Risk Profiling of Methylmercury in the Consumption of Dried Tamban (Sardinella lemuru) by the Filipino Consuming Population

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Methylmercury (MeHg) is one of the most toxic forms of mercury (Hg) produced via methylation of its inorganic form from natural and anthropogenic sources. Fish that feed on phytoplankton, such as sardines, serve as the entry points of MeHg in the aquatic food web. Dietary exposure (DE) to MeHg leads to varying health risks such as ataxia, neurodevelopmental delays, and blindness in newborns and infants. The study aimed to develop a risk profile on the potential risk associated with the consumption of Philippine dried tamban (Sardinella lemuru) through 1) conceptualization of the risk profile, 2) review of related literature, 3) formulation of assumptions (i.e. identification of variabilities and establishment of uncertainties or data gaps), 4) exposure pathway assessment, and 5) risk characterization. The risk of MeHg was estimated using the total mercury (THg) concentrations in dried tamban samples collected from the major fishing grounds of sardines in the Philippines, consumption data of the adult Filipino consuming population, and the assumed average body weights of Asian adults. The estimated DEs ranged from 0.000043–0.008724 μg/kg bw (bodyweight)/wk, which is equivalent to about 0.003–0.545% of the provisional tolerable weekly intake (PTWI) of 1.6 μg/kg bw for MeHg established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) in 2007. Our findings imply that dried tamban does not pose a major health risk to the adult Filipino consuming population. However, it is also essential to note that aside from dried tamban, there are other potential sources of MeHg in the diet such as other fish and seafood.

Keywords: Bali sardinella (Sardinella lemuru), methylmercury, Philippines, risk profile

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INTRODUCTION

Bali sardinella (*Sardinella lemuru*), locally known as tamban, is a small pelagic migratory fish that mainly feeds on phytoplankton and zooplankton (FAO 2019). It also serves as the main food source of pelagic tuna, mackerel, and other predatory fish (Luceño et al. 2014). Tamban is one of the most commercially important pelagic fish products of the Philippines, with it being the “most accessible source of animal protein for the Filipino” (Willette et al. 2011). However, several factors like climate change, pollution, and overfishing impose a threat to the industry, thus articulating doubts in the safety of the commodity nationwide (Bloom 1992). Consequently, levels of Hg content in fish products have been a predominant health concern (Mozaffarian and Rimm 2006). MeHg bioaccumulates in fish and further biomagnifies with increasing trophic levels, which results in higher levels of MeHg in large predatory fish (Rice et al. 2014; Chung et al. 2008).

Concerns on the exposure to MeHg through consumption of fish are mainly due to its potential adverse health effects. Prenatal exposure to low MeHg doses has been related to neurodevelopmental delays and psychomotor retardation (Bernhoft 2012; Berlin et al. 2015). Subsequently, higher doses have led to infants having ataxia, deafness, blindness, cerebral palsy, etc. (WHO 1990; Bernhoft 2012). The Philippine Department of Health (DOH) has published several assessments on the Hg exposure of residents near Hg mines in Palawan (1994) and in Davao del Norte (1997), where there is also a reported 0.02424 ppm mean MeHg concentration (91.72% of THg) in tamban sampled in its markets – citing higher proportions of MeHg than inorganic Hg in their blood, which was mainly attributed to the dietary intake of the locals, with fish being a staple in their diets (Akagi et al. 2000; Maramba et al. 2006).

While there are no other available assessments on human exposure to MeHg through consumption of fish in the Philippines, the Department of Environment and Natural Resources (DENR) has recently launched the findings of the Minamata Initial Assessment, which enabled the establishment of baseline Hg inventory to enumerate the possible anthropogenic sources of Hg and Hg-contaminated areas in the country (Villanueva 2019). The assessment was able to identify numerous potential sources of Hg contamination in the country such as the Palawan Quicksilver Mines in Puerto Princesa City, Mambulao Bay in Camarines Norte, Mabuhay Vinyl Corp. in Lanao del Norte, and Lumanggang Creek in Compostela Valley, etc. (Villanueva 2019).

Through consultations with the Philippine Food and Drug Administration (FDA) and Bureau of Fisheries and Aquatic Resources (BFAR), MeHg in dried tamban was deemed a priority combination due to the high consumption of dried tamban, presence of numerous natural and anthropogenic sources of Hg (e.g. volcanoes, mining sites) in the country, and the adverse health effects of MeHg to the vulnerable population. Available data from DENR only include Hg in air and rainwater in possible anthropogenic sources of Hg (DENR 2019; Villanueva 2019). Meanwhile, data on levels of Hg and MeHg – specifically in tamban – are yet to be established.

In this regard, the establishment of baseline data in the form of a risk profile is necessary to determine the presence of any health risk imposed by the consumption of MeHg-contaminated sardines.

This study aimed to establish a risk profile to provide baseline information on the potential risk of MeHg in dried tamban (*Sardinella lemuru*) by the adult Filipino consuming population. This study is part of the Philippine Food Safety Risk Profiling Project (PRPP), funded by the Department of Science and Technology (DOST) and implemented by the University of the Philippines Diliman (UPD) in 2019, intended to support Philippine food safety risk management. The document was developed to serve as a reference material for food safety risk managers to aid in the review of existing standards and regulations, mitigation measures in food safety relative to the reduction of MeHg in sardines.

The scope of the risk profiling covers MeHg as a food hazard and *Sardinella lemuru* (tamban) as a food commodity. This included conceptualization of the food safety risk profile based on the review of literature on reported adverse health effects upon exposure to MeHg through the consumption of fish, the computation of DE and risk estimate of MeHg in dried tamban, and consolidation of possible mitigation measures. In preparing the risk profile, the project team sought to address the following risk management questions:

1. What is MeHg and why is it a concern?
2. What are the health and food safety risks associated with MeHg in food?
3. What is the potential for exposure of Filipinos to MeHg in dried tamban?
4. What measures are available to control MeHg in dried tamban?
5. What are the possible control options in managing the risk from MeHg in dried tamban?
MATERIALS AND METHODS

Conceptualization of a Food Safety Risk Profile
The Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (2009) describe risk profile as “qualitative risk assessment.” Most food safety risk profiles developed by European Commission and New Zealand Food Safety were observed similar with risk assessment reports developed by FAO and WHO consisting of the following steps: hazard identification, hazard characterization, exposure assessment, and risk characterization.

The outline of the risk profile developed for the project, under which this study was conducted was conceptualized with reference to the Codex Alimentarius Commission (CAC/GL 63-2007 and CAC/GL 30-1999), FAO/WHO (2003), and the United States Environmental Protection Agency (US EPA 2012).

This study sought to profile the risk of consumption of MeHg in dried tamban due to the consumer demand the commodity in the country, while the hazard was identified due to lack of available local baseline information. The FDA, BFAR, and the Risk Analysis Expert and Food Safety Advisor of the PRPP then verified – through consultation meetings – that it is essential to establish a risk profile for this food hazard: commodity combination. This risk profile focuses on MeHg as the hazard and dried tamban in the Philippines as the food commodity.

Review of Related Literature
The review of related literature in this study covered the scientific studies, standards, monitoring, evaluation, health risk assessment, reports of illnesses, and statistics regarding MeHg in dried tamban. The terms “methylmercury,” “tamban,” “Bali sardinella (Sardinella lemuru),” “risk profile,” and “Philippines” were used either individually or in combinations with each other to search online databases such as Google, Google Scholar, ScienceDirect, Wiley Online Library, ResearchGate, Taylor & Francis Online, Elsevier, National Center for Biotechnology Information, FAO/WHO Joint Expert Committee on Food Additives, CAC, etc., for literature dated from the year 2000 up to present. The scoured literature was then organized and summarized. The information collected for the first two components of the risk profile served as the initial risk profile and was used as the basis for the development of sampling guidelines for the dried tamban.

Access to data relevant to the study of MeHg in dried tamban was requested from collaborating agencies such as the BFAR, FDA, and DOST–Food and Nutrition Research Institute (FNRI). Then, the information obtained was used in the exposure pathway assessment part of this study.

Identification of uncertainties and variabilities to formulate assumptions

Uncertainties. The uncertainties are the data gaps needed to be addressed or minimized to further the risk assessment. Thus, coming up with a more comprehensive estimation of the risk for the Filipino consuming population (see Table 4).

Variabilities. Variabilities were also identified along the process of risk profiling. These are the information used in risk profiling that is constantly varying and cannot be represented by a single value but can be addressed with precision (FAO 1995).

- Difference in the bioaccumulation mechanisms among fish species
- Difference in fish size and age per fishing ground
- Presence of natural and anthropogenic sources of Hg
- Level of THg or MeHg present per fishing ground
- Difference in the consumption of tamban per province
- Difference in the consumption of tamban per age group

Assumptions. Due to the various uncertainties and variabilities, the following assumptions were made to obtain the estimated DE of MeHg in dried tamban in the Filipino consuming population:

1. All data belonging to Sardinella longiceps in government databases are treated to be data for Sardinella lemuru species.

   a. This assumption was based on the results of the study conducted by Willette and Santos (2013), which indicated that the widely applied nomenclature of Indian oil sardine (Sardinella longiceps) is incorrect, and the species is instead the Bali sardinella (Sardinella lemuru). This is also aligned with the BFAR Administrative Circular No. 1 s. of 2019, indicating correcting the nomenclature of Indian oil sardine (Sardinella longiceps) to Bali sardinella (Sardinella lemuru) covering all related PSA publications, databases, and references.

2. The MeHg concentration in raw dried tamban does not decrease after cooking (e.g. frying, pasteurization) (Charette et al. 2021).

3. THg concentrations are treated as 100% MeHg.

4. Consumption in g/d is the same for the entire 1 wk (i.e. daily intake was multiplied by 7 d to account for the weekly intake in reference to the HBGV set for MeHg).
4. Dried tamban consumption is the same for both male and female consumers.

5. The bw of the adult Filipino population is equal to the assumed bw for the adult Asian population (55 kg) (WHO 2020).

6. The 97.5th percentile consumption data of the adult Filipino consuming population was used to provide the most conservative estimation of the DE (WHO 2020).

Exposure Pathway Assessment

Survey and sampling. In preparation for sampling, interview questionnaires were developed to collect data on the fishing grounds of tamban, as well as their knowledge of anthropogenic sources near the fishing grounds. Pre-testing of the key informant interview questionnaire was conducted through interviews of stakeholders and on-site observation in the Navotas Fish Port Complex.

The selection of locations for the survey and sampling was based on various factors such as production data from the Philippine Statistics Authority (PSA 2018), disaggregated consumption data on dried tamban from the 2013 National Nutrition Survey (NNS) [notarized memorandum of understanding (MOU) 2020, pers. comm.], sources of variability (e.g., presence/absence of volcanic and anthropogenic activities, seawater characteristics), and limitations (e.g., duration and time of the survey, survey cost, availability of data). Selected locations for survey and sampling conducted from October–November 2019 were as follows: Puerto Princesa, Masbate, Cebu, Zamboanga, Batan, and Capiz.

Actual interviews were done on the same day of the sample collection. Key informant interviews with municipal fishermen were conducted for the identification of the specific fishing grounds and potential anthropogenic sources of Hg. The key informants were asked for their consent to the interview activity by signing a consent form.

For the actual sampling, a total of 24 seawater samples and 24 dried tamban samples were obtained – with four replicates per sampling location. Seawater samples were obtained from the actual fishing grounds. Each 1-L sample was stored in a pre-labeled HDPE bottle with a screw cap. Meanwhile, the dried tamban samples were weighed (1 kg each bag) and packed in pre-labeled Ziploc® bags. The dried tamban and seawater samples were stored in separate Styrofoam™ boxes. The seawater samples were stored with ice and/or Thermofreeze® sheets to preserve sample integrity.

Sampling design. A directed or targeted sampling design (CAC/GL 71-2009) was used for the collection of concentration data and current aquaculture practices relevant to the levels of THg in tamban in the Philippines. This sampling plan was particularly biased to places, which were assumed to have higher exposure levels of Hg in terms of consumption of dried tamban and the proximity of the fishing grounds to volcanic and mining areas, to account for the worst-case scenario on possible exposure to THg.

Sample analysis. As a substitute for MeHg levels, THg levels in dried tamban were determined since there was no local laboratory capable of testing for MeHg, and testing overseas would have compromised the integrity of the dried tamban and seawater samples.

The dried tamban samples were submitted to the Philippine Coconut Authority (PCA) for THg analysis and moisture analysis. The samples were digested using a microwave digestion system, with reference to AOAC Official Method 974.14. Then, Hg was determined using an inductively coupled plasma–optical emission spectrometry in-house validated method by PCA, wherein the method was validated using the Eurachem Laboratory Guide to Method Validation, 2nd Edition (2014). For moisture analysis, a gravimetric method using an air oven was used, with reference to AOAC Official Method 930.04. Meanwhile, seawater samples were submitted to FASTLab Cubao for total organic carbon (TOC) analysis using combustion (Baird and Bridgewater 2017) and THg analysis using cold vapor atomic absorption spectrometry (AAS) (Baird and Bridgewater 2017).

DE assessment. Disaggregated consumption data on dried tamban from the 2013 NNS were acquired through an MOU with the Philippine DOST-FNRI (pers. comm. 2020) to establish the baseline DE estimate of Filipinos.

The DE was estimated and calculated using the equation provided by FAO/WHO (2011):

\[
\text{Dietary exposure} = \frac{(\text{Food consumption} \times \text{Chemical concentration in the food})}{\text{Mean body weight (kg)}}
\]

The estimated DE of the Filipino adult consuming population was calculated using the following information: 1) THg concentration of dried tamban samples; 2) the 97.5th percentile daily dried tamban consumption value of the adult Filipino consuming population (pers. comm. 2020); and 3) an assumed average weight of 55.0 kg for Asian adults (WHO 2020).

Calculation of Risk Estimate for Risk Characterization

A risk estimate was generated using an integration of the adverse health effects of exposure to MeHg in the
RESULTS AND DISCUSSION

Conceptualization of a Food Safety Risk Profile
The outline of the risk profile of MeHg in dried tamban in the Philippines was conceptualized in such a way that will serve as a template for other stakeholders who will also conduct risk profiling activities for other food hazard: commodity combinations.

The results of the 1) consultation with the agencies and experts, 2) review of literature, and 3) exposure pathway assessment were segregated according to the outline of the food safety risk profile conceptualized for the project – under which this study was conducted.

Review of Related Literature
Risk profiling utilizes a review of related literature to give an overview of the available information from various sources regarding the food safety risk profile sections “2. Hazard and Food” – particularly the subsections “2.1 Hazard Identification” and “2.2 Hazard Characterization” – and “3. Availability of Hazard Control Measures.” Key findings during the development of the risk profile are discussed hereafter, addressing the risk management questions identified.

Hazard identification. MeHg is considered to be the most toxic form of Hg due to its effects on human health (Sevillano-Morales et al. 2015). It is produced through the methylation of inorganic Hg by microorganisms – commonly, sulfate-reducing bacteria – present in the environment due to natural or anthropogenic sources (Chung et al. 2008; Regnell and Watras 2018).

MeHg bioaccumulates in fish and further biomagnifies with increasing trophic levels, resulting in higher levels of MeHg in large predatory fish (Chung et al. 2008; Rice et al. 2014). Several factors may affect the rate of Hg bioaccumulation in fish such as fish age, fish length, trophic position, presence of natural and anthropogenic Hg sources, dissolved organic carbon (DOC) in water, etc. According to McIntyre and Beauchamp (2006), fish age – along with trophic position – contributes significantly to the Hg biomagnification in the aquatic food web. Likewise, fish length is usually positively correlated to the level of Hg contamination and fish age and is found to be a reliable indicator of higher THg levels in fish (Sackett et al. 2013). Meanwhile, fossil fuel combustion of power plants (e.g. coal, diesel) and artisanal small-scale gold mining (ASGM) activities were determined to be major contributors to Hg pollution (BRI-IPEN 2014). The presence of organic carbon in the water also affects bioaccumulation, as organic carbon is known to strongly bind with and transport Hg in bodies of water (Lavoie et al. 2019).

Hazard characterization. MeHg is readily absorbed in the GI tract (approximately 95% of dose), enters the bloodstream, and crosses the blood-brain/blood-placenta barrier (NRC 2000; Rice et al. 2014; WHO 2017). Body burdens caused by exposure to MeHg include neurological, cellular, cardiovascular, hematological, pulmonary, renal, immunological, endocrine, reproductive, and other toxicological effects (Rice et al. 2014). Prenatal exposure to low MeHg doses has been related to neurodevelopmental delays and psychomotor retardation (Bernhoft 2012; Berlin et al. 2015). Subsequently, higher doses have led to infants having ataxia, deafness, blindness, cerebral palsy, etc. (WHO 1990; Bernhoft 2012).

The main route of human exposure to MeHg is via the consumption of contaminated fish (Berlin et al. 2007). Thus, various countries and standard giving bodies have implemented a range of control measures to lessen the exposure to MeHg. In 2007, the JECFA confirmed the set PTWI for MeHg at 1.6 µg/kg bw (TRS 940-JECFA 67/57) and the NOAEL (no observable adverse effect level) of 1.5 µg/kg bw for MeHg using developmental neurotoxicity as the toxicological endpoint in humans (CXS 193-1995 e. 2019). In the same report in 2007 (TRS 940-JECFA 67/57), JECFA stated that intakes for pregnant women, infants, and children should not exceed the PTWI due to their increased vulnerability to MeHg exposure.

Exposure Assessment
Survey and sampling. The results of the interview verified the initial information gathered from the review of related literature, on the location of fishing grounds of tamban and the presence or absence of potential anthropogenic sources of Hg in the identified sampling locations (see Table 1).

Results of the sample analyses were utilized in the exposure assessment and risk characterization. Dried tamban samples were tested for THg and moisture content, while seawater samples were tested for THg and TOC content.

Levels of THg in dried tamban. In this study, THg levels were assumed to be equal to MeHg levels, based on the widely cited study by Bloom (1992) entitled “On the chemical form of mercury in edible fish and marine invertebrate tissue”, which stated that MeHg constitutes > 95% of THg in fish, and the study by Akagi et al. (2000),
Table 1. THg levels in dried tamban (Sardinella lemuru) in the Philippines in 2019.

<table>
<thead>
<tr>
<th>Fishing ground</th>
<th>City/Province</th>
<th>No. of samples (n)</th>
<th>Fish length (cm; mean ± SD)</th>
<th>Anthropogenic sources (Y/N)</th>
<th>THg a,b (ppm)</th>
<th>ML c (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moro Gulf</td>
<td>Sangali, Zamboanga</td>
<td>4</td>
<td>16.93 ± 0.51</td>
<td>Y</td>
<td>0.000006 d</td>
<td>0.000671</td>
</tr>
<tr>
<td>Sibuyan Sea</td>
<td>Roxas, Capiz</td>
<td>4</td>
<td>14.77 ± 0.50</td>
<td>Y</td>
<td>0.000006 d</td>
<td>0.000387</td>
</tr>
<tr>
<td>Manila Bay</td>
<td>Limay, Bataan</td>
<td>4</td>
<td>11.0 ± 0.44</td>
<td>Y</td>
<td>0.000006 d</td>
<td>0.000951</td>
</tr>
<tr>
<td>Visayan Sea</td>
<td>Medellin, Cebu</td>
<td>4</td>
<td>15.77 ± 0.25</td>
<td>Y</td>
<td>0.000006 d</td>
<td>0.001224</td>
</tr>
<tr>
<td>East Sulu Sea</td>
<td>Narra, Palawan</td>
<td>4</td>
<td>14.47 ± 0.25</td>
<td>N</td>
<td>0.000006 d</td>
<td>0.000165</td>
</tr>
<tr>
<td>Asid Gulf</td>
<td>Milagros, Masbate</td>
<td>4</td>
<td>12.17 ± 0.15</td>
<td>N</td>
<td>0.000006 d</td>
<td>0.000006</td>
</tr>
</tbody>
</table>

Overall mean 0.000172 ± 0.000138

a As the available laboratory analysis in the Philippines can only detect and quantify THg, this study assumed that THg is equivalent to 100% MeHg. According to Codex, a country may analyze for THg when applying the ML for MeHg – given that THg levels do not exceed the ML for MeHg in fish, further testing for MeHg can be done once THg levels exceed the ML set for MeHg (CXs 193-1995 e. 2019).
bMethod: inductively coupled plasma-optical emission spectrometry; LLD: 0.006 ppb; parameters: converted from ppb to ppm
cData were generated from this study by the PRPP in 2019.
dConcentrations less than the LLD (< 0.006 ppb) were considered as 0.006 ppb and converted to 0.000006 ppm.

wherein MeHg is equal to 56.16–99.38% of THg in fish caught from Apokon, Davao del Norte, Philippines.

Results showed that the mean levels of dried tamban per fishing ground ranged from 0.000006–0.000323 ppm THg and had an overall mean of 0.000171 ± 0.000096 ppm THg (see Table 1). All values were below the maximum level (ML) of 0.5 ppm THg for non-large predatory fish species (CXs 193-1995 e. 2015; PNS/BAFS 194:2017). This ML was established and declared in the 2015 edition of the Codex General Standard for Contaminants and Toxins in Food and Feed (GSCTFF) (CXs 193-1995) and was adopted by the Philippines through the Philippine National Standard–GSCTFF (PNS/BAFS 194:2017). However, this ML has been revoked as of the 2019 revision of the CXs 193-1995, which focused on specific predatory fish species or taxonomic groups (CXs 193-1995 e. 2019) (CAC 2019a). While ML for MeHg for additional fish species or taxonomic groups will be considered once data is available (REP19/CF) (CAC 2019b), the most recent limit on non-predatory fish has been used in this study.

Also, the THg levels obtained were lower compared to overseas data (Indonesia and China) on THg in Sardinella lemuru which ranged from 0.0065–0.1 ppm (see Table 2). Levels less than the lower limit of detection (LLD) of 0.006 ppb or 0.000006 ppm THg were observed in 18 out of 24 samples. Meanwhile, four sampling locations – namely, Cebu, Bataan, Capiz, and Palawan – had one replicate each that was determined to be an outlier using Grubb's test. Outliers in the data which are from replicates, which – although still below the ML, have the highest THg level amongst the samples in the respective provinces (Capiz = 0.000387 ppm THg; Bataan = 0.000951 ppm THg; Palawan = 0.000165 ppm THg; Cebu = 0.001224 ppm THg) – may have resulted from the variability influenced by the location in the fishing ground at which the fish was captured (Choy et al. 2009).

In the Philippine setting, variability of THg concentration by sampling location may be attributed to several factors such as fish age, trophic position, fish length, and Hg input from anthropogenic sources, which affect the level of contamination in an area (McIntyre and Beauchamp 2006; Sackett et al. 2013). For example, samples from Sangali, Zamboanga having the highest mean THg may be attributed to their length (longest) and exposure to potential Hg sources (e.g. several gold mining sites within the Zamboanga Peninsula, diesel power plant near the sampling location) (DENR-MGB 2019). Meanwhile, a relatively high value of 0.000951 ppm THg may have been observed in one replicate from Limay, Bataan – despite their length (shortest) – due to high Hg exposure from a coal power plant and a copper and gold mining site, both located in the municipality of Limay, Bataan (DENR-MGB 2019).

Levels of THg and TOC in seawater. All seawater samples from the fishing grounds of dried tamban contained THg levels lower than 1 ppb THg (LOD using cold vapor AAS). Assuming that the values are equal to 1 ppb THg as worst-case, the THg levels in the seawater are under the maximum contaminant level of 1.8 µg/L Hg (US EPA 2019) and 2.0 µg/L Hg (Philippine DAO 1990-34) in seawater. Thus, the current THg levels in seawater for the identified fishing grounds do not pose a significant risk to the exposed species in the environment.

Meanwhile, results of the TOC analysis using the combustion method showed values ranging from 1.20–2.41 mg/L TOC with an overall mean of 1.63 mg/L TOC.
Table 2. Philippines vs. overseas data on THg and MeHg concentrations in *Sardinella lemuru*.

<table>
<thead>
<tr>
<th>Country</th>
<th>Form</th>
<th>Purpose of study</th>
<th>Fishing ground</th>
<th>No. of samples (n)</th>
<th>Concentration ± SD (ppm)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philippines</td>
<td>Dried</td>
<td>To determine the THg levels in dried tamban from various fishing grounds in the country.</td>
<td>Moro Gulf, Sibuyan Sea, Manila Bay, Visayan Sea, East Sulu Sea, Asid Gulf (n = 4 per fishing ground)</td>
<td>24</td>
<td>0.000171 ± 0.000096</td>
<td>NA</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Fresh</td>
<td>To identify the Hg concentration in fish from ASGM sites in Sekotong and Taliwang</td>
<td>Sekotong Sea West Lombok Regency, West Nusa Tenggara Province</td>
<td>35</td>
<td>0.1</td>
<td>NA</td>
</tr>
<tr>
<td>China</td>
<td>Fresh</td>
<td>To determine Hg and MeHg levels of wild marine species as affected by industrialization activities in the country.</td>
<td>Dapeng Bay</td>
<td>5</td>
<td>0.0065 ± 0.0015</td>
<td>0.0057±0.0015</td>
</tr>
</tbody>
</table>

TOC is composed of DOC (passes through a 0.22 μm filter) and POC (particulate organic carbon) (filtered out of the sample) (Bruckner n/d.).

As a reference, a threshold of < 8 mg carbon/L was reported in a study, wherein DOC values exceeding the threshold resulted in a negative correlation between Hg bioaccumulation and DOC (Moore *et al.* 2003). In support of this, findings of the study conducted by French *et al.* (2014) showed that DOC promoted MeHg bioaccumulation at low DOC concentrations (< 8.6–8.8 mg carbon/L). Consequently, DOC inhibited MeHg bioaccumulation at DOC concentrations higher than the threshold concentration due to the formation of Hg species that cannot be readily absorbed by marine animals through water uptake. Comparing the results of the current study with the threshold concentration of < 8 mg carbon/L, assuming that TOC is equal to DOC as worst-case, the TOC levels of 1.20–2.41 mg/L TOC obtained from the seawater samples may promote MeHg bioaccumulation in fish as the threshold has not yet been reached. As for the sources of TOC, some of the identified sampling locations (e.g. Bataan, Capiz, Palawan, and Zamboanga) had agricultural farms near the bodies of water, which may be possible sources of humic substances, which partly comprise the TOC content (Jaffè *et al.* 2008).

**DE assessment.** The calculated DE (see Table 3) ranging from 0.000043–0.008724 μg/kg bw/wk for the consuming population, ages 20 yr and above, shows that dried tamban only contributes to about 0.003–0.545% of the PTWI. Hence, given the available data at the time of evaluation of the DE of the consuming population, the consumption of dried tamban does not pose an appreciable health risk to the healthy Filipino consuming population, ages 20 yr and above. Note that this estimated DE is based on the assumptions, uncertainties, variabilities, and data gathered in this study.

Estimated MeHg intake via dried tamban consumption, derived from THg levels, were compared to the PTWI for MeHg because according to JECFA (2007), the PTWI for MeHg should be used when calculating the DE to Hg from fish and shellfish. Also, it is allowed for countries importing fish to analyze for THg when applying the ML for MeHg, given that THg levels do not exceed the ML for MeHg in fish – further testing for MeHg can be done once THg levels exceed the ML (CXS 193-1995 e. 2019). Although a recent study by Lescord *et al.* (2018) has shown that the assumption from Bloom (1992) cannot be used for non-predatory fish due to varying bioaccumulation rates among trophic levels and species, assumptions were still made due to the limitations of the study. Thus, the THg levels were assumed to be equal to the MeHg levels and were compared to the PTWI for MeHg as a worst-case scenario for the calculation of DE.

**Calculation of Risk Estimate for Risk Characterization**

Using the maximum THg level of 0.001224 ppm in dried tamban, a healthy Filipino adult weighing 55 kg needs to
consume at least 71.9 kg/wk of dried tamban just to reach the PTWI. However, due to numerous assumptions, it is essential to prioritize addressing the data gaps identified to make a more comprehensive risk characterization.

Control Measures Employed

In response to risk assessments conducted in various countries, a range of control measures have been implemented to reduce consumer exposure to MeHg via fish consumption. These include fishing bans, the establishment of MLs, and consumer advice. In addition, a global treaty called the Minamata Convention on Mercury was established aiming to control and limit the usage and emission (air and water) of Hg by various industries (UNEP 2019).

The Philippines has signed the convention on 10 Oct 2013 but still has not ratified it (Minamata Convention on Mercury 2020). Also, there is currently no standard set for the allowable Hg content specific to tamban. The Philippine National Standard (PNS) (BAFS/PNS 138:2014) for THg is 1 mg/kg in fresh-chilled, fresh-frozen, and treated tuna, and 0.1 mg/kg MeHg in thermally processed fish products (PNS/BFAD 06:2006; ICS 67.120.30). The value is adopted from the Codex GSCTFF MLs of 1 mg/kg in large predatory and 0.5 mg/kg in non-predatory fish (CXS 193-1995 e. 2015; PNS/BAFS 194:2017). This is consistent with the allowable limit stipulated in the Fisheries Administrative Order No. 210 series of 2001, wherein an ML of 0.5 mg/kg Hg serves as a requirement for the exportation of fish products (DA-BFAR 2001). However, based on the findings of this study and the updated CXS 193-1995 e. 2019, it is recommended for BAFS to revisit the national standards on MeHg in fish (PNS/BAFS 194:2017).

As for the regulatory agencies, the DENR and DA-BFAR have their roles in the monitoring of Hg in the environment (i.e. air, water, soil) and fish/fishery products, respectively (Official Gazette 1990; DA-BFAR Fisheries Administrative Order No. 213 s. 2001; Official Gazette 2004). According to the Air Quality Executive of DENR, there will be an issuance of corresponding policy directives whenever significant Hg levels are obtained from monitoring activities (Teves 2018). Meanwhile, BFAR has the authority to declare fishing bans nationwide. Advisories on fishing bans are disseminated by BFAR to Local Government Units (LGUs) for enforcement to protect consumers from potential health risks arising from the consumption of contaminated fish and fishery products.

As for consumer advice, the following recommendations were issued by USFDA and US EPA for women who might be/are pregnant, breastfeeding mothers, and children to reduce exposure to MeHg: 1) avoid consumption of large predatory fish such as sharks, swordfish, etc.; 2) limit fish consumption up to approximately 340 g/wk and eat fish/shellfish in variety, prioritizing fish with low Hg levels; and 3) keep updated with local advisories regarding the safety of fish caught in your local freshwater/coastal areas (USFDA 2019).

Analysis of the Developed Food Safety Risk Profile

The list of information needed to complete a risk profile or make a comprehensive decision based on a risk profile was consolidated in Table 4. It also details which information is readily available and which are still lacking, especially in the Philippine context. In identifying the gaps, the risk managers are also presented with options for further action.

CONCLUSION

A risk profile that brings together information on the risks that may be associated with MeHg in Sardinella lemuru in the Philippines was developed. Through the
Table 4. Results of the analysis of the developed food safety risk profile of MeHg in dried Tamban (Sardinella lemuru).

<table>
<thead>
<tr>
<th>Needed information</th>
<th>Available information</th>
<th>Gaps identified</th>
</tr>
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<tbody>
<tr>
<td><strong>Hazard identification</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Sources of the hazard</td>
<td>– Primary sardines fishing grounds in the Philippines from published technical paper series of BFAR(^a) (Willette et al. 2011)</td>
<td>– Limited to no available published Philippine studies regarding the Hg levels present in major fishing grounds</td>
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<tr>
<td>b. Hazard in the specified food</td>
<td>– Philippine sardines production from PSA(^b) online database</td>
<td></td>
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<tr>
<td></td>
<td>– Mineral statistics and mineral industry statistics from DENR–Mines and Geoscience Bureau(^c) regional online database</td>
<td></td>
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<tr>
<td></td>
<td>– Publication entitled “Mercury Assessment for the Philippines” by Ms. Pausing, Project Manager from DENR-EMB(^d) (2008)</td>
<td></td>
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<tr>
<td></td>
<td>– Primary findings of Minamata Initial Assessment by DENR published in a Philippine Star News Article entitled “Philippine soon to be mercury free—DENR” by Villanueva (2019)</td>
<td></td>
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<tr>
<td></td>
<td>– Overseas studies regarding MeHg in non-predatory fish</td>
<td></td>
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<tr>
<td></td>
<td>– Information on MeHg from specialized agencies and organizations such as FAO/WHO(^d) and CAC(^e), and government regulatory bodies such as USFDA(^f), etc.</td>
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<tr>
<td><strong>Hazard characterization</strong></td>
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<tr>
<td>a. Distribution and pharmacokinetics</td>
<td>– Overseas studies on distribution and pharmacokinetics and adverse health effects of MeHg</td>
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<tr>
<td>b. Adverse effects</td>
<td>– Dose-response studies and HBGVs from JECFA(^g) (2007)</td>
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<tr>
<td>c. Dose-response</td>
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<tr>
<td>d. Establishment of safe limits: Filipino adult</td>
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<tr>
<td>consuming population</td>
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<tr>
<td>e. Philippine reports of poisoning or illness</td>
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<tr>
<td><strong>Exposure assessment</strong></td>
<td></td>
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<tr>
<td>a. Dietary hazard concentration in tamban in the</td>
<td>– Mercury concentration in Bali sardines collected from sampling activity</td>
<td></td>
</tr>
<tr>
<td>Philippines compared with the overseas data</td>
<td>– Mean consumption of Filipino consumers by age or physiologic group from DOST-FNRP(^h)</td>
<td></td>
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<tr>
<td>b. Consumption information to establish baseline DE</td>
<td>– Average bw of the Asian population from WHO(^i)</td>
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<tr>
<td>estimate</td>
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<tr>
<td>c. Comparison of Philippine DEs with overseas</td>
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<tr>
<td>estimates</td>
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<tr>
<td>d. Major contributing foods</td>
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</tbody>
</table>

\(^a\)Bureau of Fisheries and Aquatic Resources  
\(^b\)Philippine Statistics Authority  
\(^c\)Department of Environment and Natural Resources–Mines and Geoscience Bureau  
\(^d\)Food and Agriculture Organization/ World Health Organization  
\(^e\)Codex Alimentarius Commission  
\(^f\)United States Food and Drug Administration  
\(^g\)Joint FAO/WHO Expert Committee on Food Additives  
\(^h\)Department of Science and Technology–Food and Nutrition Research Institute  
\(^i\)World Health Organization

Risk profiling process, data gaps were identified including monitoring data on MeHg levels in dried tamban and seawater, lack of available local analysis for MeHg, etc. During the exposure assessment, it was determined that all samples obtained were below the Codex ML of 0.5 ppm MeHg for non-predatory fish species (CXS 193-1995 e. 2015; PNS/BAFS 194:2017). Aligning this with the consumption data, findings on DE showed that dried tamban only contributes to about 0.003–0.545% of the PTWI of MeHg and does not pose a major health risk in the healthy Filipino consuming population ages 20 yr and above. However, it is essential to note that there are other potential sources of MeHg in the diet such as other fish and seafood. In this regard, a total diet study can be
conducted to estimate the total intake in consideration of other potential sources of MeHg.

Thus, it may be considered to provide consumer advice on fish consumption to serve as a guide for the consuming population in the Philippines to reduce exposure to MeHg in the consumption of fish. Other control options include the enhancement of data traceability along the food supply chain and the conduct of massive information education drives accompanied by proper risk communication. Risk awareness seminars may be conducted to improve public knowledge on the hazard and its implications to human health.

ACKNOWLEDGMENTS

The project team wishes to acknowledge the following agencies:

- DOST as the funding agency;
- UPD, College of Home Economics, Department of Food Science and Nutrition as the implementing agency;
- DOST–Philippine Council for Industry, Energy, and Emerging Technology Research and Development as the funding monitoring agency; and
- UPD, Office of the Vice Chancellor for Research and Development, Research Management Office as the implementing monitoring agency.

The project team would also like to thank the following collaborating offices:

- DOST-FNRI for access to food consumption data on fish;
- BFAR Provincial Fishery Offices plus LGUs and local non-government organizations for assistance during the sampling activities; and
- UP Pilot Food Plant for assistance in the storage of dried tamban samples.

The project team would also like to thank the following laboratories for the conduct of analytical services relevant to the generation of data on hazard levels:

- Department of Agriculture–PCA; and
- FAST Laboratories.

REFERENCES


APPENDIX

Ethical Considerations
The exposure pathway assessment conducted for the PRPP, particularly in this study, involved interactions with the stakeholders. As such, the project has applied for ethics clearance through the National Ethics Committee (NEC) of the DOST–Philippine Council for Health Research and Development and the Philippine National Health Research System. The application has been approved “with the NEC Code: 2019-014-Rustia-Hazards.”

Risk Profile Outline
The parts of this risk profile are the following:

1. Hazard identification
   a. Sources of the hazard (MeHg)
   b. Hazard in the specific food (MeHg in dried tamban)

2. Hazard characterization (evaluation of adverse health effects)
   a. Distribution and pharmacokinetics
   b. Adverse effects
   c. Dose-response
   d. Establishment of food safety limits: general population (health-based guidance values)
   e. Philippine reports of poisoning or illness

3. Exposure assessment
   a. Hazard concentrations in tamban in the Philippines
   b. Philippine data for dietary hazard concentrations compared with overseas data
   c. Consumption information to establish baseline dietary exposure estimate
   d. Comparison of Philippine dietary exposures with overseas estimates

4. Risk characterization
   a. Estimate of risk for the Philippines
   b. Adverse effect levels applied to Philippine exposures
   c. Uncertainties and variability

5. Availability of hazard control measures
   a. Existing control measures in the Philippines: regulatory and advisory
   b. Control measures employed overseas
   c. Control options

Additional Information
1. Hazard identification is the identification of biological, chemical, and physical agents capable of causing adverse health effects and which may be present in a particular food or group of foods (FAO/WHO 2003).
2. Hazard characterization is the qualitative and/or quantitative evaluation of the nature of the adverse health effects associated with biological, chemical, and physical agents, which may be present in food. For chemical agents, a dose-response assessment should be performed (FAO/WHO 2003).
3. Exposure assessment includes the following: dietary hazard level in soy sauce in the Philippines compared with overseas data; consumption information to establish baseline dietary exposure estimate; comparison of Philippine dietary exposures with overseas estimates; and major contributing foods.
4. Risk characterization includes the following: estimate of risk for the Philippines; adverse effects levels applied to Philippine exposures; and uncertainties, variabilities, and assumptions.
5. Justifications of variabilities are as follows:
   a. Difference in the bioaccumulation mechanisms among fish species. Bioaccumulation and biomagnification result in higher MeHg levels in large predatory fish (McIntyre and Beauchamp 2006). Hence, studying species that comprise the diet of predatory fish [e.g. tamban serves as the main food source of pelagic tuna, mackerel, and other predatory fish (Luceño et al. 2014)] is very beneficial in formulating control measures to reduce MeHg levels from its primary sources.
   b. Difference in fish size and age per fishing ground. The level of contamination may be attributed to several factors such as fish age, trophic position, fish length, and Hg input from anthropogenic sources (McIntyre and Beauchamp 2006; Sackett et al. 2013). According to McIntyre and Beauchamp (2006), fish age – along with trophic position – contributes significantly to the Hg biomagnification in the aquatic food web. Likewise, fish length is usually positively correlated to the level of Hg contamination and fish age and is found to be a reliable indicator of higher THg levels in fish (Sackett et al. 2013).
   c. Presence of natural and anthropogenic sources of Hg and level of THg or MeHg present per fishing ground. Meanwhile, fossil fuel combustion of power plants (e.g. coal, diesel) and ASGM activities were determined to be major contributors to Hg pollution, with ASGM contributing to approximately 800 tons of Hg releases in land and water every year (BRI-IPEN 2014).
   d. Difference in the consumption of tamban per province and age group. The data from DOST-FNRI was used in this risk profile. The DOST-
FNRI has the authority to conduct NNSs, which provide a key source of data on food, health, and nutrition for the Philippine national government in response to their mandate to define the nutritional status of the Filipino citizens [EO 128 sec. 22, cited by DOST-FNRI (2015)]. Likewise, the WHO recommends that national authorities conducting their own dietary exposure assessments use national food consumption and concentration data while applying international nutritional and toxicological reference values (WHO 2020).

Hence, the 56.0 g/d dried tamban consumption by the 97.5th percentile of the consuming population (n = 1988) from DOST-FNRI (2020) was used to estimate the dietary exposure of Filipinos to MeHg in dried tamban. The use of high percentile consumption (97.5th) of the consuming population avoids underestimation of high exposure levels – underestimation may occur when consumption of the whole population is used due to the inclusion of non-consumers (WHO 2020).