Balanced Fatty Acid Intake Benefits and Mercury Exposure Risks: An Integrated Analysis of Chinese Commercial Freshwater Fish and Potential Guidelines for Consumption

Zhimin Zhang\textsuperscript{a}, Min Zhang\textsuperscript{ab}, Jun Xu\textsuperscript{c} & Dapeng Li\textsuperscript{ab}

\textsuperscript{a} College of Fisheries, Huazhong Agricultural University, Wuhan, P.R. China
\textsuperscript{b} Freshwater Aquaculture Collaborative Innovation Center of Hubei Province, Wuhan, P.R. China
\textsuperscript{c} Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, P.R. China

Accepted author version posted online: 29 May 2014. Published online: 30 Oct 2014.


To link to this article: http://dx.doi.org/10.1080/10807039.2014.920226

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Zhimin Zhang,1 Min Zhang,1,2 Jun Xu,3 and Dapeng Li1,2
1College of Fisheries, Huazhong Agricultural University, Wuhan, P.R. China; 2Freshwater Aquaculture Collaborative Innovation Center of Hubei Province, Wuhan, P.R. China; 3Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, P.R. China

ABSTRACT

Fish-related consumption advisories have emerged based on the benefits of omega-3 fatty acids (omega-3 FA) intake and risks of Hg exposure from marine fish. However, only a few were based from freshwater fish. We integrated omega-3 FA and Hg data available from commonly eaten freshwater fish in China to provide a new perspective on consumption of these fish and also created a guide on the cost of basic omega-3 FA intake of 1750 mg/week. Results show that freshwater fish exhibited low omega-3 FA and Hg levels. The Hg bioaccumulation of functional feeding groups was significantly different ($p < .05$). Carnivorous species indicated relatively high Hg levels, whereas planktivorous fish species showed high omega-3 FA levels and extremely low costs for basic omega-3 FA intake. Results indicate that an advisory regarding reasonable fish consumption is necessary to maximize omega-3 FA and to minimize Hg exposure risks to fish consumers. This study provides temporary advisories and guide research for the creation of a proper dietary pattern. The advisory could reduce confusion and enforce benefit and risk communication for freshwater fish consumers. However, additional biomonitoring data in fish are needed to create more appropriate and specific freshwater fish consumption guidelines for the public.

Key Words: omega-3 fatty acids, mercury, Chinese freshwater fish, benefit and risk, consumption advisory.
INTRODUCTION

Fish is an important food and is considered a source of high-quality protein, essential fatty acids, and other nutrients essential for humans. Compared with fatty meat products, fish is low in saturated fat and high in omega-3 fatty acids (omega-3 FA), such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Nesheim and Yaktine 2007). Omega-3 FA has health benefits that have been proven effective in reducing the incidence of adult cardiovascular diseases (Kris-Etherton et al. 2002; Virtanen et al. 2005) and in improving the mental development of children (Helland et al. 2003). However, the environment has been polluted by human activities, including increased agricultural modernization, industrialization, urbanization, and transportation development (Wong et al. 2002; Vorosmarty et al. 2010; Duarte et al. 2013; Li et al. 2014). A significant amount of toxic chemical contaminants, especially methylmercury (MeHg), have accumulated in marine and freshwater environments. Such pollutants have contaminated fish through the bioconcentration of the food web; these contaminants are absorbed by humans through fish consumption, which could generate biomagnification (Harada 1995; NRC 2000).

Since the MeHg poisoning outbreaks caused by environmental pollution in Japan from the 1950s to the 1960s, human MeHg biomonitoring has gradually developed. This monitoring involved numerous investigations of human hair and blood Hg levels and investigations of factors associated with human life (Schober et al. 2003; Legrand et al. 2010). Fish consumption is the primary transmission route of human exposure to Hg outside of occupational exposure. The negative effect of Hg is of great concern because of contaminated fish consumption. Several researchers who have conducted epidemiological studies on populations with regular fish and seafood consumption have concluded that MeHg exposure has negative effects on humans. Maternal MeHg exposure adversely affects the developing nervous system of the fetus in utero such as visual response memory (Steuerwald et al. 2000; Stewart et al. 2002). MeHg exposure in the general adult population may elicit myocardial infarction and coronary heart disease (CHD) (Salonen et al. 1995; Wennberg et al. 2012). Based on the evidence, researchers derived human biomonitoring values (Legrand et al. 2010), and relevant authorities have issued generic recommendations for fish consumption for different populations (Health Canada 2002; AHA 2010). However, numerous studies and advisories given to the public have mostly involved marine fish and other seafood (Kris-Etherton et al. 2002; AHA 2010; Gerber et al. 2012). Only a few have reported both benefits of omega-3 FA and risks of Hg from freshwater fish (Loring et al. 2010). This case is similar to that in China. Some consumers who commonly eat freshwater fish were confused whether they should follow the advice or limit the fish they eat. China is the leading fish producer in the world for the past two decades and the greatest contributor in freshwater fisheries.

Freshwater fish is also the most important aquatic product in India, Vietnam, Bangladesh, and other developing countries in Asia. A number of people in these countries rely on freshwater fish as their source of primary essential fatty acid and animal protein (FAO 2012). Unfortunately, a generic advice for freshwater fish consumption that covers health benefits and chemical exposure risks is a pending issue. Moreover, numerous studies assessed the risk of exposure to contamination without considering the benefits of fish consumption, and vice versa (Meng et al.
These studies assessed whether fish is contaminated with toxic pollutants and if such pollutants are at permissible levels. Given that chemical pollutants in edible fish do not exceed the maximum threshold, however, excessive consumption over a period of time may adversely affect consumers’ health (Ginsberg and Toal 2000). This risk is a reasonable and leading cause for the prevalence of available fish consumption advisories.

Considering the variations and complexities associated with public fish consumption, this study presents an integrated analysis of species-specific benefit with risk assessment for the most commonly consumed freshwater fish species in China. The objectives of this study include the following: use currently available data to implement a concurrent assessment of health benefits of omega-3 FA and exposure risks of Hg from fish, thereby emphasizing the necessity and importance of freshwater fish consumption advice; form a preliminary fish-category framework for different populations while estimating cost for basic weekly intake of omega-3 FA from different fish species; and identify limitations in existing data and further biomonitoring and research needs for the development of an advisable consumption guide for the public. The results of our study will provide insights for responsible decision-making agencies and consumers regarding the best management option to balance the benefits and risks of freshwater fish consumption.

METHODS AND MATERIALS

Data Sources

**Mercury and omega-3 FA**

We used the following key words to conduct a comprehensive search for information on the content of Hg and omega-3 FA in freshwater fish in China: heavy metals, Hg, fish, fatty acids, EPA, DHA, and China. We also surveyed the related literature and searched relevant articles. Numerous studies from various databases and reports (ISI Web of Knowledge and Google Scholar) relating to these keywords were gathered (including Chinese- and English-language references). One study by Jin et al. (2006) was excluded because the examined fish was from a sampling site that was seriously polluted by local chemical factories, which is not representative of the general scenario in China. Several references were also excluded because the Hg concentrations presented were in dry-weight basis in fish muscle (Zhou and Wong 2000; Fu et al. 2010); majority of the obtained studies reported their data in wet-weight basis and were included in this study. We used data from infra-specific freshwater fish species outside of China as a quantitative index of omega-3 FA because of the lack of omega-3 FA on catfish and black bass. All data collected were referenced from the listed articles. However, we do not assert that we found all relevant studies. A total of 43 publications listed in the online supplementary information (SI) were used in this study.

**Fish production and market price**

The freshwater fish production data by the Chinese Ministry of Agriculture were obtained from the China Fisheries Yearbook (from 2003 to 2011). The individual
harvest production in the past 9 years of the 13 top consumed freshwater target fish was provided in this study. Individual fish species were solely involved in aquaculture production. To calculate the cost of fish consumption for obtaining sufficient omega-3 FA intake, we surveyed the retail price of farmer markets and superstores of the target fish species in 2013 in eight Chinese cities: Beijing, Hangzhou, Shanghai, Fuzhou, Guangzhou, Dongguan, Wuhan, and Changsha. The individual fish price was averaged. The cost-calculation of 1750 mg omega-3 FA per week from fish was based on the individual mean price.

Data Collection and Compilation

Data on omega-3 FA and Hg levels in a range of fish species had discrepancies. These data were extracted from texts and tables as well as from measurements in the image analysis of published graphs. All omega-3 FA and Hg levels were expressed as concentrations in wet weight of fish muscle. Unvarnished data and information from the studies were cited. Data of a specific species from the study in the same small water environment, such as a pond, were averaged. However, data from studies in a different ecosystem with several sampling sites, such as the Yangtze River, were originally cited in the current work. The corresponding Hg and omega-3 FA concentrations of individual fish species in this study were estimated according to the obtained data. The original MeHg concentration data were sparse. However, Hg in fish muscle tissue is predominantly MeHg; thus, the conversion of total Hg to MeHg in fish should be dependent on a relevant conversion factor based on published literature (Bloom 1992; Capelli et al. 2004; Storelli et al. 2005). We further assumed that 100% of the total Hg was present as MeHg.

Mercury Exposure in Relation to Functional Feeding Groups

The feeding habits of fish species are significantly different. To explore the relationships between functional feeding groups and Hg accumulation, we grouped different target species according to feeding habits. The fish species were divided into four groups: herbivorous, planktivorous, omnivorous, and carnivorous. More information about these species is listed in the SI.

Exposure and Intake Evaluation

A specific range of omega-3 FA concentrations in fish can substantially lower the risk of CHD. This finding has been proven through observational evidence, prospective studies, and randomized trials in humans (Hu et al. 2002; Kris-Etherton et al. 2002). Mozaffarian and Rimm (2006) pooled numerous studies on CHD-related deaths and summarized that 250 mg/day of EPA and DHA is the reasonable target intake to reduce CHD mortality for general populations. For that reason or others, successive intake advisories have been issued by several national and international organizations (Health Canada 2002; AHA 2010). The 200 to 500 mg/day of EPA and DHA or 2 to 3 meals per week guidelines are generally accepted and suggested. Consequently, we arbitrarily set 250 mg/day of EPA and DHA as the adequate omega-3 FA intake. The typical body weight on 60 kg per capita was considered the default value for reference, which corresponded to an intake of 29 mg/kg bw/week of omega-3 FA from fish. Joint FAO/WHO Expert Committee on Food Additives
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(JECFA) and the U.S. Environmental Protection Agency (USEPA) provisioned that the tolerable weekly intake (PTWI) and RfD for MeHg is 1.6 µg/kg bw/week and 0.1 µg/kg bw/day (equivalent to 0.7 µg/kg bw/week), respectively (USEPA 1997; JECFA 2003). These guidelines were combined to assess the benefits and risks of species-specific consumption.

In this study, we selected a proper and acceptable portion of approximately 200 g as a reference standard for fish consumers. This value was lower than the USEPA-suggested default value of 8 oz (227 g) of cooked fish fillet for the general adult population. However, our selected value was higher than the simulated average meal size by the National Health and Examination Survey (NHANES; women: 120 g; men: 160 g) (Rheinberger and Hammitt 2012). We used the following formulas to estimate the MeHg exposure and omega-3 FA intake levels:

\[
E_m = (C_{fm} \times 1000 \mu g/mg) \times (MS \times 1 kg/1000g) \times N/BW;
\]

\[
I_o = (C_{fo} \times MS) \times N/BW,
\]

where \(E_m\) is the weekly per capita exposure levels of MeHg (µg/kg bw/week); \(I_o\) is the weekly omega-3 FA intake levels (mg/kg bw/week) per capita; \(C_{fm}\) and \(C_{fo}\) are the concentration of Hg (mg/kg) and omega-3 FA (mg/100g) in a given species of fish, respectively; \(MS\) is one meal size (g/meal); \(N\) is the number of fish meals per week (meals/week); and \(BW\) is the consumer body weight (kg).

Statistical Analysis

Prior to statistical analysis, three Hg concentration extreme outliers (one from the omnivorous group and two from the planktivorous group) were removed from the dataset. The functional feeding group was considered a factor, whereas Hg values were considered variables when one-way factor ANOVA was used to determine the differences in accumulating Hg levels. Student–Newman–Kuels test was also employed for multiple comparison of the functional feeding groups. The dataset for Hg was determined as heterotropic and exhibited unequal variance by using Levene’s test. We then rectified the violations of parametric methods by log translation, thereby transforming the Hg value. Differences were considered statistically significant at the 5% level \((p < .05)\). Statistical analyses were performed using SPSS software (version 17.0) for Windows.

RESULTS

Share of Freshwater Fish

Summarized in Figure 1 are the data output of typical freshwater fish species in China and shows considerable fish production in the past 9 years. Freshwater fish was the main source of fish food supply (Figure 1A). The largest share was from grass carp, followed by silver carp and common carp (Figure 1B). The most commonly eaten freshwater fish (MFF) dominated the total freshwater fish (TFF) (85.2%, 19.97 million tons in 2011) and the total fish (TF), which included freshwater and marine fish in China (60.4%, 19.97 million tons in 2011). Therefore, freshwater fish showed
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Figure 1. Freshwater fish production per year in China from 2003 to 2011. (A) present area and (B) stack area of fish production. MFF: the most common eaten freshwater fish analyzed in our study; TFF: total freshwater fish; TF: total fish, including total freshwater fish and marine fish.

a stable increasing trend. These results indicate the importance of freshwater fish in fish production and as a primary source of animal food.

Mercury Exposure in Relation to Functional Feeding Groups

From Figure 2 can be observed that all samples were less than the safety limit of Hg in aquatic products (0.5 mg/kg wet weight) set by numerous countries and organizations. Differences in Hg levels were found as a function of feeding habits ($p < .05$). The carnivorous group had significantly higher Hg levels than the other groups and exhibited the highest average Hg content at 0.1 mg/kg. The average Hg level for herbivorous fish, which had the lowest Hg level, was 0.01 mg/kg. The three non-carnivorous functional feeding groups did not show remarkable differences in Hg content. Nevertheless, an increasing trend was shown in the Hg levels of the herbivorous group to the omnivorous group. The median values for all four groups were higher than the average values (Figure 2). Great variations in Hg levels for fish in each functional feeding group were evident.

Human Exposure Levels Related to Weekly Fish Servings

Shown in Figure 3 are the species-specific simultaneous benefit and risk analysis for freshwater fish consumption and the amount of fish servings based on the recommended dose relationship of omega-3 FA and MeHg on human health. We applied this method assuming that consumers are amenable to a weekly consumption of specified fish servings and specific fish. From Figure 3A can be observed
that omega-3 FA from individual fish species were clearly inadequate for one fish serving per week for target populations who did not exceed the MeHg limitation (0.7 µg/kg bw/week) (USEPA 1997). Most predaceous fish, especially catfish and mandarin fish, had significantly larger contribution rates of Hg than other fish species. Two planktivorous fish, namely, bighead carp and silver carp, manifested an advantage in providing intake level of omega-3 FA despite not arriving at a mean weekly intake of 29 mg/kg bw (Figure 3A). According to the contribution rate of omega-3 FA and Hg risk trade off, we categorized grass carp, blunt snout bream, tilapia, yellow catfish, crucian carp, and snakehead fish as potential fish, but categorized common carp, black bass, topmouth culter, catfish, and mandarin fish into another category (Table 1). Given that more fish servings per week have been suggested, fish consumers may be distinctively exposed to different benefit and risk balances.

Target populations encounter discrepant trend of exposure to MeHg and omega-3 FA intake when ingesting different fish for three (Figure 3B) and seven (Figure 3C) servings per week. From Figure 3B can be observed that the consumption of bighead and silver carp did not result in excessive MeHg levels and provided sufficient omega-3 FA intake, which indicates that these fish species have significantly positive benefits and low negative risks. With the exception of black bass, the other four carnivorous fish exceed Hg recommendations without reaching omega-3 FA recommendation. However, weekly MeHg intake from these species was still less than the JECFA PTWI value (1.6 µg/kg bw) (Figure 3B). The remaining species demonstrated a similar status shown in Figure 3A. Extreme variations can be observed in Figure 3C. Weekly demands for omega-3 FA could be achieved with eight freshwater fish species.
species. However, half of these species, particularly mandarin fish (almost 3.5 μg/kg bw/week), were seriously above the JECFA PTWI MeHg threshold. In this case, the benefit and risk levels were gradually magnified by the different species depending on the increase in fish servings per week. Hence, we estimated only the species-specific benefits and risks associated with other fish servings, such as two, four, five, and six servings per week, as the figures were not generated.

**Consumption Framework**

Fish consumption is of vital concern particularly for vulnerable groups, including women of childbearing-age and pregnant women. We attempted to structure fish categories and provide potential advisory for the vulnerable group and general population. Shown in Table 1 is the derived consumption framework. This framework for the vulnerable group was based on the increasing beneficial effects of omega-3
Table 1.  Fish-category framework for consumption.

<table>
<thead>
<tr>
<th>Population groups</th>
<th>Categories</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>General population</td>
<td>First choice</td>
<td>Silver carp, bighead carp, crucian carp, yellow catfish, snakehead fish</td>
</tr>
<tr>
<td></td>
<td>Second choice</td>
<td>Grass carp, bluntsnout bream, tilapia, black carp</td>
</tr>
<tr>
<td></td>
<td>Third choice</td>
<td>Mandarin fish, catfish, topmouth culter, black bass, common carp</td>
</tr>
<tr>
<td>Vulnerable group</td>
<td>First choice</td>
<td>Silver carp, bighead carp</td>
</tr>
<tr>
<td></td>
<td>Second choice</td>
<td>Grass carp, bluntsnout bream, black carp, tilapia</td>
</tr>
<tr>
<td></td>
<td>Third choice</td>
<td>Mandarin fish, catfish, topmouth culter, black bass, common carp, snakehead fish, crucian carp, yellow catfish</td>
</tr>
</tbody>
</table>

aGeneral adult populations. bPregnant women, women of childbearing age, and nursing mothers. cSimultaneously can meet omega-3 FA and not exceed MeHg limits less than seven servings. dDid not meet the recommended omega-3 FA and did not exceed the thresholds of MeHg at seven servings. eDid not meet the recommended omega-3 FA but can exceed the thresholds of MeHg less than seven servings.

Consumption of fish species will result in sufficient intake of omega-3 FA (29 mg/kg bw/week) and will not exceed MeHg thresholds. The fish species was qualified into the first category (Table 1) when the consumption of this fish was no more than seven servings per week. Fish species were listed in the second category if they have inadequate but potentially increasing omega-3 FA levels and if the MeHg level does not exceed the threshold even though seven servings of the fish were consumed. For the general adult group, common carp and black bass should be managed slightly different from their group. When an individual ate above the frequency, he/she could possibly surpass the limit for MeHg (1.6 μg/kg bw/week) and gain less omega-3 FA than the basic recommended intake level of 250 mg/day (1750 mg/week). Therefore, we downgraded the two species in the third category, that is, these fish species cannot provide people with sufficient omega-3 FA while surpassing the MeHg threshold when eaten below seven servings per week. On the one hand, the vulnerable group that consumes carnivorous fish three servings per week will be exposed to excessive MeHg (Figure 3B). On the other hand, two planktivorous fish could be the ideal targets for consumption. The fish-category framework would potentially guide the decision-making of fish consumers and advance the development of freshwater fish consumption advice.

Cost-Dependent Omega-3 FA from Fish Consumption

Fish consumers usually choose from a variety of fish species. Aside from the benefit and risk levels based on nutrients and contaminants in a specific fish, price may significantly affect the decision of fish consumers. Shown in Figure 4 are the
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**Figure 4.** Estimated costs and servings for achieving 1750 mg/week of omega-3 FAs from commonly eaten freshwater fish. The values are based on the average price of live weight equivalent from eight Chinese cities, namely: Beijing, Hangzhou, Shanghai, Fuzhou, Guangzhou, Dongguan, Wuhan, and Changsha, in 2013 and an assumed 200 g of fish consumption for an individual weighing 60 kg.

In order to achieve the recommended 1750 mg/week of omega-3 FA from fish, the corresponding costs and servings per week were calculated. The costs for achieving 1750 mg/week of omega-3 FA from fish were based on the average price of live weight from eight Chinese cities. The recommended servings were calculated based on an assumed 200 g of fish consumption per individual weighing 60 kg.

We noted differences in the costs and recommended servings per week among the fish species included in this study. Two planktivorous fish had the lowest weekly costs calculated below 7 RMB. With approximately two fish meals, one could follow the general recommendation of omega-3 FA. However, herbivorous grass carp and blunt snout bream were estimated to have about sevenfold costs compared with the two planktivorous species. The most expensive costs were of the carnivorous species black bass and mandarin fish, which cost above 59 RMB per week. This value was comparative with that of omnivore species, except for crucian carp. The cost calculation of 1750 mg of omega-3 FA intake and average servings per week for the common commercial freshwater fish species in our study were approximately 37 RMB and 7 servings, respectively.

**DISCUSSION**

Fish production in China has greatly increased during the past years because of the increased consumption demand and improved living standards. The annual per capita food fish supply reached approximately 31.9 kg (more than three servings per week) and is distinctly higher than the average world food fish supply of 18.4 kg per capita (about two servings per week) in 2009 (FAO 2012). Freshwater fish is a growing resource base that accounts for a large proportion of national output and constitutes an important part of the human diet (Figure 1). As people become more aware of the persistently valuable source of omega-3 FA and other nutrients from fish, fish consumers may attain long-term growth opportunities for balanced...
Table 2. Top output of freshwater fish (2003–2011) in China and corresponding concentrations of omega-3 FA (EPA and DHA) and Hg concentrations.

<table>
<thead>
<tr>
<th>Fish species</th>
<th>Omega-3 FA (mg/100 g)</th>
<th>Hg (mg/kg)</th>
<th>Omega-3 FA: Hg&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bighead carp</td>
<td>360</td>
<td>0.04</td>
<td>90</td>
</tr>
<tr>
<td>Black bass</td>
<td>73</td>
<td>0.06</td>
<td>12</td>
</tr>
<tr>
<td>Black carp</td>
<td>97</td>
<td>0.01</td>
<td>97</td>
</tr>
<tr>
<td>Bluntsnout bream</td>
<td>64</td>
<td>0.02</td>
<td>32</td>
</tr>
<tr>
<td>Catfish</td>
<td>216</td>
<td>0.12</td>
<td>18</td>
</tr>
<tr>
<td>Common carp</td>
<td>80</td>
<td>0.06</td>
<td>13</td>
</tr>
<tr>
<td>Crucian carp</td>
<td>205</td>
<td>0.06</td>
<td>34</td>
</tr>
<tr>
<td>Grass carp</td>
<td>84</td>
<td>0.03</td>
<td>28</td>
</tr>
<tr>
<td>Mandarin fish</td>
<td>235</td>
<td>0.15</td>
<td>16</td>
</tr>
<tr>
<td>Silver carp</td>
<td>486</td>
<td>0.05</td>
<td>97</td>
</tr>
<tr>
<td>Snakehead fish</td>
<td>241</td>
<td>0.08</td>
<td>30</td>
</tr>
<tr>
<td>Tilapia</td>
<td>62</td>
<td>0.02</td>
<td>31</td>
</tr>
<tr>
<td>Topmouth culter</td>
<td>140</td>
<td>0.09</td>
<td>16</td>
</tr>
<tr>
<td>Yellow catfish</td>
<td>155</td>
<td>0.05</td>
<td>31</td>
</tr>
</tbody>
</table>

The minimum recommended ratio 42 (18)<sup>b</sup>

<sup>a</sup>Ratios of mg omega-3 FA to µg Hg of species-specific fish. <sup>b</sup>Minimum recommended intake ratio of 250 mg of omega-3 FA to (0.1 × 60) µg of Hg for the vulnerable group and 250 mg of omega-3 FA to (0.23 × 60) µg of Hg for the general adult populations.

nutrition and good health in the future. Other than the nutrients in fish, the dietary exposure to Hg is a critical process in the assessment of potential health effects to humans. Different trophic levels or closely related taxon have different wide ranges of Hg concentrations (Al-Majed and Preston 2000). Original data from previous publications could not be obtained. Thus, a detailed statistical comparison is impossible. However, the comparison of means for different species and functional feeding groups was still instructive. The integrated results in this study indicated parallel conclusion by binary relation of Hg concentration and functional feeding groups.

This study further demonstrated a direct relationship between enrichment of Hg and feeding habits. In one document from the USEPA, higher Hg concentrations in American noncommercial fish (mainly freshwater fish species) (USEPA 2004) were found than those of the freshwater fish in the current study and also indicated a remarkable relationship. Fish in vivo do not or insufficiently synthesize long chain omega-3 FA, but fish feeding on phytoplankton and zooplankton can produce long chains of omega-3 FA (Ackman et al. 1964; Barclay et al. 1994). This finding was partly consistent with the observation in our study (Table 2).

In some cases, the health benefits of consuming fish linked to the intake of these nutrients may be outweighed by the risks associated with Hg exposure. Therefore, a consumer may acquire high risks of Hg exposure when consuming fish without relative fish consumption advice. The functional difference is greatly important and should be treated as a preliminary indicator for the consumption guide. However, the selection of species-specific fish and corresponding consumption frequency
should be properly considered to reduce health risks to acceptable levels while obtaining the recommended intake levels of omega-3 FA.

To better communicate with freshwater fish consumers, a conservative and plain analysis pattern for deriving fish-category framework is adapted on the basis of two primary variable factors: omega-3 FA and Hg. This method can avoid deviation from the recommended benchmark dose. One of the most important findings in this study is the link of the differences in fish consumption frequency with benefit and risk assessments for different fish species. On the one hand, the result is contrary to reports of many existing studies that showed that the average Hg values less than the action levels of several international bodies, such as the USEPA and the U.S. Food and Drug Administration. On the other hand, compared with the top 30 seafood item frequency of consumption rank from NHANES (1999–2002), 50% of these items (15 marine species) contained more than 350 mg of EPA and DHA per 100 g of fish muscle, whereas only 14% (2 freshwater species) were at the level in our target fish. By contrast, Hg levels less than 0.06 mg/kg were 71% (10 species) for freshwater fish and at most 33% for seafood items (at most 10 species). Mandarin fish has the highest average Hg concentration of 0.15 mg/kg, which is lower than several most popular marine species: tuna (0.24 to 0.48 mg/kg) and cod (0.16 mg/kg) (Mahaffey et al. 2011).

Similarly, the Hg concentrations of seafood grouped into the green category, which was the best choice for consumption (Monterey Bay Aquarium Seafood Watch rankings, May 2011), were clearly higher than the corresponding content of any freshwater fish species. The lowest mean level of omega-3 FA of this group is close to 600 mg/100 g (Gerber et al. 2012). These freshwater fish should have significantly different potential consumption rates and ingestion frequencies than those of marine fish. The discrepancies could be ascribed to the differences in species and environment factors. Compared with freshwater fish, marine fish have more complicated food web structures and larger body sizes, and therefore having significantly higher concentrations of contaminants in the muscle tissue (Burreau et al. 2006; Burger and Gochfeld 2011). If the consumption advice between marine fish and freshwater fish was not balanced, some consumers could be confused with the current consumption recommendation of seafood and marine fish (Smith and Sahyoun 2005). Such results highlight that establishing a comprehensive assessment for freshwater fish consumers, especially those in South-East Asia, is necessary.

Fish species in this study were divided into three fish categories to specify potential consumption choices for target population by combining the benefit and risk levels with consumption frequency per week (Figure 3). Consumption of some fish species varies considerably in benefit and risk; thus, the benefit and risk levels of individual species should be estimated. If consumers are aware of the benefit and risk of consuming fish, then building a consumption framework is more effective to launch a benefit and risk communication based on the characteristic of fish species. Changes in consumption behavior would be promising for healthy diets. A framework should guide research to this direction in the future. Moreover, the public should be aware of the concurrent benefit and risk of consuming fish. However, consumers may encounter different health effects. Hence, specific guides for different populations should be produced. We found a significant difference especially
in the first category between the general population and the vulnerable group in terms of the experienced benefit and risk.

More species are suitable for the general population consumption. Caution should be implemented by the vulnerable groups when choosing fish to eat. In previous studies, a quantitative assessment of benefit and risk developed by Ginsberg and Toal (2009) also stressed that vulnerable groups should carefully choose what top marine trophic level fish they should eat on the basis of the dose relationships of omega-3 FA benefits and MeHg risks. However, Loring et al. (2010) applied the method to eight commonly consumed Alaskan fish to conclude inconsistent consumption advice for two freshwater fish and one marine fish from different sample sites. Data shortcoming and biomonitoring needs have been revealed and should be addressed to improve the fish consumption guidelines. Currently, launching region-specific advice or targeting specific populations or sub-populations at risk is laudable (McLaughlin and Gessner 2007). Hg accumulation in aquatic food webs is a function of not only fish species and regions but also of fish size and other factors.

Some studies have shown that the same species with discrepant sizes can result in very different Hg concentrations (Cizdziel et al. 2002; Burger and Gochfeld 2011) and different omega-3 FA levels. Therefore, optimum marketable fish size based on the co-assessment of benefit and risk for each species could be implemented to benefit public health. This method could be employed by initially conducting foundational research to optimize fish size. The optimum fish size should provide maximum potential benefit and minimal possible risk. Consumers could passively benefit from this implementation and immensely achieve a win-win scenario with proactive choices if the identified optimum fish size management strategy is feasible in market circulations. Hence, the relationships among fish size, benefit, and risk levels are very conducive for establishing better consumption guidelines for specific fish for consumers.

Some uncertainties and differences, such as species, meal size, and assessment methods, are unavoidable in the assessment process, although the objectives were related to the negative effects of Hg and the positive effects of omega-3 FA. Up to now, qualitative analysis and quantitative estimates of the benefits and risk of fish consumption have been reported, however, a type of defect inherent in these studies exists (i.e., the dose–response relationships of these discussed components caused by their complexities of pharmacodynamics within human and individual differences; Ginsberg and Toal 2009; Rheinberger and Hammitt 2012). Subsequently, additional details including other nutrients, such as protein and vitamin E, and contaminants, such as persistent organic pollutants, could exist in these fish species and should be further considered (Du et al. 2012; Meng et al. 2007; Yang 2002). Consumption guidance has theoretical uncertainties up to some extent even in current popular and controversial seafood advisories. More effective assessments are needed to develop a better fish advisory based on these necessary improvements.

Our analysis supports the advisories that request the target population, especially the vulnerable group, to reduce consumption of some fish, such as mandarin fish and catfish, due to the low ratios of omega-3 FA to Hg less than the minimum recommended intake ratio (42:1 for the vulnerable group), and to give priority to several fish species. Thus, the first category fish, should be recommended because of their relatively high ratios and omega-3 FA content (Table 2). The present study
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showed that black carp had high ratio of omega-3 FA to Hg, but this species also exhibited the lowest content of 0.01 mg Hg/kg fish. It appeared that unlimited consumption for black carp was potentially safe for pregnant women. However, this result poses a challenge to the notion that carnivorous fish are associated with high enrichment of Hg (Régine et al. 2006; Figure 2). Thus, the consumption of black carp is inconclusive because of limited data information. On the basis of our primary framework, the planktivorous fish are the most appropriate choice for consumption to maximize the health benefits of omega-3 FA while minimizing the risks of Hg to consumer health. The general population can have more choices such as crucian carp and yellow catfish. The craving of fish lovers for different tastes while avoiding excessive Hg exposure can be satisfied by consuming fish in the second category. The appropriate amount and frequency of fish consumption are positively associated with reduced fatal CHD mortality and healthy neurodevelopmental effects (He et al. 2004; Rheinberger and Hammitt 2012). The target population should reduce their consumption frequency of the third category fish. Furthermore, no more than one serving per week for the vulnerable group is encouraged. By comparison, the general population should avoid consuming more than three servings per week. Fish nutrients and contaminants should be simultaneously considered when analyzing the effects rendered by fish consumption (He et al. 2004; Tsuchiya et al. 2008).

Unlike the extensive work in marine fish globally, limited information is available about freshwater fish in China. Some omega-3 FA data have been available recently, and some Hg data have been published in previous years. These mean that if the fish-category framework will be distributed to consumers, much foundational work should be first conducted. The consumption advisory should state the benefit and risk in relation to fish ingestion, specify the species to eat, and provide the corresponding frequencies of consumption. The information could result in consumers shifting to alternative choices. This study provided a fish consumption framework on individual fish species for different consumer groups. However, consumers have no ability to rationally decide accordingly because of the lack of data as aforementioned. Biomonitoring data in future for these species should be further gathered.

Nutrients and contaminants in fish have gradually become key factors to drive the creation of consumption advisories. Several economic and social elements that influence consumer choices should also be considered. Education, sex, and income have contributed to the gap between consumer perception and scientific evidence related to the potential health benefit and risk from fish consumption (Verbeke et al. 2007). Exploring the gap and communicating the benefit and risk from fish consumption will continue to benefit consumers (Cohen et al. 2005). Currently, people in villages often eat less fish than those in cities in China (Zhai and Yang 2006). The differences in economic levels rendered this scenario. This study provides a simple reference based on the potential cost and recommended servings of obtaining omega-3 FA and provides for the first time some benefits and risk considerations for consumers. Some differences in costs and fish servings per week were found (Figure 4). Consumers could consider health requirements and cost when choosing fish species to consume. If they prefer to consume fish frequently, consumers can select fish with high omega-3 FA in their fish servings per week to minimize Hg exposure. It is a fact that great quantities of fish production are associated with large amounts of fishing population and fishery practitioners reaching 20.6 million and 14.6 million
in 2011 in China, respectively (FAO 2012). The consumers may have more chances to eat many fish species and thereby ingest much omega-3 FA. However, they will have an increased risk of Hg exposure. From a health perspective, individuals with high fish consumption should be greatly aware of the types of fish that are better for frequent consumption and adjust their dietary behavior (Domingo 2007). Furthermore, estimating the effect of this guide on consumer perception and intention to eat fish is incumbent on benefit and risk managers.

CONCLUSION

In this study, we conducted a functional feeding group analysis of commonly consumed freshwater fish on the cognitive foundation related to feeding habits and Hg accumulation. This study is the first to provide an integrative health benefit and risk assessment based on omega-3 FA and Hg levels of species-specific freshwater fish consumption, as well as their costs calculation to establish a tentative freshwater fish-category framework. Consumers should be acquainted with fish feeding habits and make a coarse consumption choice to minimize negative health effects on the basis of the characteristics of functional feeding groups in the absence of national or local consumption advisory. Preliminarily, we found significant differences in concurrent benefit and risk levels in these fish. This result will be of great interest to freshwater fish consumers and to relevant national agencies. Some conditions, such as lack of available data and uncertainty, restrict the presented advice. Human biomonitoring information and new data on omega-3 FA and Hg and other harmful substances in fish are urgently needed for appropriate public health recommendations. When relevant agencies decide to create fish consumption advice for the public, reweighing both benefit and risk is essential. The fish-category framework for consumption can be further revised. Furthermore, “optimal-size” fish consumption guidelines, integrated with the benefit and risk levels of species-specific fish, can be specially developed for advancing the fish consumption advice in the future.

ACKNOWLEDGMENTS

The study was funded by the Key Projects in the National Science & Technology Pillar Program during the Twelfth Five-Year Plan Period (2012BAD25B04), Special Fund for Agro-Scientific Research in the Public Interest Project (Grant No. 201203083), the Fundamental Research Funds for the Central Universities (Grant No. 2013PY078), and the Earmarked Fund for China Agriculture Research System (CARS-46).

SUPPLEMENTAL MATERIAL

Supplemental data for this article can be accessed on the publisher’s website.
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