PERSPECTIVES ON METHYL MERCURY EXPOSURE LOCALLY, NATIONALLY, AND GLOBALLY

by

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ABSTRACT

Methyl mercury exposure by consumption of fish and marine mammals is associated with a variety of negative health outcomes, particularly during early developmental stages. In British Columbia, there is a lack of knowledge relating to exposures in the freshwater angler population, identified elsewhere as a population at risk. Exposure assessment methods can help to characterize the risk to populations from dietary fish consumption. In Canada, the Aboriginal population is particularly vulnerable due to traditional dietary intake of fish and marine mammals; however, managing the risk from methyl mercury needs a careful approach as changing cultural practices can negatively affect social determinants of health. Globally, the use of mercury in gold mining is increasing exposure to methyl mercury among communities consuming contaminated fish. An informed understanding of patterns of exposure, health outcomes, and culture provides a basis to construct effective policies for the protection of human health.

Keywords: methyl mercury; Aboriginal health; global health; environmental health; gold mining

Subject Terms: Mercury -- Toxicology -- Risk factors – Canada; Fish as food -- Risk assessment – Canada; Mercury -- Government policy – Canada; Mercury -- Health aspects; Mercury -- Health aspects -- Developing countries; public health research -- developing countries

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INTRODUCTION

Marginalized populations such as Canada's Aboriginal peoples and the global poor commonly experience negative physical, cultural, and economic impacts of methyl mercury exposure. Methyl mercury exposure has been linked to severe health consequences, including impaired cognitive function, neuropsychological damage, cardiovascular disease, weakened vision, and death.[1-5] Exposure is especially damaging to those in early developmental stages.[5]

Although fish consumption confers cardioprotective and neurodevelopmental benefits, the awards are found at moderate levels of consumption, and can be negated by associated mercury exposure.[2, 3, 6] Research findings inform recommendations on exposure limits through fish consumption advisories and guidelines.[7] These guidelines must target vulnerable populations, and contain species, age, and gender specific information to maximise utility. Freshwater anglers can be particularly vulnerable to methyl mercury exposure because of higher than average fish consumption, ingestion of freshwater species known to have elevated mercury concentrations, and a lack of knowledge about species and location specific contamination.[7] There is reason to believe that British Columbia's freshwater anglers may be at risk for health effects associated with methyl mercury exposure.

Canada's Inuit suffer from dangerously high exposure to methyl mercury, because of traditional fish and marine mammal consumption.[8] Policies aimed at managing the methyl mercury risk to Canada's Aboriginal peoples must be culturally sensitive, taking care to avoid inadvertently exacerbating social, cultural, and economic realities.[9] For example, among Inuit, Métis and First Nations, advisories against fish and marine mammal consumption can negatively affect key determinants of health such as the maintenance of cultural and environmental connections.[9]

Mercury is also a problem in the developing world, where large amounts of mercury are released through gold mining in impoverished areas, leading to heightened exposure through fish consumption in contaminated lakes and rivers.[10] Solutions that aim to alleviate poverty, provide economic alternatives, and end the need for mercury in mining can ensure that banning the mercury trade will not economically devastate these communities.[11]

During my practicum with the British Columbia Centre for Disease Control, I conducted a literature review of methyl mercury risks to freshwater sport angling populations. In addition, I helped design a study to assess the attributable exposure to methyl mercury through consuming sport-caught freshwater fish among Vancouver Island licensed anglers. This was in response to a British Columbia Ministry of Environment request for a study to characterize the methyl mercury exposure to this population. Data collection has not yet taken place for this study.

This capstone paper integrates my practicum experience with many of the theories and perspectives taught in the Population and Public Health Masters program at Simon Fraser University. Concepts drawn from environmental health inform much of the discussion on exposure, biological mechanisms, and environmental justice. Theories based on a postcolonial framework inform the discourse on Aboriginal health, illustrating the distinct need for this population to sustain their traditional culture. Our awareness of social and global determinants of health highlights the need to contextualize the problem and related policies, recognizing that inequity, poverty, culture, and environmental toxicity interact with each other. This paper employs a cell-to-society approach towards exploring the problem of methyl mercury exposure locally, nationally, and globally. Key findings pertinent to public health policy are discussed.

METHYL MERCURY EXPOSURE

Mercury occurs naturally in the environment, originating in soils and rocks.[12-16] This naturally occurring mercury is released into lakes, rivers and oceans through weathering, volcanoes, and forest fires.[12, 16] Pulp and paper processing, fossil fuel and garbage burning, mining, soil erosion and leaching due to deforestation, and other anthropogenic activities also release mercury into the biosphere.[2, 12-15, 17] Mercury levels on the ocean's surface are now three times natural levels, as two-thirds of all mercury now released into the atmosphere stems from anthropogenic sources.[18]

Mercury is absorbed by humans from artificial and natural sources, including dental fillings, air, soil, and water pollution, though primarily from food.[2, 12, 14, 15, 19-22] Ambient levels of mercury are extremely low in air and water, and are not a major source of exposure, whereas most mercury exposure is due to three sources; fish consumption, dental amalgams, and vaccines.[1] Dental amalgams expose patients, as well as those administering the fillings, to small doses of mercury vapour that can lead to reversible effects on the kidney, mild cognitive changes and memory loss.[1, 21] The historic use of thimerosal as a preservative is the source of mercury in vaccines.[1] The health outcomes associated with the form of mercury found in thimerosal, the ethyl mercury radical ($CH_3CH_2Hg^+$), are still a contentious topic.[1] However, based upon a precautionary approach there has been a sharp decline in the use of this preservative, following a re-evaluation of the health risks associated with ethyl mercury.[1, 23, 24]

Fish consumption is responsible for the highest attributable proportion of mercury ingested in the human diet.[1] In fish, mercury is most commonly found in the 'organic' form, methyl mercury (CH_3Hg^+).[1] The only methyl mercury exposure pathway in humans is through consuming fish and sea mammals.[1] The less toxic 'inorganic' mercury is usually at much higher levels in the aquatic environment. Inorganic mercury is converted to methyl mercury through processes related to microbial activity.[1] Methyl mercury is more bioavailable to fish than inorganic mercury because the former is better able to bind to the proteins that form fish tissue, after being absorbed from either water or digested organisms.[25] Levels found in fish eating birds demonstrate the increased amount of mercury entering the food chain over the past century from the environmental sources noted above. [1]

Mercury bioaccumulates in fish and biomagnifies at a higher level in the food chain.[1, 26] Trace amounts are found in most fish, while specific levels relate to the amount of mercury found in the ecosystem, the age of the fish, as well as the fish's trophic level, as predatory fish generally have higher mercury concentrations than do non-predatory fish.[1, 2] For recreational fishing, provincial governments are responsible for monitoring mercury, and producing safe consumption standards.[27]

In humans methyl mercury is almost completely absorbed by the gastrointestinal tract, readily absorbed into the bloodstream and dispensed throughout the body.[1, 28] The proportion of methyl mercury to other forms of less harmful mercury varies widely between, and within species. Recent studies examined the percentage of total mercury that was in the methylated or organic form. In sablefish, organic mercury accounted for 81-95%,[16] tuna, 61-94%,[29, 30] swordfish, 43-76%,[29] and in marlin, 51-63%[30]. Because of variability relating to the proportion of methyl mercury to total mercury, a fixed conversion factor to characterize methyl mercury levels, when total mercury levels are known, is inappropriate.[29] As such, Health Canada assumes conservatively, for the purpose of health risk assessments, that 100% of total mercury is in the methyl mercury form.[16]

HEALTH CONSEQUENCES OF MERCURY EXPOSURE

Methyl mercury is more toxic to the central nervous system than inorganic mercury, because of differences in dose, distribution and half-life.[31] Inorganic and methyl mercury metabolise differently in the body.[32] Inorganic mercury displays less bioavailability than methyl mercury, because the methyl group enhances blood solubility, thereby increasing dose and distribution through the body.[31] For this reason, there is greater risk from exposure to methyl mercury than from an equal exposure to inorganic mercury.

Tests on monkeys demonstrate that the half-life of methyl mercury is longer in the brain (38-56 days) than in blood (14 days) following doses between 10 and 50 µg/kg/day over at least 1.7 years.[33] Tests on monkeys also demonstrated significantly higher levels of inorganic mercury in the brain among those given methyl mercury than those given inorganic mercury, as inorganic mercury is unable to pass readily through the blood-brain barrier.[34] Therefore, inorganic mercury found in the brain is likely derived from *in situ* demethylation. Inorganic mercury was observed to have a half-life in the brain of between 230-540 days in autopsied monkeys who had been receiving long-term subclinical exposure to methyl mercury through a daily dose of 50 µg/kg body weight for 6 to 18 months.[35] This immobility is likely caused by inorganic mercury binding to selenium, creating a stable compound.[34]

Although methyl mercury is clearly more toxic, it remains a contentious issue whether the proximate agent toxic to the brain is organic or inorganic mercury.[36] Almost all remaining mercury found in the autopsied monkeys' brains following methyl mercury exposure was inorganic, as this has a much longer half-life in the brain than methyl mercury.[35] This suggests inorganic mercury derived from methyl mercury demethylation within the brain may be the primary toxic agent.[36] However, rat bio-assay data suggest otherwise. Rats given methyl mercury experienced more severe brain damage than those exposed to ethyl mercury, although the latter converted more rapidly to inorganic mercury and led to higher concentrations of inorganic mercury in brain tissue.[36, 37] Although subsequent concentrations of inorganic mercury were higher in the brain of rats given equimolar doses of ethyl mercury than those given methyl mercury, those given ethyl mercury displayed no damage to the cerebellum.[37] Conversely, widespread granular cell necrosis was evident in the cerebellum of all female rats and six of nine male rats given methyl mercury.[37] This suggests that intact methyl mercury is the proximate toxic agent to the brain; although inorganic mercury concentrations were higher in the brain of rats given doses of ethyl mercury and total mercury concentrations were equal, only methyl mercury led to observable damage to the cerebellum.[36, 37] The specific mechanisms by which mercury causes damage are still poorly understood, likely because of the long latency period between exposure and the first symptom.[34]

Methyl mercury is particularly damaging to the fetal brain, as it crosses the placenta and "*inhibits the division and migration of neuronal cells and disrupts* *the cytoarchitecture of the developing brain.*"[1, 2] Methyl mercury disrupts development, and the extent of the damage depends on what neurons are forming at the time of exposure.[38] Although the developing brain is the target of toxicity, its dose of mercury is only measurable through indirect biomarkers such as maternal blood and hair.[39] Methyl mercury concentrations in the blood of infants are approximately twice as high as those found in maternal blood.[40] Using measurements of maternal blood as a proxy of exposure to the fetus underestimates the level of exposure to the developing brain.[41] This is due to the ease of transfer through the placenta, and fetal trapping of methyl mercury.[41] Also, the blood-brain barrier does not fully form until the middle of the first year after birth.[38] The concentration in the adult brain is five to ten times higher than in whole blood concentrations.[39] However, animal studies suggest that relative concentrations are even higher in the fetal brain.[39] Maternal hair is a better proxy of exposure as it is more indicative of the mobility of methyl mercury in the body.[39] Exposure to methyl mercury also occurs through breast milk, although exposure before birth is significantly higher.[40]

A study of 779 children in the Seychelles Child Development Study prenatally exposed to methyl mercury from fish assessed the relationship between exposure and development. [42] Extensive age appropriate tests failed to provide convincing evidence of an association between methyl mercury exposure and development outcomes.[42, 43] However, among Faroe Islands and New Zealand children, methyl mercury intake below levels in the Seychelles study was associated with neuropsychological changes.[5, 44] Moreover, levels of methyl mercury exposure several orders of magnitude lower than these studies have been found to impair children's performance during tests of response time.[45] In the United States, 15% of women of childbearing age have blood methyl mercury levels above the Reference Dose (RfD) of 0.1 micrograms per kilogram of body weight per day, which was based in part on the Faroe and New Zealand studies.[46] Approximately 60,000 children are exposed to levels above the RfD in utero, 40,000 of which are exposed at levels at least 3.5 times the RfD, the range where the Faroe Islands and New Zealand studies found negative neurodevelopmental effects.[46]

It remains unclear whether a safe threshold of exposure exists for methyl mercury during neurodevelopment, or what that threshold may be. Regulators assume that thresholds exist for non-carcinogens; however, evidence shows that methyl mercury, lead, radon, ETS, and polychlorinated biphenyl display toxicity at levels far below those used in animal testing.[47] Furthermore, research into the impact of lead exposure on IQ suggests that harm to neurodevelopment can be most potent at low levels, as there is a "*steeper dose-response relationship at low blood lead levels*".[47] Further research is needed to clarify the effects of low level methyl mercury exposure, especially during early developmental stages.

Informed by the research from the Faroe Islands and New Zealand, the United States Food and Drug Administration (US FDA) and Health Canada recommend that fish with a mercury content above 1ppm (shark, swordfish, tilefish and king mackerel) not be consumed by pregnant women, nursing mothers, and young children.[1, 7, 46] The US FDA advises women who may become pregnant, are pregnant, or are nursing to limit sport-fish consumption to one 6 oz meal per week, and young children to no more than 2 oz per week.[7] Also these groups should limit consumption to 12 oz, or three to four meals of other fish with levels below 0.5ppm.[7] Those not fitting these categories should limit consumption to 7oz per week of fish with levels of 1ppm, or 14 oz fish with levels of 0.5ppm.[7] A January, 2001 US federal advisory warning women against consuming certain fish because of methyl mercury contamination was shown to reduce intake of these species.[48]

The WHO also has guidelines for a provisional tolerable weekly intake (PTWI) of methyl mercury in children of 1.6 µg/kg body weight, based on an uncertainty factor of 6.4 applied to the estimate of 1.5 µg/kg body weight per day, being the level of steady-state methyl mercury intake that is not expected to have an appreciable adverse effect on children.[49] In Canada, the provisional total dietary intake for young children and women of child-bearing age is 0.20 µg/kg bw/day, similar to the WHO recommendation.[16] The suggested daily dietary exposure limit to methyl mercury in Canada for adults is 0.47 µg/kg of body weight per day.[16]

There are clear benefits associated with consuming fish, especially those species with high levels of n-3 polyunsaturated fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA).[2] Moderate consumption, characterized as 1-2 servings per week, reduces risk of coronary death by 36%, and total mortality by 17%.[2] Tests of infant cognition using visual recognition memory at 6 months in a US cohort of 135 mother-infant pairs showed higher fish intake to be associated with higher infant cognition.[50] However, higher methyl mercury intake was associated with lower cognition, meaning women should choose fish varieties with lower methyl mercury levels.[50] The benefits of fish intake are found at moderate levels of consumption, as a benefit threshold is evident.[2] As such, consuming high levels of fish may be less beneficial, especially as this is likely to correlate to an increase in harmful methyl mercury exposure.

The American Heart Association recommends consuming fish rich in n-3 fatty acids EPA and DHA, for their cardioprotective effects.[6] However, cardiovascular disease is statistically associated with chronic methyl mercury exposure, perhaps because mercury exposure increases lipid peroxidation, which may lead to myocardial infarction.[3, 4] A case-control study examined whether mercury concentrations in toenail clippings were associated with a diagnosis of myocardial infarction.[3] The cases were 684 men from eight European countries and Israel diagnosed with myocardial infarction and were compared to 724 men serving as controls.[3] Evidence showed a relationship between toenail levels and myocardial infarction, with an odds ratio (OR) of 2.16 (CI 95%, 1.09,4.29) for the highest versus lowest quintiles of toenail mercury concentrations.[3] The source of mercury exposure was unknown, though believed to be primarily from fish consumption.[3] With this level of associated risk, it is likely that high levels of mercury contamination can reduce the cardioprotective value of fish consumption.[3] Indeed, the study found that mercury exposure negated the cardioprotective effects of DHA among participants.[3] Because cardiovascular disease involves multiple risk factors, prospective studies are needed to strengthen support for the purported link between mercury and cardiovascular disease.[1] However, even low level mercury exposure has been found to chronically affect cognitive abilities in adults according to a study assessing visual memory scores.[51]

Severe methyl mercury exposure has occurred at the population level on numerous occasions, leading to widespread fatality and morbidity.[1] In the early 1970's, bread made from seed coated in the toxin was responsible for hundreds of deaths, and thousands of less severe outcomes, in Iraq.[52] Methyl mercury poisoning, dubbed Minamata disease, caused 1043 fatalities after residents in a south-western region of Kyushu Island in Japan consumed fish and shellfish contaminated by methyl mercury discharge from a chemical plant.[53, 54] Typical signs of Minamata disease range from constriction of the visual field to extensive lesions in the brain and mental retardation.[54]

The brain and central nervous system is the region of most concern, as neuropathological examination shows methyl mercury to cause destruction of neurons in the visual cortex, as well as cerebellar granule cells.[1] This typically follows a latency period of weeks to months after acute levels of exposure.[1]

RISK COMMUNICATION

The purpose of risk communication is to foster knowledge and understanding of a risk, promote trust and credibility, and advance cooperation and dialogue.[55] The goal is to ensure that the population is suitably concerned about a risk, so that they take fitting actions such as modifying their behaviour.[55] The public has often been left out of the policy process for several reasons including public perceptions have been rejected as irrational, though their involvement is key to ensuring successful risk communication.[56, 57] Successful risk communication must provide clear messages relating risks and uncertainties, and state the cause and degree of disagreements between experts.[57]

One successful example of risk communication concerning environmental hazards has been in curtailing child exposure to environmental tobacco smoke (ETS) in Norwegian homes.[58] In Norway, no restrictions exist for smoking in homes where children are present.[58] In 1995, children three years of age or younger were exposed to ETS in 32% of households.[58] A survey indicated that a large population was unaware of the health risk ETS posed to children.[58] Therefore, it was postulated that educating parents about this risk would lead to a reduction in child exposure to ETS.[58] In 1995 the Norwegian Cancer Society initiated a risk communication campaign for this purpose.[58]

The campaign aimed to increase the amount of face-to-face information regarding ETS risks provided in clinical settings to parents.[58] The cancer society developed material for general practitioners, midwifes, and medical staff at mother-child clinics in order to reach those at a lower socioeconomic status, where child ETS exposure was most common.[58] In 2001, although there was no significant reduction in the percentage of parents who smoked, ETS exposure to children occurred in 14% fewer homes.[58] Furthermore, there was a 62% reduction in cigarettes smoked in homes where child ETS exposure was present.[58] This was due to higher risk awareness among smokers, and changes in attitudes regarding the right to expose children to ETS.[58] Experience from the Norwegian ETS reduction program suggests that awareness of health risks to children is a powerful motivator for behaviour change.[58]

Risk communication about methyl mercury exposure must particularly target vulnerable populations such as high fish or marine mammal consumers and women of childbearing age, and provide specific information about what fish to avoid, and amounts deemed safe. They must also target health professionals, teachers in health clinics, personnel dealing with fishing, fishing clubs, bait shops and the fish-consuming public.[59]

Risk communication about environmental contamination in Canada's Aboriginal communities has proven a challenge, and is discussed in further detail in the section below on Canada's Aboriginal Population.

FRESHWATER ANGLERS IN BRITISH COLUMBIA

There are no data available relating to the amount of sport-caught freshwater fish consumed in British Columbia. Although there has been research into the levels of consumption of commercially available fish, there remains a dearth of knowledge about the fish consumption patterns of British Columbia's licensed freshwater anglers. This knowledge is important to the Government of BC, because while fish consumption has well documented health benefits, some fish are known to have elevated levels of mercury.[2, 20, 26, 28, 60-62] The Environmental Health Division of the British Columbia Centre for Disease Control has been asked by the Ministry of Environment to research the situation.

In order to send messages such as advisories to avoid sport-caught fish in certain areas, information is required about the amount of fish that is being consumed.[20, 25, 26, 61-63] It is insufficient just to have data on mercury levels of fish. If sport fishermen or their families and friends are eating very large quantities of fish with elevated mercury content, the accumulation of mercury can cause negative health outcomes.[2, 17, 20, 25, 26, 28, 63] However, it may not be beneficial to target populations eating small quantities of fish with high mercury content, as it is likely that among these populations the mercury exposure attributable to sport-caught fish consumption is negligible.[62] Freshwater anglers have been shown elsewhere to be a population at risk for high mercury intake, and it is possible that this pattern applies to those based on Vancouver Island.[17]

If sport anglers are increasing their levels of mercury exposure through lake- or river-caught fish consumption, this population should be targeted for intervention where these levels are found to be above safe guidelines (0.47 µg/kg of body weight per day).[16] However, if consumption of commercially bought fish is the primary exposure pathway, it may be more appropriate to target messages towards commercially bought than sport-caught fish consumption. Fish consumption surveys are a tool used to determine the relative and absolute portions of sport-caught and commercially bought fish in one's diet.[61]

In Sweden, a study examined methyl mercury exposure in 127 women consuming fish at least four times per week.[64] Of these participants, 79% consumed fish potentially high in methyl mercury, and ten percent consumed these fish more than once per week, inconsistent with an advisory recommending against consuming more than one meal of such fish per week.[64] Those complying with consumption advisories had significantly lower methyl mercury concentrations in their hair and blood.[64]

In Wisconsin, researchers conducted a survey to assess the usefulness and effectiveness of mercury related sport fishing advisories.[62] Over two-thirds of those surveyed who had consumed sport-caught fish were aware there had been advisories in place, suggesting some people were ignoring the advisories.[62] However, those who had eaten sport-caught fish did not have higher hair mercury levels than those who had not. It appeared that being aware of mercury advisories had no impact on overall mercury levels.[62] In this study population, it is probable that mercury intake from sport-caught fish was not a major source of mercury in the diet, compared to consumption of commercially bought fish.[62] These data raise the question of why messages were being targeted towards sport anglers, rather than to the general population who may be at risk from consuming commercially available fish.

In contrast, native Americans living adjacent to a deactivated mercury mine in California were sampled to assess mercury levels using blood tests.[20] Those who had consumed sport-caught fish were observed to have elevated mercury levels up to 10-fold the established safe levels, in 20% of the population monitored.[20] Commercially bought fish consumption was not predictive of blood mercury, as sport-caught fish consumption was the primary exposure pathway.[20]

In the United States, 3015 women of childbearing age from 11 states were asked about household fish consumption.[65] The study found that 80% of children consumed similar amounts of fish to their mothers, suggesting that targeting advisories towards women could also protect their children.[65] Furthermore, although 71% of women were aware of the dangers of methyl mercury to the developing child, most were unaware of state fish consumption advisories.[56] Better communication efforts are clearly needed to warn women of childbearing age about the dangers of fish consumption, as this population has been shown to be less aware of this risk than the general population.[56, 66] Of 830 adult sport fish consumers from Great Lake States, 58.2% of men were aware of sport fish advisories, compared to only 39.1% of women.[67] It is important that women of childbearing age be aware of fish advisories, and the risks associated with methyl mercury exposure as they may become pregnant.[56, 66] One suggestion is that advisories should be given to women during their first antenatal care visit, at approximately 12 weeks of gestation.[64]

Data characterising the efficacy of advisories for both store-bought and sport-caught fish are inconsistent, and more research is needed to develop better risk communication practices.[66] However, some efforts have been successful at changing fish consumption behaviours, and have led to demonstrably lower methyl mercury levels in biomarkers.[48, 64]

In British Columbia, Bull Trout and Lake Trout are known to have some of the highest levels of mercury because of their high level on the food chain.[25] There have been three freshwater fish consumption advisories for BC, at Jack of Clubs Lake and Pinchin Lake, where mines had flourished, and at Williston Reservoir, where mercury was released due to flooding caused by the construction of a reservoir.[25] Canadians are instructed to follow advisories from the provincial governments in order to enjoy sport-caught freshwater fish.[27] However, as shown in the Wisconsin case, without proper knowledge of consumption patterns, there are clear limitations inherent in such advice.

Health Canada suggests that the general population in British Columbia need not worry about ingesting unhealthy amounts of mercury, as the commercially available fish eaten most widely exhibit low levels.[27] However, if consumed regularly, some fish have concentrations high enough to lead to negative health outcomes, particularly for members of vulnerable populations.[1] In BC's lower mainland, there are documented cases of sickness caused by significantly elevated blood mercury levels.[68] Two of these cases involved preschool aged children of Asian descent who had blood mercury levels 8 and 20 times the safe limit, likely caused by consuming Alaskan black cod.[68]

Despite government reassurances, mercury intake may be a real threat to some British Columbians, and more research is necessary to assess these unnoticed risks. Without information on fish-mercury levels specific to location and species, and data on human consumption, we still lack the knowledge necessary to determine the risks associated with sport-caught fresh water fish in BC. An outline for a study designed to determine methyl mercury exposure among licensed freshwater anglers on Vancouver Island is included as an appendix.

EXPOSURE ASSESSMENT METHODS

Various methods are used to determine consumption levels of sport-caught fish. These include: i) telephone recall; ii) face to face interviews; iii) mailed questionnaires; iv) diaries; and v) on-sight creel observations.[61] Data on fish consumption are collected for various reasons not always related to human health.[61] The type of exposure assessment method used will bias the type of data gathered and determine what population will respond.[61] For instance, creel surveys are useful in obtaining data on high frequency consumers.[61] Likewise, face-to-face interviews at fishing locations are more likely to target higher frequency anglers.[61] In order to target licensed angling populations, mail surveys are most common.[61]

Key differences among the various assessment approaches relate to whether the respondents must recall past consumption and behaviours, or if they describe current activities.[61] Also important is where the data are collected; close to the fishing site or at home.[61] Approaches can be self administered, such as mail surveys, or done by an interviewer.[61] Table 2 summarizes some of the benefits and drawbacks of each method.[61]

Selection Criterion	Telephone Survey	Mail Survey	Diary	Personal Interview	Creel Survey
I. Target Population/Subpopulation					
Survey sample known prior to conducting survey	yes/no[a]	yes	yes	yes/no[b]	yes/no[c]
Can be used where low literacy rates might be encountered	yes	no	no	yes	yes
II. Accuracy[d]					
Reliability					
Potential for response reliability	moderate/ high	low/ moderate	low/ moderate	moderate/ high	moderate/ high
Validity					
Validity of consumption estimates	low	low/high[e]	moderate	low/ moderate[f]	moderate[f]
Validity of species identification	low	moderate	moderate	moderate/ high[g]	high
Bias					
Potential to minimize recall bias	moderate	low/high[e]	moderate	moderate/ high[g]	not applicable
Potential to minimize prestige bias	moderate	low	low	moderate	moderate
Measurement error					
Opportunity for respondent to ask for clarification	moderate/ high	low	low	high	high
Potential for respondent participation	moderate	moderate	low	high	high
III. Time Frame					
Immediate data from respondent	yes	no	no	yes	yes
IV. Resources					
Interviewer burden	moderate	low	low	high	high
Respondent burden	low	moderate	high	low	low
Relative cost	moderate	low/ moderate	low	high	high
V. Harvest Characteristics					
Many access points	yes	yes	yes	yes/no[b]	yes/no[h]
High fishing or hunting pressure	yes/no[i]	yes	no	yes	yes/no[j]
Large geographic area	yes	yes	yes	no	no

[a]Yes if phone numbers are obtained after the sample population has been preselected, no if random-digit dialing (RDD) or general directory frames are used, unless geographically delimited using 3-digit prefix.
[b]No for interviews conducted at fishing or hunting access points, yes for off-site interviews.

Table 1: Comparison of Fish Consumption Assessment Approaches

Data from these approaches can enable assessment of the level of freshwater fish consumption by anglers, to identify where problems related to mercury contamination may exist.

CANADA'S ABORIGINAL POPULATION

Methyl mercury exposure disproportionately affects Aboriginal populations in Canada, as fish and marine mammals account for a large component of the traditional diet.[69] Many Métis and First Nations communities suffer from adverse effects related to exposure, though Inuit communities residing in Canada's north face the most severe consequences from these risks.[8, 9, 70, 71] A proliferation of studies across Canada has documented levels of methyl mercury above acceptable limits in both traditional foods and human subjects.[72] The negative impacts of methyl mercury within Aboriginal communities is exacerbated by the subsequent perceptions of a contaminated traditional diet, leading to social and cultural changes.[9, 72] Environmental dispossession is a term sometimes used to characterise how environmental degradation can sever the cultural connection between a land and its people.[9] Appreciating the impacts of methyl mercury on Aboriginal peoples in Canada demands an understanding of the nexus between culture and the physical environment.

Action levels for mercury in high fish consuming Aboriginal communities must reflect subsistence ingestion rates. The action level is the chemical concentration in food such as fish above which consumption poses a health risk.[73] Health Canada defines this level at 0.5 ppm for fish, while the U.S. Environmental Protection Agency maintains a level of 0.1 ppm, for the general population.[73] However, these levels are misleading for subsistence angling communities, according to a study of Tribes residing in the Columbia Basin.[73] As Aboriginal consumption rates are often much higher than the general population, action levels must reflect lower levels of mercury in fish.[73] For the subsistence ingestion rate of Columbia Basin Tribes, researchers suggested a level of 0.05ppm in order to sufficiently protect public health.[73]

Exposure to methyl mercury in Aboriginal Canadians tends to be higher in northern Canada, thereby affecting the Inuit more than other groups.[8] The Inuit diet presents the greatest risk for methyl mercury exposure because of marine mammal consumption, as whales and seals can have the highest concentrations of methyl mercury found in the food chain.[70] The attributable proportion of methyl mercury from marine mammal consumption was found to be the largest risk factor for dangerously elevated levels in Nunavik. [70] However, in Nunavik, 40% of fish sampled were shown to have levels of methyl mercury exceeding safe guidelines because of methylation in reservoirs.[8] A study of 917 Inuit from 14 communities examined dietary patterns and methyl mercury in blood biomarkers.[70] Twenty-eight percent of the subjects from the general population of Nunavik had mercury levels above acceptable Health Canada guidelines (99.7 nmol/L), with 72% of women of reproductive age above their recommended blood level (28.9 nmol/L).[70] Furthermore, methyl mercury exposure in preschool-aged children negatively impacted visual information processing, and was associated with higher tremor amplitude.[70] Likewise, in one Inuit community on Baffin Island, 83% of men and 73% of women exceeded the provisional tolerable daily intake of methyl mercury based on a diet high in marine mammals. [8]

Elemental mercury is volatile, so elemental mercury travels long distances towards Polar Regions through global circulation patterns.[74] Mining, coal burning, waste incineration among other activities stemming from the industrial revolution increase the amount of mercury released into the atmosphere.[74] Methyl mercury levels in marine mammals consumed by the Inuit, such as beluga whales, have increased dramatically in recent years. Between 1981 and 2007 some Arctic marine mammals displayed a 10-fold increase in methyl mercury levels.[74] Climate change is likely to exacerbate this trend.[74, 75] Methylation is facilitated by biotic processes that are temperature dependent, so global warming is predicted to increase methyl mercury in the biosphere.[75]

The importance of the traditional diet to Aboriginal health must inform risk management of methyl mercury exposure in Aboriginal populations.[8] High exposure to methyl mercury does lead directly to negative physical health outcomes in many Aboriginal communities, however, the perception of a contaminated food web can also be influential in determining Aboriginal health.[72] The knowledge that traditional foods like fish and marine mammals are contaminated by mercury produces profound social, cultural and economic impacts, harmfully impacting social determinants of health.[72] Environmental dispossession affects Aboriginal peoples disproportionately in Canada, as it impedes their capacity to exploit traditional resources, integral to the protection of culture and way of life.[9]

A qualitative study reported on consultations with 26 community health representatives from Aboriginal communities across Canada to identify pathways by which environmental dispossession effects determinants of health.[9] Six determinants were subsequently identified; balance, life control, education, material resources, social resources, and environmental and cultural connections.[9] Environmental and cultural connections as a determinant of health is unique from the wider Canadian community, as in Aboriginal cultures it is key to health and wellness.[9, 76] Therefore, understanding the impact of methyl mercury on Aboriginal peoples must be based on more than crude methyl mercury exposure values, and must recognize how exposure and perceptions of contamination intersect with social and cultural factors.

Traditional food is an important source of social and cultural benefits, and impacts both physical and spiritual health.[9] Contamination of traditional foods such as fish and marine mammals has a broader impact than the direct health consequences noted above. The experience in the Ojibway community of Grassy Narrows First Nation in north-west Ontario is one revealing example. During the late 1960s to early 1970s, a chlor-alkali plant pumped 10 tons of mercury-rich effluent into the English-Wabigoon River, 180km upstream from the community, contaminating fish and leading to some of the highest methyl mercury levels found in a Canadian population.[9] This revelation diminished the Ojibway's connection to the land, as they could no longer rely on fisheries for food, and their cultural and economic base.[77] This environmental dispossession led to an increase in violence, boredom, unemployment, and initiated feelings of powerlessness and dependency.[9] The corruption of the natural environment proved to be an assault not only on physical health, but their cultural identity.[9] Indeed, environmental dispossession by means of methyl mercury contamination can jeopardise health beyond direct health consequences by acting on social determinants of health.

Communicating and managing risks from contaminated traditional foods has been particularly challenging in Inuit communities.[9, 78] Lessons based on past experience point more towards how *not* to approach the problem than towards successful best practices.[79] Barriers to successful risk management in Northern Aboriginal communities include language and knowledge systems that have difficulty integrating 'invisible knowledge' of contamination.[79] Also, these populations had difficulty believing, comprehending, and trusting advice provided by people from outside their communities, as outsiders were regarded with scepticism, suspicion and mistrust.[79] Effective risk communication in Canada's North relies on several factors.[79] The history of how cases in a particular community were dealt with in the past proved critical to building public trust of authorities.[79] Furthermore, simpler materials were generally more effective, and perceptions of the seriousness of the risk proved important.[79] Risk communication programs must be based on honesty and respect for Aboriginal communities, and this can come about by engaging Aboriginal communities in the policy and program development process, ensuring both are consistent with their concerns and priorities.

Aboriginal perceptions of health are inseparable from the physical environment, as traditional beliefs position them as part of the land.[72] Knowing that foods such as fish and marine mammals are contaminated impacts culture and social norms. Ensuing changes to diet and lifestyle leads to more sedentary behaviour, family and community violence, drug abuse and suicide.[72] Policies addressing methyl mercury must balance the risk of exposure against the impacts of diminishing environmental connections.

The function of the scientific community in risk communication is to provide information about the health risks associated with methyl mercury exposure, and to provide guidance to reduce these risks.[80] Public health practitioners must ensure that Aboriginal populations are sufficiently protected, while remaining sensitive to the socio-cultural risks of behaviour modification.[78] Successfully managing this risk to Aboriginal communities demands an integrated approach, recognizing the importance of both standard risk assessment processes and risks to other determinants of health.[78] The point at which the physiological risks of methyl mercury exposure prevail over the negative consequences of socio-cultural disruption is best defined by data from child development studies, as it is of utmost importance to protect those in early developmental stages, and future generations.[78]

COSTS OF GOLD MINING IN DEVELOPING NATIONS

International trade produces a net flow of mercury from industrialized nations to the developing world, where the use of mercury is not adequately controlled.[81]. Widespread poverty and increasing gold prices are causing a proliferation of small gold mining operations that use mercury to amalgamate gold.[81] Ten to fifteen million miners currently take part in such activities worldwide, accounting for 10 percent of anthropogenic loading of mercury into the atmosphere.[81] This process leads to methyl mercury contamination of fisheries, directly affecting human health, and the resultant environmental dispossession triggers conversion to less nutritious foods, increases sedentary behaviour, degrades economic viability, and diminishes social cohesion.[81] However, preventing the use of mercury in mining through a trade ban may have dire consequences for the world's poor in 55 countries.[11] There are methods for reducing the release of mercury during amalgamation, and subsequent exposure.[82] As mercury-free mining technologies are too expensive for most small-scale miners, these methods should be used as a harm reduction strategy until alternatives are more accessible.[11]

In gold mining using mercury amalgamation, liquid mercury binds to gold, forming an amalgam.[83] This amalgam is heated, producing mercury vapour and gold.[83] During this process, exposure through inhalation of mercury vapour is often greater than 50 $\mu g/m^3$, fifty times greater than the World Health

Organization's public exposure guidelines.[81] To gold miners, this exposure is much more dangerous than through fish consumption.[83] However, the process results in environmental contamination, and communities experience elevated exposure to methyl mercury through fish intake.[10, 81, 84-88] Mercury amalgamation is often practiced in houses where children are present, with no separation between working and housing areas.[83] Indeed, the work is often carried out by children as young as seven years old.[83]

In the Madeira Basin of the Amazon, researchers examined the Riverside People for methyl mercury exposure through fish contamination in an area that had undergone extensive gold mining since the 1920s.[88] Hair mercury concentrations were taken in the heavy fish eating population. Ninety-five percent of infants were exposed to mercury levels greater than the lowest observed effect level (LOEL) of 0.7µg/kg body weight, through placental exposure, mother's milk, and fish consumption.[88] Furthermore, 45% of mothers and women of childbearing age risked ingestion of mercury above this level.[88] The study documented neurological damage from methyl mercury poisoning in young children.[88] Similarly, in the Tapajos River Region of the Amazon mercury amalgamation methods used in gold mining caused a health risk to the population through fish consumption.[84]. Indeed, mercury released by this method is a widespread problem in the Amazon, as exposure through fish consumption leads to adverse health effects.[10]

In Tatelu, North Sulawesi Province, Indonesia, gold mining increased methyl mercury concentrations in fish, with over 45% of specimens collected from the market having levels above World Health Organization guidelines of 0.5µg/g.[87] This led to elevated methyl mercury levels in hair and blood samples taken from the population.[87] Elsewhere, among the Wagane community of Native Amerindians in French Guiana, gold mining resulted in increased methyl mercury levels found in hair samples, above levels believed to be safe.[85]

A ban on mercury trade would decrease methyl mercury exposure globally.[89] However, the impact of such a move on the world's poor could prove harmful, as miners in developing nations have few economic alternatives.[11] Restriction on the mercury trade must be accompanied by community capacity-building measures to ensure that economic alternatives exist, and transfers of technology to the local level that ensure mercury does not escape into the biosphere.[11]

Gold mining using mercury is an important source of methyl mercury exposure in the developing world, as the release of mercury into the environment elevates concentrations in fish consumed by community members.[81, 90] There is ample evidence of negative health impacts stemming from exposure to methyl mercury in mining areas.[89] It is important to reduce mercury contamination to protect traditional ways of life from the harmful effects of environmental dispossession.[9] Policies must focus attention reducing exposures to women and children, as methyl mercury is especially harmful during early developmental stages.[5, 7, 81, 88]

The Global Mercury Project, a United Nations initiative aimed at limiting mercury contamination, provides technical and political guidance to countries where mercury amalgamation gold mining is practiced.[91] They endorse the following measures to meet this challenge: People should not heat mercury to recover gold without a retort to contain and recycle mercury vapours. Amalgamation must not occur in residential areas or within 100 metres from any residential buildings, or within 100 metres of any natural water body. When not in use, mercury should be kept in unbreakable, air-tight containers, and covered by one centimetre of water to prevent evaporation. Mercury disposal must be done safely, away from water bodies, by burying it in holes five metres deep, and when this is full, it must be covered by a half metre of either clay or laterite soil, compacted, covered with soil, and re-vegetated. Amalgamation should occur only in centralized locations, in an area free from flooding, and the manager of this location must hold a license. Also, pregnant women and children below 16 years of age should not enter the location where amalgamation occurs.[82] Programs to facilitate the adoption of these measures are underway in Brazil, Indonesia, Sudan, Tanzania, Lao Peoples' Democratic Republic, and Zimbabwe.[11]

DISCUSSION

Methyl mercury in the physical environment stems from both natural and anthropogenic sources. (2, 12-15, 17) It is not possible to reduce the weathering, volcanoes, and forest fires that naturally release mercury into lakes and rivers. However, we are empowered to mitigate environmental mercury concentrations by preventing its escape during pulp and paper processing, fossil fuel and garbage burning and mining, and also by slowing deforestation that causes soil erosion and leaching.(18, 92) Reducing mercury releases at their source is a viable way to affect downstream exposure.(92) Global mercury concentrations increased 1.2 to 1.5% annually between 1977 and 1990; decelerating this rate through decreasing mercury emissions will ultimately reduce exposure.(18) Lessening fossil fuel consumption will affect environmental mercury levels in two ways, as a reduction directly reduces mercury emissions into the atmosphere, and helps to mitigate climate change, which is likely to increase mercury levels in the biosphere.(74, 92)

In addition to reducing mercury emissions, the human health risks of mercury can also be reduced by minimizing exposures after releases have occurred. Protecting individuals from methyl mercury exposure necessitates specific, targeted risk communication. The public faces mixed messages relating to the dangers of fish consumption. Fish is known to have both nutritional benefits, and associated risks.(2) Species specific information must be made readily available, so individuals can make informed decisions about their health. Furthermore, information must target vulnerable populations such as women expecting to become pregnant, pregnant and nursing women, and children, to minimize risks to healthy childhood development.[7]

Environmental Justice brings together concepts from civil rights and environmentalism.[93] This paradigm recognizes that environmental degradation disproportionately impacts certain vulnerable populations.[93] These populations face disproportionate harms through elevated exposure to hazards, unequal access to the policy-making process, inequities in regulatory enforcement, and disparities in socioeconomic status, power, and health.[93] Through this lens, we can better understand the causes and impacts of harms associated with methyl mercury exposure to Canada's Aboriginal peoples and the developing world.

A careful approach is necessary to address methyl mercury exposure to Canada's Aboriginal peoples. This population, and particularly the Inuit, are especially vulnerable to excessive methyl mercury exposure.[8] Because of their northern geographic location, the Inuit encounter especially high levels of contamination of their traditional foods.[74] This is especially unjust given that they are not responsible for the high levels of mercury released into the biosphere. To make matters worse, programs and policies aimed at reducing exposure to methyl mercury entrench environmental dispossession.[9] In communities where exposure is indeed a major risk, such as in northern areas, care is needed to maintain traditional connections to the land while steps are taken to reduce methyl mercury exposure. Protecting those in early developmental stages must be of paramount importance, and their protection justifies measures aimed at modifying traditional food consumption patterns.[78] In First Nations and Métis communities where exposure is not a significant risk, policy makers must promote the maintenance of Aboriginal cultures by encouraging the continuation of traditional food consumption.[8] Furthermore, policy makers must act against unsubstantiated perceptions of contamination, to improve environmental and cultural connections, a key determinant of Aboriginal health.[8]

Global economic inequities put pressure on those in developing nations to engage in activities that not only negatively affect their own health, but that of their communities. Such is the case with gold mining using mercury amalgamation. Communities in gold mining areas using this method often rely on fish for nutrition and economic viability. These vulnerable populations are disproportionately exposed to methyl mercury contamination of fish, because of a lack of regulatory enforcement, and empowerment. Despite the knowledge that mercury exports to developing nations such as Brazil will be used irresponsibly, European nations continue to export mercury at alarming rates.[89]

Mercury contamination of fish stocks leads to a less nutritious diet, sedentary behaviour, reduced economic viability, and a decrease in social cohesion, as communities in the developing world face environmental dispossession.[81] A ban on mercury exports to the developing world, where mercury contamination increasingly contaminates fish, would benefit environmental health and food sovereignty. Over 140 environmental organizations advocate for banning the trade of mercury as an "*economic and moral imperative*".[11] However, a comprehensive program aimed at community capacity-building where locals rely on such methods for economic viability must accompany such a ban.[11] The cycle of poverty that drives the use such of dangerous methods of resource extraction will continue unless action is taken to lift these communities out of poverty. International aid targeted toward these areas, in the form of education, health infrastructure, and other economic capacity building measures, is required. Furthermore, help by way of technology transfers is needed, as current gold mining technologies that are mercury-free are too expensive for the majority of small-scale miners.[11]

Careful risk management and communication can alleviate some of the harms associated with methyl mercury exposure. Risk communication must be culturally appropriate and target vulnerable populations in order to produce the greatest benefit. Strategies targeting Canada's Aboriginal peoples must be sensitive to the unique needs of these cultures to maintain their traditional culture, avoiding further environmental dispossession when possible, while ensuring that the public is adequately protected. In the developing world, industrialized nations must help to reduce the need of impoverished communities to degrade their environment through mercury amalgamation mining. Approaches informed by social and environmental justice will help ensure solutions are fair, effective, and forthcoming.

APPENDIX

Study Outline

Study to Assess the Attributable Exposure to Methyl Mercury Through the Consumption of Sport-Caught Freshwater Fish among Vancouver Island Licensed Anglers

Research Objectives

The goal of this research project is to address the question:

<u>What is the likelihood of Vancouver Island based licensed anglers having elevated mercury levels caused by consuming sport-caught freshwater fish?</u>

In order to address this question, other data must be collected relating fishing and consumption habits. The specific aims therefore include determining:

i) The amount and frequency of sport-caught fish consumed by freshwater anglers
ii) The lakes and rivers individuals are fishing in, and the lakes' respective mercury levels where available
iii) The type of species being caught
iv) The proportion of total fish intake that is from sport-caught fish compared to commercially bought fish
v) The purchasing preferences for other potential sources of Hg
vi) The number of BC anglers who have unhealthily elevated levels of mercury in their blood
vii) The socio-demographic characteristics and body weights of the population

Methods/Activities

SETTING

The research will be conducted with support from the BC Centre for Disease Control, the National Collaborating Centre for Environmental Health, and the Faculty of Health Sciences at Simon Fraser University.

RESOURCES

Funding for project expenses will be provided by the BC Centre for Disease Control and Prevention.

SPECIFIC ACTIVITIES

The researcher will conduct a mail out survey of BC licensed anglers living on Vancouver Island. The aim of the survey is to gather data necessary to answer the research objectives, and will also ask respondents whether they will be willing to submit to blood testing to determine blood methyl mercury levels.

a) Define Research Question and Design

- i) Review literature to determine the best methods for conducting an exposure assessment to satisfy the research goals.
- ii) Gather examples of approaches used elsewhere to satisfy similar research goals, including survey instruments, methodologies, results, and discussions (i.e. limitations)
- iii) Further clarify the research objectives
- iv) Identify demographic subgroups who may be included in the analysis
- v) Identify the dependent and independent variables

b) Design the Questionnaire

- i) Construct questions that are able to resolve the research objectives
- ii) Explore whether there are important questions that could be asked to allow for future research that is connected with the study
- iii) Explain informed consent expressly on the survey instrument
- iv) Ask whether respondents would be willing to provide biomarkers (blood, tissue, or hair samples) in order to calibrate the survey

c) Ethics Approval

- i) Submit application for ethical approval for the project to the SFU Department of Research Ethics
- ii) Make any necessary changes to the study design, survey instrument in order to gain ethics approval
- iii) Resubmit as necessary

d) Identifying the Sample

- i) The Sampling Frame consists of a database of all Vancouver Island based licensed freshwater anglers. The sampling unit will be determined, and will likely be either the individual licensed angler, or the household to which they belong
- ii) In order to achieve a representative sample and reduce costs a stratified random sample will be used to identify the survey population

e) Recruiting Sample and Collecting Data

- i) The questionnaire will be mailed out to all units in the sample. The four-wave Dillman method will be used to reduce response bias. This method involves sending out postcard reminders, and resending the survey over a specified period.
- ii) Respondents will mail the questionnaires back to the researcher using a self-addressed, stamped envelope.

f) Selection of sample and collection of biomarkers

i) Those respondents who agree to be tested for biomarkers will be contacted by telephone, email, or mail, and instructed on how to provide blood for the study, through laboratory services within their communities.

g) Data Analysis and Report Presentation

i) Based on data collected through the mail-out survey, descriptive data on population demographics, consumption patterns, and purchasing preferences will be ascertained. **Population demographics:** Number of respondents (N), response rate, sex, age, and first language spoken.

Consumption Patterns: Fishing frequency, consumption frequency as 5th, 25th, 50th, 75th, and 95th percentile; relative frequency of species caught; percentage of anglers consuming caught-fish individually or sharing with family members, and of those who share with family members aged 10 and below; parts of fish consumed; and preparation method.

ii) Blood-mercury data collected from consenting survey respondents will provide information on blood mercury levels at the 5th, 25th, 50th, 75th, and 95th percentile. Based on consumption habits, the researchers will determine:

a) whether the sample population has a mean mercury level above that of the general population
b) the 5th, 25th, 50th, 75th, and 95th percentile blood mercury level in the population
c) patterns of fish consumption that are associated with elevated blood mercury levels (caught vs. bought, species, lake location, frequency)
d) trends in demographic data of those anglers that display elevated levels of blood-mercury

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