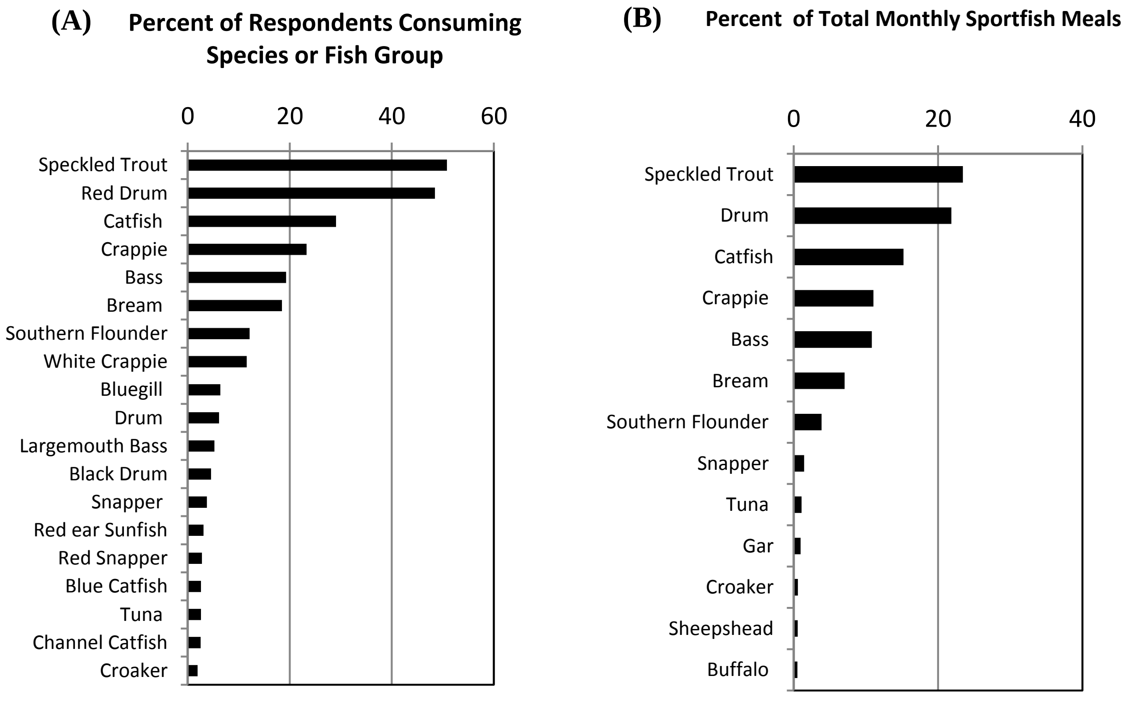

Fig. 1A) Percent of responders (n=1218) consuming each species or fish group; B) Percent of total monthly sportfish meals by species or fish group.

The mHg exposure of each individual was assigned to one of the populations of interest based on the individual's gender, ethnicity/race, age, location, fishing license type, income, education, language, sportfish consumption rate, population type (i.e., sensitive population (for this study, women of child-bearing age), general population, senior population) and advisory awareness. Analysis of dose frequency distributions by species and population type permitted estimation of the proportion exceeding the U.S. EPA's mHg Reference Dose (RfD) (0.1 µg/kg-d). The RfD is the EPA's estimate of a maximum acceptable oral dose of a toxic substance over a lifetime that is likely to be without an appreciable risk of deleterious effects to the human population (including sensitive subgroups), with uncertainty spanning perhaps an order of magnitude. It should be noted that using the RfD, while protective of sensitive subgroups may overestimate the risk to adult males as it is based on the risk to the developing fetus. Various rankings of species were conducted (Figure 1) based on the estimated species-specific Hg dose. Species were ranked based on the proportion of respondents with a species-specific Hg dose >RfD. The primary fish species or

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fish groups of potential concern include those for which over 0.5% of the population had estimated Hg doses exceeding the EPA's RfD based on species-specific fish consumption and mean fish tissue Hg level; and 5% had Hg doses exceeding the RfD based on the 90th percentile fish tissue Hg concentrations. The cut-off values were selected arbitrarily, but with the aim of identifying the top species of primary concern. Population groups were ranked based on the proportion of individuals with a total Hg dose >RfD.

Meal limit recommendations were derived from mean and 90th percentile fish tissue Hg concentrations, based on EPA guidance [3] and the following assumptions: body weight is 65 kg (average of the assumed male and female body weights) and meal size is 227 grams per meal. Statistical analyses were conducted with SAS (v 9.2, SAS Institute Inc., Cary, NC), R (v 2.12.0, Free Software Foundation, Boston, MA), Scout (v 1.0, National Exposure Research Laboratory, Las Vegas, NV), and Microsoft Excel and Access (Microsoft Corp., Redmond, WA).

III. RESULTS

A. Species-Specific Fish Tissue Hg Levels

Mercury was detectable in 99.7% of all edible finfish samples collected between 1994 and 2010 (n=15,030). Species with the highest mean Hg levels include the saltwater species king mackerel, cobia, wahoo, blackfin tuna and greater amberjack, and the upper trophic level freshwater species bowfin and spotted bass [5]. Forty-four percent of fish samples exceed the US EPA's mHg fish tissue criterion of 0.3 ppm, which is based on the US EPA's RfD. The overall range of fish tissue Hg concentration was the detection limit (0.001 ppm) to 5.9 ppm for king mackerel; with an overall geometric mean of 0.2 ppm, and a 90th percentile of 0.8 ppm.

B. User Supplied Sportfish Consumption Data

Ninety-eight percent of respondents reported that they eat fish (commercial or sportfish); and 95% of respondents reported that they eat the fish they catch [4]. The mean monthly consumption frequency of all fish (both commercial and sportfish) was four meals per month. Sportfish made up about half (48%-51%) of total fish consumed in all geographic areas. Overall the most frequently consumed sportfish are: speckled trout, drum (mostly red drum), catfish, crappie, bass and bream. An estimated 5% of respondents ate more than four meals per month of sport-caught finfish. Three percent of all respondents ate more than four meals per month of speckled trout; 2% ate more than four meals per month of each of red drum, catfish, bass and crappie (mostly white crappie); 1% ate more than four meals of bream per month (mostly bluegill and red ear sunfish); and < 1% ate more than four meals per month of southern flounder, largemouth, white, spotted and striped bass, gar, buffalo, bowfin, black and freshwater drum, mullet, sheepshead, tuna, white trout, channel, blue, and flathead catfish; red snapper; and black crappie. Statistically significant differences in sportfish consumption were observed by gender and license type. With respect to the type of fishing license, Sportsman's Paradise and Saltwater license holders had the highest sportfish consumption rates. Female respondents had a significantly lower mean sportfish consumption frequency than males.

C. Dose Estimates

1) Species-Specific Doses:

Various rankings of species were conducted (Figure 2) based on the estimated species-specific Hg dose. The primary fish species or fish groups of potential concern include those for which over 0.5% of the population had estimated Hg doses exceeding the EPA's RfD based on species-specific fish consumption and mean fish tissue Hg level. These include: crappie, bass, catfish and bream (Figure 2C). Conducting this analysis using the upper 90th percentile of fish tissue Hg concentrations indicated that the species of potential concern (where >5% the population had Hg doses exceeding the EPA's RfD) include those listed above, as well as speckled trout and red drum. These species were also some of the highest contributors to the total Hg dose, contributing between 65 and 62% of the total estimated Hg dose, based on mean and 90th percentile fish tissue Hg levels, respectively (Figure 2A). Fish with the highest percent of consumers with doses exceeding EPA's RfD were those with the highest Hg concentrations, such as bowfin, buffalo, freshwater drum, spotted bass, wahoo, cobia, king mackerel, flathead catfish, grouper and tuna (Figure 2B).

2) Species-Specific Monitoring and Advisories:

Largemouth bass, bowfin, freshwater drum and black crappie had the highest fish tissue Hg means among the inland species sampled (Figure 3A). Largemouth bass comprised 30% of all Hg detections; while bowfin, freshwater drum and black crappie comprised 11%, 10%, and 9%, respectively [5]. These more contaminated species also dominated monitoring activities, comprising 60% of all fish samples collected throughout the sampling program's lifespan.

Species with the highest active Hg advisory counts include: bowfin, largemouth bass, freshwater drum, black and white crappie, and spotted bass (Figure 3B).

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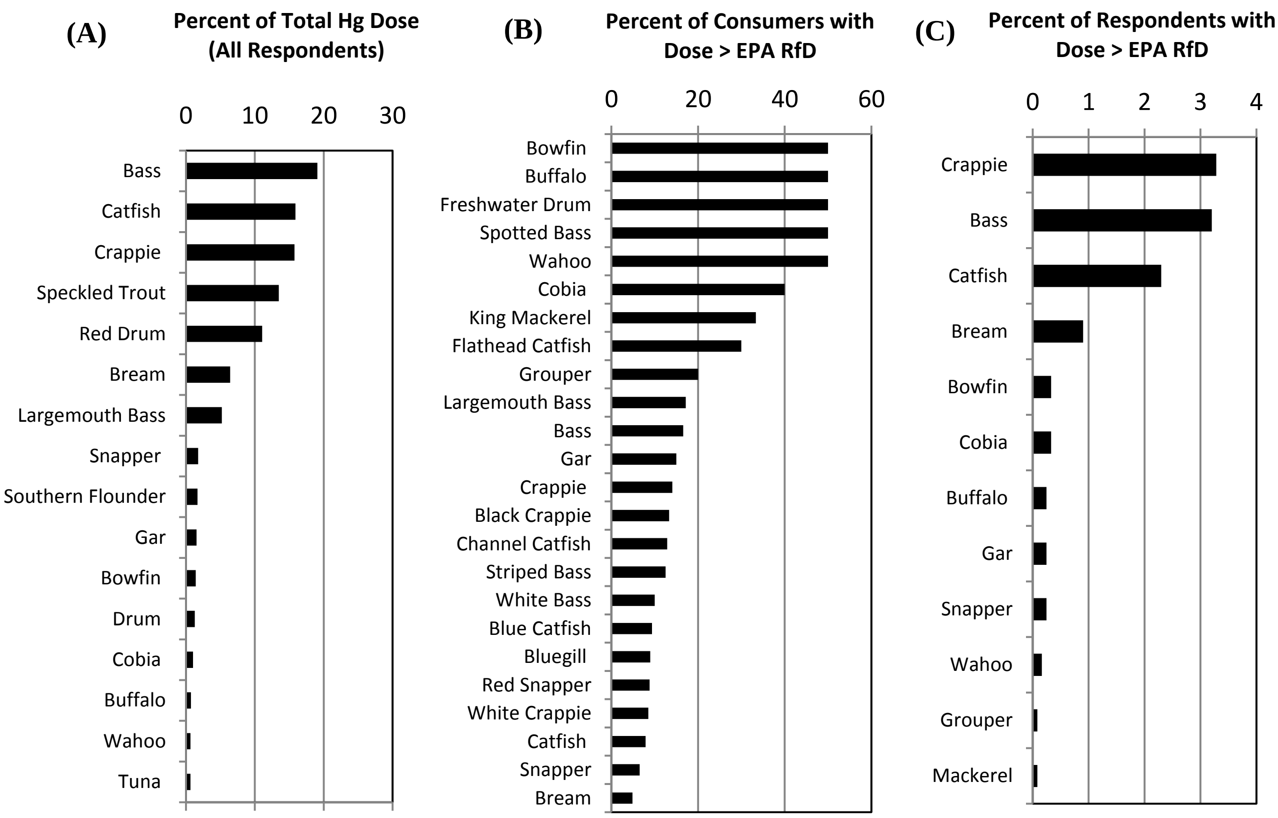

Fig. 2 A) Percent of total Hg dose (all respondents) by species or fish group. B) Percent of species- or group-specific consumers with estimated Hg dose greater than EPA's Reference Dose (RfD: 0.1 ug/kg-d). C) Percent of all respondents with estimated Hg dose greater than the EPA's RfD. Results are based on mean Hg levels in the three most frequently eaten sportfish reported by respondent fishers (n=1218).

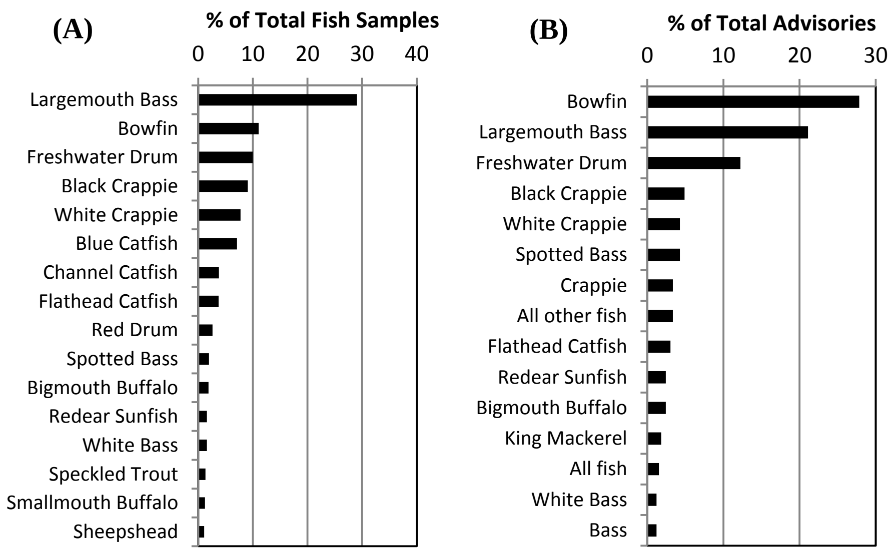

Fig. 3A) Percent of total fish samples by species or fish group collected by LA's Fish Advisory Program (1993-2010); and B) Percent of species- or fish group-specific fish consumption advisories for Hg. Note: Species listed on <1% of samples or advisories omitted.

3) Population Specific Doses:

When individually reported species-specific fish consumption rates are taken into consideration, 20% of the respondent population exceeded the EPA's mHg RfD based on mean fish tissue Hg levels. By population type, the sensitive population (women of child-bearing age) had a highest percentage of the population with an estimated Hg dose exceeding EPA's RfD (28%), compared to the general (19%) and senior populations (16%). Figure 4 presents the frequency distributions of estimated mHg dose by license, population type, ethnicity/race and location. By race/ethnicity, African Americans had the highest percentage of the population with doses exceeding the EPA's RfD (48%), however, due to low sample size it was not possible to evaluate Asians and Hispanics. By location and license, the groups with the highest percent of the population with doses

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exceeding the EPA's RfD were northerners (30%), and basic (freshwater only) (31%) and hook and line (32%) license holders. By education, the groups with the highest percent of the population with doses exceeding the EPA's RfD were those with less than a high school education (30%). Conducting this analysis using the upper 90th percentile Hg fish concentrations for each species consumed suggested that 70% of the population exceed recommended mHg exposure limits. Groups with the highest proportion exceeding the EPA RfD, based on the 90th percentile of fish tissue Hg levels were: the sensitive population (68%); Native Americans and African Americans (84 and 78%, respectively); northerners (81%); basic license holders (84%); and those with a technical school education (74%). It should be noted here that the sample size for Asians and Hispanics was very low (n<15).

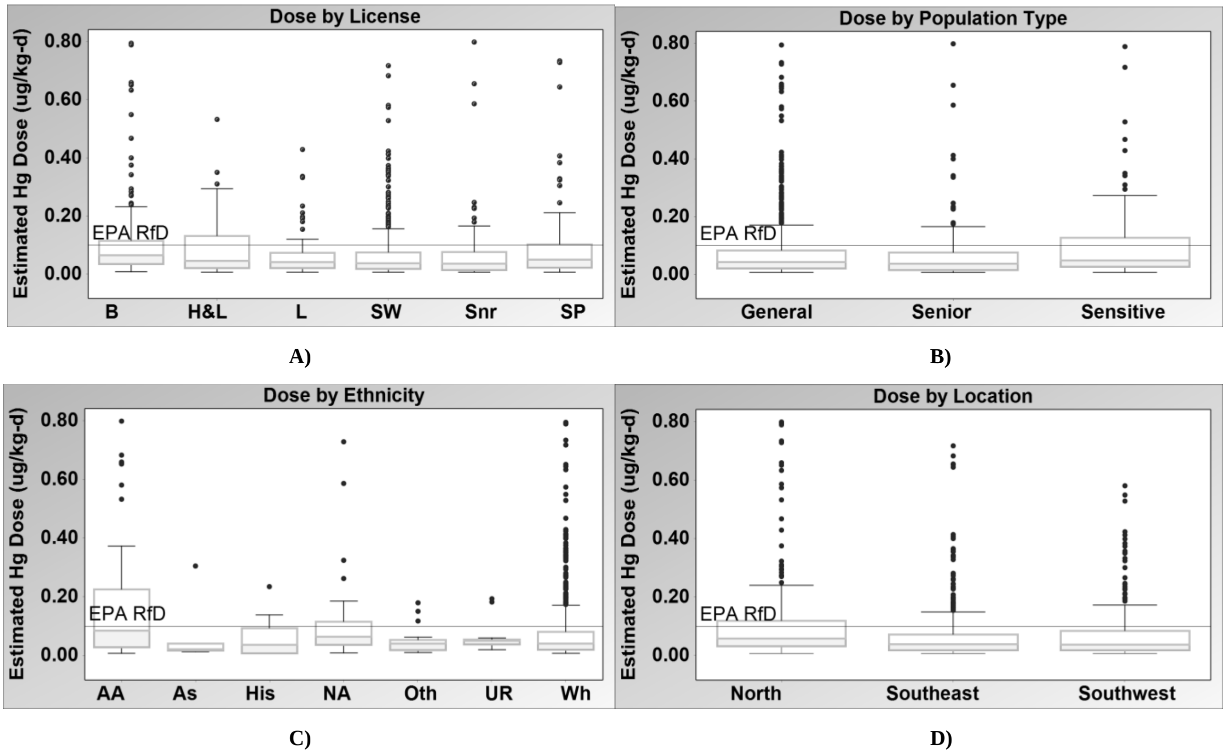

Fig. 4 Distribution of estimated Hg dose by: A) License, B) Population Type, C) Ethnicity, D) Location, and E) Education. Hg doses are based on mean fish tissue Hg levels in the three most frequently eaten sportfish reported by respondent fishers (n=1218). Fishing license codes are as follows: B= Basic, H&L= Hook and line; L= Lifetime, SW= Saltwater, Snr= Senior, and SP= Sportsman's Paradise. For population types, seniors are those 65 years and older; the sensitive population are women of childbearing age (18-45 years) and children; and the general population includes all others. Ethnicity codes are as follows: AA= African-American, As= Asian, His= Hispanic, NA= Native American, Oth= Other ethnicity, UR= Unreported and Wh= White. It should be noted that the population size for Asians and Hispanics were low (<15) with n=7 and n=11, respectively, thus may not be representative of the group. Box plots present the 25th, 50th, and 75th percentiles, while the whiskers extend to the minimum and maximum or to a distance 1.5 times the interquartile range (IQR) away from the median, whichever is smaller. Points that fall outside of the whiskers were considered outliers (o) but were retained in the data set for all statistical analyses.

To see if there was a difference in species-specific Hg doses by location we evaluated fishers from the north and south [4] separately. In the north, all but one species among the top fifteen Hg dose contributors was freshwater (i.e., red drum); whereas in the south, five of the top fifteen Hg contributors were saltwater fish (i.e., speckled trout, red drum, flounder, red snapper, cobia). In general, in the south, more saltwater fish contributed to Hg dose than in the north. Meal limits were derived based on an assumed body weight of 65 kg and mean size of 227 grams per meal. Fish which can be eaten in excess of four meals per month based on the 90th percentile fish tissue Hg levels (where the number of fish samples (n) >30) include: flounder (southern) and drum (red, black, unspecified). Fish which can be eaten in excess of four meals per month based on the mean fish tissue Hg levels (where n >30) include those fish listed above as well as: sheepshead, speckled trout, carp, bream (bluegill, red ear, unspecified), and catfish (channel, blue). Fish which should not be eaten in excess of four meals per month based on the mean fish tissue Hg levels (where n>30) include: king mackerel, cobia, tuna, bowfin, greater amberjack, bass, freshwater drum, flathead catfish, grouper, crappie, buffalo and snapper.

IV. DISCUSSION

The results in this study may be used to derive estimates for sport fishers in other areas (particularly the Gulf Coast region) where geographic and population characteristics are similar, provided that the limitations in the study are considered. Lincoln *et al.* reported the results of a similar survey of LA recreational fishers conducted in 2006 [6]. Among the top fifteen finfish species or groups with the highest mean meal frequencies, many species were observed both in this study and in Lincoln *et al.*, [6]. These include spotted seatrout (speckled trout), red drum, white and black crappie (or sacalait), flounder (southern), bream (including bluegill, perch and unspecified), largemouth bass, channel and flathead catfish (or freshwater catfish), black drum

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and red snapper. As expected, the Lincoln study reported much higher sportfish consumption frequencies for coastal fishers, indicating geographic differences do exist within the state. Fish consumption studies conducted across the U.S. have also shown regional variation, including differences for coastal areas compared with inland areas, seasonal differences in available species, and regional preferences for certain types of seafood (Javitz, 1980; Miller and Nash, 1971; Rupp *et al.*, 1980). Ebert *et al.* (1994) proposed that regional or local differences in climate, fishing regulations, accessibility to good fisheries, and availability of desirable target species contribute to the variability in fish consumption rates. The time period or season covered by different surveys may also affect sportfish consumption rates estimates. Thus, it is difficult to interpret apparent differences in consumption when comparing results to those of other studies conducted in different locations, with various methodologies, time frames or other parameters.

A. Species of Potential Concern

On a statewide basis, the primary fish of potential concern were crappie, bass, catfish, bream, red drum and speckled trout. These species contributed the most to estimated Hg dose despite the fact that they had relatively low mean Hg levels, as they were the species most frequently eaten. Lincoln *et al.* [6] also identified speckled trout, red drum, bass (largemouth), crappie and catfish (freshwater) as some of the highest Hg dose contributors in LA coastal fishers. They also identified several saltwater species as high Hg contributors: cobia, snapper, flounder, black drum, white trout, grouper, greater amberjack and king mackerel. Lincoln's study targeted coastal LA fishers, and given the geographic variability we observed in the species contributing to Hg dose**,** this difference between our results was not unexpected. In general, we observed more saltwater fish (i.e., cobia, red snapper, flounder and black drum) among the top twenty contributors to Hg dose in the south, compared to the north.

1) Outreach Recommendations:

Despite their contribution to total Hg dose, some of these species of potential concern, such as catfish, bream, red drum and speckled trout, were identified as preferable because of their low Hg levels. Other preferable fish included: flounder, sheepshead and carp. Outreach messages should still include these fish as those which are safer to eat, but recommended meal limits should be stated where applicable. Based on the 90th percentile fish tissue Hg levels, bass should be limited to one meal per month; catfish, crappie and bream to 2 meals per month; speckled trout and carp to 3 meals per month; sheepshead to 4 meals per month; and drum and southern flounder to 5 meals per month. Fish which should not be eaten in excess of four meals per month should also be listed in all outreach materials. These include: king mackerel, cobia, tuna, bowfin, greater amberjack, bass, freshwater drum, flathead catfish, grouper, crappie, buffalo and snapper. While these species had the highest Hg levels, they were not among the most frequently eaten fish, and were not significant contributors to the total estimated Hg dose.

2) Monitoring Recommendations:

In general, the more contaminated species, like largemouth bass, bowfin, freshwater drum and black crappie, dominated monitoring activities throughout the sampling program's lifespan; and also had the highest active Hg advisory counts. This is not unexpected as these species are higher trophic level species which generally accumulate higher Hg levels, thus are good indicators of Hg contamination for screening purposes. However, monitoring of more frequently eaten fish, such as speckled trout, red drum, bream and shellfish is advisable when screening indicates high fish tissue Hg levels. Resources do not always allow in-depth location-specific monitoring. This is especially true in the case of saltwater fish. It is more time-consuming to catch tuna than bass. Given the migratory nature of these fish, species-specific fish and shellfish contaminant levels can be obtained from other Gulf Coast States. Comparison of fish tissue contaminant levels and fish consumption rates among coastal populations in the Gulf States would also enable an assessment of the value of a Gulf-wide advisory.

3) Advisory Development Recommendations:

Even with changes to the sampling regime, advisories will continue to be focused on species with higher Hg levels unless fish consumption data are incorporated into the advisory process. One suggestion is to adjust the recommended meal limit that triggers an advisory to one appropriate to the consumption of each species (e.g., the 90th percentile species-specific consumption rate for the total population of fishers or consumers only). LA uses a default of 4 meals per month meal limit to trigger an advisory based on guidelines presented in the LA's "Protocol for issuing public health advisories for chemical contaminants in recreationally caught fish and shellfish" [7]. If the Hg levels in a species result in a recommended meal limit of 4 meals per month or more, no advisory is triggered. Meal limits of three or less trigger either an advisory, or further monitoring and review. This value may be raised in the case of frequently eaten species, such as shellfish and catfish, to a more appropriate amount for statewide consumers, or for location-specific consumers. There are some limitations with this approach highlighted by the discrepancies in fish consumption rates observed between our survey [4] and the Lincoln survey [6]. Such an approach would require data from a representative statewide cross section of the population of recreational, commercial and subsistence fishers.

B. Populations of Potential Concern

The results of this study indicated that portions of the LA population are likely to exceed recommended mHg exposure limits. The analysis indicated that between 20% and 70% of the entire sample population; and 28% to 68% of the sensitive

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sample population may exceed recommended mHg exposure limits, based on mean and 90th percentile fish tissue Hg levels, respectively. Lincoln's survey of LA's coastal recreational fishers observed that 40% of the sample population (n=402) had higher Hg levels corresponding to doses exceeding the EPA's mHg RfD [6]. These results fall within the range of our estimates. With respect to the sensitive population, these estimates are higher than blood Hg levels reported in the National Health and Nutrition Examination Survey (NHANES) which indicated that 8% of U.S. women of childbearing age exceed the recommended mHg exposure limits [14].

These findings highlight the fact that fish consumption advisories targeted to LA anglers, a predominantly adult male population, may fail to significantly impact the sensitive population of greater concern. The sensitive subpopulation (women of child-bearing age) have the highest percent of the population exceeding the RfD. Based on results not presented here, this may not be due to a higher rate of fish consumption but perhaps due to consumption of higher Hg fish. Population-specific advisories with information about good fish (high nutrient low Hg fish) and bad fish (low nutrient high Hg fish) should be provided in educational outreach materials to sensitive populations to encourage more appropriate fish consumption patterns and decrease Hg exposure. Accordingly, more emphasis should be placed on procuring resources for providing outreach and informational material to health clinics, pediatricians and gynecologists, especially in areas with a high proportion of commercial fishers and Native and African Americans.

While these results demonstrate that mHg exposure is occurring, whether the population is at risk for developing adverse health effects is beyond the scope of this study. The effect of these levels of mHg exposure on the neurologic impairment of children from mothers who consume large amounts of fish during pregnancy remains unanswered, in part, due to the difficulty in observing and quantifying these low-dose effects. As the RfD was based on maternal exposures, it may also not accurately reflect the at-risk population of seniors. Some studies have shown an association with increased myocardial infarction with Hg levels close to the EPA's RfD [15-18]. A benchmark dose for cardiac disease has not been identified, but could be lower than that set for fetal exposures. Until mHg dose response effects are elucidated further, the best advice is to restrict fish intake to levels which result in mHg doses less than EPA's RfD. In addition, as women of child-bearing age appear to be more highly exposed than other subgroups, fish consumption recommendations should be more clearly delineated for adult men and non-pregnant women than children and pregnant women.

Since the initiation of this study, LA's Fish Advisory Program has seen first a sharp decrease in program funds by Louisiana legislators, and then in 2010, a complete elimination of the program, despite the predominance of local seafood in the regional diet, and the potential for exposure and adverse health effects. This in turn has reduced the State's ability to track and prevent mHg exposure. As a result, there is a need to evaluate program activities and optimize the use of limited funds. The results from this study can be used to ensure optimal utilization of available funds for monitoring, advisory development and outreach activities. Results from this study will also provide legislators with information upon which they can evaluate the need for the services that the Fish Advisory Program renders to its citizens.

C. Limitations

There are limitations of this approach. Estimates of dose derived here are based on a simplified model, thus results are used for screening purposes only. The risk rankings presented in this study are valid only for a single contaminant, due to the lack of monitoring data for other seafood contaminants; thus, the recommendations presented here are not specific to any site or other contaminant. Risk estimates do not consider the benefits from species-specific nutrient levels. Due to the socioeconomic importance of seafood to LA residents who derive much of their protein, nutrients and fatty acids from seafood, estimation of potential risks should be evaluated against the benefits fish consumption provides. Exposure estimates presented in this article could be improved upon if data on body weight and meal size were available from the survey responses; however, this information was not collected. These results are based only on the three most frequently eaten finfish, thus dose estimates do not take into account Hg intake from less frequently eaten finfish, shellfish or commercial seafood. Survey respondents were skewed towards Caucasian males from the southeast who are more likely to hold a saltwater license and to own boats for coastal and offshore saltwater fishing. As children and commercial and subsistence fishers were not surveyed, conclusions presented here are only applicable to adult recreational fishers, who are expected to eat less fish than commercial and subsistence fishers. This survey may under-represent non-license holders, who can account for as much as 25% of fishers [3]. This could include on-reservation Native American fishers, migrant workers and homeless people. Some of these groups might contain a disproportionately high number of subsistence fishers and thus might be groups at higher overall risk [3]. As this survey was only distributed in English, respondents with limited or no English proficiency were under-represented as well.

V. CONCLUSIONS

The goal of this study was to identify species and populations of potential concern using species-specific fish consumption data from a population-based survey of LA's recreational fishers (n=1774), and regional fish tissue Hg concentration data (n=15,030). Estimates of species-specific mHg doses were derived for each respondent based on mean and 90th percentile fish tissue Hg levels; and compared to the EPA's RfD for mHg.

Fish groups of potential concern, contributing the most to the total Hg dose, were drum (primarily red drum), speckled trout,

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catfish, crappie, bass and bream. Several species within these fish groups had low Hg levels but were frequently consumed. Populations of potential concern, based on the proportion of individuals exceeding the EPA's RfD, included women of childbearing age, African- and Native-Americans, fishers from northern Louisiana, and fishers with Hook and Line and Basic (freshwater only) fishing licenses. While these results demonstrate that mHg exposure is occurring, whether the population is at risk for developing adverse health effects is unknown.

More emphasis should be placed on providing outreach and informational material to health clinics, pediatricians and gynecologists, especially in areas with a high proportion of commercial fishers and Native and African Americans. Outreach materials should identify which fish are safer for sensitive populations to eat, and associated meal limit recommendations, to minimize mHg exposure without impacting the nutritional benefits fish provide. Based on the 90th percentile fish tissue Hg levels, bass should be limited to one meal per month; catfish, crappie and bream to 2 meals per month; speckled trout and carp to 3 meals per month; sheepshead to 4 meals per month; and drum and southern flounder to 5 meals per month. Concurrently, monitoring for fish tissue Hg levels in these generally low Hg species should also be increased. Outreach materials should also include a list of species which sensitive populations should avoid or restrict: king mackerel, cobia, tuna, bowfin, greater amberjack, bass, freshwater drum, flathead catfish, grouper, crappie, buffalo and snapper. Monitoring activities for these high Hg species can be reduced outside of screening if outreach materials identify these species as those with generally high Hg levels.

Even with changes in sampling to frequently consumed species with lower Hg levels, advisories will continue to focus on species with higher Hg levels unless fish consumption data are incorporated into the advisory process. One suggestion is to adjust the recommended meal limit that triggers an advisory to one appropriate for each species (90th percentile of the population consumption rate or other value). To do this, area- and population-specific fish consumption surveys are required. Fish consumption surveys are generally not used for the advisory process. The main limitation of fish consumption surveys is time, effort and financial resources required for obtaining population-specific fish consumption data. Since exposure is a key element in the estimation of risk, consumption surveys should be used to provide critical information for effective and targeted risk communication and for prioritizing the allocation of limited public health resources. To enable a better characterization of a broader population, future surveys should be distributed to commercial and subsistence fishers in multiple languages; and include questions about meal size, children's consumption patterns, individual body weight, and all finfish, shellfish and commercial seafood consumption. Incorporation of the aforementioned variables may result in different conclusions with regard to identifying the species and populations of potential concern [19].

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