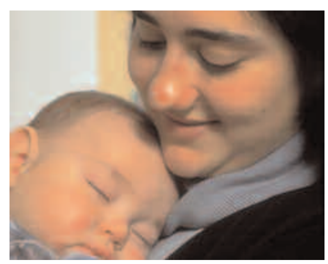
Fish Consumption

Benefits and Risks for Women in Childbearing Years and Young Children



Summary Report

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Medical Officer of Health

Toronto Public Health

Fish Consumption:
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Executive Summary

In recent years, the evolving science and debate concerning the benefits and risks from consuming fish has resulted in confusion as to how much, or even if, fish should be consumed and by whom. Toronto Public Health has recognized the need to provide useful, clear and relevant information to Toronto residents who are concerned about making the healthiest choices when they eat fish, including prior to or during pregnancy or breastfeeding, or when they serve fish to young children.

Fish consumption is an integral component of individual and community culture and preferences. The health benefits and risks vary according to the fish species, size, cultivation as well as amount and means of consumption. While there are a number of contaminants of concern in fish, the primary focus is methylmercury, a persistent substance that can be harmful to the developing brain and nervous system.

The risks and benefits are not distributed evenly across the population; that is, some subgroups are more vulnerable to the risks from contaminants from eating fish than other subgroups. Consequently fish consumption recommendations must be tailored for different subgroups of the general population. This report focuses on women of childbearing age, pregnant or breastfeeding women and young children age 0 to 4 years. Precautionary advice is aimed at directly protecting the most vulnerable individuals, children, particularly during fetal and infant stages, but also to minimize the body burden of methylmercury in women before they become pregnant. This report also discusses the risks for individuals from ethnocultural communities with more frequent fish consumption than is typical for the general population of Canadians.

Toronto Public Health's analysis suggests that eating more than two fish meals per week can put vulnerable subgroups at risk of unacceptable mercury intake. Vulnerable subgroups can eat up to two fish meals per week but should choose fish species carefully, with emphasis on low mercury species, while avoiding, or eating only rarely, high mercury species, such as fresh or frozen tuna, shark, marlin or swordfish among others. Pregnant or breastfeeding women, in particular, should choose from low mercury species alone and should eat no more than two fish meals per week. Advice also suggests that pregnant or breastfeeding women and young children should limit consumption of canned light tuna to one can per week and eat canned white tuna rarely. In addition to minimizing risk from contaminants, fish species choice should also be informed by knowledge of the ecological concerns and sustainability of various global fisheries or aquaculture practices. Toronto Public Health is producing appropriate health promotion materials to better inform Toronto residents of benefits, risks and ecological concerns to guide their fish species choices. Advice to moderate fish consumption to avoid methylmercury exposure should be disseminated to vulnerable subgroups via the health care community as well.

This report calls for action from federal agencies to address the gaps identified in research, policy and practices, particularly to make publicly available information on

high mercury fish species at point of purchase and to revise national fish consumption guidelines that consider the variability in vulnerability and fish consumption frequencies.

Lastly, federal and provincial governments are called upon to improve efforts to reduce the release and cycling of mercury in the environment and to examine and implement best practices in fisheries and aquaculture to restore the safety and availability of this important food source.

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Introduction

In recent years, strategies to minimize population exposure (particularly that of vulnerable subpopulations such as women of childbearing age, pregnant women, women who are breastfeeding and young children) to environmental contaminants from fish has become an issue that local health units are integrating into health promotion programs and materials. Historically, there has been considerable attention paid to educating Ontario anglers regarding the contaminants in fish caught from local waterways. Recent local public health initiatives however, have turned to consider ways to inform people about the contaminants that may be found in store-bought fish. The Region of Waterloo Public Health (2004) released a position paper and recommendations concerning the risks of exposure to methylmercury (MeHg) in fish for vulnerable subpopulations. Based on this work, the Ontario Public Health Association (2004) later adopted a resolution which made fish consumption recommendations that were a departure from those of Health Canada (2002). Health Canada is currently reviewing its own information and advice on consuming fish to minimize MeHg exposure (J. Salminen, Chemical Health Hazard Evaluation Division, Health Canada, personal communication, 2005).

Since the OPHA resolution of 2004, debate over the risks and benefits of fish for the general population and for the identified sensitive subpopulations has broadened and intensified. There has been new science on contaminants in fish (aside from MeHg) as well as the benefits from the essential fatty acids found in fish. A number of researchers have attempted to weigh the risks and benefits of consuming fish including quantifying the impact on various aspects of population health (see for example, Mahaffey, 2004; Smith & Sahyoun, 2005; Willett, 2005; Teutsch and Cohen, 2005; Cohen et al., 2005c). Adding to the debate is attention to the impact of global fish consumption on the sustainability of the world's fisheries (UN, 2005). Few of the risk-benefit commentaries have incorporated consideration of sustainability (see Brunner, 2006; McMichael & Butler, 2005; and Anderson, 2004 for exceptions). The debate appears to have resulted in confusion as to how much, or even if, fish should be consumed and by whom. In its own program work, TPH has recognized the need to provide useful, clear and relevant information to Toronto residents who are concerned to make the healthiest choices when they decide to eat fish during pregnancy or nursing or for their young children.

This report outlines Toronto Public Health's (TPH) fish consumption advice for vulnerable subgroups including women who are in their childbearing[1] years, are pregnant or breastfeeding, and for the parents or caregivers of young children. The advice is intended to assist individuals in these subgroups who already consume fish in making informed choices in the types they eat and frequency of fish meals. It is based on the findings of a larger technical report which summarizes the science on the health benefits and risks from consuming fish with a focus on the implications for the vulnerable

[1] Childbearing years refer to the reproductive age span of women. It is generally accepted that this refers to women between 15-49 years of age. While the focus in this report is women who may become pregnant (or are planning a pregnancy) it is clear that not all women between these ages are likely to become pregnant. As well, it is noted that women outside this age range may also become pregnant.

subgroups of interest. While a large focus is on the issue of exposure to MeHg, exposure to other contaminants in fish is discussed as well.

Fish Benefits – Omega-3 Polyunsaturated Fatty Acids

This section will discuss briefly the benefits of fish consumption from the standpoint of fish as a major dietary source of two long-chain omega-3 polyunsaturated fatty acids (n-3 PUFAs), docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA). These two n-3 PUFAs are deemed physiologically important because of their role in forming a class of biologically active lipids known as "eicosanoids". Because different types of eicosanoids affect various aspects of cellular function, they can influence human health and development in several ways. Omega-3 PUFAs have been studied in association with a variety of health impacts including their role (see reviews by Ruxton et al., 2004; Calder, 2005; Schachter et al., 2005; Davisglus et al., 2002):

- in improving cardiovascular health;
- as a treatment for various types of inflammatory disease, such as rheumatoid arthritis, asthma, bowel disease;
- in pregnancy outcome;
- brain and retinal development and function;
- as a treatment for various mental health and behaviour disorders, such as dementia, bipolar disorder, depression, Attention Deficit Hyperactivity Disorder (ADHD), autism.

DHA and EPA are available largely from foods of marine and aquatic origin; fish and fish oils are the major dietary source of these n-3 PUFAs. However, the contribution from other sources such as meat, poultry and the increasing range of enriched foods (such as eggs, dairy and bread products) may be approaching that of fish in the North American diet (Kris-Etherton et al., 2000). As well, the human body can transform an essential n-3 PUFA, alpha-linolenic acid (ALA), which comes largely from plant sources, to derive DHA and EPA. However, current thinking is that the rate of conversion does not produce adequate quantities of DHA or EPA for optimal health benefits and therefore a pre-formed source of these n-3 PUFAs is valuable (Brenna 2002; Burdge & Calder, 2005).

The health benefits linked to n-3 PUFAs that are of greatest relevance to the population subgroups of interest here will be discussed in the sections to follow.

DHA Benefits & Requirements During Pregnancy and Early Life

This section considers the evidence for benefits to the pregnant woman and the developing fetus, as well as to the infant, from one of the two long-chain n-3 PUFAs found in fish, namely DHA. DHA is considered physiologically necessary and important for fetal growth, and the development and functioning of the central nervous system in mammals. During pregnancy, DHA is transferred from the mother to the fetus across the placenta. Newborn plasma measures of DHA correlate to maternal intake of DHA from the diet during pregnancy (FNB IOM, 2002). Similarly, during lactation, maternal DHA is transmitted to the infant through breast milk and reflects maternal intake from diet.

Although DHA can be synthesized by both mother and fetus from plant-derived ALA, it has been argued that a dietary source of pre-formed DHA may be necessary for a number of reasons. First, the fetal and newborn infant's capacity to synthesize these fatty acids is highly variable and lower than for adults. This suggests that there may be limited ability at these stages to fulfill the developmental needs for DHA and that the fetus and infant is dependent on what it derives from the mother (Innis & Elias, 2003; Uauy et al., 2000; Brenna, 2002; Burdge & Calder, 2005). In addition, it appears from animal studies that this form of DHA (i.e. from fish rather than from biosynthesis) may build up in fetal brain tissue preferentially (FNB IOM, 2002). Finally, the rate of conversion of DHA from ALA is strongly influenced by the ratio of linoleic acid (an omega-6 PUFA) to ALA because of competition for the same enzymes. A high ratio, such as is commonly found in current diets, can inhibit DHA biosynthesis (Simopoulos, 1991; FNB IOM, 2002).

Some have estimated, based on the rate of build up of DHA in fetal tissues, which is most pronounced in the last trimester, that during pregnancy and lactation women require double their normal intake of DHA from diet to accommodate the needs of the fetus or infant (UK SACN, 2004). A working group of international scientists recommended that minimally 300 mg per day of DHA is an adequate intake for pregnant or lactating women (Simopoulos et al., 1999). In contrast, a recent review by the Food and Nutrition Board (FNB) of the U.S. Institute of Medicine concluded that the evidence is "not available" to show that increasing intake of DHA by pregnant and lactating women beyond what is currently the observed population median intake had any significant physiological benefit to the infant (FNB IOM, 2002: 471). The FNB consequently based its determination of a Dietary Reference Intake for n-3 PUFAs during pregnancy on the current median population intake. For specific fatty acids, such as DHA, this translates to considerably less than that reported by the working group Simopoulos and colleagues (1999). While we do not have detailed Canadian data on current dietary intake of specific n-3 PUFAs, two small Canadian studies have concluded that at least a portion of pregnant women in Canada may not be consuming enough n-3 PUFAs to support the requirements of the developing fetus (Denomme et al., 2005; Innis & Elias, 2003).

DHA Benefits to Pregnancy Outcome

A number of studies have examined the impacts of DHA on pregnancy outcome including on length of gestation or risk of prematurity, as well as on fetal growth rate and the risk of low birth weight. It has been hypothesized that n-3 PUFAs might lengthen gestation by altering the production of prostaglandins, substances which are linked with several physiological changes leading to the onset of labour (Allen & Harris, 2001). Similarly, fetal growth may be improved by n-3 PUFA derivatives through changes in blood viscosity that lead to increased placental blood flow (Rogers et al., 2004). Two types of studies have sought to examine the effects of DHA on pregnancy outcome. While not all of the studies have reported consistent findings, the studies of different types have tended to reach opposing conclusions. On the one hand, observational studies, where women's fish consumption during pregnancy is assessed, have demonstrated minimal or no effect on gestation and only modest positive effects on the fetal growth rate. In contrast, randomized controlled trial studies of pregnant women taking fish oil supplements have tended to show a positive effect on gestation but no influence, or a negative effect, on fetal growth (Rogers et al., 2004).

The inconsistency in study results is highlighted by comparing the findings of two relatively recent, large cohort studies. For example, a study of over 2,000 pregnant women in Massachusetts (Project Viva) looked at both the impact of seafood consumption and intake of fish oil supplements. Researchers found that higher intake of n-3 PUFAs was associated with about a 90 gram smaller weight at birth, while there was no impact on length of gestation (Oken et al., 2004). A longitudinal cohort study of over 11,000 women from Bristol, England (the Avon Longitudinal Study of Parents and Children – ALSPAC) examined fish intake in late pregnancy. In contrast to Project Viva, the ALSPAC researchers found that the babies of mothers who had the highest fish consumption were about 80 grams larger at birth than those whose mothers ate no fish (Rogers et al., 2004). However, once they controlled for factors such as mother's smoking or socioeconomic level, these birth weight differences disappeared. The one significant finding of the ALSPAC study was a higher than expected rate of intrauterine growth retardation (IUGR) when mothers ate no fish compared to those whose intake was high. Similar to the study by Oken and colleagues (2004) however, this observational study found no relationship between fish intake late in pregnancy and length of gestation.

DHA Benefits to Neurological Development

Another area of inquiry regarding benefits of n-3 PUFAs concerns the impacts on early neurological development. Typically the arguments for advising pregnant or nursing women to continue to eat fish have focused on the reputed benefits of n-3 PUFAs to development of the fetal/infant brain and nervous system. DHA in particular, is seen to contribute to optimal brain and visual function due to its structural role in these tissues although a more specific functional role for DHA in the brain is not clearly understood (McCann & Ames, 2005). This section will discuss the strength of evidence in support of that hypothesis.

Research with animals, including primates, indicates that restricted dietary DHA leads to lower brain DHA and an associated range of negative effects on visual acuity, learning, behaviour and brain hormone levels (Carlson, 2005; McCann & Ames, 2005; Innis, 1991; Neuringer et al., 1986). Aside from animal studies, understanding of the impact of n-3 PUFA intake on early human neurological development has been based largely on randomized clinical trials of infants receiving formula supplemented with DHA, rather than from maternal intake of fish or fish oils during pregnancy or lactation. These clinical studies with DHA-supplemented formula have not yielded consistent findings, however, they suggest some improvements to cognition and visual acuity. Evidence of positive effects appears to be most consistent among premature rather than full term infants with postnatal DHA supplementation as compared to infants fed regular formula (Willatts & Forsythe, 2000; Simmer, 2001; FNB IOM, 2002; Uauy et al., 2003; Cohen et al., 2005c).

As mentioned above, breastfed infants receive DHA though their mother's milk in direct proportion to maternal intake from diet. The evidence of a relationship between DHA content in human milk and visual and neurological development in breastfeeding compared to formula-fed infants has been studied. While differences in development of breastfed compared to formula fed infants have been found, it has not been satisfactorily proven that DHA alone is the causal reason (McCann & Ames, 2005; Heird & Lapillonne, 2005; Innis 2004; Reynolds, 2001; Gibson & Makrides, 2001). Regardless of the limited ability to draw conclusions about postnatal effects from DHA, there are certainly many other important health reasons to continue to emphasize prolonged breastfeeding of infants (AAP, 2005; CPS 2005; TPH, 2004).

Relatively few observational studies have assessed the effects on early neurological development from maternal intake of n-3 PUFAs from fish or fish oil supplements during pregnancy or lactation.[2] A randomized clinical trial among 341 Norwegian women investigated the impact on infant cognition of maternal fish oil supplementation during pregnancy and the first three months of lactation (Helland et al., 2001). Although the researchers did not show overall differences in cognitive assessment between infants whose mothers took cod liver oil compared to the controls receiving corn oil supplements, they did determine that brain maturation was more advanced in those newborns with the highest DHA levels in umbilical plasma (Helland et al., 2001). A sub-sample of the subjects was further assessed at age four and mental processing scores were found to be higher among the group of children whose mothers were supplemented with cod liver oil, compared to controls (Helland et al., 2003).

The ALSPAC cohort study mentioned earlier has looked at the correlation between fish intake of mothers during pregnancy as well as infant's fish intake and developmental test scores at 15 and 18 months of age in a large sample of children (n = 7,421) (Daniels et al., 2004). This study found that both fish intake by the pregnant mother and by the infant (at 6 months) were linked with "modest but consistently higher" scores from some tests of language comprehension and social activity (Daniels et al., 2004: 398). The relationship was strongest (that is the odds ratio was highest) when mothers consumed between 1 to 3 meals (average serving size about 4 ounces or 115 grams) per week. However, the researchers also observed a "threshold effect" in that there was a "benefit from eating fish at least once every 2 weeks, but no incremental increase in benefit with more frequent fish consumption" (Daniels et al., 2004: 400). In other words, eating *some* fish rather than no fish during pregnancy may have a benefit to infant cognitive development, but more frequent consumption did not necessarily yield increasingly greater gains. Of note, these researchers found no difference in the impact on a child's developmental test score when mother's fish intake of oily versus white fish was separated. Total mercury from cord tissue in a convenience sample of 1,221 of the ALSPAC study births confirmed that mercury levels were relatively low [median value of 0.01 µg/g wet weight or 0.01 parts per million (ppm)] in this population and did not show links with the developmental scores (Daniels et al., 2004).

[2] This review largely leaves aside the studies examining impacts of DHA on visual development.

Fish and seafood intake during the second trimester of pregnancy and hair mercury at delivery among a sample of women in the Boston area (from Project Viva), were compared with infant cognition at six months of age (Oken et al., 2005). Test results for 135 mother-infant pairs indicated that higher maternal fish consumption during pregnancy was associated with better infant cognition, but that higher maternal hair mercury levels were associated with lower cognitive scores among the infants. The highest test scores were found among the infants whose mothers had eaten more than two fish meals (3 to 5 ounce or about 85 to 145 gram servings) per week and had the lowest mercury hair levels (≤ 1.2 ppm). The authors concluded that the developmental benefits were likely due to eating fish species that were relatively low in mercury and rich in the beneficial n-3 PUFAs.

On balance, the evidence is limited and inconclusive to date, but suggestive that during pregnancy moderate consumption of fish that is low in mercury can be of some benefit to infant neurological development. The findings in relation to pregnancy outcome however, are not consistent and do not allow for firm conclusions regarding any benefit to gestation length and fetal growth from maternal fish consumption.

In summary, DHA is incorporated into the membranes of neural cells in the developing fetal nervous system. DHA can be derived from ALA but pre-formed DHA from fish may be a more important source, particularly during pregnancy. Whether dietary intake of pre-formed DHA beyond the current median population intake by pregnant and lactating women enhances development of the brain and nervous system continues to be the subject of ongoing research and debate. Some suggest that current North American population intake, including that of pregnant women, appears to be adequate given a lack of evidence for deficiencies related to low DHA or other n-3 PUFA intake (FNB IOM, 2002). Others suggest however, that increasing intake of DHA from fish in pregnant and lactating women is important because current dietary intake may be inadequate and may not be meeting the needs of the fetus and infant (Denomme et al., 2005; Innis & Elias, 2003; Simopoulos et al, 1999).

DHA and EPA Benefits for Adult Health

Because women in their childbearing years represent a substantial segment of the population of adults, it is worthwhile considering the state of evidence for health benefits to the adult woman from n-3 PUFAs in fish. The heart health protective impacts of n-3 PUFAs are extensively researched, with a much greater volume of studies compared to those considering impacts on pregnancy outcomes or on early neurological development.

There have been dozens of studies including both randomized controlled trials and cohort studies where the impact of fish oil supplements or fish consumption has been assessed in relation to the incidence of myocardial infarctions and sudden cardiac death, coronary heart disease (CHD) mortality rates, and other CHD risk factors (UK SACN, 2004; Kris-Etherton et al., 2002). EPA and DHA, either consumed as fish or taken as a supplement, can also contribute to the secondary prevention of cardiovascular disease in patients who have known CHD. EPA is a precursor of certain eicosanoids such as prostaglandins, leukotrienes and thromboxanes, which have beneficial effects in preventing CHD, arrhythmias, and thrombosis. As well, these eicosanoids lower plasma triglycerides and reduce blood clotting (Smith & Sahyoun, 2004). The weight of evidence has supported a link between n-3 PUFAs and reduced risks for indicators of cardiovascular disease (Kris-Etherton et al., 2002).

Recently however, there have been two thorough meta-analyses of the available studies which have yielded conflicting conclusions. Bucher and colleagues (2002) concluded there was a lower risk of death and CHD events in those with higher intake of n-3 PUFAs. Subsequently, a Cochrane systematic review by Hooper and co-workers (2004) concluded that, while there is no need to recommend people stop taking supplements or eating fish, "it is not clear that dietary or supplemental omega 3 fats reduce or increase total mortality, combined cardiovascular events, or cancers in people with, or at risk of, cardiovascular disease or in the general population" (p. 20). The authors observed that when the results of one large study conducted in Wales, U.K. [the Diet and Angina Randomized Trial (DART 2) (Burr et al., 2003)] are removed, their results agree with the findings of the meta-analysis by Bucher and colleagues (2002). The DART 2 study found that there was no reduction in mortality among those subjects advised to eat fatty fish and among subjects on fish oil supplements there were *higher* risks of cardiac and sudden death (Burr *et al*, 2003). While it would be convenient to disregard the results of DART 2, this study involves a large cohort (n = 3,114) and has followed its subjects (angina patients) for longer than any other intervention study (36 to 108 months follow up). Among the possible explanations for the negative results from the DART 2 study, Hooper and colleagues (2004) suggest that the cumulative intake of MeHg from fish may negatively affect cardiovascular health and that these impacts are seen in the long-term, whereas the benefits of n-3 PUFAs are more apparent in the short-term[3].

In terms of advising women on fish consumption, although women in their reproductive years make up a large component of the adult population, they are not generally at a high baseline risk for cardiovascular disease. It is important to acknowledge as well that there is also strong science to support the positive role of other dietary and health practices that reduce risks of CHD in the general population. Among others, these include: fat intake of no more than 30% of calories, saturated fat intake of no more than 10% of calories, cholesterol intake of no more than 300 mg/day, trans fatty acid consumption as low as possible (no more than 1% of energy intake), weight management, limited sodium intake and increased vegetable and fruit consumption (Krauss et al., 2000; USDA, 2005). There is also increasing evidence of a strong link between plant-based PUFAs and cardioprotective effects (Kris-Etherton et al., 2002). Finally, other dietary patterns that include large amounts of fruits, vegetables, legumes, whole grains, nuts and low-fat dairy (such as vegetarian/vegan or Mediterranean-type diets) have also been found to provide important protection against CHD (Hu & Willett, 2002; Giugliano & Eposito, 2005; Willett, 2006).

[3] For discussion of research concerning the cardiovascular effects from exposure to MeHg, please see the technical report, section 3.1.2.3.

In summary, most research and scientific opinion has weighed in favour of a heart protective benefit from eating fish and, specifically, from intake of the n-3 PUFAs in fish. Popular press, the medical community and health organizations have come to promote fish consumption for heart health on the perceived strength of the evidence. Some members of the scientific community have earlier acknowledged that the relationship between fish consumption and reduced risk of CHD are not likely to be solely related to intake of n-3 PUFAs (Daviglus et al., 2002; Gochfeld & Burger, 2005). The findings of the recent Cochrane systematic review lend support to this view (Hooper et al., 2006). It is beyond the scope of this report to resolve the issue of whether or not n-3 PUFAs, or some other constituent of fish, are protective of heart health. Given that the vulnerable subgroups of interest in this analysis are at generally low risk for CHD and that there are other well-documented nutritional patterns that also reduce risks for cardiovascular disease, it is inadvisable to base fish consumption advice for women in their childbearing years, pregnant or breastfeeding women, or for young children, on patterns intended to be cardioprotective for the general population of adults.

Risks from Contaminants in Fish

While fish are nutritionally important they also may contain environmental contaminants, usually at low levels. Contaminants that have been detected in fish include methylmercury (MeHg), some organochlorines, such as dioxins and polychlorinated biphenyls (PCBs), and brominated fire retardants, such as polybrominated diphenyl ethers (PBDEs) (Health Canada, 2002, 2004; USDHHS/EPA, 2006; Hites et al., 2004; Bethune et al., 2005; Tlustos et al., 2005; Herrmann et al., 2005).

Toxicological Concerns of Methylmercury Exposure

This section focuses on the adverse health effects of MeHg for several reasons. 1) MeHg has been most frequently detected in a wide variety of fish species compared to other contaminants in sampling programs (McBride et al., 2005); 2) MeHg is found in commonly consumed commercial fish, such as tuna, therefore it is considered a priority in terms of public health; 3) the health effects of exposure to MeHg due to fish consumption have been well demonstrated and reviewed extensively (JECFA, 2000, 2004; NRC, 2000; UNEP, 2002); and 4) MeHg exposure is closer to the threshold of concern than exposure to the other contaminants from fish consumption.

About 70% of the environmental burden of mercury is due to human activity (UNEP, 2002). In Canada, environmental emissions of elemental mercury occur during the use, disposal or incineration of products such as switches, batteries, fluorescent lamps, among others, and from coal-fired power plants, dental and medical facilities. Mercury is transformed through microbial action to MeHg (organic mercury) that can then biomagnify or concentrate up the food chain, particularly in the aquatic food chain. The most important and largest source of MeHg exposure to people is from fish and shellfish consumption (Mahaffey, 2004).

MeHg content in fish varies depending on species and the size of fish. Larger predatory fish contain higher levels of MeHg due to the process of bioaccumulation (ATSDR, 1999). The majority of MeHg residues in fish are bound to protein in muscle tissues or in the fish flesh as opposed to the fat (Pollution Probe, 2003; US EPA, 1997).

About 95% of ingested MeHg is absorbed into the human bloodstream, penetrates all membranes and is distributed readily throughout the body to all tissues, including the brain. Since the rate of excretion is slower than the rate of uptake, MeHg accumulates in the tissues. MeHg also crosses the placenta and the blood-brain barrier without difficulty (ATSDR, 1999). The brain, particularly the developing brain, is the tissue most sensitive to effects from MeHg (NRC, 2000).

Exposure to MeHg is of special concern during pregnancy. The level of exposure to the fetus is relatively higher than that of the mother. The concentration of MeHg in the umbilical cord blood at birth (an indication of fetal exposure) has been estimated to average 1.7 times the concentration in the mother's blood (Stern & Smith, 2003). Based on animal data, the concentration of MeHg in the fetal brain also consistently exceeds the maternal brain by a factor of 1.5, after long term exposure (JECFA, 2000). Exposures occurring before pregnancy are also of concern, as this contributes to the overall body burden of MeHg in the woman and may later result in exposure to the fetus because physiological changes during pregnancy result in release of contaminants from maternal tissues. The newborn and infant are also susceptible to harm (although less than the fetus) from primary exposure to MeHg because the protective blood-brain barrier does not develop fully until age six months (Rodier, 1995).

MeHg is known as a potent human neurotoxin, however, there is some evidence that associates MeHg exposure from fish consumption with reproductive toxicity and increased risks of cardiovascular disease in humans as well (UNEP, 2002; JECFA, 2004). However, for the vulnerable subgroups identified here, the discussion will focus on the evidence for adverse effects upon the nervous system, particularly for the fetus, infant and child.

Health Effects in the Young from Methylmercury

Methylmercury is highly toxic and the central nervous system is its principal target tissue. The effects of acute or high dose exposure are known from past large-scale poisoning events among people in Iraq and Japan (UNEP, 2002; Clarkson et al., 2003). Studies of the population impacts from these poisoning episodes have indicated that the developing central nervous system is more susceptible than the adult's to the action of MeHg. In infants exposed to *high* levels of MeHg while in their mothers' wombs, the symptoms may be similar to cerebral palsy, such as gross motor and mental impairment, sometimes accompanied by blindness and deafness (UNEP, 2002). In milder cases, the effects may only become apparent later in childhood as motor and cognitive problems, including late onset of walking and talking (Bakir et al., 1973; IPCS, 1990; JECFA, 2000; NRC, 2000).

There is considerable ongoing research to characterize the effect on childhood neurological development of *in utero* exposure to *low* levels of MeHg coming, not from a poisoning but from maternal consumption of fish. Low-level exposure to MeHg has been associated with deficits in attention, fine-motor skills, language development, visual-spatial abilities and verbal memory among the children exposed in the womb (USEPA, 2000; NRC, 2000; Aschner, 2002). Studies among several populations with relatively frequent fish consumption indicate such neurological and neuropsychological effects from exposure in the womb (for example, Denmark's Faroe Islanders - Grandjean et al., 1997; New Zealand - Crump et al., 1998; Brazil – Lebel et al., 1996; and Canada – McKeown-Eyssen et al., 1983).

Debate in the scientific literature about effects from low-level exposure exists however, largely linked to the divergent findings of the two largest of the existing longitudinal cohort studies. Research among the Faroe Islanders has found that prenatal MeHg exposure is consistently and significantly associated with deficits in motor, attention, and verbal skills including the latest assessment of the children at age 14 (Grandjean et al., 1997; Debes et al., 2006). In contrast, a major study in the Republic of Seychelles has continued to show no neurodevelopmental effects in the children from maternal fish consumption during pregnancy (Myers et al., 2003; Huang et al., 2005).[4] The divergent results of these two methodologically similar cohort studies have been explained as possibly due in part to differences in aspects of their dietary patterns, including contaminant intake. For example, along with fish, the Faroese diet contains a significant amount of whale meat which may have higher concentrations of mercury, as well as PCBs, another type of neurodevelopmental toxicant. As well, some have speculated that a higher DHA intake from the fish species in the Seychelles Island diet (compared to cod, the mainstay of the Faroese diet) may have masked any association between MeHg exposure and child development in the Seychelles cohort (JECFA, 2000). Animal studies and some limited human epidemiological data also suggest that content of selenium, which appears to have a protective effect, may differ in the diets of these two study populations (Chapman & Chan, 2000). Variability in response to MeHg due to dietary modifiers that influence mercury absorption or neurotoxic impacts has been identified as a data gap and important area for further research (Hubbs-Tait et al., 2005).

Postnatally there is also vulnerability to the neurological effects associated with mercury as the brain is still developing. The infant may be exposed to MeHg through breast milk or, as their diet expands, through their own consumption of fish. Less is understood about the effects of exposure to low levels of MeHg during childhood compared to what is known about fetal or infant exposures. The limited evidence that exists however, suggests

[4] The Seychelles Child Development Study researchers recently suggest that despite not finding evidence of impacts at younger ages, as they evaluate their cohort at age 16, the possibility of detecting adverse effects from prenatal exposure as children enter adolescence must be considered (Davidson et al. in press). They reason that some impacts may not be evident until adolescence, a reflection of the marked changes in brain structure and function that are known to occur at this stage. [This current interpretation is based in part on secondary analyses, using non-linear models, of data from their cohort at 9 years of age which indicated that in those at the higher exposed end of their sample (> 10-12 ppm Hg in maternal hair) there was evidence of an adverse association on one of their developmental endpoints (Huang et al., 2005).] Davidson and colleagues (in press) refer also to both animal and human evidence as supporting the idea of latent or delayed impacts from earlier exposure to neurological toxicants.

that while childhood exposures are a concern, exposures in the womb have the greatest impact (Grandjean et al., 1997).

Despite the scientific debate concerning impacts from prenatal or early life exposure, the most recent expert review has erred on the side of caution by concluding that the issue is not whether MeHg poses a risk but rather how to minimize exposure so as to protect the most vulnerable individuals in the population (NRC 2000; Stern et al., 2004). Indeed, Rice (2004) states that there appears to be no threshold for neuropsychological effects from MeHg with exposure during development which lends further support to precautionary action to minimize exposure in early life.

Mercury Levels in Commercial Fish

Regulatory authorities set limits on the amount of mercury that is allowed in commercially available fish; these limits are referred to as 'action levels'. In Canada, the sale of fish containing more than 0.5 ppm of total mercury is not permitted (Health Canada, 2002). Some species, however, such as shark, swordfish, and fresh or frozen tuna, are exempt from this guideline (CFIA, 2002). These fish are known to contain larger amounts of mercury (generally between 0.5 and 1.5 ppm) and are described as suitable only for occasional consumption (CFIA, 2002). Health Canada manages the risk from mercury exposure associated with these fish differently, that is, by issuing advisories recommending appropriate restriction on the amount and frequency of consumption rather than by prohibiting commercial sale of these fish (Health Canada, 2002). However, there is no requirement for mercury labeling of these high mercury fish, or any other species, at the point of purchase, including in restaurants.

Information on mercury concentrations in fish from different parts of the world demonstrates that mercury levels vary depending on the fish species and the water body from which fish have been harvested, among other factors (UNEP, 2002). Table 1 (in Appendix 1) presents the average mercury values reported for various fish species available for purchase here in North America. Most of these data are taken from U.S. sources (e.g. US DHHS/EPA, 2006; Burger & Gochfeld, 2004) because available Canadian data are limited in numbers of samples and in the range of species tested. Since the regulatory 'action level' in the United States (1 ppm) is higher than in Canada (0.5 ppm), average mercury levels in fish species from U.S. markets are potentially skewed upwards. Where comparisons between U.S. and Canadian data are possible, the U.S. fish mercury values appear to be higher for some species (e.g. King Mackerel, canned light tuna and cod), lower for others (e.g. swordfish, fresh or frozen tuna), and similar for still other species of fish (e.g. canned albacore tuna and trout).[5]

Methylmercury - Assessing and Measuring Population Exposure

Regulatory authorities have developed "tolerable" intakes for MeHg which refer to an estimate of the daily exposure that can occur over a lifetime without an increased risk of adverse effects. One international agency has established a provisional tolerable weekly intake (PTWI) of 1.6 μg/kg/week of MeHg for pregnant women (equivalent to 0.23

[5] For full details see Table 5 in the technical report available at www.toronto.ca/health.

µg/kg/day) (FAO/WHO JECFA, 2003). Health Canada's provisional tolerable daily intake (pTDI) is 0.2 µg/kg/day (Health Canada, 1998). The US EPA's oral reference dose (RfD) for mercury is 0.1 µg/kg/day (US EPA, 2001). Together, the Faroe, Seychelles and New Zealand studies form the basis for the current "tolerable" intake levels estimated by different agencies. Canadian and U.S. "tolerable" intakes differ because the two agencies assessed uncertainty differently.

The average intakes of mercury for Canadians have been estimated[6] to be 0.022 µg/kg/day (ranging from 0.012 in females over 65 years to 0.062 in 0-1 month old infants) (Dabeka et al., 2003). These estimated intakes are an order of magnitude below both the Canadian and U.S. EPA "tolerable" intake values of 0.2 and 0.1 µg/kg/day, respectively. One limitation of this study is that intake calculations (food frequency and portion sizes) were based on data from the *1972 Nutrition Canada Survey*. However, based on Statistics Canada 2004 survey data on fish consumption frequency, and taking into consideration today's customary portion size, the Canadian population likely consumes more fish per day currently than it did in 1972.

The U.S. Centers for Disease Control and Prevention (US CDC) conducts biomonitoring through the ongoing National Health and Nutrition Examination Survey (NHANES) as a way to assess the exposure of the U.S. population to environmental chemicals. A mercury blood level of 5.8 µg/L has been used to estimate the fraction of U.S. women in their childbearing years (ages 16 to 49) having exposure that exceeds the RfD[7] (Schober, 2003). While all women in this age group tested from 1999 to 2002 had blood mercury levels below those associated with neurological effects in the fetus (58 µg/L), about 6% had blood mercury levels above the U.S. EPA's RfD or "tolerable" intake level (Jones et al., 2004).[8] Comparable national population data collection or related estimates have not yet been done in Canada although Statistics Canada plans to test blood mercury through the upcoming Canada Health Measures Survey to be conducted in 2007 and 2008[9].

Some population sub-groups in Canada may have higher than average fish consumption resulting in higher intake of mercury. For example, in a study of blood mercury levels of

[6] Food mercury values were determined for foods purchased from supermarkets in two Canadian cities (Whitehorse and Ottawa) in 1998 and 2000. Chemical analysis was conducted on foods prepared as for consumption.

[7] Although blood mercury level is used as a biomarker for mercury intake, a specific value for the blood mercury concentration that corresponds to the RfD ("tolerable" intake) for mercury has not been established (Rice, 2004).

[8] Recently Mahaffey (2005), summarizing relatively new science on maternal-fetal methylmercury kinetics, has suggested that a benchmark dose of 58 µg/L in cord blood is equivalent to 35 µg/L in maternal blood because of substantial evidence showing the degree to which methylmercury concentrates across the placenta. She suggests further that assessing the percent of adult women of reproductive age with a blood mercury value over 3.5 µg/L (and not 5.8 µg/L) is more appropriately indicative of the proportion of the unborn at risk of potentially unacceptable methylmercury exposure *in utero*. According to 1999-2002 NHANES data, about 10.2% of the sample of adult women of reproductive age had a blood mercury value greater than or equal to 3.5 µg/L (Mahaffey, 2005).

[9] The only national biomonitoring study on methylmercury was conducted between the years 1970 and 1992 on aboriginal populations (Wheatley & Paradis, 1996). Over 30,000 people participated and methylmercury was sampled in blood, cord blood and hair.

Ontario fish eaters, Cole and colleagues (2004) found that Asian-Canadian (AC) subjects (Chinese and Vietnamese) ate considerably more fish overall than European-Canadian (EC) subjects (AC median = 213 fish meals/year; EC median = 169 fish meals/year). While much of this was sport-fish caught in inland Ontario lakes, commercial fish still comprised an important part of the Asian-Canadian diet. The Asian-Canadian subjects also had substantially higher mean total blood mercury level than that for the European-Canadian subsample (7.9 versus 2.0 µg/L). One quarter of the sample of women of reproductive age (n = 6 of 35), all of whom were of Asian origin, had total blood mercury levels above 10 µg/L and were counselled on how to reduce mercury exposure (Cole et al., 2004).

Children of Chinese origin were found to have higher blood mercury levels, total fish intake and EPA levels compared to children of other ethnic origins among a sample of 201 preschoolers living in the Vancouver area (Innis et al., 2006). Their median blood mercury level was 2.1 µg/L (range 0.2 to 13.6 µg/L). Eighteen percent of the Chinese children and none of the non-Chinese children had blood mercury levels above 5.8 µg/L (the U.S. EPA's blood level deemed equivalent to the RfD). Further, children over three with higher blood mercury were more likely to have a low score on one test of behaviour (attentional focusing) (Innis et al., 2006). Imported fish is the major type of fish consumed by the Chinese children in this study. In a recent case, two young boys of Asian ethnicity presenting with unexplained neurological symptoms, were found to have grossly elevated blood mercury levels (80 and 200 µg/L respectively), apparently due to high consumption of one species of predatory fish purchased from a local supplier (Copes et al., 2004).

The U.S. CDC biomonitoring study mentioned earlier also indicates that aside from specific ethnic variability, blood mercury levels are higher among coastal populations and among health conscious urban dwellers in their samples (Mahaffey, 2005).

Fish Consumption Recommendations & Advisories

This section compares and considers the consumption recommendations and advisories of various agencies. Consumption recommendations focus on frequency of fish meals to confer optimal health benefits, whereas advisories aim to limit intake of fish to minimize methylmercury exposure and prevent adverse health effects. Generally, consumption recommendations have been aimed at the general adult population, while fish advisories are more often focused on vulnerable subgroups, or in the case of sport fish, at high fish consumers of any age or sex.

A number of authorities have made recommendations encouraging more frequent consumption of fish by the entire population for the heart protective benefits. The American Heart Association (AHA, 2005) recommends that healthy people eat at least two fish meals (no specific serving size) per week with emphasis on fatty fish (such as salmon, herring and mackerel) and use liquid vegetable oils containing alpha-linolenic acid. The U.K. Scientific Advisory Committee on Nutrition (2004) recently recommended an increase in fish consumption to at least two portions (140 gram serving size) of fish per week, of which one should be an oily fish. Health Canada does not currently offer specific guidance on fish consumption other than advisories, generally aimed at vulnerable subgroups, to limit intake of some species of fish which are discussed later.

In *Nutrition for a Healthy Pregnancy - National Guidelines for the Childbearing Years*, Health Canada's approach to promoting adequate essential fatty acids intake by pregnant women is to encourage daily consumption of non-hydrogenated plant-based oils rather than by eating fish (Health Canada, 1999).

In terms of advice to limit exposure to MeHg, Health Canada's most recent fish advisory proposes that Canadians limit their consumption of shark, swordfish, fresh and frozen tuna to one meal per week. Women of childbearing age, pregnant women and young children are advised to limit consumption of these species to one meal per month (Health Canada, 2002). Health Canada specifically excludes canned tuna from its limiting advice because canned tuna is subject to the 0.5 ppm guideline, whereas fresh/frozen tuna is not subject to the guideline. Health Canada has indicated that it is currently reviewing its risk management strategy for MeHg exposure from fish (J. Salminen, Chemical Health Hazard Evaluation Division, Health Canada, personal communication, 2005). As well, Health Canada (2004) has collected data with respect to mercury (and other contaminant) levels in commercial fish available in Canadian cities and is currently testing imported fish from Asian markets in Toronto for both contaminants and PUFAs.

As part of the Ontario sport fish monitoring program the *Guide to Eating Ontario Sport Fish* is published biannually by the Ministry of the Environment (OMOE). The consumption advice provided in the Guide is to be considered in the context of overall fish consumption. The most recently published edition provides separate consumption advice for sensitive sub-populations[10], a departure from earlier versions. While the focus of the Guide is on locally caught fish, it also recommends that sensitive subgroups reduce sport fish consumption by one meal per month for every two meals of store-bought fish (OMOE, 2005).

Based on its own analysis of risks and benefits of fish consumption, the Ontario Public Health Association (OPHA, 2004) advises women of childbearing age, pregnant women and young children to consume only one serving of fish per week that is likely to be low in MeHg and high in n-3 PUFAs. The OPHA also recommends that this population subgroup limit consumption of canned albacore tuna to one can per month, and that fresh or frozen predatory fish be avoided (OPHA, 2004).

Methylmercury Exposure and Fish Consumption Scenarios

To estimate the potential exposure to MeHg from fish with different levels of MeHg content, Toronto Public Health constructed various hypothetical consumption scenarios for both women of childbearing age (60 kg) and children 4 years of age (16.5 kg) (Richardson, 1997). The variables included were: 1) consumption frequencies [3.3 meals

[10] In the *Guide to Eating Ontario Sport Fish,* sensitive subpopulations include women of childbearing age and children under 15 years of age.

– the current Canadian average, plus 4, 8 and 25 fish meals per month), 2) portion size[11] (170 grams for adults and 85 grams for children) and 3) species of fish (representing low, medium or moderately high[12] mercury species)[13]. The calculations included only commercial fish and did not capture sport-fish consumption. The estimated intake values were compared to both the Health Canada pTDI and the U.S. EPA RfD. The findings below assume that the most protective pattern of fish consumption for these vulnerable subpopulations is one that maintains mercury intake below *both* Health Canada's pTDI and the U.S. EPA RfD.

In brief, the findings from the consumption scenario modeling indicate that:

Women who may become pregnant can eat two fish meals per week and keep mercury intake below "tolerable" levels by:

- choosing only among species with low to medium mercury levels (i.e., ≤ 0.2 ppm Hg)
- avoiding (preferably) or eating only rarely (that is, less than once a month) fish species that are high or moderately high in mercury (i.e., > 0.2 ppm Hg)

To ensure optimal protection of the fetus and breastfeeding infant however, pregnant women or women who are breastfeeding should take care to eat *no more than* two fish meals per week and:

- choose only fish from the low mercury category (i.e., < 0.05 ppm Hg)
- avoid medium and moderately high or high mercury fish (i.e., ≥ 0.05 ppm Hg)

Young children can safely eat two fish meals per week by:

- choosing only species low in mercury (i.e., < 0.05 ppm Hg)
- avoiding or eating only rarely (that is, less than once a month) fish species with medium to high mercury (i.e., ≥ 0.05 ppm Hg)

The consumption of canned tuna requires special consideration as it is an affordable, widely available and commonly consumed type of fish and it appeals to most children. It is quite possible that an individual's fish consumption could consist mostly of canned tuna as a result. Canned tuna, on average, does not exceed the Canadian action levels of

[11] Fish consumption advisories and recommendations have not been consistent in specifying portion size. The adult portion size of 170 gram (roughly 6 oz.) was chosen because: a) it is a customary portion size for many consumers, b) this portion size was used by the US EPA in its consumption guidelines, and c) this portion size would provide the amount of EPA + DHA needed for the cardioprotective effects of two fish meals per week as recommended by the American Heart Association (Kris-Etherton et al., 2002). The portion size for children was estimated to be half that of an adult, or 85 grams.

[12] The distinction of "moderately high" (versus "high") is made because commercial fish are subject to the Health Canada "action level" of 0.5 ppm which limits most high mercury fish species available to the consumer. This exercise assumes that these subgroups are not eating those high mercury "gourmet" species such as fresh/frozen tuna, shark, swordfish and others that are only covered under Health Canada's fish advisories.

[13] For the purposes of this analysis, fish mercury content was categorized as follows: low - < 0.05 ppm; medium - 0.05 to 0.2 ppm; moderately high - > 0.2 ppm.

0.5 ppm[14]. However, there is a clear difference in mercury content between canned light tuna, which is mainly made from the skipjack tuna species (but can also be from the larger yellowfin species) and white tuna, which can only contain the albacore tuna species in Canada as stipulated by the Fish Inspection Regulations (2000). Light canned tuna is considered in the medium mercury content category while white tuna is considered moderately high in mercury, relative to the Canadian action level of 0.5 ppm. White canned tuna may have as much as three times the amount of mercury as light tuna (US DHHS/EPA, 2006; Burger and Gochfeld, 2003). Published and anecdotal clinical case reports indicate that very frequent consumption of canned tuna has been correlated with neurological symptoms and high blood mercury levels in individual adult patients (Hightower & Moore, 2003; Kales & Goldman, 2002).

To explore whether or not there should be limits or specific advice on consuming canned tuna, a separate series of scenarios were modeled using published mercury values for canned tuna.[15] This exercise indicated that women who may become pregnant, pregnant or nursing women and young children should guide their consumption of canned tuna by the following to remain below both the U.S. and Canadian "tolerable" limits:

Light canned tuna (skipjack species):

- Women who may become pregnant can eat about three (3) cans[16] per week
- Young children can eat about one can (or ~2 half-can portions) per week
- Pregnant (or breastfeeding) women can eat about one can per week (and should ensure they keep other fish meals in the low mercury category)

White canned tuna:

- Women who may become pregnant should eat no more than one can per month
- Young children should avoid or eat only rarely (that is, less than once per month)
- Pregnant (or breastfeeding) women should avoid or eat only rarely (that is, less than once per month)

This advice on consumption of canned light or white tuna for pregnant or breastfeeding women contrasts with the recent precautionary advice from Consumer Reports magazine (2006) for pregnant women to avoid *all* canned tuna entirely. Their advice reflects a concern that light canned tuna is not always sufficiently labelled as to the tuna species and, if made from the yellowfin species, it can be highly variable in mercury content[17].

[14] See Table 5 of the technical report.
[15] It should be noted that existing published Canadian data (see e.g., Forsyth et al., 2004) have tested only small numbers of yellowfin light canned tuna samples therefore the analysis focused on data for mercury in light canned tuna made from the skipjack species from U.S. sources (Burger & Gochfeld, 2004).
[16] Note that one can of tuna is typically 120 grams drained weight per meal and therefore is a different portion size than other fish meals.
[17] A recent study in the U.S. indicates that there can be moderately to high mercury levels in light canned tuna made from the yellowfin species, particularly those originating from Latin American countries that tend to practice non-dolphin friendly methods of tuna catching (Malsch & Muffett, 2006). A small number of canned light tuna samples tested by Health Canada indicate that while the mean and median mercury concentrations of skipjack versus yellowfin tuna are not substantially different (generally yellowfin was

Discussion and Implications

The majority of risk-benefit analyses concede that despite the co-existence of persistent contaminants and essential nutrients in fish, it remains an important dietary constituent and that at certain life stages, a source of pre-formed EPA and DHA may be beneficial (Mahaffey, 2004). There is however, apparently less agreement as to how much fish and which types can best provide the reputed health benefits. As well, there are noteworthy differences in the messages reported to the public on the extent of the health benefits from the n-3 PUFAs from fish. Health Canada has not been prescriptive in recommending specific fish consumption frequency to gain benefits from n-3 PUFAs for any segment of the population. The American Heart Association and others however, have emphasized that the heart protective benefits from fish come from eating *at least* two fish meals per week (Kris-Etherton et al., 2002; UK SACN, 2004). While this report cannot resolve the issue of whether or not n-3 PUFAs, or some other constituent of fish, are protective of heart health, the preceding sections of this report suggest nonetheless, that it may be inadvisable to recommend such a fish consumption frequency for cardioprotective impacts alone for all subgroups of the general population.

Despite different approaches and methodologies to studying the issue, recent risk-benefit reviews have converged in calling for careful, specific and responsible risk communication when constructing fish consumption advice (see e.g. Mahaffey, 2004; Smith & Sahyoun, 2004; Gochfeld & Burger, 2005; Cohen et al., 2005). This section helps clarify some of the specific considerations of fish consumption recommendations including, how much and what types of fish can/should be eaten, so as to minimize risks to vulnerable subgroups and not only for purported health benefits to the general population.

Some evidence indicates that increased intakes of DHA may have beneficial effects on the development of the fetal nervous system and on visual and cognitive development during infancy. Few studies in humans are available to evaluate the dose-response relationship between DHA and neurodevelopmental benefits however. Gochfeld and Burger (2005) reviewed available studies and identified a maternal fish intake of 8 to 15 grams per day (equivalent to about 1.5 to 2.5, 170 gram fish meals per month) as the threshold for benefits to pregnancy outcome. This finding is close to that of the ALSPAC study which proposed that the neurodevelopmental benefits in the infant from maternal fish consumption during pregnancy were gained from as little as two (115 gram) fish meals per month but that increasing fish consumption beyond that may not necessarily yield greater gains (Daniels et al., 2004).

Paradoxically, the stages of development when the benefits of n-3 PUFAs may occur correspond to the most vulnerable periods for the neurotoxic effects of MeHg exposure.

lower in mercury than skipjack), the range was higher for yellowfin, likely related to one sample which, at 0.59 ppm, exceeded the Canadian tolerance for total mercury in seafood (Dabeka et al., 2004).

Women of childbearing age and young children are at low risk for CHD, but are considered a sensitive population with respect to exposure to MeHg because of the potential impacts on the developing nervous system of the fetus and young child. Establishing a balance between the consumption of optimal amounts of n-3 PUFAs from fish and minimizing exposure to MeHg to prevent adverse effects on the developing nervous system is a risk communication challenge. While there is admittedly uncertainty on both sides of the risk-benefit equation, there appears to be consensus among scientific, medical and public health agencies that the risks to the developing fetus from mercury exposure are to be minimized as far as possible (for example see: NRC, 2000; OCFP, 2003; AMA 2004; Consensus Statement on Methylmercury and Public Health, 2004[18]; OPHA, 2004, among others).

The consumption scenarios indicate that with a consumption frequency of more than two fish meals per week, it becomes increasingly difficult to stay below both the U.S. and Canadian mercury "tolerable" intake levels for pregnant or nursing women, women of childbearing age and young children. These vulnerable subgroups should choose fish species carefully, with emphasis on low mercury species (that is below 0.05 ppm Hg), while avoiding, or eating only rarely, higher mercury species. Pregnant or nursing women should choose from low mercury species alone. These conclusions mirror those of recent risk-benefit analyses by others (Smith & Sahyoun, 2004; Gochfeld & Burger, 2005).

Careful, focussed risk communication aimed at vulnerable subgroups should have the effect of moderating consumption to low mercury species rather than reducing overall fish consumption. Oken and colleagues (2003) observed that Boston women in an obstetrical-gynaecological practice reduced their total fish consumption by 17% (from 7.7 to 6.4 meals per month) after the 2001 fish advisories of the U.S. FDA. However, this reduction was explained largely by these women avoiding higher mercury fish such as canned tuna (0.8 fewer meals) and "dark meat fish" (0.2 fewer meals). In a quantitative risk-benefit analysis of hypothetical changes in population fish consumption, an expert panel from the Harvard Center for Risk Evaluation recently concluded that the greatest net public health gains from consuming fish are likely to be achieved by getting women of childbearing years to shift the type of fish they eat (to low mercury species) without reducing their overall fish consumption, while simultaneously increasing fish consumption among other adults in the population (Cohen et al., 2005).

Other Considerations in Fish Consumption Advice Messages

Alongside the considerations already discussed, related issues must inform fish consumption advice to vulnerable subpopulations. As well, this section identifies needs for future research, policy and outreach.

[18] This 2004 document signed by many U.S. national, state and local health-based organizations, is endorsed by (among others) the American Academy of Pediatrics (AAP), the American Public Health Association (APHA), Physicians for Social Responsibility, the Children's Environmental Health Network, the American Nurses Association and the American College of Preventive Medicine.

Identifying Low Risk Fish Species

First among these additional considerations is how to identify the types of fish that can be eaten for optimal health benefit with minimal risk that is, species that are low in mercury but high in n-3 PUFAs. Not all types of fish have equivalent amounts of n-3 PUFAs nor do all fish accumulate MeHg to the same degree. It is generally observed that species high in n-3 PUFAs are not necessarily high in mercury and vice versa. For example, herrings and sardines are small fish that fit both these criteria while being readily available and generally very affordable. Other low mercury fish species such as trout or tilapia, can also be eaten more frequently and will provide other nutritional benefits despite lower concentrations of n-3 PUFAs. Table 1 in Appendix 1 summarizes some of the available data for various species of fish. This table is one tool but it is not a comprehensive listing of the mercury content of all fish species available in Toronto markets. Clearly there is a need to expand such information and make it more widely available so that fish consumers can make informed decisions when choosing fish species.

Toronto Public Health is committed to expanding its health promotion work in this area, however, it also requires that federal and provincial agencies conduct more research and make data on current levels of mercury in fish available in Canada more publicly accessible, particularly for use by local public health units. A recently released U.S. survey conducted by the Center for Science in the Public Interest (2006) indicated that nearly a third of women who were pregnant, nursing or planning to become pregnant were not aware of the harm to the fetus from eating fish with high mercury. As well, only one in five respondents was able to correctly identify high mercury fish species.[19] Finally, the great majority of individuals preferred a system of point of purchase labels to identify fish species with high mercury as opposed to the current practice of government advisories (CSPI, 2006). At a minimum, it seems appropriate that fish retailers be required to post the Health Canada advisories so that consumers can more readily identify the high mercury fish species such as fresh/frozen tuna, shark or swordfish that are exempt from the Health Canada guidelines for allowable levels in fish.

Other Contaminants in Fish

Salmon fits two important criteria as a fish species that is low in mercury and high in n-3 PUFAs. Over the last two decades there has been a significant increase in the availability of farmed salmon (Foran et al., 2005). The risks associated with eating farmed and wild salmon, have been debated in recent scientific literature (e.g., Rembold, 2004; Hampton, 2004; Wilson, 2004; Williams, 2005; Willett, 2005; Foran et al., 2006). The main contaminants of concern in farmed salmon are polychlorinated diphenyls (PCBs) and other organic contaminants [such as polybrominated diphenyl ethers (PBDEs or flame retardants and dioxins], which accumulate in fish from the practice of feeding fish meal to salmon throughout their lifespan (Carlson & Hites, 2005). Health Canada (2004) however, has stated that the levels of PCBs in farmed salmon available in Canada are well below tolerable maximum intakes for these contaminants. Unlike MeHg that accumulates in the muscle of the fish, these contaminants accumulate in fatty tissues

[19] Twenty-one percent of consumers surveyed stated that salmon was a high mercury fish (CSPI, 2006).

therefore, fish preparation and cooking methods can substantially reduce intake of these fat-soluble contaminants (Salama et al., 1998; Zabik et al., 1995).

The available literature (mainly representing the conclusions of one team of scientists whose analyses rely on a single historical dataset of PCB levels from salmon) has suggested that farmed and some wild salmon should be eaten in moderation (for example, Hites et al., 2004; Foran et al., 2005; Huang et al., 2006). Hites and co-workers (2004) have recommended eating one meal per month or less of farmed salmon (or alternatively taking fish oil supplements) to minimize unacceptable risks for cancer (and potentially for impacts on the developing fetus as well). Some unpublished data (e.g. Health Canada, 2004; SOTA, 2004) show however, that PCB levels have decreased recently in the farmed salmon currently available in Canada. As well, the reported levels of PCBs are lower (by an order of magnitude) than those in Great Lakes fish for which there are fish consumption guidelines available (see Technical Report Section 4.2.2. Province of Ontario - Sport Fish Program for further discussion). While epidemiological data assessing health impacts from consuming farmed salmon are not available, one longitudinal cohort study has reported clear long-term impacts on cognitive and behavioural development in children whose mothers frequently consumed Lake Michigan fish, which are relatively high in PCBs, before and during pregnancy (Jacobson & Jacobson, 2003; Jacobson & Jacobson, 1996).

Without further published data examining the impacts on neurodevelopment from current levels of PCBs in farmed salmon available in Canada, it is difficult to assess with confidence whether or not there is a need to recommend modest consumption of farmed salmon among vulnerable subgroups. Because PCBs and other organic contaminants such as dioxins persist in the body relatively longer than contaminants like methylmercury, advice to limit exposure for girls and young women may be prudent nonetheless (Foran et al., 2006). TPH will continue to follow this issue to assess whether further specific limitations on consuming farmed salmon to minimize risks are warranted.

Fish Oil Supplements

Some researchers recommend that children, women of childbearing age, pregnant women, and nursing mothers, not at significant risk for sudden cardiac death associated with coronary heart disease, should obtain n-3 PUFAs from supplements (Hites et al., 2004; Foran et al., 2005a; Huang et al., 2006; Smith & Sahyoun, 2005; Wilson, 2004). However, fish oil supplements may also contain methylmercury and PCBs.

The concentrations of contaminants in fish oil supplements appear to be decreasing over time (Jacobs et al., 2004). However, studies conducted in the last ten years have concluded that fish oil supplements may be significantly contributing to an individual's levels of PCBs or dioxin-like compounds (Jacobs et al., 2004; Jacobs et al., 1998; Tsigouri & Tyrpenoui, 2000). In contrast, two studies conclude that the contaminant levels in fish oil supplements are low and that supplements may be a safer alternative to eating fish (Foran et al., 2005; Foran et al., 2003). It is of note that only one of these studies includes fish oils from or purchased in Canada (Jacobs et al., 1998).

Marine algae-based fish supplements, another source of preformed n-3 PUFAs, are reputed to be much lower in contaminants compared to fish-based oils (Hernandez, 2004). However algae-based supplements are considerably more costly and therefore may not be a reasonable option for most women wishing to gain the benefits from n-3 PUFAs. With the preliminary analysis presented in the technical report it is not possible to say with any certainty whether fish oil supplements are a preferred alternative to minimize exposure to persistent contaminants. TPH will continue to monitor the research on this topic and integrate new information as needed and appropriate.

Advice to High Fish Consumers

Another important consideration is to identify ways to tailor fish consumption advice for specific subgroups within the vulnerable subpopulations identified. Toronto is a culturally and ethnically diverse city. Differences in dietary patterns are clearly an important expression of that diversity. Some ethnocultural communities in Toronto likely have very high frequency of fish consumption (well beyond the current Canadian average of 3.3 fish meals per month). For example, subjects of Asian origin/ethnicity were found to have the highest fish consumption frequency in two Canadian studies (e.g. Cole et al., 2004; Innis et al., 2006). A sample of Asian-Canadian fish eaters in Ontario ate about 4 meals per week (Cole et al., 2004). According to the consumption scenarios presented here it is possible to consume fish twice a week without exceeding the current mercury "tolerable" intake levels. However, the scenarios indicate that it is more difficult to consume fish daily and stay within "tolerable" levels without specific knowledge on choosing fish that have low mercury content. Indeed, the studies cited above both showed that higher blood mercury level was not only related to higher fish consumption but also to types of fish eaten. It is important to acknowledge the cultural and nutritional significance that fish plays in the diet of these groups. However, the vulnerable subgroups among them should be the focus of health promotion outreach on choosing fish species carefully to minimize mercury exposure while maintaining the nutritional and cultural benefits. Health professionals who work with pregnant or nursing women or who deal with nutritional issues for families with young children should aim to identify high fish consumers and provide information around choice of fish species for their clients. However, given the reliance of some ethnocultural communities on imported fish from specialized markets, there is also an urgent need for data on the variability in mercury content of available imported fish species in Canada. Health Canada has currently undertaken to collect additional data with respect to mercury (and other contaminant) levels in commercial fish available in Canada, including a "pilot study" testing imported fish from Asian markets in Toronto. Government regulatory agencies should be proactive in sampling and testing contaminant levels in a broad range of imported fish species available to Canadians. Government agencies should also be proactive in developing precautionary guidance on commercial fish consumption for frequent fish consumers.

Impacts on Global Fisheries & Environmental Considerations

Alongside the individual or population-level risks and benefits of consuming fish, an increasingly important factor in choice of fish species must be awareness of the impact on world fisheries and stocks of certain species. While the analysis presented here indicates that with careful choices, the vulnerable subgroups addressed may safely eat two fish meals per week or 8 meals per month, that frequency represents at least double the average Canadian fish consumption of 3.3 fish meals per month according to Statistics Canada (2004). The United Nations (2005) reported recently that usage of the world's capture fisheries is now well beyond levels that can be sustained at current or future demands. Aquaculture (fish farming) has increased availability of fish, but can have numerous environmental impacts itself, especially salmon farming. Ecological considerations are an important factor given the commitments of the Toronto Food Charter. In May 2000, City Council committed to striving to ensure "a viable and sustainable food production system". Given that much of the city's food is produced far afield and transported from long distances, the City must respect the ecological and economic impact that local food consumption can have on distant lands and peoples. Alongside summarizing information on mercury and n-3 PUFA levels in various fish species, Table 1 in Appendix 1 also identifies potential ecological concerns. The table shows that it is possible to choose fish species that satisfy all of these considerations (denoted by the bolded text in unshaded rows), as well as being cost effective, with species such as Atlantic mackerel, herring, sardines and smelt being the most advantageous.

Federal bodies such as the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) need to examine and improve fish management practices (including wild and farmed) so as to ensure sustainable, safe fish stocks for Canadians. The CCFAM should develop strict environmental and safety standards for Canadian fisheries, similar to the certification standards put forward by the Marine Stewardship Council (MSC) which recognizes well-managed, environmentally-responsible fisheries internationally. The MSC also supports an international seafood eco-labelling program based on the 1995 Code of Conduct for Responsible Fisheries from the Food and Agriculture Organization (FAO) of the United Nations. This eco-labelling program allows consumers to identify and purchase fish that come from sustainable fisheries. In addition, there is a need to ensure that aquaculture operations are addressed in the development of best management practices for fisheries. The Aquaculture Task Group of the CCFAM should partner with organizations such as the World Wildlife Fund's Center for Conservation Innovation (CCI) which is currently working to identify and develop best management practices "to reduce the environmental and social impacts of aquaculture" (WWF, 2006). TPH will continue to explore ways to integrate credible, accessible information for the public on fish choices that have minimal ecological impact on marine wildlife into any web and print resources that are developed.

Finally, contaminant accumulation is limiting fish as a reliable healthy food. Concerted effort needs to be directed towards protecting this food supply so that Canadians can choose to eat fish for their nutritional and health benefits. The federal and provincial governments need to continue their work in reducing the release of contaminants into the environment at the international, national and local levels. The Canada-wide Standard (CWS) for mercury, developed in 2000 by the Canadian Council of Ministers of the Environment (CCME), identifies a number of priority sources of mercury to address in Canada. TPH has previously commented on where the CWS requires strengthening. In

June of 2006 the Premier announced a significant delay in the Ontario phase out of coal-fired power plants, one of the priority sources of mercury. This delay represents a substantial set-back to achieving the targets of the mercury CWS nationally.

Pollution Probe and its environmental and health partners recently called for the CCME to develop and implement a comprehensive mercury elimination and reduction strategy for Canada. These organizations call for the national mercury strategy to phase-out all non-essential and ensure no new uses of mercury in products. In addition, they urge that such a strategy increase the recovery, collection and recycling of mercury-containing products to a rate of 80% or better, thereby matching the actual or targeted recovery rates of other jurisdictions such as the European Union and the United States, respectively (Pollution Probe, 2006). At a minimum, it is appropriate to call for the federal Minister of the Environment and the CCME to strengthen the CWS and ensure it is more aggressively implemented by all provinces in Canada to help restore the safety of fish as a food source for everyone.

Conclusions

Fish consumption is a complex field of study which requires understanding of cultural patterns, food preferences, and the availability and accessibility of diverse fish species. The scientific debate concerning health risks and benefits from fish consumption is not resolved in this review. Authoritative agencies have been specific in recommending that the general public consume *at least* two fish meals per week to gain cardioprotective benefits. In some cases, this same advice has been extended to pregnant and breastfeeding women as well. In contrast, others have recommended that vulnerable subgroups limit fish meals to no more than once each week to avoid exposure to methylmercury. The diversity of fish consumption habits among Toronto's multi-ethnic population necessitates an approach that counterbalances such divergent fish consumption advice, especially for those who already enjoy fish regularly. Toronto Public Health is mindful of the health benefits and cultural significance of fish but stresses that the most prudent fish consumption advice focuses on ways to minimize the risks, particularly for those most vulnerable to toxic exposure including pregnant or breastfeeding women, women of childbearing age and young children.

Available data on mercury content of commercially available fish plus the estimate of mercury intake resulting from the consumption scenario modeling exercise suggest that with a consumption frequency of more than two fish meals per week, it becomes increasingly difficult to stay below both the U.S. and Canadian mercury "tolerable" intake levels. Vulnerable subgroups should choose fish species carefully, with emphasis on low mercury species, while avoiding or eating only rarely, higher mercury species. Pregnant or nursing women in particular should choose from low mercury (i.e., < 0.05 ppm Hg) species alone. Advice also suggests that pregnant or breastfeeding women and young children should limit consumption of canned light tuna to one can per week and eat canned white tuna rarely. At the same time, it is important that individuals in these categories not be discouraged from eating fish for their nutritional value and for the known or suggested health benefits, particularly for brain and nervous system development, acknowledging that they may not need to consume fish as frequently as recommended for heart health protective benefits.

It is likely that some ethnocultural communities in Toronto are at risk of higher exposure to methylmercury from high frequency of fish consumption. It is important to acknowledge the cultural and nutritional significance that fish plays in the diet of these communities. However, TPH nutrition and prenatal programs should focus on identifying frequent fish consumers and provide them with information on choosing fish species carefully to minimize mercury exposure while maintaining the nutritional benefits. Identifying high consumers might be possible if physicians and other health professionals documented fish consumption practices of their patients or clients.

Intertwined with these risks and benefits of consuming fish, another important factor in choice of fish species must be awareness of the state of global fish stocks and the impact of fish farming practices on the environment and contaminant levels in farmed fish. Fish consumption advice should include information that allows consumers to make species choices that support sustainability, pollution prevention and environmental protection.

Lastly, federal and provincial governments need to continue their work in reducing the release of contaminants such as mercury into the environment and to implement policies that reduce the level of contaminants in fish and restore the safety of this healthy food choice.

Appendix 1

Table 1 Summary of Omega-3 fatty acid (EPA and DHA) Content, Methylmercury Levels and Ecological Concerns for Selected Fish Species, in Rank Order Overall

Species (170 gm edible portions, raw weight)	Omega-3 fatty acid [a] (EPA + DHA) (grams)	Mean Mercury Concentration[b] (ppm)	Ecological Concerns[c]
Mackerel, Atlantic	**3.90**	**0.05**	**LOW**
Salmon, Chinook (wild)	**3.32**	**0.01**	**LOW-MEDIUM** - **Fairly well managed; loss of habitat remains a concern**
Salmon, pink, canned[d] (wild)	**2.82**	**ND**	**LOW** - **best managed of all salmon species**
Herring, Atlantic	**2.68**	**0.04**	**LOW**
Sardines, Atlantic	**1.54**	**0.02[e]**	**LOW**
Trout, mixed species (freshwater)	**1.26**	**0.07**	**LOW**
Smelt	**1.18**	**0.11**	**LOW**
Oyster (wild)	**0.95**	**0.01**	**LOW-MEDIUM**
Shrimp (North American)	**0.82**	**ND**	**LOW-MEDIUM** - **Some concerns about bycatch[f] and habitat damage**
Pollock, Atlantic	**0.72**	**0.04**	**LOW**
Oyster (farmed)	**0.67**	**ND**	**LOW**
Catfish (farmed)	**0.47**	**0.05**	**LOW**
Scallops	**0.34**	**0.05**	**LOW-MEDIUM** - **Sea scallops caught by dredging causes severe damage to seafloor habitat and significant bycatch. Farmed scallops or those caught by professional divers can be better alternatives.**
Clams (farmed)	**0.24**	**ND**	**LOW**
Tilapia	**0.15**	**0.01**	**LOW**
Salmon, Atlantic[g], farmed	3.16	0.01	HIGH - Farmed salmon raised in open net cages can pose a threat (through competition and disease) to wild salmon and the marine environment. - Dependence on wild fish used in fish-feed
Shrimp (Tiger, imported)	0.82	ND	HIGH - Trawling for wild-caught tropical shrimp (also called prawns) accounts for about 25% of global bycatch. - Tiger shrimp is the most commonly farmed species in south-east Asia. Mangrove forests are

Species (170 gm edible portions, raw weight)	Omega-3 fatty acid [a] (EPA + DHA) (grams)	Mean Mercury Concentration[b] (ppm)	Ecological Concerns[c]
			routinely destroyed to create ponds for shrimp aquaculture.
Snapper, mixed species	0.52	0.19	MEDIUM-HIGH - Significant overfishing and bycatch with some species
Ocean Perch, Atlantic	0.50	ND	HIGH - Stocks have been subject to intensive fishing pressure over the last 10 years, vulnerable to overexploitation.
Tuna, light, canned	0.46	0.12	MEDIUM - Considerable concern about the amount and type of bycatch.
Haddock	0.32	0.03	MEDIUM-HIGH - Stocks slowly recovering from overfishing, also concerns about habitat damage due to use of bottom trawl gear. IUCN lists as vulnerable.
Halibut, Pacific	0.62	0.25	LOW
Tuna, white, canned (Albacore)	1.48	0.35	HIGH - Use of longlines to catch white (albacore) tuna from the Pacific results in high bycatch.
Shark	1.43	0.99	HIGH - With few exceptions, sharks are at historically low levels throughout the world.
Swordfish	1.10	0.98	HIGH - Bycatch is an ongoing concern for swordfish caught outside North America. - Vulnerable to overexploitation since they mature late and take a long time to replace their numbers. - IUCN[h] lists as vulnerable
Halibut, Atlantic	0.62	0.25	HIGH - IUCN lists as endangered
Mackerel, King	0.54	0.73	LOW
Grouper, mixed species	0.42	0.47	HIGH - Many species overfished. IUCN lists as threatened.
Cod, Atlantic	0.32	0.10	HIGH - Heavily fished over the past 50 years resulting in massive population declines. IUCN lists as vulnerable.
Roughy, orange	ND	0.56	HIGH - Long-lived fish, vulnerable to exploitation

Notes:

[a] Data source USDA National Nutrient Database for Standard References, Release 17-1. [electronic version] Retrieved April 12, 2005 from http://www.nal.usda.gov/fnic/foodcomp.
[b] Data source US DHSS/EPA (2006).
[c] Information from this section came from four sources:

- Monterey Bay Aquarium Seafood Watch Program (MBASWP), http://www.mbayaq.org/cr/seafoodwatch.asp
- UK Marine Conservation Society, http://www.fishonline.org/
- International Union for the Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species, http://www.iucnredlist.org/
- David Suzuki Foundation. 2006. State of the Catch. Author: Suzanne Tank. http://www.davidsuzuki.org/files/Oceans/StateoftheCatch.pdf

[d] Canned salmon typically contains wild pacific salmon, usually either "pink" or "chum" species.
[e] Institute for Agriculture and Trade Policy's Food and Health Program, Smart Fish Calculator. http://www.iatp.org/foodandhealth/fishcalculator/index.cfm.
[f] Bycatch refers to unwanted fishes and animals caught accidentally in fishing gear and discarded overboard, dead or dying.
[g] "Atlantic" here refers to the species of salmon, rather than the geographic location of origin. Note that wild Atlantic salmon stocks are severely depleted and therefore not widely available in retail markets (See: Atlantic Salmon Federation. (2004). Status of North American Wild Salmon. http://www.asf.ca/reports/2004state/popn2004_8x11_e.pdf).
[h] The International Union for the Conservation of Nature and Natural Resources is the world's largest conservation network with 82 member States and numerous government agencies and non-governmental organizations including Canada's Department of Fisheries and Oceans.
ND – below the level of detection

Glossary of Terms

Adipose tissue: Connective tissue that is composed of adipocytes or fat cells. Adipose tissue synthesizes and stores fat, an important source of energy, and also cushions and insulates the body.

Alpha-linolenic acid (ALA): A member of the group of essential fatty acids called omega-3 fatty acids, essential dietary requirement for all mammals. It is obtained only from plants and sources such as soybean, walnuts and flaxseed are particularly rich food sources of ALA. The body can convert ALA to the two longer chain omega-3 fatty acids mainly found in fish, eicosapentaenoic acid and docoshaexaenoic acid.

Arachidonic acid (AA): A polyunsaturated essential omega-6 fatty acid, which is required by most mammals, including during development. It is found in cell membranes and is particularly abundant in brain tissue.

Arrhythmias: An alteration in rhythm of the heartbeat either, in time or force

Attentional focussing: An aspect of children's behavioural function that is assessed through caregiver-administered questionnaires. Attentional focussing relates to a child's ability to maintain their focus and persist at a given task until it is completed (Rothbart et al., 2001).

Autoimmune disorders: An organism's immune response against its own cells and tissue, which is induced by the failure to recognize its constituent parts as its own.

Benchmark dose (BMD): Referring to the dose of a substance that is expected to result in a pre-defined level of effect or response (Setzer Jr. & Kimmel, 2003). It is one approach to studying dose response of toxicants, used to set regulatory levels.

Bioaccumulating: Referring to pollutants that are excreted more slowly than they are absorbed and are thus stored in the body for long periods of time. Total pollutants in the body (the "body burden") may increase if the organism is repeatedly exposed to bioaccumulating substances for a long period of time.

Bioconcentration: The accumulation of a chemical in tissues of an organism (such as a fish) to levels greater than in the surrounding medium in which the organism lives. Differs from the term bioaccummulation in that it refers to uptake of substances from water, whereas bioaccumulation refers to uptake from all sources.

Biomagnificiation: Referring to the phenomenon where levels of persistent contaminants (such as methylmercury or PCBs) are progressively greater at higher levels of the food chain. Biomagnification occurs when predator organisms absorb the load of contaminants stored (i.e. bioaccummulated) in the tissues of their prey organisms.

Biomarker: Biological materials, enzymes, hormones, genetic material etc., that change when exposed to contaminants. These can be used as indicators of the effects of an environmental exposure at the cellular or subcellular level.

Biomonitoring: Biomonitoring involves measuring and analyzing chemicals, hormone levels or other substances in biological materials (e.g., blood, urine, breath) to estimate exposure, or to detect biochemical changes in the exposed subject before or during the onset of adverse health effects. Biomonitoring sometimes refers to a specific indicator for a particular disease/functional disturbance (e.g., a blood test for lead).

Blood-brain barrier: A term that encompasses multiple mechanisms that control access of blood components to the brain; the fetal and neo-natal blood–brain barrier is more permeable than the adult barrier to small lipophilic molecules.

Brominated fire retardants (BFRs)**:** Organic substances, containing the element bromine, that inhibit the flammability of combustible materials. BFRs are commonly applied to the materials used in making electronic products, clothes and furniture to make these items resistant to catching on fire or to slow the spread of flames.

Carcinogenicity/Carcinogen: A substance such as a chemical, or an agent such as ionizing radiation, that is capable of causing cancer.

Contaminants: Substances foreign to a natural system or present at unnatural concentrations; unwanted substances that have entered the air, food, water or soil. Contaminants may be chemicals, living things (e.g., bacteria or viruses) or the products of radioactivity. Some contaminants are created by human (e.g., industrial) activities while others are the result of natural processes.

Dioxins (dioxins and furans): Two families of organochlorine chemicals, with numerous types in each group, that are closely related by their structure and toxicity. These chemicals are by-products of combustion, degradation of other chemicals, and some industrial processes.

Docosahexaenoic acid (DHA): an omega-3 essential fatty acid. This 22-carbon (long chain) polyunsaturated fatty acid, (along with eicosapentaenoic acid- see below) is most often found in fish or in marine mammal oil. It is believed to be important for the development of the eyes and brain of mammals.

Dose-dependent: Referring to the effects of exposure to a contaminant or substance. If the effects change when the exposure dose changes, the effects of that contaminant or substance are said to be dose-dependent.

Eicosanoids: A class of biologically active lipid molecules derived from the transformation of polyunsaturated fatty acids by different enzymes. Eicosanoids include molecules such as prostaglandins, leukotrienes and thromboxanes that are involved in a variety of cellular functions.

Eicosapentaenoic acid (EPA): An omega-3 essential fatty acid, so called because it is an essential dietary requirement for all mammals. This 20-carbon (long-chain) fatty acid, along with docosahexaenoic acid, is most often found in the oils of fattier fish such as cod, herring, mackerel or salmon, among others. It is believed to play a role in enhancing cardiovascular health in adults.

Exotic species: Organisms that are not native to a given area but have been introduced accidentally or deliberately (by human activity). Exotic species can be harmful to the ecosystem to which they are introduced because they may outcompete existing, native species.

Fish advisories: Public notices issued by local, provincial or national environmental or health agencies that warn about the need to limit or avoid consumption of certain fresh or salt water species, generally those that are predator species at the top of aquatic food chains. Most advisories are directed at subsistence fishers, but also at pregnant or nursing women and young children, as well as women of childbearing age.

Inorganic mercury: Mercury combined with elements such as chlorine, sulphur, or oxygen. Most are white powders, or crystals, except for mercuric sulphide which is red and turns black after exposure to light.

Intrauterine Growth Retardation (IUGR): A condition where the fetus is less than 10% of predicted weight for gestational age or the newborn is below 10% of predicted weight at birth. IUGR may have many possible causes, the most common one being inadequate maternal-fetal circulation.

Linoleic acid: A polyunsaturated omega-6 fatty acid. Found especially in plants and plant oils (such as peanut oil) it is considered an essential fatty acid.

Lipophilic: Literally "fat-loving" or "water-averse." Refers to substances that have an affinity for or dissolve in fat and as a result, often concentrate up the food chain, reaching their highest levels in high fat foods such as whole milk, cheese, fatty meats and oily fish.

Longitudinal cohort studies: A type of epidemiological study which samples a cohort, or group experiencing some event (typically birth or a given exposure) in a selected time period, and follows this group at intervals through time to examine health outcomes or effects.

Mediterranean diet: A pattern of diet characteristic of people from a number of countries in the Mediterranean basin during the early 1960s. Although actual national diets vary, such a diet is defined by researchers as being generally comprised of: high intake of fresh plant foods (vegetables, legumes, nuts, seeds, cereals, fruits); fat intake mainly of unsaturated fats (largely olive oil) with low intake of saturated fats; low to moderate consumption of dairy products, eggs, red meat and wine (Serra-Majem et al, 2006).

Meta-analysis: A statistical method that combines the results of a number of studies examining related research hypotheses of interest. Meta-analyses allow for the evaluation of results from a larger sample size and thereby provide the ability to make firmer conclusions than can be achieved from a single study.

Metabolic pathways: A series of chemical reactions that occurs within cells and is brought about by the action of enzymes on an initial substance. Each pathway results in either the formation of a product to be used or stored by the cell, or the initiation of another metabolic pathway.

Metabolic regulation: The feedback and modulation of the sequence of enzyme steps occurring in the biochemical modification (synthesis or breakdown) of chemicals in an organism or in its cells.

Methylmercury: Organic mercury compound formed by microbes in soil and sediment.

Microgram (mcg or µg): A unit measure of weight that is equivalent to $1/1000^{th}$ of a milligram or one millionth of a gram.

Minamata disease: An abnormal condition affecting the peripheral nerves and that is related to methylmercury poisoning (typically from eating contaminated seafood). This condition is characterized specifically by impairment of mental functions, constriction of the visual field and progressive weakening of muscles. Minimata disease was named after a well known methylmercury poisoning incident in the 1950s among people in an area of Japan where industrial releases of mercury contaminated fish in Minimata Bay.

Neurodevelopment: Also known as neural or neurological development, this refers to the complex cellular and molecular processes that characterize the emergence and differentiation of the nervous system from the embryonic stage through to adulthood.

Omega-3 (n-3 or ω-3) fatty acids: Essential polyunsaturated fatty acids, some of which are found in oil from fatty fish and others from vegetable sources (such as vegetable oils or leafy green vegetables). Omega-3 fatty acids are classified as essential because they cannot be synthesized in the body; they must be obtained from food sources.

Organochlorine contaminants: A wide variety of synthetic organic (carbon-based) compounds containing chlorine that are particularly notable for their persistence and stability. Some have been deliberately manufactured (e.g., several pesticides, including DDT, or industrial chemicals such as PCBs) though many of these are now banned or greatly restricted in use. Others are breakdown or reaction products like dioxins formed from incineration of products like PVC plastic.

Organic mercury: Mercury combined with carbon. Examples of organic mercury compounds are methylmercury, dimethylmercury and mercuric chloride.

Parts per million/billion (ppm/ppb): Terms used to describe small (though possibly harmful) concentrations of a contaminant in media such as soil, water or air. Parts per million is the number of units of mass per million units of total mass, whereas parts per billion refers to the mass units per 1000 million (or billion) units of total mass. One ppm is equivalent to one milligram per kilogram (mg/kg) in a solid or one milligram per litre (mg/L) in a liquid or one milligram per cubic meter (mg/m^3) in a volume of air. Similarly, one ppb is equivalent to one microgram per kilogram (μg/kg) in a solid or one microgram per litre (μg/L) in a liquid or one microgram per cubic meter ($\mu g/m^3$) in a volume of air.

Plasma: the straw-coloured liquid component of blood which is the transport medium for blood cells and other substances.

Polybrominated diphenyl ethers (PBDEs): One sub-group of the brominated flame-retardant family of compounds. They have been used in a wide array of household products, including fabrics, furniture, and electronics and are known to be persistent and bioaccumulating. (See also brominated fire retardants)

Polychlorinated biphenyls (PCBs): A family of structurally similar synthetic organic compounds that were used for their electrical insulating and lubricant properties. While they had numerous applications in the past, PCBs are no longer manufactured and use is restricted because of carcinogenic properties and persistence in the environment.

Polyunsaturated fatty acids (PUFAs): The building blocks of fats, which are used by the body for energy and tissue development. Polyunsaturated refers to the fact that one or more pairs of carbon-carbon double bonds is absent within the fat molecule (whereas saturated fats contain such carbon-carbon double bonds.) PUFAs are beneficial in lowering cholesterol levels and can be found in nuts, seafood and vegetable oils such as canola or soybean oils.

Randomized controlled (or randomized clinical) trial (RCT): A type of experimental study where an intervention or allocation of treatment is under the control of the researcher. Subjects in the study are randomly assigned to either receive a treatment or not receive the treatment (or receive a placebo). Subjects in the treatment and non-treatment groups are then compared for the effects observed or for how they perform in different tests of function. RCTs are often used to test the efficacy of medicines or other treatments.

Reference dose (RfD): The estimate of daily oral exposure to the people, including sensitive subgroups such as children, that is deemed not likely to cause harmful effects during a lifetime. "RfDs are generally used for health effects that are thought to have a threshold or low dose limit for producing effects" (US EPA website, undated).

Reproductive toxicity: Chemical substances or agents that cause adverse effects on the male and female reproductive systems. Toxicity may be expressed as alterations of sexual behaviour, decreases in fertility, loss of the fetus or abnormal fetal genital development during pregnancy.

Selenium: A micronutrient found in soil. It is toxic in large amounts, but in trace amounts, it is essential. Major human food sources of selenium are seafood and meats. Selenium is believed to play a role in protecting against or reducing the toxic effects of mercury.

Sustainable ecosystem: An ecological system (that is, a grouping of organisms, plants, animal, micro-organisms, etc., and its surrounding environment, that lives together and functions as a unit) that meets the needs of its organisms without compromising the environment or the needs of future generations of organisms in that system.

Thrombosis: Condition where a blood clot (or thrombus) within an artery or vein obstructs local blood flow causing tissue damage and hemorrhage. Usually a result of arteriosclerosis or diseased arterial blood vessels characterized by thickened and hardened arterial walls.

Toxicology: The study of poisons, including the source, effect, and treatment of poisoning.

Triglycerides: The form of fats (a compound of glycerol and fatty acids) found in the body and that are derived from fats eaten in foods or that are made in the body. Triglycerides plus cholesterol form the lipids or fats found in blood plasma.

Weight of Evidence: Referring to the approach to estimating either human health risks or benefits (from exposures or treatment interventions, respectively) that evaluates evidence from all the best available science and data collected by accepted scientific methods. In particular, it includes consideration of data from a variety of types of studies and sources including laboratory or animal studies, various epidemiological studies in humans and where relevant, wildlife studies. The more extensive the research, and the more consistent the results across different studies (and in different species), the stronger is the weighting given to a judgement that there may be a risk or a benefit to human health from exposure to a given contaminant or treatment, respectively. (Adapted from Cooper et al., 2000).

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