MERCURY THREAT TO WOMEN & CHILDREN ACROSS 3 OCEANS

ELEVATED MERCURY IN WOMEN IN SMALL ISLAND STATES & COUNTRIES

Lee Bell, IPEN

November 2018

BIODIVERSITY RESEARCH INSTITUTE
innovative wildlife science

IPEN
a toxics-free future

MERCURY THREAT TO WOMEN & CHILDREN ACROSS 3 OCEANS

ELEVATED MERCURY IN WOMEN IN SMALL ISLAND STATES & COUNTRIES

Lead Author

Lee Bell

IPEN Mercury Policy Advisor

NOVEMBER 2018

Contributing authors: David Evers[1], Sarah Johnson[1], Mark Burton[1], Kevin Regan[1], Imogen Ingram[4], Joe DiGangi[2], Jennifer Federico[2], Jan Samanek[3], Lenka Petrlik[3]

[1] Biodiversity Research Institute (BRI), Maine, USA
[2] IPEN, Göteborg, Sweden
[3] Arnika Association, Prague, Czech Republic
[4] Island Sustainability Alliance (Cook Islands)

IPEN is a network of non-governmental organizations working in more than 100 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals.

www.ipen.org

Biodiversity Research Institute is a non-profit ecological research group whose mission is to assess emerging threats to wildlife and ecosystems through collaborative research, and to use scientific findings to advance environmental awareness and inform decision makers. BRI is the leading international institute supporting the global mercury monitoring efforts for the Minamata Convention on Mercury.

www.briloon.org

KEY FINDINGS

- 757 women of child-bearing age from 24 locations in 21 countries participated in this study. 58% of the women who participated had mercury levels greater than 1 ppm—the level that approximately corresponds to the US EPA reference level.* 75% of women had mercury levels greater than 0.58 ppm mercury, a more recent, science-based threshold based on data indicating harmful effects at lower levels of exposure. Mercury is a health threat to women and the developing fetus.
- The majority of sampled women of Small Island Developing States (SIDS) in the Caribbean, Indian Ocean and Pacific Ocean have elevated mercury body burden above the US EPA reference level, primarily due to contamination of their fish-rich diet.
- Distant air emissions of mercury from sources such as coal-fired power plants and mercury use in small-scale gold mining contaminate ocean fish that serve as a primary protein source for SIDS populations. SIDS are impacted by the negative consequences of these polluting activities yet receive none of the benefits.
- Mercury contamination of the Pacific Ocean has spread as far as the Hawaiian Island of Molokai, where high levels of mercury were recorded in women.
- Coal-fired power plant and cement plant emissions contribute mercury contamination to adjacent waterways and elevate mercury levels in Sri Lankan women living nearby.
- Indigenous women on St. Lawrence Island (Alaska) have mercury levels of concern due to their subsistence diet of sea mammals and fish. Consumption of locally available seals may be a key source of mercury exposure caused by distant industrial emissions.
- Women who ate few fish, small fish or who ate fish infrequently recorded the lowest mercury levels in this study.
- Burning coal for energy and using mercury in small-scale gold mining are primary drivers of atmospheric and ocean mercury contamination leading to elevated mercury body burden in women living in SIDS and SIDS-like locations.

* This is the daily exposure that US EPA considers "likely to be without an appreciable risk of deleterious effects during a lifetime."

CONTENTS

Executive Summary **5**

1. Introduction **10**
1.1 Biomonitoring 11
1.2 Expanding recent hair monitoring studies 12
1.3 Synergies between the Mercury Treaty and the Paris Agreement: Ocean mercury contamination and the coal connection 13
1.4 Economic impacts of elevated mercury body burden 15

2. Methodology **16**
2.1 Sampling Method 16
2.1.1 Target group 16
2.1.2 Participant selection 17
2.1.3. Ethics review and confidentiality of participants 17
2.1.4. Sample collection protocol 18
2.1.5. Sample analysis – mercury measurement 18
2.1.6. Assessment of results 20

3. Sampling locations **22**
3.1 Sampling location descriptions 22
3.1.1 Pacific countries: Cook Islands, Fiji, Kiribati, Marshall Islands, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu 22
3.1.2 United States of America: St. Lawrence Island (Alaska) and Molokai (Hawaii) 26
3.1.3 The Caribbean: Antigua and Barbuda, Barbados, Dominican Republic, Grenada, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, ... 28
3.1.4 The Indian Ocean: Comoros and Rodrigues 36
3.1.5 Sri Lanka 37

4. Results of sample analysis **40**

5. Assessment and Discussion **45**
5.1 General Comments 45
5.2 Assessment 47
5.3 High mercury levels in the Pacific SIDS 48
5.4 Elevated mercury levels in most of the Caribbean SIDS 53
5.5 Indian Ocean SIDS – Comoros has the highest levels of mercury recorded for SIDS 57
5.6 The influence of marine mammal consumption on mercury exposure – Alaska 57
5.7 Sri Lanka (Puttalam Lagoon): localized emission impacts from coal-based power and cement plant 61

References **63**

Acknowledgements **65**

EXECUTIVE SUMMARY

OVERVIEW

Mercury is a potent neurotoxin, especially to the developing brain, and can affect the developing fetus months after the mother's exposure. The harmful effects that can be passed from the mother to the fetus include neurological impairment, IQ loss, and damage to the kidneys and cardiovascular system. At high levels of mercury exposure this can lead to brain damage, mental retardation, blindness, seizures and the inability to speak. While researchers have studied mercury body burden in specific regions of the world, information on developing and transition countries is lacking. This study builds upon previous mercury monitoring activities by IPEN and BRI and is focused on measuring the mercury body burden of 757 women of child-bearing age in Small Island Developing States (SIDS) and SIDS-like locations in the Pacific Ocean, the Caribbean and the Indian Ocean. SIDS-like locations are islands, often remote, where industrial development levels are low and the population relies on local fisheries as a major source of dietary protein. The main difference is that they don't have political nation state status. The data indicates that there is a serious and substantial threat to women and children's health from mercury exposure in most of the locations where sampling took place.

METHODOLOGY

Sampling was undertaken across the globe during 2018 by public interest Participating Organizations (POs) of IPEN, civil society organizations (CSOs) in the Caribbean and, in some cases, medical professionals working cooperatively with identical methodologies and sampling protocols at all locations. Logistics, communications, shipping and networking were ably supported by the Island Sustainability Alliance – Cook Islands (ISACI), the Basel Convention Regional Centre (BCRC) for the Caribbean, Arnika Association (Czech Republic), Biodiversity Research Institute (BRI, US) and IPEN. The POs and CSOs reached out to communities that may be susceptible to mercury contamination of food supplies such as fish, which can transfer their methylmercury (MeHg) body burden to humans when consumed. Nearly all the locations sampled, with the exception of Sri Lanka, were SIDS or exhibited SIDS-like characteristics of being remote island communities with limited dietary protein other than seafood.

The study resulted in samples being taken from 757 women in 24 locations across 21 countries. The methodology for the study required on-the-ground teams to identify groups of 30-35 women of child-bearing age (denoted as 18 - 44 years old) in one or two locations in each country and invite them to participate. The women provided signed consent to participate in the study. Participants were required to provide a small sample of hair and to complete a questionnaire to assist with contextual analysis. The samples of hair were shipped to the laboratories of BRI in the United States for analysis. Women in this age range were selected as they constitute part of the vulnerable sub-population groups at risk from mercury, a powerful neurotoxin that can affect the health of the mother and impact on a range of developmental endpoints in the developing fetus with lifelong consequences.[1]

Sample results were assessed against the internationally recognized reference level of 1 ppm total mercury (THg), above which health effects to the developing fetus of pregnant women may occur. The basis for the use of this reference level in this study is that it corresponds closely with the US EPA's reference dose (RfD) of 0.1 µg/kg bw/day and a blood mercury concentration of 4 - 5 µg/L.[2] For some time, the scientific literature has suggested that adverse effects on the sampled individual begin to occur at or above the reference level of 1 ppm.[3,4] However, the latest scientific literature concludes that negative developmental effects may occur at even lower levels[5] and that a threshold level of 0.58 ppm should be adopted as the level below which impacts on the developing fetus are negligible.[6] For the purposes of this study we used the accepted threshold of 1 ppm to assess elevated mercury levels in participants. However, where appropriate we have also included references to the proposed science-based threshold concentration of 0.58 ppm for comparison.

1 Bose-O'Reilly, S., *et al.* (2010) *Mercury exposure and children's health*. Curr Probl Pediatr Adolesc Health Care, 2010 Sep; 40(8):186-215.

2 US EPA (1997) Mercury study report to Congress, Volume IV, *An assessment of exposure to mercury in the United States*, EPA-452/R-97-006.

3 Trasande L, Landrigan PJ, Schecter C (2005) *Public health and economic consequences of Methyl Mercury Toxicity to the Developing Brain*, Environ Health Perspect 113:590-596.

4 Grandjean P, Weise P, White RF, Debes F, Araki S, Yokoyama K, Murata K, Sorensen N, Dahl R, Jorgensen PJ (1997) *Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury*. Neurotoxicol Teratol 19:417-428.

5 Murata K, Weihe P, Budtz-Jorgensen E, Jorgensen PJ, Grandjean P. (2004) *Delayed brainstem auditory evoked potential latencies in 14-year-old children exposed to methylmercury*. J Pediatr 144(2):177-183.

6 Grandjean P, Pichery C, Bellanger M, Budtz-Jørgensen E (2012) *Calculation of Mercury's effect on Neurodevelopment*. Environ Health Perspect. 2012 December; 120(12).

KEY FINDINGS

Of the 757 women of child bearing age who took part in this study 58% had a mercury body burden (as measured in hair) that exceeded 1 ppm Hg—the level that approximately corresponds to the US EPA reference dose. Locations where the mean (average) level of participants exceeded the 1 ppm reference level for mercury were Barbados, Comoros, Cook Islands, Fiji, Grenada, Kiribati, Marshall Islands, Molokai, St. Vincent and the Grenadines, Solomon Islands, Sri Lanka, Tonga and Trinidad and Tobago. In addition, 75% of all women who participated had mercury levels greater than 0.58 ppm mercury.

The majority of sampled women of SIDS in the Caribbean, Indian Ocean and Pacific Ocean have elevated mercury body burden above the US EPA reference level, primarily due to contamination of their fish-rich diet. Mercury contamination of the Pacific Ocean has spread as far as the Hawaiian Island of Molokai, where high levels of mercury were recorded in women who eat fish frequently. The most likely cause of the elevated levels among women who live in locations where there is minimal local mercury pollution is distant air emissions of mercury from sources such as coal-fired power plants and other industries, as well as air emissions from mercury use in small-scale gold mining. This contaminates ocean fish that serve as a primary protein source for SIDS populations.

Coal-fired power plant emissions are known to have long-range pollution impacts, but this study also notes that local impacts from these power stations are relevant. In one location studied, coal-fired power has contributed to contamination of waterways used for subsistence fishing, leading to elevated mercury levels in Sri Lankan women living nearby. Indigenous women on St. Lawrence Island (Alaska) have mercury levels of concern due to their subsistence diet of sea mammals and fish. Human consumption of locally available seals may be a key source of mercury exposure for Yupik women, as studies demonstrate the seals have elevated mercury levels due to fish consumption which, in turn, have been impacted by long-range emissions from industry.

According to the questionnaire data, women who ate few fish, small fish, fish from lower trophic levels or who ate fish infrequently recorded the lowest mercury levels in this study.

Burning coal for energy and using mercury in small-scale gold mining are primary drivers of atmospheric and ocean mercury contamination leading to elevated mercury body burden in women living in SIDS and SIDS-like locations.

CONCLUSION

This study has collated the hair sampling results from over 750 participating women to assess their hair mercury levels and therefore their body burden. The results were surprisingly high, even when compared to previous IPEN/BRI studies across the globe. This evidence, combined with past IPEN/BRI mercury sampling studies in both fish[7] and women of child-bearing age, consolidate the evidence that clearly shows industrial mercury emissions such as coal-fired powered stations are a primary driver of ocean contamination. Small-scale gold mining (ASGM) using mercury is the other major contributor to atmospheric contamination that is polluting ocean food chains both close to and distant from the source activity. While ASGM location sampling was not within the scope of this report, previous biomonitoring by IPEN/BRI in ASGM locations has shown very high levels in women of child-bearing age.[8]

The absence of local mercury polluting industries, gold production or other sources of significant mercury emissions in most SIDS, coupled with the remote distribution of the islands, indicate mercury contamination of seafood as the primary factor in the elevated mercury body burden in most of these women. This is supported by a strong correlation between those women with a high fish diet and elevated mercury levels as well as some locations where women had a low fish diet and low mercury levels. This points to a serious food chain contamination problem caused by global mercury deposition from industrial emissions to oceans. Subsequent bacterial methylation of mercury in oceans[9] results in its magnification through the food chain, impacting women reliant on fish as dietary protein in SIDS.

Data about mercury levels in women from the Caribbean Islands and in Indian Ocean Islands has, until now, been almost non-existent. The results in this study demonstrate that island communities bear a very heavy burden of potential health impacts, and the subsequent economic impacts, that mercury pollution of the food chain causes. Importantly, results from some locations where mercury levels are very low indicate that consumption of mercury-contaminated fish is the driver for elevated levels. For most of the women who participated in this study and the

7 Evers, *et al.* (2014). *Global mercury hotspots: New evidence reveals mercury contamination regularly exceeds health advisory levels in humans and fish worldwide.* Biodiversity Research Institute. Portland, Maine. IPEN. Göteborg, Sweden. BRI-IPEN Science Communications Series 2014-34. 20 pages.

8 Bell. L., Evers. D., Johnson. S., Regan. K., DiGangi. J., Federico. J., Samanek. J. (2017) *Mercury in Women of Child-bearing Age in 25 Countries.* A joint study by the Biodiversity Research Institute and IPEN. September 2017. Berkeley, California.

9 Sunderland, E. M., D. P. Krabbenhoft, J. W. Moreau, S. A. Strode, and W. M. Landing (2009), *Mercury sources, distribution, and bioavailability in the North Pacific Ocean: Insights from data and models*, Global Biogeochem. Cycles, 23, GB2010, doi:10.1029/2008GB003425.

communities they live in, there are very few protein alternatives available. Mercury sources such as coal-fired power represent a double threat to SIDS communities – rising seas caused by climate change are flooding islands while the mercury in the emissions poisons their food sources.

The solution to this problem is not for women to avoid eating fish but for non-SIDS nations to stop emissions of mercury from coal-fired power plants and other industrial sources, implement renewable energy and stop trading mercury, so much of which ends in ASGM use.

1. INTRODUCTION

The Minamata Convention on Mercury (the Mercury Treaty) was adopted in October 2013 and entered into force on the 16th August 2017, giving it the power of binding international law for those Parties that have ratified it. The creation of the Mercury Treaty serves to remind us that the global community now recognizes mercury as a global threat to human health, livelihoods, and the environment, and is now prepared to commit to further action to reduce global exposure to mercury. IPEN was closely engaged with the negotiations leading up to the adoption of the Minamata Convention, seeking to strengthen its provisions wherever possible and providing support and information to Treaty delegates to inform them of the wide range and severity of mercury pollution issues faced globally, as well as potential solutions.

Since the Mercury Treaty entered into force IPEN has remained active in the ongoing Treaty negotiations around technical matters related to implementation of the Treaty and gathering of data to support mercury reduction activities. IPEN continues to conduct a range of Mercury Treaty-related enabling activities, release publications and develop awareness-raising campaigns that include mercury monitoring and biomonitoring. Parties to the Treaty recognize that specific data is required to establish baselines of global mercury contamination levels so that the effectiveness of the Treaty measures may be assessed over time. Biomonitoring activities are crucial to fill data gaps on potential mercury impacts, particularly in developing countries and countries with economies in transition.

This study was undertaken to generate mercury biomonitoring data in locations where significant gaps exist and to answer questions that arose from previous joint sampling studies conducted by IPEN, BRI and UN Environment. A number of these studies suggested that there may be significant mercury contamination issues affecting women in the Pacific Islands. In particular, we sought to answer the question of whether all Pacific Islands are impacted to a similar degree by mercury deposition to oceans and subsequent fish contamination, or whether it was a localized issue for one or two island nations. Extending this hypothesis further, we sought to inquire as to whether SIDS in other regions experienced similar mercury contamination issues potentially related to elevated seafood mercury levels. We were able to extend our sampling activities for this study to diverse geographic locations such as the Caribbean, Indian Ocean and Pacific Ocean locations and Sri Lanka.

1.1 BIOMONITORING

Mercury biomonitoring is an essential element of any effective strategy to assess and reduce global mercury pollution. Recognizing this need, IPEN has developed an important collaboration with the Biodiversity Research Institute (BRI), a non-profit, ecological research group with more than 25 years of experience assessing emerging threats to wildlife and ecosystems. BRI is a leader in ecological research related to mercury monitoring and toxicology. This study represents one of IPEN and BRI's largest partnership programmes to date, with hair sampling of women of child-bearing age taking place in SIDS across the globe. At their laboratory in the state of Maine, US, BRI processed over 750 hair samples for this study, which were provided by women concerned about their mercury body burden and the potential impacts on a fetus. Hair samples were collected by IPEN Participating Organizations as well as civil society organizations, in cooperation with local communities. This form of mercury monitoring can act as an impetus for countries to ratify and implement the Mercury Treaty and reduce mercury pollution while establishing a baseline to observe any future reductions in mercury among their populations as a result of reduction measures. Parties to the Mercury Treaty have agreed that there is a need to generate mercury monitoring data from around the globe that can used to evaluate the effectiveness of the Treaty over time in reducing mercury pollution.

In 2014, IPEN launched the International Mercury Treaty Enabling Activities Program (IMEAP), with the aim of supporting preparations for developing countries and countries with economies in transition for rapid ratification and early implementation of the Mercury Treaty. IPEN successfully completed mercury-related research projects and associated activities in 29 countries via IMEAP. Through this process, member organizations communicated to IPEN the need to conduct targeted mercury biomonitoring to address widespread data gaps, to further elevate mercury awareness, and to promote ratification of the Mercury Treaty. In 2015, IPEN developed a mercury biomonitoring programme focusing on vulnerable sub-populations identified in the Mercury Treaty preamble, as well as in Article 16 (Health aspects), Article 18 (Public information, awareness and education), Article 19 (Research, development and monitoring), Article 22 (Effectiveness evaluation) and Annex C – Artisanal and small-scale gold mining (ASGM) and National Action Plans (NAPs) of the Treaty. In many developing and transition countries, there is a paucity of mercury biomonitoring data with which to inform policy decisions and generate public awareness about the hazards of mercury exposure.

IPEN, through its earlier mercury biomonitoring project collaboration[10] with BRI, gained valuable insights into potential locations for monitoring while building capacity within its network to implement a broader range of monitoring activities. The IPEN/BRI Project Team determined that there was a need to generate data from around the globe, with particular emphasis on Small Island Developing States (SIDS) in the Pacific Ocean, Indian Ocean and the Caribbean.

1.2 EXPANDING RECENT HAIR MONITORING STUDIES

In a 2015/16 study[11] (published in 2017), IPEN and BRI partnered with UN Environment (formerly UNEP) to conduct mercury biomonitoring of women of child-bearing age. Sampling was conducted in four Pacific SIDS and two non-Pacific countries. Data from that report for the countries of Cook Islands, Marshall Islands, Kiribati, and Tuvalu have been combined with the broader database of this report, as they used identical methodologies and sampling protocols, to provide a more complete picture of the Pacific SIDS situation. In the subsequent IPEN/BRI global study,[12] *Mercury in Women of Child-bearing Age in 25 Countries*, the Solomon Islands, Tonga and Vanuatu were added to the sampling database. In this study, samples from Samoa and Fiji have built further upon this sampling database. The mercury monitoring results from the 2015/16 study and subsequent global study were significantly elevated for nearly all Pacific Islands. Given the lack of local pollution sources, this could be attributed to mercury contamination of fish, which is a key component of island diets and the predominant protein source for hundreds of thousands of Pacific Islanders. The main finding of the collaborative study between IPEN, BRI and UN Environment was that Pacific Islanders studied face a serious problem with mercury contamination of fish that comprise a major part of their diet. The problem may have significant ramifications for all Pacific Islanders, as nearly all of those assessed exceeded the 1 ppm threshold level for mercury contamination of their hair. The addition of three Pacific Islands in this study expanded that database with similar results,[13] suggesting a widespread contamination issue may be having population-level effects, which requires additional monitoring. The additional data in this

10 Evers, D. *et al.* (2014) *Global mercury hotspots: New evidence reveals mercury contamination regularly exceeds health advisory levels in humans and fish worldwide.* Biodiversity Research Institute. Portland, Maine. IPEN. Göteborg, Sweden. BRI-IPEN Science Communications Series 2014-34. 20 pages.

11 Bell, L., (2017) *Mercury Monitoring in Women of Child-Bearing Age in the Asia and the Pacific Region.* A joint study by UN Environment, Biodiversity Research Institute and IPEN. April 2017. Berkeley California.

12 Bell. L., Evers. D., Johnson. S., Regan. K., DiGangi. J., Federico. J., Samanek. J. (2017) *Mercury in Women of Child-bearing Age in 25 Countries.* A joint study by the Biodiversity Research Institute and IPEN. September 2017. Berkeley California.

13 The levels for Samoa were significantly lower than for most other Pacific SIDS, and this appears to be due to the consumption of near-shore reef fish, which are low in mercury.

study (which now includes additional Pacific and Indian Ocean SIDS as well as eight Caribbean SIDS) confirms the value of widespread biomonitoring to establish baseline levels to measure the effectiveness of the Mercury Treaty over time.

1.3 SYNERGIES BETWEEN THE MERCURY TREATY AND THE PARIS AGREEMENT: OCEAN MERCURY CONTAMINATION AND THE COAL CONNECTION

A secondary element of our study was to establish if global mercury contamination of the oceans by global coal-fired thermal power generation and other industrial sources of mercury had extended beyond the Pacific Ocean, creating similar impacts in other geographic locations. A part of the premise of this hypothesis is that Parties to the Minamata Convention may have to take much stronger action under this Treaty and/or other Multilateral Environmental Agreements (such as the Paris Agreement) that address climate change given the synergies that can be achieved.

Methylation of mercury in the ocean results from atmospheric deposition from known mercury sources such as coal-fired power plants, cement kilns, metal processing smelters, chlor-alkali plants, vinyl monomer production facilities in China, and gold production. The primary industrial source is identified as coal-fired power stations.[14] Following atmospheric deposition, naturally occurring bacteria convert elemental mercury and other mercury compounds into methylmercury,[15] which is far more bioavailable than other forms of mercury and which accumulates through the food chain, resulting in high concentrations in top feeding predatory fish such as swordfish, shark and king mackerel.[16] Mercury also accumulates in fish further down the predatory chain but not at such high concentrations.

The Minamata Convention requires Parties to apply Best Available Techniques and Best Environmental Practices (BAT / BEP) for mercury emission and release control on known sources such as coal- fired power stations. However, this provision only applies to *new* plants and can only be legally enforced five years after the Treaty enters into effect for any given Party. The implementation of BAT / BEP for coal-fired power plants includes the installation of air pollution control devices (APCD) and can

14 AMAP/UNEP, (2013). *Technical Background Report for the Global Mercury Assessment 2013.* Arctic Monitoring and Assessment Programme, Oslo, Norway/UNEP Chemicals Branch, Geneva, Switzerland. vi + 263 pp

15 Harris RC, Rudd JW, Amyot M, Babiarz CL, Beaty KG, Blanchfield PJ, *et al. Whole-ecosystem study shows rapid fish-mercury response to changes in mercury deposition.* Proc Natl Acad Sci USA. 2007;104(42):16586–16591.

16 Kim *et al.* (2006) *The Effect of Fish Consumption on Blood Mercury Levels of Pregnant Women.* Yonsei Med J. 2006 Oct 31; 47(5): 626–633.

reduce mercury emissions from individual facilities by between 24 and 70%.[17] There are three key problems with this approach. The first is that it has no impact on existing coal-fired power stations, which are likely to have older equipment and higher pollution levels. Currently the estimated number of coal-fired power stations globally is around 3,700; however, there are currently proposals or construction underway for an additional 1600 facilities, increasing global coal power capacity by 43%.[18] If all these facilities are constructed within the next four years, then BAT / BEP for mercury will not apply to 5,300 coal-fired power plants unless countries take action outside of the Mercury Treaty to implement such measures (and some have done so already).

The second issue is that there is no limit on the number of new coal-fired facilities that a Party can construct. Even when the time limit is reached, where BAT / BEP must be implemented for new facilities, the number of facilities that may be constructed is limitless. In turn, the sheer volume of mercury emissions may swamp the reductions generated by BAT / BEP implementation.

A third issue is the concept of BAT / BEP itself. The premise of developing BAT / BEP guidance for coal-fired power plants is based on the practical question: "How can we optimize the operation of a polluting facility to reduce the amount of pollution it creates?" It is not based on the question, "How can we generate electricity with minimum pollution release?" As a result, the implementation of renewal energy generation is considered a separate issue to the more efficient operation of coal- fired power plants under the Treaty and its BAT / BEP guidance.

The Paris Agreement seeks to limit the rise in global temperature to well below 2 degrees Celsius above pre-industrial levels and to attempt to prevent the rise from exceeding 1.5 degrees Celsius. The substitution of coal-fired power with other energy sources such as renewable energy generation is an obvious measure to prevent additional sources of carbon pollution. The Minamata Convention on Mercury seeks to reduce mercury emissions by adding additional pollution controls to coal-fired power stations over time. There are clearly synergies to achieve both objectives by limiting and reducing the amount of new and existing coal-fired power generation through substitution with renewable energy. In both cases the benefits of reduction of impacts on human health and the environment

17 Wang, S. X., Zhang, L., Li, G. H., Wu, Y., Hao, J. M., Pirrone, N., Sprovieri, F., and Ancora, M. P.: *Mercury emission and speciation of coal-fired power plants in China*, Atmos. Chem. Phys., 10, 1183-1192, https://doi.org/10.5194/acp-10-1183-2010, 2010.

18 Tabuchi, Hiroko (2017) "As Beijing Joins Climate Fight, Chinese Companies Build Coal Plants," The New York Times, July 1, 2017. Accessed online at https://www.nytimes.com/2017/07/01/climate/china-energy-companies-coal-plants-climate-change.html

will last for generations. The impact of those reductions will depend on the urgency with which measures such as substitution are taken. Given the current trends in mercury pollution and climate change, it is likely that ambitious action, swiftly implemented, will be required both within and outside the frameworks of the Paris Agreement and the Mercury Treaty to prevent long-term consequences linked to coal-fired power production.

1.4 ECONOMIC IMPACTS OF ELEVATED MERCURY BODY BURDEN

While the health impacts of elevated mercury levels in the human body are well documented, a recent ground-breaking study[19] by Trasande *et al.* has also estimated the economic losses attributable to lost productivity in those populations where levels of mercury body burden exceed 1 ppm. The study analyzed hair samples from 15 developing countries and countries in economic transition. The results showed that 61% of all participants had hair mercury concentrations greater than 1 ppm. Using a linear dose response relationship and an assumed 0.18 IQ point decrement per part per million (ppm) increase in hair mercury concentrations, an estimate of lost productivity was developed. This data was used to estimate increases in intellectual disability and lost Disability-Adjusted Life Years (DALY). A total of USD$77.4 million in lost economic productivity was estimated assuming a 1 ppm reference level, and USD$130 million if no reference level was used. For many of the 21 countries identified in the report, the human health issues revealed through the sampling process are critical to address, but the Trasande *et al.* study points to far-reaching economic impacts from mercury pollution that will be borne by those countries least able to address the source of the mercury pollution and least able to bear such costs. Therefore, it is important to consider the whole scope of mercury pollution impacts in terms of human health, economic burden and ecological integrity.

19 Trasande L, DiGangi J, Evers D, Petrlik J, Buck D, Samanek J, Beeler B, Turnquist MA, Regan K (2016) *Economic implications of mercury exposure in the context of the global mercury treaty: hair mercury levels and estimated lost economic productivity in selected developing countries*, Journal of Environmental Management 183:229 - 235, doi: 10.1016/j.jenvman.2016.08.058 https://www.ncbi.nlm.nih.gov/pubmed/27594689

2. METHODOLOGY

In preparation for the implementation of this project, IPEN and BRI adapted a methodology based on the framework for hair sampling previously developed by IPEN, BRI and UNEP in a 2016 mercury biomonitoring project for the Asia and the Pacific Region[20] and for a much larger 2017 IPEN/BRI global hair monitoring study.[21] The methodology takes into account scientifically sound and acknowledged human hair monitoring protocols, including both technical and practical matters as well as an ethics review by the Institutional Review Board by the University of Southern Maine in Portland, US. In addition, ethics review processes have taken place in some of the countries where sampling has been conducted for this study. The methodology covers sampling method, collection of data, mercury measurements, sample storage and shipping, as well as assessment and evaluation of the results.

2.1 SAMPLING METHOD

2.1.1 Target group

The focus of this project is the vulnerable sub-population group of women of child-bearing age in Small Island Developing States. The definition of 'child-bearing age' differs to some degree between various institutions. Studies undertaken by United States researchers use the age range of 18 - 44 years due to federal government limitations on sampling of biological material from minors. For this project, the target group for sampling is women of child-bearing age from 18 - 44 years, as it would allow comparison with other studies using this range while meeting legal requirements of the BRI laboratory based in the US. The gender-specific impacts of toxic pollutants on women are increasingly being recognized as a global priority for investigation and redress. IPEN and UN Environment announced the establishment of a partnership[22] on this issue at the 3rd United Nations Environment Assembly in Nairobi, Kenya. This study seeks to further information on the impacts of mercury on women.

20 Bell, L. (2017) *Mercury Monitoring in Women of Child-Bearing Age in the Asia and the Pacific Region.* A joint study by UN Environment, Biodiversity Research Institute and IPEN. April 2017. Berkeley, California.

21 Bell, L., *et al.* (2017) *Mercury in Women of Child-bearing Age in 25 Countries.* A joint study Biodiversity Research Institute and IPEN. November 2017. Berkeley, California.

22 The full statement regarding the partnership on women and chemicals is available at https://ipen.org/documents/statement-partnership-between-ipen-and-unep-focus-women-and-chemicals

2.1.2 Participant selection

Female participants were selected based on the criteria of (1) their age (18 - 44 years); (2) willingness to participate; and (3) having sufficient hair to provide a sample for analysis. IPEN Participating Organizations (POs) and non-affiliated civil society organizations (CSOs) identified and convened participants at each location to administer the consent forms and questionnaire, and conduct hair sampling according to the specified protocols. The POs and CSOs gathered samples in a scientifically sound manner that is consistent with recognized standards for sample collection of human hair for mercury monitoring.[23] All were issued with the standardized methodology and protocols developed by BRI and IPEN to ensure consistency and comparability between this study and previous hair mercury monitoring studies conducted by IPEN and BRI. Locations where sampling took place were based on advice from local POs and CSOs, which considered issues of access, cultural sensitivities, timing and cooperative approaches with local communities and civil society organizations that supported the sampling.

2.1.3. Ethics review and confidentiality of participants

Prior to implementing this sampling project, the overall methodology was reviewed and approved by the Institutional Review Board of the University of Southern Maine in the US to ensure it met contemporary standards for ethical implementation of studies involving human subjects. The sample collection protocol incorporated documents and procedures consistent with this ethics approval. Participants were asked to sign a consent form if they were willing to have a hair sample collected for analysis.

A questionnaire was then administered to the participant by the IPEN PO or CSO representative, supported by a local, native language-speaking volunteer to ensure that the process was understood by participants and that accurate information could be collected from the questionnaires. Where English was not an appropriate language, participants were provided with a translation of relevant documentation, including waivers, questionnaires and sample results.

The right of confidentiality was granted to each individual participant unless she voluntarily decided to sign a document to waive it. To protect confidentiality of participants, several controls were implemented. Project-related data is presented as an aggregated analysis that does not enable public identification of individual participants. Each hair sample shipped to the BRI laboratories was labelled with an individual sample

23 United Nations Environment Programme and the World Health Organization (UNEP/WHO), (2008) *Guidance for identifying populations at risk from mercury exposure.*

ID code and country location code so that BRI does not have access to the identity of individual sampling participants. The same ID code is affixed to the front page of each completed questionnaire, allowing the data from questionnaires to inform the interpretation of sample analysis by IPEN without compromising confidentiality. The PO or CSO that conducted the sampling holds the master list linking the ID code to the name of the participant to allow them to provide contextual, health-related feedback to the individual participant along with the results of their individual hair sample analysis for total mercury concentrations.

Once individual participant sample data is generated and communicated back to the participant, that individual has the right to release that information if she chooses to do so. This is consistent with an individual's right to know about their personal health information and disclose it if they wish to.

2.1.4. Sample collection protocol

All POs and CSOs tasked with coordinating the collection of samples were provided with detailed sample collection, packaging and shipping protocols to ensure minimisation of any cross-contamination and to standardize sample collection for comparative analysis. Before taking any samples, the participant was invited to sign the consent form. If the participant declined, no sample was taken. After the participant signed the consent form, the sampler then administered the questionnaire.

Following the completion of documentation, the sampler, while wearing a pair of nitrile examination gloves (for collecting and handling each sample), would use an alcohol wipe to clean the cutting surfaces of the stainless-steel scissors for cutting the hair sample. Hair samples were obtained from individuals by cutting a small bundle of hair approximately 8 - 10 cm long and the thickness of a pencil (about 30 hair strands) from the occipital region of the skull as close as possible to the scalp.

The hair sample was then secured with a small self-adhesive label, using an arrow to indicate the direction of the scalp and leaving 3 - 4 cm of hair exposed from the label.

2.1.5. Sample analysis – mercury measurement

Once correctly packaged and labelled the samples were shipped by courier along with a data sheet listing each sample origin and a corresponding sample ID code. As soon as shipments arrived in the US, the hair samples were analyzed for total mercury at BRI's Wildlife Mercury Research Laboratory following EPA method 7473 by gold-amalgamation atomic absorp-

Figure 1. Occipital Region: Target sample area

Figure 2. Correct labelling and storage of sample

tion spectroscopy following thermal desorption of the sample using a Milestone DMA-80. A blank and two calibration standards (DORM-3 and DOLT-4) are used in each of the two detector cells. Instrument response is evaluated immediately following calibration, and thereafter, following every 20 samples and at the end of each analytical run, by running two certified reference materials and a check blank. Instrument detection limit is approximately 0.050 ng.

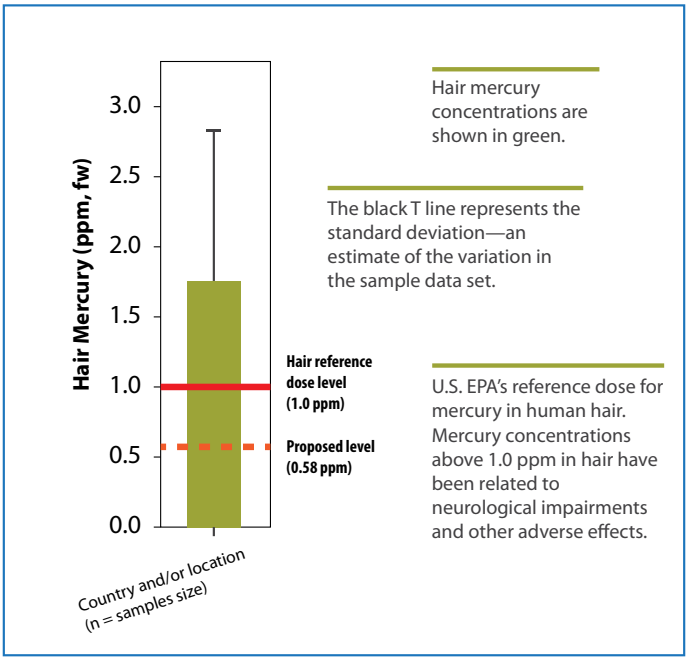
An acetone wash of the hair samples followed by a rinse with milli-Q water can be used to remove external contamination, such as hair products.

Results of total mercury are then recorded for each sample in parts per million (ppm) and recorded in tables by location.

2.1.6. Assessment of results

The interpretation of sample results was based on the comparison of data generated from the field samples with a reference level of 1 ppm (parts per million), which equates approximately to the US EPA's reference dose for mercury in human hair.[24] Mercury concentrations above 1 ppm in hair have been related to neurological impairments in adults.[25,26] These data will help determine contaminant concentrations in participating human subjects and potentially identify regions that require more intensive investigation. In addition, recent advances in the study of mercury impacts on the developing fetus suggest that levels of mercury body burden for women of child-bearing age, as measured in hair concentrations of total

Figure 3. Interpreting the hair mercury concentration chart



24 US EPA (1997) Mercury study report to Congress, Volume IV, *An assessment of exposure to mercury in the United States.* EPA-452/R-97-006

25 Yokoo, E.M., Valente, J.G., Grattan, L., Schmidt, S.L., Platt, I. and Silbergeld E.K. (2003) *Low level methylmercury exposure affects neuropsychological function in adults.* Environmental Health 2(1):8.

26 Karagas, M., Choi, A.L., Oken, E., Horvart, M., Schoeny, R., Kamai, E., Grandjean, P., and Korrick, S. (2012) *Evidence on the human health effects of low level methylmercury exposure.* Environmental Health Perspectives, 120: 799-806.

mercury (THg), above 0.58 ppm may have subtle but problematic impacts on the cognitive development of the unborn child.[27] For this reason, IPEN has applied the additional threshold of 0.58 ppm against the reported sampling results to assess relative levels of the groups studied.

27 Grandjean P, Pichery C, Bellanger M, Budtz-Jørgensen E (2012) *Calculation of Mercury's effect on Neurodevelopment.* Environ Health Perspect. 2012 December; 120(12).

3. SAMPLING LOCATIONS

In this section, further details are provided on selected locations where sampling has been conducted. A particular focus is provided on those locations where mercury levels in samples were elevated, including, but not limited to, Pacific and Caribbean Islands.

3.1 SAMPLING LOCATION DESCRIPTIONS

3.1.1 Pacific countries: Cook Islands, Fiji, Kiribati, Marshall Islands, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu

Data collected from hair sampling in this study builds upon sampling conducted in the Pacific Islands by IPEN and analyzed by BRI and published in April 2017 as the result of a joint IPEN/BRI/UN Environment study[28] focused on hair sampling for mercury among women of child-bearing age. Data is also incorporated from a separate, broader global study[29] that included additional Pacific Island nation data in November 2017. This study also includes new data from Fiji, Samoa and Molokai (Hawaii). Combining the data from the Pacific Ocean Small Island Developing States allows for a broader interpretation of results and supports the hypothesis that atmospheric mercury deposition from industrial sources such as coal-fired power generation is increasingly contaminating the food chain in terms of seafood and especially fish.

It is notable that, in the case of all Pacific Islands where sampling took place, no major industrial facilities that are known as a source of mercury pollution exist. Some islands have small landfills that could contain some discarded mercury-added products and subsequent leachate, but there appears to be no significant sources of mercury emissions and releases on any of the populated islands that would contribute to the elevated levels reported by women of child-bearing age in all but two Pacific Islands. This phenomenon is discussed further in section 5.

28 Bell, L. (2017) *Mercury Monitoring in Women of Child-Bearing Age in the Asia and the Pacific Region.* A joint study by UN Environment, Biodiversity Research Institute and IPEN. April 2017. Berkeley, California.

29 Bell, L., *et al.* (2017) *Mercury in Women of Child-bearing Age in 25 Countries.* A joint study Biodiversity Research Institute and IPEN. November 2017. Berkeley, California.

Figure 4. The Pacific Small Island Developing States (SIDS)

Cook Islands

The nation of Cook Islands is a remote group of 15 South Pacific islands spread over 2.2 million square kilometers. Sampling was conducted in two locations in the Cook Islands group.

Location A: Rarotonga – village-based participants

Sampling was conducted in Rarotonga among women who were originally from other villages in Rarotonga or islands in the Cook Island group.

Location B: Rarotonga – urban participants.

The second location for sampling in Cook Islands was among office workers based in Rarotonga.

Fiji

Fiji is a Pacific Island nation of Melanesian people with a significant Indian population descended from contract labourers brought to the island during a period of British colonial rule. Fiji is a tropical island with a land area of 18,376 km^2, a coastline of 5,010 km and a population of 912,241. The capital Suva is situated on the island of Viti Levu (where 70% of the population lives) and has a population of around 86,000 people. About

Figure 5. Fiji is constituted of Vanua Levu, Viti Levu and associated islets

50% of people live in urbanized settings. Fiji has a significant economy and exports sugar, fish and bottled water. FAO notes, "*Fish and fishing are extremely important to the economy of Fiji. A large number of people are employed in the fisheries sector and fish makes an important contribution to the diet of local residents. In addition, fishing is cherished for its recreational and social aspects. Per capita consumption of fish in 2013 was estimated at being about 35.6 kg (live weight equivalent).*"[30]

The Republic of Kiribati

The Kiribati Islands consist of three main groups separated by long distances in the southwest Pacific Ocean. The three groups are the Gilbert group on the equator, the Phoenix Islands in the east, and the Line Islands further east. The total land mass is 811 square kilometers. Participants in the sampling project were from the Betio district of the capital island Tarawa.

The Republic of Marshall Islands

The Marshall Islands are a nation of 29 coral atolls and 1,156 islands and islets in the Pacific Ocean located close to the equator just west of the international date line. Sampling was conducted in the capital of Majuro, which has a population of around 27,800 people who are predominantly Micronesian.

Samoa

Samoa consists of two islands, Savai'i and Upolu, which hosts the capital Apia. It is a Polynesian nation which came under the control of New Zealand at the beginning of World War 1 and gained independence in 1962. With a population of 195,000 and a land mass of 2,935 km^2, Samoa is a

30 Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles*. The Republic of Fiji FAO http://www.fao.org/fishery/facp/FJI/en

tropical island nation dependent on agriculture and fisheries for export income and food security.

Figure 6. The islands of Savai'i and Upolu, which form Samoa

According to FAO, "*Total fisheries production was estimated at about 8,700 tons in 2015, the bulk of which came from capture fisheries. The production from freshwater aquaculture ponds amounted to 13 tons of Nile tilapia. Per capita consumption of fish and fisheries products amounted to 48.5 kg/year in 2013, accounting for about 24 percent of animal protein. In total, an estimate of over 10,000 people has been made for engagement in subsistence fisheries. Coastal fishing is undertaken by villagers operating in shallow lagoon waters adjacent to their lands and is for both subsistence and commercial purposes.*"[31]

The results for the Samoan sampling were unusual compared to other Pacific nations and inshore reef fishing may have some bearing on the results. This is discussed further in Section 5.

The Solomon Islands

The Solomon Islands are a group of six major islands and over 900 smaller islands with a population of 635,027 people and a land mass of 28,400 square kilometers. The island group lies east of Papua New Guinea and northwest of Vanuatu. Sampling was conducted in Honiara, which is the capital of the Solomon Islands and is based on the island of Guadalcanal.

The Kingdom of Tonga

The Kingdom of Tonga is a Polynesian archipelago which consists of a group of 169 islands with a population of 103,252 people.[32] Only 39 of the islands are inhabited. The surface area of the islands is around 750 square kilometers, but they are dispersed across 700,000 square kilometers in an 800 km line north to south. Participants that provided samples came from

31 Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles.* The Independent State of Samoa http://www.fao.org/fishery/facp/WSM/en

32 Tongan Department of Statistics http://tonga.prism.spc.int/#population-statistics-including-administrative-information-and-statistical-tabulation-of-the-2011

various locations, including Kolofo'ou, Ma'ufanga, Kolomotu'a, Halafo'ou, Vaololao and Halafo'ou.

Tuvalu

Tuvalu is a nation of nine islands in the southwest Pacific Ocean formerly known as the Ellice Islands. They have a combined land mass of 27 square kilometers. Around 94% of the ethnic Tuvaluan population are Polynesian. Those on the island of Nui are of Micronesian origin. Sampling was conducted in Funafuti Island, the administrative capital of Tuvalu. Women who participated were from a range of Tuvaluan Islands.

The Republic of Vanuatu

Vanuatu is a Melanesian society consisting of 80 islands in the South Pacific Ocean distributed across 1300 kilometers with a population of 234,023. The surface area of the islands is approximately 12,200 km^2. Its capital, Port Vila, is situated on the island of Efate. Sampling was conducted with participants from Port Vila.

3.1.2 United States of America: St. Lawrence Island (Alaska) and Molokai (Hawaii)

St. Lawrence Island (Alaska)

Hair sampling in Alaska took place at two locations on St. Lawrence Island, which is located in the northern Bering Sea off the northwest coast of Alaska. It is only 40 miles from the Chukotkan Peninsula of Russia. This location was selected because the Arctic has become a hemispheric sink for persistent chemicals that travel hundreds of miles into the region, through a process known as global distillation, and accumulate in the bodies of wildlife and people. This region of the Arctic may also be a deposition zone for mercury and the hair sampling may provide some initial indication as to whether this is occurring via dietary indicators. St. Lawrence Island is approximately 100 miles long and 20 miles wide at the widest point. It is comprised of volcanic mountains (inactive) as well as wetlands and streams. There are approximately 1,600 people who live on the island in two communities — Gambell and Savoonga. They are Yupik people who have relied on traditional foods, including fish and marine mammals, for centuries for their physical, spiritual, and cultural sustenance.

According to the questionnaire data obtained at the time of sampling, the diet of the women who provided hair samples is dominated by walrus and

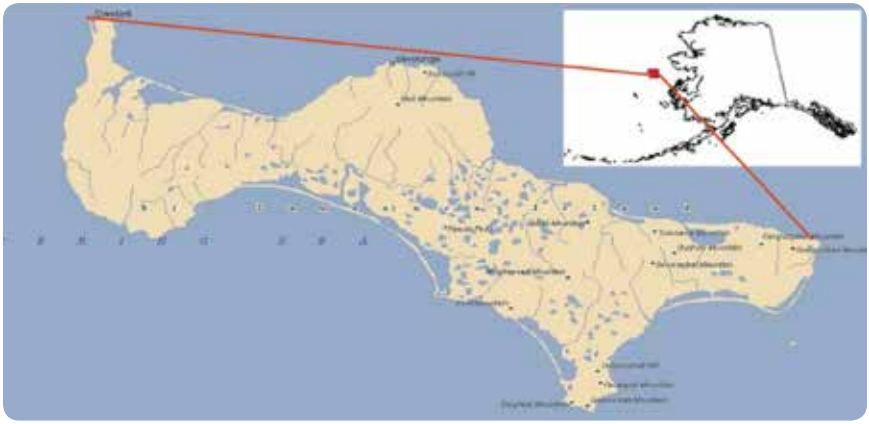


Figure 7. Map of St Lawrence Island noting sampling locations at Gambell and Savoonga

seal meat (and to a lesser extent, whale meat and blubber). The marine mammals include the Pacific walrus (*Odobenus rosmarus divergens*), ringed seal (*Pusa hispida*), bearded seal (*Erignathus barbatus*), spotted seal (*Phoca largha*), ribbon seal (*Histriophoca fasciata*), and bowhead whale (*Balaena mysticetus*). A variety of fish species and marine invertebrates are also eaten, including sockeye salmon (*Oncorhynchus nerka*), chum salmon (*Oncorhynchus keta*) and halibut (*Hippoglossus stenolepis*). In addition, crustacea are also eaten, including clams, tunicates and crab. A significant number of women among the sample cohort exceeded the 1 ppm threshold level (30%) and the 0.58 ppm level (70%). This is discussed in more detail in section 5 due to the unusual influence of marine mammals in the local diet.

Molokai (Hawaii)

Molokai is one of the five major islands of the Hawaiian group, spans 61 km in length and is 16 km wide, and has a population of 7,345. Along the south shore, remnants of over 60 ancient Hawaiian fishponds which once held hundreds of tons of fish speckle the coastline, coining Molokai the name "'Molokai Āina Momona" (Fat Land or Land of Plenty). Seventy-two percent (72%) of Molokai's population is of native Hawaiian ancestry. Molokai has no stoplights and no buildings taller than a coconut tree. At least one-third of the average Molokai family's diet comes from traditional, subsistence activities (hunting, fishing, gathering, and farming). It is common practice to exchange fish for venison and breadfruit for taro, and to give food to kupuna (elders) who can no longer fish or hunt for themselves.

Figure 8. The Hawaiian island group (top) and Molokai (bottom)

Despite declining resources, Molokai residents persist by supplementing their diet with subsistence foods grown, gathered, caught, fished, and hunted. People not only subsist on traditional foods as a cultural practice, but out of necessity. Burdened with a 12% unemployment rate coupled by a high cost of living, high shipping costs of goods brought by barge and expensive 100% diesel powered electricity, the people turn to traditional life skills to stretch their dollars.

Sampling locations included two areas: Ho'olehua and Kaunakakai. Ho'olehua is about 6.5 km from the northwest coast of Molokai and Kaunakakai, the main town, is about 200 m away from the south coast. The entire island is considered rural and undeveloped. The career background of the women participants included homemakers, teachers, teacher assistants, a grocery store clerk, community college administration, a small business entrepreneur, employees of non-profit organizations, a masseuse, farmers and hospitality workers.

3.1.3 The Caribbean: Antigua and Barbuda, Barbados, Dominican Republic, Grenada, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago,

Previous sampling of island nations by IPEN and BRI has focused on the Pacific Island nations. The underlying hypothesis is to test whether isolated nations dependent on fish are experiencing elevated levels of mercury exposure as a result of their high seafood diets. Most SIDS have relatively small economies and many of the population rely on seafood as a staple protein. Results of mercury hair sampling among populations of women of child-bearing age in the Pacific Islands support the proposition that elevated levels of mercury in seafood are leading to higher exposures in the women providing hair samples and, by extrapolation, many of the population who share a fish-rich diet. In order to test this proposition in other geographic areas, IPEN has focused on the Caribbean Island nations

Figure 9. The Caribbean Islands

that share similar developmental attributes to Pacific SIDS, including a reliance of seafood for protein.

Antigua and Barbuda

Antigua and Barbuda are situated in the eastern Caribbean at the north of the Leeward Islands and is comprised of three islands: Antigua (280 km^2), Barbuda (161 km^2) and Radonda (1.6 km^2). The islands have a total coastline of 153 km and a population of 100,000. St. John, the capital, has a population of 23,000, and 25% of the population lives in urban areas. Antigua is generally composed of low-lying coral and limestone with some peaks. Barbuda is predominantly flat with a large lagoon on its west side. Redonda is a small, uninhabited rocky island. According to Commonwealth data, an artisanal fishing fleet is well established for domestic supply and limited export. Target species are tuna-like fish, queen conch, groupers, grunts, snappers, and sturgeon. There is currently no commercial exploitation of inland fishery resources, although the traditional harvest of some freshwater and estuarine species on a recreational or subsistence basis does occur.

Barbados

Barbados is a tropical Caribbean Island nation of 430 km^2. It is relatively flat and has extensive agriculture dominated by sugar production and fisheries, which has led to it becoming one of the more developed coun-

tries in the Caribbean. Tourism has been developing rapidly as part of the economic structure. Originally uninhabited, Barbados was claimed by the British in 1627 who used forced labour to develop a plantation economy. The current population of 292,336 are descended from mostly from African laborers sent by the British. Barbados gained independence from the UK in 1966. The capital, Bridgetown, has a population of 110,000 and about a third of the population live in urban areas. Fish is an important part of the local diet and consumption of fish was estimated at 40.1 kg per capita in 2013. According to the FAO, "*there are around 3000 active fishers in Barbados in 2015. Fish is landed at some 13 major landing sites all around the island. The fishing fleet comprises small open boats propelled by oars and outboard engines that fish for reef and coastal fishes to decked vessels which fish for tunas and swordfish on voyages lasting up to 14 days. There are also traditional vessels powered by inboard engines that fish for flying fish and large pelagic species, which land their fish on a daily basis.*"[33]

Dominican Republic

The Dominican Republic is situated on an island once known as Hispaniola that is now divided into two countries – the other being Haiti. Originally inhabited by the Taino indigenous people, the arrival of Christopher Columbus in 1492 saw the beginning of Spanish rule. In 1697 the Spanish acknowledged the rule of the French on the western third of the island,

Figure 10. Fisherman's catch in Dominican Republic. Source: El Dinero Newspaper

33 FAO Fisheries and Aquaculture Department, *Fishery and Aquaculture Country Profiles* Barbados. http://www.fao.org/fishery/facp/BRB/en

Figure 11. Map of Hispaniola - the island divided into the nations of Haiti and the Dominican Republic

which became known as Haiti. Independence was eventually achieved in 1844. With a land mass of 48,320 km^2, the Dominican Republic is a relatively large Caribbean island nation and has a sizeable population of 10,734,247. The capital, Santa Domingo, has a population of around 970,000. The Dominican Republic has traditionally relied on sugar, coffee, and tobacco as an economic base, but in recent decades has expanded its tourism, construction and other economic sectors, which now exceed the agricultural sector for income generation.

Fisheries are an important part of the economy and social life in the Dominican Republic, but the sector has been under increasing strain from overfishing, pollution, global warming and illegal fishing.[34] While in 1996 the annual catch was around 18,000 tons, it had virtually halved by 2015 to 8,900. Imports of fish to satisfy local demand continue to grow. Fish consumption in 2013 was estimated at 9.6 kg per capita.[35]

Grenada

Grenada was initially inhabited by Carib Indians prior to contact with western explorers. The French colonized the island in the 1600's, establishing sugar plantations with labour of African slaves. In 1762 the British took the island and expanded sugar and cacao production along with

34 FAO (2018) Agronoticias: Agriculture News from Latin America and the Caribbean. *Fishing in the Dominican Republic decreased by 50% over two decades.* http://www.fao.org/inaction/agronoticias/detail/en/c/1127314/

35 FAO Fisheries and Aquaculture Department, *Fishery and Aquaculture Country Profiles (2018).* Dominican Republic. http://www.fao.org/fishery/facp/DOM/en

Figure 12. Grenada and associated islands

spices. Independence was gained from the UK in 1974.

Located north of Trinidad and Tobago, Grenada has a land area of 344 km^2 and a population of 111,724. The capital of St. George's has a population of 7,500. The fisheries sector in Grenada has become a major economic contributor, evolving from mainly artisanal fishing a couple of decades ago to a more commercial operation and export earner. The fisheries industry is important to both economic development and food security, with catches estimated around 2,800 tons in 2014. FAO notes that, "*Annual per-capita fish consumption in Grenada was estimated at 28.7 kg in 2011. The fish catch in Grenada is mainly marketed fresh, fresh on ice and, to a lesser extent, frozen. There are six main market centres on the island of Grenada and one on Carriacou.*"[36] Administration of the Grenadines island group is divided between St. Vincent and the Grenadines and Grenada.

St. Kitts and Nevis

The mountainous volcanic island state of St. Kitts and Nevis lies approximately 110 km west of Antigua and Barbuda and 417 km east southeast of Puerto Rico with a land mass of 261 km^2 and a coastline of 135 km. The islands are separated by a 3 km wide channel known as The Narrows. The population of the country in 2013 was 54,000 and the capital Basseterre (situated on the island of St. Kitts) has a population of 13,000. Over 40% of the islands remain forested, with tropical rainforest and dense scrubby cover. The sugar industry once dominated the island

Figure 13. St. Kitts and Nevis

36 FAO Fisheries and Aquaculture Department, *Fishery and Aquaculture Country Profiles* Grenada. http://www.fao.org/fishery/facp/GRD/en

economy but was closed in 2006 due to increasing losses and has been superseded by tourism as the mainstay of the economy.

The islands were originally populated by Amerindians from South America when Europeans first attempted colonization in 1623. England and France fought over the territories during the 17th and 18th centuries, with the English eventually taking control of both islands in 1816. Self-government was achieved in 1976 and full independence followed in 1983. Despite being a sugar monocrop economy until the 1970's, St. Kitts and Nevis recognized the limitations of their agricultural base and thereafter had some success in promoting a diversified manufacturing base including electronics assembly, food-processing, beverages and clothing production. Fisheries are divided into two clear categories. The first is an artisanal and subsistence fleet producing around 730 tons of seafood a year, while the second is the largely foreign-owned and -crewed high seas fleet producing 65,000 tons a year. The artisanal fleet concentrates its activity on reefs, slopes and coastal ocean zones targeting reef fish and pelagic species such as needlefishes, dolphinfish, flying fishes and tunas. In 2013, per capita seafood consumption was estimated at 32.3 kg.[37]

St. Lucia

The island nation of St. Lucia is located south of Dominica and north of Barbados, where it forms part of the Windward Islands group projecting from the eastern Caribbean into the Atlantic. St. Lucia has an English and Creole French (Patwah) speaking population of 164,994. The oval-shaped island has a surface area of 616 km^2 with 158 km of coastline. Historically, early Arawak settlers were displaced by the Caribs around 800 CE. Between 1660 and 1814 conflicts for control of the island took place between the French, English and Caribs on many occasions, with the British ultimately taking control as a colonial power in 1814 with a plantation-based agricultural economy. St. Lucia established self-governance in 1967 and full independence in 1979. The agricultural origins of the economy have been partially maintained, and 30% of the land mass

Figure 14. St. Lucia

37 FAO Fisheries & Aquaculture, *Fishery and Aquaculture Country Profiles (2018)* St Kitts and Nevis http://www.fao.org/fishery/facp/KNA/en

is still under cultivation. The volcanic nature of the island is evident in its mountainous topography, which includes Mt. Gimie (950 m), Gros Piton (798 m) and Petit Piton (750 m) positioned along the 43 km length on the island. Despite land clearing for agriculture and some problems with deforestation, forest still covers over 75% of the island, including rainforest areas of high biodiversity.

The capital, Castries, with a population of around 68,000, functions as the administrative centre of an economy based on tourism (around 65% of GDP), off-shore finance, and a small but significant agriculture sector based on crops such as bananas, avocados and mangoes. In the last decade, St. Lucia's fishery has evolved from artisanal to a more commercial-based orientation, with 2,900 people engaged in marine fishing and 137 people (21% women) directly employed in aquaculture. In 2013, annual per capita consumption of fish products was estimated at 23.8 kg, though it should be noted that the tourism industry places a significant demand on seafood consumption, with over $USD 7 million in seafood imports required to meet demands.[38]

St. Vincent and the Grenadines

St. Vincent and the Grenadines are islands that are remnants of volcanic activity (and have a live volcano), with a total land mass of 389.3 km^2 (St. Vincent 344 km^2 and the Grenadines 45.3 km^2). They have rugged mountainous topography which is heavily forested. The population of 110,000 has a large urban component, with 50% of the population living in urban areas, including the capital Kingston with a population of around 17,000.

According to the Food and Agriculture Organization of the United Nations, "*Fish is an important protein source in the Vincentian diet second only to chicken. On average, domestic production of fish to the Vincentian market place meets the local demand and some is exported. In the high season, there is a surplus which is generally stored at sales outlets with cold storage facilities. Some fishers find additional storage outside of the market. The challenge with supply and demand in St. Vincent and the Grenadines is one of distribution. It is not unusual for there to be surplus fish at the Kingstown Fish Market or in Union Island and a shortage in a community to the North or in the center of the island. The local supply is augmented by imports of salted cod, mackerel, smoked herring, frozen shrimp and fillet Sword Fish.*"[39]

38 FAO Fisheries & Aquaculture, *Fishery and Aquaculture Country Profiles (2018)* Saint Lucia http://www.fao.org/fishery/facp/LCA/en

39 Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles*. Saint Vincent and the Grenadines. http://www.fao.org/fishery/facp/VCT/en

Trinidad and Tobago

Trinidad and Tobago are the most southerly of the Caribbean SIDS, lying just 11 km off the Venezuelan coast. The country has a land mass of 5,128 km^2 (Trinidad - 4,828 km^2 and Tobago - 300 km^2) and is believed to have been a part of the South American continent as recently as 10,000 years ago. It is high in biodiversity and has numerous river systems and a mountain range running through the north coast. The population was estimated at 1,218,208 in 2017, and the capital Port-of-Spain has a municipal population of approximately 37,074; a metropolitan population of approximately 128,026; and a transient daily population of approximately 250,000. The city serves primarily as a retail and business centre. It is located on the Gulf of Paria, on the northwest coast of the island of Trinidad.

Tobago's main city is Scarborough with 4,800 residents. The country has significant oil and gas production and a well-developed economy and finance sector. Tourism is also a key industry for this Caribbean nation. Heavy industry contributes significant local pollution in some areas. The artisanal fishery in Trinidad and Tobago is substantial. The fishing fleet of around 1,900 vessels operates from more than 100 landing sites (80 in Trinidad and 20 in Tobago).[40] The fishing fleet comprises primarily artisanal boats called "pirogues", which are generally equipped with one or two outboard engines, and targets coastal and demersal pelagics. The landing of all fish species in Trinidad and Tobago in 2005 was estimated in the vicinity of 13,500 tons. The inshore artisanal fishery contributed an estimated 75% - 80% of this landing. There are seven significant wholesale fish markets in Trinidad and Tobago. The estimated per capita consumption of fish amounted to 25.9 kg in 2013.

Locations for sampling included women from Ortoire Village (location 1) and women who work near Beetham Landfill (location 2).

Location 1 - Ortoire Village: The village is a quiet seaside community located on the southeast coast of Trinidad in the county of Mayaro. Mayaro Beach stretches for 9 miles and is the longest beach in Trinidad. Ortoire village is considered a fishing community; however, over the years, the whole county of Mayaro has also grown into a community where oil development takes place. Oil companies have worked towards developing the area as well as employ many of the villagers who were once fishermen. As a coastal community, many residents of Ortoire Village consume fish on a regular basis. Ortoire River is the longest river in Trinidad and runs just

40 FAO Fisheries and Aquaculture Department, *Fishery and Aquaculture Country Profiles.* The Republic of Trinidad and Tobago (2018). http://www.fao.org/fishery/facp/TTO/en#CountrySector-Statistics

north of Mayar county through Ortoire Village. The population of Mayaro is approximately 6,348.

Location 2 - Workers near Beetham Landfill: The Beetham landfill is the largest landfill in Trinidad and Tobago and was initially developed in a mangrove swamp with shallow ground water. It is located on the outskirts of the capital, Port of Spain (7 km away). There is no separation of waste, and, as such, mercury wastes are co-mingled with other wastes deposited there. There is no lining or barrier to prevent leaching and informal open burning also occurs at the landfill. It is therefore assumed that the Beetham landfill is a mercury hotspot.

3.1.4 The Indian Ocean: Comoros and Rodrigues

Comoros

The Comoros Islands are an archipelago of four volcanic islands (Grand Comore, Moheli, Anjouan and Mayotte) northeast of Madagascar and 1,140 km east of the Mozambique coast. The islands have a surface area of 1,861 km^2 and coastline of 427 km. Historically settled by African and Arab communities from the sixth century onwards, the French held colonial control over most of the island group from the mid 1800's until 1975, with the exception of Mayotte, which remains a French administration. The Comoros has little economic development and its inhabitants are primarily employed in agriculture, of which fisheries is a substantial artisanal activity with production of around 10,000 tons per annum – most of which is consumed domestically. Over five thousand vessels (many without motors) land the catch, which contributes heavily to the food security of the country, with an estimated per capita consumption of 25.2 kg in 2011.[41] Most of the islands are characterized by very deep water very close to shore.

Rodrigues (Mauritius)

Rodrigues is a small island situated 650 km east of Mauritius and is a dependency of that SIDS seeking full autonomy. The island of Rodrigues is only 18 km long and 8 km wide, and has a population of 38,000 which is dominated by Creole culture. The island is formed by a volcanic ridge on the Mascarene Plateau and is thought to be several million years old. It has abundant flora and fauna and some mountainous areas. The tropical island is surrounded by coral reefs and relies heavily on fisheries and agriculture for food security, although tourism has become an important

41 FAO Fisheries & Aquaculture, *Fishery and Aquaculture Country Profiles (2015)* Comoros. http://www.fao.org/fishery/facp/COM/en

Figure 15. Artisanal fisherfolk Rodrigues. Source: Mauritius Attractions

income source for the island. With 1,997 registered fishing boats and a catch of 2,300 tons per annum[42] the nature of fisheries is localized and artisanal.

3.1.5 Sri Lanka

Kalpitiya Peninsula and the Puttalam lagoon

The location chosen in Sri Lanka is located in the Kalpitiya Peninsula and between the Indian ocean and Puttalam lagoon. A significant industrial source of mercury emissions at the location is the Norochcholai coal-fired power plant. This location is different from all other locations in this report in that it is not a SIDS (although it is a coastal location with a population dependent on fish for protein) but was selected to assess the impact of a coal-fired power station on local mercury exposure. All other locations in this study are remote from coal-fired power stations and the contamination of fish is largely attributable to distant industrial sources and ASGM. In this case the hypothesis that coal-fired power emissions and releases can potentially contaminate local waterways is tested by examining human exposure. As the levels among women in this location are elevated, it suggests the need for a more in-depth assessment of fish contamination levels and potential improvements that could be made to reduce industrial emissions. A cement plant is also located on the eastern side of the lagoon and uses around 30% of the power station ash to mix with its products. On some occasions strong winds have resulted in large quantities of ash from stockpiles being blown across the land and

42 Republic of Mauritius (2016) Ministry of finance and Economic Development. Statistics Mauritius. Digest of Statistics on Mauritius. August 2017.

Figure 16. Coal-fired power station on the Kalpitiya Peninsula, Sri Lanka

Figure 17. Poorly controlled ash from the coal-fired power plant is blown into the air during strong winds. Source: The Sunday Observer, Sri Lanka

lagoon. The cement plant also has significant emissions, which may have an impact on mercury levels in the local fish. The Puttalam lagoon has a large, diverse fishery that is suffering degradation from industrial effluent, agricultural run-off, rubbish dumping and overfishing.[43]

43 Miththapala, S. (2011) *An Environmental and Fisheries Profile of the Puttalam Lagoon System.* IUCN, International Union for Conservation of Nature, Sri Lanka Country Office.

Figure 18. Coal ash blown into the air has previously contaminated local vegetation and waterways. Source: The Sunday Times, Sri Lanka

The high reliance of local people on fishery products from the Puttalam lagoon (and to a lesser extent, the ocean coast), which is suffering degradation due to industrial emissions and releases as well another pollution sources, provides a useful comparison with data from remote SIDS.

4. RESULTS OF SAMPLE ANALYSIS

4.1 HAIR SAMPLE ANALYSIS

The total mercury (THg) concentrations detected in the hair of the participants from all countries where sampling occurred varied considerably and were influenced by diet, exposure scenarios and, in at least one case, proximity to localized mercury pollution.

Table 1 below provides the analytical results for hair sampling, including the average mercury concentrations for each group, the standard deviation from the mean by group, the highest levels recorded by location, and the percentage of the sampled group that exceeded the 1 ppm reference level and the 0.58 ppm level.

TABLE 1. HAIR SAMPLING RESULTS FOR TOTAL MERCURY (Hg) CONCENTRATION BY LOCATION

Location	Number of samples	Mean Hg Concentration (ppm)	No. of samples greater than 1 ppm[a]	Percent greater than 1 ppm	Percent greater than 0.58 ppm[b]	Highest Hg level (ppm)
Pacific Islands						
Cook Islands A	30	3.607 ± 1.613	28	93	93	6.96
Cook Islands B	30	3.669 ± 2.197	29	97	100	8.54
Fiji	30	1.696 ± 0.789	26	86	100	4.59
Kiribati	30	3.427 ± 1.272	30	100	100	6.24
Marshall Islands	30	3.258 ± 2.219	29	97	97	11.31
Samoa	30	0.695 ± 0.464	4	13	43	2.55
Solomon Islands	29	1.634 ± 0.579	26	90	97	3.12
Tonga	30	3.677 ± 2.573	29	97	97	14.74
Tuvalu	30	2 ± 0.649	28	93	97	3.40
Vanuatu	30	0.717 ± 0.611	6	20	50	2.97
United States						
St. Lawrence Island (Alaska)	33	0.824 ± 0.450	10	30	70	1.90
Molokai (Hawaii)	30	2.615 ± 1.543	29	97	97	7.30

(Continued next page)

Location	Number of samples	Mean Hg Concentration (ppm)	No. of samples greater than 1 ppm[a]	Percent greater than 1 ppm	Percent greater than 0.58 ppm[b]	Highest Hg level (ppm)
Indian Ocean						
Comoros	26*	4.060 ± 6.669	23	88	92	27.92*
Rodrigues	40	0.911 ± 0.978	9	23	57	5.0
Caribbean						
Antigua and Barbuda	35	0.979 ± 0.637	15	42	68	2.998
Barbados	24	1.385 ± 0.972	14	58	79	3.986
Dominican Republic	36	0.178 ± 0.127	0	0	2.7	0.645
Grenada	36	1.381 ± 1.289	14	39	72	4.786
St. Kitts and Nevis	24	0.523 ± 0.328	2	8	50	1.187
St. Lucia	35	0.821 ± 1.149	9	25	48	6.492
St. Vincent and the Grenadines	37	2.040 ± 2.706	18	48	70	12.669
Trinidad and Tobago 1	36	1.941 ± 3.896	16	44	69	23.615
Trinidad and Tobago 2	30	1.158 ± 0.894	16	53	66	3.839
Other						
Sri Lanka	36	2.742 ± 2.803	28	77	97	15.584

a) 1 ppm corresponds closely with the US EPA's reference dose (RfD) of 0.1 µg/kg bw/day and a blood mercury concentration of 4 - 5 µg/L. b) Recent studies conclude that negative developmental effects may occur at even lower levels and that a threshold level of 0.58 ppm should be adopted as the level below which impacts on the developing fetus are negligible.

** In total 28 samples were taken in Comoros, but two of those samples had very elevated levels (99 ppm, 3058 ppm) and may be caused by surface contamination of the hair and are now subject to further evaluation. As such the values for these samples have not been included in this table at this time.*

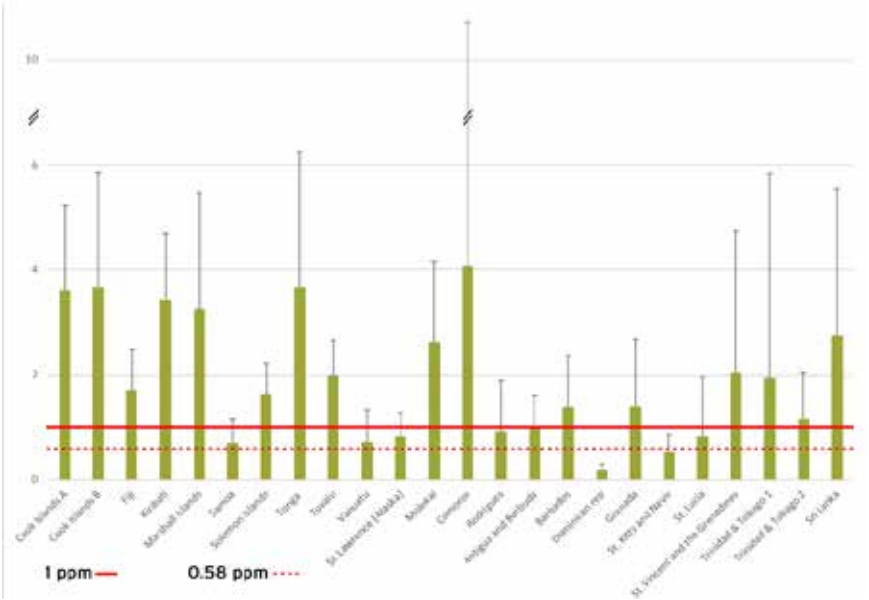


Figure 19. Mean mercury levels reported for all participants in each location. Red line equals 1 ppm reference level and dashed red line equals 0.58 ppm proposed reference level.

The following chart provides data on the percentage of all participants who recorded a result greater than 1 ppm total mercury in hair. The subsequent chart presents the percentage of all participants who recorded a result greater than 0.58 ppm total mercury in hair. The Pacific chart includes Molokai due to its geographic relationship, although it is listed under the US locations in other tables. Notable features of the chart directly below are the very high proportion of participants with elevated mercury levels for the majority of the Pacific locations as well as Molokai and Comoros. In addition, the majority of Caribbean locations have high proportions of participants with elevated results, with the exception of the Dominican Republic.

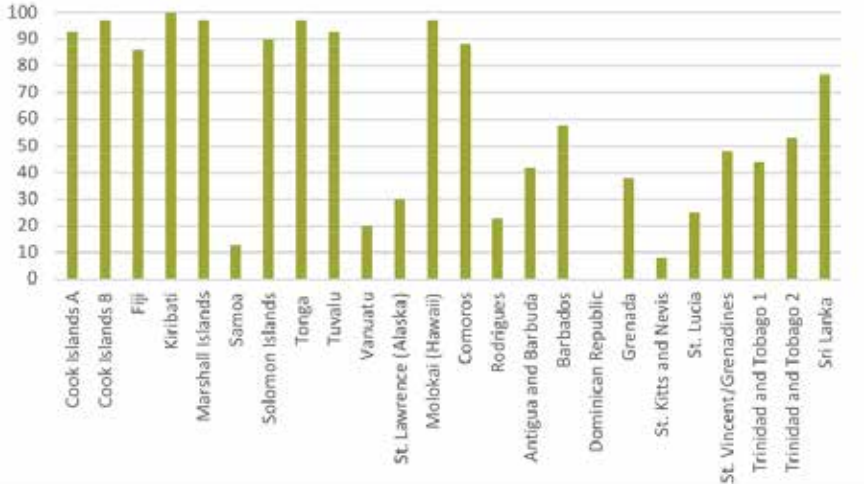


Figure 20. Percent of hair samples over reference level (Hg 1 ppm) by location

The chart below presents the results of all hair sampling locations for those participants whose levels exceeded the proposed lower reference level of 0.58 ppm mercury (body burden as measured in hair), above which recent studies have suggested that deleterious effects may occur in the unborn fetus. When the 0.58 ppm proposed reference level charts are compared to the 1 ppm reference level charts, the number of participants who exceed the lower threshold increases significantly in nearly all locations (although some locations had such a high percentage exceeding 1 ppm the differences are minimal).

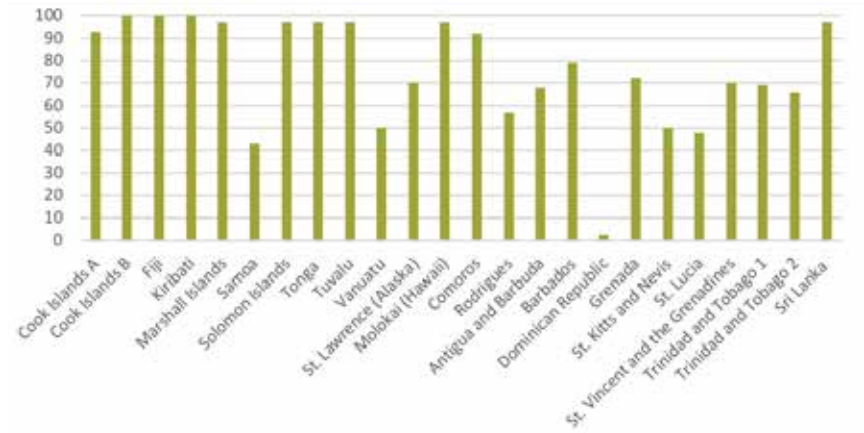


Figure 21. Percent of hair samples over proposed reference level (Hg 0.58 ppm) by all locations

5. ASSESSMENT AND DISCUSSION

5.1 GENERAL COMMENTS

In previous hair sampling projects IPEN focused initially on Pacific Islands and then on a much broader global study. One theme that became clear in those projects was a trend towards elevated levels of mercury in participants in geographically remote locations, with a high level of reliance for fish as a protein source (and in some cases marine mammals). It was noted in those reports[44] that many of the locations had no source of local mercury pollution that could result in such elevated levels for those participant groups. Based on existing data from the analysis of mercury levels in fish,[45] it became clear that the primary source of mercury exposure for these populations was dietary intake from fish contaminated with methylmercury.

As noted earlier in this study, mercury enters the ocean via deposition from atmospheric sources of mercury, which is then converted by bacteria into methylmercury which, in turn, is absorbed by fish through the food chain. Higher trophic level species such as tuna, swordfish and sharks absorb high levels of mercury through predation on fish at lower trophic levels. An analysis of the relevant literature indicated that the largest source of mercury emissions to atmosphere, after small-scale gold mining using amalgamation, is coal-fired power generation. Other industrial sources such as metallurgy, cement kilns and waste incinerators are smaller but significant contributors.

Atmospheric emissions from distant coal-fired power generation have again featured as the most likely source of seafood contamination, and therefore human exposure, in this study. Drawing upon our findings in past hair monitoring projects, IPEN has carefully selected a range of sampling locations representative of SIDS. Not every location is a SIDS in the sense of meeting political definitions, but all locations share common factors such as being remote island communities with a fish-rich diet

44 Bell, L., *et al.* (2017) *Mercury in Women of Child-bearing Age in 25 Countries.* A joint study Biodiversity Research Institute and IPEN. November 2017. Berkeley, California.
Bell, L. (2017) *Mercury Monitoring in Women of Child-Bearing Age in the Asia and the Pacific Region.* A joint study by UN Environment, Biodiversity Research Institute and IPEN. April 2017. Berkeley, California.

45 Evers, *et al.* (2014) *Global mercury hotspots: New evidence reveals mercury contamination regularly exceeds health advisory levels in humans and fish worldwide.* Biodiversity Research Institute. Portland, Maine. IPEN. Göteborg, Sweden. BRI-IPEN Science Communications Series 2014-34. 20 pages.

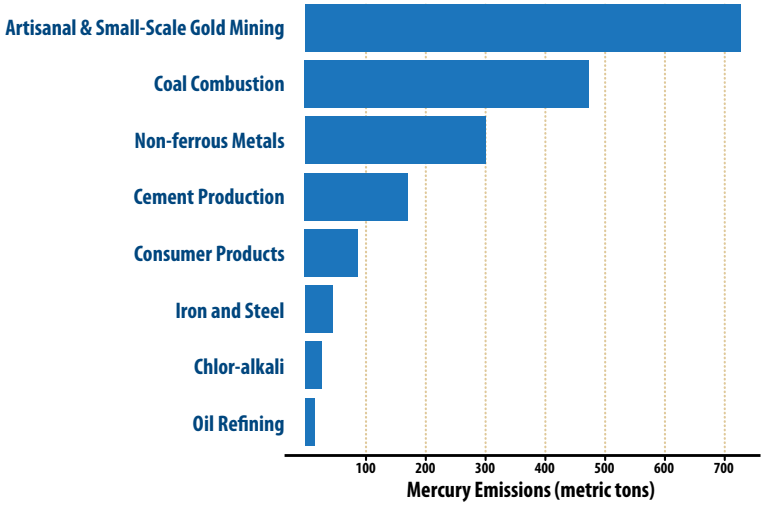


Figure 22. Anthropogenic mercury emissions by source (UN Global Mercury Assessment 2013)*

and minimal industrialization. The intention is to test the hypothesis that all SIDS and SIDS-like locations, with little industrial development and reliant on a fish-rich diet for protein, experience elevated levels of mercury exposure in women of child-bearing age due to global atmospheric mercury deposition to oceans and subsequent fish contamination.

For this study we expanded the range of Pacific SIDS sampling and included Molokai (Hawaii) in data representations for the Pacific due to its similarities in terms of isolation and fish-rich diet. In addition, IPEN has focused on Caribbean SIDS to explore whether similar elevated mercury exposure for women of child-bearing age is a feature in other geographical regions that have multiple SIDS populations. To broaden the scope further, IPEN included two Indian Ocean locations (Rodrigues and Comoros) which are SIDS or SIDS-like locations. The Alaskan site of St. Lawrence Island was included (although technically it is a part of a state of the US) as it met the geographic characteristics of a SIDS in that it is a remote island where the population relies heavily on subsistence fishing. It was also useful as a data source to investigate the exposure for women of child-bearing age where a large part of the diet is marine mammals along with fish. A location in Sri Lanka differed significantly from all

* *Note:* A revised Global Mercury Assessment for 2018 will soon be released, but is currently in draft form and cannot be quoted. However, an advance version indicates that, while sectors maintain a similar ratio to each other, all sectors have significantly increased in terms of total mercury emissions except for the chlor-alkali sector, which has reduced.

other sites and was included to assess the exposure of women close to a coal-fired power plant with a fish-rich diet for comparison with women exposed through diet in remote locations far from coal-fired power stations.

In general terms the levels of mercury found in most SIDS participants, whether in the Pacific Ocean, Indian Ocean or the Caribbean, were significantly elevated compared to non-SIDS and non-ASGM locations assessed in past IPEN studies. Two thirds of the locations where sampling took place reported a mean mercury body burden of 1 ppm or greater. For 87% of the locations tested, the average level of mercury body-burden among each group of participants was above 0.58 ppm.

In broad terms these results confirm our concerns that across the globe, women in small island locations who are dependent on fish as a primary form of protein, are being exposed to elevated and potentially dangerous levels of mercury from distant industrial emissions via the food chain. Coal-fired power represents a double threat to these populations given its driving role in climate change and sea level rise. In many of these locations, particularly the Pacific, the homes and health of women are under threat from the double impacts of coal-fired power. The results of this hair sampling suggest that there are few island locations immune to the twin threats posed by burning coal - rising sea levels and mercury contamination.

5.2 ASSESSMENT

With few exceptions (these are discussed below) the SIDS and SIDS-like locations where sampling was conducted reported elevated levels of mercury that can only be attributed to a fish-rich diet.

Overall, sampling was conducted in 24 locations in 21 countries, engaging 757 participants who were all women of child-bearing age (18-44 years). Of those 757 female participants, 58% (n= 439) had hair samples that exceeded 1 ppm total Hg. When assessed against the proposed body burden threshold of 0.58 ppm for total mercury, 75% (n= 568) of all women participants exceeded this level.

In the Pacific locations, 80% of participants exceeded the 1 ppm total mercury reference level and 88% exceeded the 0.58 ppm proposed reference level.

In Indian Ocean locations (Rodrigues and Comoros), 48% of participants exceeded the 1 ppm total mercury reference level and 71% exceeded the 0.58 ppm proposed reference level.

In Caribbean locations, 35% of participants exceeded the 1 ppm total mercury reference level and 58% exceeded the 0.58 ppm proposed reference level.

In St. Lawrence Island, Alaska, 30% of participants exceeded the 1 ppm total mercury reference level and 70% exceeded the 0.58 ppm proposed reference level.

In the Kalpitiya Peninsula, Sri Lanka, where a large coal-fired power station is located on a sand bar between the ocean and a fishing lagoon, 78% of participants exceeded the 1 ppm total mercury reference level and 97% exceeded the 0.58 ppm proposed reference level.

5.3 HIGH MERCURY LEVELS IN THE PACIFIC SIDS

Consistent with previous sampling activity results from Pacific Islands, the trend in this sampling round reveals mostly elevated levels among the communities who participated. It remains a great concern that 80% of participants recorded levels above 1 ppm Hg, with many recording significantly higher levels consistently within their group.

The geographic distances between SIDS in this region is significant in terms of the consistency of results and the impact of mercury on fish diets. Molokai is included in the grouping of Pacific SIDS in this instance (but is grouped in the US location elsewhere in this report) due to its geographic location and similar characteristics to SIDS in terms of artisanal fishing, island geography and dependence on a fish diet for protein. While high percentages of the participants had a result above 1 ppm in most Pacific locations, Samoa and Vanuatu were much lower (though still significant at 13% and 20%, respectively); however, when assessed for participants with a level > 0.58 ppm, the results were clearly much higher (43% and 50% respectively).

Results from most of the Pacific SIDS were among the highest levels recorded in any IPEN sampling activities, with consistently elevated average levels for each cohort. Mean levels were very high in the Cook Islands A & B locations (3.607 ppm ± 1.613 ppm (fw) and 3.669 ppm ± 2.197 ppm (fw), respectively), Kiribati (3.427 ppm ± 1.272 ppm (fw)), Marshall Islands (3.258 ppm ± 2.219 ppm (fw)), Tonga (3.677 ppm ± 2.573 ppm (fw)) and Tuvalu (2 ppm ± 0.649 ppm (fw)). The mean levels for Fiji (1.696 ppm ± 0.789 ppm (fw)) and the Solomon Islands (1.634 ppm ± 0.579 ppm (fw)) were slightly lower, but still elevated to such an extent to be a matter of concern. As were the significantly lower mean levels for Vanuatu (0.717 ppm ± 0.611 ppm (fw)) and Samoa (0.695 ppm ± 0.464 ppm (fw)), which are assessed in more detail below. A common factor among the question-

Figure 23. Kaunakakai Wharf in Molokai. Source: Mercy Ritte

naire data for the Pacific SIDS with higher average levels of mercury in hair was the frequency of fish consumption of species in the higher trophic levels. Many individuals consumed fish from these groups almost daily, which would contribute significantly to their dietary intake of mercury.

Molokai is one of the larger five islands of the Hawaiian group and has been included in this sampling to assess the extent to which island populations in the Pacific may be impacted by mercury across large distances. The mercury levels among the Molokai cohort were among the highest in the current study and slightly below the highest Pacific SIDS results, with a mean of 2.615 ppm ± 1.543 ppm (fw). Assessment of the questionnaires indicate that women in the sampling group had a very high frequency of fish consumption and that those fish are in the group noted as having high

Figure 24. Keawanui fish pond in Molokai. Source: Mercy Ritte

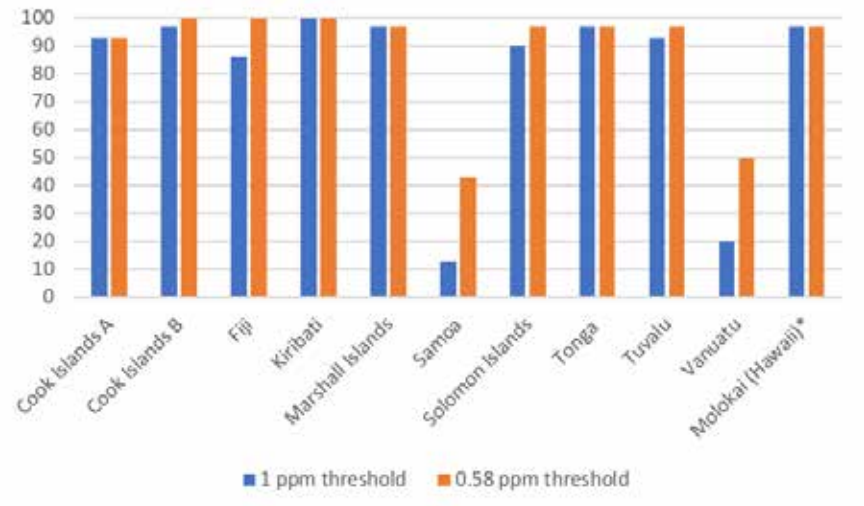


Figure 25. Percent of Pacific hair samples over the 1 ppm and 0.58 ppm reference level, including Molokai

concentrations of mercury such as mahi-mahi and tuna. The uniformity of high frequency of consumption in this group is the likely cause of the elevated mercury body burden levels given the absence of any significant industrial development or other mercury pollution sources on Molokai.

The exception to these very high levels was noted in sampling on Samoa and Vanuatu. Samoa, while reporting only 13% of the group above the 1 ppm level, still recorded 43% above the proposed 0.58 ppm threshold. The mean for the Samoan cohort was 0.695 ppm ± 0.464 ppm (fw). This may imply that, over time, younger women of the group will accumulate higher levels of mercury and surpass the 1 ppm level. Sampling took place on the island of Savai'i and included ten women from Tafua Village, twelve from Asau Village in the north, and the remaining eight were from Salelologa, the main town of Savai'i. However, it was also noted in the questionnaire data that the bulk of the fish consumed by these participants were small, close-to-shore reef fish, which tend to have relatively low mercury concentrations. This may account for the relatively low mercury levels in hair when compared to other Pacific sites (although they are still significant levels). This differs significantly from most other Pacific Island SIDS where much larger, predatory fish species are consumed regularly as they form the main source of dietary protein.

The following chart highlights the very high levels of mercury found in the hair of participants in most Pacific locations, with the exception of Samoa and Vanuatu.

In Vanuatu the levels were also relatively low, with a mean for the cohort of 0.72 ppm ± 0.61 ppm (fw) compared to other Pacific Islands, but showed a very similar profile to Samoa in terms of the ratio of those women who had levels in excess of the proposed threshold of 0.58 ppm but not 1 ppm. Indeed, the mean for the group exceeded the lower reference level. Data from the questionnaires in the case of Vanuatu indicated that the lower levels were largely attributable to the fact that most women ate canned fish. A study based on commonly consumed fish in Fiji[46] provides more insight into this phenomenon. The study clearly shows a significant difference in the concentration of methylmercury in wild-caught local fish species and locally available canned fish of several varieties. The canned fish had very low levels by comparison with wild caught fish.

TABLE 2. MERCURY (Hg) LEVELS (RANGE AND AVERAGE) IN DIFFERENT FRESH FISH AND SHELLFISH FROM THE FIJI ISLANDS, WITH LENGTH AND WEIGHT DATA WHERE AVAILABLE.

Seafood Sample	N	Average Length (cm)	Average Weight (kg)	Range [Hg] (mg/kg)	Average [Hg] (mg/kg) ± SD
Albacore Tuna	31	72.7	21.3	0.03 - 1.01	0.34 ± 0.22
Yellowfin Tuna	24	71.3	15.2	< 0.02 - 0.40	0.11 ± 0.11
Skipjack Tuna	12	45.7	2.4	< 0.02 - 0.16	0.06 ± 0.04
Bigeye Tuna	3	103.3	28.3	0.28 - 0.80	0.53 ± 0.21
Marlin	5	167.6	67.4	0.45 - 5.60	1.76 ± 1.94
Reef fish	5	17.2	0.09	< 0.02 - 0.04	0.04 ± 0.01
Barracuda	4	61.25	1.32	0.18 - 0.38	0.26 ± 0.07

(Continued next page)

46 Kumar, M., Aalbersberg, W. G., & Mosley, L. (2004). *Mercury levels in Fijian seafoods and potential health implications.* University of South Pacific. Report prepared for the World Health Organization.

(Table 2. continued)

Seafood Sample	N	Average Length (cm)	Average Weight (kg)	Range [Hg] (mg/kg)	Average [Hg] (mg/kg) ± SD
Mussels	3	-	-	< 0.02 - 0.04	0.03 ± 0.01
Shellfish	3	-	-	< 0.02 - 0.05	0.03 ± 0.01
Crab meat	3	13.3	-	0.03 - 0.07	0.05 ± 0.02
Parrot fish	2	31 - 35	0.75	< 0.02	< 0.02
Wahoo	1	92	6	0.17	0.17
Goatfish	1	28	0.31	0.03	0.03
Rabbit fish	1	32	0.5	0.15	0.15
Peacock cod	1	33	0.62	< 0.02	< 0.02
Unicorn fish	1	39	1.07	< 0.02	< 0.02
Opah	1	111	65	0.27	0.27

Source Kumar et al. 2004

The difference in mercury concentrations between canned fish (see Table 3 below) and wild caught fish in this region (see Table 2 above) is very significant, with canned fish having very low levels of mercury (which is likely attributable to the use of much smaller fish in canning industry). Similarly, reef fish have some of the lowest mercury concentrations among all fish assessed in the fish concentration survey and may in part explain the lower, but significant levels found among the Samoan sampling cohort.

TABLE 3. MERCURY (Hg) LEVELS IN CANNED FISH SOLD IN THE FIJI ISLANDS.

Canned Fish Type	N	[Hg] Range (mg/kg)	[Hg] Average mg/kg) ± SD
Canned Albacore	6	0.16 - 0.27	0.20 ± 0.03
Canned Skipjack	9	0.06 - 0.11	0.08 ± 0.02
Canned Tuna in Oil	3	0.05 - 0.16	0.09 ± 0.05
Canned Mackerel	6	0.18 - 0.22	0.21 ± 0.01
Canned Salmon Style Mackerel	6	0.17 - 0.29	0.23 ± 0.05

Source Kumar et al. 2004

5.4 ELEVATED MERCURY LEVELS IN MOST OF THE CARIBBEAN SIDS

IPEN has not previously conducted any systematic sampling for mercury biomonitoring in the Caribbean region. In this instance IPEN was offered support by the Basel Convention Regional and Coordinating Centre for the Caribbean (BCRC) in organizing grass-roots, civil society organizations to conduct hair sampling using the approved protocols and methodologies, which were applied in all other locations reported in this study. The work of the BCRC has been instrumental in completing this ground-breaking mercury biomonitoring work in the Caribbean, while assisting to generate much needed data that has previously been virtually non-existent.

The focus on Caribbean SIDS was intended to assess any parallels between mercury levels found in Pacific and other SIDS and to see if it was possible to draw inferences as to reasons for the levels that were reported. In nearly all cases, Caribbean SIDS have a similar profile in terms of being remote from heavy industrial development, ASGM activities or other mercury pollution sources that could significantly influence mercury levels in women of child-bearing age. The exception to this may be Trinidad and Tobago, which has well developed oil and gas production. There are some studies indicating heavy metal contamination of some localized marine waters around Trinidad and Tobago, with speculation that dental amalgam waste[47] and industrial sources[48] may be influencing water quality. Further detailed research is required to correlate these potential mercury sources with fish contamination levels and dietary consumption, determine if there is any general or specific connection, and to assess whether the contamination is localized to specific areas around Trinidad and Tobago.

It was also the case that many of the Caribbean SIDS were effectively developing countries with low average incomes and very restricted land areas to raise livestock as a contributory source of dietary protein. In effect these island states are, for the most part, as similarly reliant on locally caught fish protein for dietary needs as the Pacific Islands, although the types and frequency of fish consumption may vary. Some of the specific data from sampling and questionnaires is highlighted below.

Mean concentrations of mercury were elevated in most Caribbean locations, with the notable exception of the Dominican Republic (0.178 ppm

47 J. G. Singh, "A Study of Heavy Metals and Hydrocarbons Found in Trinidad," University of the West Indies St. Augustine, 1989. Journal of Water Resource and Protection Vol.2 No.8(2010), Article ID:2460,8 pages DOI:10.4236/jwarp.2010.28089

48 Rojas de Astudillo, L, Chang Yen, I, & Bekele, I. (2005). *Heavy metals in sediments, mussels and oysters from Trinidad and Venezuela*. Revista de Biología Tropical, 53(Suppl. 1), 41-51.

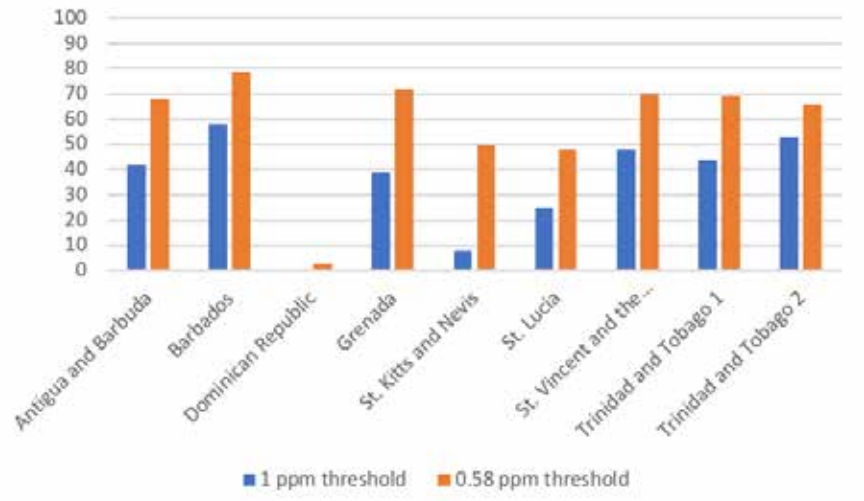


Figure 26. Percentage of Caribbean hair samples over the 1 ppm and 0.58 ppm reference level

± 0.127 ppm (fw)). The very low levels in the Dominican Republic (no test results were above 1 ppm Hg, and only 1 participant marginally exceeded the 0.58 ppm Hg level) are most likely attributable to the fact that very few of the cohort ate fish frequently (or in some cases at all), and that those who did consume fish predominantly ate sardines and salt cod/ bacalao. These fish generally have low mercury levels and the infrequency with which participants in the Dominican Republic consumed them would minimize dietary mercury exposure from seafood.

The following chart summarizes the findings from the Caribbean region in terms of the number of participants who had total mercury measured in their hair samples exceeding 1 ppm and 0.58 ppm. Many of the locations reported elevated results, with notable exceptions being the very low results from the Dominican Republic. Most other Caribbean countries had significantly more participants' samples returning a result in excess of 0.58 ppm than 1 ppm. The chart below demonstrates relatively consistent results (between 50-70% of total participants) for Caribbean SIDS in terms of the percentage of participants whose results indicated that their mercury body burden exceeded 0.58 ppm Hg.

The overall percentage of Caribbean participants whose hair levels exceeded 1 ppm Hg was 35%, while a much higher percentage (58%) exceeded the proposed 0.58 ppm threshold, indicating that atmospheric deposition

of mercury is a significant contributor to marine contamination in the Caribbean.

A significant number of the Caribbean locations where sampling was conducted had mean levels for their sampling cohort above the 1 ppm Hg reference value. The mean levels with standard deviation are as follows: Antigua and Barbuda (0.979 ppm ± 0.637 ppm (fw)); Barbados (1.385 ppm ± 0.972 ppm (fw)); Dominican Republic (0.178 ppm ± 0.127 ppm (fw)); Grenada (1.381 ppm ± 1.289 ppm fw)); St. Kitts and Nevis (0.523 ppm ± 0.328 ppm (fw)); St. Lucia (0.821 ppm ± 1.149 ppm (fw)); St. Vincent and the Grenadines (2.040 ppm ± 2.706 ppm (fw)); Trinidad and Tobago 1 (1.941 ppm ± 3.896 ppm (fw)); and Trinidad and Tobago 2 (1.158 ppm ± 0.894 ppm (fw)).

Analysis of the questionnaires of participants from the two Caribbean SIDS that reported the next lowest levels to the Dominican Republic indicate that the frequency of fish consumption was much lower than those SIDS with elevated levels. For those that did eat fish, the most common response was that they consumed a fish meal about once per week or two weeks. Notably, the two most common forms of seafood consumed were shrimp or lobster, which have much lower levels of mercury than higher tropic level species. The combined low frequency of fish consumption of species that accumulate lower mercury levels may account for lower mercury levels in these Caribbean SIDS.

Figure 27. Hair sample being taken in Trinidad and Tobago

Figure 28. Hair samples being taken in Barbados. Source: Caribbean Youth Environmental Network (CYEN), Barbados

Participants from Trinidad and Tobago ate fish much more frequently from higher trophic levels. Although most respondents indicated that they ate shrimp, many also noted that they frequently ate mahi-mahi, king-fish, tuna, mackerel, shark and salmon, some of which have high mercury concentrations.

The high frequency of consumption of higher trophic order fish may be a significant contributor to the elevated level of mercury found in women who participated in sampling in both Trinidad and Tobago locations.

The highest percentage of participants to record levels over 1 ppm Hg from any Caribbean location were from Barbados (58%). Analysis of the questionnaires strongly points to the reason. Levels of consumption of Marlin were remarkably high, with most respondents indicating it was among the 2 preferred species to eat regularly. Participants also ate a variety of fish frequently (between 2-5 times per week), including kingfish, swordfish, mahi-mahi, tuna, shark and salmon. The prevalence of higher trophic species in the diet of Barbados women is likely to be a strong influence on their mercury body burden levels.

In St. Vincent and the Grenadines, the highest average levels for any cohort were reported with a mean of 2.040 ppm ± 2.706 ppm (fw). This group reported eating a wide range of fish species frequently, including kingfish, dolphinfish, mahi-mahi, jacks (the national dish), marlin, tuna, barracuda and lionfish, as well as crustacea such as lobster, shrimp and

conch. The frequency and higher trophic order of the species consumed is a likely contributor to the elevated mercury levels in this group of women.

5.5 INDIAN OCEAN SIDS – COMOROS HAS THE HIGHEST LEVELS OF MERCURY RECORDED FOR SIDS

Mercury contamination of seafood does not appear to be confined to the Pacific or Caribbean on the basis of some of the results we received from the Indian Ocean SIDS, Comoros and Rodrigues. While in Rodrigues 23% of the cohort exceed the 1 ppm reference level and 57 % exceeded the 0.58 ppm proposed reference level, Comoros far exceeded even these elevated levels.

The average level recorded for Comoros was the highest for any SIDS where IPEN has conducted sampling registering at 4.060 ppm ± 6.669 ppm (fw). Of the cohort providing samples, 88% of the women exceeded the 1 ppm reference level and 92% exceeded the 0.58 ppm proposed reference level. It should be noted that there was significant standard deviation in the scores and two results were left out of the analysis as they were suspected of being outliers due to hair surface contamination. The outliers measured at 99 ppm and 3058 ppm. These samples are to be reviewed by the lab to ascertain the cause of the contamination.

In any event, consistently elevated levels of mercury among women providing samples in these isolated islands dependent on fish for protein are a clear indicator that mercury pollution is not limited to the Pacific or Caribbean region. More investigation is necessary in this regional location to confirm and support what appears to be a significant seafood contamination issues in this area of the Indian Ocean.

5.6 THE INFLUENCE OF MARINE MAMMAL CONSUMPTION ON MERCURY EXPOSURE – ALASKA

The results of hair sampling from the communities of Savoonga and Gambell in St. Lawrence Island, Alaska, revealed that consumption of sea mammals—specifically seals—may be a significant source of dietary mercury.

While the mean level of mercury in hair for the group was below 1 ppm (0.82 ppm ± 0.45 ppm (fw), 30% of the women who provided samples exceeded the 1 ppm reference level and 70% exceeded the proposed threshold of 0.58 ppm. This is of particular interest due to the diet of these women. Fish are eaten, but, for those women who provided questionnaire data, generally only during the three summer months, although some dried and fresh fish is also consumed throughout the year. In addition,

Figure 29. Alaskan Walrus. Source: Anderson, Santa Barbara City College, US

the sockeye salmon and other commonly eaten Alaskan fish species are reported to have low levels of mercury[49]. Large halibut can have excessive mercury levels and Alaskan government fish advisories[50] indicate elevated levels of mercury in halibut exceeding 40 pounds. When fish are eaten by the women who participated in this study, the frequency of fish meals is much less than that of marine mammals, which make up the bulk of the local diet. It appears that the low frequency of the fish diet in non-summer months, dominated by fish of low mercury concentrations, is unlikely to account for the elevated mercury levels in women's hair.

The marine mammals commonly consumed are primarily Pacific walrus (Odobenus rosmarus divergens), a variety of seals, and bowhead whale (Balaena mysticetus) meat or blubber. The bowhead whale has spiritual and cultural significance to the Yupik people of St. Lawrence Island and it is possible that one or more species of these mammals may be a source of dietary mercury contamination. While studies have been conducted to assess the levels of mercury in marine mammals in Arctic waters, walrus does not feature as a species of concern. However, many seal species have been found to exhibit relatively high mercury concentrations in their meat. This includes the species commonly eaten by the women of St. Lawrence Island. The mean concentration of mercury in these seal species exceeds the US EPA mercury consumption guideline of 0.3 ppm Hg/

49 State of Alaska (SOA). Bulletin No. 6, June 15, 2001. Mercury and National Fish Advisories Statement from Alaska Division of Public Health: Recommendations for Fish Consumption in Alaska.

50 Hamade, A. (2014) *A Risk Management Strategy to Optimize the Public's Health.* Alaska Scientific Advisory Committee for Fish Consumption Section of Epidemiology. Division of Public Health Department of Health and Social Services. State of Alaska.

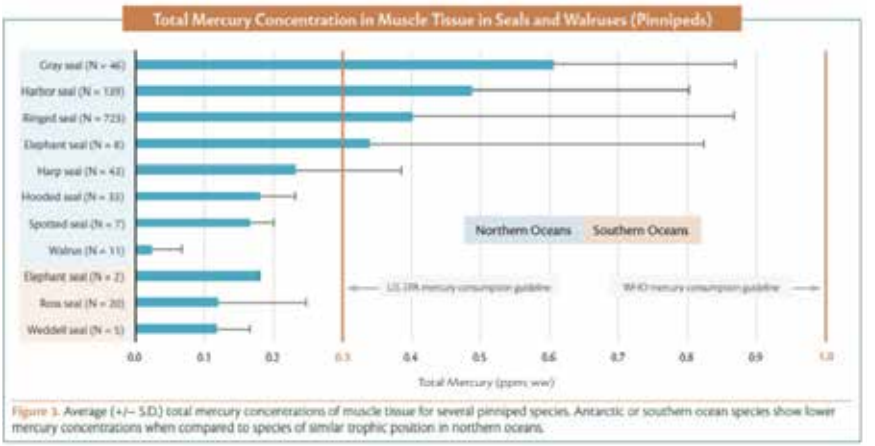


Figure 1. Average (+/– S.D.) total mercury concentrations of muscle tissue for several pinniped species. Antarctic or southern ocean species show lower mercury concentrations when compared to species of similar trophic position in northern oceans.

Figure 30. Mercury concentrations in pinnipeds of the polar regions. Evers *et al.* 2016

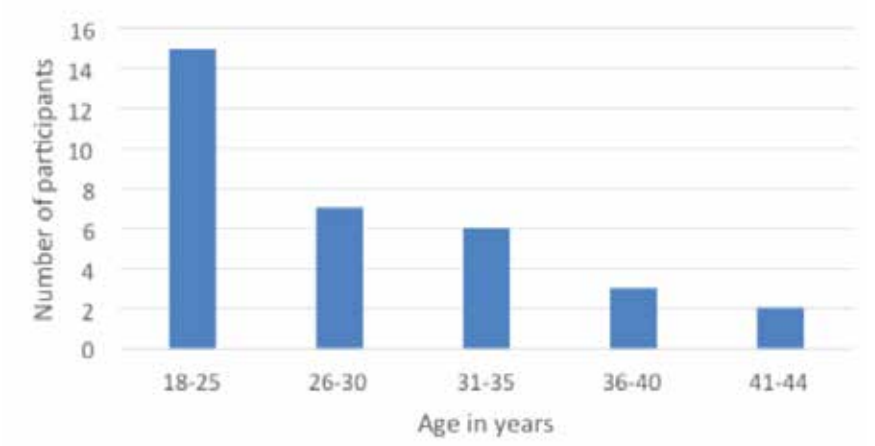


Figure 31. Sub-groups of Yupik women participants by age

wet weight[51] (see Figure 30). Taking into account the low mercury levels in commonly eaten fish species and walrus, the elevated mercury levels in seals are most likely to be the source of elevated mercury levels among some women in the St. Lawrence Island communities. Organ tissues such as liver and kidney tissues may contain higher levels of mercury than

51 Evers, D.C., Buck, D.G., Dalton, A.K., Johnson, S.M. 2016. *Mercury in the Global Environment: Marine Mammals.* Biodiversity Research Institute. Portland, Maine. BRI Science Communications Series 2016-03. 8 pages.

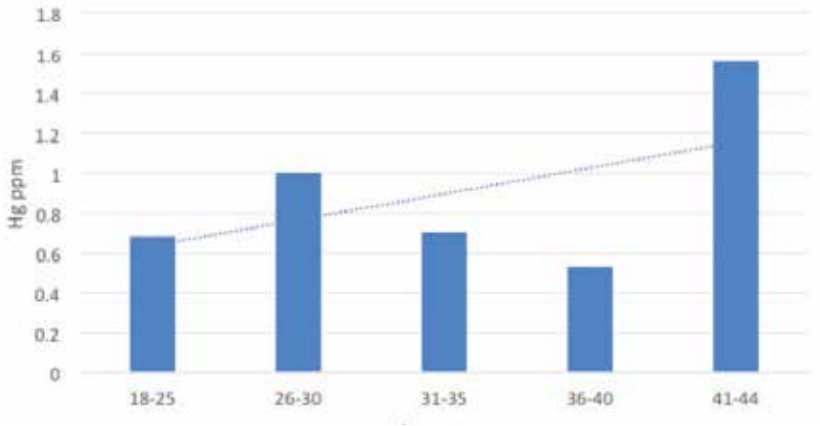


Figure 32. Hair mercury (Hg) trends by age bracket: Alaska (mean)

muscle tissue[52], and should be analyzed in detail to determine if they contribute mercury to the diet of the Yupik people and, if so, to what extent. Further research should be conducted on the specific marine mammals consumed by the St. Lawrence Island communities to confirm if seals may be the major source of dietary mercury in this location.

An opportunistic analysis of the age-related data for women sampled in Alaska also points to mercury accumulation trending upward with age, suggesting that long-term exposure to contaminated food sources is resulting in increased body burden over time. However, there was no attempt made to balance the sampling cohort according to age ranges (e.g. there were 15 women in the 18 - 25 age bracket and only 2 in the 40 – 44 age bracket), so the results are indicative only and would require a much larger study with balanced groupings to confirm this trend. When the mean concentrations of mercury by age bracket are assessed, there is a strong indication of increasing levels as the participants age. However, this may be affected by the frequency of consumption of mercury-impacted mammals and fish by an individual.

The questionnaires showed that the frequency of marine mammal consumption was very similar between all women in Savoonga and Gambell. This is not unusual given that the community shares the catch of walrus, seal, whale or fish (arising from traditional hunting activity), and other

52 Welfinger-Smith, G., Minholz, J., Byrne, S., Waghiyi, V., Gologergen, J., Kava, J., Apatiki, M., Ungott, E., Miller, P., Arnason, J., and Carpenter, D., (2011) *Organochlorine and Metal Contaminants in traditional Foods from St. Lawrence Island, Alaska*, Journal of Toxicology and Environmental Health, Part A. 74:18, 1195-1214.

food sources are limited in availability. To conclude, more research is required to determine which elements of the food sources of inhabitants of St. Lawrence Island are impacted by mercury and to what degree. This may require specific sampling of those seal species that are eaten on St. Lawrence Island as well as other marine mammals consumed to determine if specific organs that are consumed (liver, kidneys, etc.) contain elevated mercury levels and may be contributing to mercury exposure. While many respondents from St. Lawrence Island indicated that they only ate fish in summer, other information suggests that dried fish may be consumed by many members of the community throughout the year and this should also be assessed for mercury concentrations and exposure contribution.

5.7 SRI LANKA (PUTTALAM LAGOON): LOCALIZED EMISSION IMPACTS FROM COAL-BASED POWER AND CEMENT PLANT

The results from the Sri Lankan location at Puttalam lagoon were significantly elevated, with a mean of 2.74 ppm ± 2.8 ppm (fw). Of all women who participated in the sampling, 77% had a body burden of mercury exceeding the 1 ppm reference level. In addition, 97% of the women had a level over the proposed 0.58 ppm reference level. Of great concern is that 50% of the women had a level that exceeded 2 ppm Hg and 13% exceeded 4 ppm Hg.

The women in this location are heavily dependent on fish for protein and most participants reported eating at least 2 fish meals per day or more consisting of a wide range of fish species from the lagoon, which supports

Figure 33. Indian Anchovy (Stolephorus indicus) harvested in the Puttalam Lagoon. Source: Sriyanie Miththapala

over a hundred species of edible fish[53] and crustacea. This is the highest level of fish consumption seen among any locations sampled by IPEN/BRI in all hair sampling studies.

The high level of fish consumption and very close proximity of two major industrial emissions sources points strongly to localized mercury contamination from industrial sources. Authorities should conduct further investigations to assess which fish are contaminated and to what degree, and issue advisories to assist the local population to reduce dietary exposure. Further, the environmental practices of thee industrial plants should be closely reviewed, and all efforts taken to ensure they operate according to Best Environmental Practices (BEP) using Best Available Techniques (BAT).

53 Miththapala, S. (2011) *An Environmental and Fisheries Profile of the Puttalam Lagoon System.* IUCN, International Union for Conservation of Nature, Sri Lanka Country Office.

REFERENCES

AMAP/UNEP (2013) *Technical Background Report for the Global Mercury Assessment 2013.* Arctic Monitoring and Assessment Programme, Oslo, Norway/UNEP Chemicals Branch, Geneva, Switzerland. vi + 263 pp

Bell, L., Evers, D., Johnson, S., Regan, K., DiGangi, J., Federico, J., Samanek, J. (2017) *Mercury in Women of Child-bearing Age in 25 Countries.* A joint study Biodiversity Research Institute and IPEN. November 2017. Berkeley, California.

Bell, L., (2017) *Mercury Monitoring in Women of Child-Bearing Age in the Asia and the Pacific Region.* A joint study by UN Environment, Biodiversity Research Institute and IPEN. April 2017. Berkeley, California.

Bose-O'Reilly, S., *et al.* (2010) *Mercury exposure and children's health.* Curr Probl Pediatr Adolesc Health Care, 2010 Sep; 40(8):186-215.

Evers, *et al.* (2014) *Global mercury hotspots: New evidence reveals mercury contamination regularly exceeds health advisory levels in humans and fish worldwide.* Biodiversity Research Institute. Portland, Maine. IPEN. Göteborg, Sweden. BRI-IPEN Science Communications Series 2014-34. 20 pages.

Evers, *et al.* (2016) *Mercury in the Global Environment: Marine Mammals.* Biodiversity Research Institute. Portland, Maine. BRI Science Communications, Series 2016-03. 8 pages.

Grandjean P, Weise P, White RF, Debes F, Araki S, Yokoyama K, Murata K, Sorensen N, Dahl R, Jorgensen PJ (1997) *Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury.* Neurotoxicol Teratol 19:417-428.

Grandjean P, Pichery C, Bellanger M, Budtz-Jørgensen E (2012) *Calculation of Mercury's effect on Neurodevelopment.* Environ Health Perspect. 2012 December; 120(12).

FAO (2018) Agronoticias: Agriculture News from Latin America and the Caribbean. Fishing in the Dominican Republic decreased by 50% over two decades. http://www.fao.org/inaction/agronoticias/detail/en/c/1127314/

Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles. Barbados.* http://www.fao.org/fishery/facp/BRB/en

Food and Agriculture Organization of the United Nations (2015) *Fishery and Aquaculture Country Profiles. Comoros.* http://www.fao.org/fishery/facp/COM/en

Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles. Dominican Republic.* http://www.fao.org/fishery/facp/DOM/en

Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles. Grenada.* http://www.fao.org/fishery/facp/GRD/en

Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles. St Kitts and Nevis.* http://www.fao.org/fishery/facp/KNA/en

Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles. St Lucia.* http://www.fao.org/fishery/facp/LCA/en

Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles. Saint Vincent and the Grenadines.* http://www.fao.org/fishery/facp/VCT/en

Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles. The Independent State of Samoa.* http://www.fao.org/fishery/facp/WSM/en

Food and Agriculture Organization of the United Nations (2018) *Fishery and Aquaculture Country Profiles. Trinidad and Tobago.* http://www.fao.org/fishery/facp/TTO/en#CountrySector-Statistics

Harris RC, Rudd JW, Amyot M, Babiarz CL, Beaty KG, Blanchfield PJ, *et al. Whole-ecosystem study shows rapid fish-mercury response to changes in mercury deposition.* Proc Natl Acad Sci USA. 2007;104(42):16586–16591.

Karagas, M., Choi, A.L., Oken, E., Horvart, M., Schoeny, R., Kamai, E., Grandjean, P., and Korrick, S. (2012) *Evidence on the human health effects of low-level methylmercury exposure.* Environmental Health Perspectives, 120: 799-806.

Kim Euy Hyuk, Kim In Kyu, Kwon Ja Young, Kim Sang Wun, and Park Yong Won (2006) *The Effect of Fish Consumption on Blood Mercury Levels of Pregnant Women.* Yonsei Med J. 2006 Oct 31; 47(5): 626-6330

Miththapala, S. (2011) *An Environmental and Fisheries Profile of the Puttalam Lagoon System.* IUCN, International Union for Conservation of Nature, Sri Lanka Country Office.

Murata K, Weihe P, Budtz-Jorgensen E, Jorgensen PJ, Grandjean P. (2004) *Delayed brainstem auditory evoked potential latencies in 14-year-old children exposed to methylmercury.* J Pediatr 144(2):177-183.

Republic of Mauritius (2016) Ministry of finance and Economic Development. Statistics Mauritius. Digest of Statistics on Mauritius. August 2017.

Sunderland, E. M., D. P. Krabbenhoft, J. W. Moreau, S. A. Strode, and W. M. Landing (2009), *Mercury sources, distribution, and bioavailability in the North Pacific Ocean: Insights from data and models*, Global Biogeochem. Cycles, 23, GB2010, doi:10.1029/2008GB003425.

Tabuchi, Hiroko (2017) "As Beijing Joins Climate Fight, Chinese Companies Build Coal Plants'"The New York Times July 1, 2017. accessed online at https://www.nytimes.com/2017/07/01/climate/china-energy-companies-coal-plants-climate-change.html

Trasande L, Landrigan PJ, Schecter C (2005) *Public health and economic consequences of Methyl Mercury Toxicity to the Developing Brain*, Environ Health Perspect 113:590-596.

United Nations Environment Programme and the World Health Organization (UNEP/WHO), (2008) *Guidance for identifying populations at risk from mercury exposure.*

US EPA (1997) Mercury study report to Congress, Volume IV, *An assessment of exposure to mercury in the United States*, EPA-452/R-97-006.

United States Environmental Protection Agency [USEPA]. 2000. *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories.* Volume 1: Fish Sampling and Analysis (3rd edition). US EPA, Office of Water. EPA 823-B-00-007. Washington, DC. 485 pp.

Wang, S. X., Zhang, L., Li, G. H., Wu, Y., Hao, J. M., Pirrone, N., Sprovieri, F., and Ancora, M. P.: *Mercury emission and speciation of coal-fired power plants in China*, Atmos. Chem. Phys., 10, 1183-1192, https://doi.org/10.5194/acp-10-1183-2010, 2010.

Yokoo, E.M., Valente, J.G., Grattan, L., Schmidt, S.L., Platt, I. and Silbergeld E.K. (2003) *Low level methylmercury exposure affects neuropsychological function in adults.* Environmental Health 2(1):8.

ACKNOWLEDGEMENTS

IPEN and Biodiversity Research Institute (BRI) would like to acknowledge the participation of 757 women in 24 communities across 21 countries who contributed samples for this study. In addition, we would like to recognize the contributions from the following IPEN Participating Organizations and civil society organizations that collected samples for mercury analysis and submitted reports characterizing the collection sites:

Island Sustainability Alliance Cook Islands Inc. (ISACI), *Cook Islands*

Mercy Ritte, *Molokai*

Alaska Community Action on Toxics (ACAT), *USA*

BWC Enterprise, *Antigua and Barbuda*

Caribbean Youth Environment Network (CYEN) *Antigua and Barbuda*

Development Indian Ocean Network (DION), *Mauritius*

Ministry of Health, Social Security and International Business, *Grenada*

Rotary Community Corps of Basseterre (RCCB), *Saint Kitts and Nevis*

Caribbean Youth Environment Network (CYEN), *St. Lucia*

Dr Roger Duncan, *Saint Vincent and the Grenadines*

BCRC-Caribbean, *Trinidad and Tobago*

Centre for Environmental Justice (CEJ), *Sri Lanka*

JEMS Progressive Organization, *Saint Vincent and the Grenadines*

Friends of Botanic Garden, *Trinidad and Tobago*

Fundacion Mujeres Salome Urena Fundamusa, *Dominican Republic*

IPEN would also like to acknowledge the contributions from Biodiversity Research Institute (BRI), for assisting in developing the methodology and protocols, and thereafter organizing the international shipments of materials and samples and conducting sample analysis. IPEN would also like to acknowledge the logistical, coordination and communications support provided by The Caribbean Basel Convention Regional Centre to facilitate sampling in that region.

IPEN gratefully acknowledges the financial support provided by the:

- Government of Germany;
- Government of Sweden;
- Government of Switzerland;
- and other donors that made the production of this document possible.

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit

Sweden Sverige

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Office for the Environment FOEN

The expressed views and interpretations herein shall not necessarily be taken to reflect the official opinion of any of the institutions providing financial support. Responsibility for the content lies entirely with the authors.

www.briloon.org

www.ipen.org