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Methylmercury bioaccumulation in sport fish and the relation to human exposure

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Methylmercury Bioaccumulation in Sport Fish and the Relation to Human Exposure

by

Wai Ching (Amy) Au-Yeung
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Abstract

Wai Ching (Amy) Au-Yeung, 2002. *Methylmercury Bioaccumulation in Sport Fish and the Relation to Human Exposure.* A thesis presented to Ryerson University in partial fulfillment of the requirements for the degree of Master of Applied Science in the Program of Environmental Applied Science and Management

A long-lasting contaminant, methylmercury (MeHg), builds up in human bodies over a lifetime. Regularly eating contaminated fish may accumulate mercury to an amount that raises health concerns, especially for children and babies. Methylmercury is found throughout the parts of the fish that are eaten; cleaning or cooking methods cannot effectively reduce mercury exposure. The main focus of this thesis concerns the fish contamination in Lake Ontario and to conserve health from eating contaminated sport fish. Although mercury (Hg) is tightly regulated, mercury levels in fish still gradually increase throughout their life spans. Through the field data provided by the Ontario Ministry of Environment (MOE), greater amounts of methylmercury are found in older fish and predatory fish that eat other fish as part of their diet. A bioenergetics computer program, called Generic Bioaccumulation Model (BGM) (Luk, 1996), simulating the bioaccumulation of Hg in fish was applied to provide a good estimation of mercury levels for different species. It is an excellent tool in predicting the trends and magnitude of mercury levels among six sport fish in Lake Ontario. In addition, an estimation of human mercury consumption from fish was also developed. In most of the fish species, there is minimal risk to humans when eating fish less than two times a week. The species Walleye (*Stizostedion vitreum*) and its quality and quantity are of greatest concern, since it exhibits the highest mercury level among the six sport fish species.

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Lists of Symbols

Symbol	Unit	Description
τ	-	body weight exponent for metabolism
α_{lr}	kcal/(wk g^{τ})	low-routine coefficient
β	-	proportion of growth rate that represents the energy for food conversion
a	-	length - weight parameters
b	-	length - weight ratio
C_{pf}	ppm	concentration of pollutant per wet weight in food
C_{pw}	ppb	concentration of pollutants in water
C_{ox}	ppm	concentration of dissolved oxygen in water
$(dP/dt)_{cl}$	ppm	rate of clearance of pollutant
$(dP/dt)_{f}$	ppm	rate of pollutant uptake through the food pathway
$(dP/dt)_{w}$	ppm	rate of pollutant uptake through the water pathway
dW/dt	-	growth rate of fish
E_{fd}	-	efficiency of assimilation of food
E_{ox}	-	absorption efficiency of oxygen
E_{pf}	-	efficiency of pollutant uptake from food
E_{pw}	-	efficiency of transfer of pollutants from water
k	wk^{-1}	growth coefficient
k_{cl}	wk^{-1}	the clearance coefficient
L	cm	fish's length
P	ppm	pollutant burden
Q	kcal	total amount of energy
Q_a	kcal	energy cost for spontaneous activities
Q_c	kcal	energy cost for utilization of food
Q_f	kcal	energy cost for foraging
Q_{lr}	kcal	energy for low-routine metabolism
Q_s	kcal	energy component for standard metabolism
q_f	kcal/(g wk)	energy equivalent (energy content) of the flesh of fish
q_{fd}	kcal/g	energy equivalence of the prey (food)
q_{ox}	kcal/(g O_2)	energy equivalence of oxygen
t	wk	age of fish
W	g	fish's weight
W_{∞}	g	fish's asymptotic weight

Chapter 1 Introduction

Fish are a significant food resource and serve as a major component in the human diet. Their quality and quantities are significant to human lives. Over the last century, the problem of water contamination has been seriously increasing. A major concern is the presence of toxic chemicals, such as heavy metals, mercury, organic pesticides and PCBs in the Great Lakes system.

Recent reports of high mercury concentrations in fish, particularly in flooded reservoirs and lakes, have renewed concerns about mercury in the environment (Beyer *et al.*, 1996). Thousands of tonnes of mercury (Hg) are released annually from industries, as well as from natural geological processes into the Great Lakes. When mercury is discharged into the water, bacteria convert it to methylmercury (MeHg), an organic form of mercury that is more readily accumulated by aquatic organisms. MeHg is efficiently transferred up the food chain to a higher trophic level until it reaches humans. Mercury contamination of fish is a serious problem in a large number of remote lakes in Canada, United States and Europe (Westcott and Kalff, 1996). In spite of the government's actions in the early 1970s reducing mercury use and direct discharges, significant amounts of Hg are still present in sediments and become available when disturbed through earthquakes, floods, etc.

1.1 Scope of Study

In this thesis, the causes, pathways, accumulation, and effects of methylmercury in fish and humans are investigated. Based on the literature review, it is believed that the size, food web, and gender of fish would affect the level of MeHg accumulated in fish bodies. This thesis is an attempt to study the effect of different factors on the accumulation of mercury in seven different fish species in Lake Ontario. Results from the study will be applied to modify a mathematical model on Hg bioaccumulation developed by Luk in 1996. This could be combined with the diet preference and eating habits of humans to produce predictions on the risk of accumulation in the human population.

1.2 Objectives

The objective of the thesis is to improve the quantitative understanding of the effect of the methylmercury bioaccumulation in fish and its relation to human exposure. The intent is to study the effect of MeHg bioaccumulation in male and female sport fish and refine a generic bioaccumulation model to study the whole-body burden of Hg in multiple species of Lake Ontario fish. After the results of the studies are available, a mathematical model will be developed to estimate the amount of human exposure that resulted from a given level of fish consumption.

1.3 Expected Results

The different forms of mercury concentrations, especially MeHg, are in fact due to differences in background inorganic Hg concentrations. Methylmercury is proved to be bioaccumulated in fish. This study should demonstrate a positive correlation between the fish size and the concentration of MeHg in fish muscle should be confirmed. According to the bioaccumulation theory, the top predatory fish should contain a higher level of mercury. For example, the Walleye consumes more mercury than the Chinook Salmon.

Suppose the half-life of methylmercury is long and there is no way to decrease the level of MeHg in fish; the literature indicates that the eggs produced by the female are a potential excretion route of mercury. As a result, there should be no differentiation in the accumulation level between the genders when the fish are still small. After the fish have reached maturity, male fish tends to have higher MeHg levels in their bodies than the female fish. Moreover, the modified bioenergetics computer model is able to predict and examine the trends of mercury level in multi-fish species in Lake Ontario. In addition, it might be possible to predict the transfer of methylmercury in the food web, from the fish themselves to humans through consumption.

The preservation of the environment is on the global agenda, and enhancing the water and biota quality in the Great Lakes is a local priority. This thesis mainly addresses a significant environmental and public health concern in Canada. The results will contribute to the knowledge and the risk of methylmercury toxicity to fish and humans. Valuable insights for developing strategies to control the pollution problem and to establish fish consumption guidelines will be gained.

Chapter 2 Literature Review

In this chapter, literature is reviewed to learn about mercury, the transport and fate of methylmercury in fish and humans. First of all, the physical and chemical properties of mercury and methylmercury are studied. Then, the sources, transportation and effects of methylmercury on the health of humans and wildlife are investigated. The serious problem of bioaccumulation and the element that affected the bioconcentration are discussed. Finally, the restrictions and guidelines of methylmercury in North America's aquatic systems are reviewed.

2.1 Physical and Chemical Properties of Mercury

Mercury (Hg), along with cadmium and zinc, falls into Group IIb of the Periodic Table. It has an atomic weight of 200.6, an atomic number of 80, melting point of –38.9°C and boiling point of 356.9°C (Waldron, 1980). It is a dense silver-white metal which is liquid at room temperatures and standard pressures (WHO, 1989). Thus, it is the only metal characterized by low electrical resistance, high surface tension and high thermal conductivity with no hardness, crystal structure, cleavage or streak at room temperature (Wren *et al.*, 1991). Mercury is among the most common of the metal pollutants present in the environment (Maier *et al.*, 2000). Its vapour pressure is sufficiently high (18 mg/m^3) to yield a hazardous concentration of vapour at room temperatures.

Several chemical forms of mercury exist: elemental mercury, inorganic mercury, and organic mercury. Elemental mercury (Hg^0) is very toxic, highly volatile and only a very low concentration has been detected in the surface of water (Carroll *et al.*, 2000). Mercury forms inorganic mercury in two ionic states: mercury (I) (Hg^+) and mercury II

(Hg^{2+}). The most common form of mercury released to the environment is the divalent form, Hg^{2+} (Maier *et al.*, 2000). Organic mercury, such as phenylmercury, methylmercury, ethylmercury and methoxyethylmercury, is of great concern because of its adverse effects on health. Methylmercury is clinically the most important chemical form, since it is one of the most hazardous environmental pollutants (WHO, 1989).

2.2 Sources and Production

Mercury and its compounds are widely distributed in the environment as a result of both natural and human activities. Mercury occurs naturally in the environment as mercuric sulfide from the degassing of the earth's crust through volcanic gases, the weathering of rock in mountains, and probably by evaporation from the oceans (Erwin and Munn, 1997, Zelikoff and Thomas, 1998). The World Health Organization (WHO) (1989) reported that between 25,000 and 125,000 tonnes of Hg are released to earth annually from natural processes.

Desirable properties such as the ability to alloy with most metals, liquidity at room temperature, electrical conductivity, ease of vaporizing and freezing, make mercury an important industrial metal. Organic mercury compounds including methylmercury have been commercially produced since 1930 (Watanabe and Satoh, 1996). A large proportion of the mercury existing in the environment is derived from industrially produced mercury. Almost 75% of the world production of mercury is related to human activities (Minnesota Department of Health, 2001a). For example, gold-mining operations use the mercury-amalgamation process, which releases a large amount of mercury into the environment. Gold-mining activities have caused substantial mercury pollution in the Madeira River in the Amazon River basin of South America (Beyer *et al.*, 1996). The world production of mercury by mining and smelting was estimated at 10,000 tonnes per year in 1973 and increased at an annual rate of about 2 % (WHO, 1989).

Mercury has over 3,000 industrial uses (Michigan State University, 2000) in many fields like industry, agriculture, the military, medicine, and dentistry (WHO, 1989). Some common uses of mercury in industrial products are, for example, electrical equipment, chloralkali, paint, thermometers, and fungicides and as preservatives in pharmaceuticals and cosmetics (Maier *et al.*, 2000). The amount of mercury released from the industrial products was calculated as approximately 10,000 tonnes per year (Mitra, 1986).

There are also many indirect anthropogenic sources: the burning of fossil fuel, municipal solid waste, the production of steel and cement, and the smelting of metals from sulfide ores. The U.S. Environmental Protection Agency (U.S. EPA) estimated that these releases increased at a level two to five times greater than those of pre-industrial times (Mahaffey, 1999). In 1973 alone, the U.S. consumption of mercury was 1,900 tonnes (Michigan State University, 2000). By 1976, about 20,000 tonnes of Hg had been emitted from burning of fossil fuels globally (WHO, 1976).

2.3 Bioaccumulation in Fish

Inorganic mercury is the general element released into air from most industries. However, it is easily converted to methylmercury by microorganisms in the sediments, which is a more toxic form of mercury to fish and eventually bioaccumulated. In order to understand the serious problem of this contaminant, it is necessary to realize the formation, fate, transportation, bioaccumulation and adverse health effects of methylmercury.

2.3.1 The Fate and Transport of Methylmercury

Through natural resources and industrial production, elemental mercury vapour is released into the air and changes into inorganic mercury by photochemical oxidation (D'itri and D'itri, 1977, Mahaffey, 1999). Ultimately, it will redeposit on the earth or be discharged into water bodies with precipitation as a global mercury cycle. The annual amount of direct depositional loading due to precipitation is approximately 30,000 tonnes which, based on the annual total global rainfall, is equal to 5.2×10^5 km^3 (WHO, 1976). Mercury production has increased the rate of Hg deposition in lakes by about 1.7 percent per year over the past 140 years (Minnesota Department of Health, 2001a).

When mercury is discharged into water bodies, it is first oxidized to the divalent mercuric ion (Hg^{2+}). In the presence of a special group of methylating microorganisms, the mercuric ion is then transformed into a highly toxic, poisonous methylmercury (CH_3Hg^+) and dimethylmercury $(CH_3)_2Hg$ (Boening, 2000) in both aerobic and anaerobic environments (Alexander, 1999). A scheme diagram of the mercury cycle in the environment is illustrated in Figure 2.1. The primary generator of methylmercury in the environment is the sulfate reducing bacteria, although a variety of microorganisms are capable of methylating mercury. The most important intracellular agent of mercury methylation is methylcobalamine (CH_3CoB_{12}), a derivative of vitamin B_{12}. Methylation reactions can be summarized by the following equations (Maier *et al.*, 2000):

$$CH_3CoB_{12}+Hg^{2+}+H_2O \rightarrow CH_3Hg^{+}+CH_3CoB_{12}^{+} \qquad \text{Eq. [2.1]}$$

Methylcobalamine methylmercury

$$CH_3CoB_{12}+ CH_3Hg^{+}+H_2O \rightarrow (CH_3)_2Hg+CH_3CoB_{12}^{+} \qquad \text{Eq. [2.2]}$$

Methylcobalamine dimethylmercury

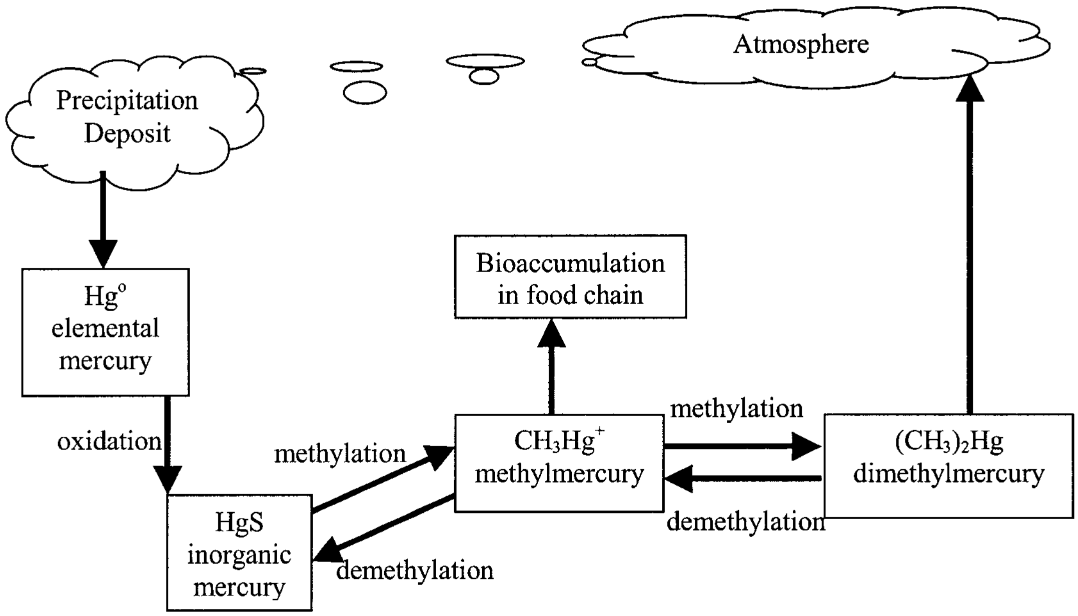


Figure 2.1 Mercury cycle

Today, many researchers report that the nutrient enrichment problem in the waterway, and consequently formation of more microbes, increases the methylation of MeHg, especially near the surface layers of sediments. WHO (1976) had also reported that there are more than 10^{10} tonnes of sediments carried to water each year; the organic rich sediment becomes a natural sink for Hg^{2+} and the formation of methylmercury is enormous in the water. The environmental significance of mercury methylation is the fate of methylmercury.

The source of methylmercury in fish has been linked extensively to the food chain. Fish fed zooplankton with a high concentration of MeHg have a significantly higher concentration of mercury in muscle than fish fed with low MeHg concentration zooplankton (Hall *et al.*, 1997). Moreover, a great increase in MeHg concentration occurs in the upper trophic level through the food chain; this is known as bioaccumulation or bioconcentration (Hemond & Fechner-Levy, 1999). Longer food chains generally result in greater bioaccumulation (Rasmussen *et al.*, 1990). Bottom fauna and plankton absorb methylmercury from the sediments and water; they are eaten by small fish that are in turn eaten by large carnivorous fish (Waldron, 1980). Finally, humans consume the predatory fish, accounting in part for the high MeHg level in humans. For example, predatory fish at the top of the aquatic food chain, such as Walleye or Northern Pike, are more contaminated than small fish such as Bluegills or Crappies of the same size. Besides, the bioaccumulation effect is generally compounded throughout the lives of the fish, and larger fish and those with longer life span will likely have greater MeHg levels.

2.3.2 Bioaccumulation of Methylmercury

Many researchers have suspected that most or nearly all of the accumulated mercury in fish is in the form of MeHg (Latif *et al.*, 2001), a highly toxic form. In 1985, Mathers and Johansen reported up to 89% of mercury in fish is MeHg, but varying percentages had been discovered by different researchers. These reports are summarized in Table 2.1. In general, it is believed that approximately 90% of total Hg in fish tissue is methylmercury.

Table 2.1. Percentages of MeHg to total Hg in fish tissues

Minimum Percentages (%)	**References**
89	Mathers and Johansen, 1985
90	Harris and Snodgrass, 1993
90	Goldstein *et al.*, 1996
95	Headon *et al.*, 1996
90	Hall *et al.*, 1997
85	Joiris *et al.*, 1999
84	Redmayne *et al.*, 2000

Methylmercury is absorbed efficiently, nearly 100%, by all living organisms (Maier *et al.*, 2000). Like many environmental contaminants, methylmercury undergoes bioaccumulation. Bioaccumulation is the process by which organisms (including humans) can take up contaminants more rapidly than their bodies can eliminate them. Thus, the amount of MeHg in their bodies accumulates over time. For a more active organism, it tends to ingest and therefore the concentration of MeHg accumulation is high. If an organism does not ingest methylmercury for a period of time, its body burden of MeHg will decline. In contrast, body burden in an organism can reach a toxic level when the organism continually ingests the chemical. In Terhaar *et al.*'s study (1977), methylmercury was accumulated by various sources at both lower and upper trophic levels. Methylmercury bioaccumulation in fish depends on many factors, the most important of which are species, size, habitat, growing rates, physiological difference and feeding preference (Al-Majed and Preston, 2000a). One kind of fish may have a much lower MeHg than another species of the same size.

According to the literature, many physical and chemical characteristics in the water affect the bioaccumulation of mercury in fish. They include dissolved organic carbon (DOC), water's pH and temperature (Watras and Huckabee, 1994, Westcott and Kalff, 1996, Boening, 2000), and selenium inputs (Biddinger and Gloss, 1984, Southworth *et al.*, 2000). A summary of effects is listed in Table 2.2. Either increases in the DOC level or temperature or decreases in the pH or selenium level in water would enlarge the mercury bioaccumulation in fish. Human activities have changed the natural biogeochemical cycle of mercury in many ecosystems. High mercury concentration in fish, particularly in newly flooded reservoirs, and in low-alkalinity lakes, has renewed concerns about mercury in the environment (Beyer *et al.*, 1996).

Table 2.2 Effects of Hg and MeHg bioaccumulation due to environmental factors

Environmental Factors	**Effects of Hg or MeHg**	**Reference**
a) Physical Conditions		
Oxygen	Oxygen increases, Hg increases	WHO, 1976
Temperature	Temperature increases, Hg increases	Biddinger and Gloss, 1984 Watras and Huckabee, 1994 Carroll *et al.*, 2000
Water colour	Water colour increases, MeHg increases	Westcott and Kalff, 1996
b) Chemical Conditions		
pH	pH decreases, Hg and MeHg increase	Watras and Huckabee, 1994 Westcott and Kalff, 1996 Hall *et al.*, 1997 Carroll *et al.*, 2000 Boening, 2000
Alkalinity	Low alkalinity, Hg increases	Beyer *et al.*, 1996 Boening, 2000
Ca^{2+}	Ca decreases, MeHg increases	Hall *et al.*, 1997
Cl^{-}	Cl decreases, MeHg increases	Hall *et al.*, 1997
DOC	DOC increases, Hg and MeHg increase	Watras and Huckabee, 1994 Westcott and Kalff, 1996 Hall *et al.*, 1997 French *et al.*, 1999 Boening, 2000
c) Effect of Selenium		
Selenium	Selenium decreases, Hg increases	WHO, 1976 Biddinger and Gloss, 1984 Beyer *et al.*, 1996 Southworth *et al.*, 2000

Apart from methylmercury absorption through the food web, large quantities of water with a high level of methylmercury pass over the fish's gills during respiration. It is first transported to the fish's gut and gills, then binds to red blood cells, and is rapidly transported to the fatty tissues and all organs, including the brain (Beyer *et al.*, 1996, Hemond & Fechner-Levy, 1999). The concentration of MeHg in exposed fish is typically high in the blood, brain, kidneys and liver (Thompson, 2000). Gonads and muscles have the lowest concentrations of MeHg (McKim *et al.*, 1976). When it is absorbed by fat, it is at least 1,000 times more soluble than it is in water (D'itri and D'itri, 1977).

Previous studies have shown that methylmercury is very persistent and takes a long period of time for degradation (Alexander, 1999). Once inside the body of a fish, it is tightly bound to the proteins in all fish tissues, including muscles, and it is slowly metabolized or eliminated from fish. The clearance aspect of methylmercury is a slow process; the half-life of MeHg in fish ranges from 1 to 11 years (McKim *et al.*, 1976, Borgmann and Whittle, 1992, Harris and Snodgrass, 1993). Thus, methylmercury accumulation in fish tissues is hundreds or thousands of times higher than the concentration of MeHg in the surrounding water. For instance, water contaminated with two parts per trillion (pptr) mercury could produce a level of 450 parts per billion (ppb) methylmercury in a Northern Pike (Minnesota Department of Health, 2001b), representing a 225,000-fold bioaccumulation of mercury. Generally, methylmercury concentration in tissues of a fish species within a given water body increases with older age and bigger size (Beyer *et al.*, 1996, Hill *et al.*, 1996).

An estimation of daily mercury intake by an adult Canadian is approximately 7.7 ug (0.11 ug/kgbw/day) (Health Canada, 1998). Of this, 70 % of the mercury will be absorbed by the body and converted to methylmercury. Mahaffey (1999) suggested that the aquatic food web provides more than 95% of humans MeHg intake. Fish are the predominant source of methylmercury for most people. The U.S. EPA estimates that approximately 85% of people consume fish over the course of a month, while 60% consume fish four or more times a month, or, on average, at least once a week.

On consumption of contaminated fish, the small concentration of mercury present in the fish is transferred to the consumer and gradually accumulates to a toxic level. MeHg is retained by the human body. Fish constitute about 27 % of the MeHg intake in humans (Mahaffey, 1999). Interestingly, methylmercury has a shorter half-life in humans than in fish, generally considered in the range of between 50 to 70 days. Relative to intake, MeHg elimination is still slow. As a matter of fact, there is no method of cooking or cleaning fish capable of removing the amount of Hg in seafood, leaving humans with a potentially high health risk even when they consume less-contaminated fish.

2.3.3 Effects on Food Chain

Mercury is toxic to aquatic organisms. Organic forms of mercury such as methyl- or butylmercury are more toxic to aquatic plants than inorganic forms. Methylmercury is recognized as one of the most hazardous environmental pollutants (Watanabe and Satoh, 1996). Developmental effects, tremors, deformities, birth defects, reproductive failure, and mortality will happen in fish with a high level of MeHg (Henry and Heinke, 1996).

Different levels of toxicity could be found in different fish at the same methylmercury concentration. For example, a fish whose brain has absorbed 7 to 15 parts per million (ppm) MeHg is probably suffering significant, potentially lethal effects. In Rainbow Trout, a whole-body concentration of about 10 ppm is associated with sublethal or lethal toxic effects. A concentration 3 ppm MeHg in a Walleye's brain is probably indicative of significant toxic effects, including death (Beyer *et al.*, 1996). Walleye seem to be more sensitive to methylmercury. On the other hand, 5 ppm MeHg in a Brook

Trout's brain could be regarded as no-observed-effect concentration. Since freshwater fisheries in North America have steadily increased during the past decade (Watras and Huckabee, 1994), mercury-contaminated sport fish would adversely affect a local economy that depended on recreational fishing (Erwin and Munn, 1997). More importantly, mercury-contaminated sport fish could harm humans and wildlife such as loons, eagles, otters, and raccoons that eat MeHg-contaminated fish (Maier *et al.*, 2000).

Humans have mercury in their bodies, but at a level that is typically not high enough to cause any health effects (Erwin and Munn, 1997). All forms of mercury are toxic to humans, but methylmercury is especially of concern because the human body has a less well-developed defense mechanism against this toxin (Maier *et al.*, 2000). In humans, methylmercury accumulates in liver, kidneys, brain or blood may cause acute or chronic health effects. Moreover, MeHg also affects the central nervous system, and in severe cases irreversibly damages areas of the brain (Thompson, 2000). Adverse effects such as impairment of vision and speech, loss of motor coordination, neuropathy and death, and psychological symptoms such as memory loss, weakness and fatigue, anxiety and flight of ideas have been reported (Huggins, 1988). Embryos and fetuses, whose nervous systems are more sensitive to MeHg than mature nervous systems, have been considered much more susceptible to methylmercury.

Currently, hair has proven to be a useful indicator medium for detecting the exposed level of MeHg in humans and estimating the transferred level to the next generation (Watras and Huckabee, 1994). The average ratio of hair-to-blood level is 250 to 1 in humans. The typical blood level of MeHg in humans is less than 1 ppm. If a pregnant woman's exposure results in approximately 5 ppm MeHg concentration in hair, adverse subtle developmental effects could be identified in the baby. If maternal hair contains a range of 10 to 20 ppm MeHg, clinically obvious changes such as delayed walking could be found in the child (Mahaffey, 1999).

Even though not many cases of humans immune diseases induced by mercury have been seen, these effects have been proved established in the immune system of rabbits, mice, and rats. In vitro evidence and occasional in vivo findings indicate that the humans immune system is also susceptible to mercury (Zelikoff and Thomas, 1998). Thus, recent epidemiologic studies in several fish-eating populations have focused on the effects of MeHg exposure. The overall neurotoxicity of MeHg in humans, nonhumans primates, and rodents appears to have similarities (Watanabe and Satoh, 1996).

2.4 Restriction Levels

The U.S. EPA has made efforts to regulate the continuing release of Hg into the environment. The U.S. EPA regulates industrial discharges to air and water, as well as regulating some aspects of mercury waste disposal. In 1976, the U.S. EPA banned most pesticide uses of mercury. In 1990, mercury used as a fungicide in interior latex paint was halted (Thompson, 2000). This action stemmed from requests by Michigan officials after a child was poisoned from over formulated mercury-containing paint used in his home.

More recently, the use of Hg compounds in exterior latex paint has also been banned. Although direct discharges of mercury from major industrial sources have been virtually eliminated, mercury from more diffuse atmospheric origins has been rising (Friedmann *et al.*, 1996). Since several bodies of water are used for commercial and sports fishing, the accumulated methylmercury in fish has received considerable attention. In the United States and Canada, numerous governmental agencies have closed fisheries or issued advisory information to the public because of elevated mercury residues in fish (Biddinger and Gloss, 1984). The U.S. Geological Survey (1997) reported 33 states in the United States have issued fish consumption advisories because of Hg contamination.

The U.S. Food and Drug Administration (FDA) has developed an action level that has enabled the agency to regulate the sale of fish and other seafood in interstate commerce based on mercury concentration. Since 1979, it has had an action level for Hg of 1 ppm in commercially sold fish based on consideration of the tolerable daily intake (TDI) for MeHg as well as information on seafood consumption (Mahaffey, 1999). The Michigan Department of Public Health issues fish consumption advisories to anglers when the Hg level exceeds 0.5 ppm in fish tissue (Michigan State University, 2000).

However, the FDA's standard applies only to fish sold on the market - primarily marine species - and not to the freshwater fish that people catch from local waters for their own consumption. The health effects of fish caught in lakes and rivers heavily polluted by mercury fall under the auspices of the U.S. EPA. In Canada, the Ministry of the Environment (MOE) (2001) in co-operation with the Ministry of Natural Resources publishes an annual Guide to Eating Ontario Sport Fish. It provides consumption advice on sport fish from Ontario waters. The consumption of sport fish containing mercury that begins at a level above 0.45 ppm is restricted, and total restriction is advised for levels above 1.57 ppm.

In human bodies, the acceptable level of mercury would be 0.02 ppm in whole blood, 0.04 ppm in red blood and 6 ppm in hair. Based on the above information, 0.47 ugHg/kgbw/day (kilogram of body weight per day) is recommended for the maximum provisional tolerable daily intake (pTDI) for the general population. This represents a 38 g of fish intake for a man with typical 80 kg weight. A lower tolerable daily intake is suggested as 0.20 ugHg/kgbw/day for women of childbearing age (Health Canada, 1998).

2.5 Mercury Contamination in Environment

This section is a historical review of mercury levels in sediment, fish and humans. During the past decade, attention to mercury pollution has escalated. Northern-tier states of the U.S., Canada, and Nordic countries have found that fish, mainly from nutrient-poor lakes and often in very remote areas, commonly have high levels of Hg (U.S. Geological Survey, 1997). In data primarily from fish and shellfish surveys from other regions of the U.S., fish sampling has shown widespread mercury contamination in streams, wetlands, reservoirs, and lakes.

2.5.1 Effects on Sediments

Aquatic organisms that live in uncontaminated sediment usually have less than 0.1 ppm MeHg (Allard and Stokes, 1989). If mercury in the sediment is high, the methylation of inorganic mercury in the sediment of lakes, rivers, and other waterways would transport methylmercury to the water. Contaminants in sediment could be transferred to the water column via a variety of processes, including diffusion and advection from sediments, sediment re-suspension and release, and biotransfer through organisms that feed at the sediment-water interface (Mason and Lawrence, 1999). It does not only affect the microorganism but is also a key step in the aquatic food chain leading to eventual human consumption.

Studies of sediment cores from Minnesota and Wisconsin lake beds show mercury concentrations in lake sediments have increased significantly since 1850 (Minnesota Department of Health, 2001a). For example, younger sediment, deposited since industrialization, has a mercury concentration that is about 3-5 times that of historical sediments (U.S. Geological Survey, 1997). Even though current sediment has a lower level of mercury due to industrial restrictions, mercury released in the past decade is still present in bottom sediments of lakes and rivers, and will continue to be a source of pollution for the foreseeable future (Henry and Heinke, 1996).

2.5.2 Effects on Fish

Fish carrying methylmercury are found dead or show symptoms of mercury poisoning. In Tennessee from 1968 to 1969, over 2,800,000 fish were killed in a reservoir with a high mercury level (Mitra, 1986). Gauthier *et al.* (1998) found substantial evidence for the occurrence of mercury-induced micronuclei, considered carcinogens, in the skin fibroblasts of Beluga Whales that inhabited the St. Lawrence estuary, which has high Hg and MeHg contaminations. The mortality was observed at concentrations of 50 ppm Hg and 5 ppm MeHg.

In the 1990s, an unacceptably high mercury level was reported in fish inhabiting water in the United States and Canada (Parks *et al.*, 1994). Mercury in such fish exceeded the federal guidelines (0.5 ppm) for consumption (Allard and Stokes, 1989), and this led to a decline in commercial fisheries. For example, in the Carson River, one of the most highly Hg-contaminated systems in the United States, water column total mercury concentration had been observed as high as 61 ppb, while some fish had a MeHg concentration four times greater than the human health consumption limit (1 ppm) (Carroll *et al.*, 2000). According to Al-Majed and Preston's experiment (2000), mercury concentrations in fish differed between species and ranged from 0.07 to 3.92 ppm in

Great Britain. A comprehensive report on mercury levels in fish from many North American researchers is summarized in Table 2.3.

Mercury concentrations show significant positive correlation with a fish's length and age. It has a curvilinear relationship with mercury, increasing in larger increments as the fish grow. There is at least a ten-fold Hg increase in fish from the age of 2 to 8 years old (Watras and Huckabee, 1994). In the theory of the food chain, predatory fish would tend to have a higher level of MeHg. Most species of fish have mercury levels of about 150 ppb, but large carnivorous species (e.g. Swordfish and Tuna) usually fall in the range of 200 to 1500 ppb (WHO, 1976). For instance, crayfish constitute more than 60% of the Smallmouth Bass's diet composition. In Allard and Stokes' (1989) study, Smallmouth Bass Hg was positively correlated with crayfish Hg. Wren *et al.* (1991) examined the relationship between MeHg levels in Walleye and Northern Pike in Ontario lakes. The mean concentrations in Walleye and Northern Pike of standardized length were 0.65 and 0.52 ppm, respectively. Walleye has a greater level of MeHg because its diet contains a higher proportion of smelt (Mathers and Johansen, 1985, Friedmann *et al.*, 1996).

Table 2.3 Fish's mercury level in North America

Year	Location	Fish Species	Mercury Level (ppm)	Reference
1987	Clay Lake, Ontario	Walleye	1.38 - 4.33 ww	Parks *et al.*, 1994
1987	Clay Lake, Ontario	Northern Pike	1.30 -3.13 ww	Parks *et al.*, 1994
1987	Ball Lake, Ontario	Walleye	0.73 - 2.27 ww	Parks *et al.*, 1994
1986	Ball Lake, Ontario	Northern Pike	0.30 - 3.13 ww	Parks *et al.*, 1994
1978-1988	Lake Ontario	Lake Trout (age 4)	0.12 - 0.24 ww	Borgmann and Whittle, 1992
1982	Lake Simcoe, Ontario	Walleye	0.10 - 2.70 ww	Mathers and Johansen, 1985
1982	Lake Simcoe, Ontario	Pike	0.05 - 0.85 ww	Mathers and Johansen, 1985
1984	Lake Champlain	Yellow Perch	0.03 - 0.22 ww	Friedmann *et al.*, 1996
1987	Lake Champlain	Yellow Perch	0.13 - 0.35 ww	Friedmann *et al.*, 1996
1991	Lake Ontario	Yellow Perch	0.08 - 0.70 ww	Friedmann *et al.*, 1996
1991	Lake Ontario	Walleye	0.65 ww	Wren *et al.*, 1991
1991	Lake Ontario	Northern Pike	0.52 ww	Wren *et al.*, 1991
1996	Kuwait Bay	varies	0.07 - 3.92 dw	Al-Majed and Preston, 2000
1994	Tunisia	Sardines	0.26 - 0.42 dw	Joiris *et al.*, 1999
1983	Lakes in Algonquin	Smallmouth Bass	0.26 - 1.56 ww	Allard and Stokes, 1989
1986	Lake Ontario	Lake Trout	0.03 - 0.21 ww	Borgmann and Whittle, 1992
1990-	Rogers Quarry, Tennessee	Largemouth Bass	0.02 ww	Southworth *et al.*, 2000
1997	Lake Roosevelt, Washington	Walleye	0.11 - 0.44 ww	Erwin and Munn, 1997
1998	Rogers Quarry, Tennessee	Largemouth Bass	0.73 ww	Southworth *et al.*, 2000

dw = concentration per unit dry weight
ww = concentration per unit wet weight

2.5.3 Effects on Humans

In humans, the health hazard of methylmercury and other organic mercury derivatives had been well recognized by the 1950s (Watanabe and Satoh, 1996). Minamata disease in Japan was first officially reported on May 1, 1956. The widespread poisoning of Japanese fishermen and their families occurred in Minamata as a result of consumption of methylmercury-contaminated fish (Michigan State University, 2000). The mercury contamination originated from an acetaldehyde factory that had dumped relatively nontoxic elemental mercury into Minamata Bay (Beyer *et al.*, 1996).

Although the methylmercury concentration in the water was not high, it was concentrated as it ascended the food chain and thus was in the fish and shellfish, which was the staple diet of the villagers. The concentration of methylmercury in the fish was high enough to cause methylmercury poisoning (Watanabe and Satoh, 1996). Residents of nearby fishing villages were poisoned over many years by unwittingly eating highly contaminated fish from the bay before the source was discovered. Methylmercury poisoning, which can have several effects such as sensory impairment, ataxia, visual symptoms (e.g. peripheral visual loss) and hearing impairment, was discovered (Zelikoff and Thomas, 1998); moreover, 121 cases of Minamata disease were reported with 46 deaths resulting.

Fetal Minamata disease was first detected in 1958, in 188 births in Japan during 1955 to 1958. The mercury concentrations in mothers' plasma and their newborn infants were similar but the concentrations in the fetal red bloods cells were approximately 30% higher than in those of the mothers. Observations on the Minamata outbreak in Japan indicated that infants are more sensitive to MeHg than adults (WHO, 1976). Mothers who themselves have only mild symptoms give birth to infants who have severe methylmercury poisoning, resulting in a condition resembling cerebral palsy but also accompanied by blindness and deafness (Mahaffey, 1999). It was reported that 22 infants were poisoned prenatally, 25 infants were born with brain damage and 6% of children developed cerebral palsy (Huggins, 1988).

As a result of what happened in Japan, local governments in North America have advised birth control to women of childbearing age who live in a polluted area and have hair mercury concentrations of 50 ppm or higher (Watanabe and Satoh, 1996). A child born to a mother with a hair mercury level higher than 6 ppm has a higher prevalence of abnormal results.

Another case studied was methylmercury poisoning in Iraq. The epidemic in Iraq was caused by exposure to MeHg when people ate homemade bread prepared from wheat seed which had been treated with a methylmercurial fungicide. Poisoning cases were hospitalized from early January 1972, resulting in hundreds of deaths (Huggins, 1988).

2.5.4 Effects on Reproduction

Researchers found higher concentrations of mercury in reproducing female sunfish than in male of the same species and age, apparently because female sunfish eat more to meet the energy and nutritional needs of reproduction (Beyer *et al.*, 1996). In wild fish, a small quantity of mercury is transferred from the female to eggs during oogenesis. Latif *et al.* (2001) studied the level of methylmercury in female fish and their eggs. They found that MeHg concentration in the female's muscle was positively correlated to that in the eggs. The percentage of MeHg in the gonads for sardines varied strongly, and was relatively high compared to liver, so that the process of laying eggs (or spawning) could be considered as releasing some methylmercury (Joiris *et al.*, 1999).

Hammerschmidt *et al.* (1999) measured the mean mercury concentrations in Yellow Perch's ovaries; they varied from 285 to 2153 ppb and 33 to 73 ppb in their eggs. A considerable amount of mercury is passed onto the embryos from their parents. Therefore, female fish should have a lower body concentration of methylmercury than male fish, especially after spawning, due to this extra clearance pathway. In some fish species, males have been found to have higher mercury levels than females of equal age (WHO, 1989).

The embryos of fish are very sensitive to mercury. Either inorganic mercury or MeHg transfer from the female to eggs during oogenesis could adversely affect fish embryos' development (Beyer *et al.*, 1996). Methylmercury has been shown to be toxic to male and female reproductive systems and is possibly capable of causing cancer or inducing genetic damage to germ cells (Mazo, 1998). In males, even low concentrations of mercury might affect fish population indirectly by impairing reproductive performance. It has also been found that (Friedmann *et al.*, 1996) dietary mercury inhibited growth in juvenile walleye and affected offspring survival. Reductions in growth could result in higher offspring mortality.

Egg fertility, hatching success and the overall reproductive success of eggs could be significantly impaired with high waterborne MeHg (Latif, *et al.*, 2001). The WHO (1989) reported Rainbow Trout eggs accumulated 42.4, 68.2, and 96.8 ppb mercury after 1, 4, and 7.5 days in an inorganic mercury concentration of 0.1 ppb water system. The level of mercury in the control eggs contained only 18.6 ppb mercury.

The increased MeHg level in water threaten the reproduction of fish, even though it is only 0.1 ppm of MeHg (Beyer *et al.*, 1996). Mckim *et al.* (1976) found that mercury concentration in eggs of Brook Trout increased concomitantly with the waterborne MeHg concentration to which the parental female had been exposed. Fertilized eggs of Rainbow Trout suffered 100% mortality after 8 days exposure to 0.1 ppb of inorganic mercury in flow-through bioassays; the survival of controls was about 85%. They also observed the Brook Trout population in three generations under different mercury concentrations in the living water. In the first generation, survival and growth were not affected at the lower concentrations of 0.03 to 0.93 ppm Hg. However, the production of eggs in the second generation declined and no more production could be found in the third generation with 0.93 ppm mercury in water. In 1987, Khan and Weis proved that 70% of killifish sperm dropped to below 10% in 0.05 ppm MeHg for 2 and 5 minutes and teratogenic effects were discovered in killifish's embryos after exposure to low concentrations of MeHg.

In mammals, the prenatal life stage is most sensitive to MeHg. All prenatal effects seem to be irreversible because they involve developing neural pathways. Methylmercury decreases sperm swimming speed and the percentage of mobile spermatozoa in a dose related pattern (Huggins, 1988). Uptake of mercury in the embryonic and fetal tissues after mercury inhalation by the mother could be observed throughout gestation and increasingly so with developmental age. The fetal central nervous system has low MeHg concentration at the early stages of pregnancy but increases at the end. Another point of significance is methylmercury concentrated in the fetuses, possibly leading to damage to newborn children, although the mother shows no symptoms of mercury poisoning (Mitra, 1986).

2.6 Observations from the Literature

This chapter reviews many observations about mercury and methylmercury. These observations are summarized and classified into four tables. Table 2.4 indicates the concentration of fish mercury of different environmental mercury levels. Tables 2.5 and 2.6 demonstrate the mercury accumulation in fish is affected by a fish's size and position in the food chain. Fish accumulate a higher levels of mercury both when they consume mercury in prey and when they become bigger and bigger in size. Furthermore, reproduction is a pathway to transfer mercury levels from one generation to the next, as shows in Table 2.7. Female fish may transfer certain levels of mercury or methylmercury to their eggs. Therefore, they tend to have lower mercury concentrations than do male fish at the same age.

Table 2.4 Observations from the literature – effect of water quality

Observations	Location	Reference
Mercury concentration in brook trout (5.2-422.8 ppm wet weight) increased concomitantly with the waterborne MeHg concentration (0.01-0.93 ppb).	Cedar Island, Wisconsin	Mckim *et al.*, 1976
Rainbow trout eggs accumulated 42.4, 68.2, and 96.8 ppb mercury after 1, 4, and 7.5 days in an inorganic mercury concentration of 0.1 ppb water system. The level of mercury in the control eggs contained only 18.6 ppb mercury.	-	WHO, 1989
Hg concentration in the inlet crayfish was more than 5 times greater than the Hg concentration in lake crayfish.	Lakes in Algonquin Region, Ontario	Allard and Stokes, 1989
Methylmercury accumulates in fish tissues is hundreds or thousands of times higher than the concentration of MeHg surrounding water.	-	Alexander, 1999
Mean MeHg concentrations in the rainbow trout (0.22-1.84 ppm wet weight), smelts, bullies and koura (0.02-0.16 ppm wet weight) and zooplankton (4.0×10^{-3}-3.6×10^{-2} ppm wet weight) increased linearly with mean MeHg concentration in water (90-510 ppb).	Taupo Volcanic Zone in New Zealand	Kim and Burggraaf, 1999
Water contaminated with 2 ppt mercury could produce level of 450 ppb (wet weight) methylmercury in a northern pike.	Lakes Minnesota and Wisconsin	Minnesota Department of Health, 2001b

Table 2.5 Observations from the literature – effect of fish size

Observations	Location	Reference
Mercury concentration shows significant positive correlation with fish's length and age. A minimum of a ten fold Hg increase in fish from 2 to 8 years old.	Newfoundland	Watras and Huckabee, 1994
Methylmercury concentration in tissues of a fish species within a given water body increases with older age and bigger size.	-	Beyer *et al.*, 1996, Hill *et al.*, 1996
Higher concentration of T-Hg for older age of mimic shiner.	Devil Lake, Wisconsin	Gorski *et al.*, 1999
MeHg concentration increased linearly with both length and age for eels.	Otago Region Rivers, New Zealand	Redmayne *et al.* 2000

Table 2.6 Observations from the literature – effect of food chain

Observations	Location	Reference
Walleye's diet contains a higher proportion of smelt than northern pike. Older fish had larger prey and higher MeHg level. In Lake Simcoe, walleye accumulated Hg in a greater maximum concentration (2.7 ppm wet weight) and at a faster rate (0.12 ppm/year) than pike (maximum concentration 0.85 ppm wet weight; rate 0.08 ppm/year).	Lake Simcoe, Ontario	Mathers and Johansen, 1985
Crayfish constitutes more than 60% of the smallmouth bass's dietary. Smallmouth bass's Hg (0.26-1.56 ppm wet weight) was positively correlated with crayfish's Hg (0.02-0.61 ppm wet weight).	Lakes in Algonquin Region, Ontario	Allard and Stokes, 1989
Mean concentrations in walleye and northern pike of standardized length were 0.65 and 0.52 ppm wet weight, respectively.	Ontario Lakes	Wren *et al.*, 1991
Fish fed the low (0.1 ppm) and high (1.0 ppm) mercury diets had mean body burdens of 0.25 ± 0.02 ppm and 2.37 ± 0.09 ppm wet weight.	North American lakes and streams	Friedmann *et al.*, 1996
Fish fed zooplankton with high MeHg (0.28-0.76 ppm dry weight) has a higher level of mercury in muscle (0.24 ppm wet weight) after 32 days than fish (MeHg = 0.12 ppm wet weight) fed with low MeHg zooplankton (0.16-0.18 ppm dry weight).	Lakes in Northwestern Ontario	Hall *et al.*, 1997
Mercury in zooplankton ranged from 4×10^{-3}-3.5×10^{-2} ppm dry weight and 0.07-3.92 ppm in various fish species.	Kuwait Bay, United Kingdom	Al-Majed and Preston, 2000

Table 2.7 Observations from the literature – effect on reproduction

Observations	**Location**	**Reference**
In the first generation, survival and growth were not affected at the lower concentrations of 0.03 to 0.93 ppm Hg. However, the production of eggs in the second generation declined and no more production could be found in the third generation with 0.93 ppm mercury in water.	Cedar Island, Wisconsin	McKim *et al.*, 1976
70% killifish sperm dropped to below 10% in 0.05 ppm MeHg for 2 and 5 minutes and teratogenic effects were discovered in killifish's embryo after exposured to low concentration of MeHg.	Long Island, New York	Khan and Weis, 1987
Male had been found to harbor higher mercury level than female of equal age.	-	WHO, 1989
Higher concentration of mercury in reproducing female sunfishes than in male of the same species and age, apparently because female eats more to meet the energy and nutritional needs of reproduction.	-	Beyer *et al.*, 1996
A considerable amount of mercury was passed on to the embryos from their parents. The mean concentrations of mercury in yellow Perch's ovaries was 285-2153 ppb wet weight, their eggs was varied from 33 ppb to 73 ppb Hg.	Wisconsin Lakes	Hammerschmidt *et al.*, 1999
MeHg in the gonads for sardines varied strongly, the process of laying eggs (or spawning) could be considered releasing some methylmercury.	-	Joiris *et al.*, 1999
A small quantity of mercury is transferred from the female to eggs during oogenesis. MeHg concentration in the walleye female's muscle (1900-3500 ppb wet weight) was positively correlated to that in the eggs (588-1714 ppb).	Clay Lakes, Ontario, Lakes Manitoba and Winnipeg	Latif *et al.*, 2001

Chapter 3 Fish Bioaccumulation Modelling

The main purpose of this chapter is to reveal the trend of bioaccumulation of methylmercury in fish. Fish field data from the Ministry of Environment's (MOE) sport fish contaminant monitoring program could be used to analyze the correlation between fish's habitat, genders and MeHg level. Thus, field data recorded from the MOE was collected, input and classified into male and female categories with Microsoft Access. Of course, the most intensive work is to analyze the data and predict the effects of MeHg accumulation in the two genders. Next, a bioenergetics-based genetic bioaccumulation model of MeHg accumulation in fish will be refined and the corresponded computer program will be modified accordingly. Eventually, a simulation program for estimating the risk associated with human exposure from fish consumption will be developed.

3.1 MOE Sport Fish Contaminant Monitoring

The Ministry of Environment (2001) is currently operating a "Sport Fish Contaminant Monitoring Program". It is the largest testing and advisory program of its kind in North America. With more than 250,000 lakes, innumerable rivers and streams and many local areas in the Great Lakes, fish have been tested from over 1,700 of Ontario's inland lakes, rivers and Great Lakes locations. Between 4,000 and 6,000 fish have been tested through the program annually for more than 25 years. The information is incorporated into the biennially updated "Guide to Eating Ontario Sport Fish" which gives consumption advice on many fish species.

In this monitoring program, different kinds of sport fish are collected by staff from the Ministries of Natural Resources and Environment, and tested at the MOE laboratory in Toronto. The length, weight and sex of each fish collected are recorded. A boneless, skinless fillet of dorsal muscle flesh is removed from the fish and analyzed for a variety of substances, including mercury, PCBs, and DDT (MOE, 2001). The results are used to develop the guidelines pertaining size-specific consumption advice for each species. This advice is based on health protection guidelines developed by Health Canada. Most of the consumption restrictions in Lake Ontario are caused by five contaminants. These five contaminants are PCBs, mercury, mirex/photomirex, toxaphene and dioxins. Figure 3.1 provides pie charts for illustrating the percentages of the consumption restrictions caused by each of the contaminants in 1999 and 2001. PCBs were reduced 5 % from 1991 to 2001. A slight increase of mirex/photomirex and toxaphene was found. Nevertheless, no changes were discovered in mercury and dioxins. There are still 25% of consumption restriction caused by mercury. It has been found in fish everywhere in Ontario and mercury concentration results in more consumption restrictions in sport fish than any other contaminants monitored by the program.

This thesis focuses on seven sport fish species that are commonly found in Lake Ontario and that people usually catch: Chinook Salmon (*Oncorhynchus tshawytscha*), Lake Trout (*Salvelinus namaycush*), Largemouth Bass (*Micropterus salmoides*), Northern Pike (*Esox lucius*), Rainbow Trout (*Oncorhynchus mykiss*), Walleye (*Stizostedion vitreum*), and Yellow Perch (*Perca flavescens*). Through the Sport Fish Contaminant Monitoring Program, field data on the weight, length, genders and the concentration of methylmercury in sport fish at different location of Lake Ontario was compiled. All the data was recorded with data management analysis software, Microsoft

Office Access 2000. Statistical analysis of all collected data was performed based on multi-variate regression analysis. To observe the effect of genders difference on a body's mercury concentration, the Hg concentration from male and female fish was analyzed for the significance of their statistical variance.

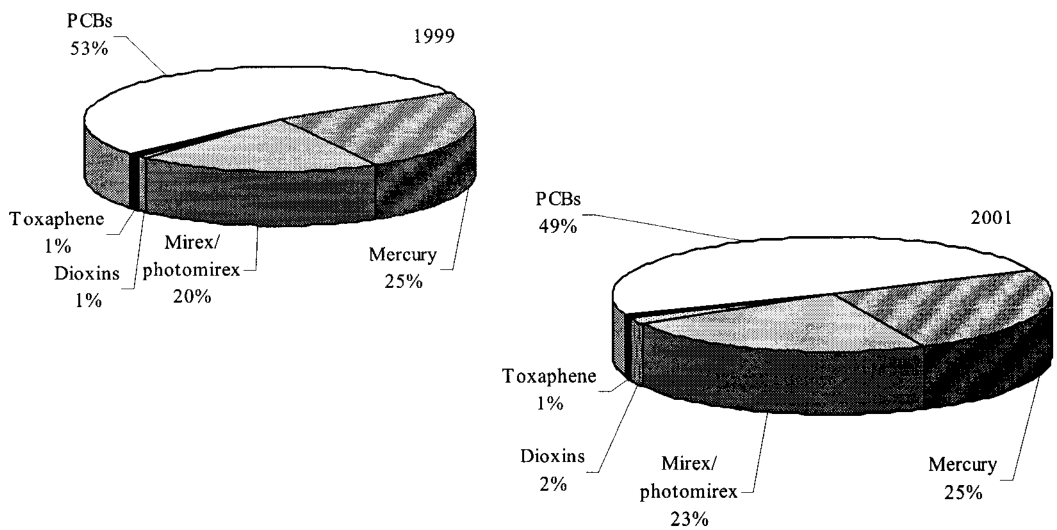


Figure 3.1 Consumption restrictions caused by contaminants in 1999 and 2001 (after MOE, 2001)

3.2 Fish Species of the Study

Based on fish temperature habitats, species can be grouped into three broad fish communities as follows: cold water, cool water and warm water. Among the seven sport fishes, Rainbow Trout, Chinook Salmon and Lake Trout belong to cold water species, Yellow Perch, Northern Pike, and Walleye are cool water species, and Largemouth Bass is warm water species. The temperature in Lake Ontario is cold in general, but a certain amount of overlap among these broad community types is possible. During the summer when Ontario water is the warmest, it is not uncommon to find some cold water species living in the same areas as cool water species, or cool water species living in the same areas with warm water species. Eating common sport fish with mercury such as Walleyes, Lake Trout, Bass and Pike is an immediate health concern (Gorski *et al.*, 1999). Largemouth Bass is not a frequently caught fish in Lake Ontario but fishers love to catch it in recreational fishing. More detail information are given in the following sub-sections.

3.2.1 Chinook Salmon

Chinook Salmon (*Oncorhynchus tshawytscha*), as shown in Figure 3.2, is one kind of spring salmon that is of great importance to both the commercial and sports fishery. It ranges in size from 30 to 100 cm in length. The body is slender and the tail is entirely spotted. Its mouth is black and its teeth are moderately sharp (Ministry of Natural Resources, 2001). It matures in its fourth or fifth year and its weight ranges from 10 to 20 pounds (Wooding, 1972). The colour of matured Chinook Salmon is greenish-blue to black on the upper sides and back, not infrequently showing a faint reddish to rusty hue. It feeds on terrestrial insects such as larvae, spiders and ants when it is small and consumes various foods including invertebrates (squid, shrimp and crab) and small fish (smelt and alewives) when it reaches maturity.

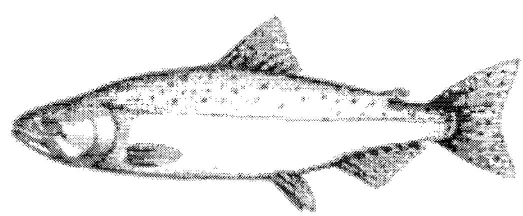


Figure 3.2 Chinook Salmon

3.2.2 Lake Trout

Lake Trout (*Salvelinus namaycush*), as shown in Figure 3.3, is a swift torpedo-shaped fish with light wormlike markings and spots on dark skin (Wooding, 1972), and is from 30 to 80 cm long (Ministry of Natural Resources, 2001). It varies in colour but generally has an over-all darkish appearance with noticeably large head, eyes and mouth. It, at one time, occurred naturally throughout the Great Lakes as a splendid game fish. During the first half of the twentieth century, it was the most valuable commercial fish in the upper Great Lakes. Unfortunately, in recent years, it has been virtually eliminated because of overfishing and pollution (MOE, 1998a). Sexual maturity is usually attained at about 6 or 7 years of age (Scott and Crossman, 1973). Small size Lake Trout feeds upon a broad range of organisms, plankton and terrestrial insects. When it grows up, it feeds on terrestrial insects and small fish such as smelt and alewife.

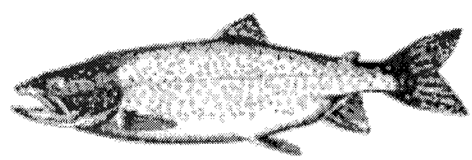


Figure 3.3 Lake Trout

3.2.3 Largemouth Bass

Largemouth Bass (*Micropterus salmoides*), as shown in Figure 3.4, has a large mouth, an upper jaw bone that extends beyond the eye, a body often with a broken horizontal stripe and a higher dorsal fin than other fish (Wooding, 1972). Its eyes are inclined to be gold in colour. The length of largemouth bass is usually 25 to 55 cm (Ministry of Natural Resources, 2001). Mostly, it is distributed in the lower Great Lakes and St. Lawrence River. Female fish probably spawn yearly between the ages of 5 and 12, and may be with several males on different nests (Scott and Crossman, 1973). Crayfish, shiner, carp, minnow, yellow perch and bluegill are its major diet composition.

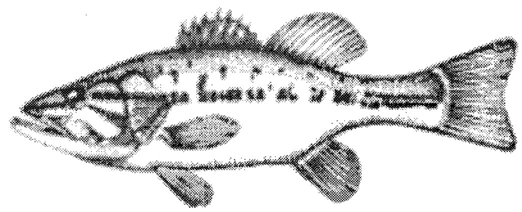


Figure 3.4 Largemouth Bass

3.2.4 Northern Pike

Northern Pike, (*Esox lucius*), as shown in Figure 3.5, is a long, slender fish with a large flat head, rounded tail fin, and paddle-like jaws containing many sharp backward-pointing teeth. It has a pattern of light yellowish spots on a dark green skin coat in contrast to the muskellunge. Individuals are usually 45-100 cm in length (Ministry of Natural Resources, 2001). In North America, it is widely introduced as a large sport fish and as a control predator. At the end of its fourth year, most male and female reach sexual maturity and are able to spawn (Wooding, 1972). In Canada, it occurs throughout Ontario, Manitoba, Saskatchewan ad Alberta (Scott and Crossman, 1973). It likes to consume a broad range of plankton and terrestrial insects when young. When it becomes bigger, it prefers to eat vertebrates and small fish such as ducklings, mice, small muskrates and smelt.

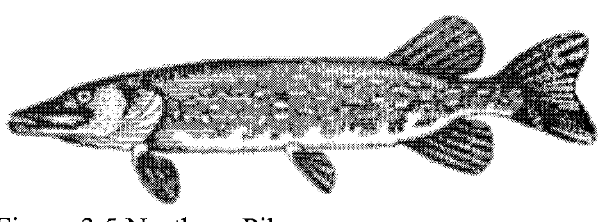


Figure 3.5 Northern Pike

3.2.5 Rainbow Trout

Rainbow Trout (*Oncorhynchus mykiss*), as shown in Figure 3.6, is similar to Lake Trout with many small black spots on its body and over its tail in radiating rows and pink laternal stripe (Ministry of Natural Resources, 2001). The name "rainbow" is given to a trout when it has a pinkish or reddish band along its sides (Wooding, 1972). It is usually 15 to 75 cm in size and is found everywhere in North America. Sexual maturity is first achieved as early as 1 year by male fish to as late as 6 years by female fish (Scott and Crossman, 1973). Small size Rainbow Trout feeds on various plankton and terrestrial insects and large size Rainbow Trout consume invertebrates (larger crustaceans, clams leeches, shrimps, snails) and small fish (alewife, sculpin, smelt, shiner).

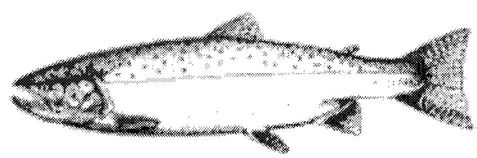


Figure 3.6 Rainbow Trout

3.2.6 Walleye

Walleye (*Stizostedion vitreum*), as shown in Figure 3.7, is a member of the Perch family (Parks *et al.*, 1994). It is 25 to 85 cm in size (Ministry of Natural Resources, 2001) with olive-brown to yellow skin. It is a cylindrical fish with a long head, large eyes, large mouth and forked tail fin. Walleye is probably the most economically valuable game fish in Canada's inland waters. Canadian commercial fisheries harvest several million pounds of Walleye annually. It probably spreads into northern Ontario and Quebec, Alberta, Lake Erie and Lake Ontario. Male Yellow

Walleye generally matures at 2 to 4 years of age, and grows to over 28 cm in length. Female Walleye grows from 35.6 to 43.2 cm or 3 to 6 years of age (Scott and Crossman, 1973). Northern pike, smelt and crayfish are probably the most important prey of the Walleye.

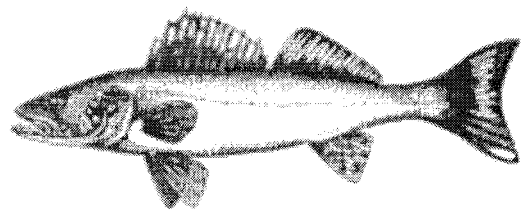


Figure 3.7 Walleye

3.2.7 Yellow Perch

One of the most diversified of all Canadian fresh-water fish families is the Perch family. It is made up of Yellow Perch, Walleyes, Sauger and the darters. Yellow Perch (*Perca flavescens*), as shown in Figure 3.8, is dark-olive green in back, yellow or green colour on its sides with 6 to 8 dark vertical bands. Its belly is a light colour; the pectoral fins are light-coloured while the pelvic fins are pale or bright orange. It has an almost circumpolar distribution in the fresh water of the Northern Hemisphere with an average length from 15 to 30 cm (Ministry of Natural Resources, 2001).

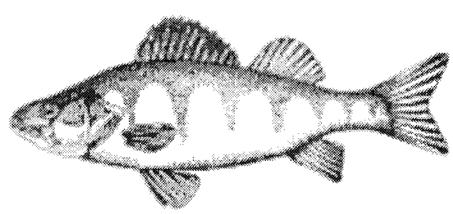


Figure 3.8 Yellow Perch

Sexual maturity is usually achieved by male fish at 3 year and female fish at 4 year of age (Scott and Crossman, 1973). Food composition of the Yellow Perch changes with size and season but is largely terrestrial insects, larger invertebrates such as crayfish and snails; and also small fish taken in open water. In many small Ontario lakes, especially those of Algoinquin Park, the Perch is the principal food of Lake Trout (Wooding, 1972).

3.2.8 Summary of Fish Characteristics

Table 3.1 shows the sport fish's length range, weight range, preferred temperature, mature age and diet composition. Among these seven fish species, the Northern Pike has the largest size while the Yellow Perch has the smallest. Warm species such as the Largemouth Bass prefer to live at a high temperature, 27°C, while cold species such as Chionook Salmon, Lake Trout, and Rainbow Trout like to live at a low temperature of 15°C. Different fish species can have life spans as much as 15 years and as low as 7 years. Largemouth Bass have a longer life span, up to 15 years. Different fish species have different life spans and size distributions correlated to age. According to research, the length ranges of seven sport fishes in different age groups are listed in Table 3.2 (Borgmann and Whittle, 1992, Scott and Crossman, 1973, Luk, 2000). Every fish species has its individual growth rate; fish species with a larger size have a greater growth rate when they are small. For example, Chinook Salmon and Northern Pike grow to 40 cm by age 1. At the same age, Yellow Perch is only 10 cm. Fish start spawning when they reach maturity and they generally mature at one-third of their fully-developed length. Based on their diet composition, the predatory level of these sport fish could be ranked in ascending order as Chinook Salmon, Rainbow Trout, Lake Trout, Yellow Perch, Northern Pike, Largemouth Bass and Walleye.

Table 3.1 Summary of characteristics for different Ontario sport fish species

Fish Species	Length Range (cm)	Weight Range (kg)	Preferred Temperature (^oC)	Life Span (Mature Age)	Diet Composition	
Chinook Salmon	30 - 100	0.5 - 18.0	15	7(4)	Young	Terrestrial insects - larvae, spider, ant
					Mature	Invertebrates - squid, shrimp, crab Small fish - smelt, shiner, sandfish, alewife
Lake Trout	30 - 80	0.3 - 4.5	15	8(6)	Young	Organisms, plankton Terrestrial insects - larvae
					Mature	Terrestrial insects - larvae Small fish - smelt, alewife
Largemouth Bass	25 - 55	0.3 - 2.3	27	15(5)	Young	Invertebrates - crayfish Small fish - shiner, carp, minnow
					Mature	Small fish - yellow perch, bluegill
Northern Pike	45 - 100	0.7 - 8.0	17	10(4)	Young	Plankton, terrestrial insects
					Mature	Vertebrates - duckling, mice, small muskrat Small fish - smelt
Rainbow Trout	15 - 75	0.2 - 5.5	15	7(1)	Young	Plankton, terrestrial insects
					Mature	Invertebrates - larger crustacean, clam leeches, shrimp, snail Small fish - alewife, sculpin, smelt, shiner
Walleye	25 - 85	0.3 - 6.0	20	15(2)	Young	Invertebrates - crayfish Small fish - smelt
					Mature	Small fish - smelt Big fish - Northern pike
Yellow Perch	15 - 30	0.2 - 0.3	20	13(3)	Young	Zooplankton
					Mature	Invertebrates - crayfish and snail Small fish - smelt, alewife

Table 3.2 Length ranges of fish in different age groups

Age	Chinook Salmon (cm)	Lake Trout (cm)	Largemouth Bass (cm)	Northern Pike (cm)	Rainbow Trout (cm)	Walleye (cm)	Yellow Perch (cm)
1	0 - 44.0	0 - 19.5	0 - 10.2	0 - 39.6	0 - 10.2	0 - 21.3	0 - 9.5
2	44.1 - 66.3	19.6 - 32.0	10.3 - 20.3	39.7 - 52.7	10.3 - 19.0	21.4 - 32.3	9.6 - 15.8
3	66.4 - 77.4	32.1 - 45.0	20.4 - 25.4	52.8 - 62.2	19.1 - 41.9	32.4 - 40.1	15.9 - 17.2
4	77.5 – 85.0	45.1 - 54.2	25.5 - 30.5	62.3 - 68.7	42.0 - 55.9	40.2 - 46.5	17.3 - 18.2
5	85.1 – 95.0	54.3 - 60.8	30.6 - 34.3	68.8 - 73.1	56.0 - 66.0	46.6 - 51.8	18.3 - 20.2
6	95.1 - 104.9	60.9 - 65.7	34.4 - 36.8	73.2 - 84.5	66.1 - 72.4	51.9 - 55.6	20.3 - 21.6
7	105.0 – 120.0	65.8 - 70.0	36.9 - 41.9	84.6 - 87.0	72.5 - 80.0	55.7 - 58.4	21.7 - 23.9
8		70.1 - 73.1	42.0 - 43.2	87.1 - 89.5		58.5 - 61.5	24.0 - 25.7
9			43.3 - 44.5	89.6 - 96.5		61.6 - 63.5	25.8 - 28.8
10			44.6 - 45.7	96.4 - 103.5		63.6 - 65.0	28.9 - 30.8
11			45.8 - 48.3			65.1 - 65.8	30.9 - 31.4
12			48.4 - 50.3			65.9 - 66.5	31.5 - 32.3
13			50.4 - 51.8			66.6 - 67.3	32.4 - 33.4
14			51.9 - 53.3			67.4 - 68.6	
15			53.4 - 54.4			68.7 - 70.6	

3.3 Generic Bioaccumulation Model (GBM)

Although public health restrictions on the consumption of mercury-contaminated aquatic organisms are in place, it is difficult to provide official health advisories for all affected waters. Factors such as age, size, metabolism, water temperature, sex, mercury concentration and speciation in both water and food could influence the accumulation of mercury in fish. Moreover, a large number of samples is required to define mercury levels in a given aquatic community (Parks *et al.*, 1994). As a result, a model in corporating field estimates of fish body size, growth rate, diet and mercury concentration in water would be the best solution to examine the seasonal patterns in methylmercury accumulation.

As summarized in Table 3.3, many different types of models are investigated to evaluate the levels of pollutants in fish. Most of them are bioenergetics models, mainly calculating the absorption and excretion amounts of pollutant(s) by fish. Others use statistical regression models to estimate a fish's pollutant concentrations. Two studies on fish physiological modelling are also found. Both of them use a bioenergetics method to define the effects of reproduction and growth by food. In Table 3.3, the researchers, test locations, fish species, model types and a brief conclusion are included. The bioenergetics model is a popular mechanistic model that provided clear representation for all major pathways of accumulation. It is utilized to effectively predict the fish's pollutants concentrations. Parameters can be directly related to physiochemical data of fish obtained from independent reference.

Table 3.3 Summary of fish modeling

Author	Location	Fish Species	Type of Modelling	Conclusions
(i) On Hg modelling				
Norstrom *et al.*, 1976	Ottawa River	Yellow Perch	Energetics	Predicted ratio of uptake to clearance is constant at all weights. Uptake of pollutant from water is based on polluted water past the gills for respiration.
Phillips and Buhler, 1978	Roaring River, Oregon	Rainbow Trout	Regression	MeHg accumulated from more than 1 source was quantitatively additive. Nearly 70% of MeHg ingested and 10% passed over the gills was assimilated.
Borgmann and Whittle, 1991	Niagara River, Burlington, W. Toronto, Cobourg, Traverse Shoal and N. Main	Lake Trout	Regression	Contaminants biomagnification is strongly influenced by food web interactions. Hg and mirex decreased steadily. DDE decreased rapidly from 1977 to 1980. PCB decreased from 1977 to 1981, increased from 1982 and increased again in 1985. PCB, DDE and mirex in Trout increased from east to west in L. Ontario. All contaminant increased with increasing age and body size.
Borgmann and Whittle, 1992	Lake Ontario	Lake Trout, rainbow smelt, slimy sculpin	Regression	Concentration responded to changes in concentration of their foods. PCBs and lipids have declined in Lake Trout from 1977-1988. Models based on chemical kinetics across gastrointestinal tract are more consistent with observed data than models based on a constant contaminant assimilation rate and direct excretion.
Harris and Snodgrass, 1993	Ottawa River, Lake Simcoe	Walleye, yellow perch	Energetics	Food uptake pathway is predicted to be responsible for 90% or more of MeHg uptake in freshwater fish.
Luk, 2001	Lake Ontario	Walleye, Yellow Perch	Energetics	Food is clearly the dominant mercury uptake pathway for fish. The higher is the position of a fish in the food chain, the greater Hg level exhibit in fish's bodies
(ii) On fish physiological modelling				
Stewart *et al.*, 1983	Lake Michigan	Lake Trout	Energetics - Growth	Conversion efficiency of energy by lake trout over their life in Lake Michigan is about twice that of converting mass to growth due to high-energy fat storage. Predation by lake trout on alewife has increased steadily since 1965.
Jensen, 1998	Lake Erie	Walleye	Energetics - Reproduction	In the food limited population growth simulations, ration was determined by food abundance, growth was determined by ration, and mortality and fecundity were size dependent.
Kershner *et al.*, 1999	Lake Erie's western and central basins	Walleye	Energetics - Growth	Walleye predatory demand declined with population size from 1988 through 1995, reduced walleye reproductive potential.

The concept of bioenergetics is based in the energy requirement of fish for normal activities and growth. As indicated in Figure 3.9, fish need energy for various life functions such as swimming and foraging activities. To satisfy these requirements, they fed on zooplanktons, crustaceous and small fishes from the diet. In addition, they take in a large volume of water through the gills for oxygen exchange. When the water and diet items are contaminated, MeHg will enter the fish's bodies through these intake pathways. Therefore, a direct correlation can usually be observed between the activity level of the fish and the pollutant accumulation.

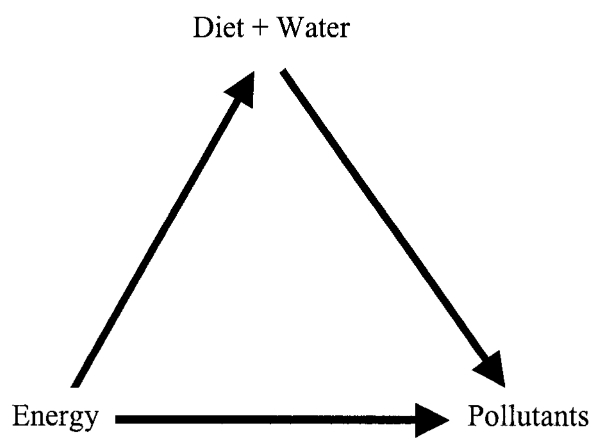


Figure 3.9 Bioenergetics concept

A bioenergetics-based generic bioaccumulation model (GBM), based on the equations of Norstrom *et al.* (1976) and developed by Luk (1996), is chosen to determine the bioaccumulation of MeHg in Lake Ontario's fish. A computer program, MercuryBioPro, was developed to implement the model using the programming software, Visual Basic 4.0. The model has been successfully applied to describe the effects of PCB and MeHg accumulation in different fish (Walleye and Yellow Perch) as a function of age and size. In this thesis, a refinement of this model with updated programming software, Visual Basic 5.0, was made based on the new insights gained from the habitat and genders' study, thereby providing more accurate predictions of the mercury bioaccumulation patterns in different fish groups. Moreover, this model is refined to see if it is possible to apply it to other species, such as Chinook Salmon, Northern Pike and Rainbow Trout. Field data from the MOE are compared to the results predicted from the model.

3.4 Bioenergetics Based Model

According to the bioenergetics equations, methylmercury uptake from fish is related to food consumption, water absorption and clearance. The idea of the model is to add the amount of MeHg consumed from water and absorbed from food, subtracting the amount of MeHg extract from the body. Pollutant uptake should be related to the flow of energy into the fish, both in the form of food and in the form of oxygen from water. The model must be able to adequately represent the bioenergetics and growth of fish. Therefore, it is necessary to know the fish's growth rate and length - weight ratio before applying the model equation. In the following sub-sections, the major equations are described in detail.

3.4.1 Length - Weight Ratio

Norstrom *et al.* (1976) proposed an equation to define the relationship between a fish's length and weight. It is used to calculate the weight (W) in grams of a fish as a function of length (L) in centimeters. The parameters a and b are length - weight parameter and length - weight ratio respectively. An equation can convert a fish's length to its weight, and subsequently energy equivalence, and is given as follows:

$$W = aL^b \qquad \text{Eq. [3.1]}$$

3.4.2 Fish Growth

Many researchers suggested the von Bertalanffy growth function (VBGF) as the best growth model for simulating the growth of fish populations. The basic concept of this model is that the rate of growth of an organism is related to the amount by which its size falls short of its maximum size. The equation allows for the estimation of the weight of fish at age t (W_t) in grams, as follows:

$$W_t = W_\infty (1 - e^{-kt})^b \qquad \text{Eq. [3.2]}$$

where W_∞ is a function of fish's asymptotic weight in grams, k is the growth coefficient per week, t is the age of fish in week and b is the length - weight ratio.

3.4.3 Bioenergetics Equation

The total amount of energy (Q) required by the fish, commonly referred to as the total metabolism. Referring to Kerr's (1971) research, the total amount of energy of fish is given in the following equation:

$$Q = Q_s + Q_a + Q_f + Q_c \qquad \text{Eq. [3.3]}$$

where Q_s is the energy component for standard metabolism, Q_a is the energy cost for spontaneous activities like swimming, Q_f is the energy cost for foraging and Q_c is the energy cost for utilization of food such as digestion and absorption.

In general, all the activity-related energy components are grouped into one term, namely the "low-routine metabolism", which is defined as:

$$Q_{lr} = Q_s + Q_a + Q_f \qquad \text{Eq. [3.4]}$$

where Q_{lr} is the energy for low-routine metabolism. In this case, Eq. [3.3] can be re-written as follow:

$$Q = Q_{lr} + Q_c \qquad \text{Eq. [3.5]}$$

Winberg (1956) had found an empirical relationship between the low-routine metabolism and the fish's weight, which is represented by the power-function:

$$Q_{lr} = \alpha_{lr} W^{\tau} \qquad \text{Eq. [3.6]}$$

where α_{lr} is the low-routine coefficient in kilocalories per week per gram, W is the weight of fish in grams and τ is the body weight exponent for metabolism.

The energy cost for utilization of food (Q_c) is directly proportional to the fish's growth rate. It implies that the size of a fish does not influence the energy cost for utilization of food. However, this energy cost may be lower if a fish has a steady growth rate. Taking energy equivalent of the flesh of fish into account, the equation for Q_c may be represented by:

$$Q_c = q_f \beta \left(\frac{dW}{dt} \right) \qquad \text{Eq. [3.7]}$$

where q_f is the energy equivalent (energy content) of the flesh of fish in kilocalories per week per gram, β is a proportionality constant and dW/dt is the growth rate of fish.

By substituting the Eqs. [3.6] and [3.7] into Eq. [3.5], the final expression of the total energy required by the fish can be written as follows:

$$Q = \alpha_{lr} W^{\tau} + q_f \beta \left(\frac{dW}{dt} \right) \qquad \text{Eq. [3.8]}$$

3.4.4 Uptake of Pollutants from Food

The amount of energy obtained from food is enough for the fish to carry out all of the required metabolic activities. The efficiency of assimilation of food is of great importance because food energy is used to support the fish's growth and respiration.

Toxicants are consumed along with food and are absorbed from the gastrointestinal tract. The toxicants are then deposited and stored in various tissues particularly in muscles. The equation for total metabolic energy from food is expressed as:

$$\left[\frac{dP}{dt}\right]_f = \left[\frac{(E_{pf}C_{pf})}{(q_{fd}E_{fd})}\right]\left[\alpha_{lr}W^{\tau} + q_f(\beta+1)\left(\frac{dW}{dt}\right)\right] \qquad \text{Eq. [3.9]}$$

where $(dP/dt)_f$ is rate of pollutant uptake through the food pathway in ppm, E_{pf} is the efficiency of pollutant uptake from food, C_{pf} is the concentration of pollutant per wet weight in food in ppm, q_{fd} is the energy equivalence of the prey (food) in kilocalories per gram and E_{fd} is the efficiency of assimilation of food.

3.4.5 Uptake of Pollutants from Water

The process of diffusion governs the capture of oxygen and discharge of carbon dioxide from the fish's body. During respiration, gases diffuse into an aqueous layer covering the epithelial cells that line on the respiratory system of fish. The diffusion is driven by the concentration gradient existing between the interior of the fish and its surroundings. Certain amounts of Hg are obtained from water. The final equation, which can be used to represent the rate of pollutant uptake through the water pathway, is as follows:

$$\left[\frac{dP}{dt}\right]_w = \left[\frac{(E_{pw}C_{pw})}{(E_{ox}C_{ox}q_{ox})}\right]\left[\alpha_{lr}W^{\tau} + q_f\beta\left(\frac{dW}{dt}\right)\right] \qquad \text{Eq. [3.10]}$$

where $(dP/dt)_w$ is rate of pollutant uptake through the water pathway in ppm as a function of the efficiency of transfer of pollutants from water (E_{pw}), the concentration of pollutants in water in ppb (C_{pw}), the absorption efficiency of oxygen (E_{ox}), the concentration of dissolved oxygen in water in ppm (C_{ox}) and the energy equivalence of oxygen in kilocalories per gram of oxygen (q_{ox}).

3.4.6 Clearance

Clearance is the only process that extracts a part of the toxicants from the fish's body. Whole body clearance of methylmercury has been shown to follow first-order kinetics under various sets of environmental and physiological conditions (Ling, 2001). It is discovered neither temperature nor metabolic rates affect the clearance of Hg in fish. However, the mercury burden in fish bodies does affect the rate of clearance. The rate of clearance of a pollutant can be expressed by the following equation:

$$\left[\frac{dP}{dt}\right]_{cl} = -k_{cl}P \qquad \text{Eq. [3.11]}$$

where $(dP/dt)_{cl}$ is the rate of clearance of pollutant in parts per million, k_{cl} is the clearance coefficient per week and P is the pollutant burden.

3.4.7 General Equation

The rate of change of total pollutant burden in the body of a fish is the summation of the pollutant intake from the food and water pathway minus the clearance rate, as given by:

$$\left[\frac{dP}{dt}\right]_{body} = \left[\frac{dP}{dt}\right]_{food} + \left[\frac{dP}{dt}\right]_{water} - \left[\frac{dP}{dt}\right]_{clearance} \qquad \text{Eq. [3.12]}$$

By substituting Eqs. [3.9], [3.10] and [3.11] into Eq. [3.12], the general equation for calculating the total methylmercury burden in the fish is represented in the following:

$$\left[\frac{dP}{dt}\right]=\left[\frac{\left(E_{pf}C_{pf}\right)}{\left(q_{fd}E_{fd}\right)}\right]\left[\alpha_{l\gamma}W^{\tau}+q_{f}(\beta+1)\left(\frac{dW}{dt}\right)\right]+\left[\frac{\left(E_{pw}C_{pw}\right)}{\left(E_{ox}C_{ox}q_{ox}\right)}\right]\left[\alpha_{l\gamma}W^{\tau}+q_{f}\beta\left(\frac{dW}{dt}\right)\right]-k_{cl}P$$

Eq. [3.13]

where $(dP/dt)_{body}$ is the rate of change of mercury burden in the body of fish.

3.5 Sample Modelling

All the input data for the program are necessary for the running of the model. The program consists of two tables for inputting all the parameters. Input Table 1, given in Figure 3.10, is divided into seven sections. The section on "The parameters of fish growth" requires values for fish growth, such as the maximum weight and the growth rate coefficient. The section "Efficiency Factors" shows all the efficiency factors for food intake, oxygen uptake, mercury uptake from food and water. "Length of simulation" is a section specifying the simulation period for fish species. In the section on "metabolic parameters", two fields for low routine metabolism and body weight exponent are detailed. The "Energy Equivalence" and "Concentrations" sections record, first, the energy equivalence for fish and oxygen and next, the concentrations of mercury and of oxygen in water. The last section, "Types of Fish", indicates the simulation fish species in the model. There are four buttons at the bottom of input Table 1: "Clear Form", "Cancel", "Default" and "Next". The "Cancel" button is used to close this input table and return to the main menu. By clicking a fish's name and "Default" button, the program suggests typical parameter values for the fish species. If these values are not accurate, "Clear Form" can be clicked to clear the values and re-enter new ones. After the values are determined, the "Next" button can be clicked to go to input Table 2.

In Input Table 2, given in Figure 3.11, there are two sections: "Initial Condition" and "Diet Composition". Since the program is used to calculate the fish's bioaccumulated mercury levels, it is unable to simulate the mercury over a fish's life period if the initial mercury concentration of a fish is zero. Therefore, a fish's weight and mercury concentration at week one is used as the initial condition. The section "Diet Composition" shows the percentage of diet, mercury concentrations in food and energy equivalence of prey of a particular fish at different age. Just as with input Table 1, the "Cancel" button at the bottom of the table is used to close this input table and return to the main menu. The "Default" button suggests typical parameter values for the fish species. The "Back" button gives the user a chance to go back and change any variables in input Table 1. If the user is satisfied with all the input values of the variables, the "OK" button can be clicked to process the model.

When the processing of the program is done, the simulated mercury concentration in a fish during its life span is generated in the format of an output table, an example of which is shown in Figure 3.12. This output table gives not only the accumulated mercury burden in the body of fish by weeks but also the clearance rate of the pollutant and the rate of pollutant uptake through the food and water pathways. All the simulated data can be exported into an excel file and the results can be plotted, as given in Figures 3.13 and 3.14. These figures demonstrate the simulated mercury concentration in Walleye as a function of time (weeks) and weight (g).

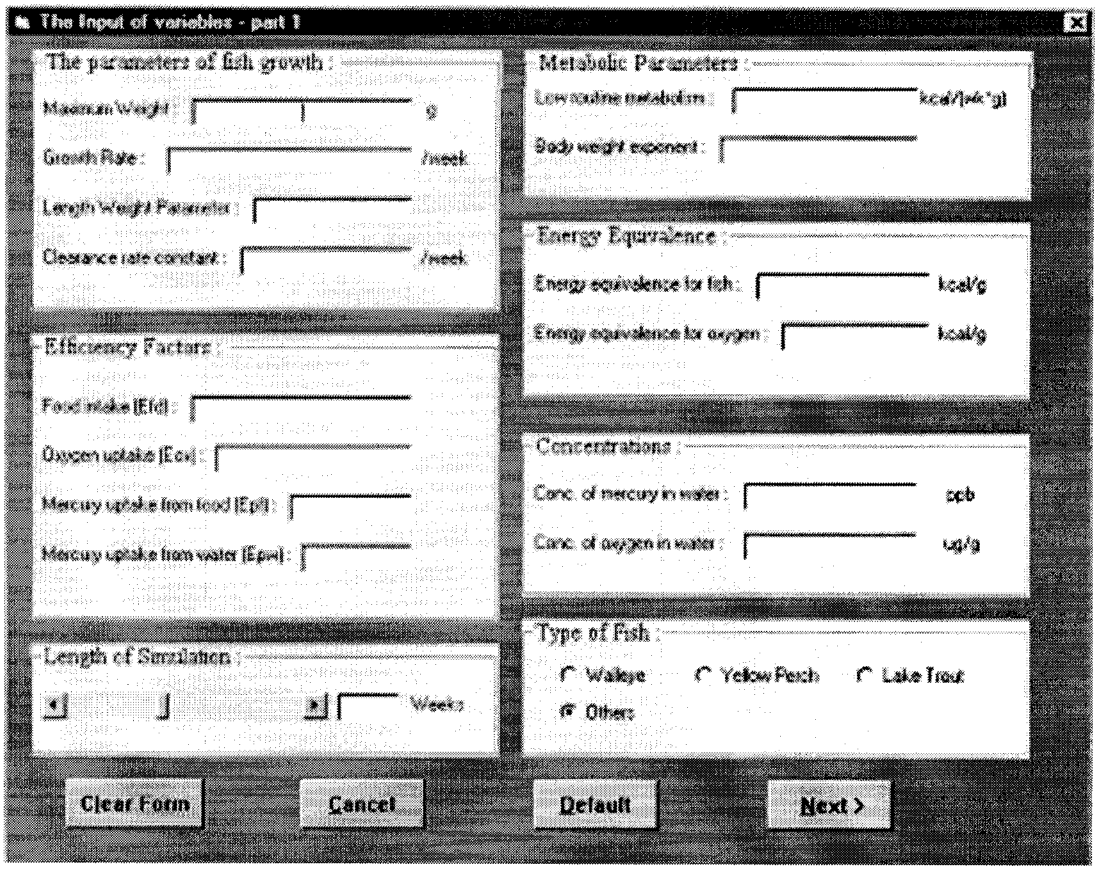


Figure 3.10 Sample input Table 1 of the mercury bioaccumulation program

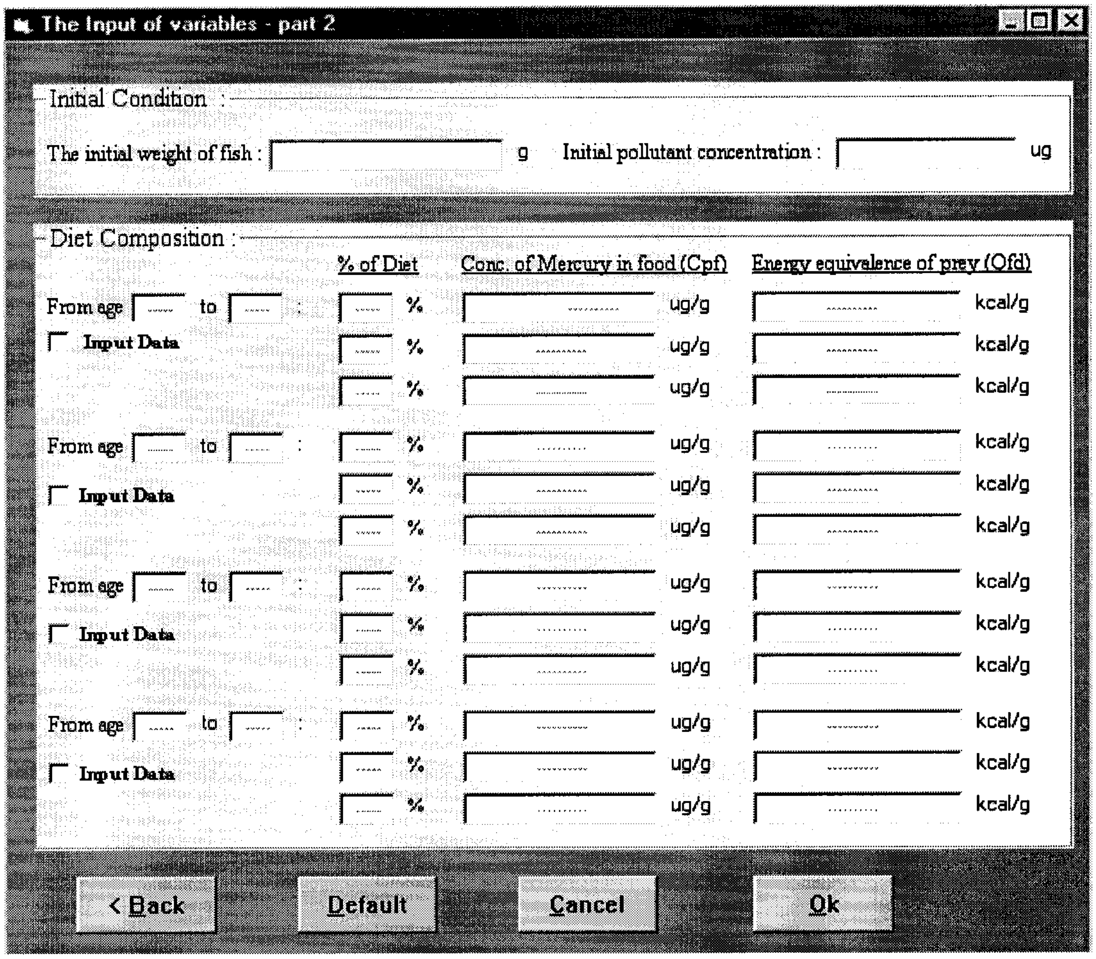


Figure 3.11 Sample input Table 2 of the mercury bioaccumulation program

The Output Table

P/W	P	dPcl_dt	dPw_dt	dPf_dt	W	Week
0.23590	0.0000	0.0000	0.0000	0.0000	0.000	1
0.21810	0.0002	0.0000	0.0000	0.0002	0.001	2
0.20758	0.0008	0.0000	0.0000	0.0006	0.004	3
0.20325	0.0019	0.0000	0.0000	0.0012	0.010	4
0.20152	0.0040	0.0000	0.0000	0.0021	0.020	5
0.20104	0.0073	0.0000	0.0000	0.0033	0.036	6
0.20124	0.0121	0.0000	0.0000	0.0048	0.060	7
0.20181	0.0187	0.0000	0.0000	0.0067	0.093	8
0.20262	0.0275	0.0000	0.0000	0.0089	0.136	9
0.20356	0.0390	0.0001	0.0000	0.0115	0.191	10
0.20459	0.0533	0.0001	0.0000	0.0144	0.261	11
0.20567	0.0710	0.0001	0.0000	0.0178	0.345	12
0.20679	0.0925	0.0001	0.0000	0.0215	0.447	13
0.20793	0.1180	0.0002	0.0000	0.0257	0.568	14
0.20907	0.1481	0.0002	0.0001	0.0303	0.709	15
0.21022	0.1832	0.0003	0.0001	0.0353	0.871	16
0.21137	0.2236	0.0004	0.0001	0.0407	1.058	17
0.21251	0.2697	0.0004	0.0001	0.0465	1.269	18
0.21365	0.3221	0.0005	0.0001	0.0528	1.508	19
0.21477	0.3811	0.0006	0.0001	0.0595	1.774	20
0.21589	0.4471	0.0008	0.0001	0.0666	2.071	21
0.21700	0.5205	0.0009	0.0001	0.0742	2.399	22
0.21810	0.6019	0.0010	0.0002	0.0822	2.760	23

Export   Ok

Figure 3.12 Sample output Table of the mercury bioaccumulation program

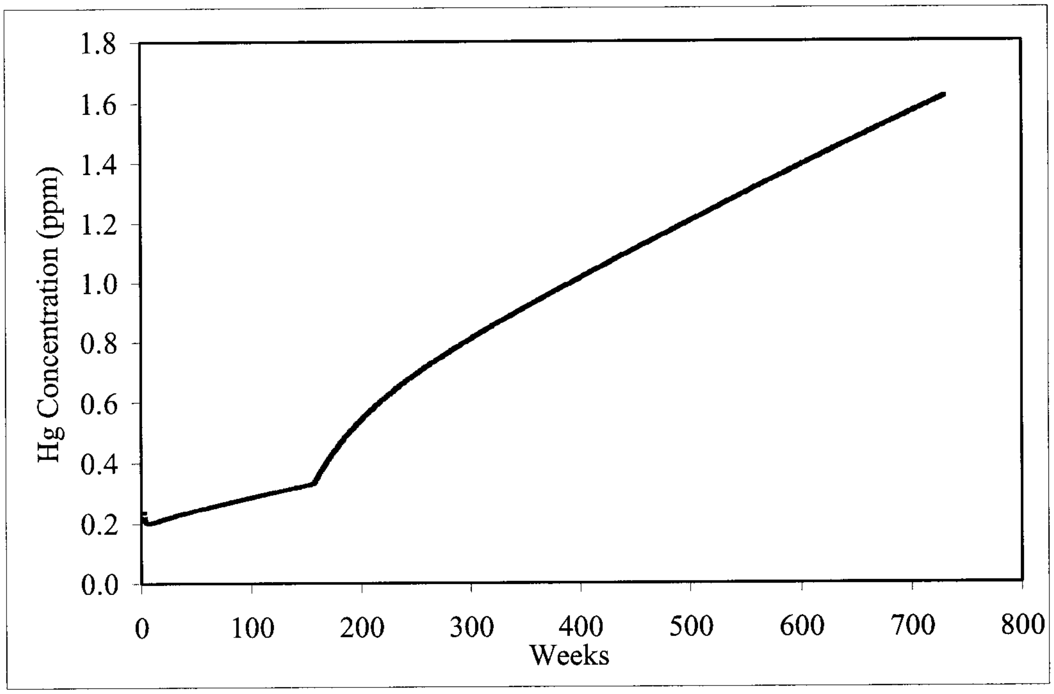


Figure 3.13 Simulated Walleye Hg concentration by weeks

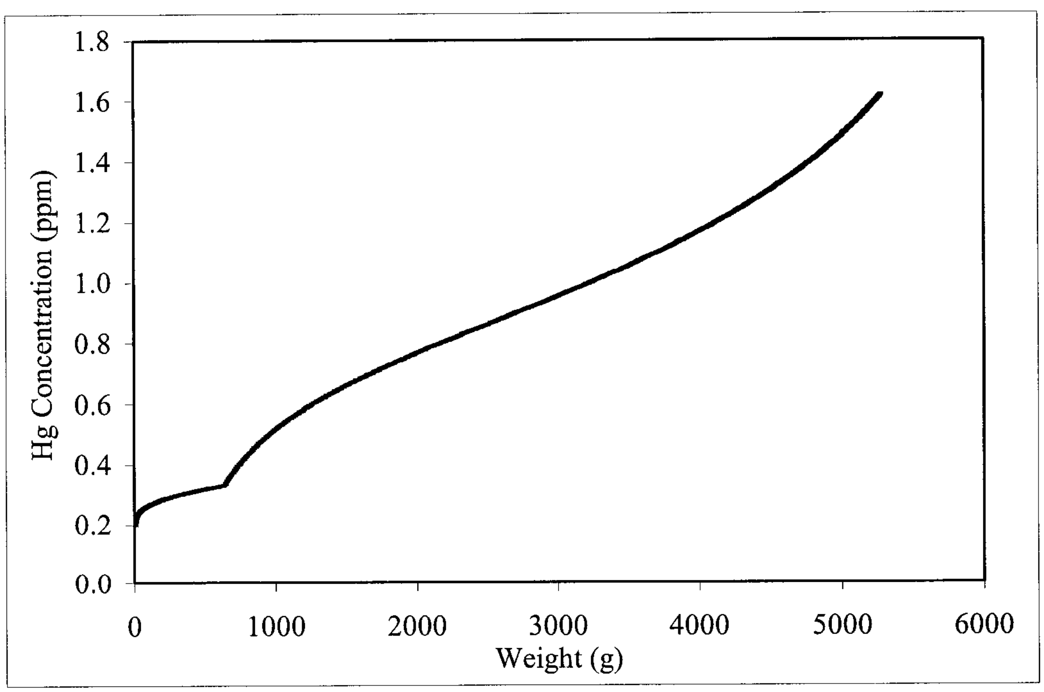


Figure 3.14 Simulated Walleye Hg concentration correlated to their weight

Chapter 4 Trends from Fish Concentration Data

Through the Sport Fish Contaminant Monitoring Program, contamination data on seven sport fish species is collected. The species selected for this study are Chinook Salmon, Lake Trout, Largemouth Bass, Northern Pike, Rainbow Trout, Walleye and Yellow Perch. All of the existing data are input into a Microsoft Access data management system and classified into seven categories, as illustrated in Figure 4.1. In each category, fish species, length in centimeters, weight in grams, mercury concentration in ppm, collection date, location and portion type, are listed.

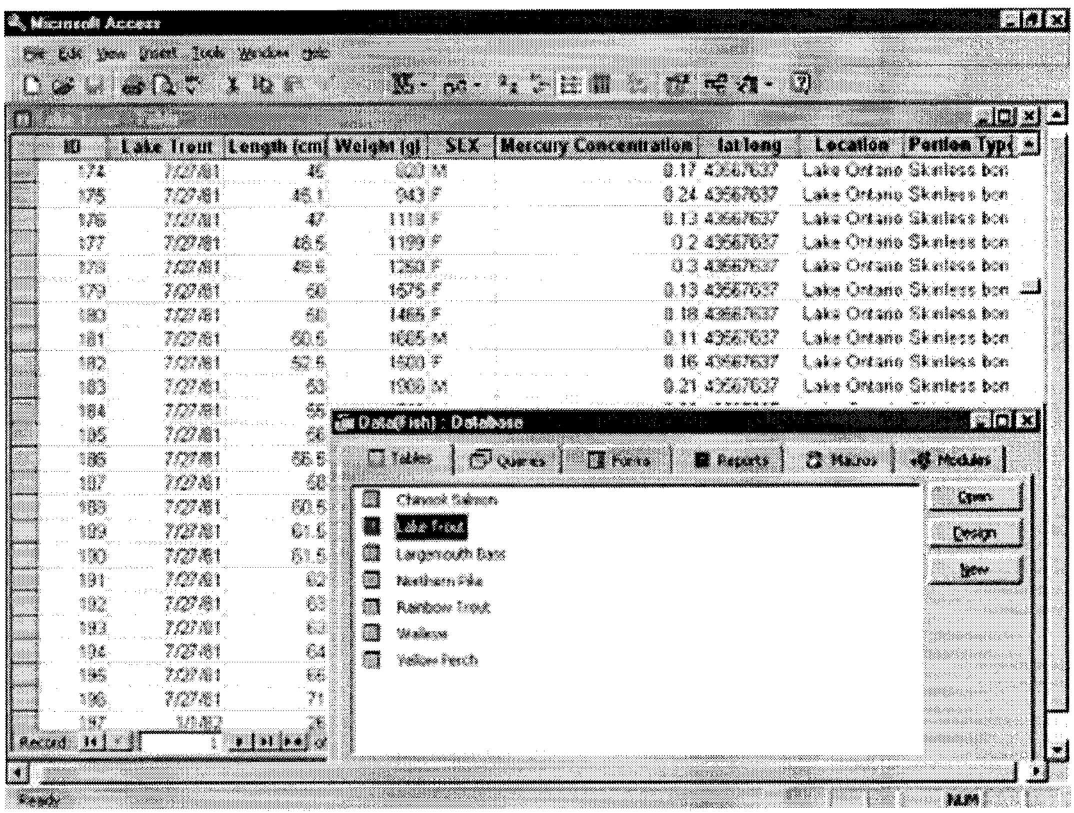


Figure 4.1 Existing data in Microsoft Access Bioaccumulation Model

A direct comparison of the suggestions from the fish guide to the field data, in terms of size and weight ranges, is given in Table 4.1. It is noted that the length of fish field data are close to the references ranges while the fish weights are not. For example, the length range of Chinook Salmon from the field data is from 16.5 to 120 cm, similar in magnitude to the fish guide's range of 30 to 100 cm. However, the field data's weight range of Chinook Salmon (4.6×10^{-2}-85.2 kg) is much wider than the suggested range (0.5 to 18 kg). Obviously, the fish's length range from the field data provides more reliable information because these are site-specific data.

Table 4.1 Comparison of the sport fish size between Ontario Fish Guide and data set

	Fish Guide		Field Data	
Fish Species	**Length Range (cm)**	**Weight Range (kg)**	**Length Range (cm)**	**Weight Range (kg)**
Chinook Salmon	30 - 100	0.5 - 18.0	16.5 - 120.0	4.6×10^{-2} - 85.2
Lake Trout	30 - 80	0.3 - 4.5	16.0 - 85.5	3.7×10^{-2} - 7.7
Largemouth Bass	25 - 55	0.3 - 2.3	15.8 - 45.7	5.5×10^{-2} - 1.5
Northern Pike	45 - 100	0.7 - 8.0	21.5 - 102.5	5.0×10^{-2} - 9.8
Rainbow Trout	15 - 75	0.2 - 5.5	7.6 - 92.0	4.7×10^{-2} - 7.9
Walleye	25 - 85	0.3 - 6.0	20.7 - 78.3	6.9×10^{-2} - 6.1
Yellow Perch	15 - 30	0.2 - 0.3	12.0 - 34.4	2.0×10^{-2} - 1.0

The main task of data analysis is to investigate the relationships between mercury concentrations in a fish's body and its habitat, gender and location, as well as the year that samples were taken. Data are exported to Microsoft Excel and analyzed. The fish-monitoring program started in the middle of 1970s. Fish have been collected and their contaminants measured every year. For mercury, more than 3,000 samples have been collected of these seven sport fish, but the number of samples in each species varies since it depends highly on the quantity of fish caught each year.

In Lake Ontario, Chinook Salmon, Rainbow Trout and Lake Trout are the most frequently caught fish because they are cold water species, which adapt to the environment of Lake Ontario. In contrast, Largemouth Bass, Walleye and Northern Pike are rare in Lake Ontario, especially the Largemouth Bass, since it is a warm water species. Detailed information of the sample distribution is given in Table 4.2. The cold species are caught almost every year but less than 200 warm species samples in total have been collected in 25 years. Concerning the mercury level in fish bodies, Table 4.3 records the minimum, maximum and average levels in all species for comparison. The lowest concentrations (0.01 ppm) are found in Chinook Salmon, Rainbow Trout and Yellow Perch and the highest concentration (1.6 ppm) is reported in Walleye.

Table 4.2 Temporal distribution of fish samples

Year	**Number of Samples**						
	Chinook Salmon	**Lake Trout**	**Largemouth Bass**	**Northern Pike**	**Rainbow Trout**	**Walleye**	**Yellow Perch**
1975	-	-	-	12	-	-	55
1976	4	-	-	5	54	-	8
1977	-	-	20	9	-	2	36
1978	4	53	-	-	1	-	19
1979	-	1	-	-	10	-	9
1980	-	21	-	31	30	-	17
1981	-	121	-	29	58	-	45
1982	-	41	-	-	28	5	20
1983	41	-	-	6	46	-	-
1984	46	30	-	-	39	-	-
1985	36	20	2	9	47	17	26
1986	40	39	-	25	63	-	11
1987	94	25	-	-	45	18	20
1988	20	15	-	-	51	8	-
1989	65	33	-	-	79	31	38
1990	130	50	7	16	77	-	-
1991	170	20	-	-	77	-	-
1992	59	-	-	-	48	-	38
1993	61	55	-	6	65	-	-
1994	86	80	-	3	51	20	-
1995	38	-	-	-	63	6	22
1996	60	60	-	2	32	14	27
1997	26	20	-	20	60	-	-
1998	17	-	5	30		20	35
1999	16	60	11	4	30	-	7
2000	32	-	-	-	3	-	-
Total	1045	744	45	207	1057	141	433

Table 4.3 Range of mercury concentrations in fish species

Fish Species	Year Range	Total Samples	Mercury Concentrations (ppm)		
			Minimum	Maximum	Average
Chinook Salmon	1976 - 2000	1045	0.01	0.67	0.24
Lake Trout	1978 - 1999	744	0.02	0.65	0.23
Largemouth Bass	1977 - 1999	45	0.07	0.94	0.25
Northern Pike	1975 - 1999	207	0.02	1.40	0.30
Rainbow Trout	1976 - 2000	1057	0.01	0.89	0.19
Walleye	1977 - 1998	141	0.04	1.60	0.54
Yellow Perch	1975 - 1999	433	0.01	1.40	0.16

4.1 Effects of Food Web

Since mercury is bioaccumulated, fish accumulate higher levels of Hg in their bodies in comparison to the lower trophic level organisms. Lake Trout is selected as an example to detect the relationship between size and mercury concentration. From the existing data, there are two sets of observations about fish size: length and weight. When all the Lake Trout data are plotted in Figure 4.2, it appears that the longer the Lake Trout, the heavier it is likely to be. In fact, some missing weight data causes zero weight values to appear in some of the Lake Trout observations. This problem is also detected in other fish species. It could produce error points and affect the analysis. Therefore, they are eventually removed to maintain the integrity of the data. Another problem is the reasonable size range. Unlike the length range, a big difference of fish weight range is obtained in the field data as compared to the fish guide's suggested range. Since fish length and weight follow an exponential regression, as shown in Figure 4.2, which is positively correlated, fish length could be utilized to carry out the rest of the analysis. The relationship between Lake Trout's length and mercury concentration is shown in Figure 4.3. In general, a longer fish contain a higher level of mercury in the body.

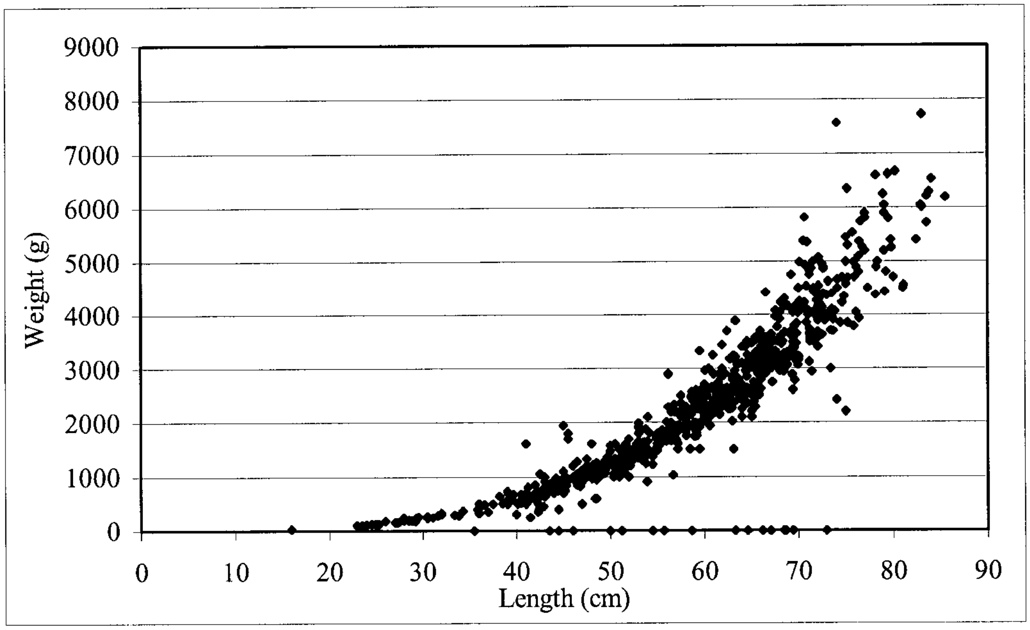


Figure 4.2 Relationship between length and weight of Lake Trout

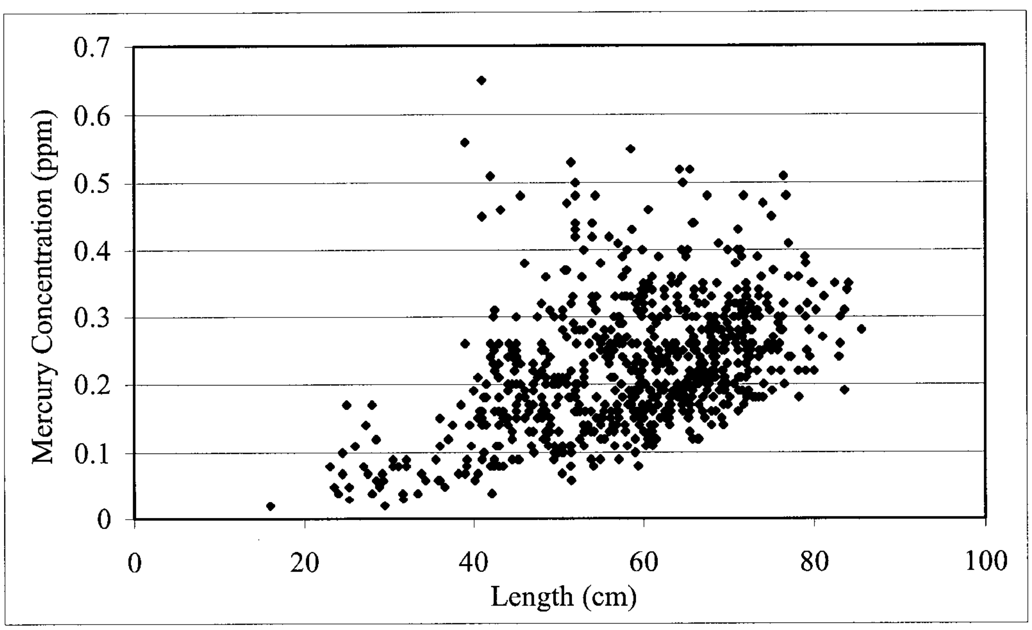


Figure 4.3 Relationship between length and mercury concentrations of Lake Trout

The data sets are divided into length groups with 5-centimeter intervals. For each length group, information about the number of samples, range of length, average length, mercury concentration and standard deviation are calculated in Table 4.4 and computed in Figure 4.4. In Lake Trout, more than half of the samples fall in length between 55 and 74.9 cm. The standard deviation is large for lengths between 35 and 44.9 cm. It indicates that the data on these groups are comparatively varied in quality.

Table 4.4 Lake Trout's mercury concentrations at different lengths

Range of Length (cm)	Number of Samples, n	Mean Length (cm)	Mean Hg Concentration (ppm)	Standard Deviation, σ
15 - 19.9	1	16.0	0.02	-
20 - 24.9	5	23.9	0.07	0.02
25 - 29.9	15	27.6	0.08	0.05
30 - 34.9	10	32.1	0.07	0.02
35 - 39.9	17	37.7	0.14	0.12
40 - 44.9	61	42.6	0.19	0.11
45 - 49.9	74	47.2	0.20	0.07
50 - 54.9	86	52.3	0.23	0.12
55 - 59.9	100	57.6	0.23	0.09
60 - 64.9	114	62.3	0.23	0.08
65 - 69.9	122	67.4	0.25	0.07
70 - 74.9	88	72.1	0.28	0.07
75 - 79.9	38	77.1	0.30	0.08
80 - 84.9	12	82.4	0.29	0.05
85 - 89.9	1	85.5	0.28	-
	Σn = 744		Mean Hg = 0.23	

Based on the assumption of normal distribution, the 95% confidence interval is indicated calculated and shown in Figure 4.4 as the upper and lower limits of the error bar. These error bars are determined by adding and subtracting the margin of error to the mean Hg concentration (i.e. $\text{Mean} \pm 1.96\,\sigma/\sqrt{n}$), where σ is the standard deviation and n is the number of samples. In Figure 4.4, a linear equation of mercury concentration, Hg, as a function of length (cm), L, could be used to define the fish's Hg concentration with 0.92 in regression value. As this value is close to 1, the best fit curve which accurately represents the set of data is given as:

$$Hg\ (ppm) = 4.0\times10^{-3}\ L - 1.9\times10^{-2} \qquad \text{Eq. [4.1]}$$

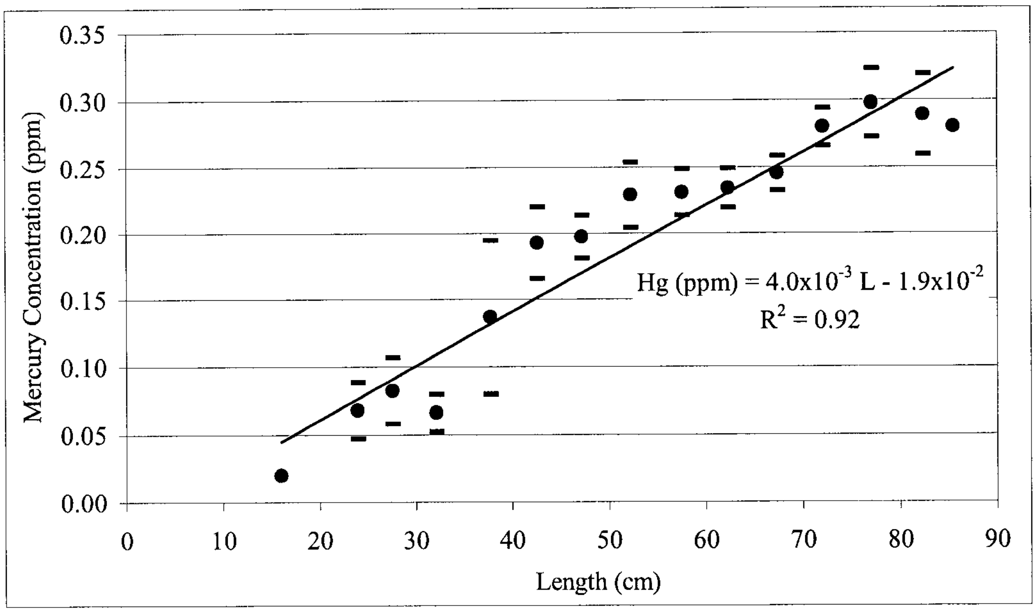


Figure 4.4 Average mercury concentrations in different sizes of Lake Trout

The same statistical method was applied to the other six fish species and plotted in Figure 4.5. Since different diet habits drive the mercury levels in fish bodies, fish accumulate Hg in different rates depending on their food consumption. Top predators, such as Northern Pike and Walleye, rely on other fish as food, tending to have higher Hg levels than do Chinook Salmon feeding on organisms low down the food chain. In other words, a steeper slope of mercury concentration should be shown in fish compared to their length if they absorb the contaminant at a faster rate. In Figure 4.5, Walleye has the steepest slope. The second fish with steeper slope is Largemouth Bass.

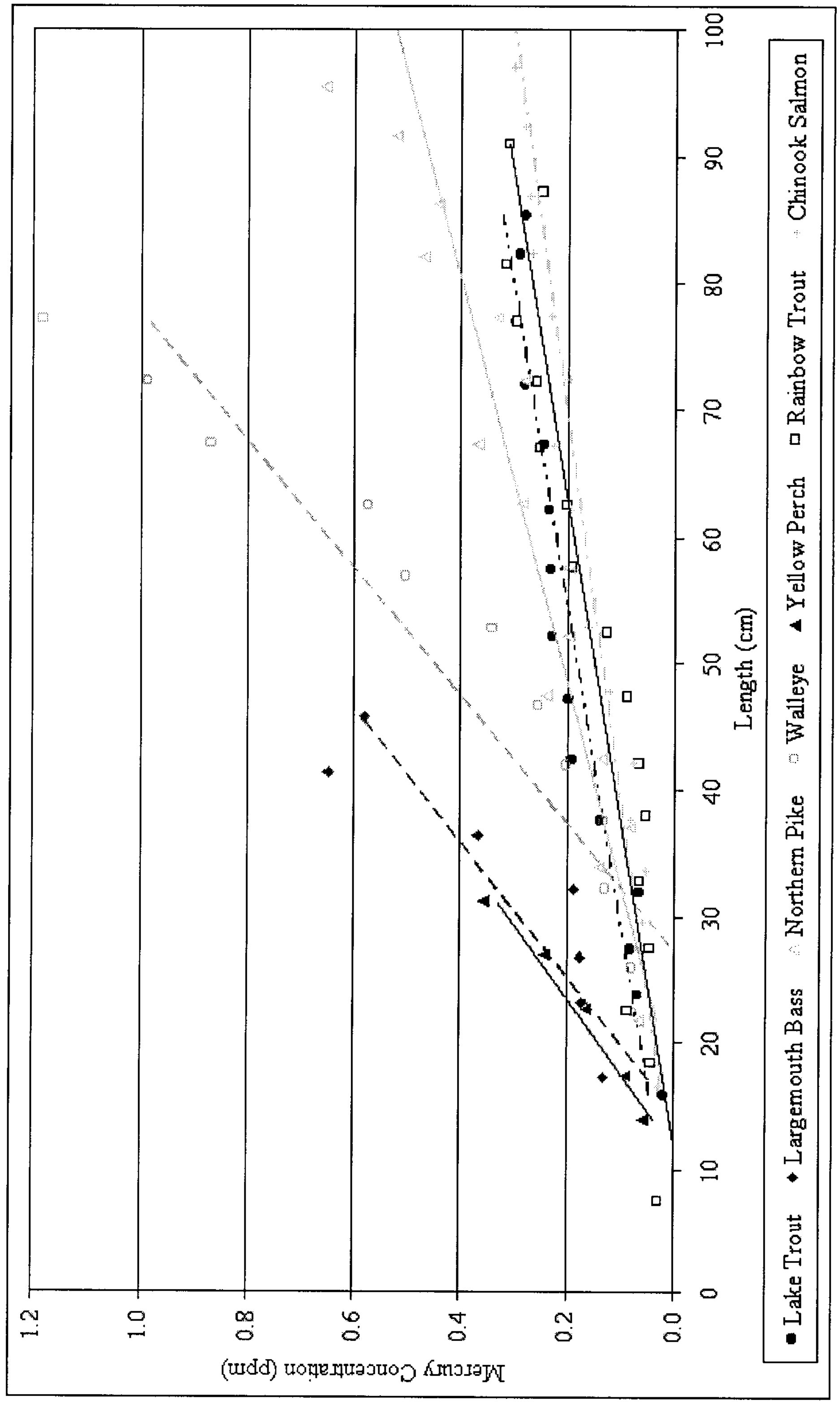


Figure 4.5 Average mercury concentrations in different sizes of seven fish species

Comparatively, Yellow Perch, Northern Pike, Lake Trout and Rainbow Trout accumulate lower mercury concentrations according to their length. The shallowest slope belongs to Chinook Salmon. A similar trend is observed, with more than 95 % consistency, if the rates of mercury accumulation in Table 4.5 are cross-refereed with the predatory level evaluated by a fish's referenced diet composition.

Table 4.5 Comparison of fish predatory levels

Predatory Level	**Fish Species**		**Observed Mercury Accumulation**	**Predatory Level**
↑	Walleye		Walleye	↑
	Largemouth Bass		Largemouth Bass	
	Northern Pike		Yellow Perch	
	Yellow Perch		Northern Pike	
	Lake Trout		Lake Trout	
	Rainbow Trout		Rainbow Trout	
	Chinook Salmon		Chinook Salmon	

In order to compare the curves, Figure 4.5 is divided into three figures: Figures 4.6, 4.7 and 4.8. In Figure 4.6, Largemouth Bass follow a similar trend of data distribution as the Yellow Perch. However, the sample numbers of Largemouth Bass are less than 50 in the past 25 years, indicating the data set is not quantitative. Remarkably, fish accumulate mercury at different rates even though they belong to one family. If the fish species is more active, it ingests more food and accumulates a higher level of mercury. In Figure 4.6, the mercury concentration is expressed as a function of the relative length of each species, which is defined as the ratio of the length to the maximum size. This representation will help to identify more clearly the effect of trophic level position on accumulation. As observed from the figure, Walleye, which occupied the highest trophic position, exhibits the highest mercury accumulation. This is followed by Largemouth Bass, and then Yellow Perch, exactly in the same descending order of trophic level as given in table 4.5. Therefore, it may be concluded that the higher trophic level fish will usually experience more Hg contamination that those at the lower end of the food chain.

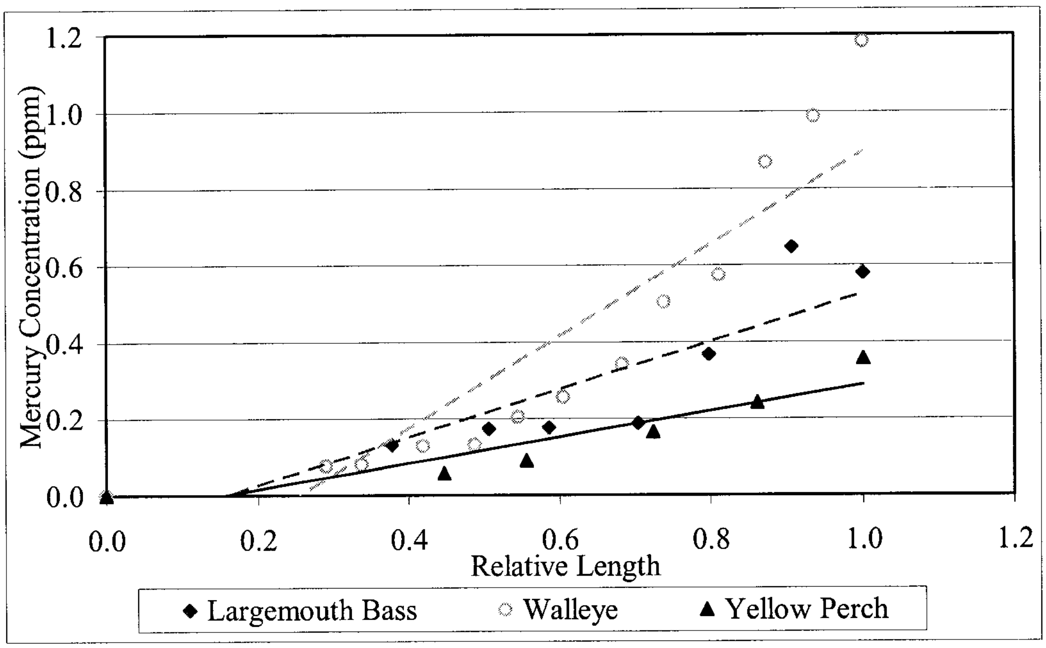


Figure 4.6 Mercury trends of Largemouth Bass, Walleye and Yellow Perch

For most frequently caught fish in Lake Ontario with similar size, such as Lake Trout, Rainbow Trout and Chinook Salmon in Figure 4.7, their mercury concentrations are alike. These three species absorb similar levels of mercury since their eating habitats are close to each other. Therefore, the same sizes of these sport fish are assumed to accumulate the same levels of a particular contaminant. Figure 4.8 is the best evidence of how fish eating habitats influence their mercury levels. The Walleye is an active fish, bioaccumulating a greater level of mercury than Northern Pike and Lake Trout. This result is consistent with the statistical analysis of Walleye, Northern Pike and

Whitefish's mercury levels in Ball Lake (Figure 4.9) that was conducted independently by the MOE in 1999.

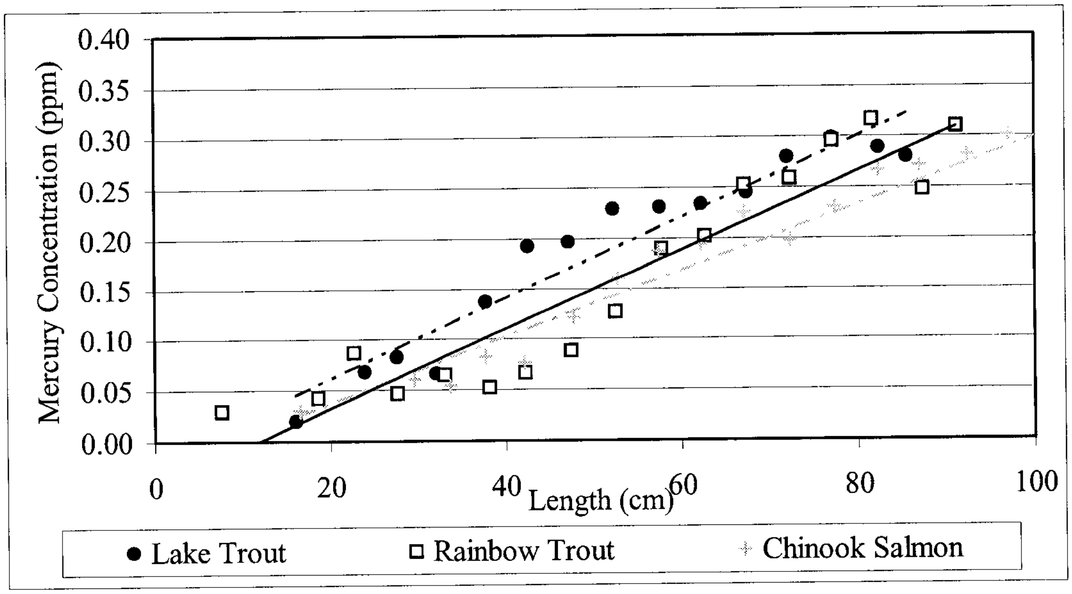


Figure 4.7 Mercury trends of Lake Trout, Rainbow Trout and Chinook Salmon

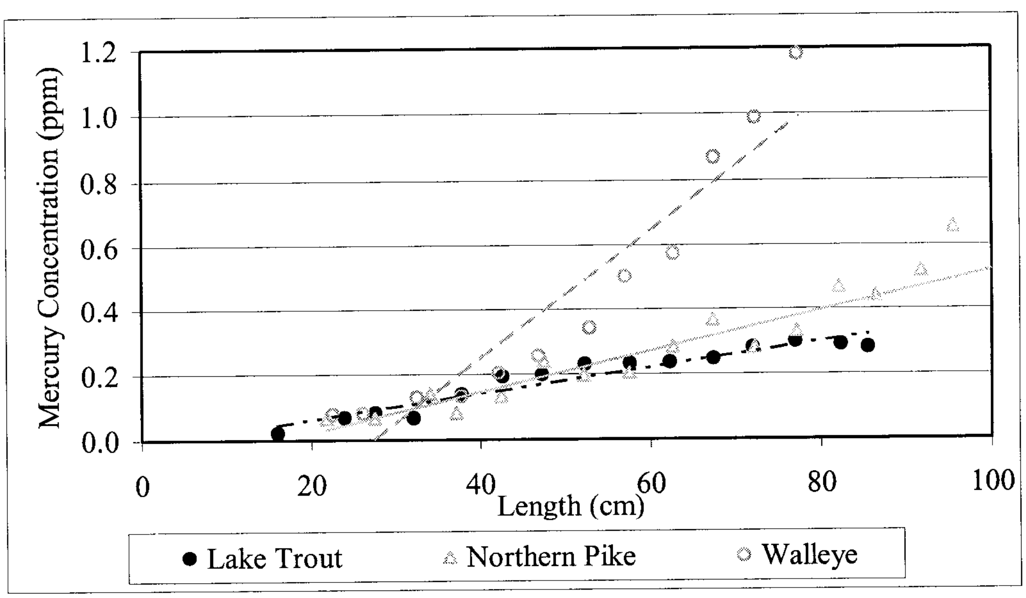


Figure 4.8 Mercury trends of Northern Pike, Walleye and Lake Trout

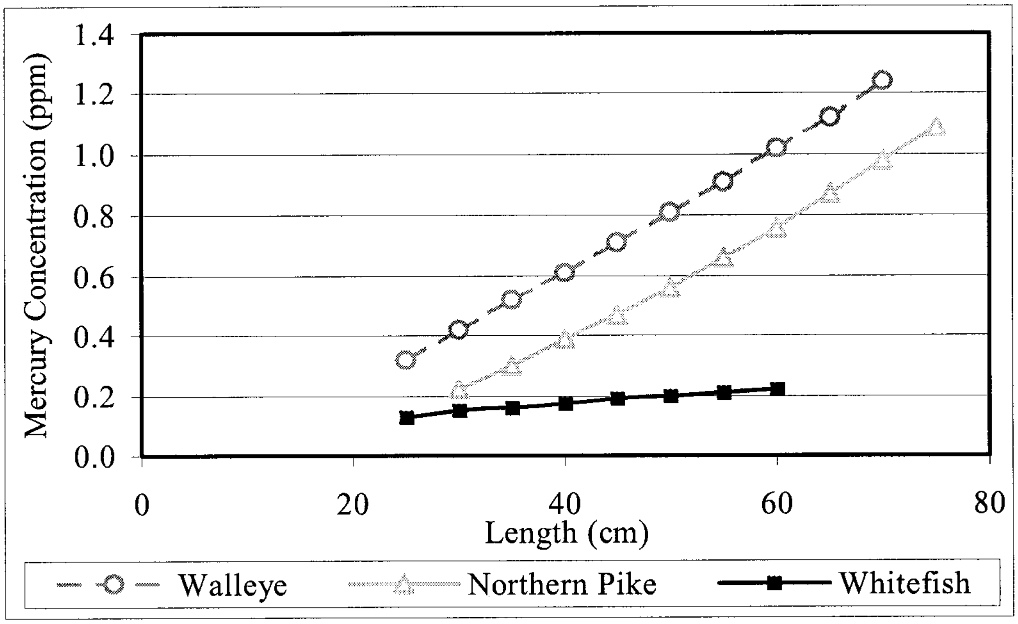


Figure 4.9 Mercury trends of Northern Pike, Walleye and Whitefish in Lake Ontario (after MOE, 1999)

Linear equations and regression values of mercury accumulation among different fish species are summarized in Table 4.6. All the fish species could be expressed by a linear best-fit curve with a high regression value, except for Largemouth Bass. Since this data set is very small and less reliable, it is discarded for the rest of the analysis. In summary, the mercury levels in fish bodies are very much influenced by their diet. Top carnivorous fish absorb mercury at a faster rate. Thus, Walleye have the highest Hg levels and Chinook Salmon the lowest. Two fish species with a similar size range and food habits could be assumed to accumulate similar levels of mercury at the same size if they belong to the same family. In general, small size fish accumulate Hg at a faster rate when the fish are small. Large size fish accumulate greater levels of Hg when they become much bigger.

Table 4.6 Linear equations of mercury accumulation among different fish species

Fish Species	**Hg Concentration (ppm)**	**Regression Value, R^2**	**Equation**
Lake Trout	$4.0x10^{-3}$ L - $1.9x10^{-2}$	0.92	Eq. [4.1]
Largemouth Bass	$1.9x10^{-2}$ L - $2.8x10^{-1}$	0.81	Eq. [4.2]
Northern Pike	$6.0x10^{-3}$ L - $1.0x10^{-1}$	0.84	Eq. [4.3]
Walleye	$2.0x10^{-2}$ L - $5.5x10^{-1}$	0.89	Eq. [4.4]
Yellow Perch	$1.7x10^{-2}$ L - $2.0x10^{-1}$	0.97	Eq. [4.5]
Rainbow Trout	$4.0x10^{-3}$ L - $4.6x10^{-2}$	0.88	Eq. [4.6]
Chinook Salmon	$3.0x10^{-3}$ L - $3.0x10^{-2}$	0.95	Eq. [4.7]

4.2 Effects of Time

Methylmercury may not only be accumulated according to fish size but also as a function of time. When a fish stays in a polluted area for a longer time, it consumes more methylmercury. Figure 4.10 shows the distribution of fish samples in a bar chart. As mentioned before, there is a lot of variation among the species. The number of samples, the mean mercury concentration and the standard deviation of Lake Trout in each year are calculated and tabulated in Table 4.7 and Figure 4.11 as examples. The field data in 1979 is less reliable, since there is only one sample. Even though the number of samples in 1978 is more than 50, the standard deviation is large, indicating the data are comparatively varied in quality. This may be due to the inaccuracy at the beginning of data collection.

The error bars are defined by using an assumption of 95% confidence under the normal distribution assumption. Smaller error bars are discovered in the years between 1980 and 1982, and in the years after 1991, meaning the data are consistent. In Figure 4.11, a sudden drop of mercury is observed in 1981 and again in 1991. The concentration of Hg in Lake Trout was unstable between 1989 and 1991. After that, the concentration gradually increased. Consistent downward trends are found in 45 cm

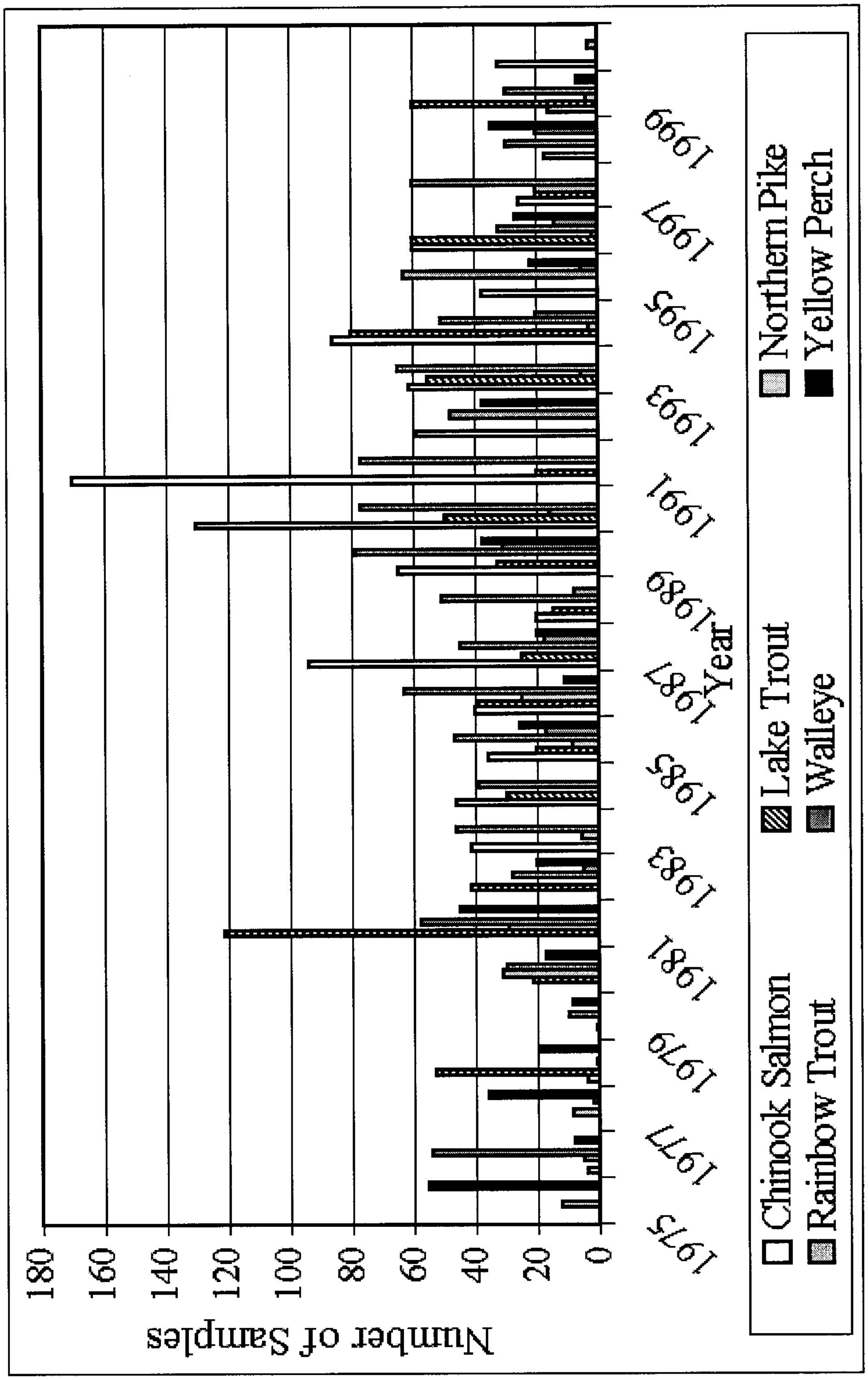


Figure 4.10 Samples size of different fish species

Table 4.7 Lake Trout's average mercury concentration

Year	Number of samples, n	Mean Hg Concentration (ppm)	Standard Deviation, σ
1978	53	0.33	0.13
1979	1	0.37	-
1980	21	0.31	0.10
1981	121	0.21	0.08
1982	41	0.26	0.07
1984	30	0.27	0.07
1985	20	0.36	0.08
1986	20	0.25	0.08
1987	25	0.31	0.08
1988	15	0.23	0.08
1989	33	0.26	0.08
1990	50	0.20	0.09
1991	20	0.12	0.06
1993	55	0.17	0.06
1994	80	0.20	0.09
1996	60	0.19	0.07
1997	20	0.20	0.04
1999	60	0.21	0.06

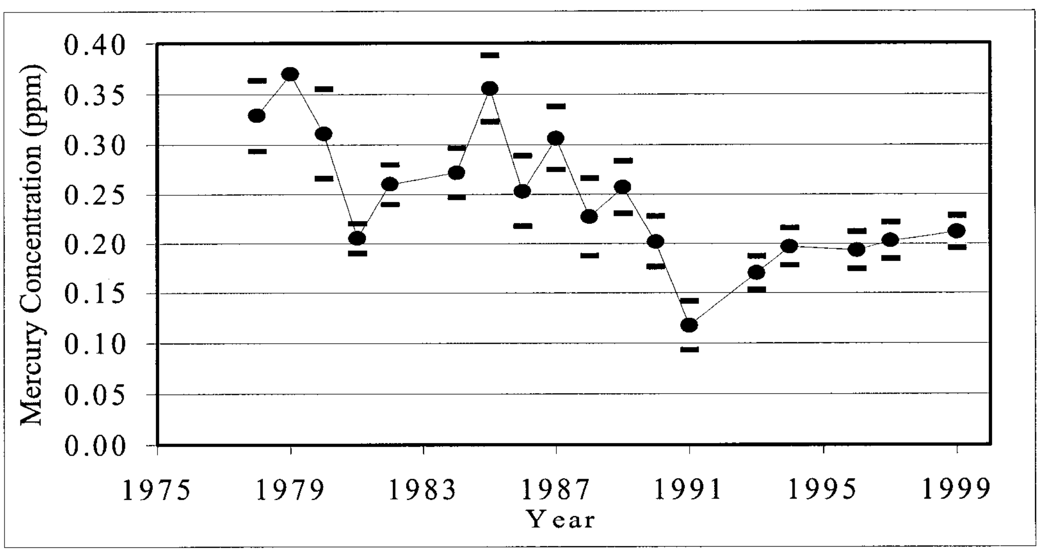


Figure 4.11 Average mercury concentration of Lake Trout

Walleye in Lake St. Clair (Figure 4.12), which were issued in the 1999 - 2000 Fish Guide. Sudden drops of average Hg concentrations in Walleye were observed in 1978, 1981 and 1991. According to the literature review, the banning of MeHg and Hg in many industries started in 1976, and most of them were halted before 1990. It is believed that these restrictions are the major reason for lowering the Hg tendency in fish.

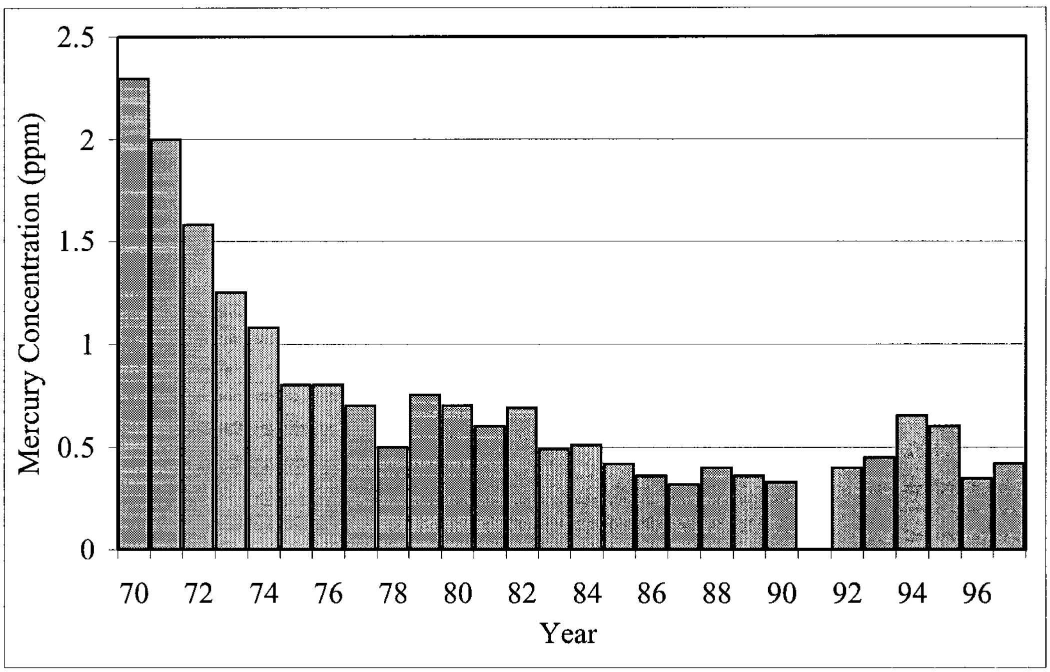


Figure 4.12 Mercury Level in 45-cm Walleye in Lake St Clair
(after MOE, 1999)

The partial banning of Hg in 1979 reduced the amount of contaminants in Lake Ontario. A sudden drop of Hg consumption rate was noticed and a great reduction of Hg concentration in fish was found. More industrial MeHg and Hg were banned in later years and an irregular Hg trend was demonstrated coincidentally. Either Hg or MeHg were completely banned in most industries in 1990, resulting in another sudden drop in the Lake Trout's Hg concentration. Even though more than 50% reduction of overall mercury has occurred; the application of the restrictions did not eliminate all pollutant sources. Mercury naturally exists in the atmosphere and is stored in sediments and waters, and consumed by algae plants and fish. Therefore, additional mercury was absorbed by Lake Trout after the year 1991. A slight decrease of Hg concentration is apparent in the year 1996. This decrease may be a general cycle of concentration adjustment that occurs every few years, adjusting the rates of consumption and clearance.

Figure 4.13 is a summary of the time distribution as it applies to other fish. It is impossible to find a consistent tendency for these six sport fish in this figure. For the purpose of comparison, the field data curves of Chinook Salmon, Lake Trout, Rainbow Trout and Yellow Perch are pulled out in Figure 4.14. Similar patterns are discovered in these four kinds of fish. They are all ranked at the lower levels of predators. Their concentrations increase and decrease at the same period of time. Mercury concentrations are influenced by contaminant levels in their food. A higher mercury contaminant is absorbed by Northern Pike than by Chinook Salmon.

As a matter of fact, a shift in the pattern of concentration between the fish is evident. While small fish have less contamination, predatory fish take time to adjust their accumulated level. Figure 4.15 demonstrates a simple example. A lower predator, Lake Trout, has a declined mercury concentration in 1981, while the top predators, such as Northern Pike and Walleye, have dropped mercury levels in the later years, 1983 and 1988. After mercury reduction had happened in Lake Trout and Northern Pike around 1991, a major decline of mercury was marked in Walleye in 1996.

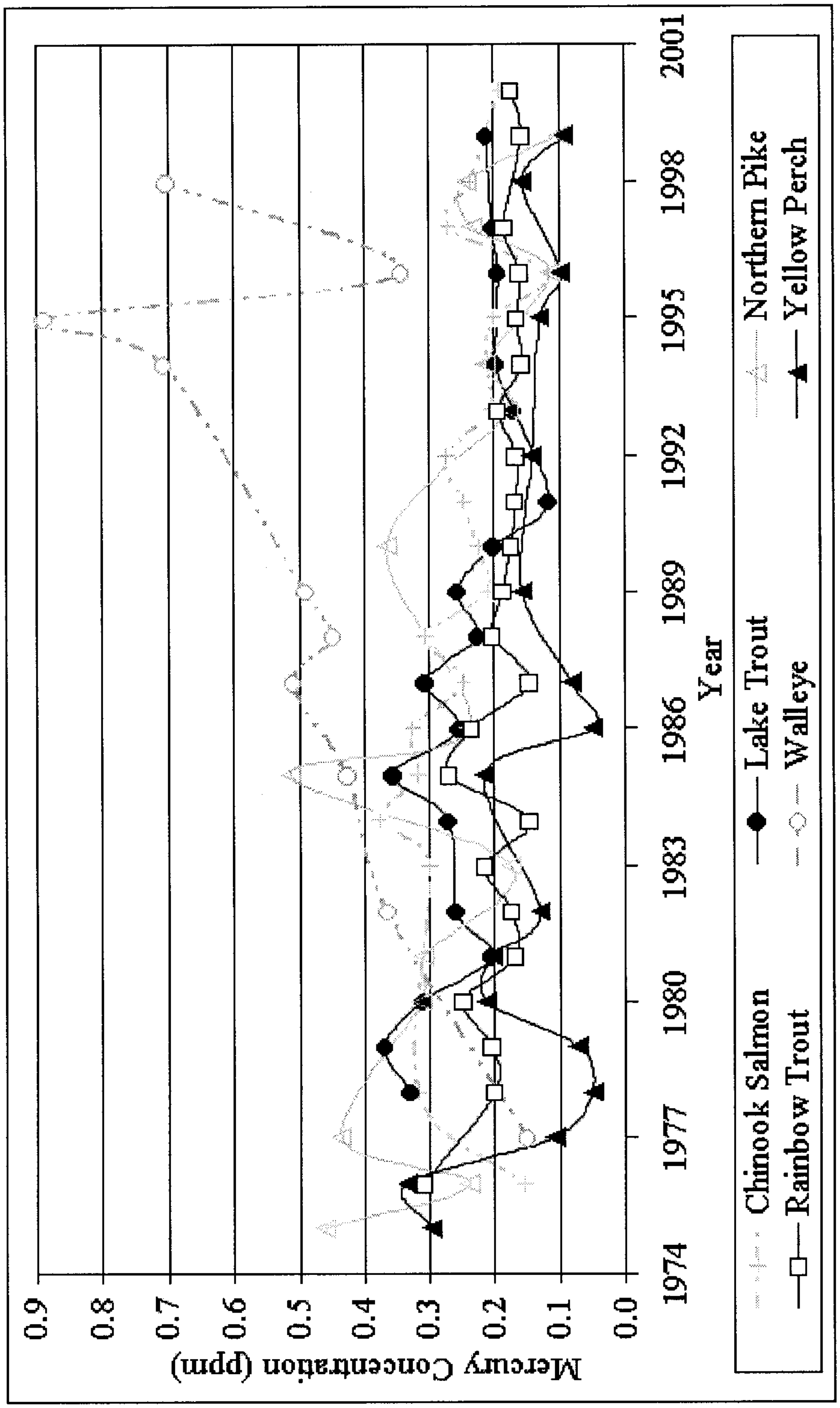


Figure 4.13 Average mercury concentrations of six sport fish species

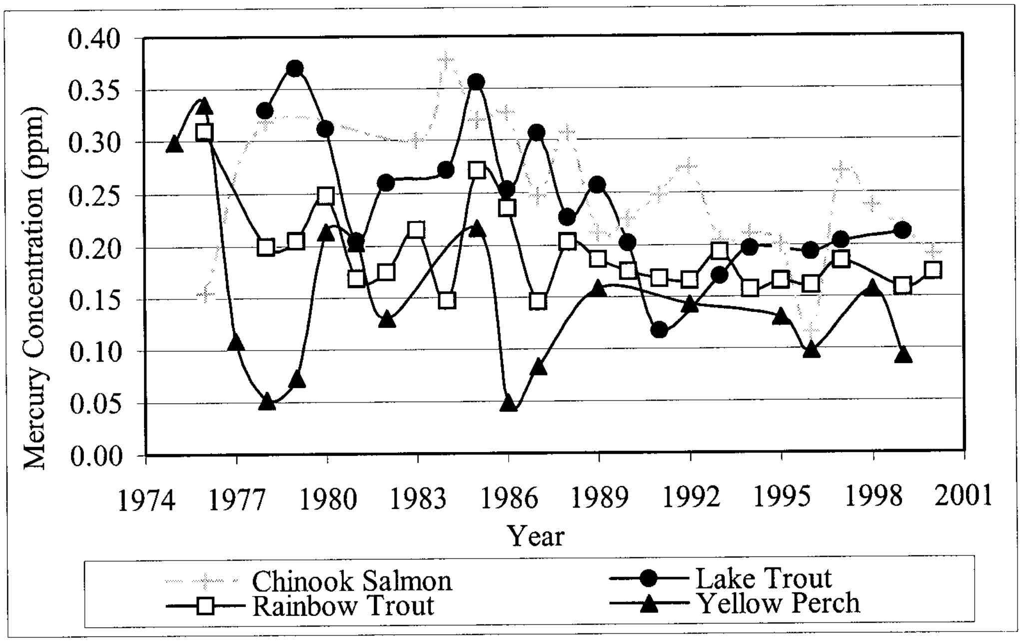


Figure 4.14 Average mercury concentrations of most-frequent-caught fish species

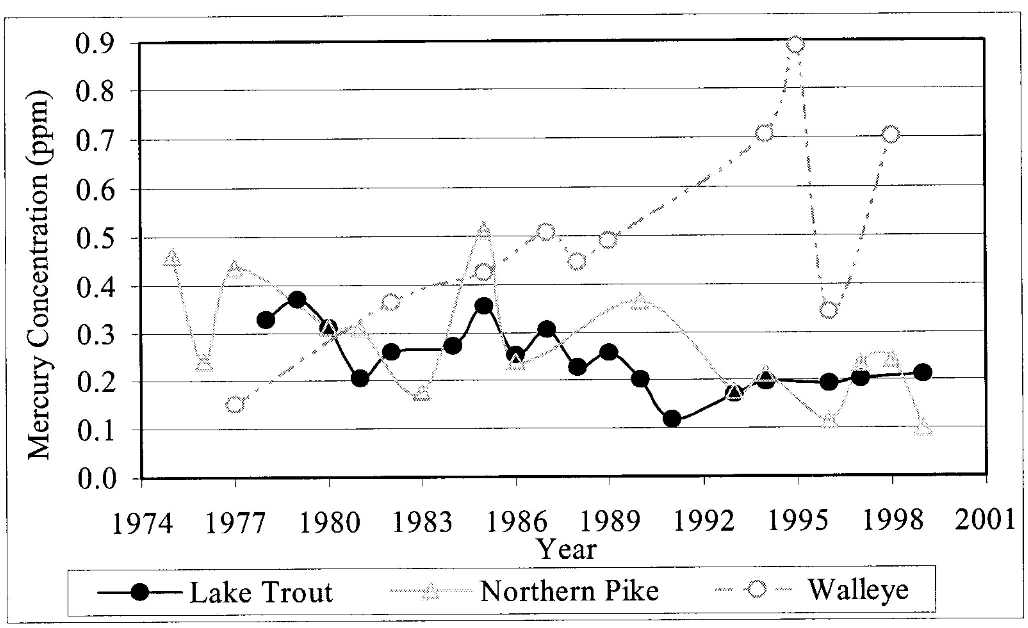


Figure 4.15 Average mercury levels of Lake Trout, Northern Pike and Walleye

In brief, a sudden drop of mercury concentration in fish is observed in 1981 and 1991 due to the enforcement of MeHg and Hg restrictions in many industries. Every few years, an adjustment in consumption and clearance rates occurred; however, the overall mercury levels in fish still gradually increasing from year to year. Under the time distribution, lower predatory fish have more immediate effects and exhibit similar patterns in their mercury concentration accumulation. Top predatory fish require one to three years to adjust their mercury levels to reflect the change in the levels of their food consumption.

4.3 Effects of Maturity

In the previous section, all the field data are utilized to perform the analysis. However, fish may not absorb as much contaminants when they are small because their diet is less contaminated. To demonstrate this, immature fish data is filtered out in the following examination. Of course, the first step is to define the mature age in fish. The normal length range of each fish species is discussed in Chapter Three. It is assumed that fish mature at one-third of their total growth length. For instance, length range of Lake Trout is from 30 to 80 cm. One third of its growth length (50 cm) is 17 cm. The mature length of Lake Trout is the adding of 30 and 17 cm, which is equal to 47 cm. Table 4.8 gives all the mature lengths in all the species. The larger is the fish size, the greater is the maturity length. The smallest mature fish size is the Yellow Perch (20 cm), while the biggest is the Northern Pike (63 cm).

Using only the mature fish data, the time distribution of all fish is re-established and formed Figure 4.16. This figure is a little different from the previous one, Figure 4.13. More steady concentrations are observed among the mature fish data. Less fluctuation is observed in the curves of Rainbow Trout, Northern Pike, Walleye and Yellow Perch. The curves of Chinook Salmon, Rainbow Trout, Lake Trout and Yellow Perch are shown in Figure 4.17. They are the most frequently caught fish with more than 200 samples, and therefore demonstrate a consistent trend of time distribution in every year, especially for the Trout species. Major mercury drops are still observed in the early 1980s and 1990s.

Table 4.8 Mature lengths of six fish species

Fish Species	**Length Range (cm)**	**Mature length (cm)**
Chinook Salmon	30 - 100	53
Lake Trout	30 - 80	47
Northern Pike	45 - 100	63
Rainbow Trout	15 - 75	35
Walleye	25 - 85	45
Yellow Perch	15 - 30	20

Predatory theory also illustrates clearly in Figure 4.18. Lake Trout accumulate a lower mercury level in 1981. A positive response of shift concentration is observed Northern Pike and Walleye in the years of 1983 and 1988. Assuming the size of caught fish is similar every year, the fish have accumulated certain levels of mercury in their bodies, regardless of attempts to eliminate the point sources of contamination. A lower fluctuation and more consistent mercury result could be confirmed if mature fish are used to conduct the analysis.

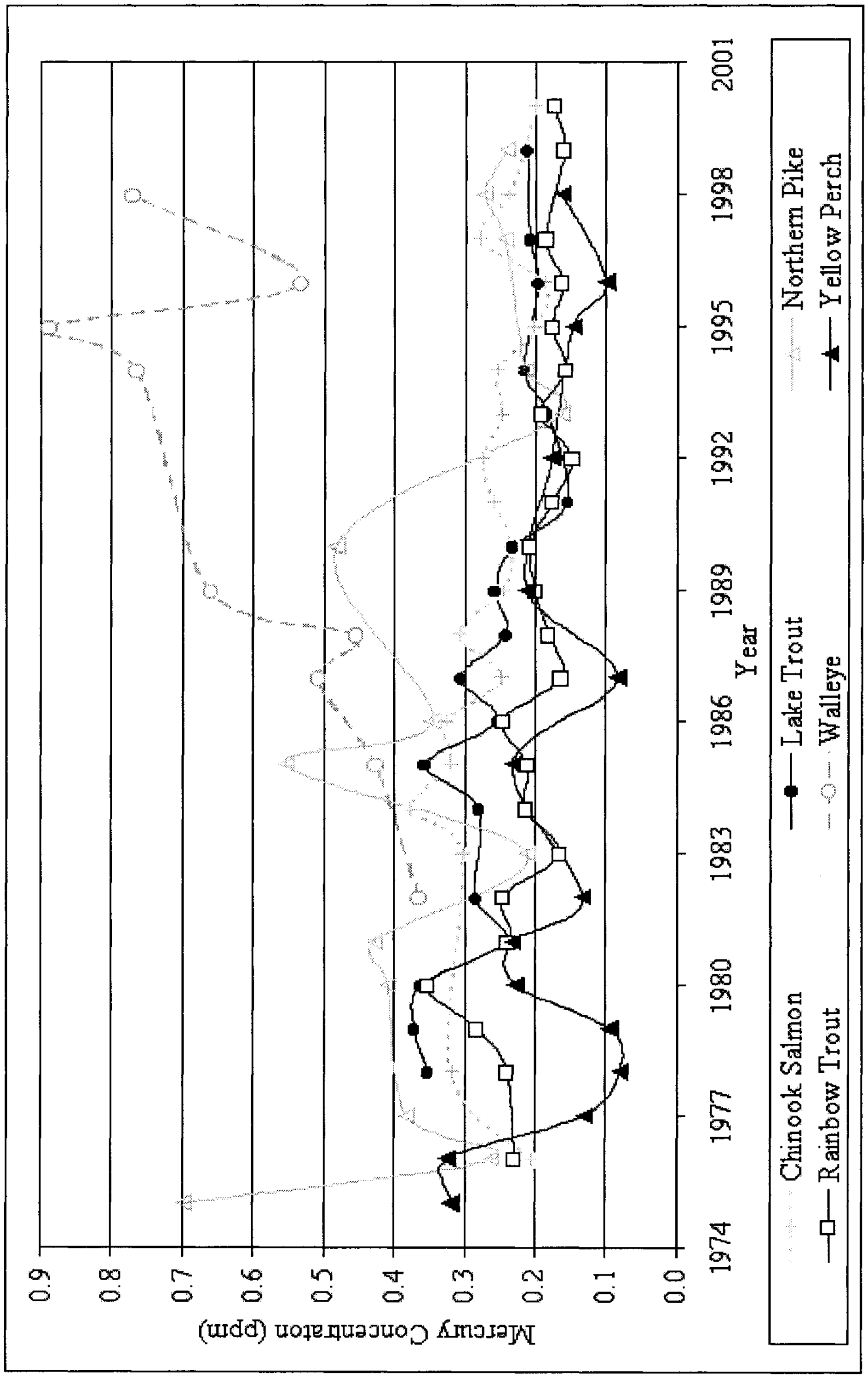


Figure 4.16 Average mercury concentrations of six mature fish

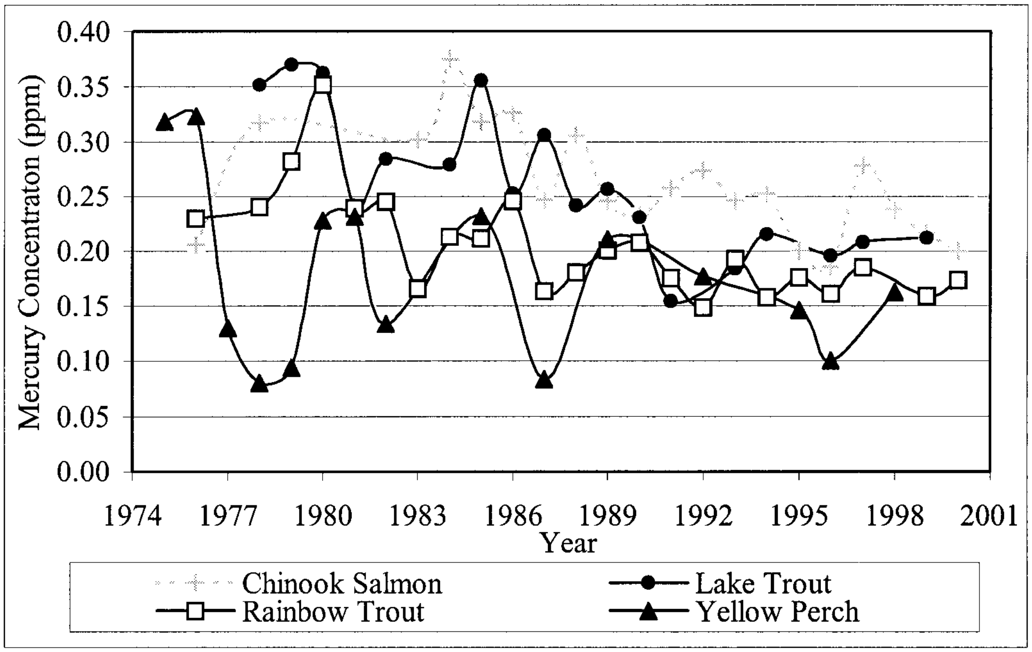


Figure 4.17 Yearly mercury trends of four mature fish species

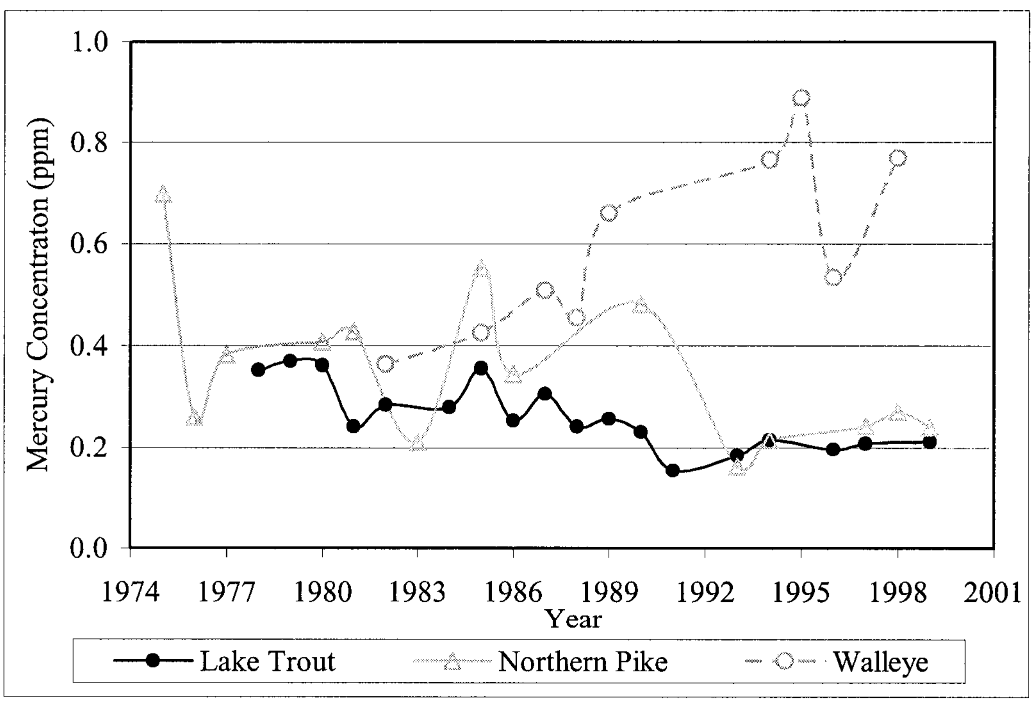


Figure 4.18 Yearly mercury trends of mature Lake Trout, Northern Pike and Walleye

4.4 Effects of Genders

Mercury concentration in fish is also influenced by gender. Based on the literature review, female fish are believed to contain a lower Hg concentration than males after they mature. The field data from the Ministry of Environment is obtained from the mercury concentration stored in fish muscle. Male fish usually develop more muscle tissue and have higher mercury levels. On the other side, female fish release certain amounts of Hg when laying eggs, which decreases their overall body levels of Hg. In order to observe the effect of gender difference on Hg accumulation, the data is separated into two sets: male and female. By using the Lake Trout as an example, Figures 4.19 and 4.20 show the mercury levels for each gender relating to the fish's length.

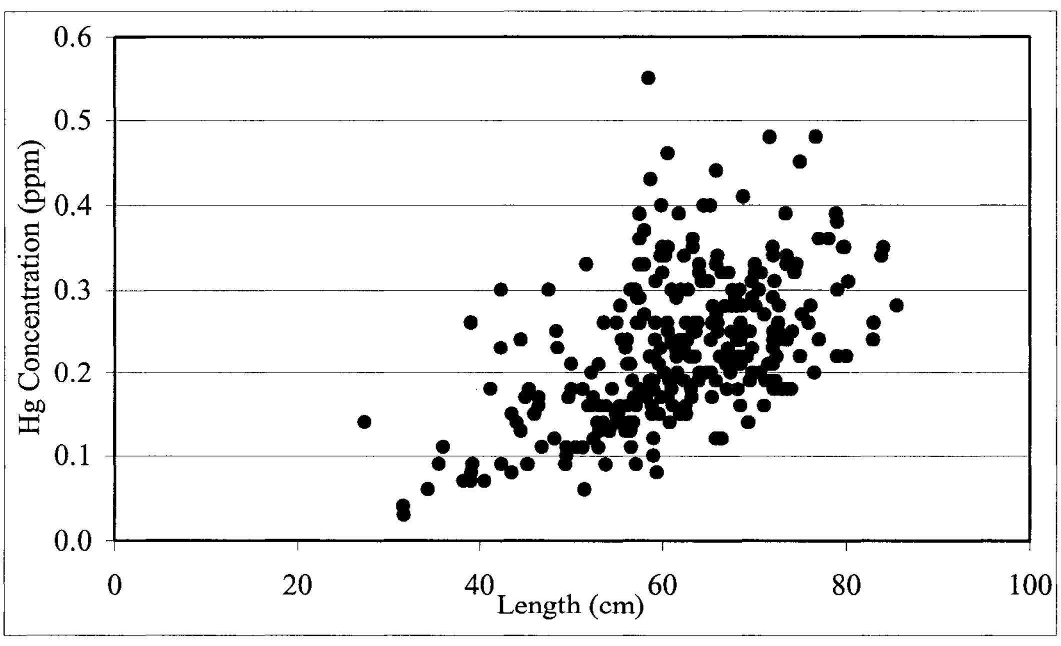


Figure 4.19 Lake Trout's male mercury concentrations according to size

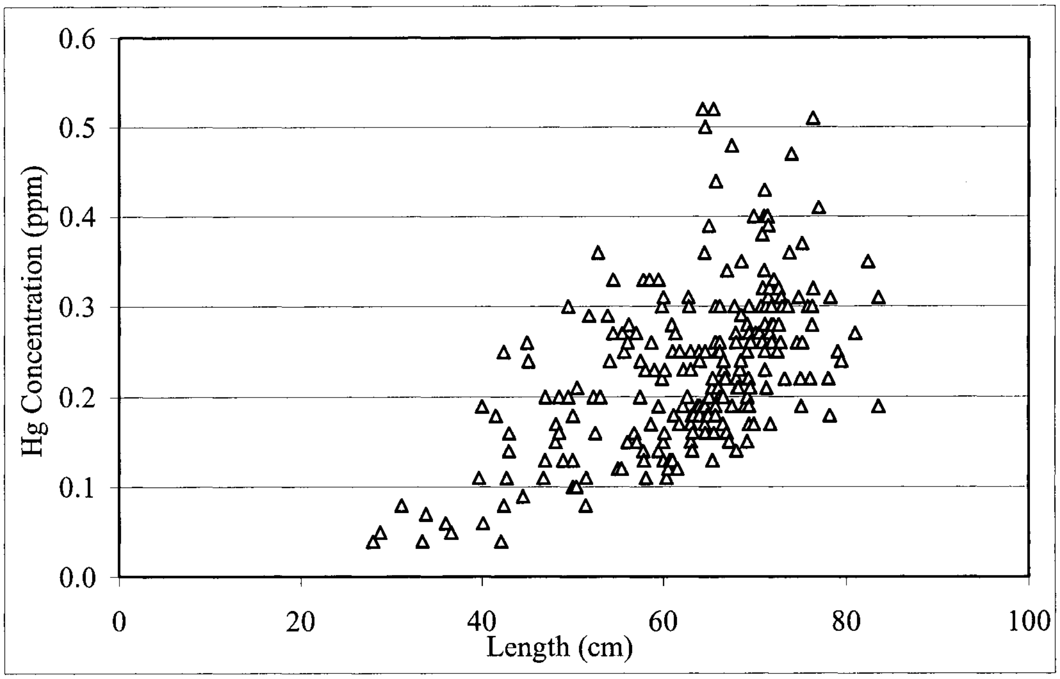


Figure 4.20 Lake Trout's female mercury concentrations according to size

A positive correlation between mercury concentration and Lake Trout length in either male or female was confirmed. When data were combined into one figure (Figure 4.21), most male fish had higher mercury levels than females when the fish were small. The reverse condition is observed in fish bigger than 50 cm. To collate the data, the fish were divided into different length groups of the same gender. Mean length, number of samples, mean mercury concentration and standard deviation of the Lake Trout across all location before and after maturity are tabulated in Table 4.9. Male samples were collected slightly more than females, and most of the data indicates that fish have reached their maturity. The largest size and the highest Hg concentration are found in male fish.

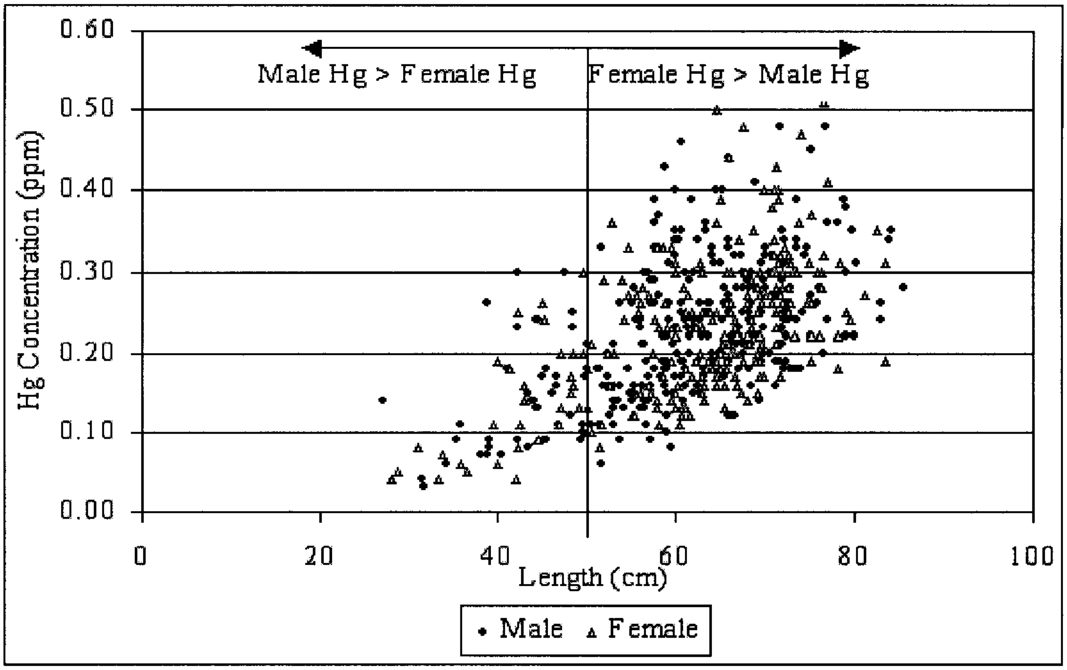


Figure 4.21 Relationship between mercury concentrations and gender of Lake Trout

Table 4.9 Gender averaged mercury concentrations in Lake Trout

	Male				Female			
Length Range (cm)	**Mean Length (cm)**	**Number of Samples**	**Mean Hg Concentration (ppm)**	**S D, σ**	**Mean Length (cm)**	**Number of Samples**	**Mean Hg Concentration (ppm)**	**S D, σ**
Before maturity								
25-29.9	27.30	1	0.14	-	28.40	2	0.05	0.01
30-34.9	32.53	3	0.04	0.02	32.77	3	0.06	0.02
35-39.9	38.00	7	0.11	0.07	37.43	3	0.07	0.03
40-44.9	42.87	10	0.16	0.08	42.17	10	0.13	0.07
45-49.9	45.84	8	0.14	0.04	45.63	3	0.20	0.08
After maturity								
45-49.9	48.84	8	0.17	0.08	48.37	9	0.18	0.05
50-54.9	52.48	26	0.16	0.06	52.08	16	0.20	0.09
55-59.9	57.71	58	0.23	0.09	57.62	27	0.22	0.07
60-64.9	62.15	55	0.25	0.07	62.60	44	0.21	0.09
65-69.9	67.40	56	0.25	0.07	67.51	57	0.25	0.08
70-74.9	72.08	42	0.26	0.07	71.95	38	0.30	0.06
75-79.9	77.37	16	0.32	0.08	76.75	16	0.29	0.09
80-84.9	82.32	6	0.29	0.05	82.60	4	0.28	0.07
85-89.9	85.50	1	0.28	-	-	-	-	-

Figures 4.22 and 4.23 are used to show the tendency curves of gender before and after maturity. The curve of the Lake Trout is very unstable for the immature males but demonstrates a clear exponential rise of Hg for the females. A more consistent pattern is observed when Lake Trout reaches maturity. Both females and males experience similar trends in the relationship between mercury concentrations and body lengths.

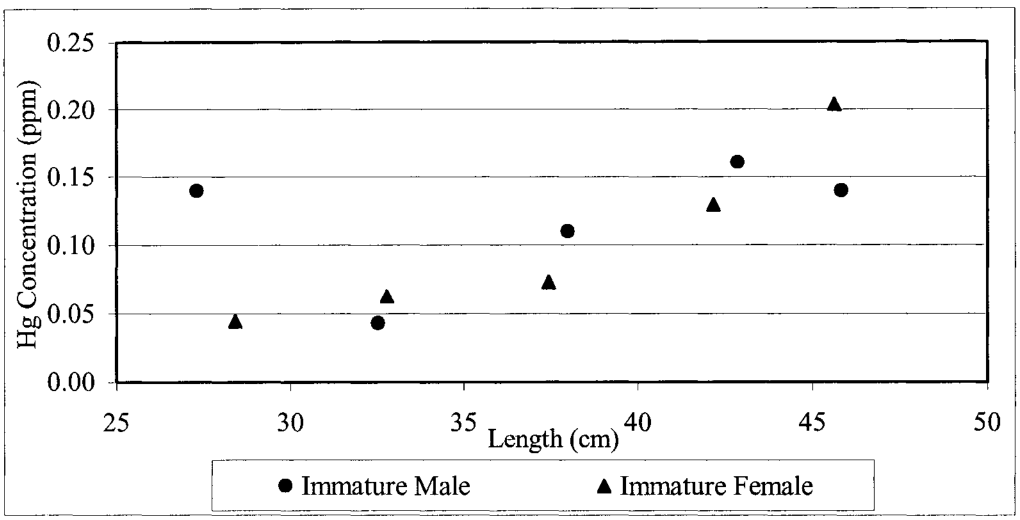


Figure 4.22 Averaged mercury concentrations of immature Lake Trout

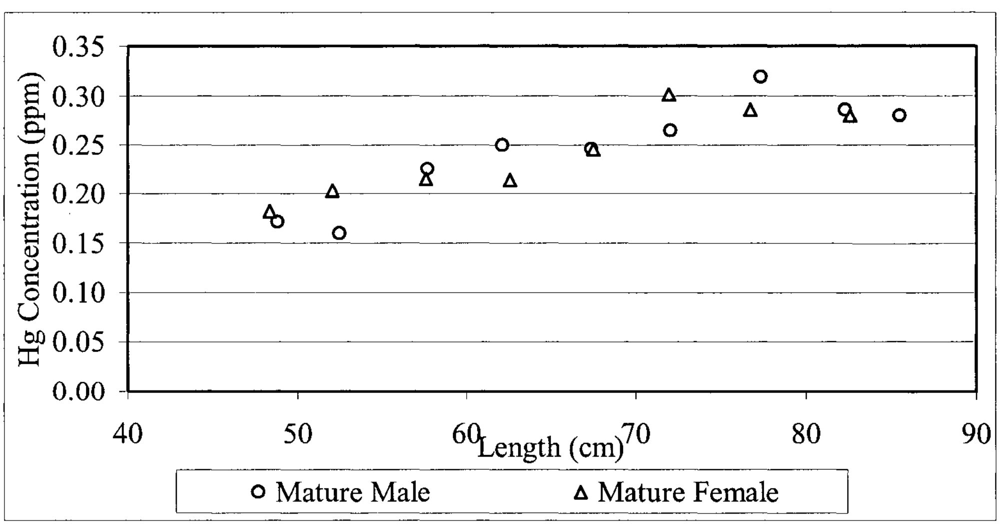


Figure 4.23 Averaged mercury concentrations of mature Lake Trout

If this analysis is applied to other fish, similar observations are detected. First, all the male and female field data are inspected in Figures 4.24, 4.25, 4.26, 4.27 and 4.28. Most data of Northern Pike and Walleye are from females when the fish become bigger. Bigger female fish are caught through the Sport Fish Contaminant Monitoring Program. The most important observation from the data is that many male fish have higher mercury levels than females when they are smaller than a certain size, but the situation is reversed thereafter. This cut-off length is observed as 65 cm, 65 cm, 40 cm, 55 cm and 22 cm in Chinook Salmon, Northern Pike, Rainbow Trout, Walleye and Yellow Perch, respectively.

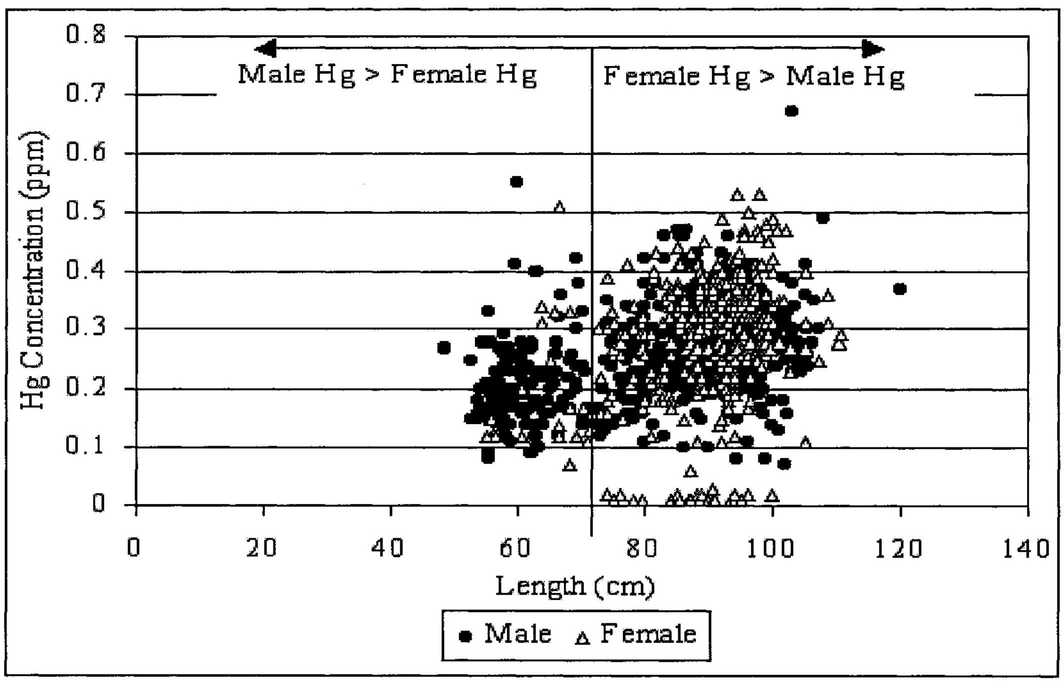


Figure 4.24 Relationship between mercury concentrations and gender of Chinook Salmon

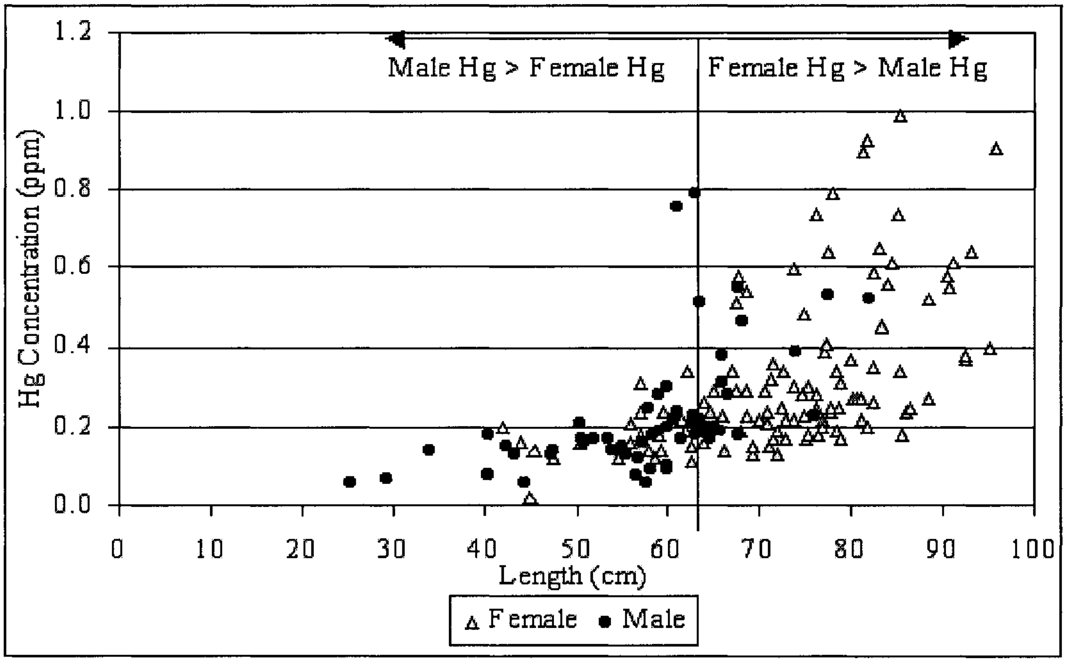


Figure 4.25 Relationship between mercury concentrations and gender of Northern Pike

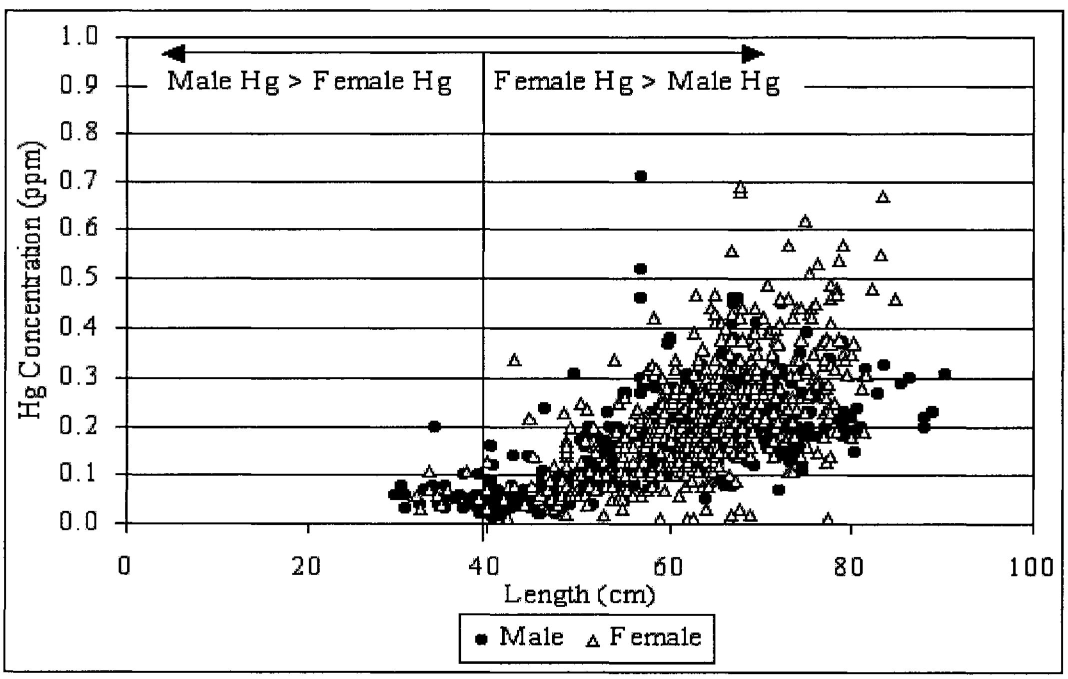


Figure 4.26 Relationship between mercury concentrations and gender of Rainbow Trout

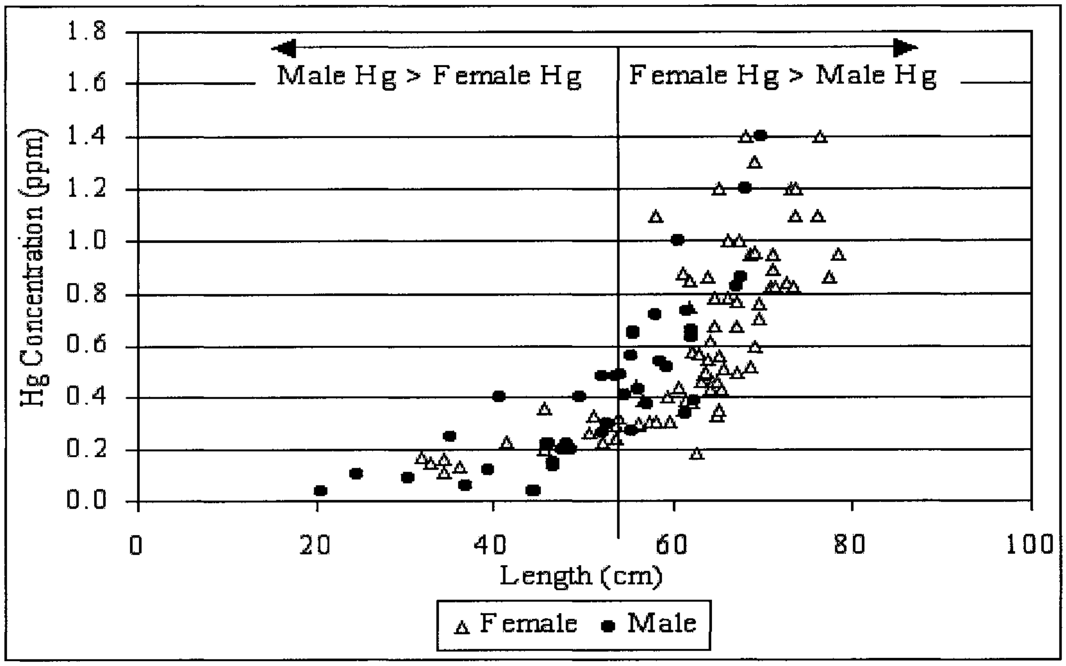


Figure 4.27 Relationship between mercury concentrations and gender of Walleye

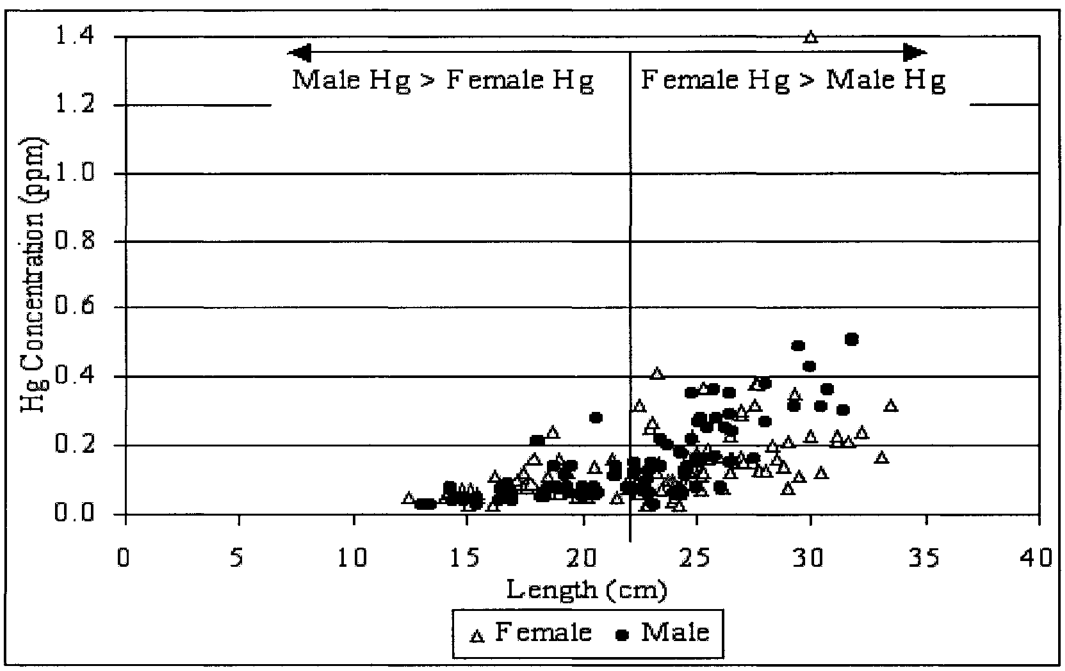


Figure 4.28 Relationship between mercury concentrations and gender of Yellow Perch

These sizes have been plotted as separation lines in the figures. When the changing point was compared to each fish's mature length in Table 4.10, they were very similar, with less than a 20% difference. When the female fish mature and become pregnant, they consume large amounts of food and mercury. They release some Hg when laying eggs, but the amounts of mercury transferred from generation to generation may be comparatively small. In summary, female fish have higher levels of mercury in their bodies than males do after maturity, which is totally opposite to the theory discussed in the literature review. It indicates that pregnant fish consuming mercury from food have a more significant effect than mercury elimination from spawning.

Table 4.10 Comparison of fish cut-off and mature length

Fish Species	**Cut Off Length (cm)**	**Mature length (cm)**	**Percent Difference (%)**
Chinook Salmon	65	53	18.5
Lake Trout	50	47	6.0
Northern Pike	65	63	3.1
Rainbow Trout	40	35	12.5
Walleye	55	45	18.2
Yellow Perch	22	20	9.1

The same statistical calculation was applied to five fish species; mean lengths and mercury concentrations are arrayed in Tables 4.11 and 4.12. Bigger male fish can be found in most of the sport fish. In Chinook Salmon and Rainbow Trout, very few data are found in immature fish. Each fish's data points are plotted in Figures 4.29, 4.30, 4.31, 4.32 and 4.33. In Lake Trout, Northern Pike, Walleye and Yellow Perch, there are similar patterns of mercury accumulation in the same gender before maturity.

The same conclusion cannot be reached for Chinook Salmon and Rainbow Trout, due to insufficient data available. After the fish mature, the following three observations become evident: 1. In Chinook Salmon and Lake Trout, the male fish follow similar mercury concentration trends as with the females. 2. In the Rainbow Trout, higher mercury concentrations are observed in the female fish rather than in the males. 3. By contrast, male fish accumulate more mercury in Northern Pike, Walleye and Yellow Perch than females of the same size.

Table 4.11 Average mercury concentrations of male fish species

Chinook Salmon		Lake Trout		Northern Pike		Rainbow Trout		Walleye		Yellow Perch	
Length (cm)	Hg (ppm)	Length (cm)	Hg (ppm)	Length (cm)	Hg (ppm)	Length (cm)	Hg (ppm)	Length (cm)	Hg (ppm)	Length (cm)	Hg (ppm)
Before maturity											
48.90	0.27	27.30	0.14	27.45	0.07	29.90	0.06	22.65	0.07	14.25	0.05
		32.53	0.04	34.00	0.14	32.58	0.07	30.50	0.09	17.79	0.08
		38.00	0.11	42.30	0.12			37.13	0.14		
		42.87	0.16	47.30	0.14			42.50	0.22		
		45.84	0.14	51.88	0.17						
				57.59	0.15						
				61.02	0.27						
After maturity											
53.88	0.18	48.84	0.17	63.74	0.30	38.01	0.05	47.10	0.22	22.59	0.13
57.58	0.19	52.48	0.16	66.84	0.34	42.19	0.06	53.12	0.40	26.40	0.24
62.24	0.20	57.71	0.23	74.00	0.39	47.06	0.08	56.89	0.51	30.90	0.38
67.28	0.23	62.15	0.25	76.75	0.38	52.41	0.13	61.60	0.63		
72.07	0.19	67.40	0.25	82.00	0.52	57.60	0.20	68.15	1.07		
77.40	0.23	72.08	0.26			62.78	0.19				
82.25	0.27	77.37	0.32			67.16	0.22				
87.01	0.29	82.32	0.29			72.45	0.22				
92.37	0.28	85.50	0.28			77.22	0.23				
97.16	0.29					81.23	0.24				
101.95	0.28					87.34	0.25				
105.90	0.32					90.30	0.31				
120.00	0.37										

Table 4.12 Average mercury concentrations of female fish species

Chinook Salmon		**Lake Trout**		**Northern Pike**		**Rainbow Trout**		**Walleye**		**Yellow Perch**	
Length (cm)	**Hg (ppm)**	**Length (cm)**	**Hg (ppm)**	**Length (cm)**	**Hg (ppm)**	**Length (cm)**	**Hg (ppm)**	**Length (cm)**	**Hg (ppm)**	**Length (cm)**	**Hg (ppm)**
Before maturity											
		28.40	0.05	43.70	0.13	33.64	0.06	33.38	0.15	13.88	0.06
		32.77	0.06	46.50	0.13			36.20	0.13	17.52	0.09
		37.43	0.07	52.45	0.14			41.50	0.23		
		42.17	0.13	57.70	0.19						
		45.63	0.20	62.18	0.20						
After maturity											
56.15	0.13	48.37	0.18	64.00	0.22	38.00	0.09	45.50	0.28	23.03	0.12
62.07	0.21	52.08	0.20	67.36	0.29	42.78	0.10	52.35	0.28	26.87	0.18
66.98	0.23	57.62	0.22	72.39	0.27	47.83	0.09	57.41	0.43	31.46	0.35
73.03	0.21	62.60	0.21	77.25	0.33	52.60	0.12	63.00	0.54		
77.28	0.22	67.51	0.25	82.10	0.47	57.80	0.19	67.39	0.83		
82.50	0.26	71.95	0.30	86.34	0.44	62.68	0.21	72.36	0.99		
86.95	0.26	76.75	0.29	91.67	0.52	67.18	0.27	77.28	1.18		
92.43	0.28	82.60	0.28	95.45	0.66	72.22	0.30				
96.99	0.32			102.50	0.38	77.07	0.32				
100.89	0.34					82.10	0.40				
106.30	0.29										
110.45	0.29										

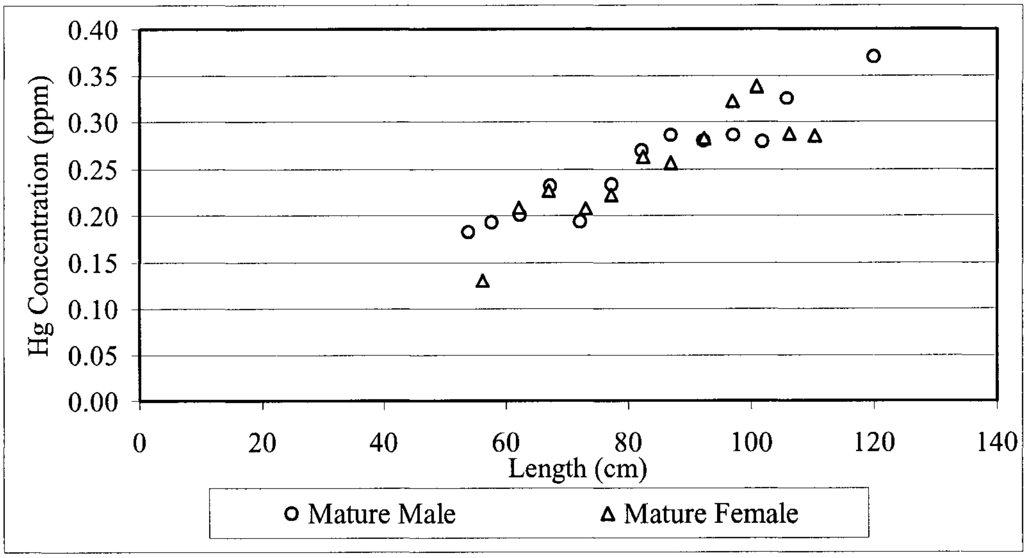


Figure 4.29 Averaged mercury concentrations of Chinook Salmon according to different maturity and gender

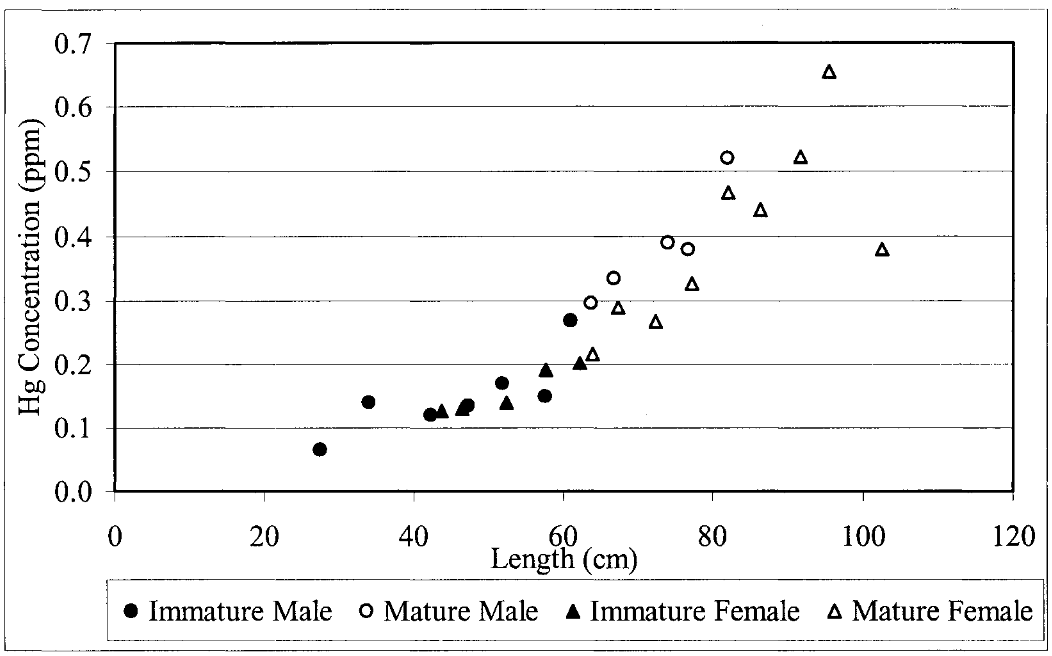


Figure 4.30 Averaged mercury concentrations of Northern Pike according to different maturity and gender

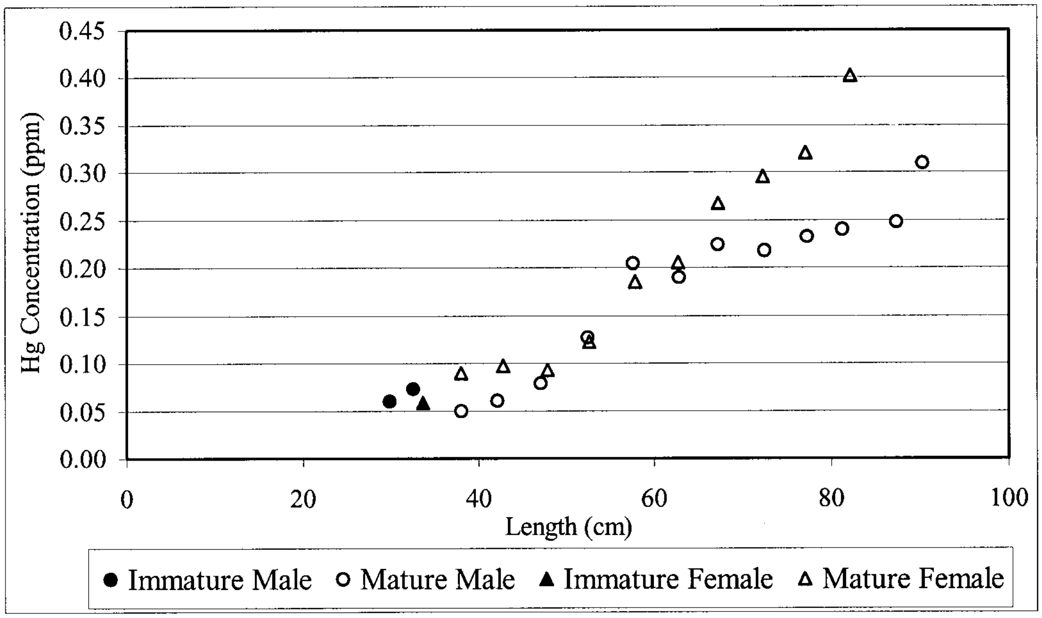


Figure 4.31 Averaged mercury concentrations of Rainbow Trout according to different maturity and gender

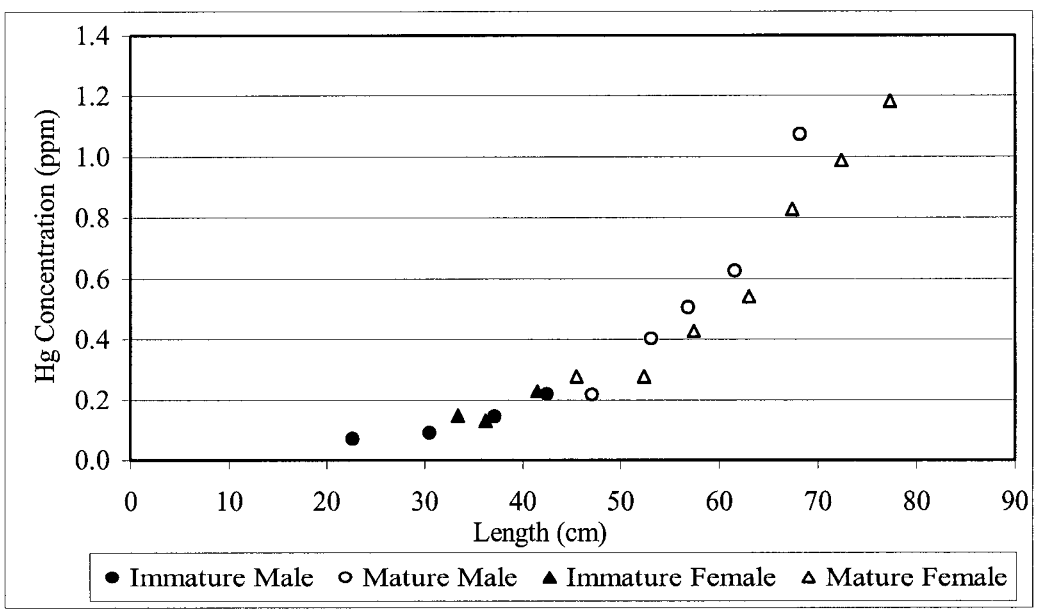


Figure 4.32 Averaged mercury concentrations of Walleye according to different maturity and gender

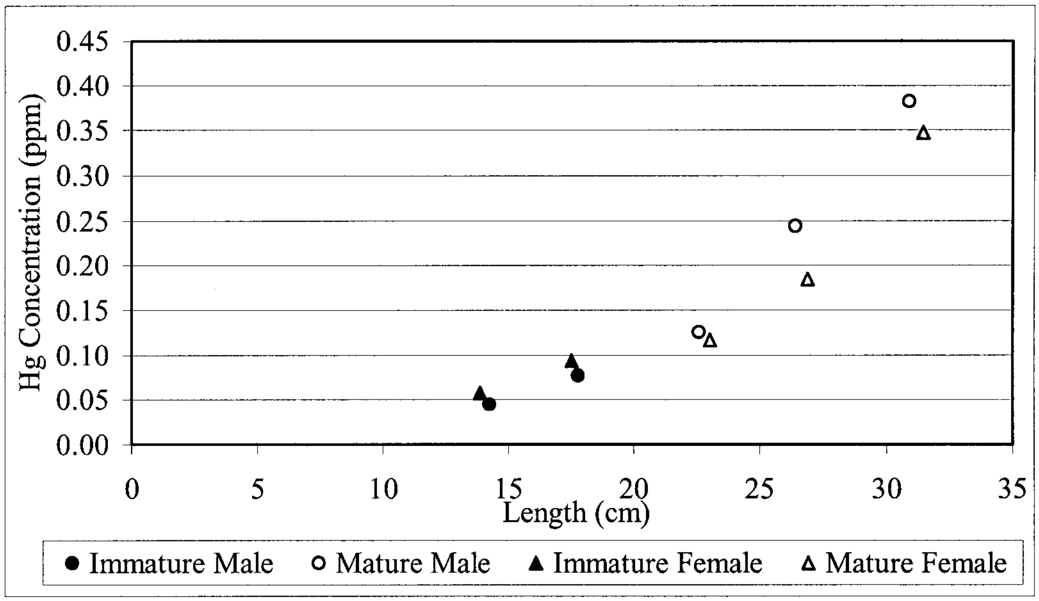


Figure 4.33 Averaged mercury concentrations of Yellow Perch according to different maturity and gender

However, these three sport fish average mercury concentrations were not significantly related to their mean length. It may be explained by habits during pregnancy. Northern Pike, Walleye and Yellow Perch's females stop eating and stay near lakeshore for a period of time before they lay eggs (Wooding, 1972). This would decline their mercury consumption and release certain amounts of mercury at the same time. In addition, the field data from the MOE record the MeHg stored in fish muscle. Male fish usually develop more muscle tissue and a higher level of MeHg. In brief, female fish would have a lower mercury level in their bodies than in males after they become prone to pregnancy.

In conclusion, female and male fish accumulate more mercury in their bodies when they are getting bigger. Among the field data points of the six species, most of the large fish are female. Some of immature female fish tend to have a greater mercury concentration than males of the same size. When the statistical calculation was applied to all six species, an initial cross-examination between genders and maturity was conducted. A brief summary is tabulated in Table 4.13. There is no clear difference in mercury accumulation among genders before maturity. It was assumed in the literature that female fish would release some mercury during pregnancy and so male fish would tend to have slightly higher levels of mercury after maturity. However, this idea did not apply to all the fish. It therefore concluded that gender would not influence mercury bioaccumulation.

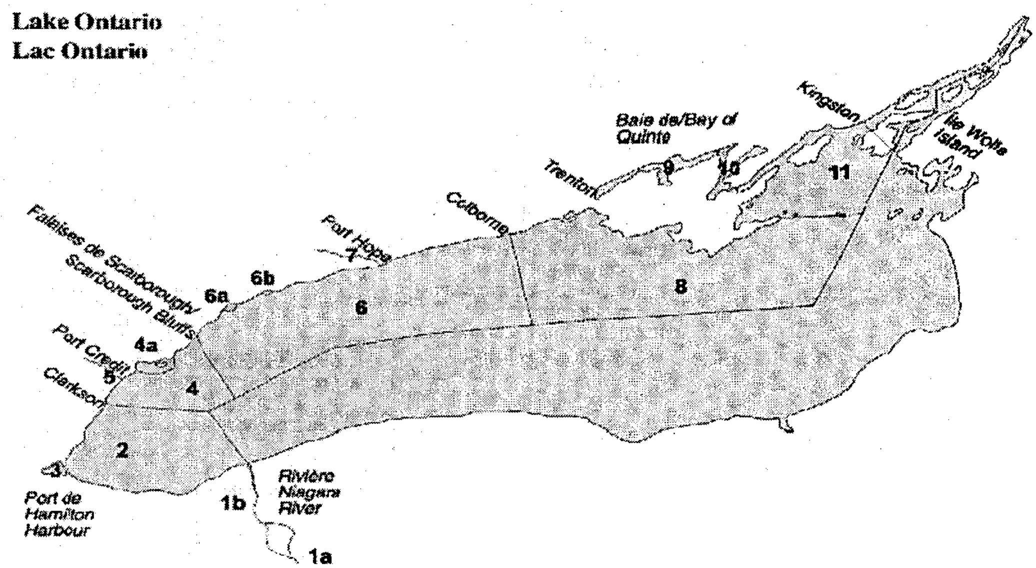
Table 4.13 Comparison of fish mercury concentrations affected by gender and maturity

Fish Species	**Before maturity**	**After maturity**
Chinook Salmon	Not applicable	Male = Female
Lake Trout	Male = Female	Male = Female
Northern Pike	Male = Female	Male > Female
Rainbow Trout	Not applicable	Female > Male
Walleye	Male = Female	Male > Female
Yellow Perch	Male = Female	Male > Female

4.5 Effects of Locations

The Ministry of Environment (2001) collects fish samples from approximately 1,700 locations in Ontario's inland lakes, rivers and the Great Lakes system every year. Figure 4.34 illustrates the eleven areas/regions in Lake Ontario. The Lower Bay of Quinte is the easternmost area and Hamilton Harbour is the westernmost area in Lake Ontario. If a fish is caught in an area near an industrial district, a greater Hg level can be detected in the fish body. According to Allard and Stokes (1989), fish living near inlets have higher concentrations of mercury because of direct pollutant sources. Even though mercury is no longer used as frequently in industries, a high level of this contaminant still remains in sediment and water that has polluted the whole area.

Lake Trout is used as an example to study the effects of mercury concentrations according to their locations. Since most fish samples are not collected in the same area, it may be too complicated to compare the fish samples for all the eleven areas. Therefore, Lake Ontario is divided into three main areas: east, west and central. Areas 1, 2, 3, 4 and 5 are arranged in Group 1 at the west end of Lake Ontario. Areas 9, 10, 11 are compiled in Group 3 at the east end of Lake Ontario. The remaining three areas located at the center of Lake Ontario is labelled as Group 2.



1a. Upper Niagara River
1b. Lower Niagara River
2. Western Lake Ontario
3. Hamilton Harbour
4. Toronto Offshore Area
4a. Toronto Waterfront Area
5. Credit River
6. Northwestern Lake Ontario
6a. Frenchman Bay
6b. Whitby Harbour
7. Ganaraska River
8. Northeastern Lake Ontario
9. Upper Bay of Quinte
10. Middle Bay of Quinte
11. Lower Bay of Quinte/Eastern Lake Ontario

Figure 4.34 Description of Lake Ontario regions for the fish monitoring program (after MOE, 2001)

In each group, sample numbers, mean length and mercury concentration in Lake Trout genders are tabulated in Table 4.14 and Figure 4.35. Most of the field data are found in Group 1 and very few data are collected in Group 3. Group 1 is the most concerned area; it covers the city of Toronto and Hamilton Harbour, which has the highest population density in Ontario. In most of the fish length ranges, greater levels of mercury are found in the males rather than in the females, respective to their lengths. When comparing the three groups, mercury concentrations in males and females (Figures 4.36 and 4.37) in Group 1 are higher than in Group 2. This is possible because the population and industry density are higher in Group 1, therefore the water at the west side of Lake Ontario is generally more polluted by mercury than at the center of Lake Ontario. The only exception is the irregular Lake Trout mercury concentration in Group 3, but this is probably due to insufficient data.

Table 4.14 Classification of Lake Trout data according to sampling area

	Male			Female		
Length range (cm)	**Sample Number**	**Mean Length (cm)**	**Mean Mercury Level (ppm)**	**Sample Number**	**Mean Length (cm)**	**Mean Mercury Level (ppm)**
Group 1: East Lake Ontario						
25-29.9	1	27.30	0.14	2	28.40	0.05
30-34.9	-	-	-	1	33.80	0.07
35-39.9	5	37.60	0.09	2	37.85	0.09
40-44.9	6	43.05	0.21	8	42.08	0.14
45-49.9	12	47.46	0.17	5	47.80	0.19
50-54.9	13	52.29	0.18	10	52.78	0.25
55-59.9	31	57.60	0.27	18	57.64	0.24
60-64.9	39	62.24	0.27	23	62.89	0.25
65-69.9	28	66.91	0.28	27	67.81	0.28
70-74.9	22	71.89	0.29	21	72.13	0.32
75-79.9	11	77.83	0.35	10	76.64	0.31
80-84.9	3	82.23	0.27	2	82.25	0.29
Group 2: Central Lake Ontario						
30-34.9	-	-	-	2	32.25	0.06
40-44.9	1	42.40	0.09	-	-	-
45-49.9	-	-	-	2	47.45	0.13
50-54.9	7	53.00	0.13	3	50.97	0.10
55-59.9	16	58.13	0.16	5	57.74	0.15
60-64.9	11	62.00	0.19	15	62.19	0.18
65-69.9	23	68.03	0.20	28	67.34	0.20
70-74.9	19	72.30	0.23	14	71.84	0.26
75-79.9	4	75.93	0.23	5	77.16	0.25
80-84.9	3	82.40	0.31	2	82.95	0.27
85-89.9	1	85.50	0.28	-	-	-
Group 3: West Lake Ontario						
30-34.9	3	32.53	0.04	-	-	-
35-39.9	2	39.00	0.17	1	36.60	0.05
40-44.9	3	42.67	0.10	1	42.10	0.04
45-49.9	4	46.98	0.12	5	47.66	0.21
50-54.9	6	52.30	0.15	3	50.83	0.16
55-59.9	11	57.42	0.21	4	57.38	0.19
60-64.9	5	61.74	0.23	6	62.53	0.18
65-69.9	5	67.22	0.27	2	65.75	0.30
70-74.9	1	72.00	0.35	3	71.23	0.38
75-79.9	1	78.10	0.36	1	75.80	0.30

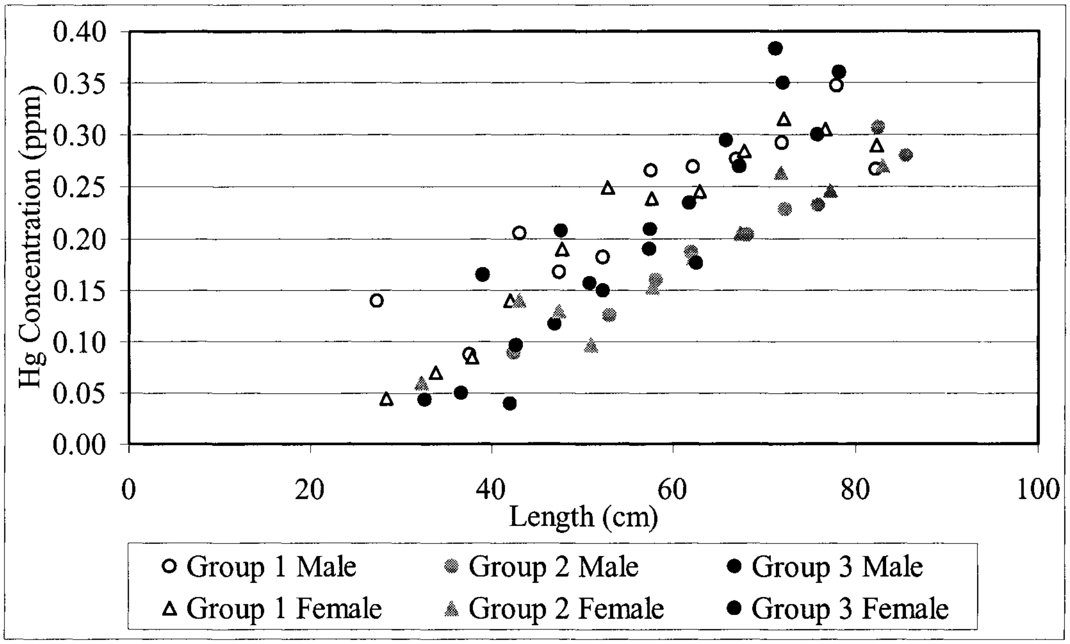


Figure 4.35 Averaged mercury levels of Lake Trout from three sampling areas by gender

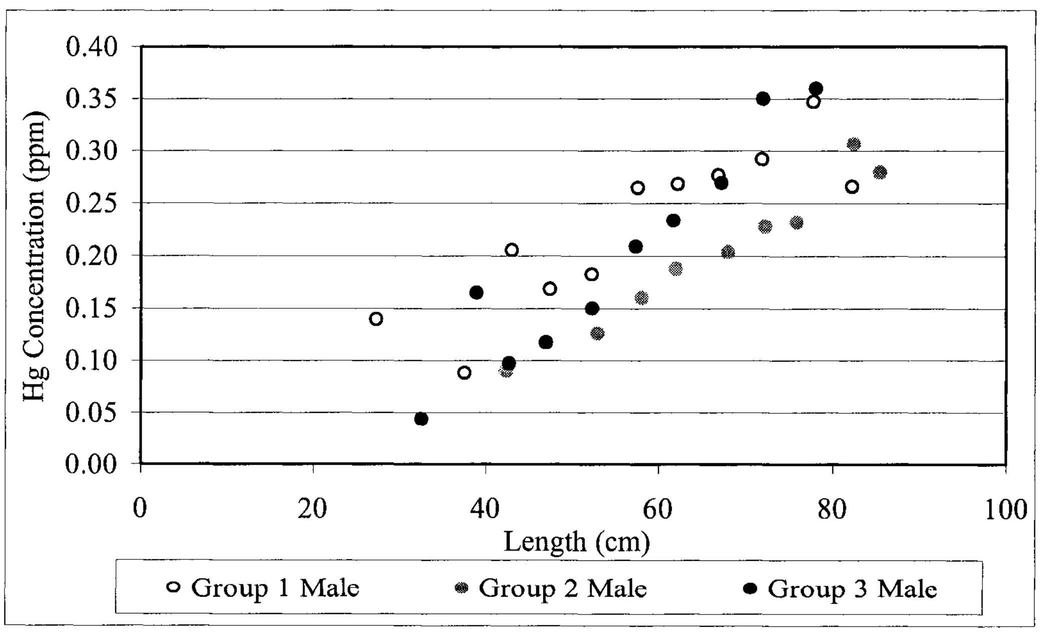


Figure 4.36 Averaged mercury levels of Lake Trout from three sampling areas in male fish

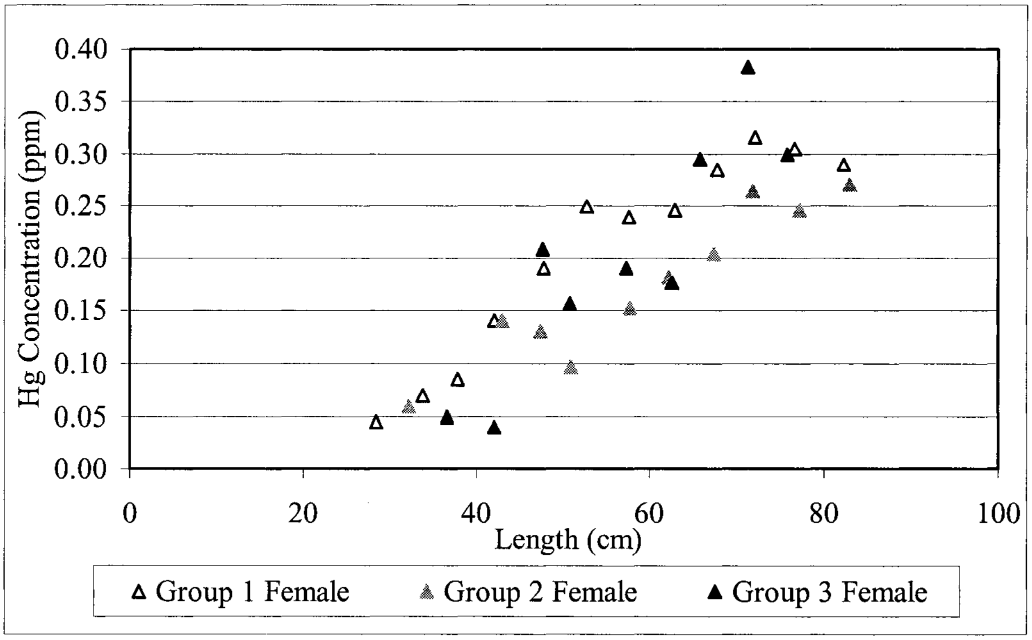


Figure 4.37 Averaged mercury levels of Lake Trout from three sampling areas in female fish

4.6 Conclusions on Observations

Mercury levels in fish's bodies can be influenced by size, diet, time, maturity, gender and location. Based on the review of the existing data, the following conclusions are drawn:

1. **Food Web**: A positive correlation between fish's length and mercury accumulation is confirmed. Due to the food selection, top carnivorous fish absorb mercury faster than low predatory fish. Similar size ranges and food selection fish species accumulate similar levels of mercury at the same size.

2. **Time**: Although mercury is tightly regulated, mercury levels in fish still gradually increase throughout their life spans. Lower predatory fish have more immediate effects and exhibit similar patterns in their mercury concentration

accumulation. Top predatory fish require a few years to adjust their mercury levels to reflect the change in the levels of food consumption.

3. **Maturity**: Since a mature fish's diet composition is more stable, a lower fluctuation and more consistent results could be confirmed if mature fish are used to conduct the analysis.

4. **Gender**: No clear distinction between the genders for mercury accumulation could be observed. The same mercury concentrations could be assumed in male and female fish of the same size.

5. **Location**: The higher-density industrial and populated areas at the west side of Lake Ontario have greater mercury levels, reflected in higher mercury accumulation in all species studied.

Chapter 5 Model Calibration and Prediction

In Section 3.4, all bioenergetics model equations were reviewed. It is necessary to collect all the parameters used in equations before applying the model. Most of the parameters can be defined through the literature. A suitable estimation is applied to the rest of them. In order to evaluate the fish's growth rate, the length range according to each species' age needs to be determined. In Section 3.2, brief descriptions of the fish's length range correlated with their age were presented. Lake Trout, as an example, have a maximum size of 73.1 cm from reference, which is 12.4 cm less than the maximum size (85.5 cm) from field data.

A fish's size is affected by the environment, since the growth rates at different locations are not the same. To calculate the field data's length range, the length ranges supplied by the MOE are multiplied by various adjustment factors. Each adjustment factor is calculated as the maximum size from field data divided by maximum size from reference in each fish species (i.e. 85.5/73.1 = 1.17 in Lake Trout). Table 5.1 shows the revised length range for Lake Trout. With this adjustment factor, the revised length range will cover the fish's length from field data. The same method is applied to the other five sport fish and all the adjustment factors are calculated.

In Table 5.2, it is obvious that the maximum size values from reference in each fish species is close to the values from field data since none of the adjustment factors is bigger than 1.20. For Chinook Salmon and Northern Pike, there is no need to apply any adjustment factors, meaning the length distributions from reference are reliable. The revised length ranges in different age of all sport fish are tabulated in Table 5.3 and Figure 5.1. The variations of fish length among different sport fish are more or less the same. All the fish species grow at a faster rate before the age of 2 and have consistent growth rates in their older age. Nevertheless, Rainbow Trout is an exception; it grows fastest between 2 and 4 years old.

Table 5.1 Revised length of Lake Trout according to adjustment factor

Age	Length Range (cm)	Adjustment Factor	Revised length Range (cm)
1	0 - 19.5	1.17	0 - 22.8
2	19.6 - 32.0	1.17	22.9 - 37.4
3	32.1 - 45.0	1.17	37.5 - 52.6
4	45.1 - 54.2	1.17	52.7 - 63.4
5	54.3 - 60.8	1.17	63.5 - 71.1
6	60.9 - 65.7	1.17	71.2 - 76.8
7	65.8 - 70.0	1.17	76.9 - 81.9
8	70.1 - 73.1	1.17	82.0 - 85.5

Table 5.2 Adjustment factor of six fish species

Fish Species	Max Size from Reference (cm)	Max Size from Field Data (cm)	Adjustment Factor
Chinook Salmon	120.0	120.0	1.00
Lake Trout	73.1	85.5	1.17
Northern Pike	103.5	103.5	1.00
Rainbow Trout	80.0	92.0	1.15
Walleye	70.6	78.3	1.11
Yellow Perch	33.4	34.3	1.03

Table 5.3 Revised length at different age of fish species

Age	Chinook Salmon (cm)	Lake Trout (cm)	Northern Pike (cm)	Rainbow Trout (cm)	Walleye (cm)	Yellow Perch (cm)
1	0 - 44.0	0 - 22.8	0 - 39.6	0 - 11.7	0 - 23.6	0 - 9.8
2	44.1 - 66.3	22.9 - 37.4	39.7 - 52.7	11.8 - 21.9	23.7 - 35.8	9.9 - 16.2
3	66.4 - 77.4	37.5 - 52.6	52.8 - 62.2	22.0 - 48.2	35.9 - 44.5	16.3 - 17.7
4	77.5 – 85.0	52.7 - 63.4	62.3 - 68.7	48.3 - 64.3	44.5 - 51.6	17.8 - 18.7
5	85.1 – 95.0	63.5 - 71.1	68.8 - 73.1	64.4 -75.9	51.7 - 57.5	18.8 - 20.7
6	95.1 - 104.9	71.2 - 76.8	73.2 - 84.5	76.0 - 83.3	57.6 - 61.7	20.8 - 22.2
7	105.0 - 120.0	76.9 - 81.9	84.6 – 87.0	83.4 – 92.0	61.8 - 64.8	22.3 - 24.5
8		82.0 - 85.5	87.1 - 89.5		64.9 - 68.2	24.6 - 26.4
9			89.6 - 96.5		68.3 - 70.4	26.5 - 29.6
10			96.4 - 103.5		70.5 - 72.1	29.7 - 31.6
11					72.2 - 73.0	31.7 - 32.2
12					73.1 - 73.8	32.3 - 33.2
13					73.9 - 74.6	33.3 - 34.3
14					74.7 - 76.1	
15					76.2 - 78.3	

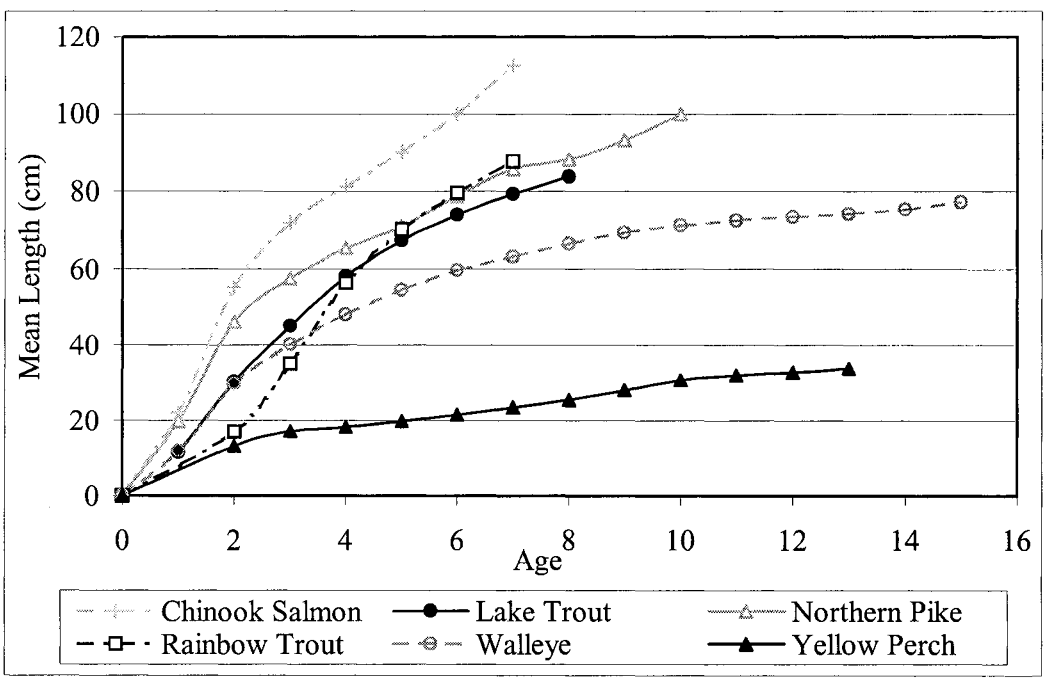


Figure 5.1 Variation of fish length among different fish species

5.1 Length - Weight Ratio

In Sub-section 3.4.1, fish length and weight are related by an exponential function. When a fish's body length and weight data are plotted in a figure, a best-fit curve can be determined in order to evaluate the length - weight parameters (a) and the length-weight ratio (b) The exponential function of all species' length - weight ratios are given in Figures 5.2 to 5.7. All the best-bit curves equations are reliable since the regression values are close to 1, higher than 0.94 in average. These equations and parameters are summarized in Table 5.4. A higher length - weight ratio is recorded in Lake Trout (b = 3.28), while Rainbow Trout (b = 2.98) has the lowest, this means that Lake Trout gain more weight than do Rainbow Trout for a given size.

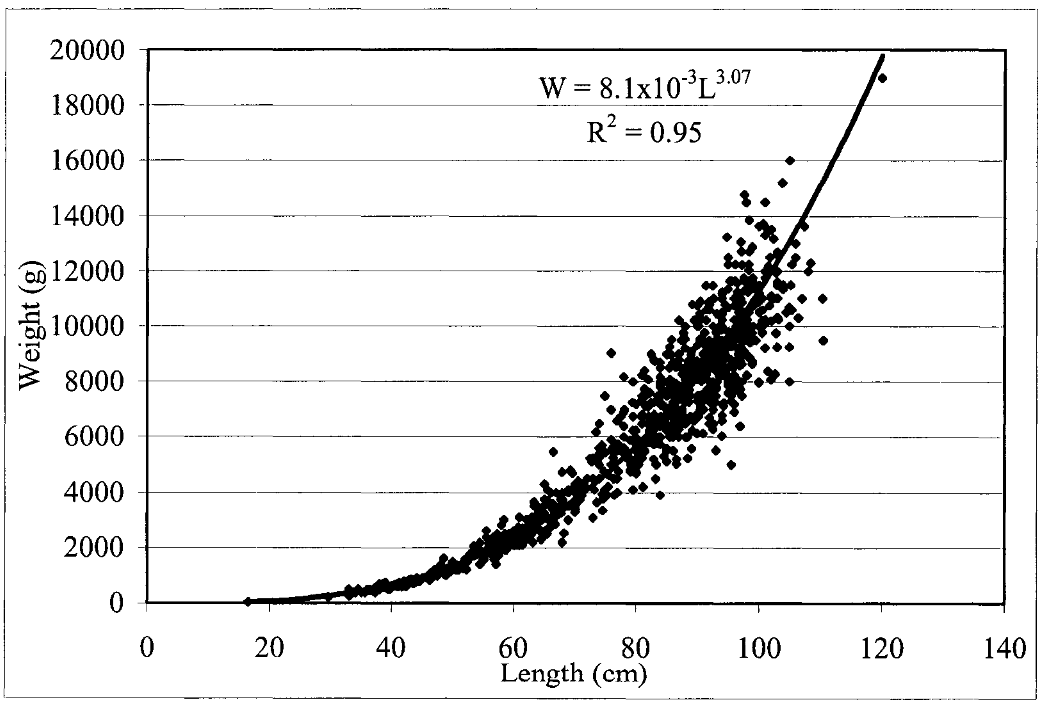


Figure 5.2 Length - weight equation of Chinook Salmon

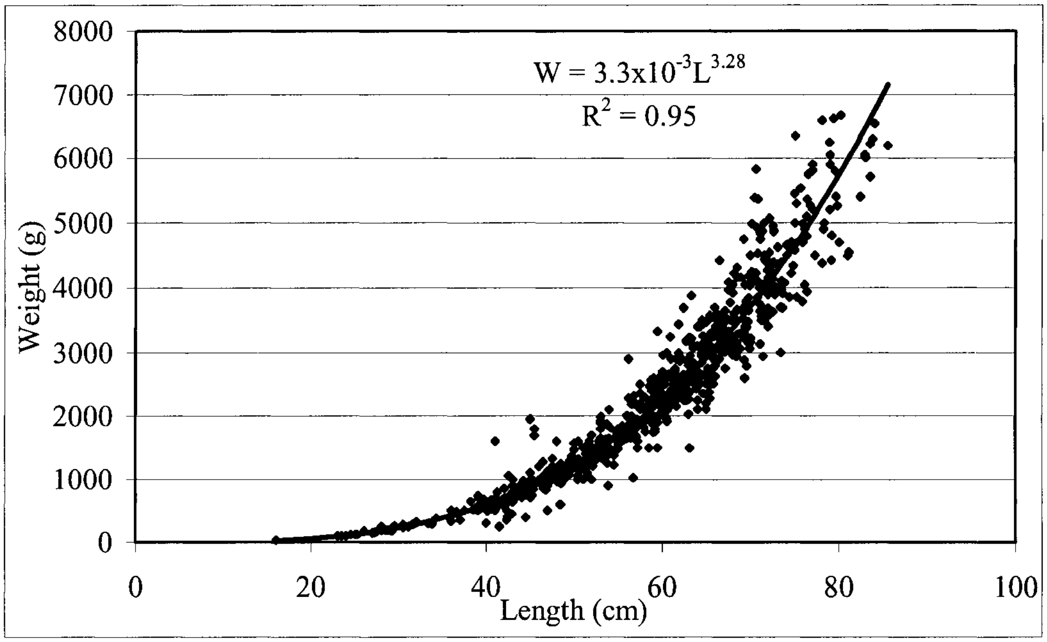


Figure 5.3 Length - weight equation of Lake Trout

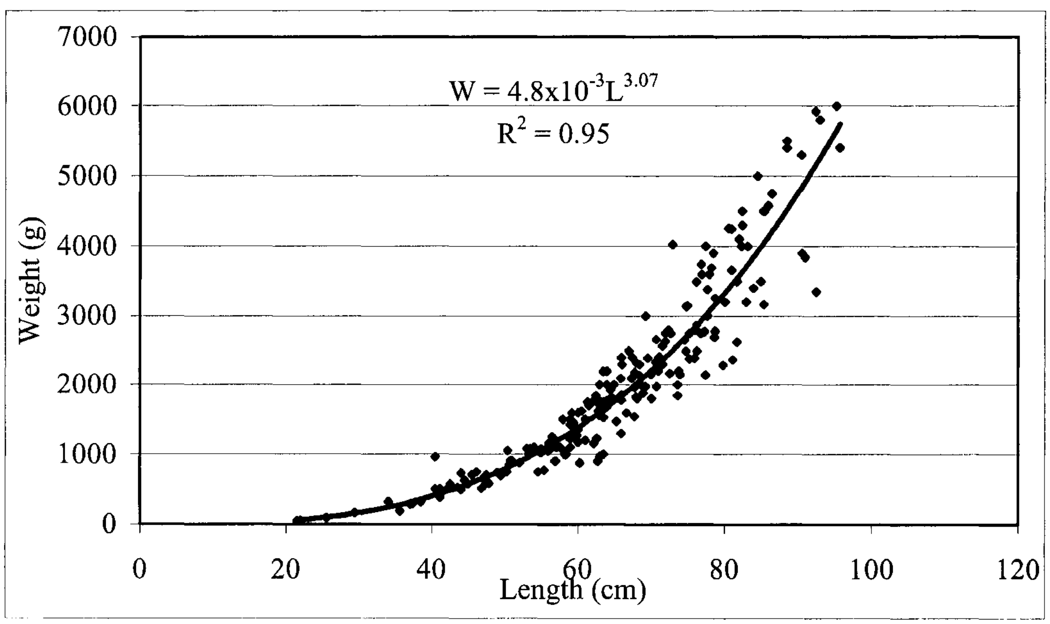


Figure 5.4 Length - weight equation of Northern Pike

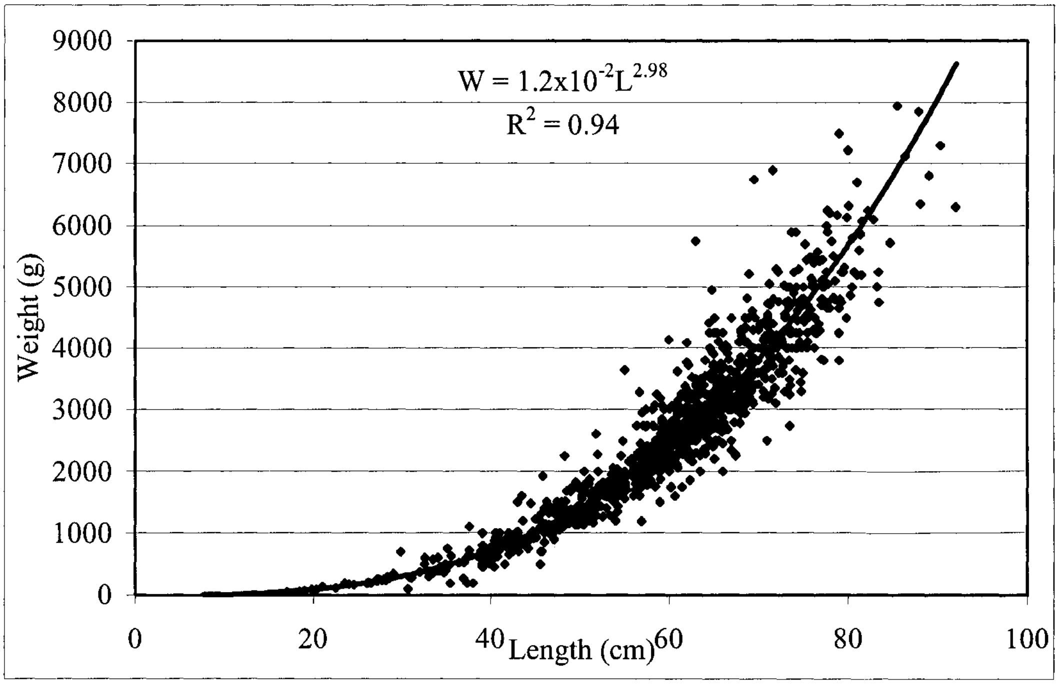


Figure 5.5 Length - weight equation of Rainbow Trout

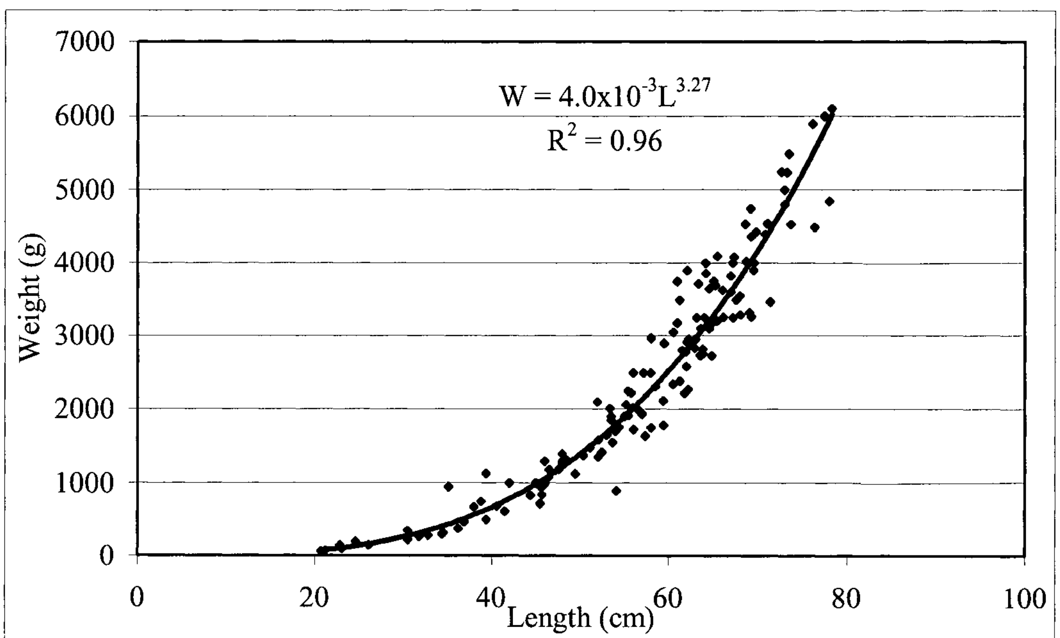


Figure 5.6 Length - weight equation of Walleye

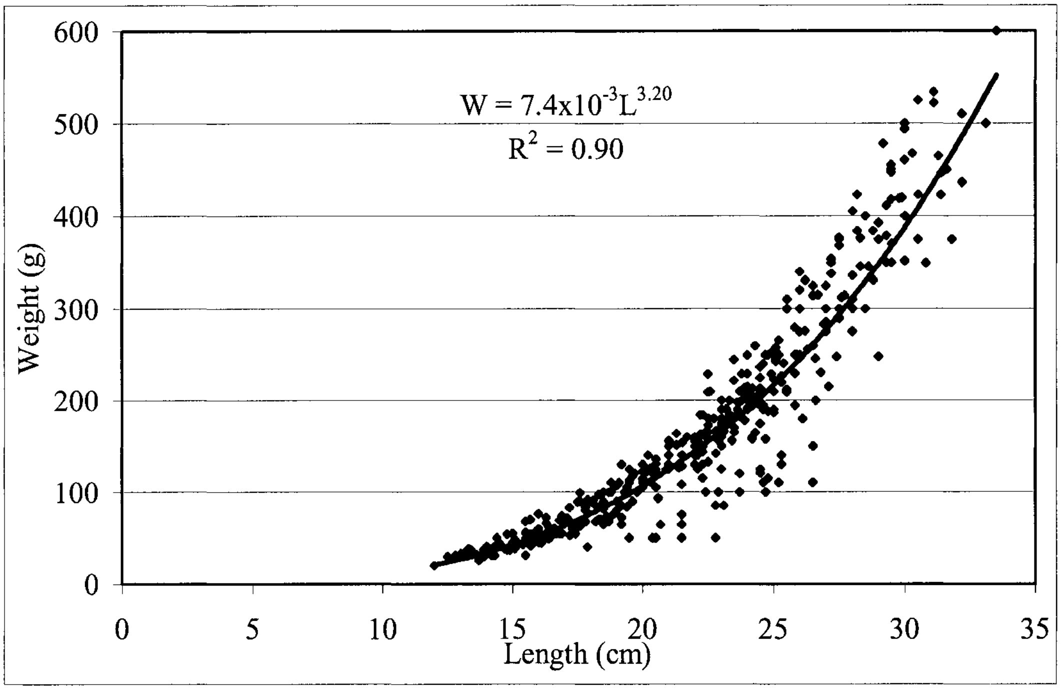


Figure 5.7 Length - weight equation of Yellow Perch

Table 5.4 Length - weight ratios of six fish species

Fish Species	**Length - Weight Equation**	**a**	**b**
Chinook Salmon	$W = 8.1x10^{-3}L^{3.07}$	$8.1x10^{-3}$	3.07
Lake Trout	$W = 3.3x10^{-3}L^{3.28}$	$3.3x10^{-3}$	3.28
Northern Pike	$W = 4.8x10^{-3}L^{3.07}$	$4.8x10^{-3}$	3.07
Rainbow Trout	$W = 1.2x10^{-2}L^{2.98}$	$1.2x10^{-2}$	2.98
Walleye	$W = 4.0x10^{-3}L^{3.27}$	$4.0x10^{-3}$	3.27
Yellow Perch	$W = 7.4x10^{-3}L^{3.20}$	$7.4x10^{-3}$	3.20

5.2 Fish Growth

When the length-weight ratios are obtained, the growth rate for each sport fish can also be evaluated. First of all, in each fish species, the average body weights of different age groups are calculated. Then, the maximum (asymptotic) weight of the fish from the field data are obtained. By substituting a range of growth rates (k) into Eq.

[3.2], the fish's weights at different age groups are calculated. These values are plotted in Figures 5.8 to 5.13 and compared with the data. The best-fit curve with k value that is closest to the field data is chosen to represent the fish growth rate. This is shown as a dark line in the figures. Obviously, the growth rate of fish decreases with increasing age.

Table 5.5 summarizes the maximum wet weight (W_∞) of fish in grams, the predicted yearly and weekly growth rates, and the length-weight ratio for each fish species. Chinook Salmon is the heaviest fish and Yellow Perch is the lightest fish among the six sport fish. For the cold fish species, including Chinook Salmon, Lake Trout and Rainbow Trout, there is a similar growth rate at approximately 5.77×10^{-3} per week.

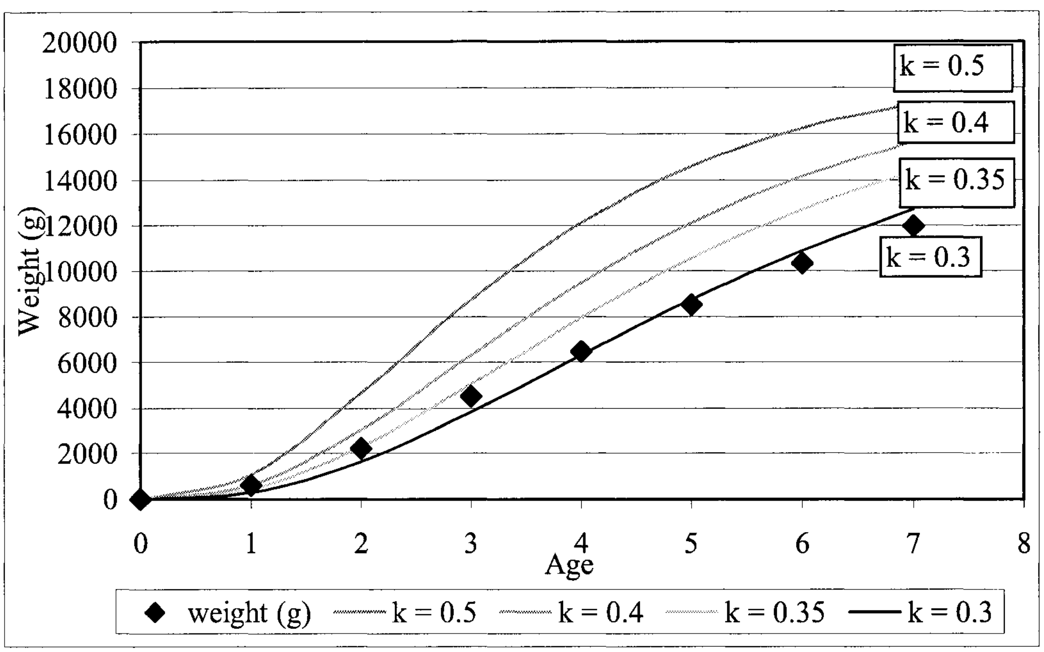


Figure 5.8 Growth rate of Chinook Salmon (dark line represents chosen value of k)

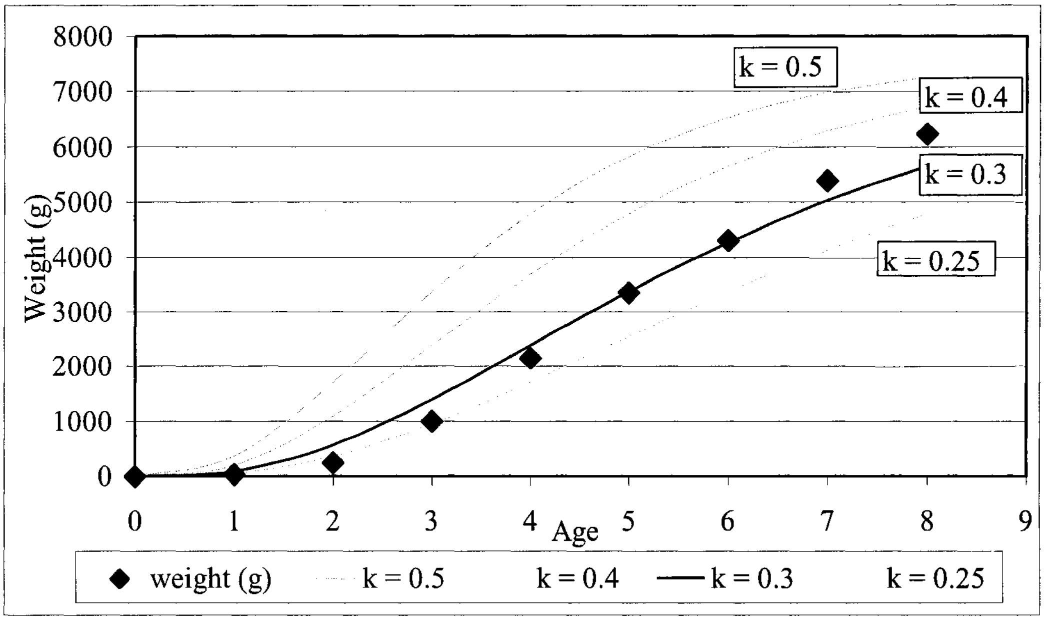


Figure 5.9 Growth rate of Lake Trout (dark line represents chosen value of k)

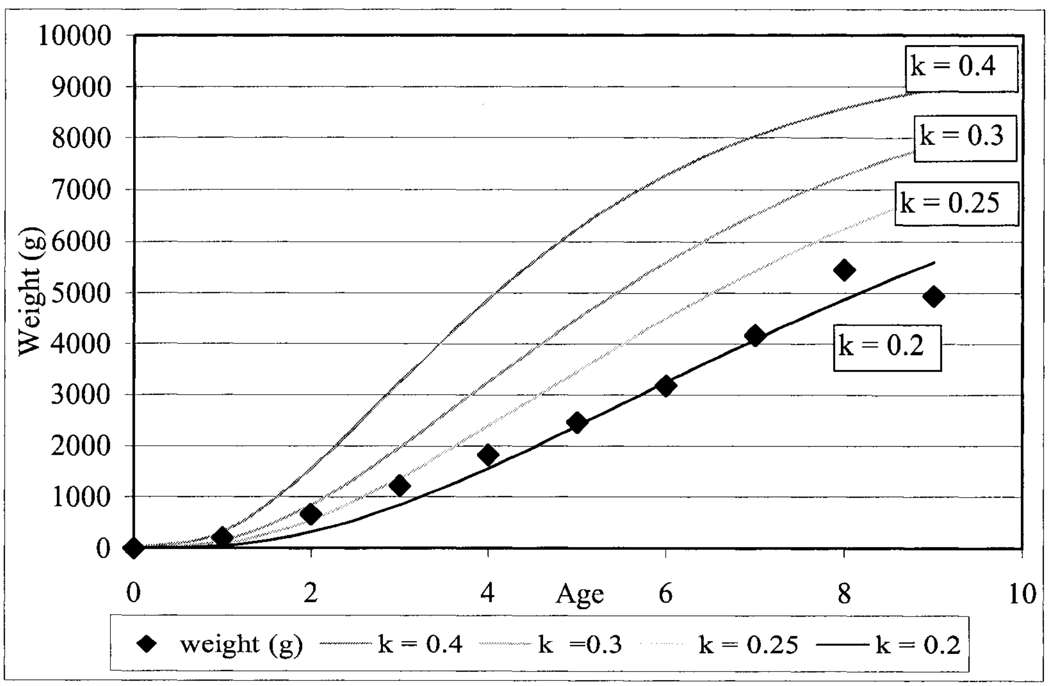


Figure 5.10 Growth rate of Northern Pike (dark line represents chosen value of k)

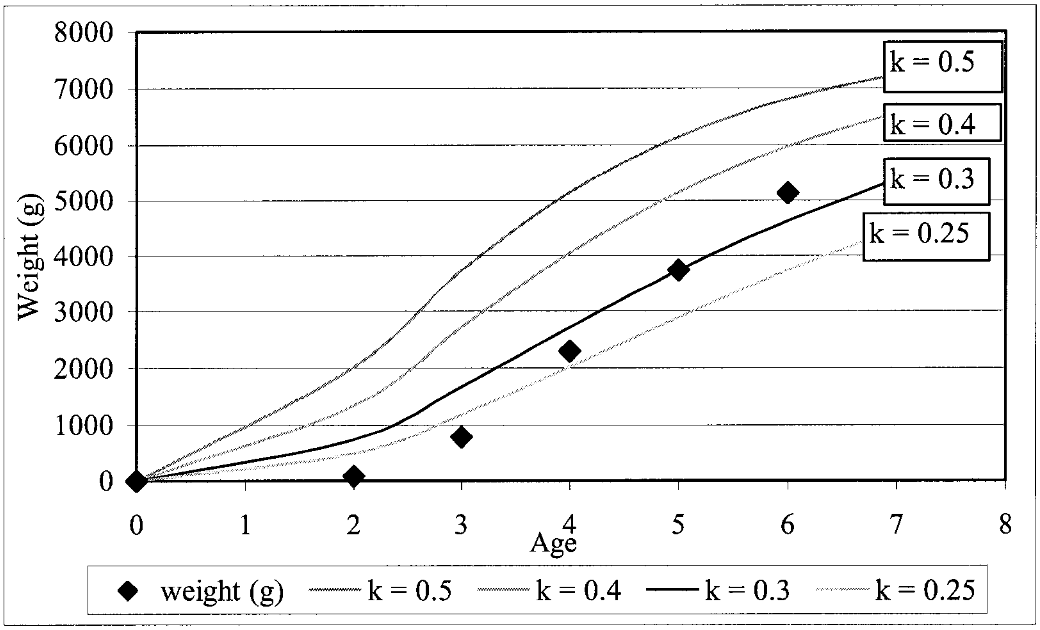


Figure 5.11 Growth rate of Rainbow Trout (dark line represents chosen value of k)

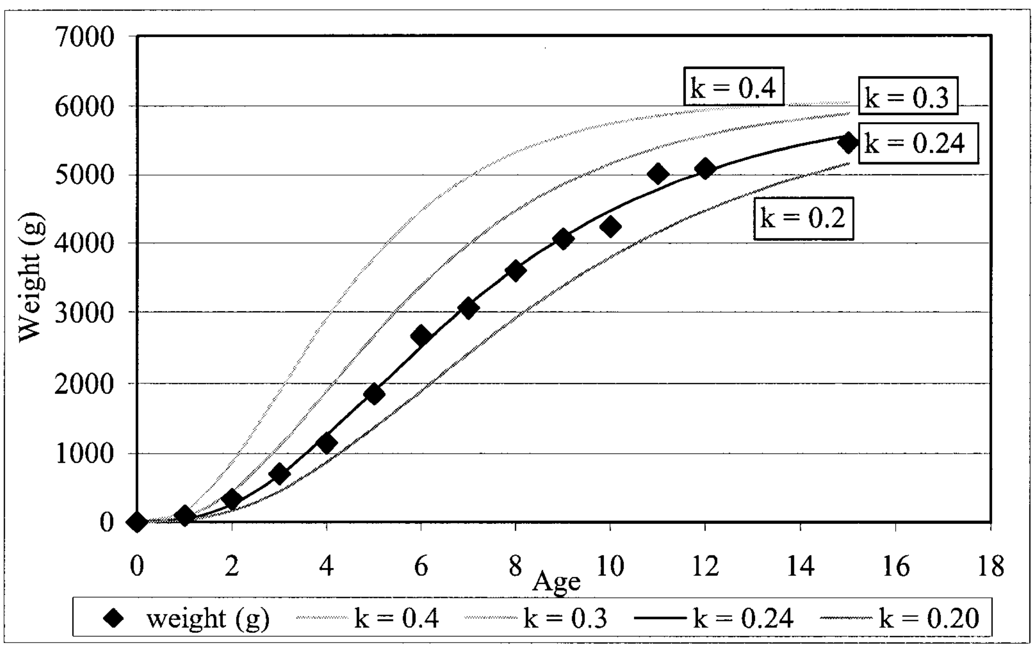


Figure 5.12 Growth rate of Walleye (dark line represents chosen value of k)

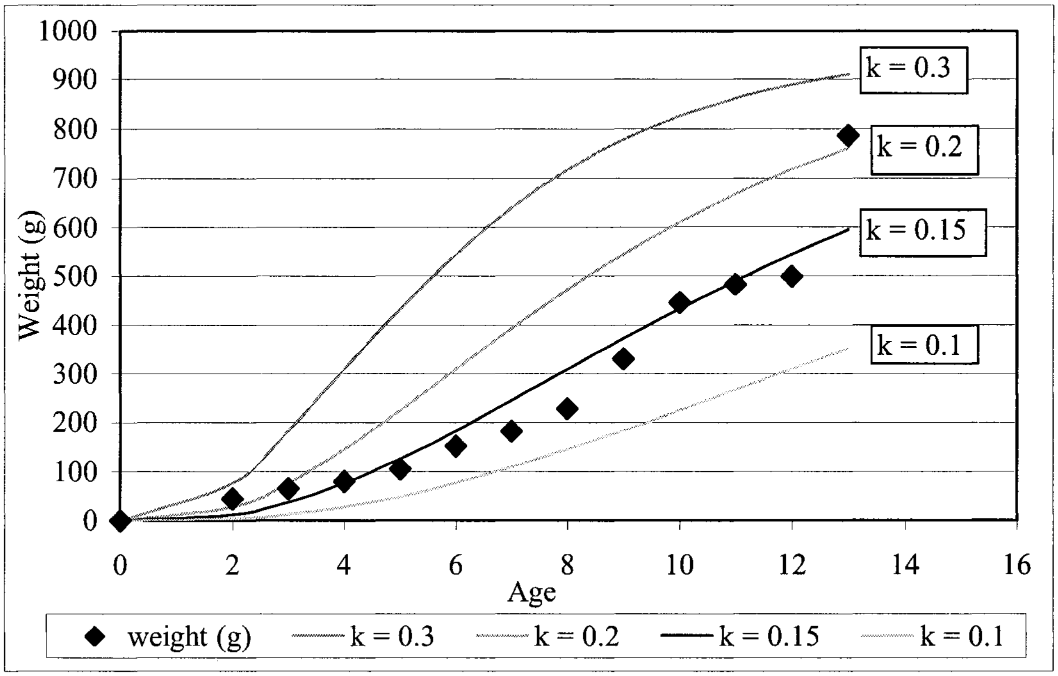


Figure 5.13 Growth rate of Yellow Perch (dark line represents chosen value of k)

Table 5.5 Calibration of variables of the growth function

Fish Species	W_∞ (g wet weight)	k (yr^{-1})	k (wk^{-1})	b
Chinook Salmon	19000	0.30	$5.77\text{x}10^{-3}$	3.07
Lake Trout	7727	0.30	$5.77\text{x}10^{-3}$	3.28
Northern Pike	9750	0.20	$3.85\text{x}10^{-3}$	3.07
Rainbow Trout	7939	0.30	$5.77\text{x}10^{-3}$	2.98
Walleye	6100	0.24	$4.62\text{x}10^{-3}$	3.27
Yellow Perch	972	0.15	$2.88\text{x}10^{-3}$	3.20

5.3 Bioenergetics Equation

The general bioenergetics equation, Eq. [3.8], depends on the fish's low-routine coefficient (α_{lr}), the fish's body weight (W), the body weight exponent for metabolism (τ), the energy equivalent (energy content) of the flesh (q_f) and the proportion of growth rate that represents the energy for food conversion (β). These parameters are detail discussed in the following subsection.

5.3.1 Fish Growth

Based on Norstrom *et al.*'s (1976) research, a fish's low –routine coefficient changes by temperature. Table 5.6 indicates the low-routine coefficient values at different temperatures (Solomon and Brafield, 1972). The highest low-routine coefficient is provided at the highest temperature. For the cold fish species, which prefer to stay in an environment at 15°C, their low-routine coefficients are about 0.15 kcal/wk/g. For Walleye and Yellow Perch, their low-routine coefficient is 0.23 kcal/wk/g, while they usually stay in 20°C water. Northern Pike have a preferred temperature of 17°C; their low-routine coefficient is interpolated as 0.18 kcal/wk/g.

The body weight exponent for metabolism in Chinook Salmon, Lake Trout, Walleye and Yellow Perch are 0.93, 0.90, 0.77 and 0.81 respectively (Luk, 2000, Harris and Snodgrass, 1993). From Section 4.1, Lake Trout follow similar mercury trends as Rainbow Trout and Chinook Salmon. It is well known that Rainbow Trout and Lake Trout come from the same family. Therefore, the body weight exponent for metabolism is assumed to be the same as that of Lake Trout, at 0.90. For Northern Pike, this value can be assumed as 0.80 (Norstrom *et al.*, 1976).

Table 5.6 Effect of temperature on the low-routine coefficient (α_{lr})

Temperature (°C)	α_{lr}
5	0.05
10	0.09
15	0.15
20	0.23
25	0.25

5.3.2 Energy equivalent

The energy equivalent (energy content) of the flesh of fish for Chinook Salmon and Lake Trout are given by the following equations, in Joules (Stewart and Ibarra, 1991, Stewart *et al.*, 1983).

For Chinook Salmon: $q_f\,(W < 4000\text{ g}) = 5763 + 0.99W$ Eq. [5.1]

$q_f\,(W \geq 4000\text{ g}) = 7598 + 0.53W$ Eq. [5.2]

For Lake Trout: $q_f\,(W \leq 1470\text{ g}) = 5700 + 3.08W$ Eq. [5.3]

$q_f\,(W > 1470\text{ g}) = 9090 + 0.78W$ Eq. [5.4]

Higher energy contents are found in these two types of fish when they are heavier. By converting these equations into kilocalories per week per gram, the equations are modified to the following:

For Chinook Salmon: $q_f\,(W < 4.0\text{ k g}) = 1.38 + 0.24W$ Eq. [5.5]

$q_f\,(W \geq 4.0\text{ kg}) = 1.82 + 0.13W$ Eq. [5.6]

For Lake Trout: $q_f\,(W \leq 1.5\text{ kg}) = 1.36 + 0.74W$ Eq. [5.7]

$q_f\,(W > 1.5\text{ kg}) = 2.17 + 0.19W$ Eq. [5.8]

The energy equivalent in Lake Trout bigger than 1.5 kg is double that of the smaller size. For the same reason as stated above, values for Rainbow Trout are adopted from the Lake Trout equations, Eqs. [5.7] and [5.8]. The energy equivalent is 1.15 kcal/wk/g for Walleye and 1.25 kcal/wk/g for Yellow Perch (Ling, 2001). The value for Northern Pike should be similar to those of Walleye and Yellow Perch since they are all rank in the top predatory level. Therefore, the average value of the two, 1.20 kcal/wk/g, is adopted.

5.3.3 The Proportionality Constant of Growth Rate

The proportionality constant of growth rate (β) represents the energy for food conversion. In order to figure out the expression of this constant, it is necessary to refer the energy for metabolism, Eq. [3.8] and consider the amount of energy obtained from food (Q_{food}). This total food energy is used to carry out all the required metabolic activities (total metabolism) as well as growth of the fish. This amount of energy is given by the equation:

$$Q_{food} = Q + q_f\left(\frac{dW}{dt}\right) \qquad \text{Eq. [5.9]}$$

By substituting Eq. [3.8] into Eq. [5.9], the total food energy can be re-written as follow:

$$Q_{food} = \alpha_{lr}W^{\tau} + q_f(\beta + 1)\left(\frac{dW}{dt}\right) \qquad \text{Eq. [5.10]}$$

Field observations discover that around 17% of total energy from food is used for the food utilization energy cost (Winberg, 1956), which is defined as:

$$Q_c = 0.17Q_{food} \qquad \text{Eq. [5.11]}$$

By substituting Eqs. [3.7] and [5.10] into the above equation, Eq. [5.11] can be re-written as,

$$q_f(\beta)\left(\frac{dW}{dt}\right) = 0.17\left[\alpha_{lr}W^{\tau} + q_f(\beta + 1)\left(\frac{dW}{dt}\right)\right] \qquad \text{Eq. [5.12]}$$

After the rearrangement of the equation, the final expression for β may be obtained as:

$$\beta = \frac{0.17\alpha_{lr}W^{\tau}}{0.83q_f\left(\frac{dW}{dt}\right)} + 0.20 \qquad \text{Eq. [5.13]}$$

It is influenced by a fish's weight, low - routine coefficient, body weight exponent for metabolism and energy equivalent of the flesh in that fish species. In summary, all the parameters for the bioenergetics equation, Eq. [3.8], are summarized in Table 5.7.

Table 5.7 Bioenergetics equation parameters of different fish species

Fish Species	**T (^oC)**	**α_{lr} [kcal/(wk.g$^\tau$)]**	**τ**	**q_f (kcal/g)**	**β**
Chinook Salmon	15	0.15	0.93	Eqs. [5.5] & [5.6]	Eq. [5.13]
Lake Trout	15	0.15	0.90	Eqs. [5.7] & [5.8]	Eq. [5.13]
Northern Pike	17	0.18	0.80	1.20	Eq. [5.13]
Rainbow Trout	15	0.15	0.90	Eqs. [5.7] & [5.8]	Eq. [5.13]
Walleye	20	0.23	0.77	1.15	Eq. [5.13]
Yellow Perch	20	0.23	0.81	1.25	Eq. [5.13]

5.4 Mercury Uptake from Food

Referring to Eq. [3.9], the amount of mercury obtained from food can be calculated with the fish's efficiency of mercury uptake from food (E_p), the concentration of mercury in the fish's food (C_{pf}), the energy equivalence of the fish's food (q_{fd}) and the efficiency of food assimilation (E_{fd}). The literature review mentioned that nearly 100% of fish's MeHg and Hg can be absorbed by their bodies (Maier *et al.*, 2000). Therefore, efficiency of mercury uptake from food can be assumed as 1.0 for all sport fish. About the concentration of mercury in food, many researchers have studied the mercury levels in different fish's prey. This information is shown in Table 5.8.

With a wide-range search from the literature, including works of Scott and Crossman (1973), Borgmann and Whittle (1992), Mathers and Johansen (1985), Jude *et al.* (1987), and Harris and Snodgrass (1993), the percentages of diet composition for the six sport fish are obtained and summarized in Table 5.9. The re-constructed concentration of mercury in food and the energy equivalence of the food are also shown in Table 5.9. Fish usually consume larger prey with more toxicants when they reach maturity. In that case, bigger fish's foods contain higher levels of Hg than do smaller ones. In addition, top predatory fish, such as Walleye, get a higher Hg diet than others.

The efficiency of food assimilation for Chinook Salmon, Northern Pike and Rainbow Trout is 0.82 (Norstrom, et al., 1976). This value is equal to 0.68 for Yellow Perch and 0.75 for Lake Trout and Walleye (Ling, 2001). The parameters of the mercury uptake equation, Eq. [3.9], for all the sport fish are summarized in Table 5.10. The actual value of the mercury concentration in food and the energy equivalence of them are calculated by multiplying those values and the percentages of diet composition.

Table 5.8 Mercury concentrations of aquatic prey organisms

Aquatic Prey Organism	**Hg Concentration (ppm)**	**Reference**
Plankton	0.03 wet weight	Mathers and Johansen, 1985
	4.00×10^{-3} - 0.04 dry weight	Al-Majed and Preston, 2000
	0.01 - 0.10 wet weight	Harris, 1991
Terrestrial Insects	0.04 wet weight	Mathers and Johansen, 1985
	0.01 - 0.13 dry weight	Tremblay *et al.*, 1996
Invertebrates	0.05 - 0.30 wet weight	Harris, 1991
Crayfish	0.04 wet weight	Mathers and Johansen, 1985
	0.02 - 0.61 wet weight	Allard and Stokes, 1989
Mayfly	0.05 wet weight	Mathers and Johansen, 1985
Vertebrates	0.05 wet weight	Mathers and Johansen, 1985
Slimy sculpin	0.02 - 0.03 wet weight	Borgmann and Whittle, 1992
Alewife	0.02 - 0.04 wet weight	Borgmann and Whittle, 1992
Rainbow Smelt	0.07 - 0.57 wet weight	Mathers and Johansen, 1985
	0.02 - 0.04 wet weight	Borgmann and Whittle, 1992
	0.02 - 0.16 wet weight	Kim and Burggraaf, 1999
White Sucker	0.06 wet weight	Mathers and Johansen, 1985
Yellow Perch	0.11 wet weight	Mathers and Johansen, 1985
Lake Herring	0.11 wet weight	Mathers and Johansen, 1985
Emerald Shiner	0.11 wet weight	Mathers and Johansen, 1985
Common Shiner	0.04 wet weight	Mathers and Johansen, 1985

Table 5.9 Re-constructed diet compositions of different fish species according to size

Fish Species	Fish Length (cm)	%	q_{fd} (kcal/g)	Cpf (ppm)	Diet Composition
Chinook Salmon	< 30.0	100.0	1.00	4.0×10^{-2}	Terrestrial insects
	≥ 30.0	8.0	1.36	5.0×10^{-2}	Invertebrates (S)
		10.5	1.36	3.6×10^{-2}	Rainbow smelt (M)
		81.5	1.60	3.0×10^{-2}	Alewife (M)
Lake Trout	< 25.8	45.0	1.36	2.4×10^{-2}	Slimy sculpin (S)
		35.0	1.36	2.2×10^{-2}	Rainbow smelt (S)
		20.0	1.60	1.7×10^{-2}	Alewife (S)
	25.8 – 49.6	17.5	1.36	3.2×10^{-2}	Slimy sculpin (M)
		45.0	1.36	2.9×10^{-2}	Rainbow smelt (M)
		37.5	1.60	3.0×10^{-2}	Alewife (M)
	≥ 49.6	30.0	1.36	3.6×10^{-2}	Rainbow smelt (M)
		70.0	1.60	4.3×10^{-2}	Alewife (L)
Northern Pike	< 60.0	80.0	1.00	3.0×10^{-2}	Plankton (M)
		20.0	1.00	4.0×10^{-2}	Terrestrial insects
	≥ 60.0	8.1	1.36	4.7×10^{-2}	Vertebrates
		35.3	1.36	6.3×10^{-2}	White sucker
		28.4	1.36	1.1×10^{-1}	Yellow perch
		20.2	1.36	1.1×10^{-1}	Lake herring
		8.0	1.36	2.5×10^{-1}	Rainbow smelt (XL)
Rainbow Trout	< 30.0	24.1	1.36	5.0×10^{-2}	Invertebrates (S)
		75.9	1.60	1.7×10^{-2}	Alewife (S)
	≥ 30.0	36.4	1.36	5.0×10^{-2}	Invertebrates (S)
		5.5	1.36	3.6×10^{-2}	Rainbow smelt (M)
		58.1	1.60	4.3×10^{-2}	Alewife (L)
Walleye	< 35.9	50.0	1.00	4.7×10^{-2}	mayfly
		50.0	1.00	4.2×10^{-2}	crayfish
	≥ 35.9	69.0	1.36	2.5×10^{-1}	Rainbow smelt (XL)
		19.0	1.36	1.1×10^{-1}	Yellow Perch
		9.0	1.36	1.1×10^{-2}	Emerald Shiner
		3.0	1.36	4.3×10^{-2}	Common Shiner
Yellow Perch	< 16.3	100.0	1.00	1.0×10^{-2}	Plankton (S)
	≥ 16.3	25.0	1.00	5.0×10^{-2}	Invertebrates (S)
		25.0	1.00	2.9×10^{-2}	Rainbow smelt (M)
		50.0	1.00	1.7×10^{-2}	Alewife (S)

Note: S = small size
M = medium size
L = large size
XL = extra large size

Table 5.10 Food uptake parameters of different fish species

Fish Species	E_{pf}	Length (cm)	C_{pf} (ppm)	q_{fd} (kcal/g)	E_{fd}
Chinook Salmon	0.80	< 30.0	0.04	1.00	0.82
		≥ 30.0	0.03	1.56	
Lake Trout	0.70	< 25.8	0.02	1.41	0.75
		25.8 - 49.6	0.03	1.45	
		> 49.6	0.04	1.53	
Northern Pike	0.80	< 60.0	0.03	1.00	0.82
		≥ 60.0	0.10	1.36	
Rainbow Trout	0.80	< 30.0	0.03	1.42	0.82
		≥ 30.0	0.05	1.50	
Walleye	0.70	< 35.9	0.05	1.00	0.75
		≥ 35.9	0.21	1.36	
Yellow Perch	0.80	< 16.3	0.01	1.00	0.68
		≥ 16.3	0.03	1.00	

5.5 Mercury Uptake from Water

In Eq. [3.10], mercury uptake through water pathways depends on many parameters: the efficiency of Hg transfer from water (E_{pw}), the Hg concentration in water (C_{pw}), the absorption efficiency of oxygen (E_{ox}), the concentration of dissolved oxygen in water (C_{ox}) and the fish's energy equivalence of oxygen (q_{ox}). In many researches, the efficiency of mercury transfer from water divided by the absorption efficiency of oxygen, (E_{pw}/E_{ox}), are provided. Luk (2000) and Norstrom *et al.* (1976) mentioned that E_{pw}/E_{ox} for Chinook Salmon, Lake Trout, Walleye and Yellow Perch is 0.16. In Harris and Snodgrass's (1993) research, E_{pw}/E_{ox} for rainbow trout is 0.28. According to DeFreitas *et al.* (1974), the study of E_{pw}/E_{ox} for Northern Pike was experienced in river water, where a higher concentration of oxygen was presented, resulting a higher value, 0.49. Since the absorption efficiency of oxygen for all the sport fish is 0.75 (Luk, 2000, Harris and Snodgrass, 1993), the efficiency of mercury transfer from water can be calculated as 0.12 for Chinook Salmon, Lake Trout, Walleye and Yellow Perch, 0.37 for Northern Pike and 0.21 for Rainbow Trout.

In North America, mercury concentrations in different locations are sampled and reported in Table 5.11. The mercury levels in lakes and rivers vary widely, from 0.02 to 7.80 pptr. These values do not represent the Hg concentration in Lake Ontario. More information is collected and tabulated in Table 5.12. In 1970, an extremely high mercury level (0.13 ppb) was recorded in Lake Ontario. Due to the success of mercury restrictions, the mercury concentration in water was brought down to 0.01 ppb by 1982. However, it increased by almost two fold within the next 15 years. Recently, the mercury in Lake Ontario has had a range of 0.02 and 0.06 ppb. The mercury concentration in water (C_{pw}) can be assumed as 0.04 ppb, which is the average value of the Hg concentration in Lake Ontario.

Table 5.11 Sample MeHg concentrations of North America waters

Location	**Hg Level (pptr)**	**Reference**
Ottawa River	4.00	Norstrom *et al.*, 1976
The Great Lakes	0. 02 - 5.00	Harris, 1991
Ottawa River	0.10	Harris and Snodgrass, 1993
Lakes in Northwestern Ontario	0.10 - 2.10	Hall *et al.*, 1997
Lake Michigan	0.32	Sullivan and Mason, 1998
Lakes Manitoba, Winnipeg and Clay Lake	0.10 - 7.80	Latif *et al.*, 2001

Table 5.12 Mercury concentrations of the Lake Ontario waters

Year	**Hg Level (ppb)**	**Reference**
1970	0.13	Government of Canada, 1991
1979	0.03	Government of Canada, 1991
1982	0.01	Government of Canada, 1991
1997	0.02	MOE, 1997
1998	0.04	Ecological Monitoring and Assessment Network, 1998
1998	0.03 - 0.06	Amyot *et al.*, 2000

On the other side, the concentration of dissolved oxygen in water (C_{ox}) is dependant on temperature (Norstrom *et al.*, 1976), as follows;

$$C_{ox} = 14.45 - 4.13x10^{-1}\ T + 5.56x10^{-3}\ T^2 \qquad \text{Eq. [5.14]}$$

Based on this equation, and the preferred temperature for each sport fish, the concentration of dissolved oxygen in water is calculated as 9.51 ppm for Chinook Salmon, Lake Trout and Rainbow Trout, 9.04 ppm for Northern Pike and 8.41 ppm for Walleye and Yellow Perch. Finally, the energy equivalence of oxygen (q_{ox}) for any fish is 3.42 kcal/g O_2 (Winberg, 1956). In summary, the parameters for the rate of mercury uptake through the water pathway equation, Eq. [3.10], are given in Table 5.13.

Table 5.13 Water uptake parameters of different fish species

Fish Species	**(E_{pw}/E_{ox})**	**E_{pw}**	**C_{pw} (ppb)**	**E_{ox}**	**T (°C)**	**C_{ox} (ppm)**	**q_{ox} (kcal/g O_2)**
Chinook	0.16	0.12	0.04	0.75	15	9.51	3.42
Lake Trout	0.16	0.12	0.04	0.75	15	9.51	3.42
Northern Pike	0.49	0.37	0.04	0.75	17	9.04	3.42
Rainbow Trout	0.28	0.21	0.04	0.75	15	9.51	3.42
Walleye	0.16	0.12	0.04	0.75	20	9.41	3.42
Yellow Perch	0.16	0.12	0.04	0.75	20	8.41	3.42

5.6 Clearance

The clearance of methylmercury in fish is based on the rate of clearance coefficient (k_{cl}). This value includes the mercury clearance through elimination and growth-dilution, and can be determined from the methylmercury half-life in fish. In the literature, MeHg half-life for fish can be as low as 1 year to as high as 11 years, depending on the species. When first kinetics order of pollutant clearance is considered, the half-life of MeHg can be expressed by the following equation:

$$P = P_o e^{-k_{cl} t} \qquad \text{Eq. [5.15]}$$

where P is the original concentration for MeHg, P_o is half of the original concentration for MeHg, k_{cl} is the clearance rate and t is the time in year.

As an example, the MeHg half-life for Lake Trout is 11 years (Borgmann and Whittle, 1991). When t is equal to 11 years for Lake Trout, and P is equal to $P_o/2$, k_{cl} for Lake Trout can be determined as 6.3×10^{-2} per year or 1.2×10^{-3} per week from Eq. [5.15]. Headon *et al.* (1996) and Philips and Buhler (1978) reported that MeHg half-life for Northern Pike is approximately 2 years and Rainbow Trout is 1 year. The corresponding clearance rates are 6.7×10^{-3} and 1.3×10^{-2} per week respectively. The MeHg half-life for Walleye and Yellow Perch are 6 and 2.5 years, which clearance rates are equal to 2.2×10^{-3} and 5.3×10^{-3} per week (Harris and Snodgrass, 1993). The generally MeHg half-life in fish is 2 years; therefore, the methylmercury clearance rate in Chinook Salmon can be estimated as 6.7×10^{-3} per week. The half-life and the clearance coefficient for Eq. [3.11] for each sport fish is summarized in Table 5.14.

Table 5.14 Clearance parameters of different fish species

Fish Species	**MeHg Half - life (year)**	**k_{cl} (per week)**
Chinook Salmon	2.0	6.7×10^{-3}
Lake Trout	11.0	1.2×10^{-3}
Northern Pike	2.0	6.7×10^{-3}
Rainbow Trout	1.0	1.3×10^{-2}
Walleye	6.0	2.2×10^{-3}
Yellow Perch	2.5	5.3×10^{-3}

5.7 Computer Model Modification

Referring to Eq. [3.12], the rate of mercury burden in a fish's body is related to the amount of mercury obtained from food and water, and the mercury extracted through clearance. All the necessary parameters for the mercury bioaccumulation model equations are shown in Table 5.15. Section 3.5 mentioned that knowing initial mercury concentration of a fish was required to simulate the fish's mercury level over its life span. Therefore, initial weight and mercury concentration for all six fish species at week one are calculated before modifying the computer program. By using Eq. [3.13] and Table 5.15, the mercury burdens in the fish's bodies at week one are calculated in Table 5.16. W_1 is the fish's weight at week one, P_o is the mercury intake from food and water pathways and P is the initial mercury burden at particular fish, in micrograms. The remaining parameters' symbols were described in detail in Chapter Three

After all the parameters for the six species were found, the source codes of the computer program were revised. In comparison to the old program, the new program adds three more sport fish species and modifies the entire updated variables. Figure 5.14 demonstrates part of the source codes in the computer program. A printout of major source codes is given in Appendix I.

By revising all the program source codes, the simulated mercury bioaccumulation program in fish can be run. Parts One and Two of Chinook Salmon's input variables are shown in Figures 5.15 and 5.16, and these are set as the default for the fish species. Then, the model is processed and an output table is generated, as given in Figure 5.17. In the figure, W is the fish's weight and P/W is the fish's mercury concentration, correlated to its weight at each week. Chinook Salmon get 9.75×10^{-2} ppm of mercury at week twenty-two, while they have 7.10×10^{-2} ppm at week two. Obviously, fish accumulate higher levels of mercury when they stay in the same environment for a longer period of time. The simulated model data can be exported to a text file and in the format of an excel file. An executive program is also attached at the back of the thesis.

Table 5.15 Model parameters values of different fish species

Symbol	Unit	Chinook Salmon		Lake Trout			Northern Pike		Rainbow Trout		Walleye		Yellow Perch	
Length-weight Ratio:														
b		3.07		3.28			3.07		2.98		3.27		3.20	
Fish Growth:														
W_∞	g	19000		7727			9750		7939		6100		972	
k	wk^{-1}	$5.77x10^{-3}$		$5.77x10^{-3}$			$3.85x10^{-3}$		$5.77x10^{-3}$		$4.62x10^{-3}$		$2.88x10^{-3}$	
Bioenergetics Equation:														
α_{lr}	kcal/(wk g^{τ})	0.15		0.15			0.18		0.15		0.23		0.23	
τ		0.93		0.90			0.80		0.90		0.77		0.81	
q_f	kcal/(g wk)	Eqs. [5.5] & [5.6]		Eqs. [5.7] & [5.8]			1.20		Eqs. [5.7] & [5.8]		1.15		1.25	
β		Eq. [5.9]		Eq. [5.9]			Eq. [5.9]		Eq. [5.9]		Eq. [5.9]		Eq. [5.9]	
Uptake of Pollutants from Food														
E_{pf}		0.8		0.7			0.8		0.8		0.7		0.8	
Fish Age	year	0-1	1-7	0-2	2-4	4-8	0-3	3-10	0-3	3-7	0-3	3-15	0-3	3-13
C_{pf}	ppm	0.04	0.03	0.02	0.03	0.04	0.03	0.10	0.03	0.05	0.05	0.21	0.01	0.03
qfd	kcal/g	1.00	1.56	1.41	1.45	1.53	1.00	1.36	1.42	1.50	1.00	1.36	1.00	1.00
E_{fd}		0.82		0.75			0.82		0.82		0.75		0.68	
Uptake of Pollutants from Water:														
E_{pw}		0.12		0.12			0.37		0.21		0.12		0.12	
C_{pw}	ppb	0.04		0.04			0.04		0.04		0.04		0.04	
E_{ox}		0.75		0.75			0.75		0.75		0.75		0.75	
C_{ox}	ppm	9.51		9.51			9.04		9.51		9.41		8.41	
q_{ox}	kcal/(g O_2)	3.42		3.42			3.42		3.42		3.42		3.42	
Clearance:														
k_{cl}	wk^{-1}	$6.7 x10^{-3}$		$1.2 x10^{-3}$			$6.7 x10^{-3}$		$1.3 x10^{-2}$		$2.2x10^{-3}$		$5.3x10^{-3}$	

Table 5.16 Initial weights and mercury concentrations of six fish species

Parameters	Chinook Salmon	Lake Trout	Northern Pike	Rainbow Trout	Walleye	Yellow Perch
Time (week)	1	1	1	1	1	1
W_∞ (g)	19000	7727	9750	7939	6100	972
k (wk^{-1})	$5.8x10^{-03}$	$5.8x10^{-03}$	$3.9x10^{-03}$	$5.8x10^{-03}$	$4.6x10^{-03}$	$2.9x10^{-03}$
b	3.07	3.28	3.07	2.98	3.27	3.20
W_1 (g)	$2.5x10^{-03}$	$3.5x10^{-04}$	$3.8x10^{-04}$	$1.7x10^{-03}$	$1.4x10^{-04}$	$7.1x10^{-06}$
α_{lr} [kcal/(wk.g^τ)]	0.15	0.15	0.18	0.15	0.23	0.23
τ	0.93	0.90	0.80	0.90	0.77	0.81
q_f (kcal/g)	1.38	1.38	1.38	1.38	1.38	1.38
β	$2.4x10^{-01}$	$2.6x10^{-01}$	$3.3x10^{-01}$	$2.5x10^{-01}$	$4.7x10^{-01}$	$5.3x10^{-01}$
Q (kcal)	$1.4x10^{-03}$	$2.4x10^{-04}$	$5.0x10^{-04}$	$1.0x10^{-03}$	$3.5x10^{-04}$	$2.1x10^{-05}$
E_{pf}	0.80	0.70	0.80	0.80	0.70	0.80
C_{pf} (ppm)	$1.4x10^{-02}$	$2.2x10^{-02}$	$3.2x10^{-02}$	$2.5x10^{-02}$	$4.5x10^{-02}$	$3.0x10^{-02}$
q_{fd} (kcal/g)	1.00	1.41	1.00	1.42	1.00	0.75
E_{fd}	0.82	0.75	0.82	0.82	1.00	0.68
$(dP/dt)_f$	$6.6x10^{-5}$	$1.1x10^{-5}$	$3.2x10^{-5}$	$5.7x10^{-5}$	$1.7x10^{-5}$	$1.5x10^{-5}$
E_{pw}	0.12	0.12	0.37	0.21	0.12	0.12
C_{pw} (ppb)	0.04	0.04	0.04	0.04	0.04	0.04
E_{ox}	0.75	0.75	0.75	0.75	0.75	0.75
C_{ox} (ppm)	9.51	9.51	9.04	9.51	9.41	9.41
q_{ox}	3.42	3.42	3.42	3.42	3.42	3.42
$(dP/dt)_w$	$2.8x10^{-7}$	$4.8x10^{-8}$	$3.2x10^{-7}$	$3.6x10^{-7}$	$6.9x10^{-8}$	$4.1x10^{-9}$
P_o (ug)	$6.7x10^{-5}$	$1.1x10^{-5}$	$3.2x10^{-5}$	$5.7x10^{-5}$	$1.7x10^{-5}$	$1.5x10^{-6}$
kcl (wk^{-1})	$6.7x10^{-3}$	$1.2x10^{-3}$	$6.7x10^{-3}$	$1.3x10^{-2}$	$2.2x10^{-3}$	$5.3x10^{-3}$
$(dP/dt)_{cl}$	$-4.5x10^{-7}$	$-1.3x10^{-8}$	$-2.2x10^{-7}$	$-7.6x10^{-7}$	$-3.8x10^{-8}$	$-7.7x10^{-9}$
P (ug)	$6.6x10^{-5}$	$1.1x10^{-5}$	$3.2x10^{-5}$	$5.6x10^{-5}$	$1.7x10^{-5}$	$1.5x10^{-6}$

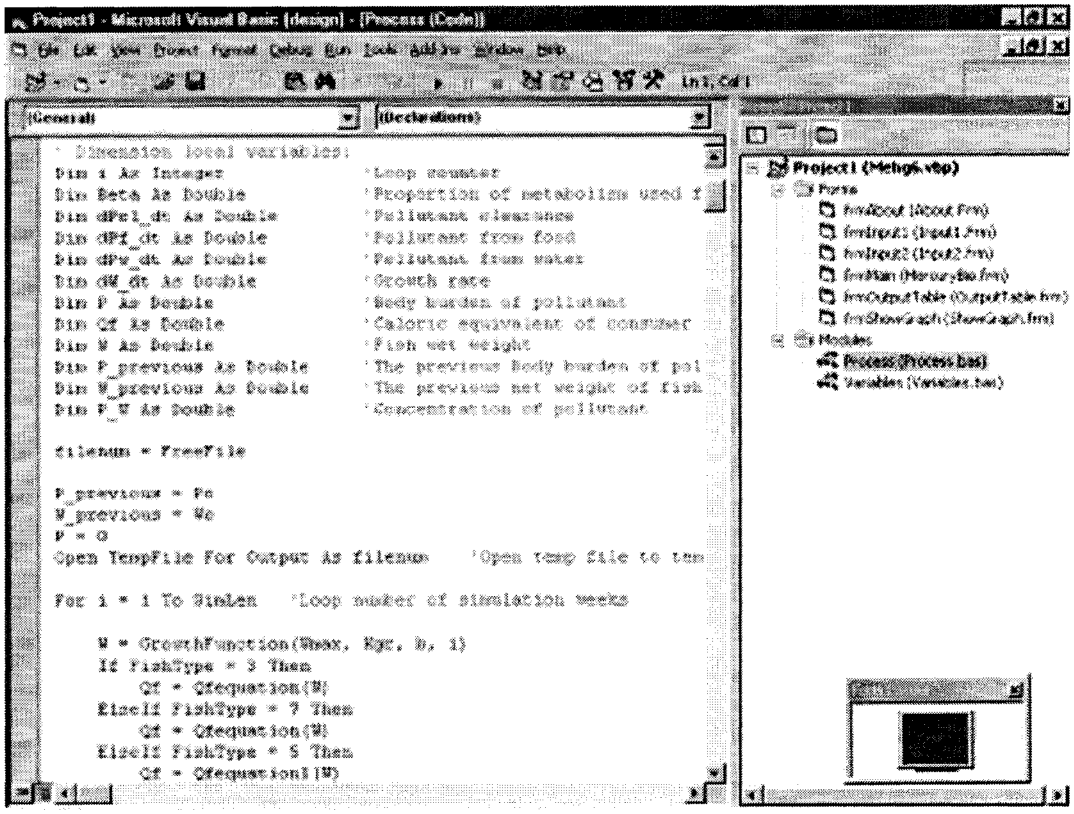


Figure 5.14 Source code of the modified bioaccumulation program

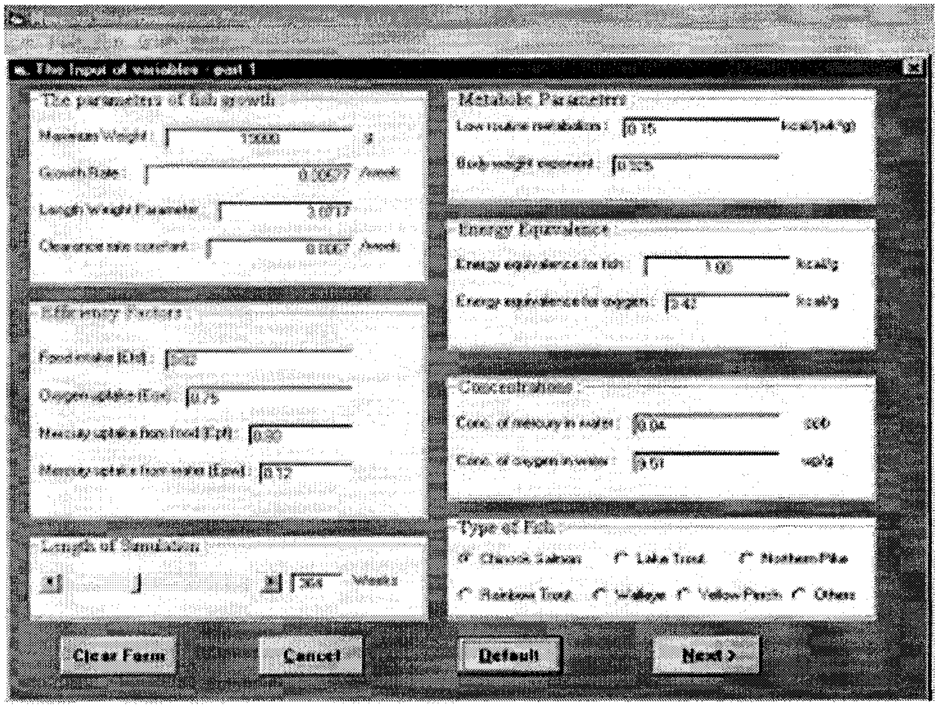


Figure 5.15 Input Table 1 of Chinook Salmon of the modified bioaccumulation program

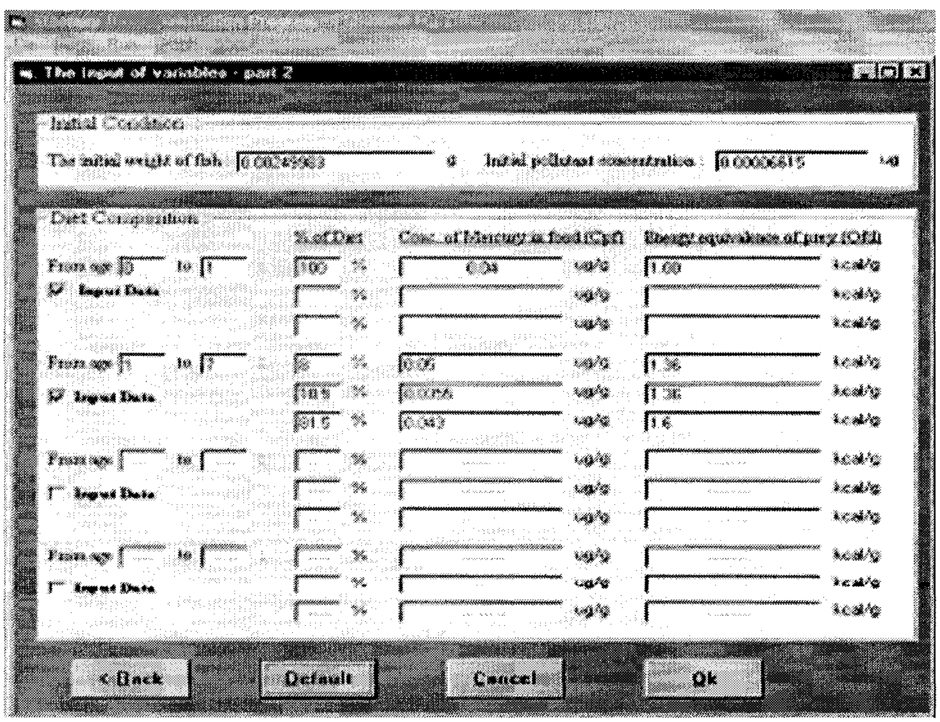


Figure 5.16 Input Table 2 of Chinook Salmon of the modified bioaccumulation program

The Output Table

Week	W	dPf_dt	dPw_dt	dPcl_dt	P	P/W
1	0.002	0.0000	0.0000	0.0000	0.0001	0.03757
2	0.021	0.0014	0.0000	0.0000	0.0015	0.07097
3	0.072	0.0039	0.0000	0.0000	0.0054	0.07509
4	0.172	0.0079	0.0000	0.0000	0.0132	0.07696
5	0.339	0.0134	0.0000	0.0001	0.0265	0.07841
6	0.587	0.0204	0.0000	0.0002	0.0468	0.07972
7	0.935	0.0291	0.0001	0.0003	0.0757	0.08096
8	1.397	0.0395	0.0001	0.0005	0.1148	0.08217
9	1.988	0.0516	0.0001	0.0008	0.1657	0.08335
10	2.724	0.0655	0.0001	0.0011	0.2302	0.08452
11	3.618	0.0811	0.0002	0.0015	0.3099	0.08566
12	4.686	0.0986	0.0002	0.0021	0.4067	0.08679
13	5.939	0.1179	0.0003	0.0027	0.5221	0.08790
14	7.393	0.1391	0.0003	0.0035	0.6580	0.08900
15	9.058	0.1621	0.0004	0.0044	0.8161	0.09009
16	10.948	0.1871	0.0004	0.0055	0.9982	0.09117
17	13.075	0.2140	0.0005	0.0067	1.2060	0.09224
18	15.449	0.2428	0.0006	0.0081	1.4413	0.09330
19	18.082	0.2736	0.0007	0.0097	1.7060	0.09435
20	20.984	0.3064	0.0008	0.0114	2.0016	0.09539
21	24.166	0.3411	0.0009	0.0134	2.3302	0.09642
22	27.638	0.3778	0.0010	0.0156	2.6933	0.09745
23	31.408	0.4164	0.0011	0.0180	3.0927	0.09847

Export   Ok

Figure 5.17 Output Table of Chinook Salmon of the modified bioaccumulation program

5.8 Model Results

Figures 5.18 to 5.23 give the simulated mercury concentrations of Chinook Salmon, Lake Trout, Rainbow Trout, Northern Pike, Walleye and Yellow Perch, as a function of the period of time spent in Lake Ontario. Meanwhile, each fish's field data is also plotted on the corresponded figure. In Section 4.2, the field data were analyzed, concluding that the mercury concentrations of fish gradually increased from time to time. The longer the fish stayed in the lake, the more mercury they consumed. Consistent with this observation, a higher mercury concentration is predicted for each species over time from the model.

Section 4.3 discussed the fish most frequently caught, which are Chinook Salmon, Lake Trout and Rainbow Trout, performing consistent mercury trends in the fish bodies. From the bioaccumulation model, the mercury data trends of these fish species match fairly well most of the field data. The simulated model data correlated with age in these fish species. Even though the field data in Northern Pike and Walleye are somewhat limited in quantity, the simulated model data are still close to the field data. The data trend in Yellow Perch seems slightly over-estimated when compared to the field data. Since the field data is widely distributed and the model trend match many field data points, the performance from the model simulation is considered acceptable. This is especially true when the model performance is evaluated against other existing models. Most of the existing model, such as Borgmann and Whittle's (1991 and 1992) regression model, Park *et al.*'s (1994) GMR regression model, and Post *et al.*'s (1996) mechanistic model, can only predict the order of magnitude of pollutant levels. In addition, very few models have been demonstrated to be applicable over such a wide range of different species spanning the food chain. The advantage of the bioenergetics model in terms of its flexibility and broad-based application is clearly demonstrated.

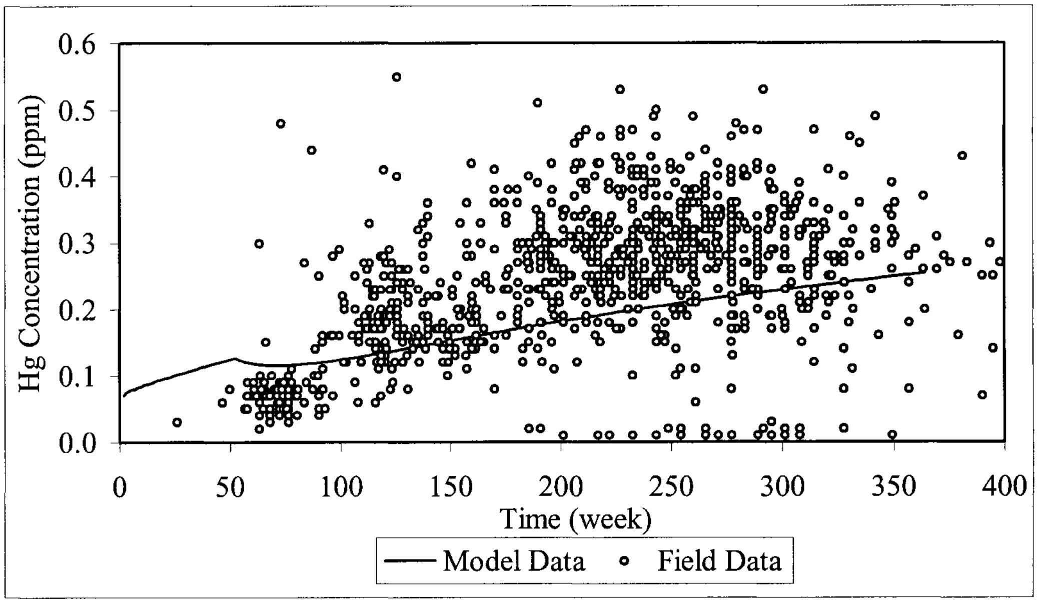


Figure 5.18 Comparison of Chinook Salmon model data and field data

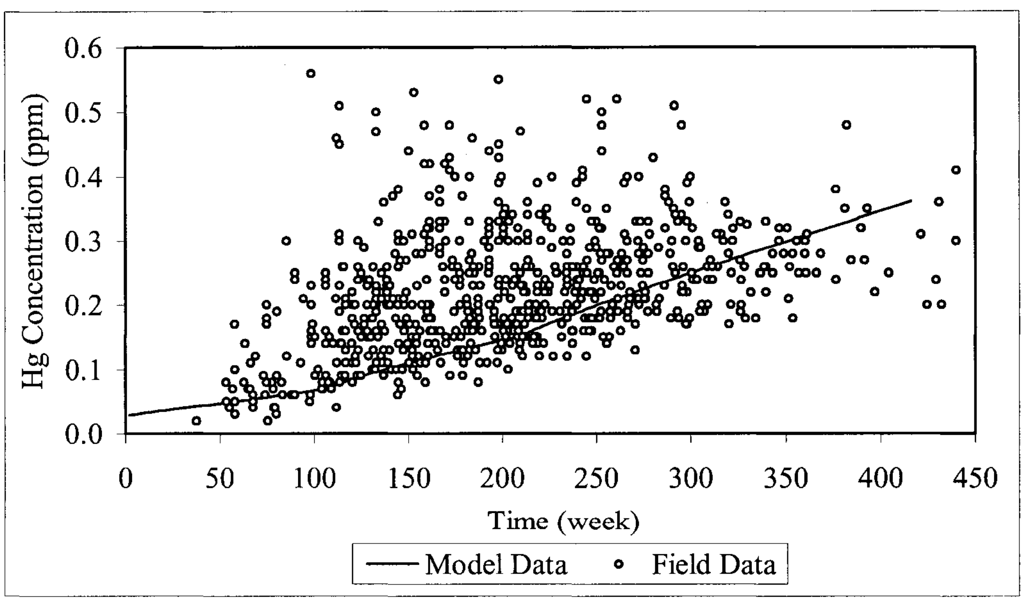


Figure 5.19 Comparison of Lake Trout model data and field data

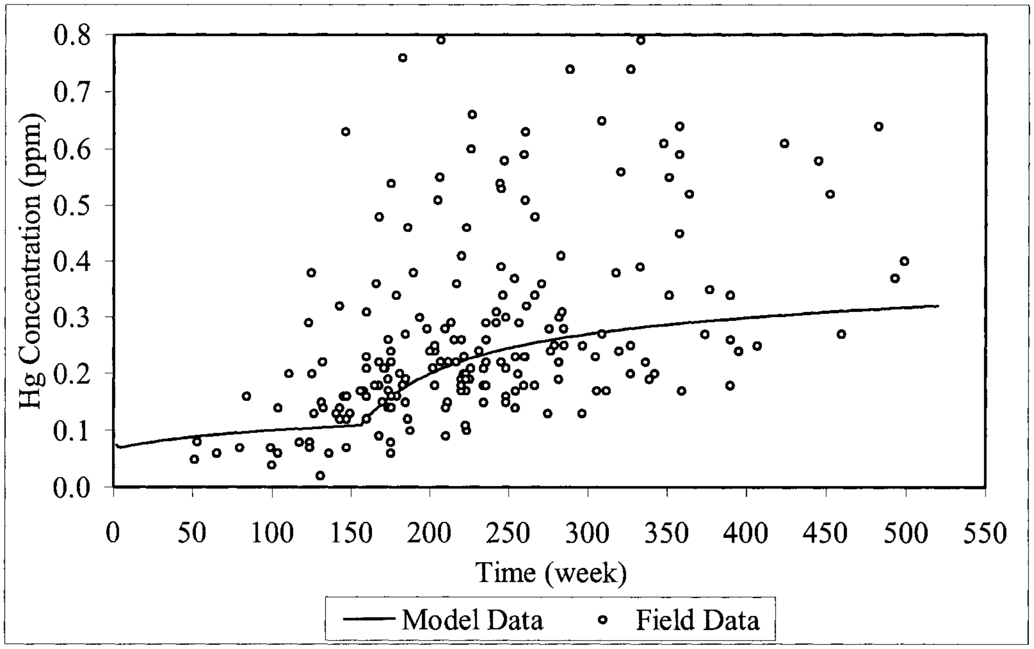


Figure 5.20 Comparison of Northern Pike model data and field data

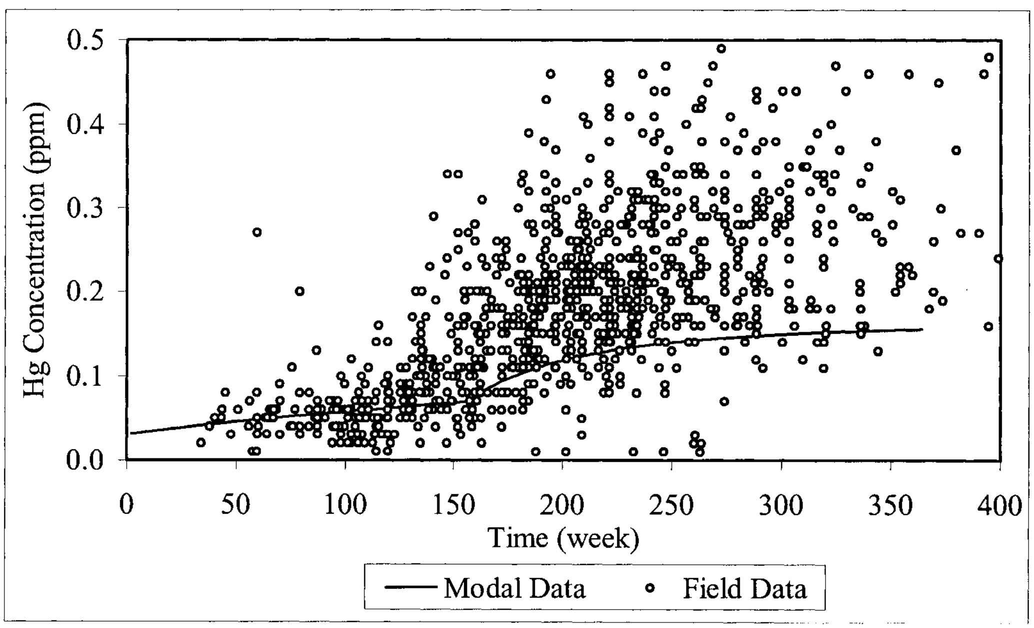


Figure 5.21 Comparison of Rainbow Trout model data and field data

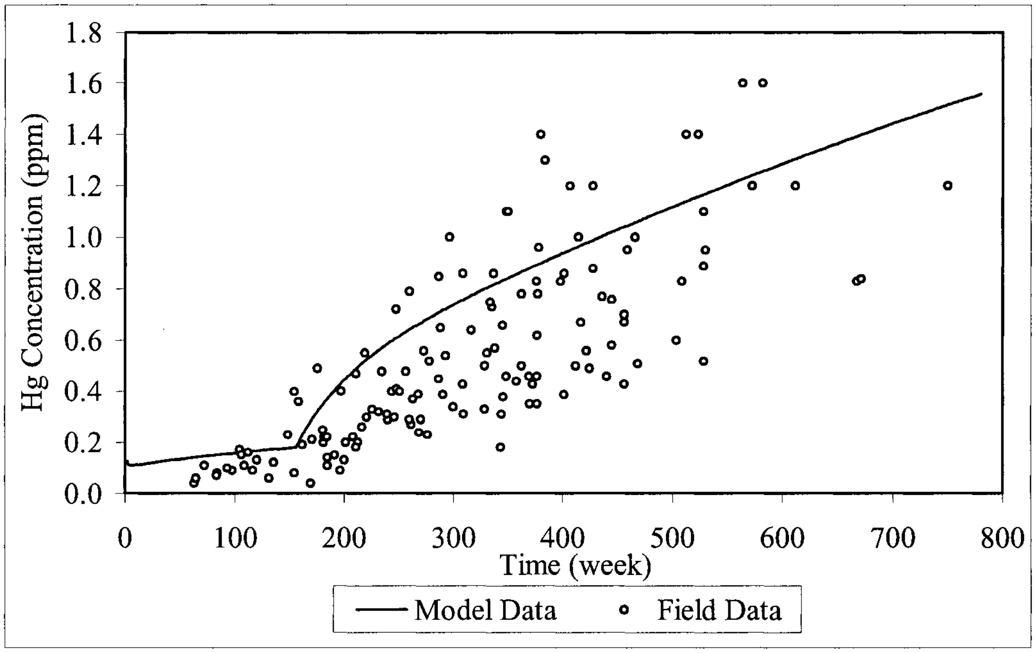


Figure 5.22 Comparison of Walleye model data and field data

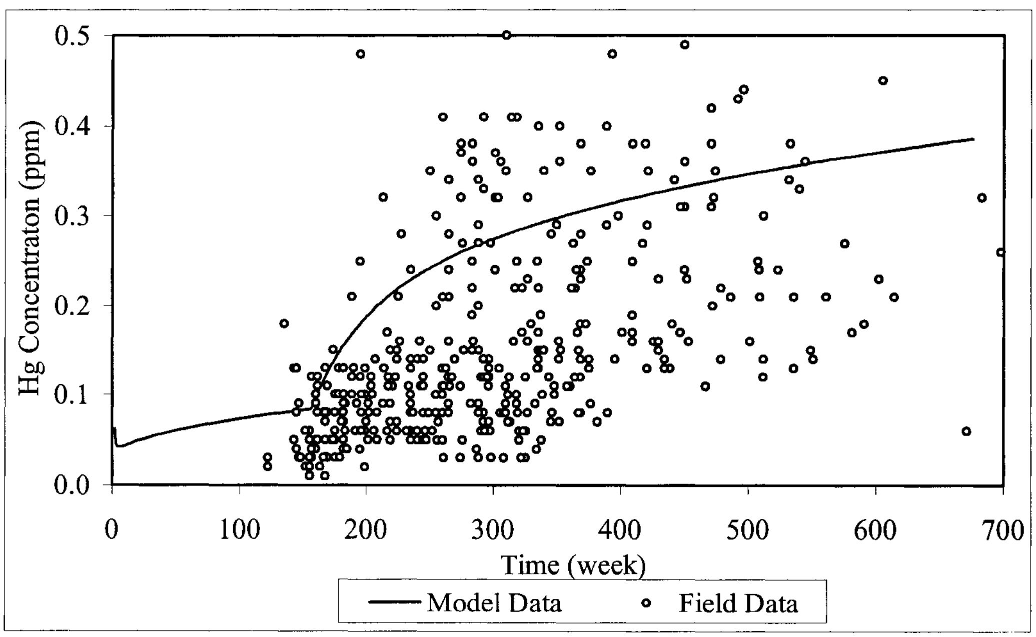


Figure 5.23 Comparison of Yellow Perch model data and field data

Since all six sport fish are exposed to similar aquatic environments, the remarkable difference in their mercury concentrations may be due to their differences in metabolism and diet composition. In many species, there is a downward shift of mercury concentration at their younger age. This reduction is caused by the rapid fish growth during the early stages of their lives. Accumulation increases only very slowly during this phrase because the diet components are relatively clean, but the fish weight increases rapidly. As a result, the mercury concentration, which is defined as accumulation per unit weight, is inevitably decreased.

In any fish species, there is an abrupt increase of mercury concentration at a certain period of time. The cut-off time occurs at 52 weeks (1 year) in Chinook Salmon, 104 and 208 weeks (2 and 4 years) in Lake Trout, and 156 weeks (3 years) in Northern Pike, Rainbow Trout, Walleye and Yellow Perch. These periods of time are recorded in Table 5.17, comparing the fish's age to the age of changing diet composition according to Table 5.15 and fish's age of maturity from Tables 5.3. Obviously, the abrupt changes are caused directly by the change in diet composition during that period. In real life, the diet composition of the fish evolves gradually over the life span. However, for the purpose of modeling, this slow evolution cannot be completely reproduced because of the lack of data. Therefore, only a segmented representation of diet component was fed into the model. As a result, the resulting pollutant accumulation curve obtained is also segmented. This may be improved if more detail information is available on the diet pattern in the future.

Clearly, food consumption is the dominant mercury uptake pathway in fish. Juvenile fish feed mainly on plankton, terrestrial insects and invertebrates, the levels of mercury in their diet lower when compared with the diet for an adult fish. This dietary change results in sudden changes of slopes in the simulated model data curves for these kinds of sport fish. In reality, the discrete change of mercury accumulation must not be occurred. Since the mercury bioaccumulation is changed by a re-constructed in diet composition according to the fish's size, this artificial fact affects the pattern of output. The mercury in fish should be continuous and accumulated by years with gradual changes. A more refine diet composition can be reconstructed to eliminate this problem.

Table 5.17 Comparison of the abrupt time, fish mature age and diet habit

Fish Species	**Model abrupt time (year)**	**Change of diet composition age (year)**	**Fish mature age (year)**
Chinook Salmon	1	1	2
Lake Trout	2 & 4	2 & 4	3
Northern Pike	3	3	4
Rainbow Trout	3	3	3
Walleye	3	3	3
Yellow Perch	3	3	3

Figures 5.24 to 5.29 show the simulated mercury concentrations of the six sport fish correlated with their weights. From the model, only the weight of the fish is demonstrated and the fish's lengths are missing. The fish's weights in all the weeks are substituted to the fish growth function, Eq. [3.2], in order to evaluate the corresponding lengths of the fish. This is used to make figures for the simulated mercury levels of the six sport fish respective to their length, Figures 5.30 to 5.35.

In Chapter Four, the field data were analyzed and reported that the mercury concentrations of fish increased with their size. The computer model simulates good and consistent mercury trends with fish sizes in Chinook Salmon, Lake Trout, Rainbow Trout, Northern Pike and Walleye when they are compared with their field data. The slight over-estimation occurs in the Yellow Perch's time distribution, but this simulated model trend reasonably covers many field data points. The model successfully predicts the trends of mercury concentration accumulated in all the sport fish; gradually increasing with their weight and length according to the simulated model data.

As the same phenomenon occurs in the time distribution, there is an abrupt increase in mercury concentration in each fish's weight and length. The cut-off sizes are 31 cm (400 g), 62 cm (500 g), 52 cm (900 g), 54 cm (1800g), 41 cm (700 g) and 14.5 cm (45 g) in Chinook Salmon, Lake Trout, Northern Pike, Rainbow Trout, Walleye and Yellow Perch, respectively. The lengths are recorded in Table 5.18 and compared with fish lengths at the change of diet composition, according to Table 5.9 and with a fish's mature lengths from Table 4.8. In most of the fish species, these abrupt changes in the model are similar to changes of diet composition in fish's lengths.

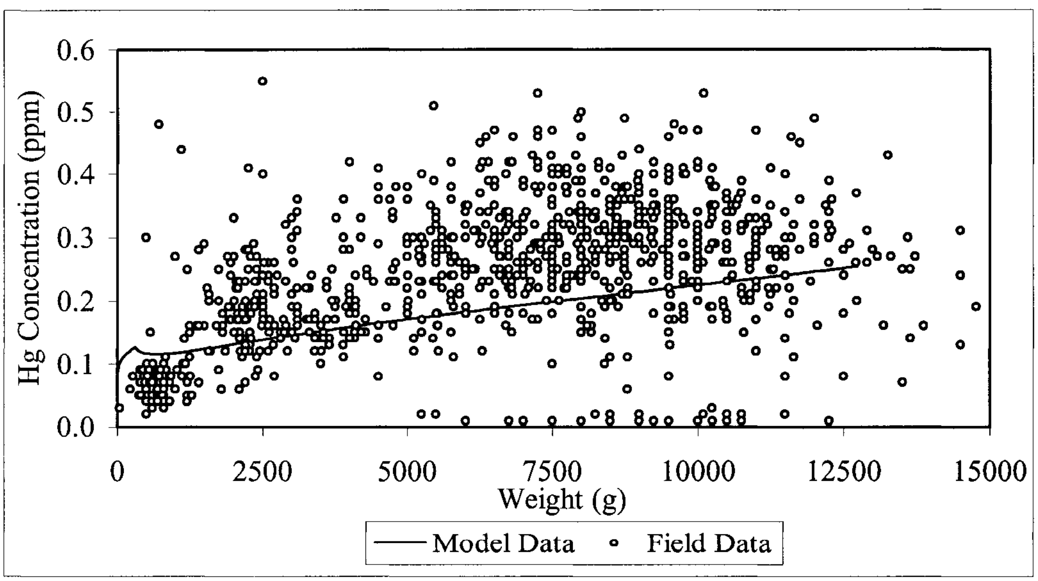


Figure 5.24 Comparison of Chinook Salmon model data and field data according to their weight

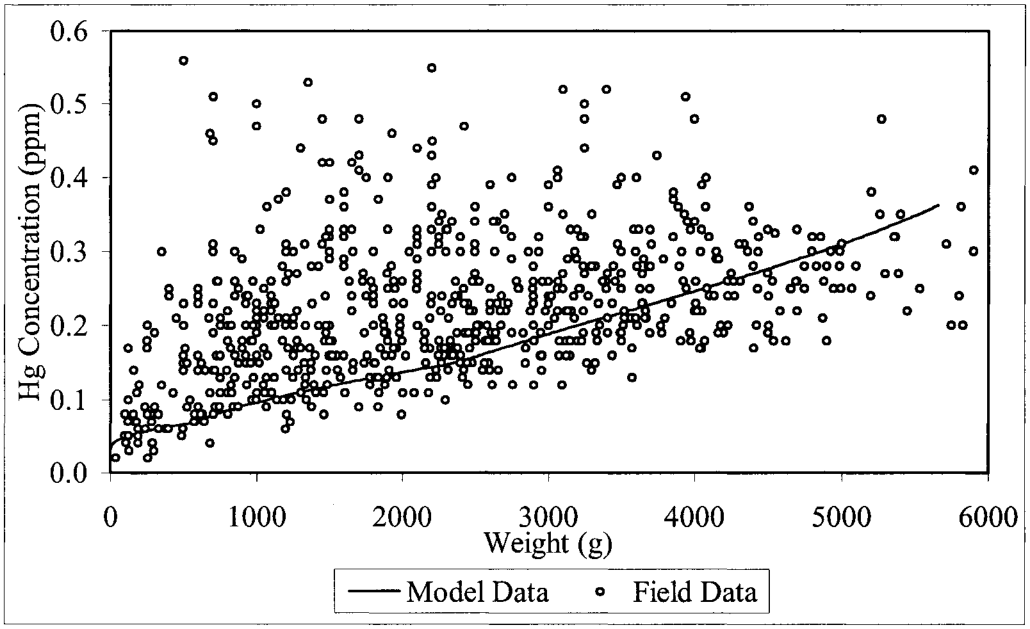


Figure 5.25 Comparison of Lake Trout model data and field data according to their weight

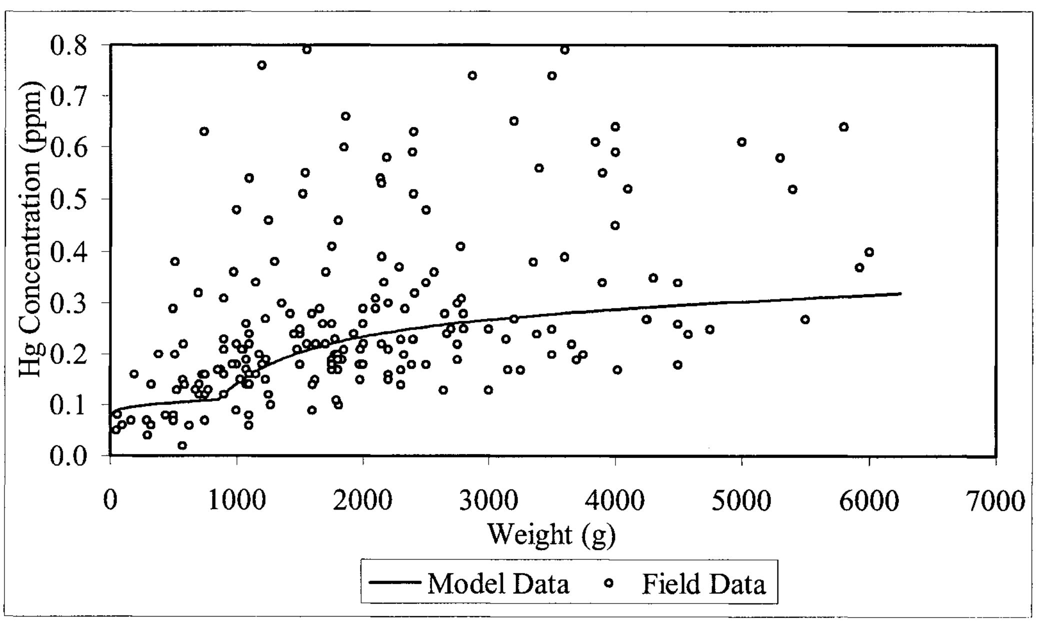


Figure 5.26 Comparison of Northern Pike model data and field data according to their weight

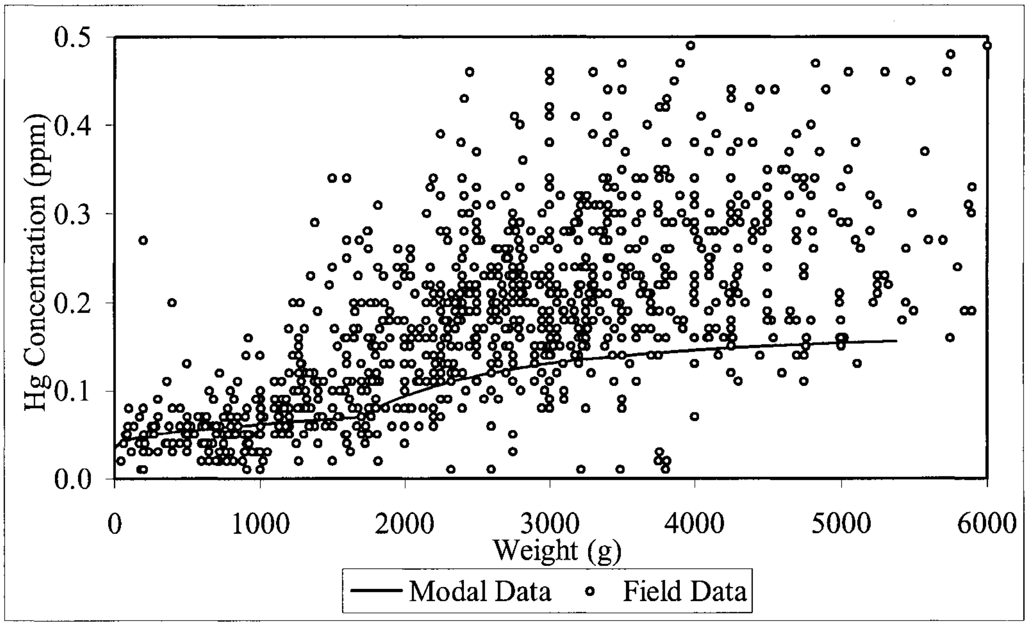


Figure 5.27 Comparison of Rainbow Trout model data and field data according to their weight

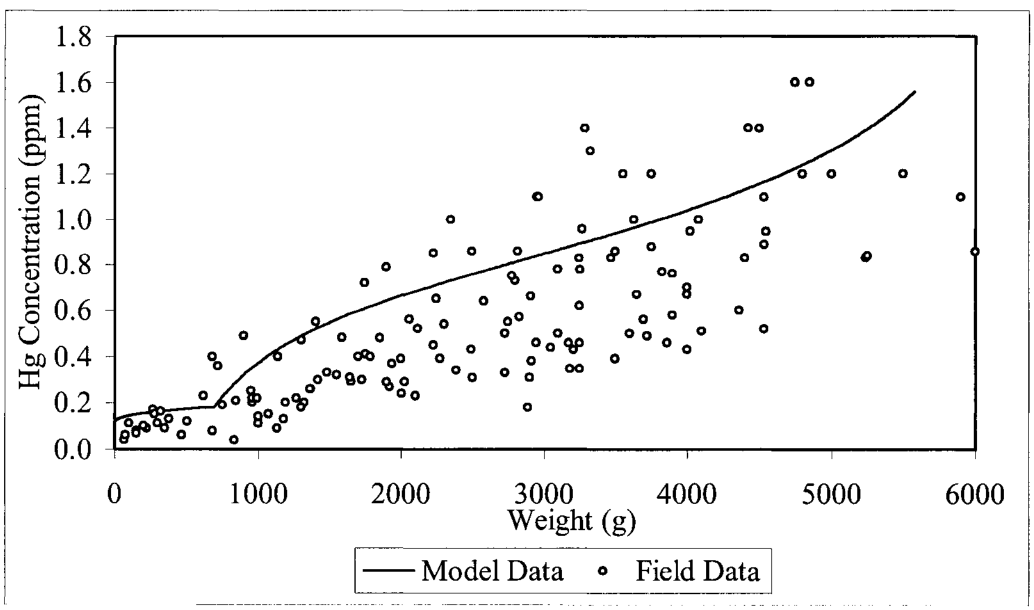


Figure 5.28 Comparison of Walleye model data and field data according to their weight

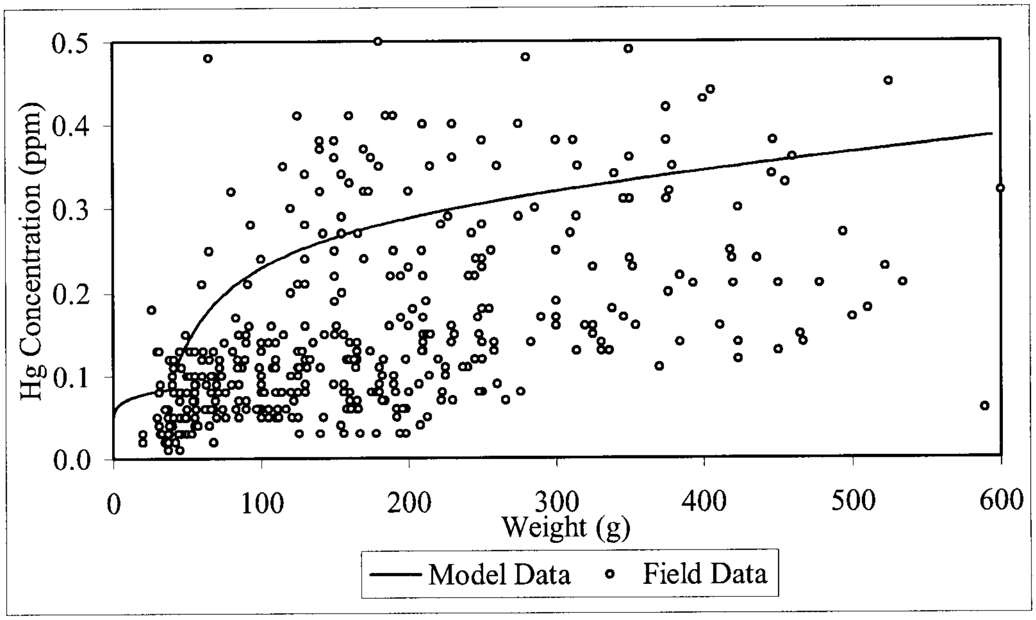


Figure 5.29 Comparison of Yellow Perch model data and field data according to their weight

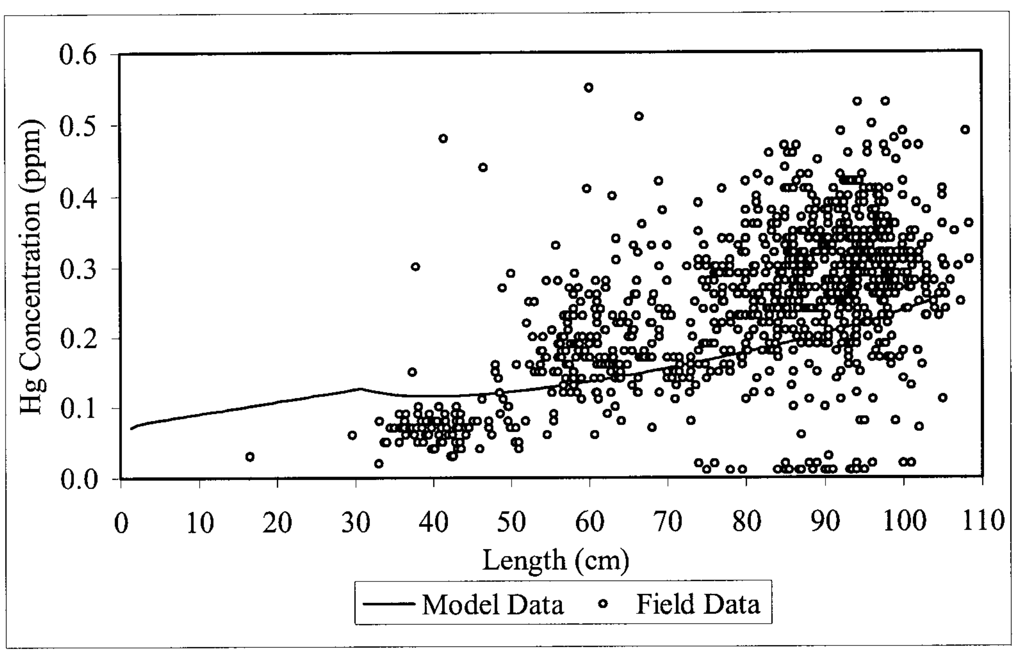


Figure 5.30 Comparison of Chinook Salmon model data and field data according to their length

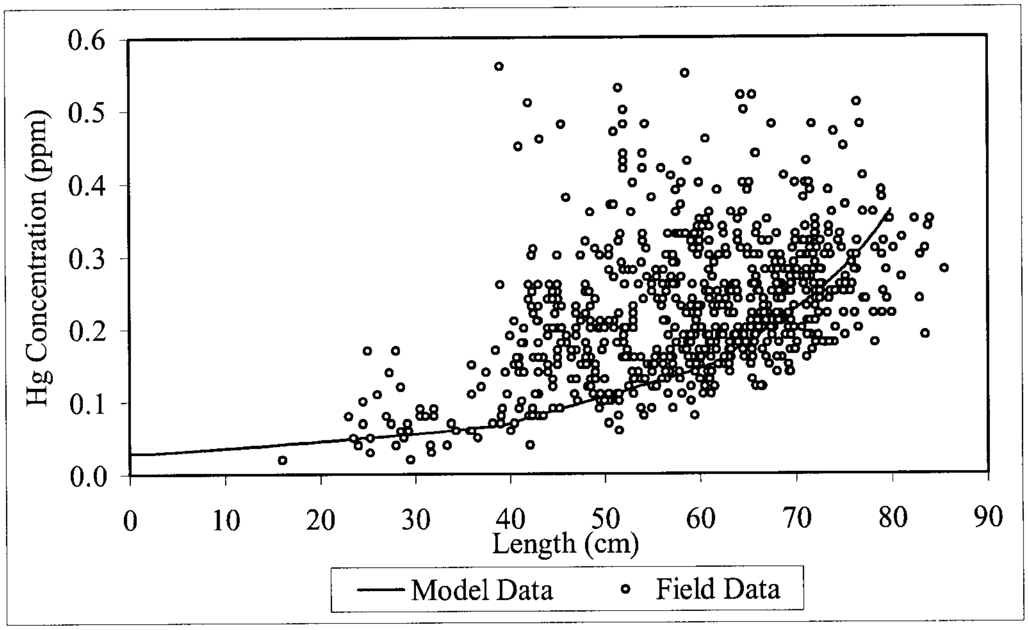


Figure 5.31 Comparison of Lake Trout model data and field data according to their length

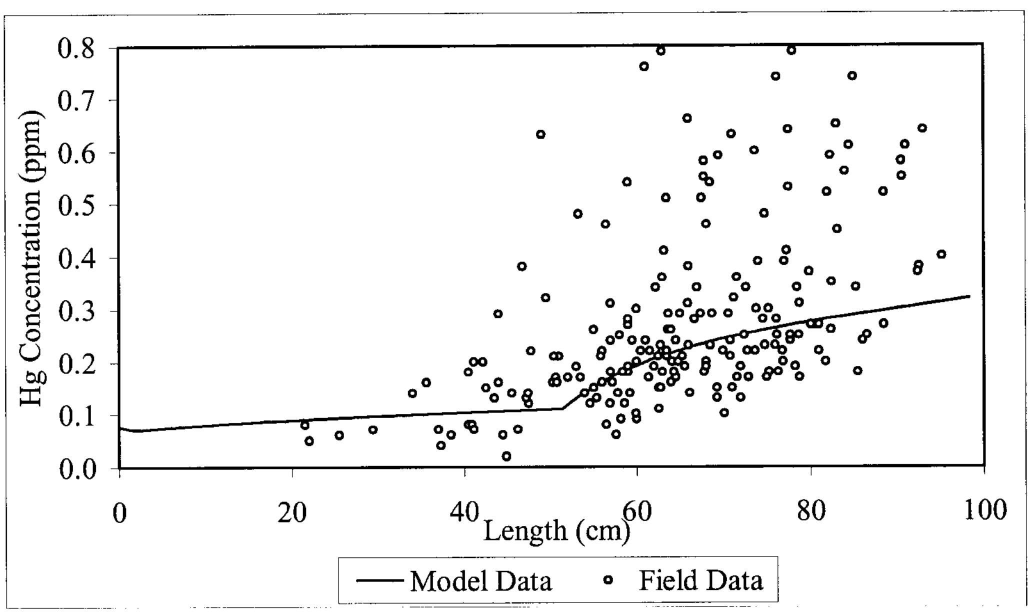


Figure 5.32 Comparison of Northern Pike model data and field data according to their length

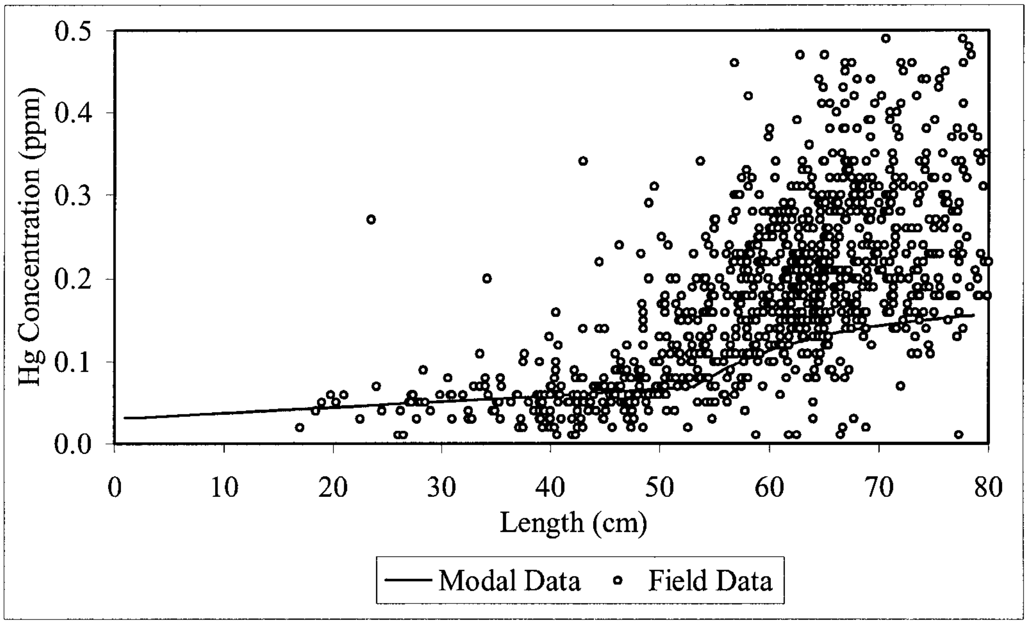


Figure 5.33 Comparison of Rainbow Trout model data and field data according to their length

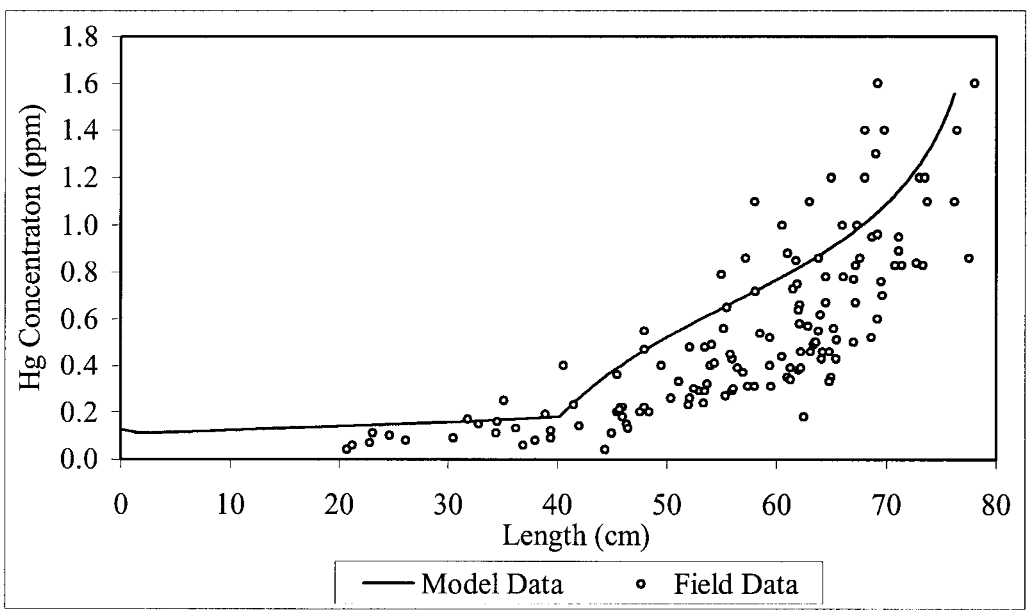


Figure 5.34 Comparison of Walleye model data and field data according to their length

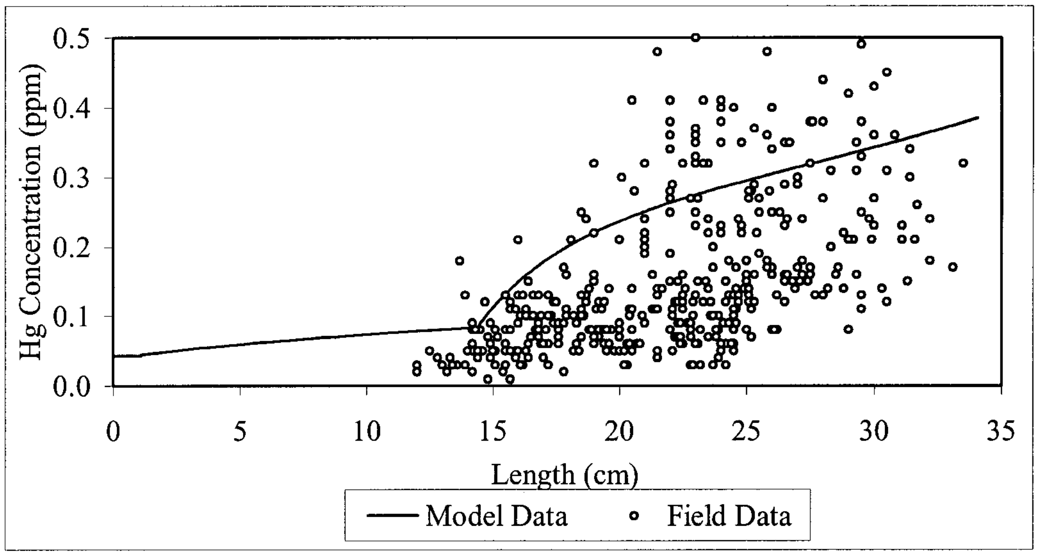


Figure 5.35 Comparison of Yellow Perch model data and field data according to their length

Table 5.18 Comparison of the abrupt length, fish mature length and diet habit

Fish Species	**Model abrupt length (cm)**	**Change of diet composition length (cm)**	**Fish mature length (cm)**
Chinook Salmon	31.0	30.0	53.0
Lake Trout	62.0	25.8, 49.6	47.0
Northern Pike	52.0	60.0	63.0
Rainbow Trout	54.0	30.0	35.0
Walleye	41.0	35.9	45.0
Yellow Perch	14.5	16.3	20.0

Tables 5.17 and 5.18 verify that in most of the fish species, the abrupt changes in the fish's curves from the simulated model are similar to the fish's length at maturity. This supports the conclusion that fish change their diet composition when they reach their maturity. In the preceding figures, few field data points are available for immature fish. It may be because the juvenile fish are prohibited to catch for protecting the fish population. Moreover, they may not be concerned since they are not old enough to potentially accumulate high mercury levels threatening human health. As a result, the

simulated results of immature fish are not compared with the field data. Among the six mature fish, the model has successfully reproduced the mercury trends in fish that are very consistent with the field data. The model has proved its effectiveness in predicting the trends of mercury bioaccumulation in all six kinds of fish.

By using this fast and user-friendly program to predict the fish's mercury level, the cost of capital, labour and expensive monitoring can be minimized. The computer program can conduct all the calculation in a short period of time once the parameters of a particular fish is collected. The results can be generated into a text format file and converted into an excel file, which is an excellent tool for data capture, charting and analysis. In fact, this program is reliable since no major adjustment is needed so far and most of the model parameters can be easily obtained from literature. It also provides accuracies order of magnitude predictions that may not be found in current similar models. Last but not least, the biggest advantage of this model is that it allows multi-species studies and other scenarios generation. In conclusion, the model has proved its effectiveness in predicting the mercury trends in all six kinds of fish. The simulated model data is able to represent the field data. In the future, an improved study can be conducted to predict a better trend of mercury bioaccumulation in fish by modifying some of the important model parameters. Since food is the major pathway of mercury consumption, more accurate mercury level in fish can be calculated if a refined fish diet composition can be re-constructed. Currently, the model is only able to study six kinds of fish. If this model is needed to apply to a fish other than these six kinds, fish monitoring in this fish is required, especially the saltwater fish. It is expected a slight difference in the metabolism between the freshwater and saltwater fish will be observed.

Chapter 6 Effects of Consumption on Humans

Fish is a major food source for humans. It provides protein and health benefits to people. However, the consumption of fish causes adverse health effects when high levels of mercury are found in fish, particularly of methylmercury. Mahaffey (1999) mentioned that fish are the predominant source of methylmercury for most people; about 95% of ingested methylmercury comes from the consumption of fish and other seafood in the U.S. From the literature review, it was discovered that MeHg is of special concern because the human body's defences against this toxin, and its rate of elimination, are not well-developed. Meanwhile, both fish and humans easily absorb MeHg: more than 95% of ingested mercury is absorbed by the human body. If people consume too many polluted fish, many health effects will result.

In fact, the U.S. EPA estimates that about 85% of people in the U.S. eat fish or shellfish over the course of a month, with about 60% consuming fish four or more times a month (Mahaffey, 1999). Moreover, approximately 1% to 5% of women of childbearing age (15-44 years old) eat 100 grams or more of fish or shellfish per day and 9.5% of women in this age group are pregnant in any one year. A great deal of concern is focused on women's dietary needs, since they will partially transfer methylmercury to the fetus. Therefore, many regulations and restrictions have arisen through various federal agencies to protect the public's health.

Health Canada (1998) suggested that 0.47 ugHg/kgbw/day (micro gram per kilogram of body weight per day) is recommended as the general population's maximum provisional tolerable daily intake (pTDI). Every few years, a survey is conducted by the MOE to monitor fishing habitats and fish consumption by humans

(MOE, 1998b). The MOE gives consumption advice to people in the Provincial Fish Guide based on this survey. Even though mercury is tightly regulated in industry and monitored in fish, mercury levels in fish still gradually increase throughout their life spans. Mercury still keeps increasing and it will be a source of major concern in the future, even if it is not such a problem right now.

In this chapter, the fish benefits and the data from the fishing habitat and fish consumption survey are discussed. In addition, the survey's data are utilized to estimate the regular quantity of fish and Hg levels that humans usually consume in their meal. The maximum pTDI is also considered and used to evaluate the maximum amount of mercury that humans can consume, based on typical human weights. When this maximum level is compared to the mercury concentration of the six fish species studied in the bioaccumulation model, it is possible to determine the restriction and human risk factor in consuming certain sizes and varieties of sport fish.

6.1 Fish Benefit

Almost any kind of fish may have real health benefits. They provide a diet high in protein and low in saturated fats if they are properly prepared. In the United States, where an estimated 250,000 people die from sudden heart disease each year, fish are seen as a healthy choice (Cohen, 2000). Half of the victims of heart disease have no known cardiovascular disease when their heart unexpectedly stops beating. Specifically, they had higher levels of trans-fatty acids and significantly lower levels of beneficial long chain omega-3 fatty acids, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Lemaitre, 2002). People with a high trans-fatty acid level have three times the risk of sudden cardiac death than do people with lower levels.

Fish oil has strong antiarrhythmic properties and plenty of EPA and DHA, omega-3 fatty acids, which reduce the risk of heart disease and high blood pressure, prevent blood clotting, and lower cholesterol and triglyceride levels. It also exerts a protective effect against cancer and helps the brain work well. A 30 percent decrease in the overall mortality rate among men consuming fish once or more each week as compared to those eating fish less than once per month has been recorded (Albert, 1998). In Portugal, researchers at the University of Lisbon conducted a study evaluating the differences in heart disease between a fishing village and an inland rural village on the island of Madeira. The mortality rate from heart disease in the fishing village was 0.31 percent during the period of 1990 to 1997, as compared to 1.21 percent in the rural village (Torres, 2000). People from the fishing village consumed 8 times more fish than did the men in the rural village, and as a result, had much higher levels of EPA and DHA in their blood. The researchers observed a good correlation between fish intake and blood levels of EPA and DHA.

Rosenberg (2002) proved that striving for a daily intake of 0.5 to 1 gram of fish oils (from fatty fish) helps protect against sudden cardiac death. It is possible to reduce the risk of heart disease-related death by 40 percent in middle-aged American men (Addis, 2002). Besides, the U.S. Food and Drug Administration recently reviewed the safety profile of EPA and DHA, concluding that a combined daily intake of these two essential fatty acids of up to 3 grams per day is safe (O'Keefe *et al.*, 2000). Sometime, one doesn't get enough omega-3 fatty acid when eating plenty of fish, since a typical diet contains a lot more mega-6 fatty acid than omega-3 fatty acid, even when clean fish is eaten. Moreover, not all fish are equally endowed with omega-3 fatty acids. For example, Black bass, Lake Trout, Salmon, Tuna (water-packed), and Whitefish are recommended fish with a high omega-3 fatty acid oil content but Cod, Halibut, Pike and Walleye are not (Addis, 2002). Unfortunately, some species of fish are contaminated with toxic chemicals, such as mercury, dioxin, DDT, and PCBs. People consume not only the omega-3 fatty acids, but also the pollutants when eating these fish.

6.2 Survey on fishing habitat and fish consumption

In 1960, the Ontario Government began monitoring contaminant levels in sport fish when concerns were first raised about how these pollutant substances were affecting aquatic life. Intensive fish monitoring programs were held in many of Ontario's inland lakes, rivers and Great Lakes, resulting in a biennially updated "Guide to Eating Ontario Sport Fish", issued to provide consumption advice on each fish species. In 1978, the MOE sport fish contaminant-monitoring program initially distributed a set of questionnaires associated with the Fish Guide about fishing habitats and fish consumption by humans (MOE, 1998b).

The questionnaires were randomly sent to people who had requested a copy of the Guide from the MOE in response to newspaper advertising. This survey was later distributed once every few years and further questioned people about their fishing frequency, their most frequently fished locations, and their fish consumption patterns, among other issues. It was used for several purposes, among them, providing information on the most effective means of distribution for the Guide, its usefulness, and the effectiveness of its consumption advice. The most recent survey report was finished in 1998. A total of 5,000 questionnaires along with business reply envelopes, were sent to distributors (LCBO, Beer Stores, MOE and MNR). They were randomly inserted in the Guides in 1995 and a total of 260 responses being received. A sample of the questionnaires appears in Appendix II. Some of the survey results are summarized and discussed in the following subsections.

6.2.1 Age group

In the survey, the questionnaires ask about the age and the location of the respondents. There are four age groups: under 15, 15-25, 26-45, and over 45. The percentage of respondents in each group is tabulated in a bar chart, Figure 6.1. In 1995, almost half of the respondents were in the 26-45 age group, while and 40% were over 45. Since this survey is attached with the Fish Guide, it can be assumed that over 85% of the most frequently fishing people are adult. Moreover, the report also stated that over 98% of the respondents were Ontario residents and over 89% of these residents were from Southern Ontario. This result is reasonable since this survey is done in Ontario and Southern Ontario is one of the most popular fishing areas in Canada.

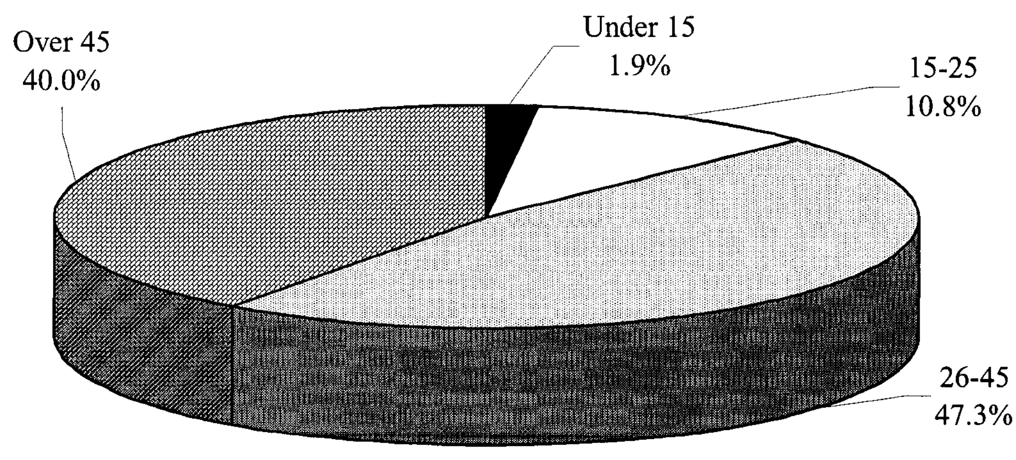


Figure 6.1 Age groupings of respondents in 1995

6.2.2 Fishing Frequency and Location

Fishing is a major recreational activity in Canada and a lot of people enjoy this. From the report, approximately 5% of the surveyed people fish daily, while 1.2% fish only once a year in Ontario, as given in Table 6.1 and Figure 6.2. A quarter of the respondents fish more than once a week; they are obviously the most frequent fishing group. A representation of the cumulative percentage of fishing respondents is prepared in Figure 6.3. More than 40% of the respondents fish at least once a week and over 70% of the respondents indicated that they fish at least once every month.

As mentioned in the previous subsection, most of the respondents were from Southern Ontario. The Great Lakes are the most popular water body for fishing, as shown in Figure 6.4. More than 90% of fishing water bodies is located among the Great Lakes. It is obvious that Lake Ontario is the most frequently fished body of water among the Great Lakes; more than 40% of respondents fished in Lake Ontario. The research of this thesis provides contamination information on sport fish in Lake Ontario, covering the most fished water bodies.

Table 6.1 Fishing frequency by respondents in 1995

Fishing Frequency	**Percentage of Respondents (%)**
Daily	4.9
> Once/week	25.7
Once/week	12.3
Once/two weeks	18.0
Once/month	13.9
Once/4 months	2.4
Once	1.2
On vacation only	6.1
Never	2.4
Other	13.1

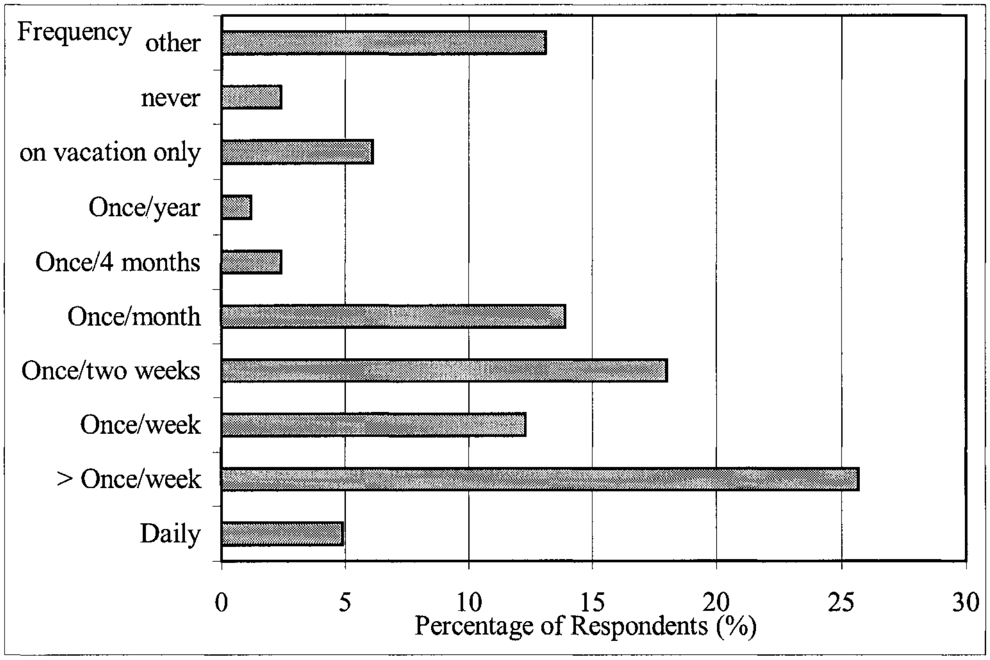


Figure 6.2 Fishing frequency by respondents in 1995

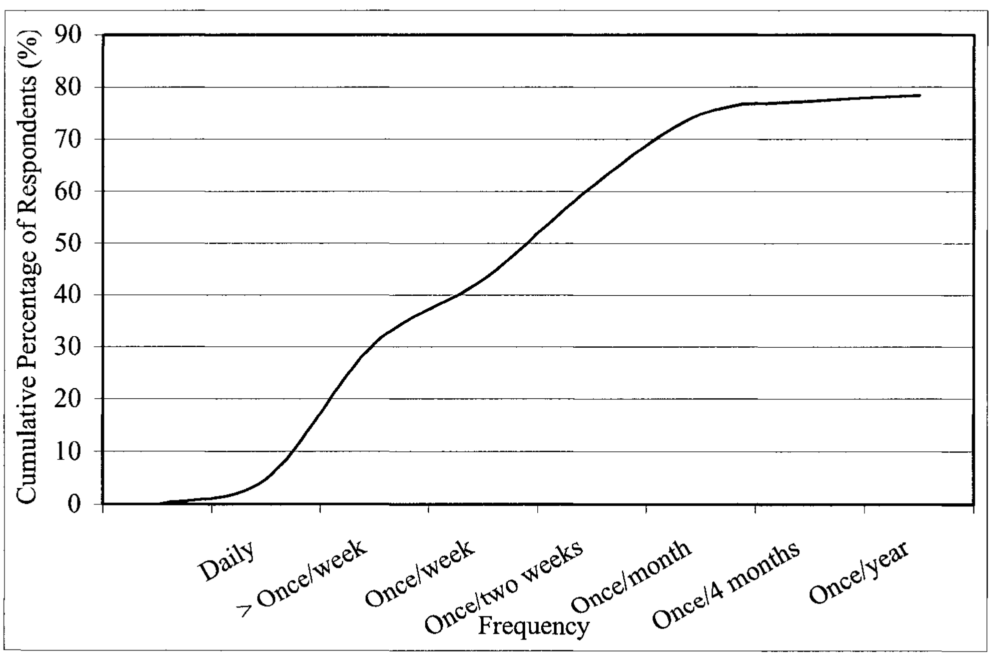


Figure 6.3 Cumulative fishing frequency by respondents in 1995

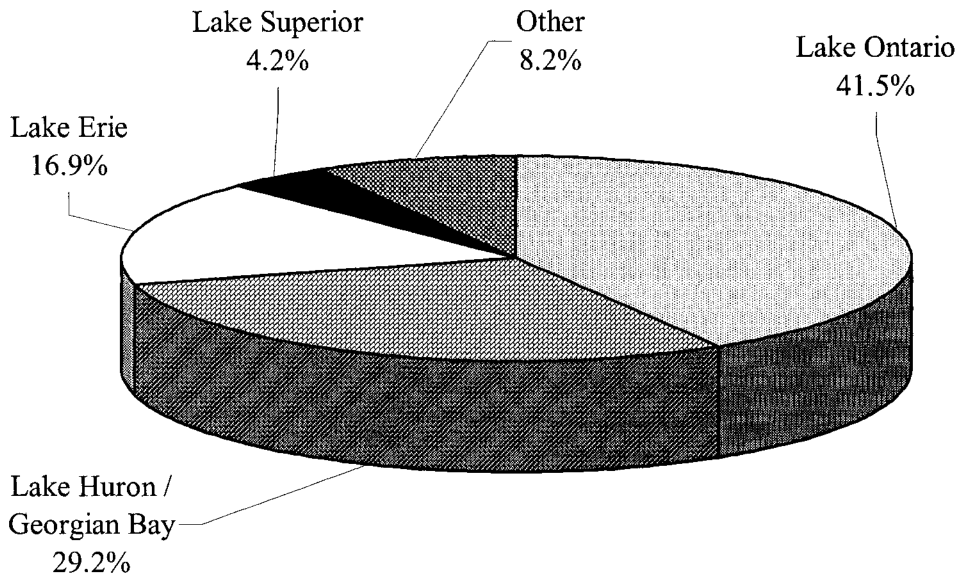


Figure 6.4 Most frequently fished water bodies in the Great Lakes in 1995

6.2.3 Fish Caught and Consumption Frequency

There are many different kinds of sport fish in Ontario. Table 6.2 demonstrates the ten most frequently caught and consumed sport fish species. Since people may catch more than one fish species while fishing, a high percentage of respondents reported on many fish species. Among these ten species, this thesis covers the mercury levels in seven of them, and in Chapter 5, six are analyzed in detail. Walleye and Yellow Perch are the most frequently caught and consumed sport fish. Over 56% of the respondents consumed Walleye. Furthermore, the survey reported there is a continuous increase in consumption of Chinook Salmon, another species studied in detail in this report.

In addition, the survey provides information on patterns of sport fish consumption. It is impossible to assume people consume all the caught fish, because some people fish for fun and may release what they catch. Table 6.3 and Figure 6.5

reported the meal frequency of sport fish in 1995. The most common meal frequency shows sport fish consumed once a month, among approximately 25% of the respondents. If the cumulative percentage of respondents is considered, as given in Figure 6.6, 51% of the 1995 respondents consumed a sport fish dish at least once a month. Almost 7% of the anglers did not consume any sport fish. It should be mentioned that only sport fish caught by the respondents are considered in the survey. Therefore, when commercial fish species are considered, the consumption would be more in quantity.

Table 6.2 The ten most frequently caught and consumed sport fish species in 1995

Fish Species	Percentages of Respondents (%)
Walleye	56.5
Yellow Perch	43.5
Smallmouth Bass	40.5
Rainbow Trout	36.2
Lake Trout	30.6
Northern Pike	28.5
Chinook Salmon	24.6
Largemouth Bass	22.4
Brook Trout	20.3
Coho Salmon	17.7

Table 6.3 Sport fish meal frequency in 1995

Meal Frequency	Percentage of Respondents (%)
Daily	1
> Once/week	2
Once/week	7
Once/two weeks	16
Once/month	25
Once/4 months	22
Once/year	6
Never	7
Other	14

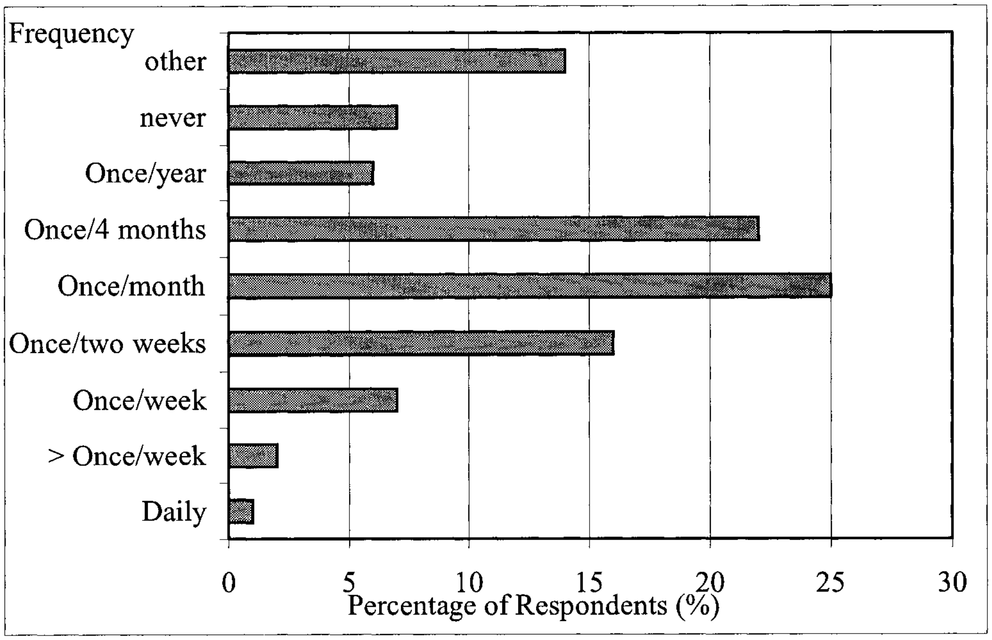


Figure 6.5 Sport fish meal frequency in 1995

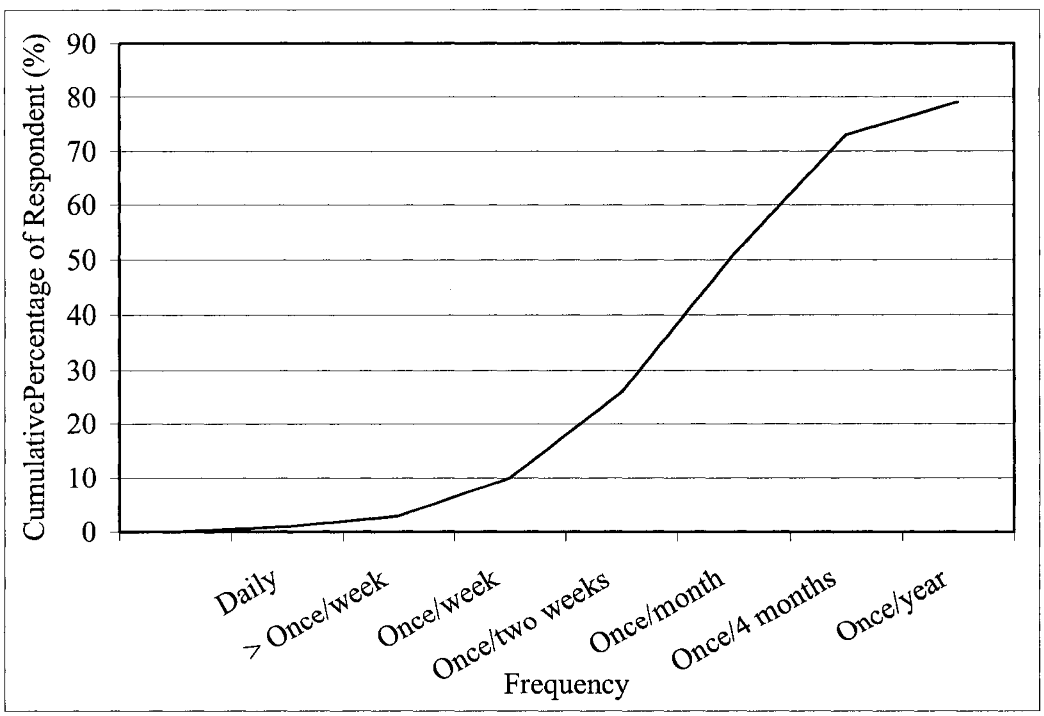


Figure 6.6 Cumulative sport fish meal frequency in 1995

The sport fish meal frequencies from Table 6.3 were converted to a daily meal frequency, as demonstrated in Table 6.4. If the meal frequency is more than once a week, it is assumed the respondents eat sport fish meals 3.5 times a week, or 0.5 meals per day. If the meal frequency is indicated as other, it is assumed the respondents eat only one sport fish meal every year. The average daily meal frequency could be determined by multiplying daily meal frequencies with the percentage of respondents. On average, consumers eat 5.2×10^{-2} sport fish meals daily, which is equal to 3.6×10^{-1} meals per week.

In reality, people may not only consume sport fish, but also commercial fish as well. The survey questioning the respondents about their frequency of the commercial fish consumed and report in Table 6.5. One-eighth and a quarter of the respondents consume commercial fish once a week and once a month respectively. Meanwhile, 14% of the respondents have never consumed any commercial fish at all. In Figure 6.7, it is clear that more than 60% of the respondents consume at least one meal of commercial fish per month. By using the same method in the sport fish, the average daily meal commercial fish can be calculated in Table 6.6. On average, people consume commercial fish 6.7×10^{-2} times per day. By adding the sport and commercial fish meal frequency, it is estimated that people consume fish 1.2×10^{-1} times a day, or 8.3×10^{-1} fish meals every week.

Table 6.4 Average sport fish meal frequency in 1995

Frequency	Daily Meal Frequency	Respondents (%)	Average Daily Meal Frequency
Daily	1.0	1	$1.0x10^{-2}$
> Once/week	$5.0x10^{-1}$	2	$1.0x10^{-2}$
Once/week	$1.4x10^{-1}$	7	$1.0x10^{-2}$
Once/two weeks	$7.1x10^{-2}$	16	$1.4x10^{-2}$
Once/month	$3.3x10^{-2}$	25	$8.2x10^{-3}$
Once/4 months	$8.0x10^{-3}$	22	$1.8x10^{-3}$
Once/year	$3.0x10^{-3}$	6	$2.0x10^{-4}$
Other	$3.0x10^{-3}$	14	$4.0x10^{-4}$
Total		$\Sigma = 100$	$\Sigma = 5.2x10^{-2}$

Table 6.5 Commercial fish meal frequency in 1995

Meal Frequency	Percentage of Respondents (%)
Daily	0.5
> Once/week	4.0
Once/week	12.5
Once/two weeks	20.0
Once/month	25.4
Once/4 months	17.0
Once/year	6.6
Never	14.0
Other	0.0

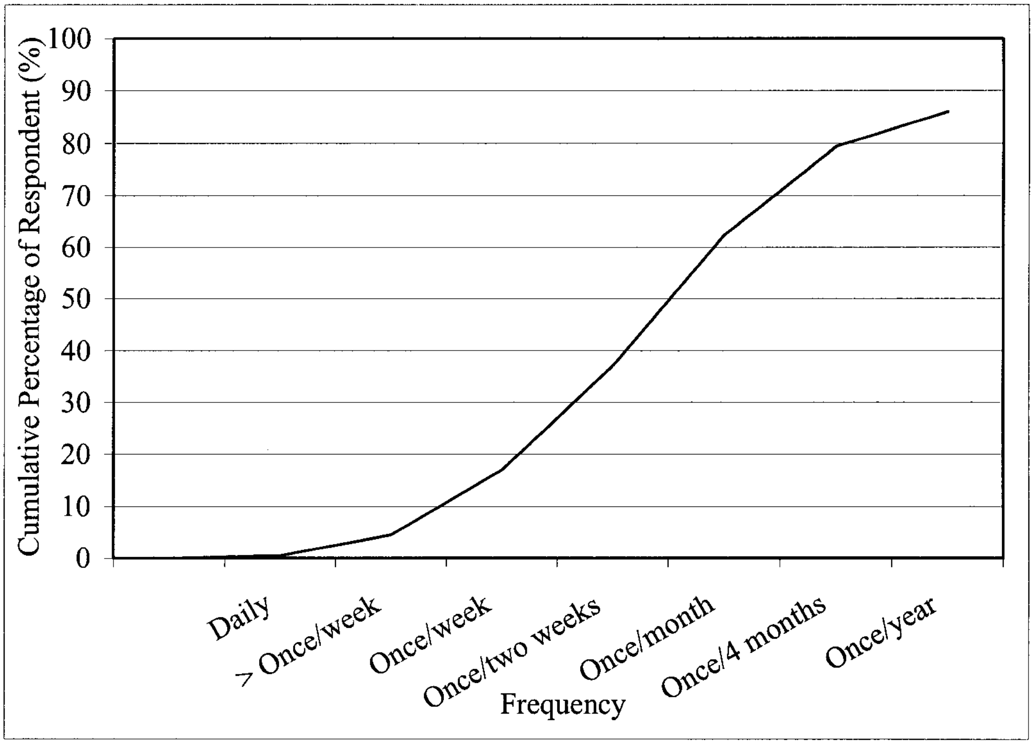


Figure 6.7 Cumulative commercial fish meal frequency in 1995

Table 6.6 Average commercial fish meal frequency in 1995

Frequency	Daily Meal Frequency	Respondents (%)	Average Daily Meal Frequency
Daily	1.0	0.5	5.0×10^{-3}
> Once/week	5.0×10^{-1}	4.0	2.0×10^{-2}
Once/week	1.4×10^{-1}	12.5	1.8×10^{-2}
Once/two weeks	7.1×10^{-2}	20.0	1.4×10^{-2}
Once/month	3.3×10^{-2}	25.4	8.4×10^{-3}
Once/4 months	8.0×10^{-3}	17.0	1.4×10^{-3}
Once/year	3.0×10^{-3}	6.6	2.0×10^{-4}
Other	3.0×10^{-3}	14.0	4.2×10^{-4}
		$\Sigma = 100.0$	$\Sigma = 6.7 \times 10^{-2}$

6.2.4 Meal Size Consumption and Portion

The respondents were also asked the quantity of sport fish eaten in a single meal. The report is summarized in Table 6.7. More than 45 % of the respondents reported eating 170 to 230 g of fish in each meal. As well, 230 g (8 oz) was the most frequently mentioned meal size in the surveys (26.6%). Not many people consume extremely small or large amounts of sport fish in a single meal. A cumulative sport fish size in meals is given in Figure 6.8. Over half of the respondents in the survey consumed at least 230 g (8 oz) of sport fish per meal.

Table 6.7 Sport fish meal size in 1995

Meal Size g(oz)	Percentage of Respondents (%)
None	7.0
< 60 g (2 oz)	2.5
60 g (2 oz)	1.5
110 g (4 oz)	11.0
170 g (6 oz)	20.8
230 g (8 oz)	26.6
340 g (12 oz)	15.0
450 g (16 oz)	10.0
> 450 g (16 oz)	5.6

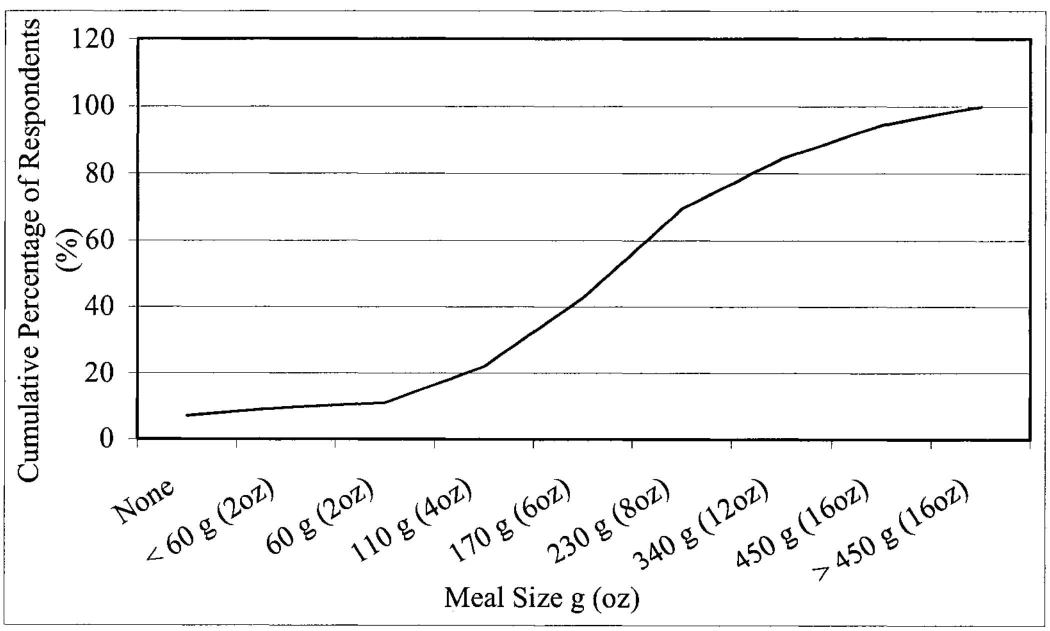


Figure 6.8 Cumulative sport fish meal size in 1995

The average size of sport fish consumed in one meal is estimated. The figure was initially calculated in grams. The size values of 30 g and 560 g are assumed for meal sizes under 60 g and over 450 g. The meal size in each size category is multiplied by the percentage of respondents in Table 6.8, from which the corresponding average sport fish meal size consumed is determined as 237.7 g in 1995. On the other hand, the same kind of information about the quantity of commercial fish eaten in a single meal is also provided in the survey. Interestingly, the average commercially purchased meal size for fish was also calculated at 237 g, which is similar to the meal size for sport fish. The average fish size in each meal is the average meal size between sport and commercial fish, which is 237.3 g per meal.

Table 6.8 Average consumed meal size of sport fish in 1995

Meal Size (g)	**Average size (g)**	**Respondents (%)**	**Average Consumed Meal Size (g)**
None	0	7.0	0.0
Under 60	30	2.5	0.8
60	60	1.5	0.9
110	110	11.0	12.1
170	170	20.8	35.4
230	230	26.6	61.2
340	340	15.0	51.0
450	450	10.0	45.0
Over 450	560	5.6	31.4
		$\Sigma = 100.0$	$\Sigma = 237.7$

The questionnaires also survey what portions of fish are consumed by people. In Table 6.9, the percentage of respondents consuming each portion type are recorded. More than 100% is found in all portion types since more than one portion may be chosen. The most frequently consumed fish portion is skinless dorsal fillet. The whole fish or fish steaks with fat trimmed is the second choice for consumption. Normally, the fish's eggs, organs and fat are of the most concern because of the potentially higher contaminant contents. Luckily, less than 10% of respondents were interested in these fish portions. However, an exception is made for MeHg since it is generally insoluble in fat, and, therefore, mostly stored in the muscle part of the fish.

Table 6.9 Portion types of fish consumption in 1995

Portion Type	**Percentage of respondents (%)**
Skinless dorsal fillet	65.7
Whole fish/fish steaks with fat trimmed	21.5
Skin on fillet	16.5
Whole fish/fish steaks, including fat	9.1
Fish eggs/livers	0.8

6.3 Human Risk of Fish Consumption

In human bodies, the recommended maximum provisional tolerable daily intake of mercury for the general population is 0.47 ug per kilogram of body weight. This means he acceptable mercury level in humans is highly dependent body weight. A heavier man can accommodate a higher level of mercury than a lighter one. In Sub-section 6.2.1, it is understood that the most frequently fishing people are adult. According to the research from Halls and Hanson (2002), there is a typical pattern of ideal weight and age distribution among white people. Male and female weight range corresponding to their age range is tabulated in Table 6.10. The average male and female weight are calculated as well as the average age and are given in the same table. People between 20 and 25, and from 40 to 55 years old were used, as examples, to determine the human risk of fish consumption.

Table 6.10 Typical pattern of weight and age distribution among white people

Age	Male Weight Range (kg)	Female Weight Range (kg)	Average Male Weight (kg)	Average Female Weight (kg)
0 - 4.9	0 - 18	0 - 18	13.0	13.0
5 - 9.9	19 - 34	19 - 31	25.0	24.0
10 - 14.9	36 - 57	32 - 56	45.0	46.0
15 - 19.9	58 - 66	57 - 59	63.0	58.0
20 - 24.9	67 - 70	60	68.5	60.0
25 - 29.9	71 - 72	61 - 62	71.5	61.5
30 - 34.9	73	63 - 64	73.0	63.5
35 - 39.9	74	65	74.0	65.0
40 - 44.9	74	66	74.0	66.0
45 - 49.9	74	66	74.0	66.0
50 - 54.9	74	66	74.0	66.0
55 - 59.9	73	65	73.0	65.0
60 - 64.9	72	64	72.0	64.0
65 - 69.9	71	63	71.0	63.0
70 - 74.9	69 - 70	62	69.5	62.0
75 - 79.9	67 - 68	61	67.5	61.0

Since the weight of male and females are different at the same age, the human risk of consumption is separated by gender. At younger ages between 20 and 25, males and females have typical weights of 68.5 and 60 kg, respectively. In older ages, from 40 to 55 years old, males and females gain a little weight and reach between 74 and 66 kg, respectively. The maximum daily mercury uptake is 0.47 ug per kilogram of body weight. Therefore, young males and older males can consume up to 32.2 ug and 34.8 ug of mercury per day. Females must consume lower mercury levels, since they have lower body weights on average. They can consume up to 28.2 ug of mercury between the ages of 20 to 25 years old, and 31.0 ug between 40 to 55 years.

Referring to Chapter 5, the mercury concentrations of different fish species at any age were calculated by using the bioaccumulation program with Visual Basic 5.0. The simulated mercury level in each half-year was used to calculate the human risk in fish consumption. As a sample calculation, Chinook Salmon's mercury concentrations respective to their weights are recorded in Table 6.11. By assuming consumers eat an average of 0.83 meals per week and that fish meal size is estimated at 237.3 g in each meal, the daily mercury consumption from fish can be calculated. It is multiplied by the fish's Hg concentration, by the number of meals per week, and by the amount of fish in each meal, and then divided by seven days. In fact, many consumers eat more than 0.83 meals of fish per week. People who eat one to four fish meals per week are of concern, and the corresponding mercury consumed from fish is also calculated in Table 6.11.

From the literature review, it was found that fish is not the only source of mercury for people. They can absorb certain amounts of mercury from breathing air, from other food sources, and from other uncertain sources. As such, a safety factor of 2 is appropriate considered to apply on the maximum acceptable daily intake of mercury from fish for the general population. As a result, young males and females can consume up to 16.10 ug and 14.10 ug of mercury daily, while older males and females can consume 17.39 ug and 15.51 ug of mercury per day, as given in Table 6.11. In general, males can accept 10% higher daily mercury consumption than can females.

This information is compared with the mercury level consumed from Chinook Salmon in Figure 6.9. There is no risk for people who eat only 1 meal or less of Chinook Salmon in a week. If a young female eats 2 meals of Chinook Salmon per week, it is not recommended to eat big fish ($\geq$ 8.25 kg in weight) because she will consume too much mercury, risking her health. The more fish consumed per week, the more stringent is this size restriction. For example, an old male consumer may be at risk if he eats a 1.9 kg Chinook Salmon, four times a week.

Table 6.11 Comparison of mercury consumption from Chinook Salmon and maximum mercury uptake from fish

Age	Fish weight (g)	Hg Level (ppm)	Hg Consumption from Chinook Salmon					Maximum Hg Uptake from Fish			
			0.83 meal per week	1 meal per week	2 meal per week	3 meal per week	4 meal per week	20 - 25 male	20 - 25 female	40 - 55 male	40 - 55 female
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.10	14.10	17.39	15.51
0.5	44.60	0.10	2.87	3.44	6.88	10.32	13.76	16.10	14.10	17.39	15.51
1.0	300.38	0.13	3.58	4.29	8.59	12.88	17.17	16.10	14.10	17.39	15.51
1.5	840.91	0.12	3.28	3.93	7.86	11.79	15.72	16.10	14.10	17.39	15.51
2.0	1648.82	0.13	3.57	4.28	8.55	12.83	17.11	16.10	14.10	17.39	15.51
2.5	2666.62	0.14	3.98	4.77	9.54	14.31	19.08	16.10	14.10	17.39	15.51
3.0	3825.81	0.16	4.42	5.30	10.60	15.90	21.20	16.10	14.10	17.39	15.51
3.5	5061.83	0.17	4.85	5.82	11.64	17.45	23.27	16.10	14.10	17.39	15.51
4.0	6320.56	0.19	5.25	6.30	12.60	18.90	25.20	16.10	14.10	17.39	15.51
4.5	7560.07	0.20	5.63	6.75	13.51	20.26	27.02	16.10	14.10	17.39	15.51
5.0	8750.10	0.21	5.98	7.18	14.36	21.54	28.72	16.10	14.10	17.39	15.51
5.5	9870.44	0.22	6.32	7.58	15.16	22.74	30.31	16.10	14.10	17.39	15.51
6.0	10908.97	0.23	6.63	7.95	15.90	23.85	31.80	16.10	14.10	17.39	15.51
6.5	11859.81	0.24	6.92	8.30	16.60	24.89	33.19	16.10	14.10	17.39	15.51
7.0	12721.67	0.25	7.19	8.62	17.24	25.86	34.48	16.10	14.10	17.39	15.51

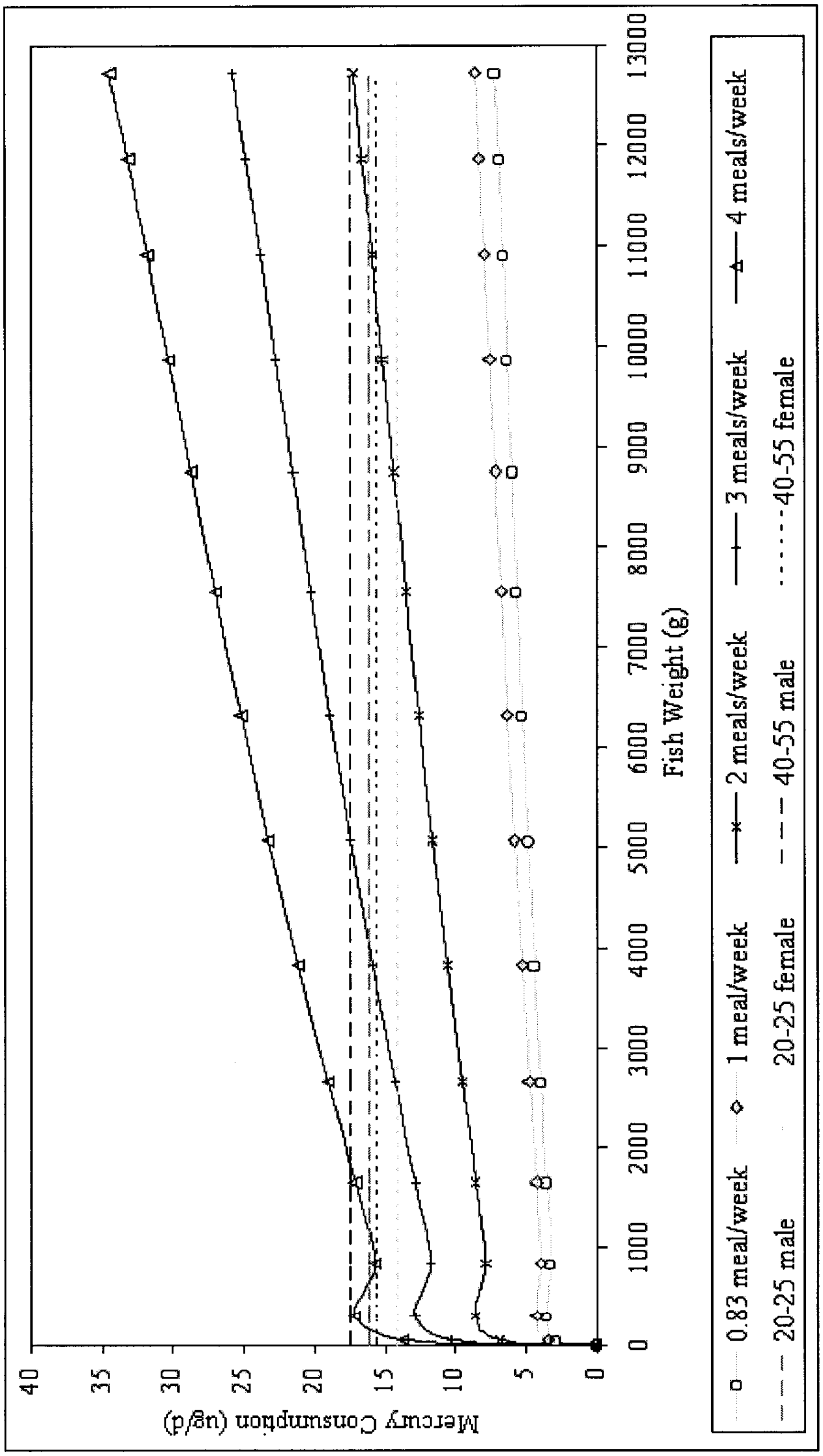


Figure 6.9 Comparison of Hg consumption from Chinook Salmon and the maximum Hg uptake in humans

The same analysis is applied to other fish species and the results appear in Figures 6.10 to 6.14 for Lake Trout, Northern Pike, Rainbow Trout, Walleye and Yellow Perch. The solid lines represent the total amount of mercury consumption of different diet habits, and the broken lines are the suggested pTDI levels for various groups of population. Whenever there is a problem detected, the solid lines are darkened.

Among the six fish species, Rainbow Trout is the lowest-risk fish species and Walleye is the highest. If a person eats Rainbow Trout as a meal, the human risk will not be an issue unless the person eats fish three or more times a week, the problem will arise if he or she consumes large size Rainbow Trout. On the other side, the fish size of Walleye is restricted in any number of meals. Yellow Perch is also a high-risk fish species. In Figure 6.14, it is obvious that people eating more than 2 fish meals per week, must eat small sizes of Yellow Perch in order to avoid excess mercury consumption.
To make it easier to understand, Table 6.12 has been prepared to show the restriction of fish for human consumption. Except for Walleye, there is no problem eating any size of these fish species if the person eats one fish meal or less per week. If a person eats four fish meals a week, he or she is not allowed to eat any size of Walleye or adverse health effect may result. Unfortunately, it is reasonable to expect that most people prefer to eat big fish because ease of preparation and absence of fine bones.

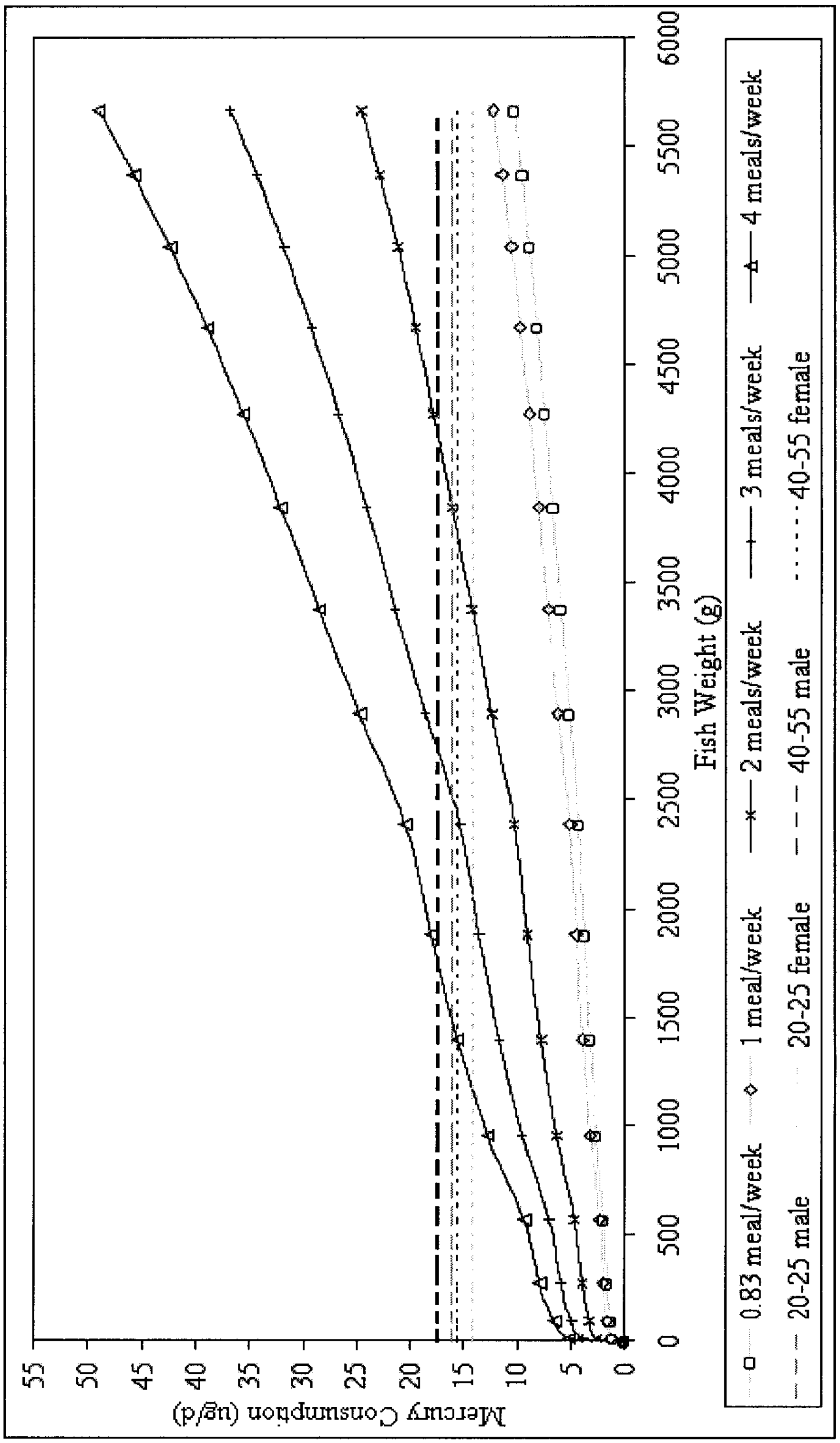


Figure 6.10 Comparison of Hg consumption from Lake Trout and the maximum Hg uptake in humans

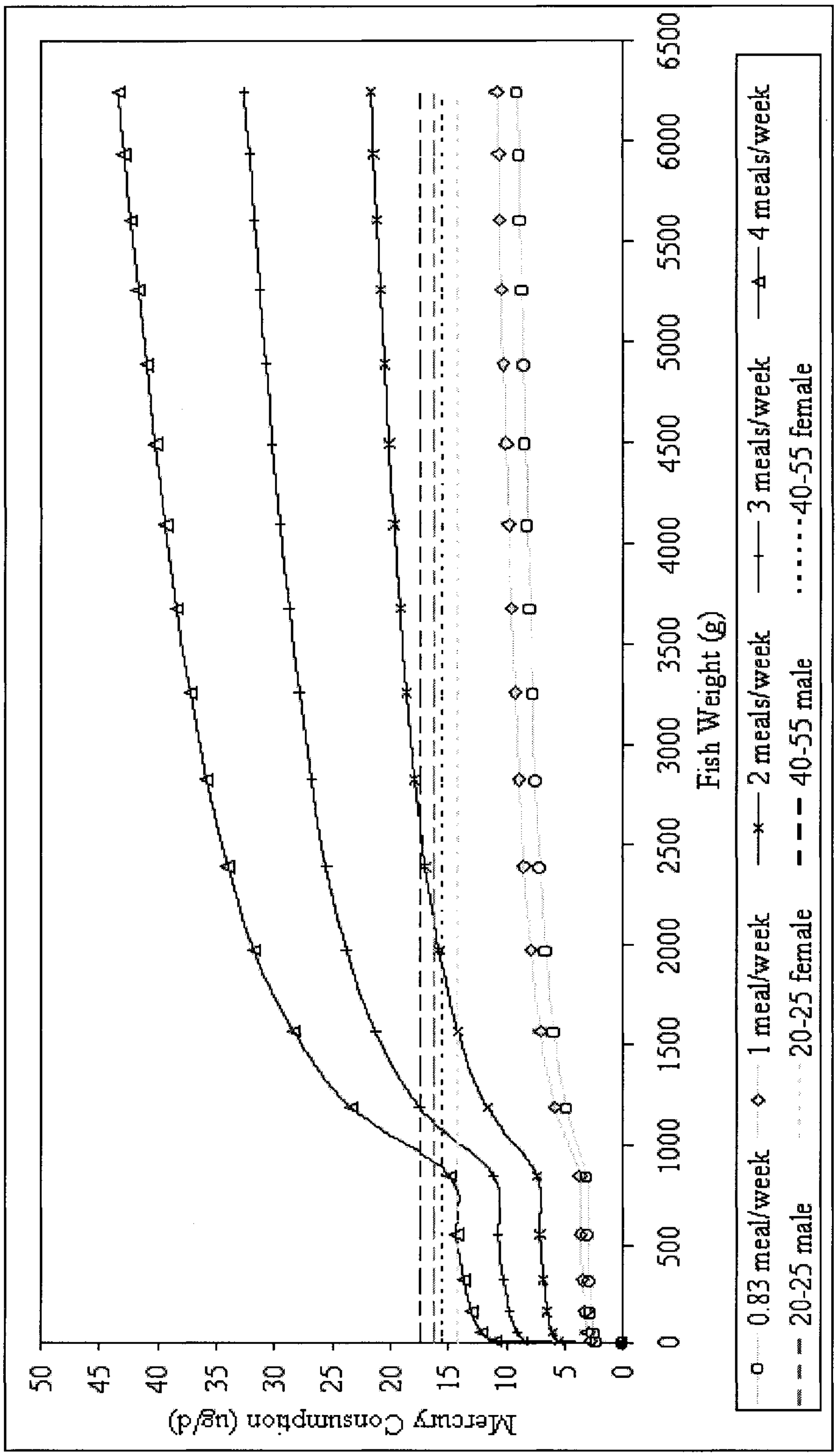


Figure 6.11 Comparison of Hg consumption from Northern Pike and the maximum Hg uptake in humans

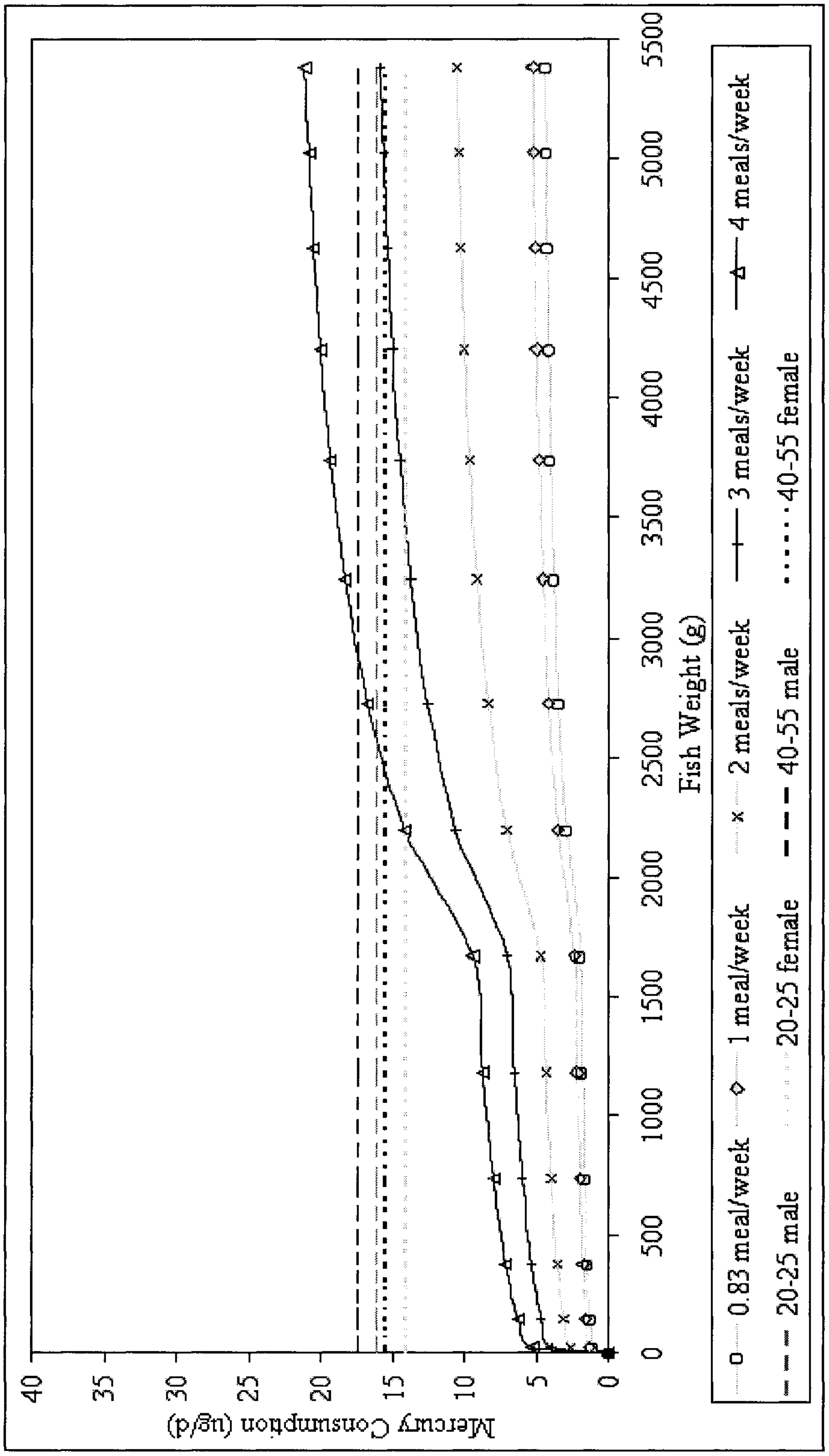


Figure 6.12 Comparison of Hg consumption from Rainbow Trout and the maximum Hg uptake in humans

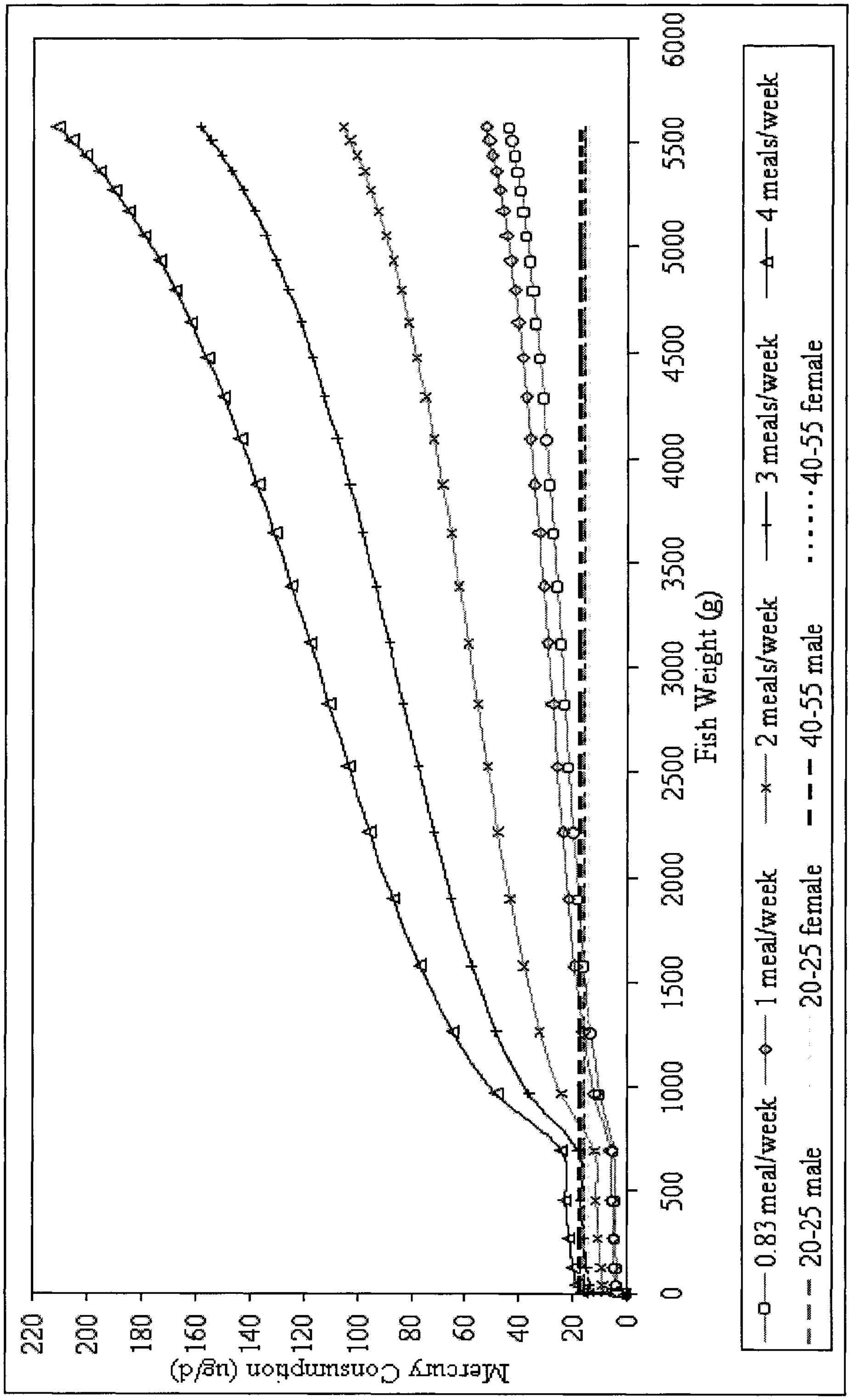


Figure 6.13 Comparison of Hg consumption from Walleye and the maximum Hg uptake in humans

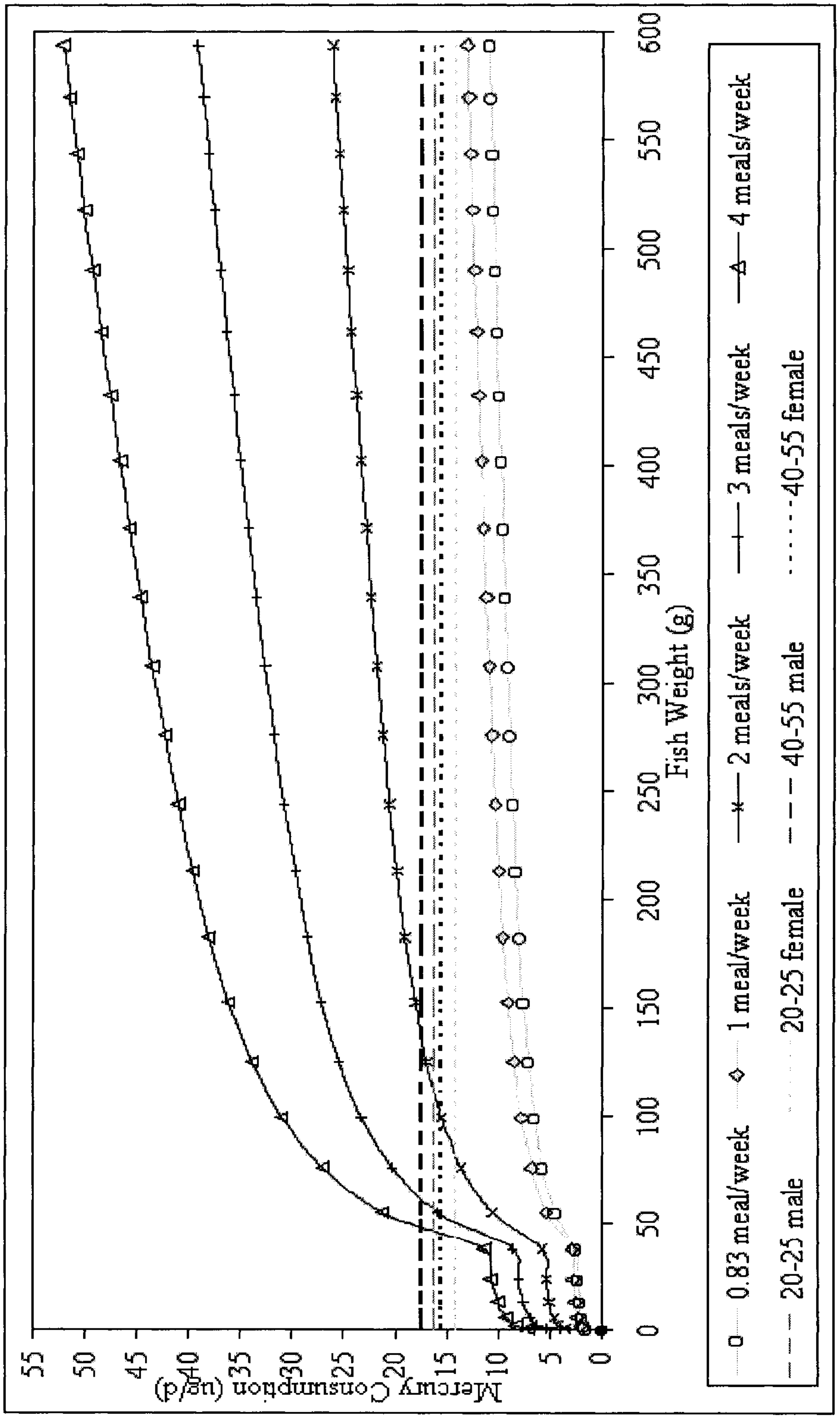


Figure 6.14 Comparison of Hg consumption from Yellow Perch and the maximum Hg uptake in humans

Table 6.12 Restriction for human consumption

Fish Species	**Male (Age Groups)**		**Female (Age Groups)**	
	20-25	**40-55**	**20-25**	**40-55**
i) Chinook Salmon (maximum size = 12.75 kg)				
0.83 meal per week	Any size	Any size	Any size	Any size
1 meal per week	Any size	Any size	Any size	Any size
2 meals per week	< 11.00 kg	< 12.70 kg	< 8.25 kg	< 10.25 kg
3 meals per week	< 4.00 kg	< 5.00 kg	< 2.50 kg	< 3.80 kg
4 meals per week	< 1.10 kg	< 1.90 kg	< 0.10 kg	< 0.80 kg
ii) Lake Trout (maximum size = 5.70 kg)				
0.83 meal per week	Any size	Any size	Any size	Any size
1 meal per week	Any size	Any size	Any size	Any size
2 meals per week	< 3.80 kg	< 4.20 kg	< 3.40 kg	< 3.70 kg
3 meals per week	< 2.50 kg	< 2.70 kg	< 2.00 kg	< 2.40 kg
4 meals per week	< 1.5 kg	< 1.75 kg	< 1.20 kg	< 1.40 kg
iii) Northern Pike (maximum size = 6.25 kg)				
0.83 meal per week	Any size	Any size	Any size	Any size
1 meal per week	Any size	Any size	Any size	Any size
2 meals per week	< 2.10 kg	< 2.60 kg	< 1.60 kg	< 1.90 kg
3 meals per week	< 1.10 kg	< 1.20 kg	< 1.00 kg	< 1.10 kg
4 meals per week	< 0.90 kg	< 1.00 kg	< 0.75 kg	< 0.90 kg
iv) Rainbow Trout (maximum size = 5.40 kg)				
0.83 meal per week	Any size	Any size	Any size	Any size
1 meal per week	Any size	Any size	Any size	Any size
2 meals per week	Any size	Any size	Any size	Any size
3 meals per week	< 5.40 kg	Any size	< 3.50 kg	< 4.65 kg
4 meals per week	< 2.60 kg	< 2.90 kg	< 2.20 kg	< 2.45 kg
v) Walleye (maximum size = 5.60 kg)				
0.83 meal per week	< 1.60 kg	< 1.75kg	< 1.30 kg	< 1.60 kg
1 meal per week	< 1.25 kg	< 1.30 kg	< 1.10 kg	< 1.25 kg
2 meals per week	< 0.75 kg	< 0.80 kg	< 0.70 kg	< 0.75 kg
3 meals per week	< 0.25 kg	< 0.40 kg	< 0.10 kg	< 0.25 kg
4 meals per week	Absolutely Restricted			
vi) Yellow Perch (maximum size = 0.59 kg)				
0.83 meal per week	Any size	Any size	Any size	Any size
1 meal per week	Any size	Any size	Any size	Any size
2 meals per week	< 0.11 kg	< 0.13 kg	< 0.08 kg	< 0.10 kg
3 meals per week	< 0.06 kg	< 0.06 kg	< 0.05 kg	< 0.06 kg
4 meals per week	< 0.05 kg	< 0.05 kg	< 0.04 kg	< 0.05 kg

6.4 Discussion

The chart for typical weight according to human age shows ideal information for white people. Many people are over-weight and so the restriction for human consumption may require correcting. In general, Asian people may have a lower average weight than white people, resulting in more restriction applied to fish consumption. In reality, the recommended maximum provisional tolerable daily intake of mercury depending on human body weight is not correct. Results from this and other studies have clearly confirmed that mercury is bioaccumulated and it is eliminated in the body at a slow rate. An old person must take in lower levels of mercury than a young person to avoid health effects.

Referring to the analysis from Chapter 4, top carnivorous fish absorb mercury more than low predatory fish due to the food selection. In human consumption, more restrictions on fish size are applied to the top predatory fish than the lower one. One-third or larger sizes of the maximum Walleye is restricted if an old man eats fish less than one time per week, while only the maximum size of the Rainbow Trout is restricted if a young man eats 3 fish meals per week. People may be interested in more than these 6 fish species as meals. If the fish species has a similar diet composition as one of them, the restriction for human consumption can be set as a reference for both fish species. For example, Brook Trout is also one of the most frequently caught and consumed sport fish. It has similar characteristics and diet composition as Lake Trout. Therefore, the restriction for Lake Trout can be used as a reference for Brook Trout as well. It should be mentioned that much of the research data used in this study is site and species specific, and exact values may not be directly transferable to all locations.

However the study clearly demonstrates a distinct pattern and some significant factors, which would be helpful to consumers in their selection of food choice. In addition, for other species, this is a complete set of protocol that is easy to follow by any researchers in further study.

In humans, fish are an important dietary component, since they contain many protein and nutrient benefits. To reduce the potential mercury exposure in the human body, people should choose smaller fish within a species, because they are typically younger and haven't been exposed to mercury for as long as the older, bigger fish. It is possible to eat a variety of fish, both for a healthier diet and to avoid exposure yourself to the same pollutants. More importantly, Lake Trout and Salmon are highly recommended fish with a lot omega-3 fatty acids oil content, and also, they are reported less contaminated in this thesis. On the other hand, Pike and Walleye are not recommended to consume not only because they have higher Hg levels in the muscle but also their oils low levels of omega-3 fatty acids are low.

Methylmercury are mainly stored in the muscle and there is no use to avoid eating fish's head, skin, steaks including fat. More importantly, it is recommended that the Fish Guide should be consulted before consuming any sport fish. If commercial fish is eaten, it may be possible to avoid eating fish from polluted areas such as the west side of Lake Ontario, or to find fish are raised in a controlled environment which do not contain as many toxins as are found in wild fish.

Chapter 7 Conclusions

Fishing is a popular recreational sport and fish are both nutritious and good to eat. But some fish may take in contaminants from the water they live in and the food they eat. These contaminants could harm people, so it is important to keep humans exposure to these contaminants as low as possible. Mercury is one of the contaminants, a metal naturally manifesting in the environment in several forms. High levels of mercury in human bodies can result in adverse health conditions.

Mercury accumulates in the fleshy part of fish in an organic carbon-containing form - called methylmercury. People who eat fish containing large amounts of methylmercury suffered permanent damage to their nervous system, kidneys and fetuses in pregnant women. Exposure to methylmercury is more of a concern for children and unborn babies because their nervous systems are still developing and the nervous system is a target organ for mercury. Methylmercury is found throughout the parts of fish eaten; therefore cleaning and cooking methods that may reduce exposure to other contaminants are not effective for reducing exposure to mercury.

The government of Canada sets standards for chemicals in fish sold commercially. Besides, the Ministry of Environment (MOE) routinely monitors contaminant levels in fish and game to detect if any sport fish have contaminant levels greater than federal standards. A Fish Guide is issued every two years to give advisories to minimize humans exposure to contaminants. Fish field data from the MOE sport fish contaminant monitoring program are used to analyze the correlation between fish's habitat, genders and MeHg level. The analysis of the fish supports the findings in the following.

A positive correlation was discovered between a fish's length and its mercury accumulation. Greater amounts of methylmercury are found in older fish that tend to eat other fish and organisms. Top predators, such as Northern Pike and Walleye, rely on other fish as food and tend to have higher Hg levels than Chinook Salmon feeding on organisms low down the food chain. In fact, lower predatory fish have more immediate effects and top predatory fish require a few years to reflect the changes in the levels of their food consumption.

If the fish is mature, they tend to have a more stable diet composition, resulting in a more consistent mercury uptake. It has been postulated by many that a different mercury accumulation is expected between fish genders. However, our study indicates that no clear distinction of mercury accumulation could be observed from the field data, and in fact the same mercury concentrations could be assumed in both male and female fish of the same size. Last but not least, a higher mercury accumulation is discovered in the fish species at the west side of Lake Ontario, which is generally considered as a more polluted area.

A bioenergetics-based genetic bioaccumulation model of MeHg accumulation in fish was refined and the corresponding computer program was modified with the programming software, Visual Basic 5.0. From the computer program, the simulated model results are in very good agreement with the field data. It has proved its effectiveness in predicting the trends of mercury bioaccumulation in all six kinds of fish. It can be concluded that the bioenergetics model is an excellent tool in predicting the trends and magnitude of mercury levels among various kinds of common sport fish in Lake Ontario. It is a very useful framework for investigating mercury accumulation in fish, and has the potential to mechanistically accommodate system-to-system variations between species and habitats.

Calibrated bioenergetics simulations of fish mercury kinetics in this thesis suggest that food is clearly the dominant mercury intake pathway in sport fish species. The variations in the mercury body burden levels among different species may be explained by their biological characteristics, which are described by growth pattern, activity level and metabolism. The higher position a fish occupies in an aquatic foods chain, the greater the chance it will have a higher level of mercury body burden. The more active is the fish, the higher is the total body burden. Bioaccumulation has proven to be both age and species specific.

Eventually, an estimation of the risks associated with human exposure from fish consumption was also developed. An estimated average of 0.83 meals per week with 237.3 g of fish per meal, together with the mercury concentration in fish species through the bioaccumulation model, were used to calculate the daily mercury consumption from fish. It was compared to the maximum acceptable daily intake of mercury from fish. Walleye is a high-risk fish species, and it is recommended that only one fish meal be consumed per week. Walleye should not be chosen if a person is a frequent fish eater, consuming four fish meals a week or more. For the other fish species, there is no health risk for people who eat fish less than once per week. If a person eats more than one fish meal per week, a smaller size is recommended for consumption. Our study is extremely useful in that it demonstrates a protocol for the refinement of fish consumption guidelines, in providing more accurate and quantitative recommendations than is currently possible.

Fish contain many protein and nutrient benefits to humans. Lake Trout, Salmon, Tuna and Whitefish are recommended fish with high omega-3 fatty acids oil content. To maintain better health and reduce the potential mercury exposure in the human body, people should choose smaller fish within a species and there is no use to avoid eating the fish's head, skin, fat and organs. The research from this thesis contributes to the knowledge and the risk of methylmercury toxicity to fish and humans. Valuable insights for developing strategies to control pollution problems and to establish fish consumption guidelines are gained.

Appendix I Major Source Codes of the Computer Program

Appendix II "Guide to Eating Ontario Sport Fish" 1995 Questionnaire

Appendix I

Major Source Codes of the Computer Program

```
Dim CpfCurrent As Double
Dim QfdCurrent As Double


Public Sub ProcessData()
'  Procedure to process data.

' Dimension local variables:
Dim i As Integer          'Loop counter
Dim Beta As Double        'Proportion of metabolism used for growth
Dim dPcl_dt As Double     'Pollutant clearance
Dim dPf_dt As Double      'Pollutant from food
Dim dPw_dt As Double      'Pollutant from water
Dim dW_dt As Double       'Growth rate
Dim P As Double           'Body burden of pollutant
Dim Qf As Double          'Caloric equivalent of consumer
Dim W As Double           'Fish wet weight
Dim P_previous As Double  'The previous Body burden of pollutant in an continous iteration
Dim W_previous As Double  'The previous net weight of fish in an continous iteration
Dim P_W As Double         'Concentration of pollutant

filenum = FreeFile

P_previous = Po
W_previous = Wo
P = 0
Open TempFile For Output As filenum   'Open temp file to temporarily store processed data

For i = 1 To SimLen  'Loop number of simulation weeks

  W = GrowthFunction(Wmax, Kgr, b, i)
  If FishType = 3 Then
    Qf = Qfequation(W)
  ElseIf FishType = 7 Then
    Qf = Qfequation(W)
  ElseIf FishType = 5 Then
    Qf = Qfequation1(W)
  Else
    Qf = Qfinput
  End If
  dW_dt = (W - W_previous)

  Beta = BetaFunction(W, dW_dt, Qf, Alpha, Gamma) 'the function to determine the value of beta in
each loop
  DietChange (i)          'the procedure to determine which set of Cpf and Qfd to be used
  dPf_dt = dPf(Epf, CpfCurrent, Efd, QfdCurrent, W, dW_dt, Qf, Alpha, Beta, Gamma)
  dPw_dt = dPw(Epw, Cpw, Eox, Cox, Qox, W, dW_dt, Qf, Alpha, Beta, Gamma)
  dPcl_dt = dPcl(P, Kcl, W)

  P = (P_previous + (dPf_dt + dPw_dt - dPcl_dt))
  P_previous = P
```

```
   W_previous = W
   P_W = (P / W)

   ' Write processed data to temp file:
   Write #filenum, i, W, dPf_dt, dPw_dt, dPcl_dt, P, P_W

Next i

Close filenum  'Close temp file

'Set ProcessID to Yes
ProcessID = ProcessID_Yes

'Enable Graph menu command
'Main!GraphCmd.Enabled = True

' Inform user that data has processed successfully
MsgBox "Processing completed.", vbInformation + vbOKOnly, "Information"

End Sub


Public Function GrowthFunction(Wmax As Double, Kgr As Double, b As Double, i As Integer) As
Double

GrowthFunction = Wmax * ((1 - Exp(-Kgr * i)) ^ b)

End Function

Public Function Qfequation(W As Double) As Double

Dim Y As Double

   Y = W / 1000
   If Y < 1.472 Then
      Qfequation = 1.3618 + 0.736 * Y
   ElseIf Y > 1.472 Then
      Qfequation = 2.1718 + 0.186 * Y
   End If



End Function
Public Function Qfequation1(W As Double) As Double

Dim Y As Double

   Y = W / 1000
   If Y < 4 Then
      Qfequation1 = 1.3769 + 0.236 * Y
   ElseIf Y > 4 Then
      Qfequation1 = 1.8153 + 0.126 * Y
   End If
```

```
End Function

Public Function dPf(Epf As Double, Cpf As Double, Efd As Double, Qfd As Double, W As Double,
dW_dt As Double, Qf As Double, Alpha As Double, Beta As Double, Gamma As Double) As Double

Dim X As Double
Dim Y As Double

X = (Epf * Cpf) / (Efd * Qfd)
Y = Alpha * (W ^ Gamma) + Qf * (Beta + 1) * dW_dt
dPf = X * Y

End Function

Public Function BetaFunction(W As Double, dW_dt As Double, Qf As Double, Alpha As Double,
Gamma As Double) As Double

Dim X As Double

X = 0.17 * Alpha / (0.83 * Qf)
BetaFunction = (X * (W ^ Gamma) / dW_dt) + 0.20482

End Function

Public Function dPw(Epw As Double, Cpw As Double, Eox As Double, Cox As Double, Qox As Double,
W As Double, dW_dt As Double, Qf As Double, Alpha As Double, Beta As Double, Gamma As Double)
As Double

Dim X As Double
Dim Y As Double

X = (Epw * Cpw) / (Eox * Cox * Qox)
Y = Alpha * (W ^ Gamma) + (Qf * Beta * dW_dt)
dPw = X * Y

End Function

Public Function dPcl(P As Double, Kcl As Double, W As Double) As Double

  dPcl = Kcl * P

' If FishType = 1 Then
'   dPcl = 0.21 * (W ^ -0.65) * P
' ElseIf FishType = 2 Then
'   dPcl = 0.14 * (W ^ -0.65) * P
' End If
End Function

Public Sub DietChange(i As Integer)

If i <= (DietAge(2) * 52) Then
  CpfCurrent = Cpf(1) * Percent(1) / 100 + Cpf(2) * Percent(2) / 100 + Cpf(3) * Percent(3) / 100
  QfdCurrent = Qfd(1) * Percent(1) / 100 + Qfd(2) * Percent(2) / 100 + Qfd(3) * Percent(3) / 100
ElseIf i <= (DietAge(4) * 52) Then
```

```
  CpfCurrent = Cpf(4) * Percent(4) / 100 + Cpf(5) * Percent(5) / 100 + Cpf(6) * Percent(6) / 100
  QfdCurrent = Qfd(4) * Percent(4) / 100 + Qfd(5) * Percent(5) / 100 + Qfd(6) * Percent(6) / 100
ElseIf i <= (DietAge(6) * 52) Then
  CpfCurrent = Cpf(7) * Percent(7) / 100 + Cpf(8) * Percent(8) / 100 + Cpf(9) * Percent(9) / 100
  QfdCurrent = Qfd(7) * Percent(7) / 100 + Qfd(8) * Percent(8) / 100 + Qfd(9) * Percent(9) / 100
ElseIf i < SimLen Then
  CpfCurrent = Cpf(10) * Percent(10) / 100 + Cpf(11) * Percent(11) / 100 + Cpf(12) * Percent(12) / 100
  QfdCurrent = Qfd(10) * Percent(10) / 100 + Qfd(11) * Percent(11) / 100 + Qfd(12) * Percent(12) / 100
End If

End Sub

Public Sub NewFile()

Dim DialogMsg1 As String

' Procedure to begin a new project file.

DialogMsg1 = "The current file has been changed since last saved. Do you wish to save it before closing
?"

If ChangeID = ChangeID_Yes Then    'If input data has changed since last save then ask user to save
before clearing
  If MsgBox(DialogMsg1, vbYesNo + vbExclamation, "Please Confirm") = vbYes Then   'If user clicks
YES then save data
    If ProjectFileTitle = "Untitled.Hg" Then    'If untitled then save as new file
      SaveAsFile
    Else   'Else save as existing file
      SaveFile
    End If
    ProcessID = ProcessID_No
    ChangeID = ChangeID_No
    ProjectFileTitle = "Untitled.Hg"
    frmMain.Caption = "Mercury Bioaccumulation Program - [ " & ProjectFileTitle & " ]"
    ClearVariable1
  Else   'User clicked NO
    ProcessID = ProcessID_No
    ChangeID = ChangeID_No
    ProjectFileTitle = "Untitled.Hg"
    frmMain.Caption = "Mercury Bioaccumulation Program - [ " & ProjectFileTitle & " ]"
    ClearVariable1
  End If
Else 'Data has not changed since last save
  ProcessID = ProcessID_No
  ChangeID = ChangeID_No
  ProjectFileTitle = "Untitled.Hg"
  frmMain.Caption = "Mercury Bioaccumulation Program - [ " & ProjectFileTitle & " ]"
  ClearVariable1
End If


End Sub

Public Sub WriteData()
```

```
'  Procedure to write data to selected file name.

' Dimension local variables:
Dim i As Integer          'Loop counter
Dim k As Integer          'Loop counter
Dim dPcl As Double        'Pollutant clearance
Dim dPf As Double         'Pollutant from food
Dim dPw As Double         'Pollutant from water
Dim P As Double           'Body burden of pollutant
Dim W As Double           'Fish wet weight
Dim P_W As Double         'concentration of pollutant


Open ProjectFileName For Output As #1 'Open file name for output
' Begin writing data to file
Write #1, Wmax
Write #1, Kgr
Write #1, b
Write #1, Kcl
Write #1, Alpha
Write #1, Gamma
Write #1, Qfinput
Write #1, Qox
Write #1, Efd
Write #1, Eox
Write #1, Epf
Write #1, Epw
Write #1, Cpw
Write #1, Cox
Write #1, SimLen
Write #1, FishType
Write #1, Wo
Write #1, Po
For k = 1 To 12
   If k < 9 Then
      Write #1, DietAge(k)
   End If
   Write #1, Percent(k)
   Write #1, Cpf(k)
   Write #1, Qfd(k)
Next

' If Data has been processed then write processed data to project file,
' else write zero data records.
If ProcessID = ProcessID_No Then
   Print #1, "[Processed Data]"
   ProcessFlag = "false"
   Print #1, ProcessFlag
Else
   Print #1, "[Processed Data]"
   ProcessFlag = "true"
   Print #1, ProcessFlag
```

```
  Open TempFile For Input As #2 'Open temp file for input

  Do While Not EOF(2) 'Check for end of file.
    Input #2, i, W, dPf, dPw, dPcl, P, P_W 'Read data line from temp file
    Write #1, i, W, dPf, dPw, dPcl, P, P_W 'Write data line to project file
  Loop

  Close #2 'Close temp file
End If

Close #1  'Close Filename

frmMain.Caption = "Mercury Bioaccumulation Program - [ " & ProjectFileTitle & " ]"

End Sub

Public Sub ClearVariable1()
frmInput1!txtMaxweight.Text = ""
frmInput1!txtGrowthRate.Text = ""
frmInput1!txtLengthweight.Text = ""
frmInput1!txtClearance.Text = ""
frmInput1!txtEfd.Text = ""
frmInput1!txtEox.Text = ""
frmInput1!txtEpf.Text = ""
frmInput1!txtEpw.Text = ""
frmInput1!txtLength.Text = ""
frmInput1!txtLowroutine.Text = ""
frmInput1!txtBodyweight.Text = ""
frmInput1!txtQf.Text = ""
frmInput1!txtQox.Text = ""
frmInput1!txtCpw.Text = ""
frmInput1!txtCox.Text = ""
frmInput1!optOthers.Value = True

End Sub

Public Sub ClearVariable2()

Dim i As Integer
Dim j As Integer

  frmInput2!txtInitialW.Text = ""
  frmInput2!txtInitialP.Text = ""

i = 1
j = 1

Do While i < 9
  frmInput2!txtDietAge(i).Text = "  ----- "
  frmInput2!txtDietAge(i).Enabled = False
  i = i + 1
Loop

Do While j < 13
```

```
  frmInput2!DietPercent(j).Text = "  ----- "
  frmInput2!DietPercent(j).Enabled = False
  frmInput2!txtCpf(j).Text = "           ----------"
  frmInput2!txtCpf(j).Enabled = False
  frmInput2!txtQfd(j).Text = "           ----------"
  frmInput2!txtQfd(j).Enabled = False
  j = j + 1
Loop

End Sub

Public Sub ReadData()
' Procedure to read data from an existing project file.

Dim Label As String        'Variable description in file
Dim T As Integer           'Time in weeks
Dim dPcl As Double         'Pollutant clearance
Dim dPf As Double          'Pollutant from food
Dim dPw As Double          'Pollutant from water
Dim P As Double            'Body burden of pollutant
Dim W As Double            'Fish wet weight
Dim P_W As Double          'concentration of pollutant
Dim k As Integer           'Loop counter


Open ProjectFileName For Input As #1 'Open project file name for input

' Begin reading data from filename
Input #1, Wmax
Input #1, Kgr
Input #1, b
Input #1, Kcl
Input #1, Alpha
Input #1, Gamma
Input #1, Qfinput
Input #1, Qox
Input #1, Efd
Input #1, Eox
Input #1, Epf
Input #1, Epw
Input #1, Cpw
Input #1, Cox
Input #1, SimLen
Input #1, FishType
Input #1, Wo
Input #1, Po
For k = 1 To 12
  If k < 9 Then
    Input #1, DietAge(k)
  End If
  Input #1, Percent(k)
  Input #1, Cpf(k)
  Input #1, Qfd(k)
Next
```

```
' Check if data has been processed
Line Input #1, Label
Input #1, ProcessFlag

If ProcessFlag = "true" Then    'File contains processed data
   ProcessID = ProcessID_Yes    'Set ProcessID to Yes

   ' Store processed data to TempFile
   Open TempFile For Output As #2 'Open temp file for output

   Do While Not EOF(1)
      Input #1, T, W, dPf, dPw, dPcl, P, P_W 'Read data line from project file
      Write #2, T, W, dPf, dPw, dPcl, P, P_W 'Write data line to temp file
   Loop

   Close #2 'Close temp file

Else 'File does not contain processed data
   ProcessID = ProcessID_No 'Set processID to No
End If

Close #1 'Close project file

'Set ChangeID to No
ChangeID = ChangeID_No

' Set project filename in Main title bar
frmMain.Caption = "Mercury Bioaccumulation Program - [ " & ProjectFileTitle & " ]"

OldRecord = 1


End Sub

Public Sub OpenFile()
'  Procedure to open an existing project file.
Dim DialogMsg As String


DialogMsg = "The current file has been changed since last saved.  Do you wish to save it before closing?"

If ChangeID = ChangeID_Yes Then   'If input data has changed since last save then ask user to save
before clearing
   If MsgBox(DialogMsg, vbYesNo + vbQuestion, "Please Confirm") = vbYes Then  'If user clicks YES
then save data
      If ProjectFileTitle = "Untitled.Hg" Then   'If untitled then save as new file
         SaveAsFile
      Else   'Else save as existing file
         SaveFile
      End If
   End If
End If

On Error GoTo CancelOpen 'If user clicks on cancel exit subroutine
```

```
' Read data of existing file.

'Set ioCMDialog properties
frmMain!CommonDialog1.Flags = OFN_HIDEREADONLY Or OFN_PATHMUSTEXIST Or
OFN_FILEMUSTEXIST Or OFN_PATHMUSTEXIST

'Open ioCMDialog box
frmMain!CommonDialog1.Action = 1

'Set file properties of selected project file
ProjectFileTitle = frmMain!CommonDialog1.FileTitle
ProjectFileName = frmMain!CommonDialog1.filename

frmMain.Caption = "Mercury Bioaccumulation Program - [ " & ProjectFileTitle & " ]"

'Read data
ReadData


Exit Sub 'Ignore CancelOpen subroutine

CancelOpen: 'User clicked cancel button
   Exit Sub
End Sub

Public Sub SaveFile()
' Procedure to save data to an existing file name.


If ProjectFileTitle = "Untitled.Hg" Then     'If untitled then save as new file
   SaveAsFile
Else     'Else save as existing file
   WriteData
   MsgBox " The file is saved as [" & ProjectFileTitle & "] ", vbOKOnly + vbInformation,
"Confirmation"
   ChangeID = ChangeID_No
End If


End Sub

Public Sub SaveAsFile()
' Procedure to save data to a new file name.


On Error GoTo CancelSaveAs 'If user clicks on cancel

frmMain!CommonDialog1.Flags = OFN_HIDEREADONLY Or OFN_OVERWRITEPROMPT Or
OFN_PATHMUSTEXIST
'Open CommonDialog Box
frmMain!CommonDialog1.Action = 2

'Set file properties of selected project file
ProjectFileTitle = frmMain!CommonDialog1.FileTitle
```

```
ProjectFileName = frmMain!CommonDialog1.filename

'Write data to filename
WriteData
'Set ChangeID to No
ChangeID = ChangeID_No
' Set filename in Main title bar
frmMain.Caption = "Mercury Bioaccumulation Program - [ " & ProjectFileTitle & " ]"

Exit Sub 'Ignore CancelSaveAs subroutine

CancelSaveAs: 'User clicked cancel button
  Exit Sub

End Sub

Public Sub RecordDietCombo()
Dim h As Integer
Dim i As Integer
Dim j As Integer
Dim k As Integer

h = 1
Do While h < 13
  If (frmInput2!DietPercent(h).Enabled = False) Then
    Percent(h) = 0
  Else
    If (frmInput2!DietPercent(h).Text) = "" Then
      Percent(h) = 0
    Else
      Percent(h) = frmInput2!DietPercent(h).Text
    End If
  End If
  h = h + 1
Loop

i = 1
Do While i < 13
  If (frmInput2!txtCpf(i).Enabled = False) Then
    Cpf(i) = 0
  Else
    If (frmInput2!txtCpf(i).Text) = "" Then
      Cpf(i) = 0
    Else
      Cpf(i) = frmInput2!txtCpf(i).Text
    End If
  End If
  i = i + 1
Loop

j = 1
Do While j < 13
  If (frmInput2!txtQfd(j).Enabled = False) Then
    Qfd(j) = 0
```

```
    Else
        If (frmInput2!txtQfd(j).Text) = "" Then
            Qfd(j) = 0
        Else
            Qfd(j) = frmInput2!txtQfd(j).Text
        End If
    End If
    j = j + 1
Loop

k = 1
Do While k < 9
    If (frmInput2!txtDietAge(k).Enabled = False) Then
        DietAge(k) = 0
    Else
        DietAge(k) = (frmInput2!txtDietAge(k).Text)
    End If
    k = k + 1
Loop

End Sub
```

APPENDIX II

"GUIDE TO EATING ONTARIO SPORT FISH" 1995 QUESTIONNAIRE

The Ministry of the Environment and Energy sport fish contaminant monitoring program would appreciate your co-operation in completing and returning this postage-free questionnaire. Please answer as many questions as possible. Your answer and comments will enable us to improve the guide and the effectiveness in the program.

1. What is your age? ( ) Below 15 years ( ) 26-45 years
( ) 15-25 years ( ) over 45 years

2. What is your sex? ( ) Male ( ) Female

3. Do you reside in: ( ) Southern Ontario ( ) Another Province
( ) Northern Ontario ( ) The U.S.A.

4. Where did you obtain your 1995 guide?
( ) Sportsmen's Show ( ) By mail from a Govt. Office
( ) L.C.B.O. Store ( ) At a Govt. Office
( ) The Beer Store ( ) From a Friend or Relative

5. How did you first become aware of the guide?
( ) Saw it on display ( ) Newspaper, Radio or TV Story
( ) Advertisement ( ) Told by Friend or Relative
( ) Told by Govt. Official ( ) Other:________________

6. Have you obtained and used the guide in previous guides?
( ) No ( ) Yes
If yes, in which year(s)?
( ) 1993 ( ) 1992 ( ) before 1992

7. How often did you go fishing in Ontario throughout 1994?
( ) Only during a vacation:_______times
( ) Daily ( ) Once every 4 months
( ) More than once a week ( ) Once only
( ) Once a week ( ) Never
( ) Once every 2 weeks ( ) ______times
( ) Once a month ( ) Other: ___________

8. What lakes and rivers in Ontario did you fish in 1994?

a) Lakes:
( ) Balsam ( ) Nipissing ( ) Scugog
( ) Buckhorn ( ) Ontario ( ) Simcoe
( ) Erie ( ) Pigeon ( ) Stony
( ) Huron/Georgian Bay ( ) Rice ( ) Sturgeon
( ) St. Clair ( ) Superior
( ) Other: (any other frequently fished lake):
____

b) Rivers:
( ) Credit ( ) Niagara ( ) St. Lawrence
( ) French ( ) Nottawasaga ( ) Saugeen
( ) Ganaraska ( ) Ottawa ( ) Thames
( ) Grand ( ) Rideau ( ) Trent
( ) Other: (any other frequently fished river):
____

9. What species of fish did you keep to eat in 1994?

( ) Brook Trout	( ) Crappie	( ) Smallmouth Bass
( ) Brown Bullhead	( ) Lake Trout	( ) Smelt
( ) Brown Trout	( ) Largemouth Bass	( ) Splake
( ) Carp	( ) Muskie	( ) Sunfish
( ) Catfish	( ) Northern Pike	( ) Walleye (Pickerel)
( ) Chinook Salmon	( ) Pink Salmon	( ) Whitefish
( ) Cisco (Herring)	( ) Rainbow Trout	( ) White Sucker
( ) Coho Salmon	( ) Rock Bass	( ) Yellow Perch

( ) Other: ________________________________
( ) did not keep fish to eat

10. How often did you eat these fish caught in 1994?

( ) Only during a vacation:_______times

( ) Daily	( ) Once every four months
( ) More than once a week	( ) Once only
( ) Once a week	( ) Never
( ) Once every 2 weeks	( ) ______times
( ) Once a month	( ) Other: ____________

11. How much fish caught by angling from Ontario waters do you eat at a single meal?

( ) None	( ) 4 oz. (110 g)	( ) 12 oz. (340 g)
( ) Under 2 oz. (60 g)	( ) 6 oz. (170 g)	( ) 1 lb. (450 g)
( ) 2 oz. (60 g)	( ) 8 oz. (230 g)	( ) Over 1 lb. (450 g)

12. a) When you catch a fish that you wish to keep, do you check this guide for consumption advice?

( ) Yes ( ) No

b) If the consumption advice for your catch is <u>not</u> in the ← category, for you follow this advice?

( ) Yes ( ) No

c) The guide consumption advice is based on a skinless, lean dorsal fillet. Is this the only portion of your catch which you consume? ( ) Yes ( ) No

If No, which portion(s) do you consume?

( ) skin-on fillet	( ) fish eggs/levers
( ) whole fish/fish steaks, including fat	( ) whole fish/fish steaks, with fat trimmed

13. a) Please indicate if you have ever consumed any of the following from Ontario waterbodies:

( ) Freshwater clams/mussels ( ) Bullfrogs ( ) Snapping Turtles ( ) Crayfish
( ) No, I have never consumed any of these

b) How frequency did you consume these in 1994? _______times

14. a) How often do you eat fish (freshwater or saltwater) purchased from a store?

( ) Never	( ) Once a month
( ) Daily	( ) Once every four months
( ) More than once a week	( ) Once a year
( ) Once a week	( ) Once only
( ) Once every 2 weeks	( ) Other: ____________times

b) If you purchase fish from a store, please indicate which fish you would normally purchase to consume.

( ) Boston Bluefish	( ) Ocean Perch	( ) Tuna
( ) Cod	( ) Rainbow Trout	( ) Turbot
( ) Haddock	( ) Salmon	( ) Walleye
( ) Halibut	( ) Smelt	( ) Whitefish
( ) Lake Trout	( ) Sole	( ) Yellow Perch

( ) Other: ______________________________

15. How much fish purchased from a store do you eat at a single meal?

( ) None	( ) 4 oz. (110 g)	( ) 12 oz. (340 g)
( ) Under 2 oz. (60 g)	( ) 6 oz. (170 g)	( ) 1 lb. (450 g)
( ) 2 oz. (60 g)	( ) 8 oz. (230 g)	( ) Over 1 lb. (450 g)

16. a) Did the information provided in this guide meet your needs?

( ) Yes ( ) No

b) Did it list the lakes and rivers you were interested in?

( ) All ( ) Most ( ) Some ( ) None

c) Could you suggest additional lakes and rivers to be tested?

____

17. Has the information in this guide led to a change in your fishing and/or fish-consuming habits?

( ) Yes ( ) No

If Yes, in what way?

( ) Awareness of contaminants in fish

( ) Eat more fish ( ) Return larger fish

( ) Eat less fish ( ) Stopped eating fish

( ) Eat fish within guidelines ( ) Changed fishing locations

If No, why not?

( ) Don't eat fish ( ) Don't catch or eat enough fish

( ) Fish caught are in the category

( ) Areas fished are not listed in the guide

( ) Other:______________________________

18. If the sport fish consumption advice were also made available through a computer bulletin board system, would you utilize this information source?

( ) Yes ( ) No

19. a) This guide has a new format for Great Lakes locations (blocks). Do you prefer this format to the individual locations listed in previous guides?

( ) Yes ( ) No

b) This guide also has new consumption symbols (meals/month). Do you prefer the new symbols to the symbols used in previous guides?

( ) Yes ( ) No

c)Any comments on this guide or suggestions for improvement would be appreciated.

____

____

____

____

Thank you for taking the time to assist us. If you have any questions or concerns, please contact the program at 1-800-820-2716 or, in the Toronto area, 9416) 235-6220.

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