Which Fish Should I Eat? Perspectives Influencing Fish Consumption Choices

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Short title: Challenges to consumption advice

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LIST OF ABBREVIATIONS:

DHA — Docosahexaenoic acid

EPA — Eicosapentaenoic Acid

FDA — United States Food and Drug Administration

Hg — Mercury

LCPUFA — Long chain polyunsaturated fatty acid

NRC — National Research Council

PCBs — Polychlorinated biphenyls

PUFA — Polyunsaturated fatty acid

US — United States

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ABSTRACT

Background: Diverse perspectives have influenced fish consumption choices.

Objective: We summarize the issue of fish consumption choice from toxicological, nutritional, ecological, and economic points of view. We identify areas of overlap and disagreement among these viewpoints. We also review effects of previous fish consumption advisories.

Methods: We reviewed published scientific literature, public health guidelines, and advisories related to fish consumption. We focus on advisories targeted at United States populations but the conclusions apply to groups having similar fish consumption patterns.

Discussion: The possible combinations of matters related to fish consumption are many, but few, if any, fish consumption patterns optimize all domains. Fish provides a rich source of protein and other nutrients, but because of contamination by methylmercury and other toxicants, more fish intake often leads to greater toxicant exposure. Furthermore, wild fish stocks are not adequate to meet the nutrient demands of the growing world population. Fish consumption choices also have a broad economic impact on the fishing industry. Most guidance does not account for ecological and economic impacts of different fish consumption choices.

Conclusion: More comprehensive advice that describes the multiple impacts of fish consumption can be developed. Despite the relative lack of information integrating the health, ecological and economic impacts of different fish choices, clear and simple guidance is necessary to effect desired changes. In addition, policy and fishery management interventions will be necessary to ensure long term availability of fish as an important source of human nutrition.

INTRODUCTION

The public receives fish consumption advice from a variety of perspectives, including toxicant, nutritional, ecological, and economic viewpoints. For example, United States (US) federal and state agencies, concerned about exposure to toxicants in fish such as methylmercury and polychlorinated biphenyls (PCBs), have issued fish consumption advisories recommending that at-risk groups limit consumption of fish (Environmental Protection Agency 2004). However, national organizations of physicians and nutritionists encourage fish consumption for the entire population as a way to increase dietary intake of the n-3 (omega-3) long-chain polyunsaturated fatty acids (LCPUFA) that may prevent cardiovascular disease and improve neurological development (Kris-Etherton et al. 2002; Kris-Etherton and Innis 2007; Lee et al. 2009). Also, environmental groups have recommended that consumers avoid certain fish based on concerns about species depletion or habitat destruction consequent to farming methods, site of origin, or type of harvesting (Monterey Bay Aquarium 2011). Whether, how much, and what type of fish a person eats is also influenced by economic and market considerations (e.g., cost and availability) as well as by taste, cultural tradition, recreational habits, and access to alternative foods.

Thus, the consumer who wants to know "which fish should I eat?" is likely to encounter contradictory advice, especially because much information considers a single perspective such as maximizing health, or minimizing ecologic harms. For example, farm-raised salmon is high in n-3 fatty acids and very low in mercury and so is promoted for its nutritional benefits, but environmental groups consider it a "Fish to Avoid" because salmon aquaculture may adversely impact ecosystem integrity and wild fish stocks (Monterey Bay Aquarium 2011), and relatively high levels of PCBs have led to concerns about cancer risk (Hites et al. 2004). Furthermore, it

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may be difficult for consumers to know whether any given fish is "good" to eat because they often do not have access to the facts they need to make fully informed choices, such as the size of the fish, or how or where it was caught.

Recent papers as well as detailed scientific reports have simultaneously addressed both the nutritional and toxicological aspects of fish consumption (FAO/WHO 2011; Mahaffey et al. 2011; Nesheim and Yaktine 2007; WHO/UNEP 2008). We have been unable to identify any review that addresses the full scope of relevant perspectives (toxicant, nutritional, ecological, and economic), and that has as a primary focus the complexity of balancing these four perspectives. Our goal is to extend the fish consumption discussion beyond the toxicant harm-nutritional benefit dichotomy that, although of clear public health importance, neglects a number of critical issues regarding fish consumption including the sustainability of fish as a food source. In doing so, we highlight areas of overlap and disagreement among the perspectives. This broader perspective may complicate fish consumption choices but has the potential to benefit all points of view. For example, the economic viability of the fishing industry depends on the maintenance of adequate fishing stocks. Similarly, nutritional recommendations to increase fish consumption will be feasible only if sufficient fish supplies are available to meet greater demand.

METHODS

A group of collaborating authors with complementary expertise in environmental toxicology, nutritional epidemiology, aquatic ecology, economics, and public health practice together defined the outline and scope of the paper. We then reviewed published literature as well as guidance disseminated by special interest and professional organizations. We review experience with previous advisories in the United States (US).

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We primarily focus on issues relevant to purchasers/consumers of store-bought rather than self-caught fish. Because of regional variability in fish species consumed and their respective profiles, we chose to concentrate on consumption advice and guidelines from the US, including the Federal government as well as state, tribal, and local governments. However, since modern fish production is largely a multi-national industry, we took a more global perspective on the economic impact of fish. Similarly, fish contaminant toxicities or nutrient benefits are applicable to all populations, although we highlight areas where changes in fish intake might have different impacts, e.g. among very low or very high consumers. Given the large scope of this paper, we did not attempt a comprehensive review of each topic. Rather, we highlight aspects of each perspective that are particularly likely to create confusion, such as the fact that both nutrients and toxicants in fish may influence the same body systems, or that have attracted the most public attention, such as the widely disseminated pocket cards focused on ecological sustainability (Monterey Bay Aquarium 2011).

RESULTS

Perspectives on fish intake

Toxicant exposure and health risks

Dietary intake of fish and seafood is the dominant source of human exposure to methylmercury, a toxicant that can have serious adverse effects on a number of body systems, especially the nervous and cardiovascular systems. Mercury is a widespread contaminant found throughout the environment (Goyer et al. 2000). Methylmercury, an organic form that is converted from inorganic mercury primarily by microorganisms in the aquatic environment, is

biomagnified in aquatic food webs, so that the highest concentrations occur in large and long-lived predatory fish and marine mammals at the top trophic levels (Goyer et al. 2000).

Community-wide methylmercury poisonings in Japan and Iraq highlighted the tragedy of high-dose methylmercury exposure as well as the particular sensitivity of the developing fetus (Bakir et al. 1973; Harada 1995). Offspring who were exposed to methylmercury in utero were born with serious neurological damage, even if their exposed mothers were virtually unaffected (Harada 1995; Igata 1993). Subsequent epidemiological studies among island populations have found more subtle adverse effects of lower levels of methylmercury exposure from habitual fish consumption during pregnancy, which have been extensively reviewed elsewhere (Clarkson and Magos 2006; Goyer et al. 2000).

Based on evidence for neurodevelopmental toxicity from these birth cohort studies, the US Environmental Protection Agency recommended a Reference Dose (RfD) of 0.1 µg methylmercury/kg body weight/day (Goyer et al. 2000). The RfD is defined as an estimate of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (Rice et al. 2003). The EPA also incorporated a 10-fold 'uncertainty factor' to allow for differences in susceptibility, distribution, and elimination (Rice et al. 2003). However, recent studies in US populations have found evidence for childhood neurodevelopmental effects of prenatal methylmercury exposure even below the RfD, as reviewed in a companion manuscript within this journal issue (Karagas et al. 2011).

In addition to methylmercury, many other pollutants can be found in fish, including PCBs and other persistent organic compounds, heavy metals, and "contaminants of emerging concern" such as pharmaceuticals and perfluorinated organic compounds. Many of these compounds have

established health effects, such as associations of PCB exposure with neurodevelopment and

cancer risk (Knerr and Schrenk 2006; Korrick and Sagiv 2008). However, in contrast to

methylmercury, fish is typically not the only route of exposure to these other contaminants.

Furthermore, because contaminant content often varies regionally, advisories to limit exposure to

other pollutants focus on the water source as well as the species of fish (Environmental

Protection Agency 2010).

Almost all fish are contaminated, to a greater or lesser degree, with environmental

pollutants. Therefore, the more fish consumed, on average, the more likely an individual is to be

exposed to methylmercury and/or other environmental toxicants. Consumers who eat fish

frequently or consume highly contaminated species may exceed exposure thresholds. Data from

the National Health and Nutrition Examination Survey suggest that about 5-10% of US women

of childbearing age have blood mercury levels consistent with intake exceeding the RfD

(Mahaffey et al. 2004). Although debate is ongoing, older women and men may also be at risk; a

somewhat less consistent literature has suggested that methylmercury exposure from fish

consumption in adulthood may be associated with an increased risk of acute coronary events,

cardiovascular mortality, and neurological symptoms (Karagas et al. 2011; Roman et al. 2011).

Nutrient benefits

Fish is high in protein, low in saturated fats, and contains a number of other healthful

nutrients such as vitamin D, selenium and iodine. In particular, fish is the primary dietary source

of n-3 LCPUFA, including docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA).

Since n-3 fatty acids are essential nutrients, and metabolism of the parent n-3 fatty acids to the

more biologically active long-chain versions is insufficient in some populations (Mahaffey et al.

2011), dietary intake from fish or from enriched foods and/or supplements is necessary to obtain adequate levels.

Much of the research examining the possible adverse health effects of suboptimal dietary n-3 LCPUFA has focused on either developmental outcomes associated with perinatal exposure, or cardiovascular risks among older adults. Other outcomes have been also associated with n-3 LCPUFAs (McManus et al. 2009), but in this paper we focus on these two endpoints because of their parallel susceptibility to both nutrient intake and methylmercury exposure.

DHA is a necessary structural component of the brain and eye, and the pre- and post-natal periods are likely a critical period for incorporation into these neural tissues (Innis 2000). These anatomic observations have been supported by findings from animal and some human studies (Anderson et al. 2005; Anderson et al. 1999; Brion et al. 2011; Innis 2000; Kramer et al. 2008). However, meta-analyses of randomized trials have not found evidence of persistent beneficial effects of LCPUFA supplementation of formula milk on the physical, visual, and neurodevelopmental outcomes of term or preterm infants (Simmer et al. 2008a; Simmer et al. 2008b). Limited evidence from randomized trials of fish oil supplements in pregnancy supports a cognitive benefit for offspring (Dunstan et al. 2008), although other trials found no beneficial effects (Helland et al. 2008; Makrides et al. 2010).

Cohort studies in the Faroe Islands, Seychelle Islands, and New Zealand focused on associations between prenatal mercury levels and child development (Goyer et al. 2000). More recent cohort studies that have examined the relationship of prenatal fish consumption with these outcomes have been generally consistent in showing either no adverse effects or improved neurodevelopment among children whose mothers ate more fish in pregnancy (Budtz-Jorgensen et al. 2007; Gale et al. 2008; Hibbeln et al. 2007; Lederman et al. 2008; Oken et al. 2008a; Oken

et al. 2008b; Oken et al. 2005). Thus, available data suggest that maternal intake of fish and perhaps, although less convincingly, n-3 LCPUFA supplements has modest beneficial effects on neurodevelopmental and cognitive outcomes of offspring. However, the conclusions that can be based upon these data are limited by a number of factors, including the potential for other neuroprotective nutrients in seafood (e.g., selenium and iodine) to be relevant, and the extent to which confounding (e.g. seafood intake as a marker of healthy lifestyle) explains observed results.

A larger and more consistent body of evidence supports a beneficial role of n-3 LCPUFA in preventing cardiovascular disease. Observational studies have found that higher habitual fish intake and higher blood levels of n-3 LCPUFA are associated with lower risks for congestive heart failure, myocardial infarction, sudden cardiac death, and stroke, as reviewed in (Mozaffarian and Rimm 2006).

While empiric evidence for the optimal amount of daily n-3 LCPUFA intake is lacking, consensus guidelines recommend intake of about 100-300 mg/day of DHA in pregnancy (Akabas and Deckelbaum 2006; Koletzko et al. 2007), and ranging from 250 to 1800 mg/day for primary prevention of cardiovascular disease (Kris-Etherton et al. 2002; Mozaffarian and Rimm 2006). Most people consume much less: e.g. mean DHA+EPA intake was 103 mg/day among US adults in the 1999-2002 National Health and Nutrition Examination (NHANES) Survey (Nesheim and Yaktine 2007). Nutritionists and these consensus guidelines have encouraged people to increase their intake of fish to achieve recommended n-3 LCPUFA intake. However, different fish types provide very different amounts of n-3 LCPUFA. For example, weekly consumption of 6 ounces of shrimp, pollock, or salmon provides an average of 35, 100, or 350 mg/day DHA, respectively (USDA Agricultural Research Service September 2009).

Integration of health risks and benefits of fish consumption

Confusion regarding which fish are healthful to eat has likely resulted from the fact that early studies assessing the health risk of toxicants found in fish (e.g., methylmercury, PCBs) did not incorporate the potential health benefits of co-occurring nutrients, and vice versa. A number of recent analyses have attempted to calculate the net health effects of different fish types using estimates of both toxicant and nutrient influences (Burger and Gochfeld 2005; Cohen et al. 2005; Ginsberg and Toal 2000; Mahaffey et al. 2011; Stern 2007; Stern and Korn 2011; Tsuchiya et al. 2008). Additionally, a few recent studies, including cohorts focused on child neurodevelopment (Lynch et al. 2010; Oken et al. 2008b) and adult cardiovascular disease (Mozaffarian et al. 2011), have estimated intake or measured levels of both methylmercury and n-3 LCPUFA.

These analyses will contribute to a clearer picture of the interactions of methylmercury and n-3 LCPUFAs on health outcomes, which will allow for guidance to the public that minimizes apparently confusing and conflicting messages about the health effects of fish consumption. However, ecological and economic perspectives, which are generally not considered in analyses weighing possible harms and benefits for health, may result in fish consumption advice or choices antagonistic to recommendations based solely upon human health.

Ecological concerns

While fish consumption may directly influence human health, human influences, including the harvesting of wild or farmed fish, can profoundly affect the health of the oceans. The rapid decline in large migratory fish species such as tuna, swordfish and shark has been well

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documented (Baum et al. 2005; Myers and Worm 2005; Pauly et al. 2002; Worm et al. 2009).

Abundance of wild fish stocks is expected to decline further in the future with the added stress

imposed by climate variability and habitat alteration, particularly for heavily overfished stocks

that are more sensitive to climate variability (Worm and Myers 2004).

Globally, the volume of fish production has increased 8-fold since 1950, from about 15 to

120 million tons/year (Figure 1) (FAO Fisheries and Aquaculture Department 2010). In part

because opportunities for additional harvests of wild-fish stocks are limited (i.e., additional

harvest could result in species collapse from over fishing), aquaculture has grown at a rate of 7-

9% per year in the past decade, making it the fastest growing food production industry in the

world (FAO 2008). Presently, farmed fish account for 23% of the fish consumed (FAO Fisheries

and Aquaculture Department 2010). Only one third of the total aquaculture production is used

directly for human consumption, with the remainder used for meal in other farming operations

(Rice and Garcia 2011).

In 2002, Pauly et al. estimated that global fishing efforts exceeded the maximum

sustainable yield by a factor of three to four (Pauly et al. 2002). Future needs will likely be even

more overwhelming. An estimated 50% increase in fish production is needed by 2050 to meet

the basic protein requirements of a growing human population and ensure global food-security

(Rice and Garcia 2011). If people try not only to meet their protein needs but also to ingest the

recommended amount of n-3 LCPUFA from fish, an even greater increase in fish consumption

would result.

Creative solutions are needed to resolve the predicament of increasing human demand for

fish protein and nutrients amidst growing concerns about the viability of wild fish stocks

globally. Aquaculture has received negative attention because of concerns about escape of

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exotic or genetically modified farmed fish species, infection of wild fish stocks with parasites that thrive in farming operations, trophic inefficiencies, enhancement of fish contaminant content, and farm-induced organic enrichment of coastal ecosystems that disrupts their natural functioning (Carniero 2011; Greenberg 2010; Hargrave et al. 1997; Hites et al. 2004; Vanhonacker et al. 2011). However, fish-farming operations can be improved with proper situation of cage-sites in estuaries with the appropriate physical conditions (flushing rates and oxygen status) and a focus on lower trophic level species such as catfish and tilapia to maximize productivity (Rice and Garcia 2011). Since markets, trade, and consumption patterns strongly influence the activities of the aquaculture community, consumer awareness and demand for sustainable farming practices and quality products can help shape this industry in the future (Khan 2010; Subasinghe et al. 2009).

Economic perspectives on fish consumption

Fisheries are a big business on a national and global scale. Indeed, this industry, and related industries such as restaurants and grocery purveyors, are key determinants of the amount, type, and form of fish that people consume by impacting the cost, availability, and desirability of different fish.

The US is one of the world's largest exporters of seafood products and the world's second largest seafood importer (Brooks et al. 2009). Over the past half-century, total global production of seafood products has continued to increase, and reached 142 million tons in 2008, with the total value of global aquaculture production estimated at $98.4 billion in 2008 (Statistics and Information Service of the Fisheries and Aquaculture Department 2010). It is obvious from these figures that fish consumption choices have a broad economic impact on the fishing industry and,

therefore, it is not surprising that this industry seeks to influence the public debate surrounding

the harms and benefits of fish intake.

As one example, canned tuna is a longtime staple in the American diet and the second

most commonly consumed type of seafood in the US, but also is the top dietary contributor to

methylmercury intake (Groth 2010). There has been an ongoing debate regarding whether

canned albacore tuna should be listed as a high-mercury fish. The US FDA did not include tuna

among the high-mercury fish named in its 2001 mercury advisory. Subsequently, a non-profit

organization filed a Freedom of Information Act request to access the documents related to the

advisory (Nestle 2006). These documents revealed that the FDA had planned to list albacore tuna

among the high-mercury fish, but dropped the warning after meeting with representatives of the

fishing industry. This example illustrates how the interests guiding a fish advisory are not

necessarily limited to public health concerns. In fact, FDA's regulatory mission is to balance

consumers' health risks against industry interests such as maintaining demand for popular fish.

These issues are not unique to the US. Although the bluefin tuna used in sushi is high in

mercury and ecologically fragile, a recently proposed international ban on bluefin fishing failed

after it was vetoed by a number of countries, including Libya, Cyprus, Malta, Spain, France and

Italy, all of which border the Mediterranean and have a stake in the trade of this highly

profitable fish (Abend 2010).

As another example, Chilean Sea Bass has emerged as one of the most popular and

profitable fish in US restaurants (Cascorbi 2006). This fish was formerly inaccessible because of

its habitat deep in the seas surrounding the Antarctic shelf, as well as being somewhat

unappealing when labeled with its official name, the Patagonian toothfish.   The rapid expansion

of the toothfish fishery in the early 1990s has been linked to the introduction of new fishing

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techniques as well as aggressive marketing especially by restaurants, where over 40% of sales

occur (Cascorbi 2006). US imports of toothfish, which account for almost half of the worldwide

catch, doubled in quantity and tripled in value from 1998 to 2003, from $10 million to over $30

million (Cascorbi 2006). This expansion occurred despite the fact that toothfish are high in

mercury (Environmental Defense Fund 2008), vulnerable to overfishing, and caught with

methods that result in substantial damage to the seafloor and bycatch of marine birds (Cascorbi

2006).

Fish consumption advisories and advice

US Federal governmental fish consumption advisories and their effects

Following a 2001 US National Research Council review of the health effects of methylmercury,

federal and state agencies established fish consumption guidelines based on species-specific

mercury levels (Goyer et al. 2000). In January 2001, the US FDA disseminated a consumer

advisory on mercury in fish directed at groups considered to be at highest risk: women who

might become pregnant, women who are pregnant, nursing mothers, and young children. The

advisory recommended avoiding the four most contaminated fish species (shark, swordfish, king

mackerel, and tilefish) and limiting overall consumption of fish and shellfish to 12 ounces per

week or less (Food and Drug Administration 2001). In 2004, the FDA jointly with the US

Environmental Protection Agency published a revised advisory, which emphasized the

nutritional benefits of fish, added a suggested restriction in consumption of canned white

(albacore) tuna, and included examples of specific species that are low in methylmercury

(Environmental Protection Agency 2004). These changes were welcome as many consumers

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may have been more aware of the content and effect of harmful substances than of nutrients in

fish (Bloomingdale et al. 2010; Verbeke et al. 2005).

Several investigators have taken advantage of existing datasets to estimate effects of the US

federal government mercury advisories on fish consumption. In a cohort study of well-educated

pregnant women in Massachusetts that straddled dissemination of the 2001 US FDA advisory,

women reported consuming less dark meat fish, canned tuna, and white meat fish after

publication of the advisory (Oken et al. 2003). Using a panel of nearly 15,000 US households,

Shimshack and Ward studied fish purchases from 2000 through 2002 (Shimshack and Ward

2010). They found that households with pregnant women or young children reduced both their

mercury and n-3 LCPUFA intakes following the 2001 advisory. The n-3 LCPUFA decline

occurred everywhere along the distribution of intakes, including among those with the lowest

intake. Results were driven by a broad-based decline in consumption of all fish. On average,

consumers, even those with a college education, did not differentially avoid high mercury fish

nor did they substitute away from high mercury species into low mercury, high omega-3 species.

However, less educated households showed no advisory-induced reduction in mercury.

In contrast, NHANES data indicate that blood mercury decreased from 1999 through

2004, without a concomitant decrease in fish consumption (Mahaffey et al. 2009). Though the

cause for this decrease remains unclear, the study authors speculated that the findings suggest a

more discerning series of choices in type of fish eaten rather than an overall reduction in fish

consumption (Mahaffey et al. 2009)

Most recently, an analysis using pooled nationally representative 2001 and 2006 Food

Safety Surveys indicated an increase in US consumers' awareness of mercury as a problem in

fish (69% in 2001 to 80% in 2006), especially among parents of young children (Lando and

Zhang 2011). However, women of childbearing age were less aware and knowledgeable about

this information than other women.

Local government (United States) fish consumption advisories and their effects

Individual US states and tribes collect data and issue advisories on mercury in fish caught

from local bodies of water. Some states and localities provide advice for commercial fish

consumption as well (Environmental Protection Agency 2010). Their recommendations may

include information on species that are of particular relevance to the local population but not

necessarily included in nation-wide US advisories. Advisories differ from state to state based on

a number of variables. For example, most target children, pregnant women, and women of

childbearing age, and a few states also provide advice for the general population (Scherer et al.

2008). While most are based on the Environmental Protection Agency's RfD for methylmercury

established in 2000 (see Toxicant Exposure and Health Risks), a few are based on the FDA

action level established in 1979, which is approximately 4 times higher (Tollefson and Cordle

1986). A few states (e.g. Alaska) have derived their own health assessments and used these in

formulating advice.

Approximately 80% of US fishing advisories are, at least in part, related to mercury

contamination. The most recent data (Environmental Protection Agency 2010) indicate that

across all 50 states, as of 2010, there were in excess of 4500 fish consumption advisories, i.e.

advice to limit or avoid consuming fish from a given water body because of contaminant risk.

These advisories cover 4 of every 10 river miles, almost 79% of contiguous coastal waters, and

40% of all freshwater surface area in the US, not including the Great Lakes, 100% of which are

under advisories. In contrast, in 2010 only 2% of the nation's river miles and 9% of the nation's

lake acres had safe eating guidelines in effect, i.e. an indication that fish from the body of water

was safe for consumption (Environmental Protection Agency 2010).

Awareness of regional fish consumption advisories in the US is generally low, ranging

from 8-32% (Anderson et al. 2004; Gliori et al. 2006; Knobeloch et al. 2005). Furthermore,

results from several surveys suggest that awareness of regional fish advisories is not more

common among higher risk subgroups, such as pregnant women, nor does awareness necessarily

predict lower mercury levels or less frequent consumption of higher mercury fish (Burger and

Gochfeld 2009; Karouna-Renier et al. 2008; Knobeloch et al. 2005; Silver et al. 2007).

Challenges to communicating effectively with high risk groups have included language barriers,

educational and literacy status, income level, cultural differences, and difficulty reaching

racial/ethnic minority groups (Imm et al. 2007; Kuntz et al. 2009; Silver et al. 2007). In addition

to these challenges, many consumers simply do not want any more information. For example,

although most surveyed fishers in the New York Bight did not have accurate knowledge on

harms and benefits of fish consumption, well over a third of them did not feel they needed more

information (Burger and Gochfeld 2009).

Other resources

In addition to advice issued by the US federal government and states, not-for-profit and

other non-governmental organizations also provide information on mercury in fish directly to

consumers. In **Table 1**, we summarize a number of fish consumption recommendations for US

populations, by target audience and messages that are conveyed. We also provide in **Table 2**

several websites that link to a number of sources of information for the public regarding fish

consumption. For example, the Natural Resources Defense Council and the Turtle Island Restoration Network provide online mercury calculators that allow consumers to calculate whether their mercury intake exceeds the Environmental Protection Agency RfD, based on their body weight and combinations and amounts of fish species consumed. Other groups, such as Physicians for Social Responsibility and Environmental Working Group, provide web-based lists of fish species with higher and lower mercury concentrations, along with consumption guidelines.

Other guides incorporate information advocating ocean conservation and warning of the environmental hazards associated with certain types of seafood consumption. Popular guides like the Monterey Bay Aquarium Seafood Watch recommendations combine information about the sustainability of fisheries and catch methods with information on contaminant burdens and nutrients in different species (Monterey Bay Aquarium 2011).

Challenges for fish consumption choice

Considerable uncertainty exists regarding the actual toxicological, nutritional, ecological and/or environmental harms and benefits of consuming any given fish. Among the hundreds of species of fish available for consumption, characteristics are highly variable. Even within species, nutritional, contaminant, and ecologic attributes can vary widely depending on the size, variant or where the fish is harvested or farmed. For example, shrimp can be rated as an ecologic "best choice," "good alternative," or "avoid" depending on its origin (Monterey Bay Aquarium 2011). Similarly, tilefish caught in the Gulf of Mexico is very high in methylmercury, whereas tilefish from the Atlantic Ocean is low in methylmercury (Sunderland 2007).

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Furthermore, there is variation in susceptibility to the benefits or harms of fish

consumption among individuals by age and other characteristics. Also, the net health effect of a

change in intake for each individual (or population) depends on baseline intake – if intake is low,

the net harm of a further reduction is likely to be greater than if intake is high (Hammitt 2004).

Incomplete information may result in expert advice that is incorrect or misleading. For

example, most US commercial fish consumption advisories to limit methylmercury exposure are

based on mean or median mercury concentrations measured in fish samples collected by the

FDA. However, these reference data may be based on a small number of fish, are often not up-

to-date, and mercury concentrations may vary widely even within the same species; for example,

some samples of high-mercury species such as swordfish may have non-detectable levels of

mercury, whereas lower risk species such as halibut may have levels above 1 ppm (Food and

Drug Administration 2011). A recent study of a number of different eco-labels for farmed fish

found that there is no evidence that these certified products are actually environmentally

preferable, in part because many of the standards applied in the different labels ignored major

environmental impacts (Volpe et al. 2011).

Once advice is issued, consumers may not respond in ways that result in better outcomes.

Economic wisdom holds that improved information enhances welfare because consumers refine

and adapt their consumption in response to new information. However, it is not clear whether

welfare actually increased following the FDA's seafood consumption advisories

(Blanchemanche et al. 2010; Shimshack and Ward 2010). Firstly, rather than substituting higher

mercury for lower mercury fish so as to reduce exposure while still obtaining benefits provided

from fish, many consumers simply reduced their overall fish intake, which also resulted in a

decreased intake of nutrients obtained from fish. Secondly, although the FDA's advice targeted

pregnant and breastfeeding women, even non-targeted adults reduced their fish consumption (Shimshack and Ward 2010; Shimshack et al. 2007). These consumers may have incurred a welfare loss because their reduction in fish intake led to a reduced intake of n-3 LCPUFA and therefore increased cardiovascular risk (Mozaffarian and Rimm 2006), possibly outweighing the gains from decreased fish intake (e.g., from decreased methylmercury exposure).

Why would people make choices that actually worsen, rather than improve, their health? Balancing risks is notoriously difficult. When individuals make judgments under uncertainty they tend to use a limited number of cognitive processes. These processes are efficient, but can sometimes lead to errors or biases (Kahneman 2003). People often overestimate some risks (e.g. the risk of harm from methylmercury exposure) while they underestimate others (e.g. the risk of harm from suboptimal nutrition) (Slovic et al. 2000). They tend to focus on worst case scenarios (Viscusi 1997). Many consumers are better aware of the content and effects of harmful substances than of nutrients in fish (Verbeke et al. 2005).

Given these uncertainties, consumers are likely to employ a bounded rationality approach to make consumption choices (McFadden 2001). That is, they recognize that the gathering and processing of information comes at a cost in terms of time and cognitive burden. Instead of striving for more information to update their beliefs about the relevant health risks, they eventually adopt simpler heuristics to make consumption choices (Gigerenzer and Goldstein 1996). The fact that consumers not targeted by FDA's 2001 mercury advisory reduced their fish consumption, even of fish lower in mercury, simply to rule out a food risk is consistent with the bounded rationality assumption.

Messages that are simple, or targeted at well known fish species, are more likely to be effective (Verger et al. 2007). In focus groups, participants preferred simple messages, however,

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they did not always respond appropriately (Nesheim and Yaktine 2007). For example almost all participants reported that they would avoid species designated 'Do not eat' regardless of whether or not they were in the targeted audience. Also, responses vary depending on whether 'risks' or 'benefits' are listed first (Knuth et al. 2003; Verbeke et al. 2008).

DISCUSSION

The possible combinations of matters related to fish consumption – including toxicological, nutritional, ecological, and economic – are many, but few, if any, fish consumption patterns optimize all four areas. We summarize these viewpoints, and the challenges they present to comprehensive advice, in Table 3.

Individual and market economics can influence seafood consumption decisions in ways that may be largely independent of specific toxicant hazards, nutrient benefits, or ecosystem effects. In addition, availability, taste preferences, cultural traditions, and cost impact consumers' fish intake (Verbeke and Vackier 2005). Ecological and economic impacts of fish choice are perhaps the least 'visible' to consumers and therefore the most difficult to incorporate into decision-making (Verbeke et al. 2007). Furthermore, when consumers choose not to eat fish, regardless of the reason, the foods eaten instead (e.g. red meat) also may have variable health, ecological, and economic impacts.

The future of fish advisories is a matter of ongoing debate and presents a number of alternative options. Agencies may recommend that populations of highest concern refrain from eating fish with high concentrations of methylmercury, similar to the 2001 FDA advisory and many state advisories. But past experience has shown that this approach excludes many "low-risk" populations that may in fact suffer harms from methylmercury toxicity, and also is likely to

reduce fish intake indiscriminately, worsening nutrition. An alternative approach is to suggest

that people should eat fish, without parsing out the contaminant or ecological harms of different

fish types. For example, the 2010 Dietary Guidelines for Americans encourage everyone,

including pregnant and breastfeeding women, to eat seafood at least twice a week. However, this

advice might expose a subset of the population to risk of substantial harm from increased

methylmercury intake, and is likely unsustainable given the projected inadequacy of fish stocks

to support population growth, even at current consumption levels.

More comprehensive advice that describes both the potential hazards and benefits of fish

consumption can be developed. However, such an approach is constrained by a relative lack of

information integrating not only health risks and benefits, but also ecological and economic

impacts. Furthermore, experience to date suggests that effective communication of multiple

competing risks is, at best difficult and, at worst may encumber consumers with irreconcilable

risk-risk trade-offs. Additionally, although consumer demand for healthful, sustainably

harvested or farmed fish can help shape fishing industry practices, it is unlikely that consumers

alone can substantially influence these practices. Policy and fishery management interventions

will be necessary to ensure long term availability of fish as an important source of human

nutrition.

CONCLUSION

On an individual level, decisions regarding which fish to eat, and whether to change fish

consumption habits, may vary widely across consumers. We have not yet met the challenge of

providing accessible information that includes nutritional, contaminant, ecological and economic

trade-offs associated with fish consumption choices including guidance to a wide range of

consumers related to baseline intake, life stage, and reliance on fish intake because of subsistence needs or cultural traditions.

Based on evidence presented in this work, fish consumption advice addressed to the general public should be clear and simple to have an impact. We suggest developing a list of fish to eat, and those to minimize or avoid, that considers these multiple perspectives and not solely the health effects of contaminants and nutrients. This list should include links to more detailed resources that can be used by those wanting more information about individual fish types, or wishing to optimize one or more parameters. The simple message needs to be provided on a national level but with the cooperation of local and regional partners (e.g. states and non-governmental organizations). Thus, adjustments could be made on a regional level if necessary so long as the framework can be followed. As further information becomes available, the list of beneficial choices as well as choices to avoid could be improved upon. Though simplicity of messaging is paramount, the underlying paradigm addressing the challenges presented in Table 3 would not be. Yet with transparency, an approach on a national level could be developed that provides clear choices protecting public and global health.

Meanwhile, we should continue to urge international organizations, governments, and their agencies to promote remediation and, where possible, elimination of sources of fish contamination, and establish policies that promote environmentally responsible and economically viable fishing practices so fish can remain a part of a healthy human diet for future generations.

REFERENCES

Abend L. 2010. Why a Proposed Ban on Bluefin Tuna Fishing Failed. Time Available at: http://wwwtimecom/time/health/article/0,8599,1973374,00html [Last accessed November 14, 2011] March 18, 2010.

Akabas SR, Deckelbaum RJ. 2006. Summary of a workshop on n-3 fatty acids: current status of recommendations and future directions. Am J Clin Nutr 83(6 Suppl):1536S-1538S.

Anderson GJ, Neuringer M, Lin DS, Connor WE. 2005. Can prenatal N-3 fatty acid deficiency be completely reversed after birth? Effects on retinal and brain biochemistry and visual function in rhesus monkeys. Pediatr Res 58(5):865-872.

Anderson HA, Hanrahan LP, Smith A, Draheim L, Kanarek M, Olsen J. 2004. The role of sport-fish consumption advisories in mercury risk communication: a 1998-1999 12-state survey of women age 18-45. Environ Res 95(3):315-324.

Anderson JW, Johnstone BM, Remley DT. 1999. Breast-feeding and cognitive development: a meta-analysis. Am J Clin Nutr 70(4):525-535.

Bakir F, Damluji SF, Amin-Zaki L, Murtadha M, Khalidi A, al-Rawi NY, et al. 1973. Methylmercury poisoning in Iraq. Science 181(96):230-241.

Baum JK, Kehler D, Meyers RA. 2005. Robust estimates of decline for pelagic shark populations in the Northwest Atlantic and Gulf of Mexico. Fisheries 30(27-29).

Blanchemanche S, Marette S, Foosen J, Verger P. 2010. "Do not eat fish more than twice a week". Rational choice regulation and risk communication: Uncertainty transfer from risk assessment to public. Health Risk Society 12(3):271-292.

Bloomingdale A, Guthrie LB, Price S, Wright RO, Platek D, Haines J, et al. 2010. A qualitative study of fish consumption during pregnancy. Am J Clin Nutr 92(5):1234-1240.

Brion MJ, Lawlor DA, Matijasevich A, Horta B, Anselmi L, Araujo CL, et al. 2011. What are the causal effects of breastfeeding on IQ, obesity and blood pressure? Evidence from comparing high-income with middle-income cohorts. Int J Epidemiol 40(3):670-680.

Brooks N, Regmi A, Jerardo A. 2009. U.S. Food Import Patterns, 1998-2007. Available at: http://www.ers.usda.gov/publications/fau/2009/08aug/fau125/fau125.pdf. [Last Accessed November 14, 2011]:United States Department of Agriculture.

Budtz-Jorgensen E, Grandjean P, Weihe P. 2007. Separation of risks and benefits of seafood intake. Environ Health Perspect 115(3):323-327.

Burger J, Gochfeld M. 2005. Heavy metals in commercial fish in New Jersey. Environ Res 99(3):403-412.

Burger J, Gochfeld M. 2009. Perceptions of the risks and benefits of fish consumption: individual choices to reduce risk and increase health benefits. Environ Res 109(3):343-349.

Carniero G. 2011. Marine management for human development: A review of two decades of scholarly evidence. Marine Policy 35:351-362.

Cascorbi A. 2006. Chilean Sea Bass Final Report. Available at: http://www.montereybayaquarium.org/cr/cr_seafoodwatch/content/media/MBA_SeafoodWatch_ChileanSeabassReport.pdf. [Last Accessed December 15, 2011]: Monterey Bay Aquarium.

Clarkson TW, Magos L. 2006. The toxicology of mercury and its chemical compounds. Crit Rev Toxicol 36(8):609-662.

Cohen JT, Bellinger DC, Connor WE, Kris-Etherton PM, Lawrence RS, Savitz DA, et al. 2005. A quantitative risk-benefit analysis of changes in population fish consumption. Am J Prev Med 29(4):325-334.

Dunstan JA, Simmer K, Dixon G, Prescott SL. 2008. Cognitive assessment of children at age 2(1/2) years after maternal fish oil supplementation in pregnancy: a randomised controlled trial. Arch Dis Child Fetal Neonatal Ed 93(1):F45-50.

Environmental Defense Fund. 2008. Seafood Selector. Available at: http://apps.edf.org/page.cfm?tagID=1521. [Last Accessed November 14, 2011].

Environmental Protection Agency. 2004. FDA/EPA Consumer Advisory: What You Need to Know About Mercury in Fish and Shellfish. Available at: www.epa.gov/ost/fishadvice/factsheet.html. [Last accessed November 14, 2011]: Environmental Protection Agency.

Environmental Protection Agency. 2010. The National Listing of Fish Advisories. Available at: http://water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/index.cfm. [Last accessed November 14, 2011].

FAO. 2008. Report of the FAO Expert Workshop on Climate Change Implications for Fisheries and Aquaculture. In: FAO. Rome, 32.

FAO Fisheries and Aquaculture Department. 2010. The State of World Fisheries and Aquaculture. Rome:Food and Agriculture Organization (FAO) of the United Nations.

FAO/WHO. 2011. Joint FAO/WHO Expert Consultation on the Risks and Benefits of Fish Consumption, 25–29 January 2010, Rome, Italy. FAO Fisheries and Aquaculture Report No. 978. Available at: http://www.fao.org/docrep/014/ba0136e/ba0136e00.pdf. [Last Accessed November 23, 2011]. Geneva, Switzerland:World Health Organization.

Food and Drug Administration. 2001. Consumer advisory: An important message for pregnant women and women of childbearing age who may become pregnant about the risks of mercury in fish. Available at: http://vmcfsanfdagov/~dms/admehghtml [Last accessed July 17, 2007].

Food and Drug Administration. 2011. Mercury Levels in Commercial Fish and Shellfish. http://wwwfdagov/Food/FoodSafety/Product-SpecificInformation/Seafood/FoodbornePathogensContaminants/Methylmercury/ucm115644htm [Last accessed November 14, 2011] Page Last Updated: 05/26/2011

Gale CR, Robinson SM, Godfrey KM, Law CM, Schlotz W, O'Callaghan FJ. 2008. Oily fish intake during pregnancy--association with lower hyperactivity but not with higher full-scale IQ in offspring. J Child Psychol Psychiatry 49(10):1061-1068.

Gigerenzer G, Goldstein DG. 1996. Reasoning the fast and frugal way: models of bounded rationality. Psychol Rev 103(4):650-669.

Ginsberg GL, Toal BF. 2000. Development of a single-meal fish consumption advisory for methyl mercury. Risk Anal 20(1):41-47.

Gliori G, Imm P, Anderson HA, Knobeloch L. 2006. Fish consumption and advisory awareness among expectant women. Wmj 105(2):41-44.

Goyer R, Aposhian V, Arab L, Bellinger D, Burbacher T, Burke T, et al. 2000. Toxicological effects of methylmercury. Washington, D.C.:National Academy Press.

Greenberg P. 2010. Four fish: The future of the last wild food. New York, NY:Penguin Books.

Groth E, 3rd. 2010. Ranking the contributions of commercial fish and shellfish varieties to mercury exposure in the United States: implications for risk communication. Environ Res 110(3):226-236.

Hammitt JK. 2004. Economic implications of hormesis. Hum Exp Toxicol 23(6):267-278; discussion 279-280, 303-265.

Harada M. 1995. Minamata disease: methylmercury poisoning in Japan caused by environmental pollution. Crit Rev Toxicol 25(1):1-24.

Hargrave BT, Phillips GA, Doucette LI, White MJ, Wildish DJ, Cranston RE. 1997. Assessing benthic impacts of organic enrichment from marine aquaculture. Water, Air and Soil Pollution 99(1-4):641-650.

Helland IB, Smith L, Blomen B, Saarem K, Saugstad OD, Drevon CA. 2008. Effect of supplementing pregnant and lactating mothers with n-3 very-long-chain fatty acids on children's IQ and body mass index at 7 years of age. Pediatrics 122(2):e472-479.

Hibbeln JR, Davis JM, Steer C, Emmett P, Rogers I, Williams C, et al. 2007. Maternal seafood consumption in pregnancy and neurodevelopmental outcomes in childhood (ALSPAC study): an observational cohort study. Lancet 369(9561):578-585.

Hites RA, Foran JA, Schwager SJ, Knuth BA, Hamilton MC, Carpenter DO. 2004. Global assessment of polybrominated diphenyl ethers in farmed and wild salmon. Environ Sci Technol 38(19):4945-4949.

Igata A. 1993. Epidemiological and clinical features of Minamata disease. Environ Res 63(1):157-169.

Imm P, Knobeloch L, Anderson HA. 2007. Maternal recall of children's consumption of commercial and sport-caught fish: findings from a multi-state study. Environ Res 103(2):198-204.

Innis SM. 2000. Essential fatty acids in infant nutrition: lessons and limitations from animal studies in relation to studies on infant fatty acid requirements. Am J Clin Nutr 71(1 Suppl):238S-244S.

Kahneman D. 2003. Maps of Bounded Rationality: Psychology for behavioral economics. American Economic Review 93:1449-1475.

Karagas MR, Choi AL, Oken E, Horvat M, Schoeny R., Kamai E, et al. 2011. Evidence on the human health effects of low level methylmercury exposure. Environ Health Perspect Submitted.

Karouna-Renier NK, Ranga Rao K, Lanza JJ, Rivers SD, Wilson PA, Hodges DK, et al. 2008. Mercury levels and fish consumption practices in women of child-bearing age in the Florida Panhandle. Environ Res 108(3):320-326.

Khan AS. 2010. The rebuilding imperative in fisheries: Clumsy solutions for a wicked problem? Progress in Oceanography 87:641-650.

Knerr S, Schrenk D. 2006. Carcinogenicity of "non-dioxinlike" polychlorinated biphenyls. Crit Rev Toxicol 36(9):663-694.

Knobeloch L, Anderson HA, Imm P, Peters D, Smith A. 2005. Fish consumption, advisory awareness, and hair mercury levels among women of childbearing age. Environ Res 97(2):220-227.

Knuth BA, N AC, Sheeshka J, Patterson J. 2003. Weighing health benefit and health risk information when consuming sport-caught fish. Risk Anal 23(6):1185-1197.

Koletzko B, Cetin I, Thomas Brenna J. 2007. Dietary fat intakes for pregnant and lactating women. Br J Nutr 98(5):873-877.

Korrick SA, Sagiv SK. 2008. Polychlorinated biphenyls, organochlorine pesticides and neurodevelopment. Curr Opin Pediatr 20(2):198-204.

Kramer MS, Aboud F, Mironova E, Vanilovich I, Platt RW, Matush L, et al. 2008. Breastfeeding and child cognitive development: new evidence from a large randomized trial. Arch Gen Psychiatry 65(5):578-584.

Kris-Etherton PM, Harris WS, Appel LJ. 2002. Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Circulation 106:2747-2757.

Kris-Etherton PM, Innis S. 2007. Position of the American Dietetic Association and Dietitians of Canada: dietary fatty acids. J Am Diet Assoc 107(9):1599-1611.

Kuntz SW, Hill WG, Linkenbach JW, Lande G, Larsson L. 2009. Methylmercury risk and awareness among American Indian women of childbearing age living on an inland northwest reservation. Environ Res 109(6):753-759.

Lando AM, Zhang Y. 2011. Awareness and knowledge of methylmercury in fish in the United States. Environ Res 111(3):442-450.

Lederman SA, Jones RL, Caldwell KL, Rauh V, Sheets SE, Tang D, et al. 2008. Relation between cord blood mercury levels and early child development in a World Trade Center cohort. Environ Health Perspect 116(8):1085-1091.

Lee JH, O'Keefe JH, Lavie CJ, Harris WS. 2009. Omega-3 fatty acids: cardiovascular benefits, sources and sustainability. Nat Rev Cardiol 6(12):753-758.

Lynch ML, Huang LS, Cox C, Strain JJ, Myers GJ, Bonham MP, et al. 2010. Varying coefficient function models to explore interactions between maternal nutritional status and prenatal

methylmercury toxicity in the Seychelles Child Development Nutrition Study. Environ Res 111(1):75-80.

Mahaffey KR, Clickner RP, Bodurow CC. 2004. Blood organic mercury and dietary mercury intake: National Health and Nutrition Examination Survey, 1999 and 2000. Environ Health Perspect 112(5):562-570.

Mahaffey KR, Clickner RP, Jeffries RA. 2009. Adult women's blood mercury concentrations vary regionally in the United States: association with patterns of fish consumption (NHANES 1999-2004). Environ Health Perspect 117(1):47-53.

Mahaffey KR, Sunderland EM, Chan HM, Choi AL, Grandjean P, Marien K, et al. 2011. Balancing the benefits of n-3 polyunsaturated fatty acids and the risks of methylmercury exposure from fish consumption. Nutr Rev 69(9):493-508.

Makrides M, Gibson RA, McPhee AJ, Yelland L, Quinlivan J, Ryan P. 2010. Effect of DHA supplementation during pregnancy on maternal depression and neurodevelopment of young children: a randomized controlled trial. Jama 304(15):1675-1683.

McFadden D. 2001. Economic Choices. American Economic Review 91:351-378.

McManus A, Howieson J, Nicholson J. 2009. Review of literature and resources relating to the health benefit of regular consumption of seafood as part of a health diet. Report 090101. ISBN 978-1-74067-544-4. Perth:Centre of Excellence Science, Seafood & Health, Curtin Health Innovation Research Institute, Curtin University of Technology.

Monterey Bay Aquarium. 2011. Seafood Watch. Available at: http://wwwmontereybayaquariumorg/cr/seafoodwatchaspx [Last accessed November 14, 2011].

Mozaffarian D, Rimm EB. 2006. Fish intake, contaminants, and human health: evaluating the risks and the benefits. JAMA 296(15):1885-1899.

Mozaffarian D, Shi P, Morris JS, Spiegelman D, Grandjean P, Siscovick DS, et al. 2011. Mercury exposure and risk of cardiovascular disease in two U.S. cohorts. N Engl J Med 364(12):1116-1125.

Myers RA, Worm B. 2005. Extinction, survival or recovery of large predatory fishes. Philos Trans R Soc Lond B Biol Sci 360(1453):13-20.

Nesheim M, Yaktine A, eds. 2007. Seafood Choices: Balancing benefits and risks. Washington, DC:The National Academies Press.

Nestle M. 2006. What to Eat. New York, NY:North Point Press.

Oken E, Kleinman KP, Berland WE, Simon SR, Rich-Edwards JW, Gillman MW. 2003. Decline in fish consumption among pregnant women after a national mercury advisory. Obstet Gynecol 102(2):346-351. PMCID: PMC1989666.

Oken E, Osterdal ML, Gillman MW, Knudsen VK, Halldorsson TI, Strom M, et al. 2008a. Associations of maternal fish intake during pregnancy and breastfeeding duration with attainment of developmental milestones in early childhood: a study from the Danish National Birth Cohort. Am J Clin Nutr 88(3):789-796.

Oken E, Radesky JS, Wright RO, Bellinger DC, Amarasiriwardena CJ, Kleinman KP, et al. 2008b. Maternal fish intake during pregnancy, blood mercury levels, and child cognition at age 3 years in a US cohort. Am J Epidemiol 167(10):1171-1181.

Oken E, Wright RO, Kleinman KP, Bellinger D, Amarasiriwardena CJ, Hu H, et al. 2005. Maternal fish consumption, hair mercury, and infant cognition in a U.S. Cohort. Environ Health Perspect 113(10):1376-1380.

Pauly D, Christensen V, Guenette S, Pitcher TJ, Simaila UR, Walters CJ, et al. 2002. Toward sustainability in world fisheries. Nature 418:689-695.

Rice DC, Schoeny R, Mahaffey K. 2003. Methods and rationale for derivation of a reference dose for methylmercury by the U.S. EPA. Risk Anal 23(1):107-115.

Rice JC, Garcia SM. 2011. Fisheries, food security, climate-change, and biodiversity: characteristics of the sector and perspectives on emerging issues. ICES Journal of Marine Science 68(6):1343-1353.

Roman HA, Walsh TL, Coull BA, Dewailly E, Guallar E, Hattis D, et al. 2011. Evaluation of the cardiovascular effects of methylmercury exposures: current evidence supports development of a dose-response function for regulatory benefits analysis. Environ Health Perspect 119(5):607-614.

Shimshack JP, Ward MB. 2010. Mercury advisories and household health trade-offs. J Health Econ 29(5):674-685.

Shimshack JP, Ward MB, Beatty TKM. 2007. Mercury Advisories: Information, education, and fish consumption. . Journal of Environmental Economics and Management 53:158-179.

Silver E, Kaslow J, Lee D, Lee S, Lynn Tan M, Weis E, et al. 2007. Fish consumption and advisory awareness among low-income women in California's Sacramento-San Joaquin Delta. Environ Res 104(3):410-419.

Simmer K, Patole SK, Rao SC. 2008a. Longchain polyunsaturated fatty acid supplementation in infants born at term. Cochrane Database Syst Rev(1):CD000376.

Simmer K, Schulzke SM, Patole S. 2008b. Longchain polyunsaturated fatty acid supplementation in preterm infants. Cochrane Database Syst Rev(1):CD000375.

Slovic P, Fischoff B, Lichtenstein S. 2000. Facts and Fears: Understanding Perceived Risk. In: The Perception of Risk London:Earthscan, 137-154.

Statistics and Information Service of the Fisheries and Aquaculture Department. 2010. Fishery and Aquaculture Statistics 2008. Rome:Food and Agriculture Organization of the United Nations.

Stern AH. 2007. Public health guidance on cardiovascular benefits and risks related to fish consumption. Environ Health 6:31.

Stern AH, Korn LR. 2011. An approach for quantitatively balancing methylmercury risk and omega-3 benefit in fish consumption advisories. Environ Health Perspect 119(8):1043-1046.

Subasinghe S, Soto D, Jia J. 2009. Global aquaculture and its role in sustainable development. Reviews in Aquaculture 1(1):2-9.

Sunderland EM. 2007. Mercury exposure from domestic and imported estuarine and marine fish in the U.S. seafood market. Environ Health Perspect 115(2):235-242.

Tollefson L, Cordle F. 1986. Methylmercury in fish: a review of residue levels, fish consumption and regulatory action in the United States. Environ Health Perspect 68:203-208.

Tsuchiya A, Hardy J, Burbacher TM, Faustman EM, Marien K. 2008. Fish intake guidelines: incorporating n-3 fatty acid intake and contaminant exposure in the Korean and Japanese communities. Am J Clin Nutr 87(6):1867-1875.

USDA Agricultural Research Service. September 2009. USDA National Nutrient Database for Standard Reference, Release 22. Available at: http://www.ars.usda.gov/nutrientdata. [Last accessed November 14, 2011]. Beltsville, MD:US Department of Agriculture.

Vanhonacker F, Altintzoglou T, Luten J, Verbeke W. 2011. Does fish origin matter to European consumers? Insights from a consumer survey in Belgium, Norway and Spain. British Food Journal 113(4):535-549.

Verbeke W, Sioen I, Pieniak Z, Van Camp J, De Henauw S. 2005. Consumer perception versus scientific evidence about health benefits and safety risks from fish consumption. Public Health Nutr 8(4):422-429.

Verbeke W, Vackier I. 2005. Individual determinants of fish consumption: application of the theory of planned behaviour. Appetite 44(1):67-82.

Verbeke W, Vanhonacker F, Frewer LJ, Sioen I, De Henauw S, Van Camp J. 2008. Communicating risks and benefits from fish consumption: impact on Belgian consumers' perception and intention to eat fish. Risk Anal 28(4):951-967.

Verbeke W, Vanhonacker F, Sioen I, Van Camp J, De Henauw S. 2007. Perceived importance of sustainability and ethics related to fish: a consumer behavior perspective. Ambio 36(7):580-585.

Verger P, Houdart S, Marette S, Roosen J, Blanchemanche S. 2007. Impact of a risk-benefit advisory on fish consumption and dietary exposure to methylmercury in France. Regul Toxicol Pharmacol 48(3):259-269.

Viscusi WK. 1997. Alarmist decisions with divergent risk information. The Economic Journal 107:1657 - 1670.

Volpe JP, Gee J, Beck M, Ethier V. 2011. How Green Is Your Eco-label? Comparing the Environmental Benefits of Marine Aquaculture Standards. Victoria, British Columbia:University of Victoria.

WHO/UNEP. 2008. Guidance for Identifying Populations at Risk from Mercury Exposure. Available at: http://www.chem.unep.ch/Mercury/IdentifyingPopnatRiskExposuretoMercuryFinalAugust08.pdf. [Last Accessed November 23, 2011]. Geneva, Switzerland:UNEP DTIE Chemicals Branch and WHO Department of Food Safety, Zoonoses and Foodborne Diseases.

Worm B, Hilborn R, Baum JK, Branch TA, Collie JS, Costello C, et al. 2009. Rebuilding global fisheries. Science 325(5940):578-585.

Worm B, Myers RA. 2004. Managing fisheries in a changing climate. Nature 429(15).

Table 1: Summary of major seafood consumption guidelines or advisories targeted at North American populations

Source	Target or vulnerable population	Contaminant exposure	Fatty acid/ nutrient intake	Ecological impact	Economic influences	Reference
2004 FDA/EPA	Women Children	■	■			http://www.fda.gov/Food/ResourcesForYou/Consumers/ucm110591.htm
Monterey Bay	General population	■	■	■		http://www.montereybayaquarium.org/cr/cr_seafoodwatch/sfw_recommendations.aspx?c=ln
EDF	General population	■	■	■		http://apps.edf.org/page.cfm?tagID=1521
US Dietary Guidelines	General population, Women	■	■			http://www.health.gov/dietaryguidelines/2010.asp
Fish for your health	Women, Children	■	■			http://fn.cfs.purdue.edu/fish4health
Blue Ocean Institute	General population	■		■		http://www.blueocean.org/seafood/seafood-guide
Kidsafe	Children	■		■		http://www.kidsafeseafood.org/
Fishwise	General population, Retailers			■	■	http://www.fishwise.org/science/purchasing-tools/
Washington State DOH	General population, Women, Children	■	■	■	■	http://www.doh.wa.gov/ehp/oehas/fish/default.htm
Connecticut State DPH	General population, Women, Children, Avid fish eaters, Fishers	■	■			http://www.ct.gov/dph/cwp/view.asp?a=3140&Q=387460
NRDC	General population	■		■		http://www.nrdc.org/oceans/seafoodguide/default.asp
Turtle Island	General population	■				http://www.gotmercury.org

Table 1 (continued): Summary of major seafood consumption guidelines or advisories targeted at North American populations

Source	Target or vulnerable population	Contaminant exposure	Fatty acid/ nutrient intake	Ecological impact	Economic influences	Reference
Food and Water Watch	General population	■ detail		■ detail	■ detail	http://www.foodandwaterwatch.org/fish/seafood/guide
Mercury Policy Project	General population, Women, Children	■ detail			▨ part	http://www.mercuryfactsandfish.org/
National Geographic	General population	■ detail	▨ part	■ detail		http://ocean.nationalgeographic.com/ocean/take-action/impact-of-seafood/#/seafood-decision-guide/
Star Chefs	Chefs			■ detail		http://starchefs.com/features/food_debates/html/sustainable_seafood.shtml
Greenpeace International	General population, Retailers			■ detail	▨ part	http://www.greenpeace.org/international/seafood/
NOAA	General population	■ detail	▨ part	■ detail	■ detail	http://www.nmfs.noaa.gov/fishwatch
Shedd Aquarium	General population			■ detail		http://www.sheddaquarium.org/3163.html
Health Canada	General population, Women, Children	■ detail	▨ part			http://www.hc-sc.gc.ca/fn-an/pubs/mercur/merc_fish_poisson-eng.php
US Institute of Medicine	General population, Women, Children, Adults at CVD Risk, Avid fish eaters	■ detail	■ detail	▨ part	■ detail	http://www.iom.edu/Reports/2006/Seafood-Choices-Balancing-Benefits-and-Risks.aspx

▨ Indicates topic addressed in part   ■ Indicates topic addressed in detail

Table 2: Some online lists of seafood guides

Sponsor	Website (as of 9/1/11)
Seafood Choices Alliance	http://www.seafoodchoices.org/resources/links.php#linksseafoodcards
Stonybrook University	http://www.stonybrook.edu/commcms/gelfond/fish/advice.html
University of Rhode Island Sustainable Seafood Initiative	http://www.seagrant.gso.uri.edu/sustainable_seafood/guides.html#list

Table 3: Challenges to developing comprehensive fish consumption advice

Viewpoint	Challenges	Examples
Toxicologic hazards Fish contaminants: MeHg, PCBs, pesticides, etc.	◆ Multiple co-occurring contaminants	◆ Synergistic adverse effects on neurodevelopment with joint MeHg & PCB exposure
	◆ Advisories for single contaminant	◆ Farmed salmon low in MeHg but can be high in PCBs
	◆ Toxicant levels vary within & across species	◆ Tilefish MeHg: high in Gulf of Mexico but low in Atlantic
	◆ Variable susceptibility to toxicities	◆ Prenatal exposure: increased susceptibility to MeHg neurotoxicity
	◆ Confounding by nutritional benefits	◆ Underestimate hazard from MeHg if confounded by n-3 LCPUFA
Nutritional benefits Fish nutrients: n-3 LCPUFA, vitamin D, iodine, selenium, etc.	◆ Multiple co-occurring nutrients	◆ For neurodevelopment, fish intake more consistently beneficial than n-3 LCPUFA supplements[a]
	◆ Nutrient levels vary within & across species	◆ Health benefits associated with high n-3 LCPUFA fish[a]
	◆ Confounding by contaminant risk	◆ Underestimate benefit from n-3 LCPUFA if confounded by MeHg
	◆ Increased fish intake (for most populations) recommended by nutrition guidelines	◆ Available fish insufficient to meet demand even without greater intake
Environmental sustainability Overfishing, habitat destruction, aquaculture	◆ Modern harvesting can deplete fish stocks, other aquatic wildlife & habitats	◆ Fishing trawls plough the sea floor removing most, if not all, aquatic life & structures in their path
	◆ Wild fish stocks insufficient to meet projected global demand	◆ ~90% of large predatory fish stocks (e.g., bluefin tuna, Atlantic salmon) are already depleted
	◆ Aquaculture can adversely impact wild fish, ecosystems, contaminants	◆ Farmed salmon can escape and outcompete wild fish, and may have higher PCB levels
Economic influences Consumer choice, industry stakeholders, fisheries management	◆ Economic assumption of improved consumer welfare with more information not necessarily true for fish choice	◆ US federal advisories led to overall decrease in fish and n-3 LCPUFA consumption, not just among targeted species & consumers
	◆ Cost & availability influence choice	◆ Choose less expensive but less nutritious food (e.g., high fat meat)
	◆ Fishing is a huge global industry influencing consumers, fisheries management & regulatory structure	◆ The fishing industry lobbied successfully to keep albacore tuna out of 2001 US FDA advisory
	◆ Industry's economic interests often in conflict with toxicant, nutritional & environmental interests	◆ Profitability encourages promotion of bluefin tuna production despite high MeHg, high trophic level & species endangerment

[a]Multiple fish nutrients may be important to observed beneficial associations of fish intake with health.

MeHg = methylmercury; PCB = polychlorinated biphenyl; FDA = US Food and Drug administration; LCPUFA = long-chain polyunsaturated fatty acids; US = United States

FIGURE LEGEND

Figure 1: World fish utilization and supply. Adapted from (FAO Fisheries and Aquaculture

Department 2010).

Fish utilization (million tonnes)

Population (billions) & food supply (kg/capita)

Food fish supply from aquaculture

Food fish supply from capture fisheries

Non-food uses

Food fish supply from aquaculture   Food fish supply from capture fisheries

Population (Billions)   Per capita food fish supply (kg)