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Mercury in Caribbean dolphins (*Stenella longirostris* and *Stenella frontalis*) caught for human consumption off St. Vincent, West Indies

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ABSTRACT

The island of St. Vincent in the Lesser Antilles supports an ongoing, legal cetacean hunt, which targets several species for human consumption. Little is known regarding the healthfulness and potential health risks of these foods in this setting. Following established methodologies we analyzed 39 raw muscle tissue samples and 38 raw blubber samples from two cetacean species for total mercury and methyl-mercury. We also analyzed samples of muscle tissue from an unknown cetacean species prepared for consumption. We report high concentrations of total mercury and methyl-mercury in these tissues as compared to published data for other seafood products. Further, our findings indicate that the traditional preparation method most often used locally in St. Vincent yields a finished food product with a much higher mercury concentration than the unprocessed tissue. Our results highlight the potential for negative human health effects related to the consumption of these food products in St. Vincent.

1. Introduction

Mercury (Hg) contamination in seafood is well documented for its negative effects on human health (McNutt, 2013). According to the World Health Organization (2007), the central and peripheral nervous system is the most vulnerable to Hg consumption, with neurological and behavioral disorders observed, including "tremors, insomnia, memory loss, neuromuscular effects, headaches and cognitive and motor dysfunction." WHO also notes renal and immunological effects in adults, the special vulnerability of children to Hg exposure, and the connection between ingestion of Hg by pregnant women and neurodevelopmental problems in the developing fetus such as "mental retardation, seizures, vision and hearing loss, delayed development, language disorders and memory loss."

According to the United Nations Environmental Programme (2013), the major anthropogenic Hg sources are artisanal and small-scale gold mining – at 727 metric tons per annum – and coal burning – at 475 metric tons. Some of this Hg is released directly into the marine environment; more is released into the atmosphere but this often finds its way into the oceans via precipitation and runoff. Elemental Hg becomes methylated in the benthic environment. Methylmercury (MeHg) is far more toxic to humans. Both forms of mercury bioaccumulate in aquatic animals, leading to increased exposure to humans as they eat seafood from higher marine trophic levels and from longer-lived species.

While seafood consumers in the United States and Europe generally understand the categories of high trophic level and long-lived marine organisms to include sharks, swordfish, tuna, & c. (Karimi et al., 2012), consumers in other parts of the world include marine mammals within their range of dietary options. The exclusion of marine mammals as food source has not always been the case in the American context (Shoemaker, 2005) and certainly is not the majority approach throughout the world's coastlines (Robards and Reeves, 2011). Marine mammal consumption and the attendant risks of mercury contamination are primarily studied in polar, sub-polar, and temperate contexts. However, tropical locations where marine mammals are consumed are also susceptible to the effects of mercury in the marine and coastal environment (Costa et al., 2012).

This report focuses on one such example of a tropical society in which the hunting and consumption of marine mammals is common (Fig. 1): St. Vincent and the Grenadines, an independent archipelagic nation in the southeastern Caribbean. The food products of this operation – meat and blubber – are consumed regularly by a majority of the population, 64% and 55%, respectively (Fielding, 2013).

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High levels of total Hg and MeHg, as well as risks to human health, have been identified in other locations where humans consume cetaceans, including Japan (Simmonds et al., 2002; Endo et al., 2003, 2005) and the Faroe Islands (Simmonds et al., 1994; Weihe and Joensen, 2012). One would reasonably expect similar results from St. Vincent. During the summer and fall of 2009 we collected muscle and blubber samples from 39 cetaceans – 28 spinner dolphins, *Stenella longirostris*, and 11 Atlantic spotted dolphins, *Stenella frontalis* – caught for human consumption. The samples were taken from the ventral abdominal wall, immediately after landing. Each sample measured approximately 1 cm^3. The tissue was kept in frozen storage until it could be exported to the United States for analysis. In addition to the fresh (i.e. unprocessed) muscle and blubber tissue, we purchased in the local market several pieces of prepared meat for comparative analysis.

2. Methods and materials

We measured total Hg concentrations using a modified EPA method 7473: *Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry* (EPA, 1998) using a Milestone DMA-80 Hg analyzer. We weighed muscle or blubber samples of about 0.2 g wet weight into quartz sample boats and analyzed them without further processing. We compared absorbances to calibration curves of 0, 10, 20, 30, 40, 60, 100, 200, 300, 400, and 500 ng Hg in 5% aqueous HCl.

Associated QA samples included two reference materials, NRCC TORT-2 and DOLT-3. Also included were method blanks, replicate samples, and spike recovery samples. Recoveries were 100% ± 7% and 102% ± 1% for TORT-2 and DOLT-3, respectively. Precision, estimated as the coefficient of variation (CV = 100% × standard deviation/mean), was about 4–5% for both CRMs, yielding the greater-than-100% values.

We analyzed samples for MeHg using a method modified from that of Hammerschmidt and Fitzgerald (2005). We extracted MeHg from weighed tissue samples of about 0.2 g with 10 ml of 5 N nitric acid heated to 55 °C for 4 h. Aliquots of the extract were analyzed by ethylation, gas-chromatographic cold-vapor atomic fluorescence spectroscopy (EPA, 1998) using a Brooks Rand MERX automated MeHg analyzer against standards from 10 to 1000 pg. Recoveries for MeHg in a series of marine tissue CRMs from the National Research Council of Canada averaged 106% ± 3%.

Fig. 1. Crews of two boats pursue marine mammals off the coast of St. Vincent.

3. Results

Results of our analysis of the fresh tissue are presented in Table 1. Total Hg concentration is observed at levels above 1 μg Hg g^{-1} (ppm) in both muscle and blubber tissue from both dolphin species. MeHg concentration is near 1 ppm in muscle tissue from both species but much lower in blubber tissue. Mercury concentrations have been widely reported in marine mammals, though the species considered in this study are less commonly represented in the literature. Concentrations of mercury in marine mammal muscle tissue can vary with taxon, size and age, and area of residence (Gaskin et al., 1974; André et al., 1990; Gonçalves et al., 1992, 1996; Cardellicchio et al., 2002; Chen et al., 2002; Capelli et al., 2008). Table 2 presents a summary of the results of four comparable studies.

The majority of studies – both referenced above and otherwise – of mercury concentrations in marine mammals take place in contexts where the marine mammals themselves do not constitute a food source for local populations. Since the specimens in our study were caught for the express purpose of being converted into foodstuffs, one must consider the human health effects of their consumption.

It is important to note, however, that the tissue under consideration thus far is not in the form in which it is regularly consumed

Table 1
Analysis of fresh (unprocessed) tissue collected for this study.

Species	Tissue	Total Hg concentration (μg g^{-1} wet wt.)					MeHg concentration (μg g^{-1} wet wt.)					*n* =
		Mean	Median	Std. Dev.	Min.	Max.	Mean	Median	Std. Dev.	Min.	Max.	
Stenella frontalis	Muscle	1.14	1.16	0.46	0.26	1.77	0.88	0.91	0.41	0.31	1.58	11
	Blubber	0.92	1.07	0.60	0.13	1.80	0.08	0.03	0.02	0.02	0.08	10
Stenella longirostris	Muscle	1.57	1.23	1.02	0.67	5.94	1.19	0.97	0.83	0.05	3.31	28
	Blubber	1.42	0.93	1.35	0.08	5.34	0.06	0.07	0.03	0.02	0.10	28

Table 2
Summarized data from comparable studies.

Species	Tissue	Location	Total mercury concentration (μg g^{-1} wet wt.)					MeHg concentration (μg g^{-1} wet wt.)					*n* =	Source
			Mean	Median	Std. Dev.	Max.	Min.	Mean	Median	Std. Dev.	Min.	Max.		
S. frontalis	Muscle	Azores, Portugal	0.50										1	Gonçalves et al. (1996)
S. frontalis	Muscle	Azores, Portugal	4.0										1	Gonçalves et al. (1992)
S. longirostris	Muscle	Taiwan	1.39		0.30	1.76	0.84	1.13		0.32	0.59	1.60	9	Chen et al. (2002)
S. longirostris	Muscle	St. Lucia, Lesser Antilles	0.87			1.33	1.10						2	Gaskin et al. (1974)

locally. In St. Vincent, cetaceans are butchered on the beach within a day of being caught (Fig. 2). The blubber is cooked in a metal drum over a flame to extrude the oil. The meat is cut into thin strips and hung to dry on portable bamboo racks, temporarily erected on the beach for this purpose (Fig. 3). When the meat achieves the desired dryness – akin to American beef jerky – it is cut into pieces of somewhat regular size and bundled for sale. These bundles, which range from 100 g to 250 g, represent the range of "serving size" of cetacean tissue. A person will usually consume an entire bundle, regardless of its weight, in the course of a single meal or snack. In addition to the fresh tissue, we analyzed four pieces of this processed meat. We were unable to determine the provenance (i.e. the species of cetacean from which it was produced). However, based upon historical catch compositions (Fielding, 2010) the tissue is most likely from one of the previously mentioned *Stenella* species or *Globicephala macrorhynchus*.

Fig. 2. A local man cuts blubber of a marine mammal as part of an *ad hoc* butchering operation on the beach.

Fig. 3. A local man places marine mammal meat on bamboo racks to dry in the sun.

The results of our analysis of the dried cetacean meat processed for human consumption are given in Table 3. In processed tissues, we observed both total Hg and MeHg at levels far exceeding 1 μg Hg g^{-1}. Indeed the processed meat shows an increase in total Hg by a factor of four to six and an increase in MeHg by a factor of five to seven, as compared to the unprocessed samples. The sun-drying process is the reason for this, as it removes moisture from the tissue, leading to the concentration of contaminants such as Hg, which do not evaporate. For reference, this mean value would be the third-highest concentration of mercury – after blue marlin and hammerhead shark – if included in the Seafood Hg Database presented by Karimi et al. (2012). This database contains grand means of mercury concentration of 1635 seafood varieties. The unprocessed *S. longirostris* and *S. frontalis* tissues would hold positions 41 and 73, respectively, within the same database.

4. Discussion and conclusions

The government of St. Vincent and the Grenadines currently has no published guidelines on Hg consumption. For reference, the U.S. Food and Drug Administration's "action level" on MeHg is 1 μg g^{-1} (FDA, 2011). Action levels do not equate to consumption guidelines, rather, "authorities may use the federal tolerances or action levels to decide whether to issue local advisories to consumers recommending limits on consumption" (FDA, 2011, 155). The EPA uses a screening value for Hg of 0.3 μg g^{-1}, based on a reference dose of 0.1 μg g^{-1} kg (body weight)$^{-1}$ day^{-1} assuming consumption of 25 g day^{-1}.

These data would suggest caution among consumers of cetacean-based food products in St. Vincent, where cetacean meat is consumed on average 25 times per year and 68% of respondents believe cetacean meat to be a "healthy" food product, according to a recent survey of 211 post-secondary school students from throughout St. Vincent and the Grenadines (Fielding, 2013). If the assessment of a food product's healthfulness is to include information regarding its concentration of environmental contaminants, the healthfulness of cetacean meat in St. Vincent is questionable indeed. However, with the presentation of these data we do not make recommendations for specific dietary guidelines in St. Vincent. It is important to take into consideration the health, economic, conservation implications of any alternative protein source that may replace cetacean products there.

Previous studies in other geographical contexts where humans consume food products derived from small cetaceans can be informative to the investigation of contaminants found in St. Vincent. Particularly relevant to this study are investigations conducted in Japan, Greenland, Canada, and the Faroe Islands, each of which has dietary guidelines in place – usually for fish since marine mammals are not a normal food source in most contexts – or acknowledges relevant guidelines from one or more international organizations.

Table 3
Analysis of processed tissue collected for this study.

Species	Tissue	Total Hg concentration (μg g^{-1} wet wt.)					MeHg concentration (μg g^{-1} wet wt.)					n =
		Mean	Median	Std. Dev.	Min.	Max.	Mean	Median	Std. Dev.	Min.	Max.	
Unknown	Muscle	7.59	7.60	0.56	6.94	8.22	6.05	5.66	1.06	4.66	8.20	4

In Japan, Endo and Haraguchi (2010) reported mean total mercury concentrations in the meat of short-finned pilot whales (*G. macrorhynchus*), striped dolphins (*Stenella coeruleoalba*), and Risso's dolphins (*Grampus griseus*) of 9.6 $\mu g\,g^{-1}$, 4.0 $\mu g\,g^{-1}$, and 4.4 $\mu g\,g^{-1}$, respectively. These concentrations were sufficient to produce high levels of Hg in hair samples from Japanese residents who ate whale meat, as compared to those who did not. Additionally, in Endo and Haraguchi's study, three of the fifty human subjects exhibited hair-sample concentrations of Hg in excess of the "no observed adversary effect level" set by the WHO at 50 $\mu g\,g^{-1}$.

In Greenland, Dietz et al. (1996) found most marine mammals to have Hg concentrations that exceeded the Danish food standard limits. In their analysis of muscle tissues of small, toothed cetaceans – including beluga (*Delphinapterus leucas*), narwhal (*Monodon monoceros*), and harbor porpoise (*Phocoena phocoena*) – this team found mean Hg levels between 0.137 $\mu g\,g^{-1}$ and 0.669 $\mu g\,g^{-1}$. These exceeded the Danish food standard limit for muscle tissue of mammals and birds, which at the time was 0.05 $\mu g\,g^{-1}$. The European Union now uses limits set by the Joint FAO/WHO Food Standards Programme (Codex Alimentarius, 1991) for MeHg at 0.5 $\mu g\,g^{-1}$ for most fish and 1.0 $\mu g\,g^{-1}$ for large predatory species. The concentrations measured by Dietz and colleagues would exceed these newer, more lenient standards as well.

In several field sites throughout the Canadian Arctic, Wagemann et al. (1996) found mean Hg concentrations in the muscle tissue of belugas to range between 0.70 $\mu g\,g^{-1}$ and 1.34 $\mu g\,g^{-1}$ and in narwhals between 0.85 $\mu g\,g^{-1}$ and 1.03 $\mu g\,g^{-1}$. All of these mean concentrations were in excess of the 0.5 $\mu g\,g^{-1}$ Canadian consumption guidelines for fish (Health and Welfare Canada, 1979).

Finally, in the Faroe Islands, Wagemann et al. (1996) report an average Hg concentration in the muscle tissue of long-finned pilot whales (*Globicephala melas*) of 3.3 $\mu g\,g^{-1}$. This concentration, combined with information on the average annual pilot whale catch and normal Faroese consumption patterns gave researchers confidence that many Faroese were consuming mercury from pilot whales in excess of the provisional temporary weekly intake of 0.3 $\mu g\,g^{-1}$ recommended by the WHO at the time (Weihe et al., 1996).

Public health reactions to these findings have varied. In the Faroe Islands, continued observance of high levels of Hg and other contaminants led medical officials in 1998 to recommend a reduction in consumption of cetacean-based food products. Continued research resulted a 2008 recommendation that pilot whales no longer be consumed in the Faroe Islands (Weihe and Joensen, 2012). This was a dietary guideline, not a law prohibiting whaling. However in other northern contexts, such as those studied by contributors to the Arctic Monitoring and Assessment Programme (AMAP), the resultant recommendations differ from the Faroese example. Hansen (2000, p. 124) reports,

> Weighing the risks against the benefits from traditional food the international human health group of AMAP decided to advice Arctic peoples to continue to eat traditional food and to breast feed their children, and to develop dietary advice for girls, women and childbearing age and pregnant women that would advocate the use of less contaminated food items, which maintain nutritional benefits.

Whether the people in St. Vincent who consume cetacean-based food products would be better protected by recommendations like those in the Faroe Islands or through advice such as that which AMAP gave to the Arctic communities is a matter to be considered by the Vincentian public health officials. Our data and other evidence regarding environmental contamination and its associated health risks may serve to encourage the government to enact dietary guidelines, or at the very least, to support further research into the presence of these contaminants in the waters from which Vincentians obtain much of their food supply.

It is interesting to note that, at present, the fisheries regulations of St. Vincent and the Grenadines do not include quotas or catch limits on cetaceans. Thus, any dietary recommendations that would result from this type of research might also have an effect on conservation. It is our hope that this and future research can provide an opportunity for the passage of meaningful public health policy in St. Vincent and the Grenadines, which in turn can promote good conservation policy without seeming to arbitrarily limit the livelihoods or cultural traditions of a unique island people.

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