DEVELOPMENT OF A RISK ASSESSMENT TOOL FOR MERCURY IN FISH

by

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ABSTRACT

Fish can accumulate high levels of mercury (Hg) and become a human health concern if consumed. The purpose of this study was to develop a risk assessment tool to determine which water bodies from certain areas in Northern British Columbia contain fish with high Hg concentrations. Raw and published data were collected from Health Canada and Ministry of Environment and amalgamated to form a large data set (3097 fish samples from 34 distinct areas between 1974 and 2000). Fish weight was standardized and a cut-off point was determined for each species for high Hg levels. This was used to develop a risk assessment tool unique to the study area to identify which species/water body combinations were high in Hg and how fish consumption strategies can be adapted to minimize exposure. Although high Hg levels were widespread, the majority of contaminated samples were from Pinchi Lake and the Williston Lake area.

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LIST OF ACRONYMS

AA – arachidonic acid

ALA – alpha-linolenic acid

ANCOVA – Analysis of Covariance

ANOVA – Analysis of Variance

ATSDR – Agency for Toxic Substances and Disease Registry

COT – Committee on Toxicity

DHA – docosahexaenoic acid

DPA – docosapentaenoic acid

EPA – eicosapentaenoic acid

FAO – Food and Agriculture Association of United Nations

FDA – Food and Drug Administration of United States

Hg – Mercury

HgS – Red sulphide cinnabar

MeHg – Methylmercury

MWLAP – Ministry of Water, Land, and Air Protection

NAS – National Academy of Sciences

NMFS –National Marine Fisheries Service

PUFA – Polyunsaturated fatty acid

SACN – Scientific Advisory Committee on Nutrition

SPSS – Statistical Package for the Social Sciences

USDA – United States Department of Agriculture

U.S. EPA – United States Environmental Protection Agency

WHO – World Health Organization

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1.0 Purpose of the Study

The overall goal of this research was to identify the areas in the Northern Interior of British Columbia where concentrations of mercury (Hg) in fish are elevated and may pose a risk to fish consumers. Further, this research provided a tool for Public Health professionals in the Northern British Columbia region when assessing the risk associated with fish consumption from various water bodies in the region. Specifically, the following questions were addressed:

1. Which areas in Northern British Columbia have the highest levels of Hg in fish, and do these levels vary in different species from the same area?
2. Are there similarities in the areas with the highest Hg levels in fish? For instance, are anthropogenic activities associated with the elevated Hg levels?
3. Are there relationships between Hg concentrations in fish and species, age, weight, location, and date of sampling?
4. Does consumption of fish from the areas exhibiting high Hg concentrations in fish pose a human health risk? If so, how should Public Health officials respond to this risk?

2.0 Background and Context of the Study

Due to its high toxicity to both humans and animals, Hg is one of the most commonly studied trace elements in the environment (Mousavi et al., 2011). Hg is third (after arsenic and lead) on the 2011 Agency for Toxic Substances and Disease Registry (ATSDR) priority list of 275 hazardous substances, which includes substances that present the most significant potential threats to human health in the United States

(ATSDR, 2011). It is released into the environment through both natural and anthropogenic sources and can exist in three forms: elemental, inorganic, and organic (Bhavsar, 2010; Mousavi et al., 2011). In freshwater ecosystems, the organic form (e.g. methylmercury) is predominant and has a high propensity to accumulate in fish tissue through ingestion and absorption (Beyrouty & Chan, 2006). Therefore, dietary consumption of fish and other aquatic animals is a major route of Hg exposure amongst human and wildlife populations (Mousavi et al., 2011) and the effects of high Hg exposure are well documented (Beyrouty & Chan, 2006).

Although methylmercury (MeHg) is produced naturally in the environment (Adriano, 2001), records of it being a potential toxicant and its use in chemical research date as far back as the 1860s (Clarkson, 2002). The commercial production of organic Hg did not begin until around 1914, when it began to be used as a crop fungicide (Barrett, 2010). Since then, MeHg has come to be known as one of the most hazardous environmental pollutants. Many endemic disasters are attributed to MeHg, such as Minamata disease in Japan and poisoning from the distribution of wheat seeds dressed with MeHg in Iraq (Mousavi et al., 2011; Legrand et al., 2005).

In Canada, Hg pollution surfaced as an issue in 1969 when fish and waterfowl populations within the basins of Wabigoon and English Rivers in Ontario were found to have elevated Hg levels (Harada et al., 2011). The pollution source was found to be a factory upstream, which used Hg as a catalyst to purify caustic soda. Two indigenous communities along the river (Asubpeeschoseewagong from Grassy Narrows and Wabaseemoong from White Dog) consumed Hg-contaminated fish from the river. Although there is debate about the actual cause of symptoms, clinical and epidemiological investigations conducted by Harada et al. (2011) found that Minamata Disease-like symptoms were common amongst the population. Follow-up research was conducted in 2002, 2004, and 2010 and the original findings of these symptoms were reconfirmed (Harada, M., et al., 2011). Even today, Hg concentrations in fish continue to be above safe levels (Kinghorn et al., 2007).

The amount of Hg released into the atmosphere has increased through other human activities, including coal and municipal waste incineration (Mousavi et al., 2011). Metal mining and smelting, the use of Hg in gold mining, chlor-alkali production (where Hg is used as an electrode in the electrochemical process of manufacturing chlorine), and bio-medical waste are also anthropogenic sources contributing to increased Hg in the environment (Mousavi et al., 2011). Other examples of anthropogenic sources of exposure include: paints and tattoo inks, dental amalgams, barometers, blood pressure monitors, gas regulators, fluorescent bulbs, wall light switches, camera batteries, thermostats, and thermometers (Mousavi et al., 2011).

2.1 Hg in the environment

Hg is naturally occurring and is found in air, water and soil; it can be detected almost anywhere in the environment, with normal background levels in sediments usually below 0.1 ppm (ranges between 0.01 to 0.2 ppm). Table 2.1 below summarizes the forms that Hg can exist within the environment. Because Hg exists in many forms, its movement within the environment is influenced by a number of factors (Adriano, 2001). It cycles naturally through the earth's crust, atmosphere, oceans, and life forms, with trace amounts in fish, plants, and animals (Rasmussen, 2005). The main ore of mercury is the red sulphide cinnabar (HgS), which is what is commonly mined. In its gaseous elemental form Hg has an atmospheric lifetime of six to eighteen months allowing it to be transported around the globe (UNEP, 2008).

The main mobilization mechanism for Hg in the environment is through the formation of organic forms. Alkylation is a process which combines inorganic Hg with one or two methyl groups forming monomethylmercury or dimethylmercury (WHO, 2006). Methylation of Hg is a detoxification process which is performed by microorganisms such as bacterium, fungi and mould; hence the rate of methylation is in part dependent on the abundance of these organisms (WHO, 2006).

2.1.1 Hg bioaccumulation in the aquatic food web

Inorganic Hg, once it has been released by natural and/or anthropogenic sources, enters aquatic environments and accumulates in sediments where it can be transformed into MeHg by sulfate-reducing bacteria under anoxic conditions (Wang et. al, 2012). Anaerobic sulfate-reducing bacteria are the main agents of Hg methylation, and anthropogenic additions of sulfate are increasing the activities of these bacteria. These bacteria may methylate Hg in a slow side reaction at 1/1000 the rate of overall sulfate reduction. Sulfate reducers growing at or near redox interfaces may be most important for methylation and Hg contamination of shallow-water food webs (Fry and Chumchal, 2012).

Uptake of MeHg from the environment by the lowest organisms of the food chain plays a key role in MeHg bioaccumulation and biomagnification in biota at higher trophic levels because most of the Hg that accumulates in species originates from consumption of organisms at lower trophic levels rather than direct aqueous accumulation. The pathway for MeHg transfer along the food web can be classified as pelagic or benthic according to the foraging habitat. A part of the MeHg in sediments can be taken up by benthic animals directly through gut digestion, or MeHg is also able to enter the water through particulate re-suspension and diffusion, where it can be absorbed by phytoplankton and then biomagnified to potentially harmful concentrations in the food web (Wang et. al, 2012).

Table 2.1 Forms of Hg (U.S. EPA, 2007)

Types of Hg	Description	Where it is found	Symptoms from exposure
Elemental or metallic	- Not carbon-containing - Silver colored metal that exists as a thick liquid at room temperature - A vapour in air	- Ambient air - Thermometers - Fluorescent bulbs - Dental amalgams	-Renal toxicity, skin rashes, hypertension, and pulmonary toxicity - Neurological changes (behavioral changes, tremors, and reduced muscle coordination) - Death, related to respiratory failure - Pink disease (symptoms include leg cramps, irritability, redness /peeling of skin, itching, fever, sweating, salivating, rashes, sleeplessness)
Organic	- Predominantly MeHg - Ethylmercury - Phenylmercuric Acetate (PMA)	- Foods such as fish - Vaccine preservatives and some antiseptics - Formerly used in some indoor paint - Sediment	- In utero exposure may cause delays in reaching developmental milestones and decrease intelligence - High doses may cause mental retardation, reduced muscle coordination, blindness, seizures, muscle weakness, and inability to speak - Effects in adult humans include kidney damage and digestive tract problems -Chronic exposure is linked to elevated blood pressure, increased risk of heart attack, heart palpitations, hand tremors, impaired hearing, dizziness, and staggering -Pink disease
Inorganic	- Not carbon-containing - Non-elemental forms of inorganic Hg, including mercuric chloride, mercuric acetate, mercuric sulfide, etc.	- Commercially available products - Medicinal homeopathic herbal remedies - Low exposure from indoor air	- Can be toxic to kidneys, stomach, intestines - Can lead to increased blood pressure - Possible embryotoxic effects including increased rates of miscarriage and stillbirth

2.1.2 Influencing factors for increased Hg concentrations in fish

The relationship between elevated Hg concentrations in fish in newly flooded areas is well documented. The flooding of vegetation and terrestrial soils through natural and anthropogenic processes contributes to elevated Hg concentrations in the food web of flooded environments (Mast and Krabbenhoft, 2010). It has been proven that reservoir formation often leads to elevated Hg levels in fish relative to pre-impoundment concentrations, even in cases where no point source discharges of Hg are evident (Mast and Krabbenhoft, 2010). In newly created reservoirs, the initial flooding of organic-rich soils can result in elevated Hg concentrations in fish for up to 10 to 20 years later (Bodaly et al., 2007). Hg accumulation may also be elevated in established reservoirs that experience annual water-level fluctuations related to water storage, power generation, or flood control (Mast and Krabbenhoft, 2010). The source of Hg in reservoirs is likely a redistribution of the element from materials already in the lake or river prior to flooding (Mast and Krabbenhoft, 2010). In situations where the reservoir is reflooded, declining water levels may allow the growth of vegetation on exposed littoral areas, which then become a new carbon source when the sediments are reflooded, causing an increase in microbial activity and MeHg production. An alternate explanation is that drying of soils and sediments results in oxidation of reduced sulfur to sulfate which stimulates sulfate-reducing bacteria and MeHg production when rewetted (Mast and Krabbenhoft, 2010). The magnitude of increases in Hg levels in the environment, and in turn, in fish depends on many factors including the area of land and vegetation inundated, water temperature, pH, alkalinity, sulfate, dissolved organic carbon and the age and retention time of the reservoir (Mast and Krabbenhoft, 2010).

The correlation between the rising concentration of Hg in fish tissue and the size and age of the fish is well documented. The levels of increase depend on trophic status and diet; the lowest levels are in aquatic plants, intermediate in invertebrates and highest in fish, and piscivorous mammals and birds (Storelli et al., 2007). "Larger, older, and higher-trophic-level fish species generally have higher MeHg tissue residues than smaller and younger organisms from lower trophic levels. Concentrations in top predator fish can be up to 10 million times higher than those in water" (Mahaffey et al., 2011). Studies also show differences in Hg concentrations in pelagic and benthic species; animals living in close association with sediments (in which they bury and from where they feed) are eventually more exposed to sediment-associated contamination than other fish (Storelli et al., 2007). Almost all of the Hg found in biological systems has been absorbed in the form of MeHg and all freshwater fish in North America, and perhaps in the world, have at least trace levels of Hg in their tissues (Bhavsar, 2010). MeHg can bioaccumulate and biomagnify within aquatic food webs and is highly absorbable to both fish and human consumers via ingestion (95 to 100%) compared to inorganic Hg (5 to 10%) (Storelli et al., 2007; Chan et al., 2003).

2.2 Northern British Columbia

Northern British Columbia's geographic area is approximately 500,000 square kilometers, which comprises more than half of the province (TourismBC, 2008). This area has many rivers and lakes and is known for its freshwater and saltwater fishing.

Hg levels in fish have been a source of concern in some regions of Northern British Columbia both in the past and at the present time. Higher than normal levels have been attributed to anthropocentric activities such as the building of reservoirs and mining close to lakes. The two water bodies that have received the most attention for high Hg levels in Northern British Columbia are Pinchi Lake and Williston Reservoir.

2.2.1 Pinchi Lake

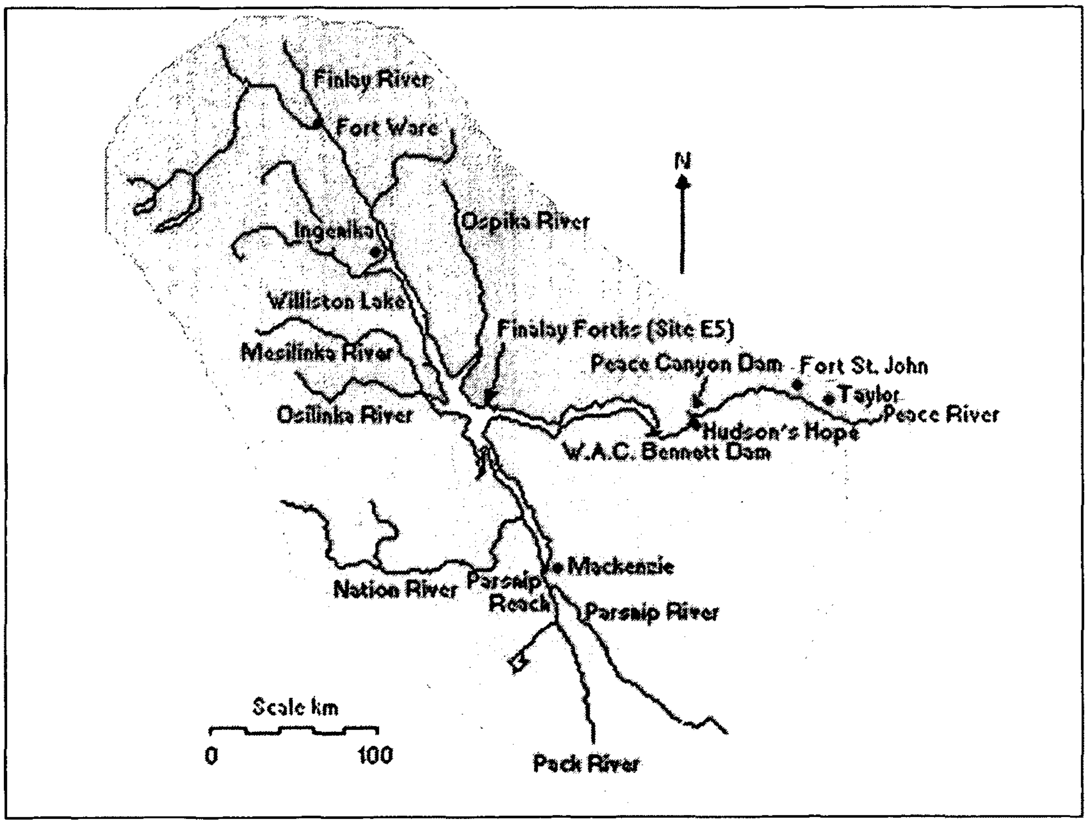
The area along the Pinchi fault in central British Columbia is a prime example of a natural Hg source found and exploited by humans leading to elevated Hg levels in the lake (Weech et al., 2004). A portion of the northern shore was mined for Hg from 1940 to 1944, at which time the mine was closed and all structures were subsequently demolished. The mine was redeveloped and operated once again from 1968 to 1975. Waste ore was routinely deposited directly into Pinchi Lake; since then, relatively high concentrations of Hg have been observed in the water, sediments, and fish in the area (Weech et al., 2004).

There has been media attention on the elevated Hg levels of Pinchi Lake's fish, as the Tl'azt'en Nation, a group of Carrier Indians who live north of Fort St James, claim that it has affected the health of the majority of their population of 1200 (The Province, 2003). In February of 2010, a consulting agency prepared a document for Teck Metals (also known as Cominco) entitled "Human Health Risk Assessment of the Pinchi Mine and Pinchi Lake Area." This document included a closure plan for the mine and concluded that "post-closure environmental conditions and land uses at the mine site described in the Closure Plan should result in acceptable risks to human health for on-site receptors" (Wilson, 2010). An assessment conducted at a later date to ensure that the post-closure conditions are indeed acceptable would be ideal.

2.2.2 Williston Lake

The Williston Lake Reservoir (Figure 2.1) is located in close proximity to Hudson's Hope, B.C.; it was created in 1968 by the impoundment of the Peace River in the Peace Canyon for the purpose of hydroelectric generation (Stockner, 2005). This reservoir is a product of the W.A.C. Bennett Dam, which flooded land surrounding the Peace, Parsnip, and Finlay rivers (creating the present three reaches) during the late 1960s through to the early 1970s. This is British Columbia's largest reservoir, with a surface area of nearly 178,000 hectares and a catchment area close to 70,000 square kilometers (Baker et al., 2000). The lake is used by the sports fishing industry as well as a First Nations community, Tsay Keh Dene, located at the mouth of the Finlay Reach.

Figure 2.1 Map of Williston Lake and the surrounding area (ILEC, 2008)



2.3 Benefits of fish consumption

The importance of fish consumption for good health and nutrition is well accepted; it has provided humanity with an important food source for thousands of years. Fish are a source of many vitamins, including niacin, vitamins B12, D, and A. Further, fish provide a dietary source of other nutrients including selenium, iodine, fluoride, calcium, copper, choline, taurine and zinc (SACN/COT, 2004; Karagas et al., 2012; FAO/WHO, 2011). The many health benefits of fish are partly due to the high concentrations of n-3 polyunsaturated fatty acids (n-3 PUFAs) present in many species (Mahaffey et al., 2011).

The n-3 PUFAs that are particularly important in human nutrition include alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), and docosahexaenoic acid (DHA). The two fatty acids that are especially important for human neurological development are EPA and DHA (Mahaffey et al., 2011). These essential fatty acids play important roles in cell membrane formation, integrity, and functions; the functioning of the brain, retina, liver, kidney, adrenal glands, and gonads; and local hormone production for the regulation of blood pressure and immune and inflammatory responses (Mahaffey et al., 2011).

Maternal intake of fish has been observed to be valuable to fulfill fetal requirements. DHA and arachidonic acid (AA), an omega-6 PUFA, are essential for the development of the central nervous system in mammals (SACN/COT, 2004). During the last trimester of pregnancy, fetal requirements for DHA and AA are very high due to the rapid synthesis of brain tissue. The main sources of the DHA and AA that accumulate in the brain are drawn from maternal circulation during pregnancy and through breast milk for newborns (Mahaffey et al., 2011; SACN/COT, 2004). In pre-term and low-birth-weight babies, DHA deficiency has been related to visual impairment and delayed cognitive development. Also, there is some evidence that increased maternal intake of fish or fish oil supplements may prolong gestation, minimizing preterm delivery and low birth weight (SACN/COT, 2004).

Multiple observational studies have monitored DHA levels in maternal blood during pregnancy, in umbilical cord blood during delivery or of maternal fish consumption during pregnancy. These studies demonstrate independent beneficial associations of DHA levels with more optimal neurodevelopmental outcomes in offspring, such as better behavioural attention scores, visual recognition memory and language comprehension in infancy and childhood (FAO/WHO, 2011).

The ingestion of fish or fish oils has been associated with an array of health benefits including improvement of blood lipid profiles, decreased risk of heart disease, lowered blood pressure, improvement in rheumatoid arthritis, enhanced eye and brain development in early life, prevention of macular degeneration, less risk of colitis and type 2 diabetes, and improvement in neurological and psychological disorders such as depression, schizophrenia and Parkinson's Disease (Ginsberg and Toal, 2008). A number of studies have shown strong evidence that fish or fish oil consumption reduces all-cause mortality and various cardiovascular disease outcomes (FAO/WHO, 2011).

2.4 Dietary concern related to fish consumption

Monomethylmercury is a neurotoxic species which bioaccumulates in fish tissue and is a principal Hg-related human health concern today (Mousavi et al., 2011). As it is readily formed in water and remains in the water column, fish take in MeHg by ingestion of contaminated prey and particles or assimilate the compound through their gills during respiration. The toxicity of low concentrations of Hg on most aquatic organisms can result in decreased growth rate, reproduction and overall ability to survive (Mousavi et al., 2011).

Hg and MeHg compounds usually affect the nervous system, the kidneys, and the developing fetus. Fetal brain Hg levels tend to be 5 to 7 times higher than in the mother's blood, with the developing central nervous system being of highest concern (WHO, 2006; Karagas, 2012). Hg toxicity can also affect fetal respiratory, cardiovascular, gastrointestinal, hematological, immune and reproductive systems.

There are several factors that determine the presence and severity of adverse health effects such as the chemical form of the Hg, the dose, the age or developmental stage of the exposed individual, the duration of exposure, and the route of exposure (WHO, 2006). Three routes of exposure are dermal contact, inhalation, and ingestion, with ingestion being the most common and hazardous.

Almost all Hg in fish is in the form of MeHg, which has a high affinity for proteins in fish muscle (Melwani et al., 2009). All humans are exposed to some level of Hg, and fish is the primary source of Hg exposure among the general population (Bhavsar et al., 2010). Because of this, many governments provide dietary advice to limit fish consumption where there are elevated Hg levels (WHO, 2006). The World Health Organization and the Food and Agriculture Organization of the United Nations recommend a maximum of 0.5 ppm in non-predatory fish and 1 ppm in predatory fish. The United States Food and Drug Administration set a maximum level of 1 ppm in fish, shellfish and aquatic animals. The European Community allows 0.5 ppm in fishery products and Japan allows up to 0.3 ppm.

Health Canada has set a guideline of 0.5 ppm for the Hg level in commercial fish; however, certain predatory fish species sold in Canada may contain Hg levels that are higher than this. In 2007, Health Canada issued a new standard which limits acceptable Hg content in predatory fish to 1.0 ppm (Health Canada, 2007b). Such predatory species include fresh/frozen tuna (*Thunnus* spp.), shark (*Selachimorpha* spp.), swordfish (*Xiaphis gladius*), marlin (*Makaira* spp.), orange roughy (*Hoplostethus atlanticus*), and escolar (*Lepidocybium flavobrunneum*). There is no limit on the consumption of fish such as salmon (*Salmo salar* (Atlantic); *Oncorhynchus* spp. (Pacific)), cod (*Gadus* spp.), pollock (*Pollachius pollachius*), sole (*Solea* spp.), shrimp (*Pandalus borealis*), mussels (*Mytilus edulis*), scallops (*Pecten maximus*), and canned light tuna (*Thunnus* spp.). There is also no limit on the consumption of the species used in this study (including bull trout, dolly varden, and lake trout, for which there are current advisories in Northern BC), nor do the guideline limits differ according to where the fish is caught (for example, inland/offshore, which province/area, etc.).

Many communities, especially First Nations, rely on fish intake as a daily component of their meals and nutrient intake and are likely at risk for chronic exposure to MeHg (Chan et al., 2011). It is important to balance the risks and benefits of fish consumption when nutritional, social, cultural, and economic benefits are concerned (Chan et al., 2011). In many communities, researchers are aware that MeHg is present in the area; however, there is a lack of comprehensive data collection and analysis. Collecting and analyzing data can be a lengthy and expensive process; limited human and financial resources make it difficult to study each community in depth. That being said, there is a current and ongoing "First Nations Food, Nutrition, and Environment Study" which analyzes food and water consumption for one hundred randomly selected First Nations communities across Canada (in British Columbia, Manitoba, and Ontario) (FNFES, 2012). This project is being conducted by the University of Northern British Columbia and has principal investigators from the University of Ottawa, University of Montreal, and the Assembly of First Nations, as well as co-investigators from Health Canada. This study also reports average total Hg in hair concentrations and conducts household interviews about traditional foods consumed in the past year (FNFES, 2012).

2.5 Benefits versus risks of fish consumption

Whether the benefits of fish consumption outweigh the risks of MeHg exposure has been a controversial issue for quite some time. The most important factors in the debate are the MeHg exposure levels in fish being consumed, and the level of risk associated with MeHg. When taking different factors into consideration, the recommendations can be quite confusing. For instance, the Food and Drug Administration of the United States (FDA) issued consumption advice in 2004, but only for children and pregnant and/or nursing women. Health Canada (2011) recommends 150g/week as a general guideline, 150g/month for pregnant women, 125g/month for children 5-11 years of age, and 75g/month for children 1-4 years of age (for non-predatory fish). To add to the confusion, the American Heart Association (2010) recommends at least 2 fish meals per week (Turyk, 2012).

Two studies from the Seychelles and Faroe islands show contrary assessments despite having similar populations with high per capita consumption of fish and MeHg body burdens higher than in the United States (Ginsberg and Toal, 2008). The Faroe study showed significant neurodevelopmental deficits at birth and into the early school years whereas the Seychelles study, at similar MeHg exposure levels, showed no evidence of harm. The National Academy of Sciences (NAS) held a peer review panel to determine the reasons for the conflicting results of the two studies and found that there were four main differences. The Faroese study used the umbilical cord to test for Hg concentration while the Seychellois survey used maternal hair; the Faroese study used domain-specific tests and the Seychellois study used globally-accepted tests (which may not have been sensitive enough to the region); the Faroese children were evaluated at age 7 and the Seychellois at age 5.5 (a less sensitive age for neuropsychological tests); the Faroese eat whale meat, which can significantly raise the concentration of Hg in the body in a short amount of time. After taking the above differences into account, NAS determined that the study from the Faroe Islands, even though they eat whale meat, fulfilled the most criteria for use of an epidemiology study in risk assessment (Jacobson, 2001). This was mostly due to the fact that the Seychelles study may have lacked sufficient power to detect the relatively small effect sizes computed for the Faroe Islands data (Price et al., 2007).

Based on these two studies and an additional one from New Zealand, a National Academy of Sciences report in 2000 (NRC, 2000) concluded that MeHg in fish is an important public health risk and a dose-response analysis for neurodevelopmental effects was developed. The U.S. EPA used this to derive a reference dose (RfD) of 0.1 μg/kg body weight/day (U.S. EPA, 2011).

Many fish consumption advisories intend to educate the public on balancing the risks and benefits of fish consumption; however, messages in the media that emphasize fish benefits have created confusion about the need for caution (Hobson, 2006). In some cases, warnings about MeHg levels in fish portray overly negative messages that cause individuals to completely avoid fish (Cohen et al., 2005; Oken et al., 2003). In 2001, when the U.S. FDA recommended "that women of child bearing age should avoid consuming specific long-lived predatory fish high in Hg and limit fish and shellfish meals, pregnant women in eastern Massachusetts decreased their total fish consumption, resulting in an estimated decline of 17%" (Turyk, 2012). On the other hand, some advocacy groups have recommended that pregnant women exceed federal fish consumption guidelines (Couzin, 2007).

There are many factors that need to be considered when estimating safe levels of MeHg intake from eating fish, making it a very difficult task. Factors such as differing sensitivity to MeHg amongst various populations; varying types, amounts, and frequency of seafood consumed; and the differences in Hg concentration of species all need to be acknowledged. Further, there is disagreement about the reliability, variability, and interpretations of existing data (Mahaffey et al., 2011). However, there are a few points that all agree with: pregnant women and young children are the most sensitive groups, MeHg is neurotoxic, and seafood is the primary dietary source. Moreover, the many health benefits associated with seafood consumption, especially during pregnancy and early life, are well known (Mahaffey et al., 2011).

Mahaffey et al. (2011) provides a comprehensive review of many risk-benefit considerations of fish consumption on child development that have been published in recent years. This work sheds light on significant advances that have been made in understanding the toxicology and epidemiology of MeHg exposures, as well as the nutritional benefits of n-3 PUFAs. However, a number of knowledge gaps still remain, including the need for much more information on the quantities of n-3 PUFAs that can be synthesized from ALA through maternal metabolism. Many studies have considered the association between fish intake and child development at relatively low exposure levels, but unfortunately, not all studies provide detailed seafood consumption results (Mahaffey et al., 2011). This makes conducting a quantitative benefit/risk assessment of DHA intake and MeHg exposure challenging because seafood consumption remains a major determining factor. It is made even more complex when additional factors are taken into account, such as exposure to lipophilic organic contaminants (such as PCBs, as they also tend to accumulate in predatory fish), other nutrients, or variability in individual body weights (Mahaffey et al., 2011).

The World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) have come together to formulate fish consumption advice. Their most recent document, "Report of the Joint FAO/WHO Expert Consultation on the Risks and Benefits of Fish Consumption" was released in 2011. This report concludes that the consumption of fish provides energy, protein, and a range of other nutrients, as well as reducing the risk of mortality from coronary heart disease. There is an absence of probable or convincing evidence of risk of coronary heart disease associated with MeHg and when comparing the benefits of n-3 PUFAs with the risks of MeHg among women of childbearing age, maternal fish consumption lowers the risk of suboptimal neurodevelopment in their offspring (FAO/WHO, 2011). However, the available data are currently insufficient to derive a quantitative framework for assessing the health risks and health benefits of eating fish for infants, young children and adolescents. This document also includes a series of steps that are recommended for member states/countries to better assess and manage the risks and benefits of fish consumption and more effectively communicate with their citizens. This includes acknowledging that fish is an important food source and is part of the cultural traditions of many peoples, emphasizing the benefits of fish consumption on reducing mortality from coronary heart disease (and the risks of mortality from coronary heart disease associated with not eating fish) for the general adult population, and emphasizing the net neurodevelopmental benefits to offspring of women of childbearing age who consume fish, particularly pregnant women and nursing mothers. WHO/FAO (2011) also recommended that jurisdictions develop, maintain and improve existing databases on specific nutrients and contaminants, particularly MeHg and dioxins, in fish consumed in their region; and to develop and evaluate risk management and communication strategies that both minimize risks and maximize benefits from fish consumption.

WHO/FAO (2011) considered seven other existing international risk-benefit activities when creating a matrix comparing levels of the n-3 PUFAs, DHA, and EPA with levels of total Hg and dioxins developed using existing data. The matrix categorized fish species by one of four levels of each of these substances.

2.6 Existing risk assessment and management strategies

It is important to understand and complete a risk assessment in order to know the true risk of consuming certain foods. Risk assessment refers to a process that characterizes the degree and nature of a given risk (Health Canada, 2007a). Through risk assessment, it can be determined if there is a need for risk management, which is prevention and control employed to reduce risk (Health Canada, 2007a). Risk management strategies have been employed in the past to reduce the risk of unacceptable exposures to Hg and the need for one was first identified by Health Canada in the late 1960s, when a standard was developed for Hg in fish (Health Canada, 2007a).

"In their everyday lives, people face hazards and must make individual decisions about the risks they face. However, the public depends upon the government to provide both safeguards and warnings about potential hazards, and to regulate or remediate where needed to reduce exposure to these hazards" (Burger, 2005). A risk assessment guide is needed to provide guidance to risk managers so that they can better understand the risk posed by MeHg in fish. This will provide them with the knowledge needed to assist in developing appropriate cost-effective intervention strategies in which the risk of fish consumption can be minimized while the benefits can be maximized.

The risk-benefit assessment used for the purposes of this thesis is the Codex Alimentarius risk assessment paradigm by WHO/FAO and will be discussed in detail below. However, there are many other international risk-benefit strategies that have been developed. The Benefit-Risk Analysis of Foods (BRAFO) has gained much attention in Europe, as well as worldwide (ILSI, 2012). This system uses a tiered approach to assess the risks and benefits of changing from the reference scenario to an alternative, resulting in a statement about which scenario is preferred in terms of health effects. In Tier 1, each risk and benefit is assessed independently, often using standard screening methods (but more refined methods may provide the benefit of needing to proceed to Tier 2). Tier 1 comprises a separate risk assessment and a separate benefit assessment. In Tier 2, risks and benefits are compared in a qualitative way without the use of a common metric. In Tier 3, risks and benefits are integrated quantitatively in a common metric, by a deterministic approach. In Tier 4, risks and benefits are integrated quantitatively in a common metric by a probabilistic approach.

Another tiered approach was developed by the Scientific Committee of the European Food Safety Authority (EFSA) which focuses on human health risks and human health benefits, and does not address social, economic and other considerations (EFSA Journal, 2010). This approach is very similar to both the Codex and the BRAFO approach and incorporates three steps: initial assessment (risks versus benefits), refined assessment (quantitative), and the comparison of risks and benefits (using a composite metric such as DALYs or QALYs). This approach identifies that separate consideration is needed where differences in the sensitivity to the agent under consideration exist or are assumed to exist in specific subpopulations.

DALY (Disability Adjusted Life Years) and QALY (Quality Adjusted Life Years) are both ways to assess the burden of disease attributable to an environmental factor. They are technically similar in that they both express health in time (life years) and give a weight to years lived with a disease, capturing both quality and quantity of life in one indicator. However, the DALY approach also gives an indication of the potential number of healthy life years lost due to premature mortality or morbidity and are estimated for particular diseases, instead of a health state. Although QALYs and DALYs stem from the same broad conceptual framework, they are not interchangeable, as they are partly based on different assumptions and different methodologies (Sassi, 2006).

Using these many risk-benefit assessments, government agencies around the world develop fish consumption advice for the public. This often results in fish consumption advisories, the development of which is also a process which builds upon existing literature and advisories issued by other governments.

2.7 Fish consumption advisories

As of 2008, all 50 states and the District of Columbia in the United States of America have issued fish consumption advisories to alert residents of consumption restrictions on certain species from local lakes and rivers (Lando and Zhang, 2011). State advisories vary in their specifics due to differences in fish species and types of pollutants in local waterbodies. In 2008, 80% of these advisories, including at least one in every state, were issued in part due to Hg contamination (Lando and Zhang, 2011).

The FDA issued national fish consumption advisories in 2001 and 2004, targeting women of childbearing age and households with young children. The efficacy of these advisories has been evaluated in different ways. Lando and Zhang (2011) examined changes in consumer awareness of Hg contamination in fish and their knowledge of the information contained in the national advisories by using nationally representative surveys in 2001 and 2006. They tried to test whether the targeted groups in the national advisories were more aware of the information contained in the advisories in 2006 than they were in 2001. The results indicated that the United States' population's awareness of Hg as a potential toxicant in fish increased from 69% to 80% between 2001 and 2006. The percent of those who could name a targeted at-risk group or fish listed in the national advisories increased and there was also an increase in the mean index score in measuring awareness of Hg in fish and knowledge of the information contained in the advisories.

Media attention and many federal, state, and local education activities surrounding the national and state fish advisories aided in alerting the public about the potential problem of Hg in fish. Despite this increase, overall knowledge about the information contained in the national advisories remains low (Lando and Zhang, 2011). Although women in general had greater gains in their level of awareness and knowledge between 2001 and 2006 than their male counterparts, women of childbearing age did not have greater awareness or knowledge than the rest of the population groups. However, adults that had children five years of age or younger in their households had greater awareness and knowledge than those who did not. It was also found that Caucasians, older adults, and highly educated consumers had higher awareness and knowledge index scores than ethnic minorities, younger adults, and less educated consumers. Further, those who lived within easy access to fresh fish and fishing had higher awareness and knowledge index scores (Lando and Zhang, 2011).

Another study conducted to assess the efficacy of the FDA's 2001 advisory found that it significantly reduced fish consumption amongst the population (Shimshack et al., 2010). This study had a rich data set with household-level consumer panel data from Information Resources, Inc. (IRI). The data set included every packaged supermarket fish purchase from a panel of nearly 15,000 households in the year before the advisory and the 2 years after the advisory (2000–2002). The consumption data were combined with detailed information on more than 5300 unique products comprising over 50 species. Home fish consumption was then translated into household Hg and omega-3 intakes based on measurements reported in the scientific literature and extensive USDA (United States Department of Agriculture) testing. The empirical findings of this study showed that Hg intakes fell 17.1% in response to the advisory on average, with the reduction being concentrated among college-educated, high fish-consuming households. However, at-risk consumers' omega-3 intakes from this food source also fell 21.4%. It appears that the recommendation to continue consuming healthful levels of seafood and to substitute towards lower Hg fish was not heeded on average (Shimshack et al., 2010).

Burger and Gochfeld (2008) interviewed 174 individuals (including students, maintenance staff, and faculty) at Rutgers University in New Jersey to assess the degree of knowledge about the benefits and risks of fish in relation to ethnicity and the degree of knowledge. Their study found that people are generally more aware of the benefits of fish consumption than the risks, and they have more specific information about those benefits than they do about the risks (Burger and Gochfeld, 2008). Further, there were ethnic differences in knowledge about: advisories or benefits, specific information about the risks and benefits, and that some fish are better or worse with respect to the risks from chemicals. Caucasians related more specific information about the risks and benefits than minorities (Burger and Gochfeld, 2008).

A review of literature reveals that awareness of warnings is sometimes ethnically related; even though minorities tend to consume more fish than their Caucasian counterparts, their knowledge of advisories is often considerably less (Burger and Gochfeld, 2006). Reasons for the lack of knowledge may be due to lower income and education; whereas the higher consumption may be culturally related. A pilot study was conducted in Philadelphia on fish consumption and advisory awareness among the Asian community by distributing questionnaires (Perez et al., 2012). This study found that the concept that fish consumption can have both harmful and beneficial effects is a difficult one for populations that rely on seafood as a major dietary and cultural component. Study data were used to evaluate the efficacy of state-issued advisories and it was found that while advisory awareness levels among study participants were greater than previously observed in Asian-American populations, consumption levels remained high. However, the sample size was quite small (n=34) and represented a very limited sample of the Philadelphia Asian-American population.

DeWeese et al. (2009) reported on the efficacy of lake-specific, risk-based, culturally sensitive fish consumption advice for tribes in the Great Lakes Region. Area-specific advisory maps, which were a combination of text and graphics and provided consumption advice as well as information on health benefits of consuming fish (in particular Ogaa/Walleye), were distributed to tribes in Wisconsin, Minnesota, and Michigan. A behavioural intervention program was developed and the efficacy of it was assessed using surveys of tribal fish harvesters and women of childbearing age. Fifty-one families from 10 tribes recorded their fish consumption during the study. The intervention involved dissemination of the advisory maps to tribal leaders, fish harvesters, women of childbearing age, children, and elders, as well as the broader tribal population. There were oral presentations which included detailed training on use of the maps, general information about the adverse health effects of Hg exposure, and information about how map-based consumption advice was developed. After the intervention, concern about Hg increased significantly among all harvesters, but not among women of childbearing age. Although nearly 100% of Wisconsin tribal harvesters and over 90% of tribal harvesters in Minnesota and Michigan surveyed found the advisory maps to be very or somewhat helpful, there was no significant increase in the number of harvesters who used maps to make choices about which lakes to harvest. The intervention effort toward women of childbearing age resulted in an increase of awareness and concern but not in behavioral changes. Overall, Ogaa harvest in Wisconsin, Michigan, and Minnesota increased during and after the map-based intervention program.

Consumers may limit fish consumption or choose among different kinds of fish based on consumption advisories and media warnings; however, there is a rich literature indicating that this is not always the case (Burger and Gochfeld, 2006). Burger and Gochfeld (2006) reviewed the issuance of fish consumption advisories, compared angler compliance and knowledge about such advisories, and proposed a framework for information needs necessary to integrate several aspects of fishing, fish consumption, and risk. They found that public health officials need to take a multi-faceted approach to managing the risk that includes cultural sensitivity and audience-specific positive information. They also suggest that more graphics and tables be added to the advisories to make the information easier to understand and absorb. "Whether and how a person responds to consumption advisories depends upon their level of trust in the conveyor of risk information, whether they are risk aversive, overall environmental concerns, and the sources of information that they encounter or listen to" (Burger and Gochfeld, 2006). Site (or region)-specific information on the reasons for fishing would allow for a communication strategy aimed at the local fishing population. Instead of just the consumption advisory information being provided to the public, risk managers must address multiple attitudes, behavioral patterns, and exposure pathways. Effective risk communication results in the target audience being provided with sufficient site- and fish-specific information. This should include the risks and benefits of consuming a given species of fish, at a given size or weight, so that they can make an informed decision (Burger and Gochfeld, 2006).

Incorporating relevant information in enough detail to fully relay the message, but not so much detail that it is overwhelming and difficult to understand can be quite challenging. Groth (2010) developed a chart to organize the 51 seafood varieties into six groups based on Hg levels to serve as a framework for improving risk communication. He used FDA data on the Hg content of each variety, and marketshare data from the National Marine Fisheries Service (NMFS), adapted by the FDA, to estimate contributions to the total amount of Hg in the US seafood supply. He multiplied the mean Hg level by the share of the market for each variety of fish and shellfish to generate Hg input factors. These were indicative of the relative inputs by each variety to the total amount of Hg in the US seafood supply. He then ranked the 51 seafood varieties by their relative contributions to total Hg, then sorted them into six categories by Hg content and examined risk communication implications of the information thus generated. According to this chart, canned light tuna is categorized as "above average" for Hg content; however, the FDA's advisory categorizes it as "low" for Hg content and recommends that pregnant women consume up to 12 grams per week (Groth, 2010). Groth (2010) identifies many deficiencies in current risk communication by the government: "it does not address the needs of consumers who eat a great deal of fish; it offers no advice about numerous moderately high Hg fish that are significant sources of exposure if eaten regularly; it inaccurately describes the largest source of Hg exposure in the American diet as a ''low-Hg'' fish; and it fails to draw distinctions among Hg levels in fish and shellfish varieties that strongly influence exposures for many consumers" (Groth, 2010).

Many other studies attempt to reveal possible reasons for why or why not advisories are effective, and what can be done to make them more effective. Studies show that advisories are often ineffective at reaching ethnic groups, as well as fishermen with low income and educational levels (Tan et al., 2011). When advisories incorporate dissimilar priorities, it can increase the complexity of the advice and send conflicting messages to the public. Tan et al. (2011) evaluated approaches of consumption advisories to improve the effectiveness of California advisories. They made several recommendations as a result of their analysis, giving policy makers a few points to think about when creating an advisory. This research found that attempts to define portion size in quantities that depart from commonly consumed quantities to control fish intake are unlikely to be heeded; instead, advisories should place emphasis on the frequency of consumption rather than portion size. They found that informants were more receptive to fish consumption advice when it was accompanied with information specific to the fish they were catching, particularly a visual depiction of the fish's Hg level; therefore, they recommend giving not just consumption advice, but Hg information for fish as well. They also recommend avoiding certain terms, symbols, and concepts that may cause confusion, as they found that for some informants, the inclusion of one or more confusing terms was sufficient reason to disregard the entire material. Lastly, they recommend using portion sizes, Hg meters to convey contaminant levels, advice categories, and population definitions effectively. They found it was helpful to use Hg meter and portion size illustrations, and to group fish into three categories for high, moderate, or low Hg levels. To ensure that the advisory will be effective on its target population, it is important to test the advisory materials among intended audiences before they are finalized (Tan et al., 2011).

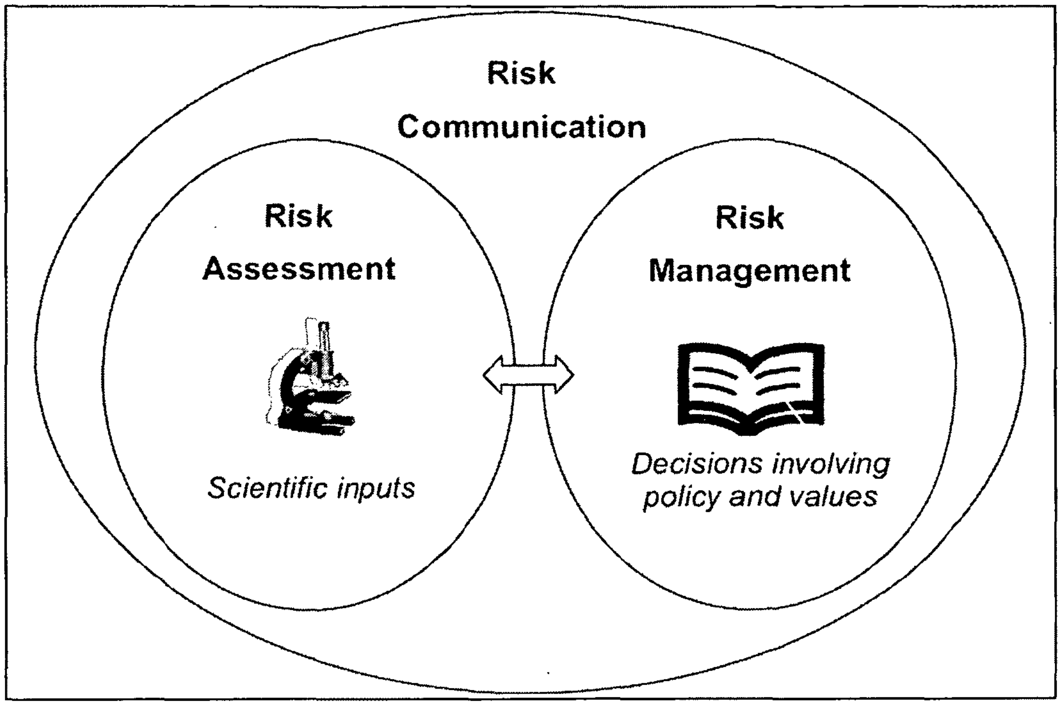
A North Carolina study assessed the determinants of subsistence fishing and tried to promote informed fish consumption among culturally distinct and lower income subsistence fishers (Driscoll et al., 2011). The study participants included African American, Hispanic, and Native American communities. Fish advisories were developed for each community to promote informed fish consumption intentions among residents who consume local fish and were successful in increasing knowledge and healthy intentions among most residents. The fish advisories were tri-fold brochures that were based on formative data collected in each community. Information that the brochures included was: a description of the health and cultural benefits of fishing and eating local fish; a description of safe levels of fish consumption for members of various subpopulations; various methods for reducing exposure to MeHg without precluding local fish consumption completely; and contact information for local organizations and resources to which residents can go for more information. Further, the brochures included community-specific social values attributed to subsistence fish consumption, commonly held beliefs, and culturally sensitive mitigation strategies. All brochures were written at a sixth grade reading level using the Flesch-Kincaid readability program. The fish advisories were effective in educating those unaware of the risk of the existence of MeHg in local fish. They also educated those who were aware of the risk that popular measures intended to reduce exposure to the contaminant were ineffective (such as beliefs that the river cleanses itself of MeHg or that the contaminant can be seen or removed in preparation). The intention of the advisories was not for the populations to cease consumption of locally caught fish altogether, but rather to continue eating locally caught fish with lower levels of MeHg. Only one of the three communities actually intended to abide by the recommendations; the other two indicated that they intended to continue consuming locally caught fish without altering their consumption patterns.

Burger and Gochfeld (2008) provided suggestions for future communication that "might improve the knowledge base for making decisions about fish consumption: 1) clearer statements about the agents causing the risk or benefit (e.g. Hg, omega-3 fatty acids), and the potential health outcomes (neurobehavioral deficits, lower cholesterol), 2) clearer statements about which fish are freshwater or saltwater fish (terms often used in advisories, but which are not generally understood), 3) clearer listing of which fish have high or low levels of contaminants, specific to geographical region, and 4) target information to minorities about the factors contributing to risks and benefits, and about fish that are high or low in contaminants" (Burger and Gochfeld, 2008).

2.8 Risk assessment by FAO/WHO

The FAO/WHO document titled "Food Safety Risk Analysis: A guide for national food safety authorities" was last updated in 2006. This document describes the structured Risk Analysis decision-making process with three distinct but closely connected components: risk assessment, risk management, and risk communication (Figure 2.2).

Figure 2.2 Generic components of risk analysis (FAO/WHO, 2006)



Definitions for the three main components of risk analysis have been provided by FAO. *Risk assessment*: a scientifically based process consisting of the following steps: i) hazard identification; ii) hazard characterization; iii) exposure assessment; and iv) risk characterization. *Risk management*: the process, distinct from risk assessment, of weighing policy alternatives in consultation with all interested parties, considering risk assessment and other factors relevant for the health protection of consumers and for the promotion of fair trade practices, and, if needed, selecting appropriate prevention and control options. *Risk communication*: the interactive exchange of information and opinions throughout the risk analysis process concerning risk, risk-related factors and risk perceptions, among risk assessors, risk managers, consumers, industry, the academic community and other interested parties, including the explanation of risk assessment findings and the basis of risk management decisions (FAO/WHO, 2006).

Risk assessment and risk management are grounded in a science-based approach; risk assessment is the scientific component of risk analysis, while risk management combines the scientific approach with other factors such as economic, social, cultural and ethical considerations (FAO/WHO, 2006). However, it is important for risk assessment to also involve judgments and choices that are not completely scientific, and for risk managers to clearly understand the scientific approaches used by risk assessors (FAO/WHO, 2006).

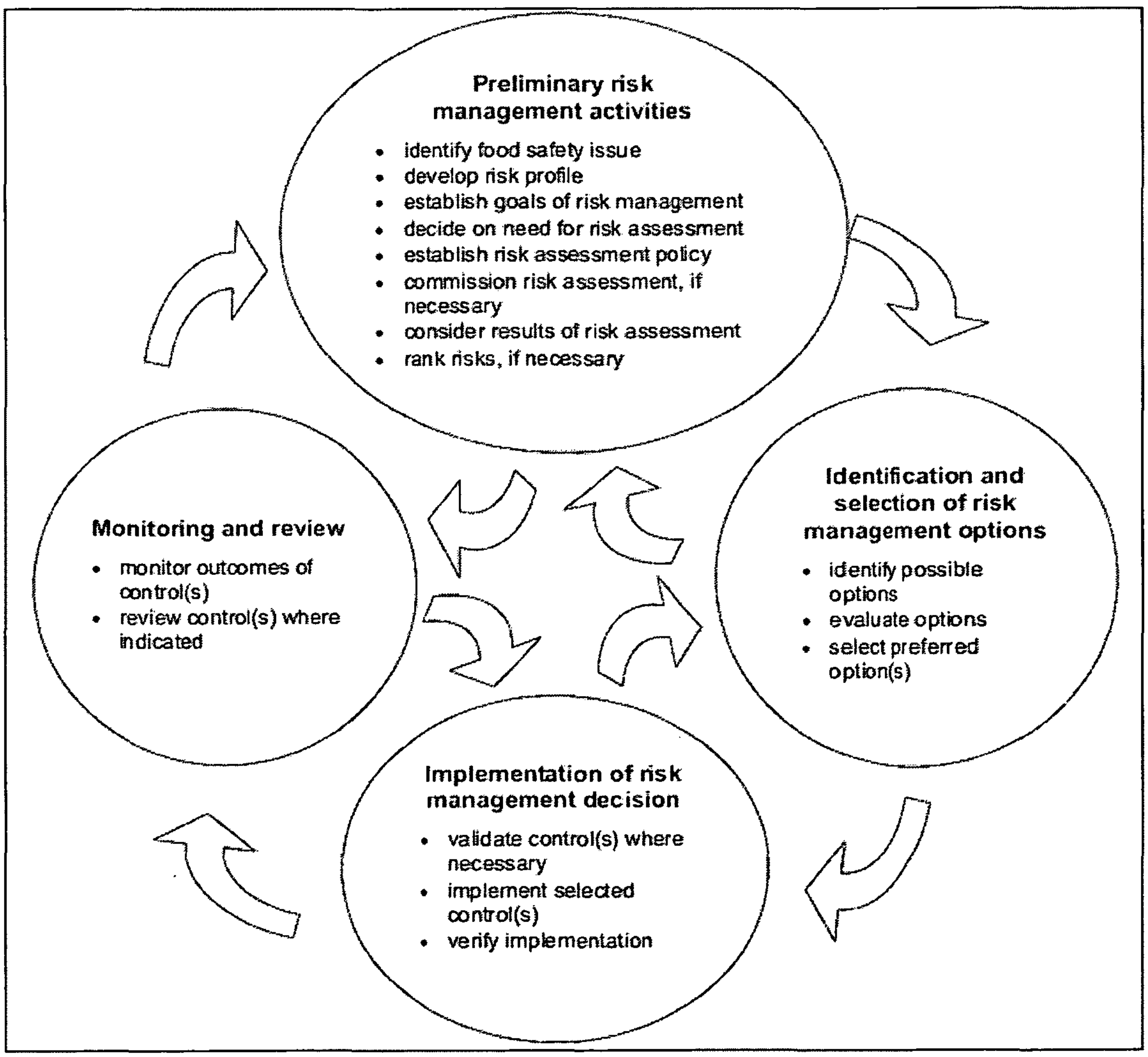
2.9 Risk management by FAO/WHO

Risk management is best accomplished by using a systematic, consistent, and readily-understood framework while employing scientific knowledge on risk and other factors relevant to public health protection (FAO/WHO, 2006). The *Food Safety and Risk Analysis* document presents a generic risk management framework, which provides a practical, structured process for food safety regulators to apply the components of risk analysis. There are three perspectives on risk that need to be addressed: technical, psychological, and sociological (FAO/WHO, 2006).

The technological perspective is limited to scientific evaluation of the likelihood and severity of harm. This may include an economic subset in which harm can be described in terms of health indices (FAO/WHO, 2006). The psychological perspective focuses on risk as a function of individual perception. This takes various attributes into consideration such as willful exposure, ability to control risk, and catastrophic nature of risk, etc. (FAO/WHO, 2006). The sociological perspective views risk as a social and cultural construct. The goal of this perspective is to distribute costs and benefits in socially acceptable and equitable ways (FAO/WHO, 2006).

The generic framework for risk management was designed to be functional in both strategic, long term situations and in the shorter term work of food safety authorities. The framework is broken down into four parts which are all interconnected: preliminary risk management activities, identification and selection of risk management options, implementation of risk management decision, and monitoring and review (FAO/WHO, 2006). Please refer to Figure 2.3 for detailed descriptions of these four categories.

Figure 2.3 Generic framework for risk management (FAO/WHO, 2006).



2.10 Risk assessment tool for the Northern Health Authority

The risk assessment tool developed in this thesis is designed to be unique to selected areas in the Northern Health Authority's jurisdiction by providing local levels of Hg in different fish species, local information on risk factors for elevated blood Hg, and a framework for information that should be collected on local patterns of fish consumption. This tool identifies which species from specific water bodies contain elevated Hg concentrations and how fish harvesting methods for these species can be adapted to minimize Hg exposure.

The risk assessment tool is a combination of existing documents including the BC HealthFile # 68m (HealthLinkBC, 2011). This HealthFile was released to promote low-risk fish consumption and to warn about fish consumption that may put British Columbians at risk for adverse Hg effects. The British Columbia Centre for Disease Control and Ministry of Health issued guidelines specific to the province on the consumption of fish and Hg because it has fish consumption patterns that are unique in Canada, as there are many coastal, Aboriginal, and Asian communities in BC who tend to eat large amounts of fish. Further, there is regional variation in Hg levels in fish available to consumers across Canada.

Providing fish consumption advice can be a controversial issue, as it is undeniable that MeHg is toxic, but also undeniable that fish has many dietary benefits. Therefore, it is important to inform the residents of Northern British Columbia about the types of fresh fish that are available in the area and the risks and benefits associated with them.

3.0 Methodology

3.1 Overall approach

3.1.1 Source of raw data. Data were collected from the British Columbia Ministry of Environment and Health Canada, which have offices located in Prince George, British Columbia. This included raw data that these agencies had collected, but not analyzed, as well as data obtained from reports that have already been published, or written for the sole use of the specific agency. In addition to Hg concentrations, fish type, fish length (tip of the snout to the tip of the longer lobe of the fin), weight, sample location, and sample year were extracted from these data sets and used for this study. In some cases, data were duplicated between the various sources. To eliminate duplicated data, data sets were examined manually after they were entered into SPSS; redundant data sets were eliminated from the statistical analysis.

3.1.2 Use of muscle tissue data only. Hg concentrations can vary between muscle tissue and organs. Most studies examining the health effects of high Hg levels in fish on human health tend to use muscle tissue data, as it is the most widely consumed part of the fish. Most of the data collected were from muscle tissue; however, there was a small amount of data on Hg levels in organ, roe, water, and sediment that were omitted for consistency.

3.1.3 Use of existing risk assessment tools. There are various risk assessment books and tools which were reviewed when creating the risk assessment tool for Northern Health. Existing government recommendations are incorporated into the tool and Health Canada's guidelines for Hg levels and advised amounts of consumption are used. The risk assessment framework that was adapted for this study is described in detail below.

3.2 Description of study area

Northern British Columbia is a vast area that consists of many bodies of water. For this study, 3097 fish samples were analyzed from 34 distinct areas (refer to Table 3.1 below). Currently in Northern British Columbia, there are only fish advisories for bull trout and dolly varden from Williston Lake and lake trout from Pinchi Lake (Environment Canada, 2010).

3.3 Fish collection and Hg analysis

Fish samples were collected over a 26 year time span by different research groups; a variety of methods were used to determine Hg concentrations in these samples. The data report total Hg concentrations; however, since total Hg in fish is comprised almost entirely of MeHg (Rasmussen et al., 2007), MeHg is used interchangeably with Hg in this study. All concentrations are presented on wet weight basis. Data on various fish species varied from location to location, and from year to year. The number of fish samples collected from the water bodies also varied from year to year.

Table 3.1 Number of fish collected from different water bodies used in this study

Lake	N
Babine Lake	301
Bear Lake	102
Brown Lake	5
Chuchi Lake	95
Cunningham Lake	57
Francois Lake	19
Grassham Lake	28
Inzana Lake	65
Kazchek Lake	46
Kemess Lake	35
McKnight Lake	8
Nations Lakes	8
Nechako Reservoir - Tahtsa Reach	16
Necoslie River - Stuart Lake	26
Pinchi Lake	162
Purvis Lake	20
Quesnel Lake	110
Rainbow Creek	11
Stuart Lake	141
Takla Lake	34
Tatchi River	72
Tchentlo	62
Tezzeron Lake	191
Tochcha Lake	11
Trembleur Lake/Middle River	105
Tsayata Lake	191
Weisner Lake	40
Whitefish Lake	66
Williston Reservoir - Finlay	334
Williston Reservoir - Ingenika	180
Williston Reservoir - Williston Lake	42
Williston Reservoir - Parsnip	166
Williston Reservoir - Peace	304
Witch Lake	44
Total	3097

3.4 Statistical analysis of data

The program SPSS for Windows, version 16 (SPSS, Chicago, Illinois, USA) was used for data analysis. Before analysing the data, several aspects of Hg fish tissue concentrations were of interest. For example, did some water bodies exhibit higher concentrations of Hg in fish tissue, on average, than fish caught in other water bodies?

Did Hg concentrations of specific fish species exhibit differences between water bodies? How did these relationships change over the study period (1974 – 2000)? The data set had several major limitations with regards to suitability for the tests used to measure these differences, and will be clarified below.

The various sources of data had information on the fish species, length, weight, Hg concentration, location and year collected. In some cases the specific fish type was given whereas in others only the general fish type is provided (for example, Sockeye Salmon in a specific case and Salmon in a general). In these cases, the fish types were not combined so that if there was significance in a specific type it could be identified. Also, some of the data did not report fish length (only 1801 fish had length values in a data set of 3097 samples). Temporal and spatial trends, as well as species, weight, and length differences were all assessed in comparison to the Hg concentrations.

3.4.1 Controlling for length:weight relationships

As mentioned above, less than half of the fish data (41%) reported fish length, while all data sources reported fish weight. In these samples it was debated whether the lengths should be estimated for the data analysis since this is the main method of identifying size of fish in many other types of studies. Length data that were available were correlated with weight and a linear equation was formed ($y = mx + b$). Since weight was available for all fish, it was used in the equation to estimate length values for all those without lengths already. There are obvious limitations with this technique and it was decided that it is much more accurate to use the actual weights of the fish instead of the estimated lengths.

3.4.2 ANOVA/ANCOVA

In order to carry out ANOVA and ANCOVA tests, data must meet certain criteria. For example, dependent variables should be normally distributed. Neither Hg concentration nor the weight of fish met this criterion. Both variables had extremely large values for skewness and kurtosis (see Table 10.7 in Appendix) which were also confirmed by statistical tests for normality (Kolmogorov-Smirnov). A square root transformation was applied to the weight, and a cube root transformation applied to Hg concentration (Tables 10.5 and 10.7). However, even having applied these transformations, the Kolmogorov-Smirnov test showed that they were still non-normal (Tables 10.6 and 10.8). Another assumption is that each variable should have a fairly similar variance. This was not the case as shown by Levene's test.

For ANCOVA, there are several other assumptions in addition to those of the ANOVA. Covariates must be linearly related to the dependent variable; this assumption was met as weight and Hg concentration were positively correlated. An assumption that was violated for this data set was that the covariate should be unrelated to the independent variable, in this case the location. Weight was highly correlated with location, which can be explained by the fact that larger bodies of water are likely to support larger fish, whereas smaller bodies of water are not able to support larger fish. Also the growth rate and trophic structure can vary among lakes due to their specific geochemistry. Another assumption is that covariates must have a homogeneity of regression effect. Essentially, there have to be equal effects on the dependent variable across all different independent variable subgroups (all slopes have to be equal). In a scatterplot of weight versus Hg concentration with location as the control variable (data not shown), it was clear that slopes were extremely different, and thus it was decided that ANCOVA should not be carried out. Given the fact that the data violates almost all of the assumptions for ANOVA/ANCOVA, doing either of these analyses will provide results that would be difficult to interpret, and worse, misleading and/or inaccurate. Consequently, ANOVA and ANCOVA were not conducted in this thesis. Instead, descriptive statistics were used and in some cases correlations were conducted, when appropriate.

3.4.3 Use of data in the Risk Assessment Tool

The results that were depicted by the data analysis were used to develop consumption advice for specific areas. The Hg concentration in fish was displayed by year, water body, species, and size of fish. This was used to identify if Hg concentrations have declined and whether it is now safe to consume fish from specific water bodies, whether the same species have elevated Hg levels in various water bodies, and whether fish size made a significant difference in Hg concentration. Answering these questions allowed us to suggest whether the public can lower Hg intake by eating different species of fish from certain lakes or by fishing for their desired species in a different lake (if Hg levels are high for that species in their usual fishing lake).

To develop the risk assessment tool, the mean Hg concentration of all species (with an N=60 or greater), was adjusted to standardize weight for each species. This was done so that the variability of Hg concentration would only reflect the difference in location. Using the results of this, the risk assessment tool is able to predict which species should be avoided from which lakes.

4.0 Results

4.1 Fish species and water bodies included in this study

A total of 20 types of fish were sampled from 34 water bodies (Table 3.1), ranging from a sample size of 2 (sturgeon) to 892 (lake whitefish). The total number of fish samples used in this study was 3097. Of these, 1801 had both length (mm) and weight (kg) values; the remainder had only weight. Samples were collected between 1974 and 2000 (samples were collected in 16 of these 26 years).

4.2 Fish weights and fish lengths

Figure 4.2.1 displays the number of fish caught as well the mean weight of those fish for the year. The data presented highlights several important points. There were a number of years in which very few fish were caught (1975, 1985, 1989, 1992, 1993, 1996), the average weight of the fish caught was very low (less than 0.742 kg). The only exception to this rule appears to be 1986, in which only 58 fish were caught, but had a mean weight of almost 2 kg (greatest mean weight in this study).

The trends in mean fish weight versus the location at which the fish were caught are shown in Figure 4.2.2. Fish caught in Tochcha Lake (lake trout in 1986) had the highest mean weight at almost 3.4 kg. However, only 11 fish were caught at this location. Quesnel Lake was next with a mean weight of 2.9 kg, with a total of 110 fish caught (rainbow trout and lake trout in 1988). Brown lake (dolly varden) and Rainbow Creek (rainbow trout) had the lowest mean weights, with 0.11 and 0.05 kg respectively. Total fish caught in these locations were 5 and 11, respectively.

Figure 4.2.1 Mean weight (kg) of fish caught vs. year caught (n=3097)

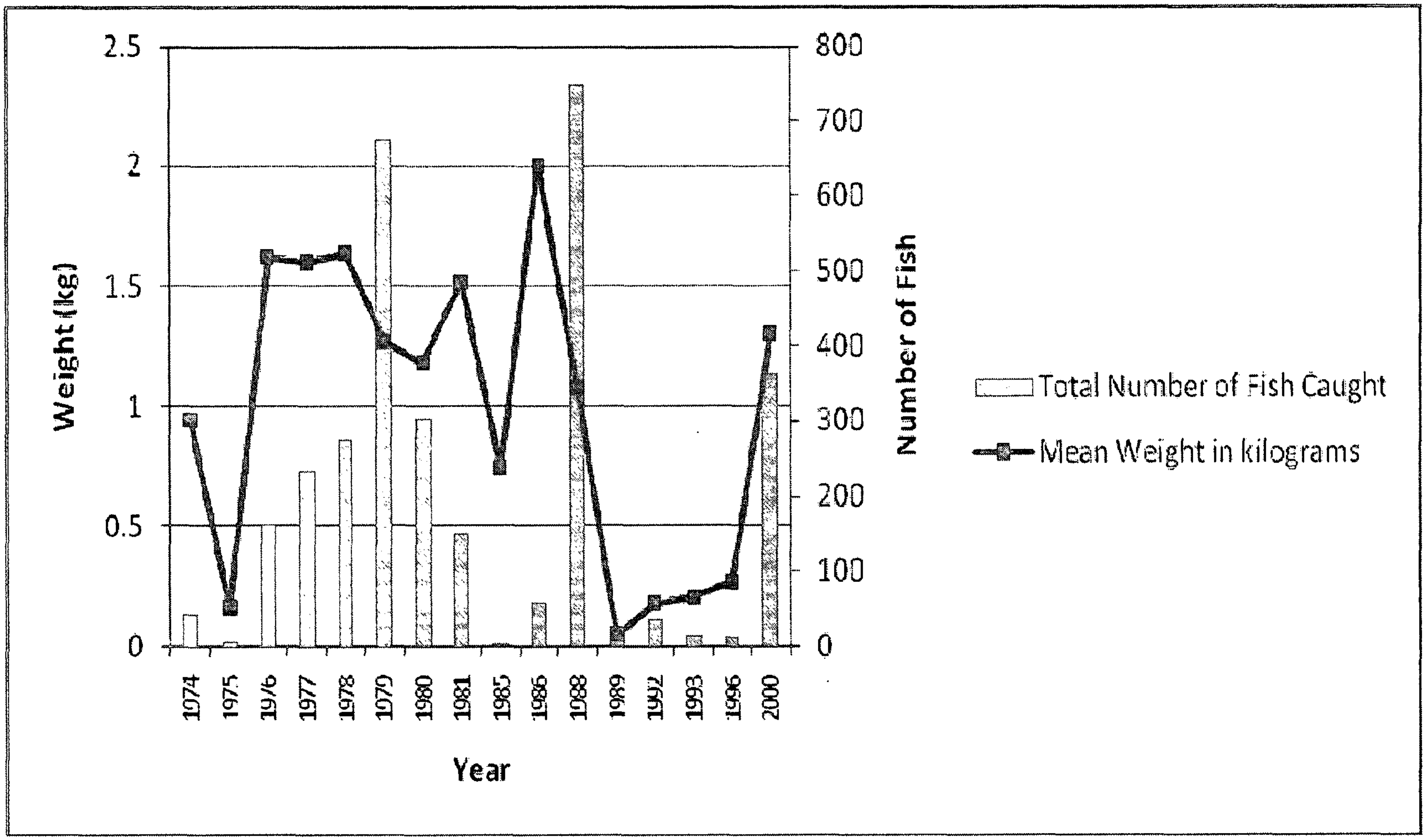


Figure 4.2.2 Mean weight (kg) of fish caught vs. location (n=3097)

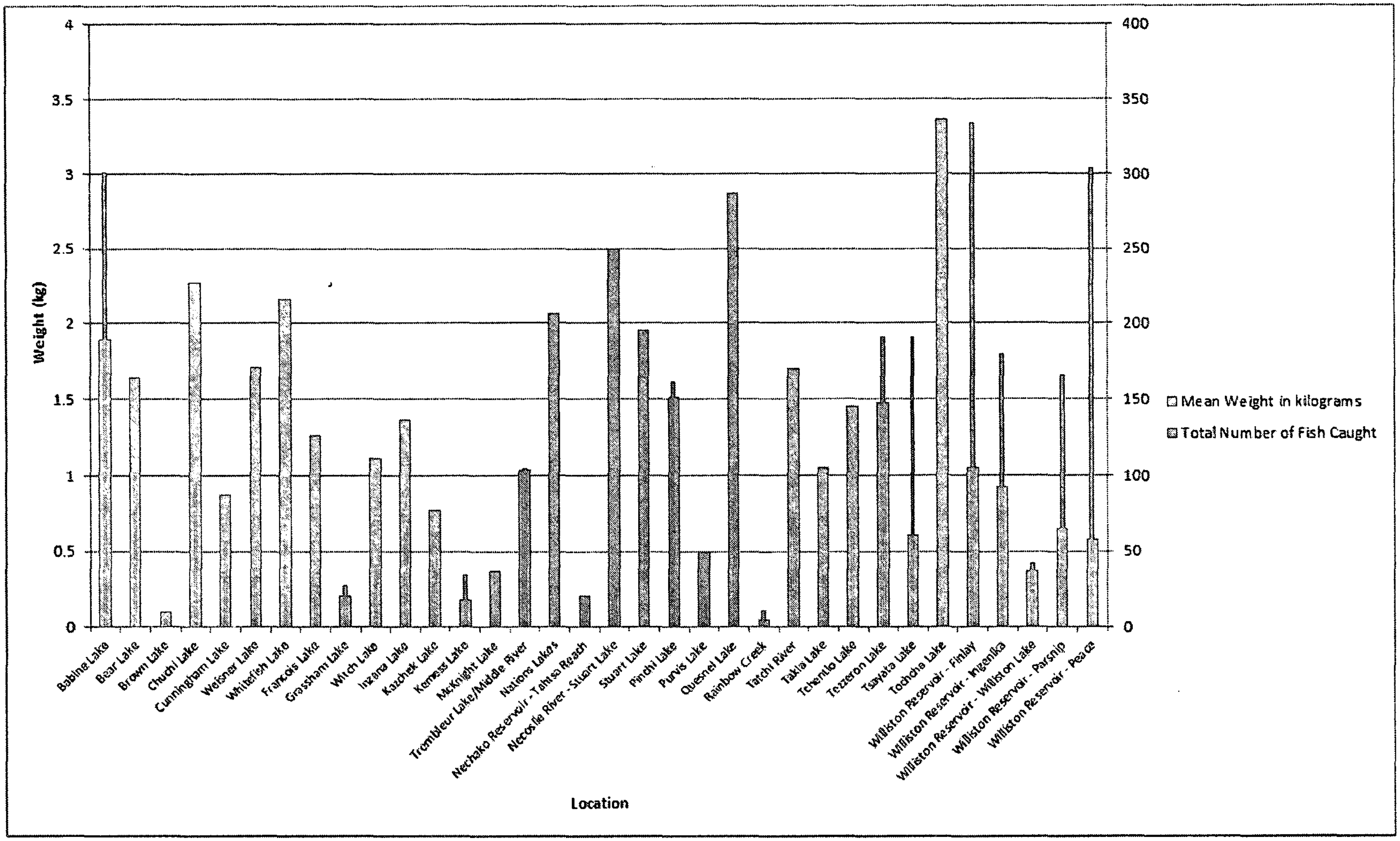


Figure 4.2.3 shows the mean weight of each fish species caught over the study period. Lake whitefish were by far the most common fish caught at 892 samples, followed by lake trout (n=660), and rainbow trout (n=365). Many species were caught for which sample sizes are extremely small: coho salmon (n=4), large scale sucker (n=3), rocky mountain whitefish (n=1), squawfish (n=1), peamouth chub (n=3) and sturgeon (n=2).

The mean length of fish caught by year is displayed in Figure 4.2.4. It can be seen that the highest mean length of fish caught was in 1978 at 518 mm (n=38), followed by 1981 at 505 mm (n=101). Lowest average lengths were seen in 1989 (93 mm, n=1) and 1992 (197 mm, n=35). Note: missing lengths were not calculated using the calculation noted in methods section for this chart; total n = 1801.

Figure 4.2.5 illustrates the mean length of fish by the location in which they were caught. The highest mean lengths were caught in Quesnel Lake (628 mm, n=55) and Witch Lake (613 mm, n=3). Lowest mean lengths were seen in Kemess Lake (197 mm, n=35), Brown Lake (217 mm, n=5), and Purvis Lake (317 mm, n=3). One fish (a Rainbow Trout) was caught in Rainbow Creek with a length of 93 mm.

It can be seen in Figure 4.2.6 that lake trout (581 mm, n=370), salmon (595 mm, n=13), sockeye salmon (560 mm, n=69), and char (562 mm, n=47) had the highest mean length. Fish with the lowest mean length were peamouth chub (253 mm, n=3) and mountain whitefish (260 mm, n=33).

Figure 4.2.3 Mean weight (kg) of fish caught vs. fish type (n=1801)

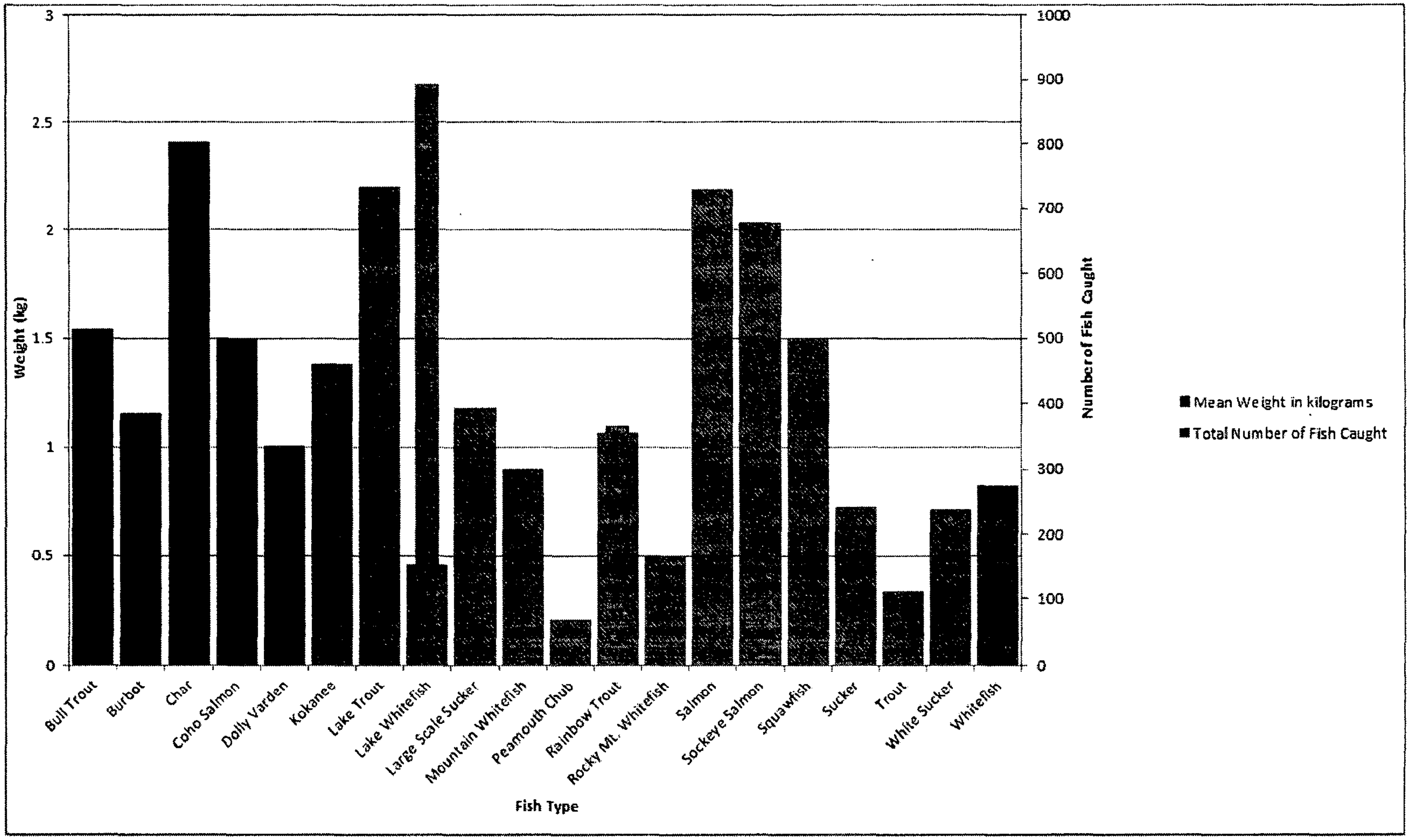


Figure 4.2.4 Mean length (mm) of fish caught vs. year caught (n=1801)

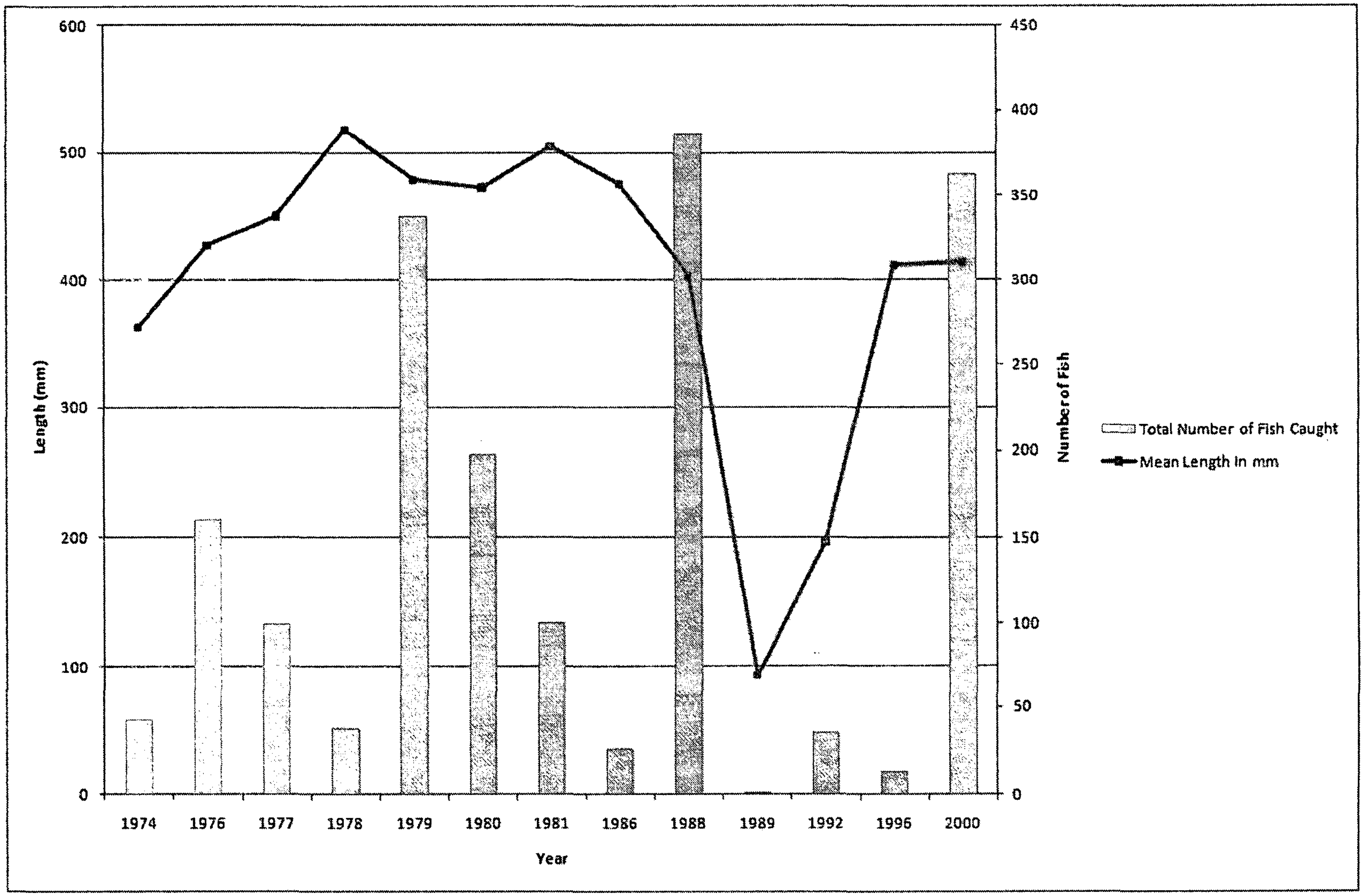


Figure 4.2.5 Mean length (mm) of fish caught vs. location caught (n=1801)

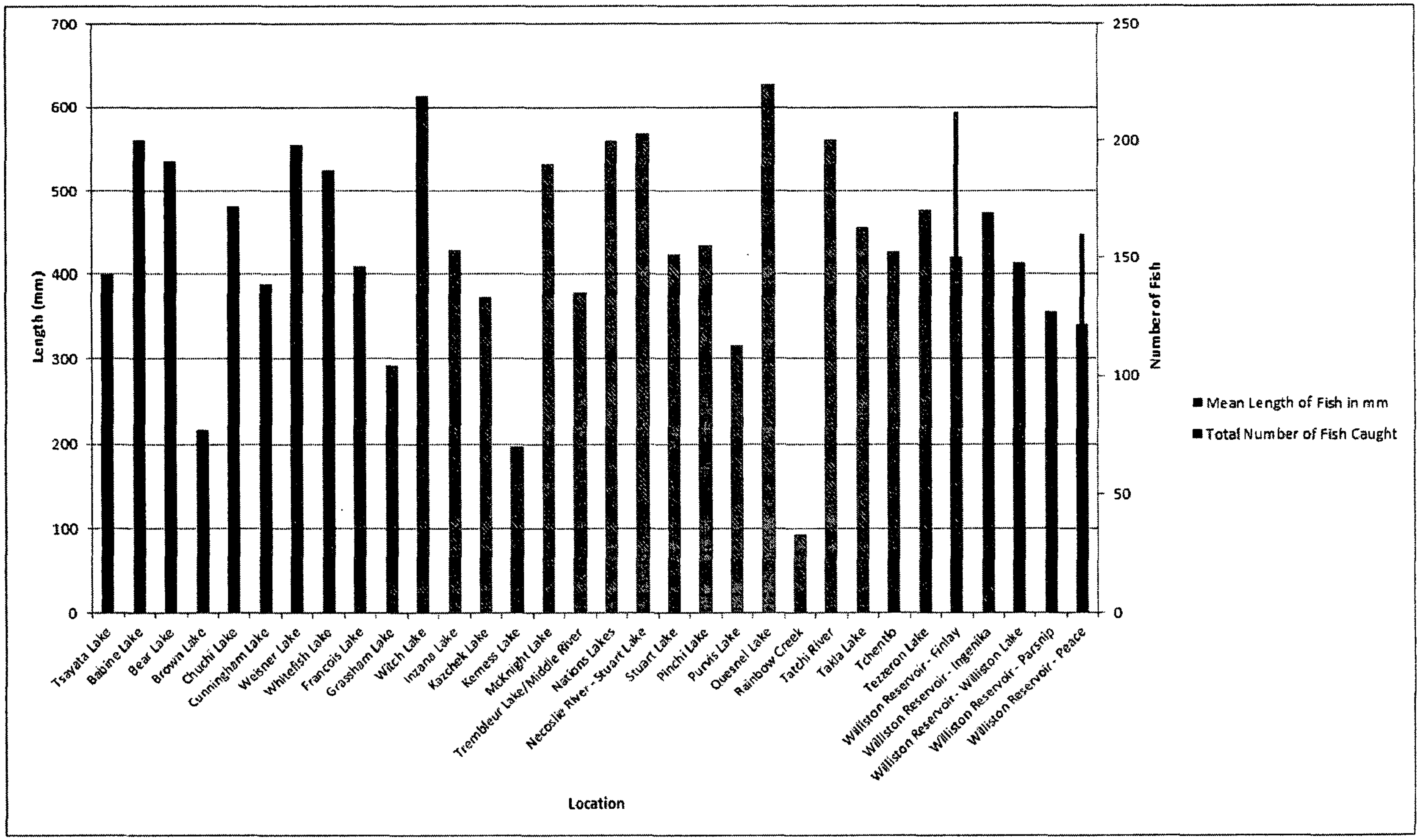
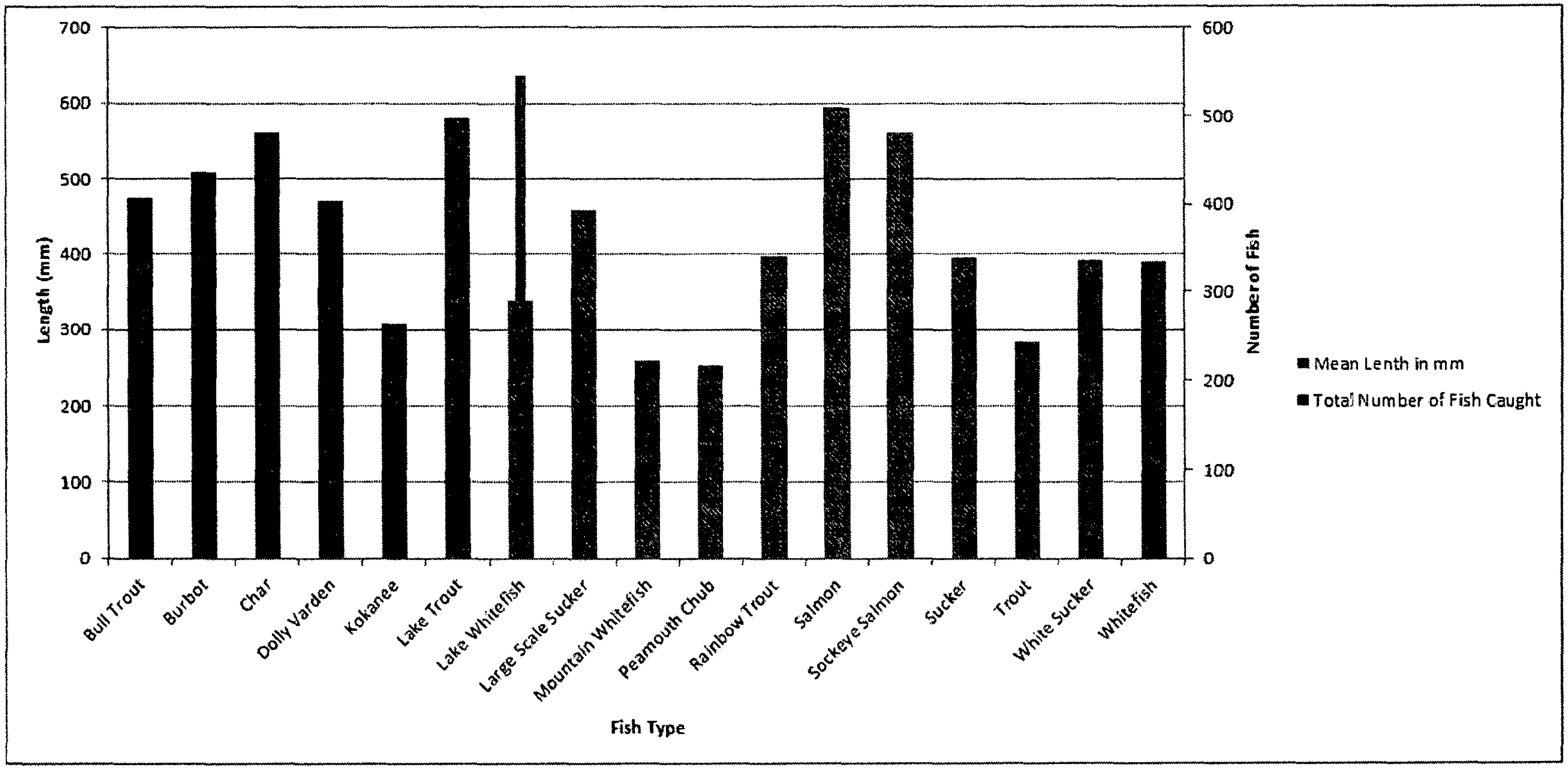


Figure 4.2.6 Mean length (mm) of fish caught vs. fish type (n=1801)



4.3 Mean Hg concentrations in fish by year, location, and species of fish

Mean Hg concentrations in this data set varied from year to year, by location, and also by species of fish. The figures below illustrate the differences.

As can be seen in Figure 4.3.1, fish caught in 1974 had the highest mean Hg concentration at 2.11 ppm (n=42). The second highest year for Hg levels was 1986, with a mean Hg concentration of 0.84 ppm (n=58). In years such as 1979 and 1988 where sample sizes were large (n=675 and n=750, respectively), Hg levels were relatively low at 0.24 ppm and 0.30 ppm, respectively. Mean Hg concentration were found to be the lowest in 1992 (0.03 ppm, n=35), 1989 (0.09 ppm, n=11), and 1993 (0.09 ppm, n=16).

Figure 4.3.1 Mean Hg concentration (ppm) of fish caught vs. year caught (n=3097)

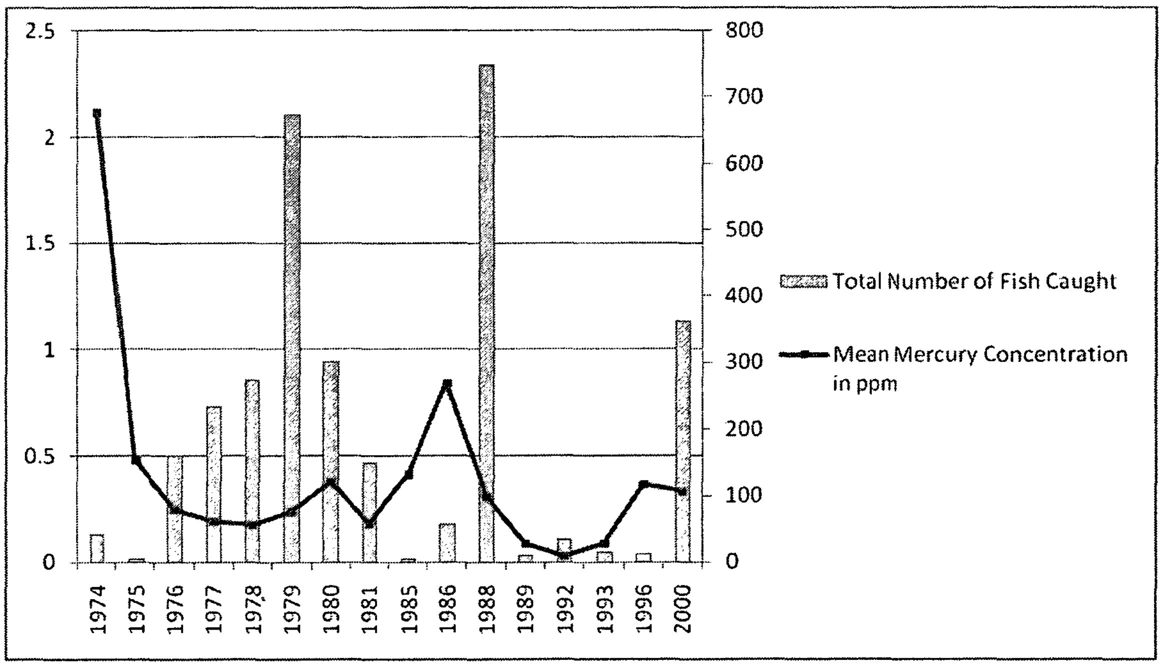


Figure 4.3.2 presents mean Hg levels by location and clearly displays that fish from Pinchi Lake have the highest mean Hg concentration (1.17 ppm, n=162). All of the fish species caught from Pinchi Lake were at or above the Health Canada's Hg reference dose of 0.5 ppm, with the exception of rainbow trout, which had a mean Hg concentration of 0.36 ppm. McKnight Lake also has a very high Hg concentration at 0.53 ppm; however, the sample size is very small with only eight fish caught at that location. Areas with lower mean Hg concentrations are Kemess Lake (0.03 ppm, n=35), Nechako River – Tahtsa Reach (0.09 ppm, n=16), and Inzana Lake (0.13 ppm, n=65). The average Hg concentration for all fish caught over the study period was 0.30 ppm (n=3097).

Large scale sucker and peamouth chub (both caught in Pinchi Lake) had the highest mean Hg levels at 2.59 ppm and 1.90 ppm respectively (Figure 4.3.3); however, it can also be seen that they have a very small sample size (n=3 for both). Bull trout had mean Hg concentration higher than 0.5 ppm at 0.70 ppm (n=313). However, almost all of the bull trout samples were taken from the Williston Reservoir from various reaches (Finlay had the biggest sample size of 160). The lowest concentration of mean Hg was found in coho salmon (0.04 ppm, n=4), salmon (0.07 ppm, n=13), kokanee (0.085 ppm, n=195), and mountain whitefish (0.10 ppm, n=60).

Figure 4.3.2 Mean Hg concentration (ppm) of fish caught vs. location caught

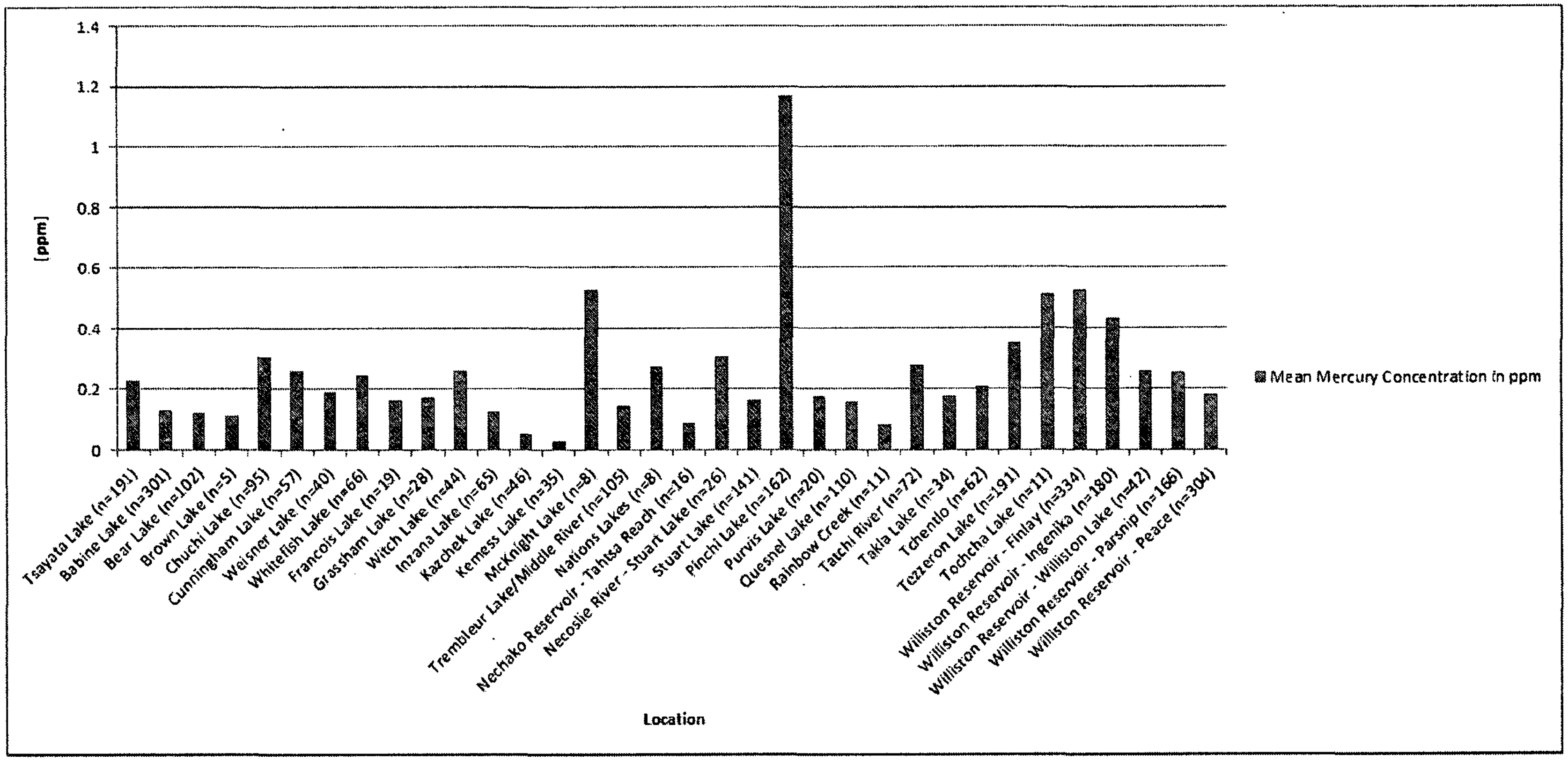
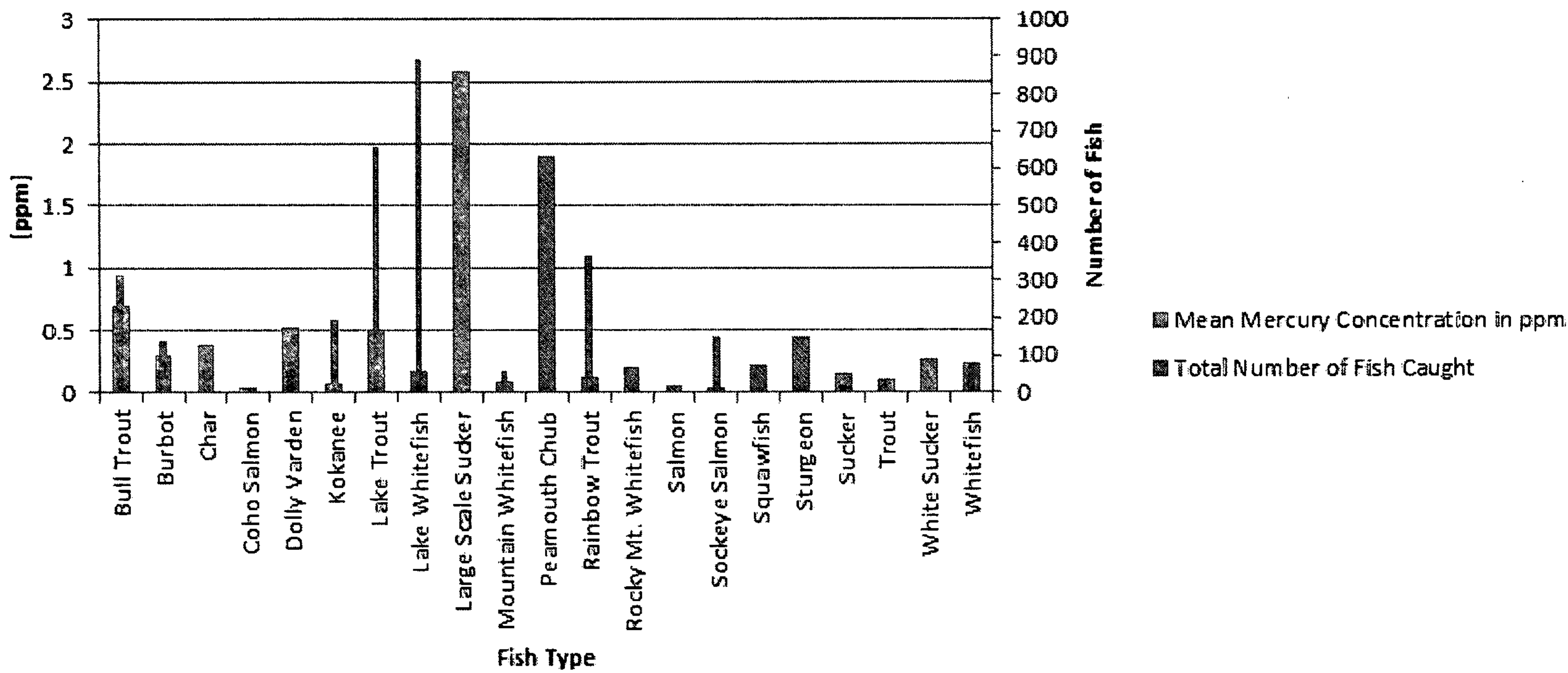


Figure 4.3.3 Mean Hg concentration (ppm) of fish caught vs. type of fish

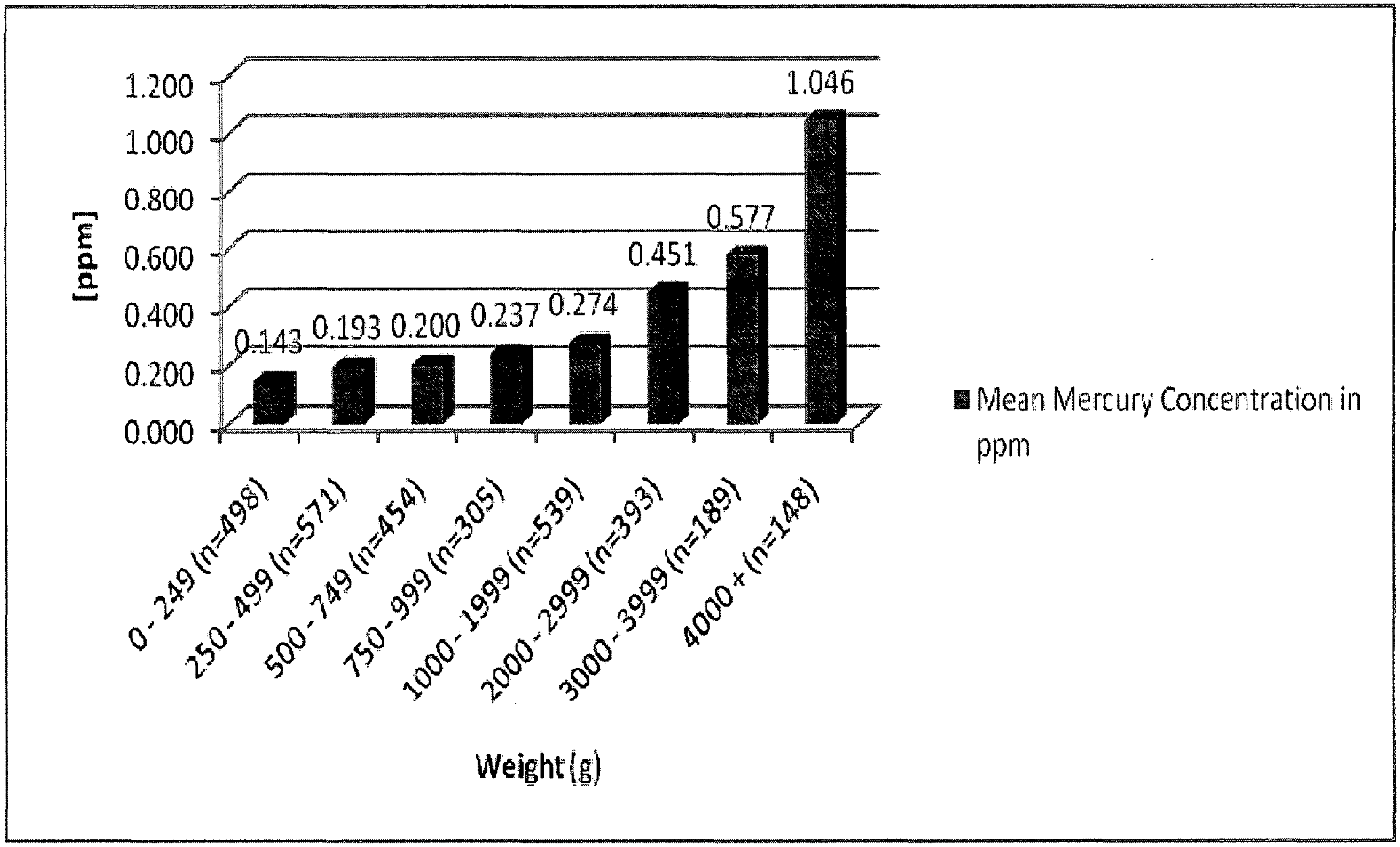


4.4 Relationship between Hg concentration and fish size

The largest sample size of lake whitefish was from the Peace Reach of Williston River (N=158, 0.130 ppm); however, the heaviest lake whitefish were found in Weisner Lake (N=20) at 1.09 kg, with a Hg concentration of 0.086 ppm. The smallest lake whitefish were caught in the Parsnip Reach of Williston River (0.262 kg) with a mean Hg concentration of 0.190 ppm. The highest levels of Hg in lake whitefish were found in Pinchi Lake, with a mean concentration of 0.495 ppm (0.535 kg). The heaviest lake trout were found in Whitefish Lake (N=40) at a mean of 2.99 kg, however, the Hg concentration was only 0.311 ppm whereas the lake trout from Pinchi Lake (N=75) had a lower weight of 2.74 kg, but a Hg concentration of 1.82 ppm. The smallest lake trout were caught in Purvis Lake (N=6), at 0.35 kg and a Hg concentration of 0.308 ppm. The smallest rainbow trout were caught in Rainbow Creek (N=11) at 0.0512 kg (0.0856 ppm Hg). The heaviest rainbow trout were 3.02 kg from Quesnel Lake (N=73), with a Hg concentration of 0.117 ppm. However, the rainbow trout with the highest Hg concentrations were also from Pinchi Lake (N=13) at 0.36 ppm and a weight of 0.309 kg.

Figure 4.4.1 demonstrates that the heavier the fish, the higher the mean Hg concentration. However, the lower and mid-weight categories do have a larger sample size; fish over 3 kg only account for approximately 11% of the total data set.

Figure 4.4.1 Mean Hg concentration (ppm) in fish tissue vs. fresh weight (gms) of fish



5.0 Development of the Risk Assessment Tool

Ideally a risk assessment tool would use more recent data and of a larger sample size (for some water bodies and fish species). Given the limitations of the data available for this study, a risk assessment tool was developed using the framework for risk analysis by WHO/FAO.

5.1 Risk analysis

As stated in the "Food Safety Risk Analysis: A guide for national food safety authorities" document, a risk analysis should: "i) follow a structured approach comprised of the three distinct components illustrated in Figure 2.2; ii) be based on the best available scientific evidence; iii) be applied consistently, for instance, to hazards of different types and from country to country; iv) be carried out in an open, transparent and well documented process; v) be clear in its treatment of uncertainty and variability; and vi) be evaluated and reviewed as appropriate on the basis of new information" (FAO/WHO, 2006). By adhering to these principals, an assessment was completed.

5.2 Risk assessment

5.2.1 Step 1: Hazard identification. The hazard in this case is clearly identified as MeHg exposure from fish consumption. It is assumed that most of the total Hg in fish will be in the form of MeHg.

5.2.2 Step 2: Hazard characterization. This step requires qualitative and quantitative evaluation of the adverse health effects of MeHg exposure, ideally using dose-response relationships that define a safe level of exposure. This step has already been done by Health Canada and the limit of a maximum of 0.5 ppm has been defined as the safe level of exposure.

5.2.3 Step 3: Exposure assessment. Exposure assessment is of course unique to each area when fish Hg levels are concerned. Therefore, it is important to identify who is consuming the fish, which fish they choose to consume, how much of each species they eat, and how much MeHg the fish in question contain. This information can be used in conjunction with the table that shows which areas have contaminated species according to the results of this study (table is presented later in the thesis).

5.2.4 Step 4: Risk characterization. A risk characterization developed for MeHg is relatively imprecise; "risk is not quantitatively characterized in terms of the probability and severity of adverse health effects relative to defined levels of exposure, but rather, presumptively 'safe' exposure levels are estimated. Such 'safety assessments' can nonetheless provide a basis for risk management decisions" (FAO/WHO, 2006).

5.3 Risk management

5.3.1 Step 1: Identify risk management options. A few risk management options can be identified which might help reduce MeHg risks at a provincial level. A general option is to control industrial Hg sources; however, this can be difficult to obtain at a provincial level, and even if successfully done, will have negligible short-term impact on the MeHg levels in fish. "Pollution control is generally outside the authority of food safety agencies, which have the primary risk management responsibility for food-borne contaminants such as methylmercury" (FAO/WHO, 2006). Risk management options that can be applied at the provincial level include the restriction of the sale of certain fish species caught from high-risk water bodies and the education of local consumers on the levels of MeHg. This would especially include members of the First Nations communities surrounding high-risk water bodies so that they are well informed and able to manage their own MeHg exposure. Table 6.2 (presented later) can be shared with public health officials and members of the public to raise awareness about contaminated species from various water bodies.

5.3.2 Step 2: Evaluate the options. The restriction of sale or consumption of any fish species is generally not considered an ideal option, as even those fish with very high MeHg concentrations still have nutritional benefits. Information-based options are likely the best option at the provincial level, as the risk depends on multiple factors. "These approaches can address the complexity of the problem, do not require costly and impractical enforcement efforts, can be implemented relatively quickly and at relatively minimal cost, and hold at least the potential for reducing MeHg exposure substantially, without adverse nutritional or economic consequences" (FAO/WHO, 2006).

5.3.3 Step 3: Implementation. Government and other stakeholders need to work together to provide adequate information to the population(s) at risk; in this case, the First Nations communities that rely heavily on fishing as a substantial part of their diet. This can be done by displaying adequate and clear signage in high-risk areas, in addition to verbal communication.

5.3.4 Step 4: Monitoring and review. This step requires risk managers to assess how well the risk management option implemented is working and weigh the need to examine new evidence and update risk assessments and management strategies. This is especially important in those areas where remedial action is being undertaken, as with the decline of MeHg concentrations in fish, the risk may be significantly reduced. It is important not to discourage the consumption of fish altogether and cause consumers to lose important nutritional benefits associated with the consumption of fish. The advice offered must be done so in such a way that consumers can continue to consume low-Hg fish for their nutritional benefits, while minimizing their Hg exposure.

6.0 Risk assessment tool for MeHg levels in fish in Northern BC

6.1 Normal range of Hg in fish in Northern BC

After following the risk assessment and management framework, it was clear that steps 3 and 4, implementation and monitoring/review, were needed. In order to take these next steps, it was important to determine what the normal range of Hg in each fish species is in Northern BC. It was not possible to include all of the fish species due to small sample sizes of some of the species; however, each species with an N greater than 60 was included. This was done by calculating an adjusted Hg concentration for each fish in the data set. Each species was analyzed separately to determine the mean Hg concentration. Next, for each species, an equation for the line of best fit ($y = Ax + B$) was formed from correlating Hg concentration (y) and weight (x). An adjusted Hg concentration was calculated for each fish using the fish's actual Hg concentration, the species mean Hg concentration, and the fish's theoretical Hg concentration calculated from the correlation (through regression analysis). Below is the equation (please see Figure 10.1 in the appendix for a scatterplot distribution of Hg concentration vs. weight for bull trout and Figure 10.2 for a sample calculation of the adjusted Hg concentration for bull trout):

Adjusted PPM = (actual ppm) x (mean species ppm/theoretical Hg concentration according to regression)

A new adjusted mean Hg and standard deviation were calculated from these adjusted concentrations and the normal range was calculated from that (± 1 S.D.). Table 6.1 below lists the adjusted mean Hg concentration, the standard deviation, and the adjusted mean and standard deviation added together for each species included in this section. The latter value provides us with the cut-off point for that particular species. Any Hg concentration higher than this value was then considered to be a higher than acceptable Hg concentration for that species.

Table 6.1 Adjusted mean Hg concentration by species and sum of SD and adjusted means used to determine cut off Hg concentrations for various fish species

Species	N	Mean Weight (kg)	Mean Hg (ppm)	Adjusted mean Hg (ppm)	Standard Deviation (SD)	Cut-off Point for Hg in Fish Species (SD + Adjusted Mean (ppm)
Bull trout	313	1.537	0.702	0.682	0.363	1.046
Burbot	137	1.150	0.309	0.310	0.155	0.464
Char	66	2.409	0.377	0.375	0.164	0.539
Dolly varden	87	1.005	0.522	0.495	0.265	0.760
Kokanee	195	1.380	0.085	0.122	0.194	0.315
Lake trout	660	2.201	0.502	0.510	0.703	1.212
Lake whitefish	892	0.455	0.168	0.168	0.265	0.433
Mountain whitefish	60	0.897	0.099	0.099	0.139	0.238
Rainbow trout	365	1.061	0.121	0.121	0.114	0.234
Sockeye salmon	147	2.035	0.054	0.052	0.029	0.081
Whitefish	81	0.819	0.237	0.237	0.135	0.371

Using this information, we were able to identify fish species from specific water bodies that exhibit higher than the normal concentrations of Hg in tissue samples. Table 6.2 shows which species from specific water bodies are considered to be above the accepted range (i.e. % of fish within a specific species that exhibit Hg concentrations above the critical cut-off point).

Table 6.2 Percentage of Hg-contaminated fish by species and water body as estimated using the risk assessment tool

Location	Bull trout		Burbot		Char		Dollly varden		Kokanee		Lake trout		Lake whitefish		Mountain whitefish		Rainbow trout		Sockeye salmon		Whitefish	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Babine Lake			14	0					71	10	108	0	11	0					93	2		
Bear Lake									40	10	18	0	24	0					20	0		
Brown Lake							5	0														
Chuchi Lake					17	6					59	0			8	25						
Cunningham Lake					2	0															49	29
Francois Lake											9	0	10	0								
Grassham Lake											5	0					23	17				
Inzana Lake					5	0					29	0			31	0						
Kazchek Lake											2	0	43	0			1	0				
Kemess Lake							6	0							13	0	16	0				
McKnight Lake							8	50														
Nations Lake											4	0					4	75				
Nechako – Tahtsa Reach																	16	6				
Necoslie River – Stuart Lake					14	29																
Pinchi Lake	3	100							37	11	75	40	51	33	2	100	13	85				
Purvis Lake											6	0	5	0	1	0	4	0				
Quesnel Lake											37	0					73	0				
Rainbow Creek																	11	0				
Stuart Lake			14	7					5	0	23	0	32	0					18	22		
Takla Lake											17	0	7	0			8	0	1	100	1	0
Tatchi River			44	7	19	0													5	80	1	0
Tchentlo					1	0					36	0	25	4								
Tezzeron Lake			12	50							84	0	65	0			29	28			1	0
Tochcha Lake											11	0										
Trembleur Lake			1	0	6	17					23	0	32	0			2	50	10	50		
Tsayata Lake			2	0							31	6	153	0			5	0				
Weisner Lake											20	0	20	0								
Whitefish Lake					1	0					40	0									19	0
Williston - Finlay	160	23	8	50			20	15	10	10			107	0			25	8				
Williston - Ingenika	45	27					35	17					57	2			30	37			10	10
Williston - Williston Lake	5	40					13	0					23	0			1	0				
Williston - Parsnip	43	0	28	14							2	0	47	0			66	0				
Williston - Peace	57	4	14	29					32	0	2	0	158	1	5	0	36	6				
Witch Lake					1	0					19	0	22	0			2	0				

This table effectively displays the number of fish caught in each water body by species and how many of those fish were above the accepted Hg concentration and in turn put into perspective how polluted with Hg a water body may be. For example, when fishing for lake trout from Pinchi Lake, 40% of samples were considered contaminated or higher than the normal variability. However, when fishing for mountain whitefish from the same lake, although 100% of the samples were considered contaminated, this information must be used with caution, as only 2 samples of mountain whitefish were collected (i.e. sample size was very small).

To simplify the Risk Assessment Tool, Table 6.3 (derived from Table 6.2) shows which fish species (minimum N=10) from specific water bodies had at least 25% or more contaminated samples. It also indicates nearby water bodies where the same species may be accessed that exhibit low Hg concentrations. This tool should help fish consumers select areas where fish exhibit safe levels of Hg.

Table 6.3 Fish species flagged as potentially contaminated with Hg after adjusting for weight

Location	Fish Type	Nearby Locations with same species which are likely not contaminated with Hg	Species in same lake which are likely not contaminated with Hg
Cunningham Lake	Whitefish	Whitefish Lake	Char
Necoslie River – Stuart Lake	Char	Trembleur Lake	No known species from this study
Pinchi Lake	Lake trout*	Stuart Lake, Tezzeron Lake	Kokanee
	Lake whitefish	Stuart Lake, Tezzeron Lake	
	Rainbow trout	Stuart Lake, Tezzeron Lake	
Tezzeron Lake	Burbot	Stuart Lake	Lake trout, lake whitefish
	Rainbow trout	Grassham Lake	
Trembleur Lake	Sockeye salmon	Babine Lake	Lake trout, lake whitefish
Williston Reservoir - Finlay	Rainbow trout	Williston Reservoir – Parsnip, Quesnel Lake	Lake whitefish
Williston Reservoir - Ingenika	Bull trout*	Williston Reservoir – Parsnip and Peace	Lake whitefish, whitefish
	Rainbow trout	Williston Reservoir - Parsnip	
Williston Reservoir - Peace	Burbot	Stuart Lake, Tatchi River	Bull trout, kokanee, lake whitefish, rainbow trout

* current fish consumption advisory for these species from these lakes

7.0 Discussion

This study has generated several interesting findings that are worth further discussion. Most importantly, there are fish within specific water bodies that had higher Hg levels than Health Canada's current guideline of 0.5 ppm. In addition to this, these high levels can be linked to fish size, species, location and the year that they were caught in. Our results provide information to identify which areas in Northern BC have the highest levels of Hg in fish, and whether these levels vary in different species from the same area; whether there are similarities in the areas with the highest Hg levels in fish; and whether there is a significant difference in species, age, weight, location, and time of sampling in comparison to Hg concentrations in fish.

7.1 High Hg levels in fish from Pinchi Lake and Williston Lake

Fish from Pinchi Lake (1.17 ppm, n=162) and a subset from the Williston Reservoir (the 'Finlay' group) (0.52 ppm, n=334) had Hg tissue concentrations that were above the Health Canada guideline. In general, this study showed that larger fish had greater Hg concentrations than smaller ones, but the fish in Pinchi Lake and Williston Lake (the 'Finlay' group) were not the longest or heaviest fish. This relationship is not surprising when one considers the history of these two water bodies.

The reasons for elevated Hg levels in fish from Pinchi Lake are clear. The Pinchi fault area geologically has naturally elevated Hg levels, there is a long history of Hg mining in the area, and elevated Hg levels have been an issue for quite some time. The Environmental Trends report of 2002 showed that as of the year 2000, Pinchi Lake still had elevated Hg levels, which is consistent with the results of this study.

When examining all of the data collected from Pinchi Lake, it is clear that Hg concentrations in fish have remained high between 1974 and 2000. The Pinchi Lake mine closed in 1975, and considering that elevated Hg levels are projected to remain high for 20 to 30 years after mine closure, high concentrations of Hg were observed in fish 25 years later in 2000. The mean Hg concentration was by far the highest in 1974 (2.11 ppm, N=42); there were only 6 samples taken in 1975, but 1986 showed a significant decline in fish tissue Hg concentrations (0.92 ppm, N=47); However, there was not much change from 1986 to 2000 (0.81 ppm, N=67). It would be valuable to test the MeHg concentrations in fish from Pinchi Lake today, 37 years post closure.

There were 8 different fish species sampled from Pinchi Lake, 7 of which had elevated Hg concentrations above the Health Canada guideline of 0.5 ppm. Although rainbow trout was the exception to this, 85% of them were still considered Hg-contaminated when normalized for weight for the creation of the Risk Assessment Tool. Large scale sucker (N=3) had the highest Hg concentration at 2.59 ppm; however, due to the small sample size definitive conclusions cannot be made. Lake trout, of which there is currently an advisory for from Pinchi Lake, had a mean Hg level of 1.82 ppm.

Williston Lake is the largest water body (in surface area) in British Columbia (Stockner, 2005). Due to its large size and various reaches, it was very difficult to distinguish which area data were collected from. In some cases, the reach was identified in the data; however, in other cases it was listed in a broader description of "Williston Lake". When the reach was known, the original location listed was kept in the analysis, making five different locations for Williston Lake.

The categorization of these five areas was somewhat arbitrary. The lake was split up into five geographical areas and samples were placed into each of those areas. For those samples that did not have a specific identifier, it was assumed that they were taken from the large, open part of the lake. Although not perfect, this method allowed us to split up this large body of water into distinct areas with large enough sample sizes that it was possible to compare and contrast them using statistical methods.

High Hg concentrations in fish from Williston Lake fish have been attributed to the flooding which occurred during the formation of the reservoir in the late 1960s and early 1970s. Hg released from flooded soils can cause elevated levels of MeHg in fish for about 20 to 30 years (MWLAP, 2002). Of the five areas of Williston, Finlay (0.52 ppm, N=334) and Ingenika (0.43 ppm, N=180) had the highest mean Hg concentrations in fish tissue. Fish from Finlay Reach were first sampled in 1980 (0.40 ppm, N=72), then in 1981 (0.43 ppm, N=24), 1988 (0.66 ppm, N=170), and then 2000 (0.35 ppm, N=68). Ingenika was only sampled in 1979 (0.30 ppm, N=74) and in 1980 (0.52, N=106). There was no particular pattern with these levels but Hg concentration in fish from Finlay appeared to rise between 1980 and 1988; but, Hg concentrations decreased in 2000. Data presented in the report "Environmental Trends in British Columbia (2002)" show that there were mean Hg concentrations > 0.5ppm in bull trout from Williston Reservoir in the year 2000 (MWLAP, 2002). The fish species that were above the Health Canada guideline of 0.5 ppm for Hg concentration in Williston Lake were dolly varden and bull trout, the same two species that have an ongoing consumption advisory.

7.2 Hg levels in fish tissue varied with fish size and sample period

Besides location and trophic level, there are many other factors that can influence Hg concentrations in fish. Fish size is one of the well-known influencing factors for elevated Hg levels. The heaviest species was char, followed by lake trout, salmon, sockeye salmon, and bull trout. The four longest species were the same, although in a different order: salmon, lake trout, sockeye salmon and char. Fish length did not seem to be as closely related to weight as would be expected. When comparing years of data collection, the heaviest fish were caught in 1986 and in between 1976 and 1978, whereas the longest fish were caught between 1978 and 1981. An explanation for this may include fish growth rate, which is the temporal change in either fish weight or length. Fish growth rate has been shown to influence Hg accumulation (and in turn, Hg biodilution) in fish muscle, as faster-growing fish have been shown to have lower Hg concentrations than slower-growing fish at a certain length (Lavigne et al., 2012). Biodilution is defined as a reduced overall accumulation of a contaminant within an organism due to an increase in body size resulting from differences in bioenergetic processes. Hg biodilution has been shown to partly explain decreased Hg concentrations in fish when it was not explained by changes in fish diet, structural alterations of the trophic web, a reduction of MeHg levels in forage fish, or by a reduction in whole-lake MeHg content (Lavigne et al., 2012). Fish growth rate has many influencing factors including the ratio between primary watershed area and lake area, the ratio between drainage area and lake area, riparian wetland coverage, land use and vegetation coverage of the primary watershed, water quality variables and the sportsfishing intensity. Lavigne et al. (2012) found that growth rate could be used as an integrated proxy to predict Hg concentration in fish muscle in two slower-growing species (walleyes and northern pike) which had higher Hg concentrations at standardized length. Thus, they concluded that proper control of fish growth rate through fishing pressure, lake ecology, and watershed management could be used to minimize the toxic risk associated with Hg exposure from fish consumption.

Quesnel Lake had the longest fish and heaviest fish (mean weight of 2.87 kg); however, Quesnel Lake did not have the highest mean Hg concentration (0.16 ppm, N=110). In comparison, Pinchi Lake had the highest mean Hg concentration (1.17 ppm, N= 162) and a mean weight of 1.51 kg. Only lake trout (N= 73) and rainbow trout (N=37) were sampled from Quesnel Lake, whereas 8 different species were sampled from Pinchi Lake, the majority of which were lake trout (N=75) and lake whitefish

(N=51). The lake trout from both lakes had similar sample sizes and similar weight, however the Hg concentrations for this species differed greatly in the water bodies, with Pinchi Lake's lake trout having a mean Hg concentration of 1.82 ppm, and Quesnel Lake's having only 0.24 ppm.

It is demonstrated in Figure 4.4.1 that the mean Hg concentration in the fish in this study (n=3097) is moderately positively correlated with the weight of fish ($r = 0.316$, $p \leq 0.0001$). In fish over 2 kg, the Hg concentration is very close to or over Health Canada's maximum of 0.5 ppm guideline. This weight category includes char, lake trout, salmon, and sockeye salmon. This finding is supported by many previous studies, including a study completed by Storelli in 2007 which analyzed Hg concentration in fish versus their size. It was found that there was a significant relationship between Hg concentration and fish size for all species (Storelli, 2007). However, it is noted by Bhavsar (2010) that Hg concentrations in fish typically increase with age, and that fish size is obtained as a surrogate measure for the duration of contaminant exposure because it is easy and inexpensive to acquire (Bhavsar, 2010).

7.3 Hg levels in fish tissue varied with species

Another possible contributing factor to varying Hg concentrations in fish is species. Figure 4.4.3 illustrates mean Hg concentration by fish species. Unfortunately, the two species (large scale sucker and peamouth chub) with the highest concentrations both have very small sample sizes of only 3 fish each. Bull trout (n=313) had a concentration of 0.70 ppm and dolly varden (n=87) of 0.50 ppm. It is interesting to note that bull trout and dolly varden were considered to be the same species until 1980, when they were reclassified as a separate species (U.S. Fish and Wildlife Service, 1998). Piscivorous fish (such as lake trout and bull trout) tend to have higher concentrations of Hg than fish that consume plankton (such as kokanee and lake whitefish) (Baker, 2002), which is supported by the results of this study.

It was found that the highest Hg concentrations in fish in this study were in those caught in 1974. Upon closer examination, as displayed in Table 10.15 in the appendix, all of the fish sampled in 1974 came from Pinchi Lake. Further, the second highest Hg levels were in 1986, which was also exclusively from Pinchi Lake. Pinchi Lake was not part of any of the sampling areas in those years in which Hg levels were the lowest.

7.4 Limitations of this study

Although we are able to draw conclusions from this study, there are many limitations which prevent us from making any strong statements. This is mainly attributed to lengthy time span over which the data were collected; this can be seen as a positive, as it gives us an idea whether fish Hg concentrations are decreasing over time. However, due to the lack of consistency in location, this is a hard pattern to accurately conclude. For instance, when looking at Pinchi Lake, it is evident that Hg levels remained high between 1974 and 2000; however, samples were only taken in four of those years. The last two years the fish were sampled in (1986 and 2000) had a 14 year gap and they had sample sizes of only 47 and 67. In order to truly capture the patterns of mean Hg concentrations in fish over the years, it would be important to take a specific number of samples closer together and from the same location(s).

Another large factor that limited the analysis was that almost half of the data set was missing fish length. As discussed earlier, due to the variability of fish weight compared to fish length, length is the most reliable method of accurately estimating fish size. Since we are correlating fish size with mean Hg concentration, this may contribute to an incorrect analysis. That said, lengths and weights of fish were highly correlated; therefore, using the weight is not completely inappropriate.

Further, the data were collected from many different agencies and existing papers; therefore, the sampling techniques may have varied quite widely. This would include the actual lab procedures used to determine the Hg concentrations, as well as the method used to weigh and measure the fish.

7.5 Development and potential application of the Risk Assessment Tool

By using the framework developed by FAO/WHO for risk assessment and management, it was clear that a risk assessment tool for the MeHg levels in fish in Northern BC would be of benefit to those who fish in the local waters and for the public health officials that provide advice and guidance. However, due to the limitations of the data set, development of the risk assessment tool presented some difficulties. By adjusting for weight (standardizing the data for differences in fish weight), the data could be presented so that each sample could be viewed as either above or below the cut-off for excessive Hg concentration.

A few tables were developed which can be used as a reference by Public Health professionals and the general public. Table 6.2 would be very useful to those trying to decide whether to consume a certain species from a certain lake, as each species is listed separately with the percentage of contaminated samples from that lake. This is important because it does not limit all fish consumption from that water body, but allows one to determine which species is a better choice. Further, the number of samples that the percentage is derived from is listed as well, which assists in making an informed decision; for instance, if only 3 samples were taken for that species from that lake and 100% were contaminated, further investigation may be warranted. However, if 100 samples were taken and 90% were contaminated, then it is pretty certain that caution should be used when consuming that species taken from that lake.

Further, to simplify for fishers that are not interested in the percentages, Table 6.3 includes a list of fish species that are considered most contaminated from specified water bodies and from which nearby water bodies contain less contaminated fish. This does not limit consumption of a specific species, but instead provides safer options; also, if it is a specific lake that is the desired fishing spot, then the fisher is aware of species that should not be consumed.

8.0 Conclusion

Several interesting and important conclusions can be drawn from this study. Studying Hg concentrations in fish over such a large time span and in many different water bodies, allows us to identify concerns for high fish Hg concentrations. This study shows that as of the year 2000 Hg concentrations in fish were still high in some areas of Northern British Columbia.

In Canada, there have been reductions in Hg emissions in base metal mining, Hg used in the manufacture of chlorine and pesticides has mostly been eliminated, and releases from paints and batteries have also declined. Further, the Canadian Council of Ministers of the Environment (CCME) has identified Hg as a priority issue (MWLAP, 2002).

There has been a considerable amount of information collected on fish Hg concentrations in Northern British Columbia since 1970; however, this information has been widely dispersed amongst many government and private agencies. There are other summaries of fish Hg concentrations in Northern British Columbia similar to this one; however, this study has some data that is not included in those others. Further, this study did not eliminate data points based on size, or missing lengths. They were accounted for and noted in the analysis, but it was believed that eliminating certain data did not provide a clear picture of the actual results. Despite the large amount of information available on fish Hg concentrations in this area, there is no ongoing monitoring program. It is highly recommended that a continuing and systemic monitoring program be put into place to update the existing and future fish consumption advisories accurately.

Most importantly, this study has produced a risk assessment tool which allows public health officials and members of the public to be able to make informed decisions about which water bodies they are fishing from. When fishing for a specific species the public is able to refer to this tool and choose to fish from a lake that has been found to have lower Hg concentrations in that specific species.

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10.0 Appendices

Table 10.1 Descriptive statistics for fish parameters used in this study

	N	Min	Max	Mean	Std. Deviation	Skewness	Skewness Std. Error	Kurtosis	Kurtosis Std. Error
Weight (kg)	3097	0.01	39.4	1.2829	1.62532	9.309	0.044	195.955	0.088
Length (mm)	1801	27	1800	435.83	165.242	0.928	0.058	4.585	0.115
Hg Concentration (ppm)	3097	0	8.31	0.3013	0.54556	8.072	0.044	93.424	0.088
Year	3097	1974	2000	1983.83	7.413	1.03	0.044	-0.014	0.088
Location	3097	1	34	19.54	11.829	-0.356	0.044	-1.406	0.088

Table 10.2 Descriptive statistics for total number of fish used in this study by water body

	Frequency	Percent	Valid[1] Percent
Babine Lake	301	9.7	9.7
Bear Lake	102	3.3	3.3
Brown Lake	5	0.2	0.2
Chuchi Lake	95	3.1	3.1
Cunningham Lake	57	1.8	1.8
Francois Lake	19	0.6	0.6
Grassham Lake	28	0.9	0.9
Inzana Lake	65	2.1	2.1
Kazchek Lake	46	1.5	1.5
Kemess Lake	35	1.1	1.1
McKnight Lake	8	0.3	0.3
Nations Lakes	8	0.3	0.3
Nechako Reservoir - Tahtsa Reach	16	0.5	0.5
Necoslie River - Stuart Lake	26	0.8	0.8
Pinchi Lake	162	5.2	5.2
Purvis Lake	20	0.6	0.6
Quesnel Lake	110	3.6	3.6
Rainbow Creek	11	0.4	0.4
Stuart Lake	141	4.6	4.6
Takla Lake	34	1.1	1.1
Tatchi River	72	2.3	2.3
Tchentlo	62	2	2
Tezzeron Lake	191	6.2	6.2
Tochcha Lake	11	0.4	0.4
Trembleur Lake/Middle River	105	3.4	3.4
Tsayata Lake	191	6.2	6.2
Weisner Lake	40	1.3	1.3
Whitefish Lake	66	2.1	2.1
Williston Reservoir - Finlay	334	10.8	10.8
Williston Reservoir - Ingenika	180	5.8	5.8
Williston Reservoir - Williston Lake	42	1.4	1.4
Williston Reservoir - Parsnip	166	5.4	5.4
Williston Reservoir – Peace	304	9.8	9.8
Witch Lake	44	1.4	1.4
Total	3097	100	100

[1] Valid percent was used in the SPSS program to distinguish whether there were any parameters missing. It is irrelevant in this table; however, in the tables that refer to length of fish it refers to those fish that had missing lengths in the original data source.

Table 10.3 Descriptive/tests of normality for fish parameters used in this study

				Std. Error
Weight (kg)	Mean		1.2829	0.02921
	95% Confidence Interval for Mean	Lower Bound	1.2256	
		Upper Bound	1.3402	
	5% Trimmed Mean		1.1093	
	Median		0.75	
	Variance		2.642	
	Std. Deviation		1.62532	
	Minimum		0.01	
	Maximum		39.4	
	Range		39.39	
	Interquartile Range		1.48	
	Skewness		9.309	0.044
	Kurtosis		195.955	0.088
Hg Concentration (ppm)	Mean		0.3013	0.00976
	95% Confidence Interval for Mean	Lower Bound	0.2822	
		Upper Bound	0.3205	
	5% Trimmed Mean		0.2225	
	Median		0.17	
	Variance		0.295	
	Std. Deviation		0.54336	
	Minimum		0	
	Maximum		8.31	
	Range		8.31	
	Interquartile Range		0.24	
	Skewness		8.072	0.044
	Kurtosis		93.424	0.088

Table 10.4 Tests of normality for fish weight and Hg concentrations

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Weight (kg)	0.217	3097	0	0.586	3097	0
Hg Concentration (ppm)	0.29, 3097, 0.00			0.407	3097	0

Table 10.5 Square root transformation of weight of all fish used in this study

				Std. Error
sqrtWeight	Mean		0.9954	0.00971
	95% Confidence Interval for Mean	Lower Bound	0.9763	
		Upper Bound	1.0144	
	5% Trimmed Mean		0.9636	
	Median		0.866	
	Variance		0.292	
	Std. Deviation		0.54058	
	Minimum		0.08	
	Maximum		6.28	
	Range		6.19	
	Interquartile Range		0.77	
	Skewness		1.315	0.044
	Kurtosis		5.709	0.088

Table 10.6 Tests of normality for weight of all fish used in this study

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
sqrtWeight	0.122	3097	0	0.92	3097	0

Table 10.7 Hg concentration (ppm) with cube root transformation for fish in this study

			Std. Error
Mean		0.5836	0.00398
95% Confidence Interval for Mean	Lower Bound	0.5758	
	Upper Bound	0.5914	
5% Trimmed Mean		0.5671	
Median		0.554	
Variance		0.049	
Std. Deviation		0.22142	
Minimum		0	
Maximum		2.03	
Range		2.03	
Interquartile Range		0.25	
Skewness		1.549	0.044
Kurtosis		5.378	0.088

Table 10.8 Tests of normality for Hg concentration for all fish used in this study

Kolmogorov-Smirnova			Shapiro-Wilk		
Statistic	df	Sig.	Statistic	df	Sig.
0.094	3097	0	0.905	3097	0

Table 10.9 Interlake differences of Hg concentrations (ppm) in fish tissue, sorted by species

Location	**Fish Type**	**Mean**	**N**
Babine Lake	Kokanee	0.0555	71
	Lake trout	0.2422	108
	Sockeye salmon	0.0514	93
Bear Lake	Kokanee	0.0315	40
Chuchi Lake	Lake trout	0.3268	59
Cunningham Lake	Whitefish	0.2718	49
Kazchek Lake	Lake whitefish	0.0502	43
Pinchi Lake	Lake trout	1.8218	75
	Lake whitefish	0.4954	51
Quesnel Lake	Rainbow trout	0.1165	73
Tatchi River	Burbot	0.2795	44
Tezzeron Lake	Lake trout	0.6064	84
	Lake whitefish	0.0895	65
Tsayata Lake	Lake whitefish	0.1876	153
Whitefish Lake	Lake trout	0.3108	40
Williston Reservoir - Finlay	Bull trout	0.846	160
	Lake whitefish	0.1873	107
Williston Reservoir - Ingenika	Bull trout	0.7027	45
	Lake whitefish	0.2251	57
Williston Reservoir - Parsnip	Bull trout	0.5135	43
	Lake whitefish	0.1895	47
	Rainbow trout	0.0415	46
Williston Reservoir - Peace	Bull trout	0.4679	57
	Lake whitefish	0.1299	158

Table 10.10 Mean Hg concentrations (ppm) in fish tissue in various fish species

Species	**Mean**	**N**
Bull trout	0.7021	313
Burbot	0.3092	137
Char	0.377	66
Dolly varden	0.5215	87
Kokanee	0.0845	195
Lake trout	0.5017	660
Lake whitefish	0.1681	892
Mountain whitefish	0.0989	60
Rainbow trout	0.1209	365
Sockeye salmon	0.0535	147
Whitefish	0.2368	81
Total	0.2886	3003

Table 10.11 Hg concentration in fish tissue collected in various years

Year	Mean	N	Std. Deviation	% of total N	Variance
1974	2.1148	42	2.7941	1.4%	7.807
1975	0.48	6	0.17967	.2%	0.032
1976	0.2456	160	0.15967	5.2%	0.025
1977	0.1915	234	0.17481	7.6%	0.031
1978	0.1746	275	0.13862	8.9%	0.019
1979	0.2374	675	0.22943	21.8%	0.053
1980	0.3763	303	0.35333	9.8%	0.125
1981	0.1826	151	0.25814	4.9%	0.067
1985	0.412	5	0.04764	.2%	0.002
1986	0.8414	58	0.56535	1.9%	0.32
1988	0.3032	750	0.54715	24.2%	0.299
1989	0.0856	11	0.03875	.4%	0.002
1992	0.0277	35	0.05096	1.1%	0.003
1993	0.0869	16	0.18297	.5%	0.033
1996	0.3662	13	0.24199	.4%	0.059
2000	0.334	363	0.45972	11.7%	0.211
Total	0.3013	3097	0.54336	100.0%	0.295

Table 10.12 Hg concentration (ppm) in all fish sampled from each location

Lake	Mean	N	Std. Deviation	% of total N	Variance
Tsayata Lake	0.228	191	0.15074	6.2%	0.023
Babine Lake	0.1316	301	0.1159	9.7%	0.013
Bear Lake	0.1228	102	0.156	3.3%	0.024
Brown Lake	0.112	5	0.02049	.2%	0
Chuchi Lake	0.3052	95	0.20086	3.1%	0.04
Cunningham Lake	0.2602	57	0.14599	1.8%	0.021
Weisner Lake	0.1915	40	0.12771	1.3%	0.016
Whitefish Lake	0.2473	66	0.1715	2.1%	0.029
Francois Lake	0.1633	19	0.12811	.6%	0.016
Grassham Lake	0.1739	28	0.06551	.9%	0.004
Witch Lake	0.2575	44	0.14002	1.4%	0.02
Inzana Lake	0.1272	65	0.08541	2.1%	0.007
Kazchek Lake	0.0533	46	0.04164	1.5%	0.002
Kemess Lake	0.0277	35	0.05096	1.1%	0.003
McKnight Lake	0.525	8	0.15866	.3%	0.025
Trembleur Lake/Middle River	0.1452	105	0.13014	3.4%	0.017
Nations Lakes	0.2725	8	0.14109	.3%	0.02
Nechako Reservoir - Tahtsa Reach	0.0869	16	0.18297	.5%	0.033
Necoslie River - Stuart Lake	0.3042	26	0.2449	.8%	0.06
Stuart Lake	0.1606	141	0.14005	4.6%	0.02
Pinchi Lake	1.1671	162	1.63217	5.2%	2.664
Purvis Lake	0.1775	20	0.11045	.6%	0.012
Quesnel Lake	0.1577	110	0.13462	3.6%	0.018
Rainbow Creek	0.0856	11	0.03875	.4%	0.002
Tatchi River	0.2781	72	0.14614	2.3%	0.021
Takla Lake	0.1762	34	0.11626	1.1%	0.014
Tchentlo	0.2065	62	0.1401	2.0%	0.02
Tezzeron Lake	0.3517	191	0.31616	6.2%	0.1
Tochcha Lake	0.51	11	0.13372	.4%	0.018
Williston Reservoir - Finlay	0.5244	334	0.72657	10.8%	0.528
Williston Reservoir - Ingenika	0.4335	180	0.38227	5.8%	0.146
Williston Reservoir - Williston Lake	0.2579	42	0.13056	1.4%	0.017
Williston Reservoir - Parsnip	0.2558	166	0.335	5.4%	0.112
Williston Reservoir - Peace	0.1829	304	0.3281	9.8%	0.108
Total	0.3013	3097	0.54336	100.0%	0.295

Table 10.13 Mean weight (kg) of fish, sorted by species

Fish Type	Mean	N	Median
Bull trout	1.5366	313	1
Burbot	1.1503	137	1.2
Char	2.4091	66	2.1
Coho salmon	1.5	4	1.5
Dolly varden	1.005	87	0.5
Kokanee	1.3796	195	1.5
Lake trout	2.2005	660	1.9
Lake whitefish	0.4547	892	0.4
Large scale sucker	1.175	3	1.15
Mountain whitefish	0.8973	60	0.8
Peamouth chub	0.2037	3	0.21
Rainbow trout	1.061	365	0.4
Rocky mt. whitefish	0.5	1	0.5
Salmon	2.1846	13	2
Sockeye salmon	2.035	147	2
Squawfish	1.5	1	1.5
Sturgeon	39.4	2	39.4
Sucker	0.7196	23	0.5
Trout	0.3339	33	0.3
White sucker	0.7045	11	0.5
Whitefish	0.8185	81	0.8
Total	1.2829	3097	0.75

Table 10.14 Mean weight (kg) of fish, sorted by location

Location	Mean	N	Median
Tsayata Lake	0.6076	191	0.5
Babine Lake	1.8967	301	1.9
Bear Lake	1.6426	102	1.5
Brown Lake	0.1062	5	0.078
Chuchi Lake	2.2763	95	2
Cunningham Lake	0.8754	57	0.8
Weisner Lake	1.7125	40	1.6
Whitefish Lake	2.1606	66	1
Francois Lake	1.2618	19	0.775
Grassham Lake	0.2036	28	0.2
Witch Lake	1.1159	44	1
Inzana Lake	1.3662	65	1.4
Kazchek Lake	0.7663	46	0.8
Kemess Lake	0.1785	35	0.032
McKnight Lake	0.3696	8	0.372
Trembleur Lake/Middle River	1.0395	105	0.5
Nations Lakes	2.0687	8	1.625
Nechako Reservoir - Tahtsa Reach	0.2039	16	0.194
Necoslie River - Stuart Lake	2.4923	26	2.15
Stuart Lake	1.9585	141	1.25
Pinchi Lake	1.5108	162	0.75
Purvis Lake	0.505	20	0.35
Quesnel Lake	2.8727	110	2.75
Rainbow Creek	0.0512	11	0.039
Tatchi River	1.7014	72	1.5
Takla Lake	1.0574	34	1
Tchentlo	1.45	62	0.8875
Tezzeron Lake	1.481	191	1.15
Tochcha Lake	3.3636	11	3.5
Williston Reservoir - Finlay	1.0578	334	0.4675
Williston Reservoir - Ingenika	0.9292	180	0.5
Williston Reservoir - Williston Lake	0.3688	42	0.2
Williston Reservoir - Parsnip	0.6482	166	0.35
Williston Reservoir - Peace	0.5778	304	0.35
Total	1.2829	3097	0.75

Table 10.15 Hg concentration of fish tissue, sorted by year, lake, and fish species.

Year	Location	Fish Type		Hg Concentration (ppm)	Weight (kg)
1974	Pinchi Lake	Kokanee	Mean	0.48	0.1625
			N	6	6
		Lake trout	Mean	4.8275	2.4188
			N	12	12
		Lake whitefish	Mean	1.79	0.3
			N	5	5
		Large scale sucker	Mean	2.5867	1.175
			N	3	3
		Mountain whitefish	Mean	0.66	0.365
			N	2	2
		Peamouth chub	Mean	1.8967	0.2037
			N	3	3
		Rainbow trout	Mean	0.39	0.3023
			N	11	11
		Total	Mean	2.1148	0.945
			N	42	42
1976	Necoslie River - Stuart Lake	Char	Mean	0.4971	2.8357
			N	14	14
		Salmon	Mean	0.13	4.1
			N	1	1
		Sucker	Mean	0.3	1.3
			N	1	1
		Total	Mean	0.4619	2.8188
			N	16	16
	Stuart Lake	Sturgeon	Mean	0.45	39.4
			N	2	2
		Total	Mean	0.45	39.4
			N	2	2
1979	Tezzeron Lake	Burbot	Mean	0.455	1.8333
			N	12	12
		Lake trout	Mean	0.6309	2.2333
			N	66	66
		Lake whitefish	Mean	0.1012	0.5606
			N	32	32
		Rainbow trout	Mean	0.1676	0.9
			N	29	29

		Whitefish	Mean	0.11	0.5
			N	1	1
		Total	Mean	0.3951	1.5281
			N	140	140
	Williston Reservoir - Ingenika	Dolly varden	Mean	0.6379	1.2179
			N	14	14
		Lake whitefish	Mean	0.26	0.66
			N	20	20
		Rainbow trout	Mean	0.189	0.3583
			N	30	30
		Whitefish	Mean	0.26	0.66
			N	10	10
		Total	Mean	0.3027	0.6432
			N	74	74
1980	Williston Reservoir - Finlay	Bull trout	Mean	0.5815	0.6885
			N	26	26
		Dolly varden	Mean	0.5664	0.675
			N	14	14
		Lake whitefish	Mean	0.1813	0.4987
			N	30	30
		Rainbow trout	Mean	0.07	0.25
			N	1	1
		White sucker	Mean	0.29	0.6
			N	1	1
		Total	Mean	0.4007	0.5994
			N	72	72
	Williston Reservoir - Ingenika	Bull trout	Mean	0.7027	1.5693
			N	45	45
		Dolly varden	Mean	0.7324	1.5381
			N	21	21
		Lake whitefish	Mean	0.2062	0.4197
			N	37	37
		White sucker	Mean	0.3333	0.4
			N	3	3
		Total	Mean	0.5248	1.1288
			N	106	106
1981	Williston Reservoir - Finlay	Bull trout	Mean	0.784	4.22
			N	5	5
		Dolly varden	Mean	0.6807	3.2167

			N	6	6
		Lake whitefish	Mean	0.146	0.46
			N	10	10
		White sucker	Mean	0.31	0.4167
			N	3	3
		Total	Mean	0.4331	1.9271
			N	24	24
1986	Pinchi Lake	Bull trout	Mean	0.6533	0.36
			N	3	3
		Lake trout	Mean	1.1033	2.2373
			N	30	30
		Lake whitefish	Mean	0.645	0.84
			N	12	12
		Rainbow trout	Mean	0.195	0.3475
			N	2	2
		Total	Mean	0.9189	1.6803
			N	47	47
	Tochcha Lake	Lake trout	Mean	0.51	3.3636
			N	11	11
		Total	Mean	0.51	3.3636
			N	11	11
1988	Williston Reservoir - Finlay	Bull trout	Mean	1.1369	2.1345
			N	84	84
		Burbot	Mean	0.3325	0.3
			N	8	8
		Kokanee	Mean	0.1922	0.254
			N	10	10
		Lake whitefish	Mean	0.2277	0.2795
			N	44	44
		Rainbow trout	Mean	0.077	0.4129
			N	24	24
		Total	Mean	0.6585	1.2144
			N	170	170
	Williston Reservoir - Parsnip	Bull trout	Mean	0.5135	1.2752
			N	43	43
		Burbot	Mean	0.3194	0.8493
			N	28	28
		Lake trout	Mean	0.315	0.595
			N	2	2
		Lake whitefish	Mean	0.1895	0.2621
			N	47	47

		Rainbow trout	Mean	0.0415	0.3365
			N	46	46
		Total	Mean	0.2558	0.6482
			N	166	166
1996	McKnight Lake	Dolly varden	Mean	0.525	0.3696
			N	8	8
		Total	Mean	0.525	0.3696
			N	8	8
2000	Pinchi Lake	Lake trout	Mean	1.3821	3.3153
			N	33	33
		Lake whitefish	Mean	0.2522	0.4618
			N	34	34
		Total	Mean	0.8087	1.8673
			N	67	67
	Tezzeron Lake	Lake trout	Mean	0.5165	2.8917
			N	18	18
		Lake whitefish	Mean	0.0781	0.5114
			N	33	33
		Total	Mean	0.2328	1.3515
			N	51	51

Table 10.16 Latin names for fish species used in this study

Common Name	Latin Name
Bull trout	*Salvelinus confluentus*
Burbot	*Lota lota*
Char	*Salvelinus fontinalis*
Coho salmon	*Oncorhynchus kisutch*
Dolly varden	*Salvelinus malma malma*
Kokanee	*Oncorhynchus nerka*
Lake trout	*Salvelinus namaycush*
Lake whitefish	*Coregonus clupeaformis*
Large scale sucker	*Catostomus macrocheilus*
Mountain whitefish	*Prosopium williamsoni*
Peamouth chub	*Mylocheilus caurinus*
Rainbow trout	*Oncorhynchus mykiss*
Rocky mt. whitefish	*Prosopium williamsoni*
Salmon	*Salmo Salar*
Sockeye salmon	*Oncorhynchus nerka*
Squawfish	*Ptychochelius*
Sturgeon	*Acipenser sturio*
Sucker	*Catostomus commersonii*
Trout	*Salvelinus malma malma*
White sucker	*Catostomus commersonii*
Whitefish	*Coregonus clupeaformis*

Figure 10.1 Scatterplot of Hg concentration (ppm) versus weight (kg) for bull trout

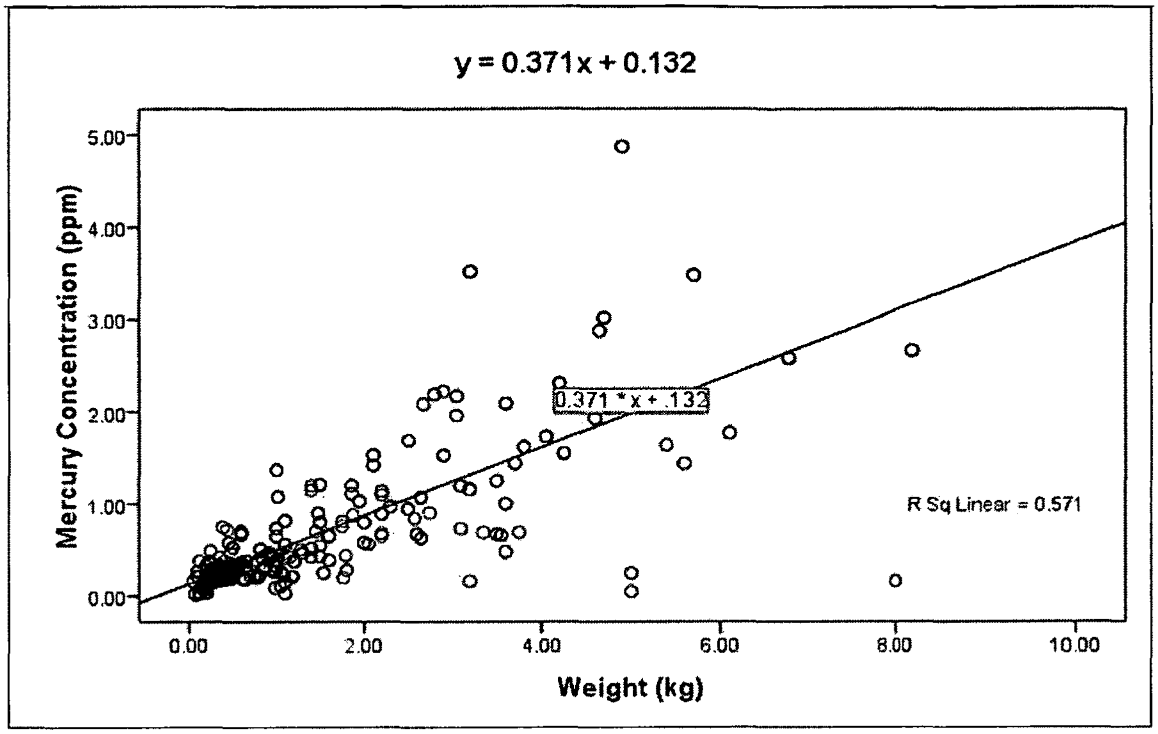

Figure 10.2 Sample calculation for adjusted Hg concentration (ppm) of fish for the Risk Assessment Tool

Calculation for a bull trout with an actual concentration of 0.07 ppm and a weight of 0.18 kg

Adjusted PPM = (actual ppm) x (mean species ppm/calculated ppm according to regression)

= (0.07) x (0.7021/((0.371 x 0.18) + 0.132)

= (0.07) x (0.7021/0.19878)

= (0.07) x (3.53204)

= 0.24724