

MERCURY CONTAMINATION IN THE NORTHEASTERN UNITED STATES:
SCIENCE-BASED DECISION MAKING ABOUT FISH CONSUMPTION

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

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August 2008

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ABSTRACT

Mercury contamination poses a known threat to human health, yet the degree of contamination and resulting human exposure remains unknown in many regions. Assessments of the relative risks of fish consumption are fundamentally limited by the availability of data characterizing fish consumption behaviors in a given region and the mercury concentrations in fish consumed by humans, as well as by a lack of scientific consensus about how a given level of mercury exposure is likely to affect a particular fish consumer. Existing mercury data and research findings are often not accessible to fish consumers or communicated clearly and consistently. This thesis integrates two related, yet distinct, perspectives regarding how the availability of scientific information affects decision making about the consumption of mercury-contaminated fish through a focused study of the fish consumption and mercury exposure of one community of Adirondack anglers, as well as through a broader consideration of how data collection efforts can best provide information to protect human health. This effort had two overall goals: (1) to characterize how the collection, interpretation, and communication of mercury data influence the availability and clarity of information for decision making about fish consumption; and (2) to recommend how data collection, risk assessment, and risk communication efforts can foster informed, science-based decision making about fish consumption.

The first part of this research effort builds upon ongoing assessments of mercury contamination by integrating available local, regional, and national fish mercury datasets with participant consumption records to estimate the mercury exposure of fish consumers (N=17), particularly anglers and families consuming fish species sport-caught from privately owned fishing preserves in the Adirondack region. We compared exposure estimates to measured mercury concentrations in participant

hair samples and to recommended health guidelines. The estimated mercury exposure of 35% of participants exceeded the USEPA reference dose for methylmercury; 35% of measured hair mercury concentrations exceeded recommended levels, and the estimated mercury exposure and measured hair mercury concentrations of 29% of participants exceeded both guidelines. Fifty years of angling catch records showed a noticeable decrease in the percentage of the total catch kept for consumption rather than caught and released; this change in angling behavior is estimated to have reduced the mean mercury exposure of our study community from preserve sport-caught fish (e.g., from the waters of private Adirondack fishing preserves alone) by 84%.

In the second part of this thesis, we review recent efforts to collect and integrate fish mercury data in the northeastern United States, a region that is particularly influenced by atmospheric deposition of mercury, and provide suggestions to improve and focus future research and monitoring efforts to better address threats to human health. Resource and sampling limitations have hindered comprehensive understanding of mercury in the environment and relative levels of methylmercury exposure through fish consumption. Because of these limitations, data collection should maximize the benefits of information gained by monitoring programs. By selecting appropriate target species – those species and sizes of fish harvested for consumption and those with the highest and most variable mercury concentrations at a given location – health and fisheries professionals can more comprehensively advise fish consumers and inform the protection of human health. Overall, the findings from this study will inform our understanding of: (1) how the availability and clarity of mercury information influence decision making about fish consumption, and (2) how a more comprehensive approach to data collection can more clearly characterize the relative risks to anglers and their families and thereby foster informed, science-based decision making about fish consumption.

BIOGRAPHICAL SKETCH

Hannah Abigail Shayler was born on January 1, 1980 to Bonnie and Gordon Shayler. Hannah grew up in Sterling, Massachusetts, and developed her appreciation for the natural world by spending countless hours exploring woods, streams, lakes, and oceans wherever and whenever she could. In 1998, after graduating from Wachusett Regional High School, Hannah began attending Connecticut College in New London, Connecticut. As an undergraduate Hannah gained a strong foundation in the environmental sciences, particularly through her freshwater ecology research efforts with Dr. Peter Siver and her participation in the Semester in Environmental Science program at the Marine Biological Laboratory in Woods Hole, Massachusetts. In 2002, Hannah graduated with a Bachelor of Arts degree in Environmental Studies and a Minor in Graphic Design. Hannah continued to work with Dr. Siver at Connecticut College for several years, primarily on efforts to make information about freshwater ecology more accessible to students and educators. In 2005, Hannah moved to Ithaca with her husband, Justin DiMatteo, to begin graduate work in the Department of Natural Resources exploring the role of the scientific community in addressing environmental challenges through research and outreach. After completing her Master's degree, Hannah will be employed by the Cornell Waste Management Institute where she will continue to pursue a career making scientific information more accessible to the public for decision making about environmental issues.

This thesis is dedicated to my husband Justin, whose unconditional support and daily encouragement have been invaluable through eleven years of my educational career.

ACKNOWLEDGMENTS

I am immensely thankful for the support of my family, friends, and fellow graduate students during the challenging times inherent to graduate research. I thank my advisor, Dr. Clifford Kraft, for providing me with this opportunity to bridge the gap between science and the public and for assembling a research group made up of people whose diverse experiences and viewpoints have uniquely shaped my research. I am grateful for the insights offered by my committee members Dr. Barbara Knuth and Dr. Clifford Scherer throughout my research, coursework, and other endeavors. Dr. Kraft and Dr. Knuth provided additional support as coauthors for the manuscript presented here as Chapter 3; many others offered suggestions for improvement as well. My successful collaboration with my co-lead author for that effort, Dr. Jesse Lepak, has proven how useful it can be to approach interdisciplinary environmental challenges by combining different ideas and perspectives; I thank Jesse for his support throughout my graduate work and for challenging me with his ideas and feedback. I also greatly appreciate Daniel Josephson's willingness to help with every stage of this project, particularly with the logistical details of planning and distributing my study instruments. Financial support for my research was provided by the Doris Duke Conservation Fellowship program, the Teresa Heinz Scholars for Environmental Research program, the Kieckhefer Adirondack Fellowship program, and the Cornell Center for the Environment. The Autotutorial Introductory Biology program (BioG 105-106) provided Teaching Assistantship support throughout most of my graduate studies, as well as a valuable opportunity to hone my skills in teaching and communicating scientific information. Finally, I would like to thank my study participants, without whom this research would not have been possible.

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CHAPTER 1

RESEARCH OVERVIEW AND FUTURE DIRECTIONS

The issue of mercury (Hg) contamination in fish has been prominent in the media in recent years, with headlines touting the dangers of fish consumption counterbalanced by clear messages from health experts stating that fish remains a safe and important component of a healthy diet. This problem continues to receive attention from university researchers, state and federal agencies, policy makers, and the public, as well as from not-for-profit and other interest groups. However, despite this attention, assessments of the relative risks of fish consumption are fundamentally limited by the availability of data characterizing fish consumption behaviors in a given region and the Hg concentrations in fish consumed by humans, as well as by a lack of scientific consensus about how a given level of Hg exposure is likely to affect a particular fish consumer. Additionally, existing Hg data and research findings are often not communicated clearly and consistently to fish consumers. It is particularly difficult for anglers and other consumers of sport-caught fish to navigate the often-conflicting advice of health advisories and agency recommendations in order to make knowledgeable decisions about how fish consumption may affect the health of their families. In order for decision making about fish consumption to be science-based – in other words, informed by appropriate data and relevant research findings – anglers and other fish consumers must be equipped with scientific information presented within a context appropriate to the demographic characteristics and behaviors of different groups of fish consumers.

This thesis integrates two related, yet distinct, perspectives regarding how the availability of scientific information affects decision making about the consumption of

Hg-contaminated fish. This thesis research effort had two overall goals: (1) to characterize how the collection, interpretation, and communication of Hg data influence the availability and clarity of information for decision making about fish consumption; and (2) to recommend how data collection, risk assessment, and risk communication efforts can foster informed, science-based decision making about fish consumption.

This effort builds upon fifty years of applied research conducted by the Adirondack Fishery Research Program (AFRP) in the Department of Natural Resources at Cornell University. The ongoing management of fisheries in the Adirondack region has created a tradition of direct communication between anglers and AFRP researchers as well as a responsibility to maintain consistent outreach efforts linked to new research findings. This relationship has addressed many resource management challenges, including the damage to lake fisheries caused by acid deposition in the 1960s and 1970s. At that time the AFRP was instrumental in not only developing management strategies to improve the health of aquatic ecosystems, but also in increasing angler awareness that environmental problems caused by anthropogenic influences are important issues in both public and private waters. Mercury contamination in fisheries in the northeastern United States, including the Adirondack region, presents a similar challenge – one that this research group is in a unique position to address.

Mercury in the Environment: Data Collection, Fish Consumption, and Human Health

Mercury is emitted from coal-fired electric utilities, waste incinerators, and other industrial and mining processes; emissions from the United States and global sources are subsequently deposited and integrated into aquatic ecosystems (CRS 2006,

Harris et al. 2007). Mercury becomes a concern when high levels of methylmercury (MeHg) bioaccumulate in fish that are then consumed by humans and other organisms (USEPA 1997, Mergler et al. 2007, Munthe et al. 2007). Methylmercury, the primary and intensely toxic form of Hg found in fish, is readily absorbed by the human bloodstream before being distributed to the brain and body tissues. Although Hg is gradually eliminated from the body, it can accumulate in the blood stream over time if consumption levels exceed the body's capacity for excretion (USEPA 2001a, USEPA and USFDA 2004). Elevated blood Hg concentrations in humans have been linked to neurological damage leading to impaired vision and loss of motor coordination and feeling; at high levels seizures, severe neurological impairment, and death may result (NRC 2000, USEPA 2001a). Methylmercury presents a significant threat to the developing central nervous systems of babies and young children and can impact cognition, memory, attention, language, and fine motor and visual spatial skills (NRC 2000, USEPA 2001a, Institute of Medicine 2007, Mergler et al. 2007).

The issue of Hg contamination has received considerable attention in the northeastern United States in the last few years, including several notable recent initiatives that are discussed more thoroughly in Chapter 3. First, researchers have pursued efforts to identify and classify Hg hotspots in the northeastern United States and southeastern Canada using data collected by fish and wildlife monitoring programs, and used measures of water quality to predict which aquatic systems would support fish exceeding the USEPA human health criterion for MeHg (see Driscoll et al. 2007, Evers et al. 2007). Additionally, increased monitoring of fish Hg concentrations have been conducted by state agencies (e.g., in New York State, see Simonin et al. 2008), and will be part of future regional efforts to establish a uniform Total Maximum Daily Load methodology for Hg across states in the northeastern U.S. (see NEIWPCC 2007).

From a public policy perspective, many researchers and federal agency scientists and policy analysts agree that more extensive monitoring networks are needed in order to evaluate the effectiveness of the 2005 Clean Air Mercury Rule (USEPA 2008) and other policies intended to reduce the emission and subsequent deposition of Hg, with the ultimate goal of protecting human health (Harris et al. 2007). In addition, legislation proposed in March 2007 to establish a comprehensive national Hg monitoring network (US House 2007, US Senate 2007) is further evidence of a growing need for continued data collection and coordinated monitoring efforts. The rationale for the proposed monitoring program has resulted directly from ongoing dialogues and workshops involving university researchers and federal agencies (particularly the USEPA, NOAA, and the USGS) and has been strongly influenced by recent research findings (see Mason et al. 2005, Harris et al. 2007). Although budget limitations make it unlikely that this monitoring network will be enacted through legislative channels, the regular appearance of the issue of Hg contamination on the legislative agenda is an excellent example of a situation in which scientific information is directly informing policy.

However, the degree of Hg contamination still remains unknown in many regions of the U.S., and current data collection strategies fail to sufficiently describe spatial or temporal trends in Hg concentration. Accurate assessments of the relative risks of harmful health effects from Hg exposure depend on data that sufficiently characterize Hg concentrations in fish species consumed by humans in particular regions. The development of targeted and effective health advisories and other risk communication efforts – and ultimately decision making about fish consumption – are therefore fundamentally limited by the availability of Hg data.

Chapter 2 of this thesis, titled “Mercury and Sport Fish Consumption: A Comprehensive Approach to Data Collection”, presents the results of research that

builds upon ongoing assessments of Hg contamination in New York State waters by using available datasets to assess the relative risks to fish consumers, particularly those consuming fish species sport-caught from the Adirondack region that may have Hg concentrations above recommended levels. In this chapter, we provide a more comprehensive perspective of how Hg contamination affects Adirondack anglers and their families by estimating Hg exposure using fish consumption records, measuring participant hair Hg concentrations, and quantifying historical angling catch records. These research findings inform understanding of: (1) how the availability and clarity of Hg information influence decision making about fish consumption, and (2) how a more comprehensive approach to data collection can better characterize the relative risks to anglers and their families and thereby foster informed, science-based decision making about fish consumption.

Chapter 3, titled “Mercury Contamination in Sport Fish in the Northeastern United States: Considerations for Future Data Collection”, presents a complimentary perspective to focus on how efforts to collect fish Hg data can best inform the protection of human health. Research and monitoring efforts are often constrained by resource limitations, thereby hindering understanding of Hg in the environment and the relative levels of Hg exposure through fish consumption. Therefore, data collection strategies should be carefully considered in order to maximize the benefits of information obtained by monitoring programs. In Chapter 3 we review recent efforts to collect and integrate fish Hg data and provide suggestions to improve and focus future research and monitoring efforts to better address threats to human health. By selecting appropriate target species – those species and sizes of fish harvested for consumption and those with the highest and most variable Hg concentrations in a given location – health and fisheries professionals can more comprehensively advise fish consumers and improve the protection of human health.

Risk Communications for Science-Based Decision Making

The USEPA and USFDA (2004) offer consumption guidelines that are primarily applicable to concerns about Hg in fish purchased from commercial sources. This agency effort: 1) emphasizes the benefits of consuming fish and shellfish; 2) advises pregnant women, nursing mothers, women of childbearing age, and young children not to eat shark, swordfish, king mackerel, or tilefish, which have the highest levels of Hg; and 3) lists five commonly-consumed fish species that are lower in Hg (shrimp, canned light tuna, salmon, pollock, and catfish) and recommends that women of childbearing age and young children can safely consume two average meals (12 oz, or age-appropriate portions) per week of fish low in Hg in order to receive the benefits of fish consumption with limited risk (USEPA and USFDA 2004). Additionally, these federal advisories for commercial fish recommend that fish consumers heed local advisories and, when no specific advice is available, limit consumption of non-commercially marketed fish from local waters to one average meal (6 oz portion) per week.

Consumption advisories issued by state agencies are therefore currently the most comprehensive risk communications materials for disseminating information about contaminants in non-commercial fish. These advisories typically provide general consumption recommendations applicable to a particular state or region (e.g., the Adirondack and Catskill Mountains in New York), and also list the fish species and water bodies in which concentrations of Hg or other contaminants are known to exceed recommended levels based on available datasets (NYSDOH 2008). However, the absence of a particular fish or water body from a health advisory does not necessarily indicate that levels of contamination in that fish species or water will not present concerns for human health.

With the exception of state-issued health advisories, there is limited information about the Hg content of non-commercial fish available for anglers and their families to use to assess the risks of consuming fish sport-caught from water bodies in the northeastern U.S. For example, although New York State has recently completed a four-year initiative to measure Hg concentrations in several sport fish species (Simonin et al. 2008), it is not feasible to sample all species from all waters. Waters on privately-owned Adirondack fishing preserves were not included in NYSDEC data collection efforts; this has raised concerns that anglers and families may be consuming fish with elevated Hg concentrations, yet may lack the data needed to make informed decisions about fish consumption. This Adirondack example, the focus of Chapter 2, is illustrative of many fisheries in the northeastern U.S.; although statewide health advisories provide consumption recommendations for all angling within a particular state (and for specific species or water bodies as applicable), these guidelines are based solely on data for the fish species and water bodies that have been tested. This emphasizes the need for complete datasets characterizing the Hg concentrations in the fish consumed by anglers, their families, and other fish consumers in a given region.

Future efforts should continue to evaluate whether health advisories issued by state agencies are the most effective means of communicating available information to fish consumers. Previous research has shown that fish consumption by anglers is largely independent of knowledge of health advisories (Knuth 1990, Connelly et al. 1992, Connelly et al. 1996). Burger (2000) proposes that noncompliance with consumption advisories may often be attributed to the deamplification of the perceived health risks of fish consumption by the angling community. Burger argues that fishing and fish consumption are familiar and enjoyable activities under one's own control, and are therefore difficult to reinterpret as risky or threatening – particularly in light of

traditional social norms within the angling community. Consumption advisories may also result in a polarized response among anglers; some individuals will stop eating fish due to an amplified perception of risk, while others will dismiss the advisories as unnecessary or inconsistent and as a result will not change their fish consumption behaviors (Connelly and Knuth 1993, Reinert et al. 1996). However, the one factor that may have the greatest influence on increasing perceptions of risk – particularly among women of childbearing age – is that Hg poses the greatest threat to unborn babies and young children.

There are also substantial benefits to fish consumption that may make individuals less likely to modify their behaviors as recommended by health advisories. In addition to the social and emotional benefits provided by recreational angling, fish meals supply important nutritional benefits, namely high-quality protein and the omega-3 fatty acids and nutrients needed for cardiovascular health and children's growth and development (USEPA and USFDA 2004, Institute of Medicine 2007). It is therefore important that anglers and their families do not replace the fish that they eat with other less healthful food items that may have negative health effects more severe than those from moderate levels of Hg exposure through fish consumption. Instead, when alternatives are available, individuals should choose to eat fish that are known to have lower levels of Hg and other contaminants yet provide the same or better nutritional benefits. For example, salmon is generally both low in Hg and high in omega-3 fatty acids (as are anchovy, sardines, and some other species; Institute of Medicine 2007). However, the mean levels of omega-3 fatty acids in other fish species frequently consumed in the United States (e.g., shrimp, light tuna, pollock, and catfish) are comparatively low, and many of the fish species rich in omega-3 fatty acids (e.g., sea bass, swordfish, some trout) may also have high Hg concentrations (Institute of Medicine 2007).

These considerations further complicate decision making about fish consumption, which is dependent upon the availability of information characterizing Hg concentrations and nutritional content in the fish species chosen by fish consumers in particular regions. Furthermore, this strategy will be fundamentally limited by the availability of both fish Hg data and an understanding of how different levels of Hg exposure and overall nutrition will affect particular groups of fish consumers (e.g., women of childbearing age and young children). Additionally, outreach and communication efforts are likely to be most effective if targeted at groups most at risk (Velicer and Knuth 1994, Flaherty et al. 2003), again emphasizing the importance of delivering risk messages within the context of the fish consumption behaviors and nutritional concerns of particular groups of fish consumers.

As with any risk communications materials, the format in which a message is presented affects information processing and behavior change. Connelly and Knuth (1998) evaluated how format, reading level, tone, and content affect target audiences' understanding and responses to a message about contaminants in fish. Based upon this research, the authors recommend that risk communications present information about contaminants in fish using both text and graphics, a combination of qualitative and quantitative information at a reading level appropriate for the target audience, and a cajoling rather than a commanding tone to communicate the message. Burger et al. (2003) found that short workshops, in addition to brochures and fish fact sheets, were very effective in communicating the main risks and benefits of fish consumption. Varied message structures that make it possible for the reader to extract an appropriate amount of information – which may be more or less detailed, depending upon the reader's background and priorities – also increase the understanding and retention of risk-related messages (Connelly and Knuth 1993, Connelly and Knuth 1998, Burger et al. 2003). Scherer et al. (1999) further investigated the role of message structure in

promoting informed decision making, and offered preliminary evidence that a dialectical message structure may be more effective than a persuasive, balanced, or narrative approach in conveying risk information to public audiences. The message structure of health advisories or other risk communication tools is therefore an important factor in promoting informed decision making and public engagement in risk issues (Scherer et al. 1999).

Based upon the relative ineffectiveness of state-issued health advisories in conveying information about the benefits and risks of fish consumption, McDermott et al. (2003) recommend an alternative approach to disseminating information about contamination in fish. The suggested approach involves: 1) considering what channels for dissemination are most appropriate for the target audience; 2) consulting with both the audience and outreach agents to develop the message content and structure; and 3) developing, pretesting, and revising materials within a subset of the target audience (McDermott et al. 2003). The success of this methodology would be facilitated by a continued exchange of information and coordination among researchers, extension agents, agencies, and members of the public.

Additionally, Williamson (2007) found that government-issued fish consumption advisories often do not incorporate the “best practices” proposed by risk communications researchers. However, the content of a health advisory will be limited by the completeness of the data used to develop that advisory, making it difficult to clearly present the very information that would increase the advisory’s effectiveness (e.g., by improving the ability of fish consumers to make informed decisions to reduce their Hg exposure). For example, Williamson (2007) outlined the best practices for presenting core consumption recommendations in health advisories, which include: 1) conveying the balanced message that fish is part of a healthy diet when consumed in moderation; 2) providing unambiguous descriptions of desired

consumption behaviors; 3) indicating the relative Hg levels of different fish species; 4) discussing the origins of those species; and 5) providing site-specific information about the fish species included in the advisory. All of these five core recommendations are dependent upon complete datasets that characterize the Hg concentration in fish species consumed by humans in particular locations; without these data, it is impossible to accurately predict the Hg exposure that would result from a specific pattern and rate of fish consumption. Consensus regarding the health effects of a given level of Hg exposure is also necessary in order to recommend desired fish consumption behaviors for particular groups of consumers.

Theoretical Considerations

Given that the health benefits of fish consumption have been conclusively demonstrated (Institute of Medicine 2007), yet there is uncertainty about the health risks of Hg exposure through moderate fish consumption, it is important to find a balance between precaution and avoiding alarmism when communicating information about Hg and fish consumption. When dealing with the complexity and scientific uncertainty related to health risk decision making and management, it is appropriate to take a precautionary approach – particularly for those individuals for whom the health effects of Hg would be most harmful. Despite scientific uncertainty, it is clear that women of childbearing age and young children should carefully evaluate their fish consumption and avoid fish with high Hg levels, particularly when alternatives are available that provide the same health benefits. It can be argued that an appropriate risk message should therefore incorporate persuasive components to prevent potential negative health effects from fish consumption by women and children, while also providing sufficient information for informed decision making for all risk groups by

using a more dialectical message structure to convey the arguments and counter-arguments related to the possible health benefits and risks of fish consumption.

Complete assessments of the relative risks of Hg exposure through fish consumption – and the resulting risk communication messages – require information about the Hg concentrations in fish consumed, an understanding of the fish consumption behaviors of a particular individual or community, and a characterization of the health risks that would be expected from a given level of exposure. However, the availability of comprehensive Hg datasets is limited; further uncertainty results from the lack of scientific consensus about the health effects resulting from moderate fish consumption. This uncertainty in turn creates complexity, which compounds the inherent complexity of communicating the concept of limiting and spacing fish meals and choosing among different types of fish. These decision making strategies require that fish consumers adopt complex behaviors; as such, complex risk messages will likely be more effective if recommended fish consumption behaviors are organized into a series of simple steps that together create a comprehensive decision-making strategy to reduce Hg exposure. This simplification requires an understanding of what information is useful for making decisions about fish consumption, as well as how fish consumers perceive risk information and subsequently translate this knowledge into fish consumption behaviors.

The theoretical framework of the risk information seeking and processing (RISP) model is a useful research tool to assess individuals' responses to health risks (Griffin et al. 2002). This model implies an “information insufficiency” gap that distinguishes what someone knows from what they need to know in order to process information, and in the case of Hg contamination, to make informed decisions about fish consumption. Providing the information that fish consumers need to address this information insufficiency will facilitate science-based decision making – decision

making processes informed by applicable data and other relevant research findings. For most fish consumers, this information gap could be filled by providing information about the Hg concentrations and nutritional content of the fish species that a particular individual actually consumes, as well as outlining behaviors to promote self-efficacy such as selecting species with lower Hg concentrations or limiting the portion size or number of fish meals. More importantly, by providing appropriate context for assessing the relative levels of risk for particular groups (e.g., women of childbearing age and young children), an individual fish consumer can effectively achieve the balance of minimizing Hg exposure and including fish in a healthy diet.

The RISP model integrates Azjen's (1988) theory of planned behavior and Eagly and Chiaken's (1993) heuristic-systematic model to more thoroughly analyze how the form of risk information processing influences the beliefs, evaluations, and attitudes that individuals draw upon when making decisions about risk situations. Griffin et al. (2002) emphasize that an individual's processing of risk information is most dependent upon existing knowledge structures, the perceived ability to obtain relevant information about the risk, and the perceived usefulness and credibility of the available information. The perceived credibility of information about Hg contamination and fish consumption may be improved by utilizing existing relationships, such as those between the AFRP and Adirondack anglers, to further facilitate the dissemination of relevant research findings and improve their usefulness and relevance for decision making by a particular individual.

Azjen and Fishbein's (1980) theory of reasoned action more simply conceptualizes and emphasizes the influences of attitudes and subjective norms on behavioral intentions, which in turn directly affect behaviors. These norms, which eventually determine behaviors such as decisions about fish consumption, are molded by social influences, normative social pressures, and social networks (Azjen and

Fishbein 1980). For example, in our study community affiliated with private Adirondack fishing preserves, over the past fifty years there has been a notable decline in the percentage of fish creel and kept for consumption, likely due to a new cultural norm to catch and release fish and in turn support a sustainable fishery. This shift in normative social pressures over time is estimated to have greatly reduced the Hg exposure of this community from consuming fish sport-caught from preserve waters (see Chapter 2). Social networks within the angling community therefore represent a means by which available information can diffuse through informal social structures such as interpersonal communications and ongoing dialogue among anglers, as well as through more formal social structures such as community meetings, club newsletters, and fisheries management reports. It is important for risk communications messages to also consider the social norms and experiences that are fundamental and valuable to a particular community – most notably, traditional angling practices and fish consumption behaviors.

Additionally, it will further strengthen risk messages to consider the factors that influence whether anglers and their families will choose to consume a particular fish meal. These criteria, such as the taste of fish, the risk of contaminants, meal variety, and nutrition, as well as the more general constraints of convenience, cost, and time (Griffin et al. 2002), are inherent components of an individual's existing knowledge structures that are used to determine the relevance and usefulness of risk messages. For example, survey respondents affiliated with private Adirondack fishing preserves considered the sustainability of a particular fishery when making decisions about consuming sport-caught fish, yet overall considered the issue of sustainability to be less important relative to other concerns (e.g., cost) when making decisions about fish meals purchased from restaurants or stores (see Chapter 2). The “best practices” for advisory development from risk communications literature (Williamson 2007)

emphasize the importance of a balanced message structure addressing both the potential benefits and risks of fish consumption; additional information relevant to the existing knowledge structures of particular groups of fish consumers (e.g., anglers) may further improve the effectiveness of risk communications efforts by providing individuals with information needed for decision making. Characterizing the angling practices and fish consumption behaviors of a particular community, as discussed in detail in Chapter 2, and understanding the influences of social norms and networks and individual knowledge structures on behaviors, will further facilitate the creation of complete datasets for risk assessment and risk communications that effectively foster informed decision making about Hg and fish consumption.

Future Directions

Assessments of the relative risks of fish consumption and subsequent risk communication efforts are fundamentally limited by the availability of datasets characterizing Hg concentrations in fish consumed by humans and knowledge of fish consumption behaviors in a given region, as well as by a lack of scientific consensus regarding the health effects of Hg exposure through moderate fish consumption. In Chapter 2, we present a focused study of Adirondack anglers and their families to exemplify how integrating fish Hg datasets with detailed characterizations of fish consumption is a useful means of assessing whether levels of Hg exposure through fish consumption exceed levels recommended by the USEPA. Additionally, measures of hair Hg concentration verify exposure assessments using fish consumption records. These exposure estimates are more meaningful when interpreted within the context of community demographics and the characteristics of an individual fish consumer; the relative risk of a given level of Hg exposure to a particular fish consumer is also dependent upon the sensitivity of that individual to possible health effects (e.g., the

developing nervous systems of fetuses and young children are particularly susceptible to harm). In Chapter 3, we focus more broadly on how future research and monitoring efforts can be improved to better address possible threats to human health. By measuring Hg concentrations in the species and sizes of fish that are harvested for consumption in a given location, particularly those with high or variable Hg concentrations, health and fisheries professionals can more effectively advise fish consumers and improve the protection of human health.

This thesis therefore primarily addresses how the careful planning and implementation of data collection efforts can provide information that is most useful for addressing the possible health risks from Hg exposure through fish consumption. Characterizations of relative risk, as well as risk communications efforts, will only be as complete and accurate as the data and research findings on which they are based. Additionally, the issue of Hg contamination will be most effectively addressed through continued collaboration and sharing of information among the researchers, state and federal agencies, policy makers, extension agents, risk communicators, and the public. Through a focused study of the fish consumption and Hg exposure of Adirondack anglers (see Chapter 2), and a consideration of how the collection of fish Hg data can best inform the protection of human health (see Chapter 3), we recommend that future efforts strive to achieve the following in order to more completely characterize and communicate the relative risks of Hg exposure to fish consumers:

(1) Targeted data collection:

- Characterize consumption behaviors of different groups of fish consumers in particular states or regions;
- Measure Hg concentrations in fish species with high and/or variable Hg concentration that are also consumed by humans;

- Test fish of harvestable size – those that are actually consumed by anglers and families;

(2) Comprehensive risk assessment:

- Quantify the Hg exposure of fish consumers by integrating available fish Hg datasets with known patterns of fish consumption – including the source, portion size, and timing of meals of different fish species;
- Ground-truth exposure estimates with measures of hair Hg concentration;
- Assess the relative risk of health effects by interpreting the rate of Hg exposure within the context of the sensitivity of a given individual, by accounting for factors such as the fish consumer's gender, age, and body weight.

(3) Risk communications for informed decision making:

- Provide fish consumers with information about the Hg concentrations in the species and sizes of fish consumed in a particular region or community;
- Consistently define the sensitive populations and fish tissue Hg concentrations used to develop fish consumption advisories by continuing research efforts to assess the health effects of both moderate and high levels of Hg exposure in different groups of fish consumers;
- Investigate alternative formats for state-issued health advisories and other risk communication efforts to ensure that available information about Hg and fish consumption is clear, complete, and directly relevant to fish consumers.

Eventually, reductions in emissions may eliminate the need for fish consumption advisories for Hg, but in the foreseeable future we can best protect human health by ensuring that sufficient information is available to characterize and

communicate the relative risks of fish consumption to facilitate informed decision making about the development of health advisories and the consumption of sport fish from freshwaters. Future research and monitoring efforts can augment existing datasets to ensure that fish consumption advisories and management efforts are as complete as possible, are locally applicable, and contain information about sport fish species that are consumed most frequently by humans. By clearly synthesizing and communicating available information, and by understanding the limitations of existing data, scientists, policymakers, public health agencies, resource managers, and fish consumers can progress towards efficiently and comprehensively addressing the challenges presented by Hg contamination.

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CHAPTER 2

MERCURY AND ADIRONDACK SPORT FISH CONSUMPTION: A COMPREHENSIVE APPROACH TO DATA COLLECTION FOR IMPROVED DECISION MAKING

Abstract

Mercury contamination poses a known threat to human and ecosystem health, yet the degree of contamination and resulting human exposure remains unknown in many regions. Information about fish consumption behaviors and the mercury levels in fish consumed is essential for developing effective and targeted risk communication programs. High mercury concentrations measured in fish from Adirondack waters – including sport fish harvested and prized by anglers – indicate an important issue for human health. This research builds upon ongoing assessments of mercury contamination in New York State waters by using available local, regional, and national datasets to assess the relative risks to fish consumers, particularly those consuming fish species sport-caught from the Adirondack region. We provide a comprehensive perspective of how mercury contamination affects Adirondack anglers and their families by estimating mercury exposure using fish consumption records, measuring participant hair mercury concentrations, and quantifying historical angling catch records. Our findings inform our understanding of: (1) how the availability and clarity of mercury information influence decision making about fish consumption, and (2) how a comprehensive approach to data collection can help characterize the relative risks to anglers and their families and thereby foster informed, science-based decision making about fish consumption.

Introduction

Effective communication between researchers and communities will help to address environmental challenges such as mercury contamination, particularly when scientific findings have direct implications for human health. This chapter presents the results of an integrated research and outreach response to a known contamination issue in Adirondack waters. Measurements of fish mercury concentration alone are insufficient to fully characterize the relative human health risks of fish consumption; instead, fish mercury data are most relevant when interpreted within the context of fish consumption behaviors and the demographic characteristics of fish consumers. We assess the relative risks faced by a group of Adirondack anglers and their families by quantifying fish consumption, characterizing participant demographics, angling behaviors, and knowledge of mercury contamination, and integrating this information with available local, regional, and national fish mercury datasets. This Adirondack case study exemplifies how a comprehensive approach to data collection and characterization of relative risk can help provide complete information for decision making about environmental problems.

Mercury in the environment and subsequent human exposure

Mercury (Hg) contamination is a known concern for human and ecosystem health (USEPA 1997, USEPA 2005), and several decades of research have shown that the northeastern U.S., including the Adirondack region, is strongly influenced by atmospheric deposition of Hg. Fish and other aquatic organisms accumulate Hg in their tissues primarily through bioaccumulation as contaminants move throughout food webs (USEPA 2001a, Power et al. 2002, Chen et al. 2005, USEPA 2005). Mercury concentrations within individual fish are influenced by diet, age, and size, the Hg input to a particular area, and biogeochemical characteristics of specific

watersheds (Driscoll et al. 1994, Power et al. 2002, Johnston et al. 2003). In general, larger, older, piscivorous fish species (those that eat other fish) tend to have elevated Hg concentrations, thereby representing an increased risk to human consumers relative to younger, smaller fish that are herbivorous or omnivorous (Bahnick et al. 1994, Power et al. 2002). Yet overall, the Hg concentrations of different species – and therefore the relative risks to fish consumers – remain poorly characterized in many popular sport-fishing areas. This includes regions of the Adirondacks with privately-owned waters that are not evaluated by state data collection efforts.

Methylmercury (MeHg), the primary form of Hg found in fish, is often assumed to comprise more than 95% of the total Hg (T-Hg) in sport fish (Bloom 1992). However, T-Hg is often measured as a proxy for MeHg due to the higher expense of conducting MeHg analyses. In this chapter, “MeHg” is used in reference to the methylated form of mercury, “T-Hg” is used for measurements of total mercury, and “Hg” is used when referring to more than one form of mercury or when the type of Hg measured has not been specified. Methylmercury is a potent neurotoxin and a known concern for human health, particularly with regard to the developing nervous systems during fetal and early child development (For a complete review of health effects, see USEPA 1997, NRC 2000, Institute of Medicine 2007, Mergler et al. 2007). Although MeHg is gradually eliminated from the body, it can accumulate in the blood stream over time if consumption levels exceed the body’s capacity for excretion (USEPA 2001a, USEPA and USFDA 2004). Given assumptions about fish consumer body weight and fish intake, the USEPA (2001b) recommends that mercury concentrations in fish should not exceed 0.3 parts per million (ppm), or 0.3 micrograms (μg) MeHg per gram (g) fish; the amount of fish that can be consumed without exceeding the USEPA reference dose varies with the individual’s body weight and the concentration of mercury found in the fish (NRC 2000).

The current reference dose for MeHg is 0.1 microgram per kilogram consumer body weight per day ($\mu\text{g kg}^{-1} \text{ day}^{-1}$), corresponding to the maximum level of exposure recorded without deleterious fetal health effects (NRC 2000, Rice et al. 2003). Mercury intake below this level is therefore unlikely to cause health effects during a person's lifetime. Despite the general lack of consensus regarding the health effects of Hg intake through moderate fish consumption, the nutritional benefits of fish consumption are well documented and may outweigh the health risks (Knuth et al. 2003, Institute of Medicine 2007, Mergler et al. 2007). The USEPA and USFDA (2004) recommend that women and children consume up to 12 ounces (oz) per week of fish with low levels of MeHg, while the Dietary Guidelines Advisory Committee and the American Heart Association recommend the consumption of at least six oz of fish per week to maintain a healthy and balanced diet (Institute of Medicine 2007). The nutritional benefits of fish consumption must therefore be weighed with the possible negative health effects from MeHg exposure exceeding the USEPA reference dose. Clearly communicating information about Hg concentrations in fish – especially in species consumed frequently by particular communities – will allow fish consumers to make informed decisions to most effectively achieve a balance between the health benefits and possible health risks of fish consumption.

Measurements of hair T-Hg concentration have been used at regional and state levels to assess the MeHg exposure of particular human populations (e.g., Montreal-area sportfishers, see Kosatsky et al. 2000; and Alaskan women of childbearing age, see Arnold et al. 2005). Additionally, the 1999-2000 National Health and Nutrition Examination Survey measured blood and hair T-Hg concentrations in young children and women of childbearing age to produce a nationwide reference data set (Schober et al. 2003, McDowell et al. 2004). Findings indicated that approximately 8% of women had Hg levels higher than the USEPA reference dose and were therefore at a higher

risk for harmful health effects (CDC 2001, Schober et al. 2003). A toxicological review by the National Research Council (NRC 2000) recommended that in light of these data, it should be a research priority to evaluate regional differences in MeHg levels in humans and assess the exposure of populations particularly at risk – including anglers. These studies provide benchmarks to which future results can be compared and support the need for increased awareness of the possible health effects of MeHg on children and women of childbearing age, as well as targeted subpopulations such as anglers. However, hair Hg data will be most informative when interpreted within the context of demographic characteristics and patterns of fish consumption to provide appropriate estimates of relative risk.

Mercury in Adirondack fisheries and angler concern

In recent years the New York State Department of Environmental Conservation (NYSDEC) has increased efforts to assess the spatial distribution and temporal patterns of Hg in fishes found throughout the state's freshwater lakes and streams. Data collected through this sampling effort has been used by the New York State Department of Health (NYSDOH) to issue consumption advisories for various fish species from the Adirondack and Catskill Mountain regions of New York State. These advisories are based upon measured Hg concentrations in fish tissue exceeding a threshold concentration – particularly in large, older individuals of chain pickerel (*Esox niger*), northern pike (*Esox lucious*), smallmouth and largemouth bass (*Micropterus salmoides* and *M. dolomieu*), walleye (*Sanders vitreus*) and yellow perch (*Perca flavescens*) (NYSDOH 2008). Sensitive groups (i.e., women of childbearing age and children under age fifteen) have been advised to avoid consuming any amount of the above mentioned species caught from Adirondack and Catskill waters, and to avoid consuming any fish from water bodies for which advisories have been issued.

These recommendations are substantially more restrictive than the general advice that no individual should consume more than one meal (8 oz) per week of any sport fish caught from the state's freshwaters.

In response to angler concerns in 2005 following the listing of the more restrictive consumption advisories for the Adirondack and Catskill regions, in 2005-2007 the AFRP measured T-Hg concentrations in four sport fish species collected from ten Adirondack lakes on private fishing preserves, including lake trout (*Salvelinus namaycush*), brook trout (*Salvelinus fontinalis*), Atlantic landlocked salmon (*Salmo salar*), and smallmouth bass. Total mercury concentrations in three fish species, including brook trout, lake trout and smallmouth bass, exceeded 0.3 ppm, the level the USEPA recommends fish tissue should not exceed given assumptions about consumer body weight and rate of fish consumption (USEPA 2001b). Mercury levels in landlocked salmon were consistently below the USEPA level of concern (AFRP unpublished data). Additionally, the tissue of some individual fish exceeded the U.S. Food and Drug Administration's (USFDA) action level of 1.0 ppm MeHg (USFDA 2000); fish with Hg concentrations exceeding this threshold may not be sold commercially. Mercury concentrations in these sport fish species – and particularly in the larger, older fish targeted by anglers – are likely to exceed the level at which the USEPA recommends limited consumption, and may therefore represent an increased risk of Hg exposure to fish consumers. While sensitive individuals are advised by the NYSDOH (2008) health advisory to avoid consuming smallmouth bass from any waters in the Adirondacks and Catskills, the advisory does not recommend that women and children further restrict consumption of brook trout and lake trout beyond the general advisory recommendation to consume no more than one 8 oz meal per week. Sensitive individuals are, however, advised to avoid consuming any amount of fish of any species obtained from listed waters (NYSDOH 2008), yet these advisories

for specific water bodies only include waters for which data are available and are therefore not comprehensive.

In summary, Hg data from privately-owned Adirondack waters that had not been included in state monitoring efforts raised concerns that anglers and their families – both in our study community and in other locations in the northeastern United States – may be consuming fish with elevated Hg concentrations. The work described in this chapter was initiated in response to that concern, with the following primary research objectives and related outreach objective:

Research Objective (1): Utilize available data regarding Hg concentrations in sport fish to assess the relative risks of fish consumption by consumers, particularly those of anglers and their families consuming fish species caught within the Adirondack region;

Research Objective (2): Evaluate whether a comprehensive approach to collect fish Hg data can fully characterize the relative risks to anglers and their families and thereby foster informed, science-based decision making about Hg and fish consumption;

Outreach Objective: Make information from available datasets, research findings, state health advisories, and agency consumption recommendations accessible to fish consumers, particularly those in our Adirondack study community, via print and Web-based summary materials.

Methods

Participants included anglers affiliated with private fishing preserves in the Adirondack region in Hamilton County and Herkimer County, NY. All research protocols, instruments, and informed consent procedures were approved by the

Cornell University Institutional Review Board for Human Participants (Protocol ID# 06-06-028).

Fish consumption records and mercury exposure estimates

Fish consumption records (Appendix B) were included in packets distributed to participating households in June 2007 and integrated with existing fish Hg datasets to assess whether Hg exposure through fish consumption exceeded levels recommended by the USEPA. Participating anglers and their families ($N=17$ total participants) kept fish consumption records for the months of June, July, and August 2007. For each fish meal consumed by each family member, participants noted the date, the fish species consumed, and the portion size. Photographs of eight oz portions of both fish filets and steaks were included to help participants judge the portion size of meals consumed. Participants also recorded whether the fish from each meal were sport-caught (with water body and location specified, if known) or purchased from a store or restaurant. Additional questions addressed whether or not the fish consumption recorded for summer 2007 was typical of the household's fish consumption, both seasonally and from year to year.

Mercury intake estimates for each participant were calculated using the portion size of a given fish meal (converted from oz to g) and the mean Hg concentration of that fish species (in ppm, or $\mu\text{g g}^{-1}$) from available datasets, as described below. Meal Hg intake estimates (in μg of Hg) and consumer body weight (in kg) were then used to determine whether each participant's Hg exposure exceeded the USEPA daily reference dose of $0.1 \mu\text{g}$ of MeHg per kg of consumer body weight. Participant "Hg exposure" therefore refers to estimates of "Hg intake" divided by consumer body weight. Least squares means estimates controlling for the random effects of individual and household with Tukey's HSD post hoc pairwise comparisons ($\alpha = 0.05$) were used

to assess differences in the mean portion size and mean Hg concentration of fish meals from different sources.

Fish tissue Hg concentrations were obtained from a variety of available datasets to provide the most appropriate mean value to estimate exposure for a given meal. Measures of T-Hg concentration were used as a proxy for measures of MeHg when MeHg data were not available. The mean Hg concentrations measured in a particular species harvested from a particular water body were used whenever possible, for example, for sport-caught fish from Adirondack waters for which AFRP data are available (AFRP unpublished data). Other mean Hg concentrations for particular species (i.e., for fish purchased from stores and restaurants) were obtained from USDA monitoring of commercial fish (USDHHS and USEPA 2006), data from state agencies (NYSDEC 2007, MEDEP 2008), regional data collection efforts (NERC dataset; see Kamman et al. 2005), and data from other research and monitoring efforts (USTFA 2008). See Appendix A for all fish Hg concentrations included in exposure calculations.

Given known concentrations of Hg in sport-caught fish, we calculated the number of fish meals that would be appropriate for a given individual to consume on a monthly basis in order to not exceed the USEPA reference dose for MeHg, assuming that only a particular species was consumed. Similar calculations were performed using AFRP fish Hg data in order to provide further context within which anglers and their families can make more informed decisions about fish consumption through a more comprehensive understanding of how measures of fish Hg concentrations correspond to relative risks of Hg exposure.

Hair total mercury analysis

We evaluated the suitability of using hair T-Hg analysis as an additional means of assessing the relative risk faced by members of a particular community due to Hg exposure through fish consumption. Hair samples from voluntary participants ($N=17$) were analyzed for T-Hg in order to ground-truth exposure estimates calculated from fish consumption data with measured empirical values. Only adult family members (aged 18+ years) were eligible to participate in this component of the study. The hair collection procedure (Appendix B) was modified from the protocol used by previous efforts (e.g., Knobeloch et al. 2005). Participants indicated their interest in submitting hair samples when returning angler surveys and fish consumption records and subsequently received hair collection kits by mail in early September 2007 in order to collect samples as close to 15 September 2007 as possible. Hair sample collection kits included a cover letter, instructions for sample collection, consent forms, a brief survey assessing other possible sources of Hg exposure (e.g., dental amalgams, flu shots, or occupational exposure), a plastic sample bag, gloves, and a postage-paid envelope for sample return.

Participants were instructed to wash, rinse, and thoroughly dry their hair and ensure that it was free of conditioners, styling products, or any other substance that might interfere with the analysis, and while wearing the gloves provided, use stainless steel scissors to cut a small section of hair from the back of the head. Participants trimmed the pieces of hair to only include the $\frac{1}{2}$ inch of hair growing closest to the scalp. This hair represents the newest growth and most closely reflects Hg exposure from fish consumption during the summer months. Participants collected approximately one teaspoon (loosely packed) of hair from different locations on the back of the head. Upon receipt, hair samples were weighed, trimmed into small pieces using stainless steel scissors, and sent for analysis. Total mercury analyses using a

modified USEPA method 1631 (USEPA 2002) were conducted by CEBAM Analytical, Inc. (Seattle, Washington). CEBAM routinely analyzes a variety of biological samples for Hg, including human hair, and is the same laboratory used by the NYSDEC for measuring Hg in fish tissue.

Hair T-Hg concentrations of participants were compared to threshold recommendations provided by the USEPA and the National Academy of Sciences (NRC 2000). The relationship between participant fish consumption, Hg intake and exposure, and measured hair T-Hg concentration was assessed using multilevel models (Snijders and Bosker 1999). Log transformed participant hair T-Hg concentration (in $\mu\text{g g}^{-1}$) was the response variable for each of 26 models; household was included as a random effect in each model to account for the fact that some households had two participants. Primary fixed effects in the model set included: participant estimated mean monthly Hg intake for July, August, and the overall summer mean (“hg_7”, “hg_8”, “hg_s”; in $\mu\text{g Hg month}^{-1}$); participant estimated mean monthly Hg exposure (“exp_7”, “exp_8”, “exp_s”; in $\mu\text{g Hg kg}^{-1} \text{ month}^{-1}$); the mean number of days that participant Hg exposure exceeded the USEPA monthly reference dose (“days”; in days month^{-1}), and participant mean fish intake (“fish”; in oz month^{-1}). Each primary fixed effect was included in a model alone, as well as in an additional model that included its respective quadratic term (e.g., “hg_7*hg_7”). Each of these models was run both including and excluding the fixed effect of participant body weight (“bw”; in kg, for a total of 20 models), with the exception of the six models including the primary fixed effect of mean Hg exposure, as these estimates already accounted for body weight.

The MIXED procedure (Littell et al. 1996) in SAS (SAS Institute Inc., Cary, NC) was used for model analysis. Akaike’s Information Criterion (AIC; Burnham and Anderson 2004) model selection techniques were used to compare the relative support

for each of the 26 models from the existing dataset by ranking the models by corrected AIC value (AICc). The Δ AICc value for each model was calculated by subtracting the AICc value of the best model (i.e., the model with the lowest AICc) from that of each of the other models in the set. The AICc weight (ω_i) values were calculated by normalizing the model likelihoods and subsequently used to assess the relative support for each model from the dataset (Burnham and Anderson 2004).

Historical angling data

The Adirondack Fishery Research Program (AFRP) has compiled fifty years of angling catch records (AFRP unpublished data) – including the names of individual anglers – that were used to quantify angling patterns over time in a number of private waters and further assess relative exposure to Hg through sport fish consumption. The dataset is summarized from anglers' diaries and cards that report information such as the date and time spent on a particular fishing trip and the length, weight, and species of catch kept for consumption. These data were primarily used to characterize: 1) monthly angling trends over a given year, and 2) over time, the change in the number of fish creeled (presumably harvested for consumption), instead of caught and released.

Consumption records from summer 2007 and measures of fish Hg concentration were integrated with historical angling data from private fishing preserves and per capita commercial fish consumption data to estimate how the relative Hg exposure of anglers and their families may have changed over time. We estimated the past Hg exposure of study participants in 1960, 1970, 1980, 1990, and 2000 by adjusting current rates and patterns of the consumption of fish sport-caught from preserve waters by the decreasing proportion of fish creeled over time (AFRP unpublished data), and by adjusting participants' commercial fish consumption (stores

and restaurants) by the increasing per capita commercial fish consumption over time (USDA ERS 2008). This simplistic analysis required several assumptions, including: 1) fish Hg concentrations remained constant over time; 2) all creel fish were consumed; and 3) the consumption of fish sport-caught from other waters (i.e., not waters of private Adirondack fishing preserves) remained the same over time.

Angler surveys

Using methods outlined by Dillman (2000), we developed and distributed a mail survey in June 2007 (Appendix B). Due to privacy considerations, survey packets (containing a cover letter, angler survey, fish consumption record, and postage-paid return envelopes) were made available to club members and staff via distribution in community spaces rather than mailed directly to the homes of all potential participants. Participation was further advertised and encouraged via project flyers. The seven page angler survey was designed to characterize demographic characteristics (e.g., place of residence and age, height, weight, gender, whether breastfeeding, and years of education of all family members), angler awareness of the issue of Hg contamination and familiarity with health advisories, and important factors for decision-making about fish consumption. The angler surveys included a combination of five-point Likert-type scales, closed-ended questions, partially closed-ended questions with unordered response categories (“check boxes”), and open-ended questions to identify additional questions or concerns about Hg in the Adirondacks or fish consumption that were not addressed.

Throughout the study, outreach materials were distributed via print resources (mailings to participants, newsletter articles, and AFRP fisheries management reports) to communicate project goals and progress and to address angler concerns identified through survey responses. Other facts relevant to decision making about Hg and fish

consumption (e.g., relevant research findings, recommendations by state and federal agencies) were available to all participants, and at the completion of the study, to other anglers and families who may be consuming sport-caught fish from the Adirondack region and elsewhere in the northeastern U.S. through a project Website.

Results

Fish consumption records and mercury exposure estimates

A total of eleven males and six females ($N=17$) completed fish consumption records in summer 2007. Participants were members of 11 different households; six households had two participants each, and five households had a single participant. Consumption data for July and August 2007 were provided by all participants; June fish consumption data were provided by ten participants. Participants ranged from 21 to 83 years old, with a mean age of 58 years. No female participant was pregnant or breastfeeding. Only two households were not full-year residents of New York State.

In summer 2007, participants consumed a mean of 4.5 fish meals per month; no participant reported a mean fish consumption rate exceeding 11 fish meals per month. Of this total, the mean monthly fish consumption of all participants included 1.3 restaurant meals, 1.9 store-bought meals, 0.9 meals of fish sport-caught from preserve waters, and 0.4 meals of fish sport-caught from other sources. The mean monthly intake of fish for all participants was 25.6 oz; the maximum mean monthly fish consumption for any participant was 59.5 oz per month. Of the total fish intake, a mean of 8.8 oz came from restaurant fish meals, 8.3 oz came from store-bought fish, and 4.9 and 3.6 oz came from fish sport-caught from preserve waters and fish sport-caught from other sources, respectively (Table 2.1).

Participants consumed fish meals of 30 different species (Appendix A). Of these, the ten most frequently consumed species were obtained from both commercial

sources (i.e., purchased from stores and restaurants) and sport-caught from both private preserves and other waters (Table 2.2). Of the 30 different fish species consumed by participants in summer 2007, the species with the ten highest mean Hg concentrations together accounted for 26.4 % of all fish meals; again, fish meals of these species were obtained from commercial sources as well as sport-caught from both preserve and other waters (Table 2.3). The mean Hg concentrations of eight of the 30 consumed species (27%) exceeded 0.3 ppm, the threshold above which the USEPA recommends limiting fish consumption, while seventeen species (56.7%) had maximum measured Hg concentration values exceeding 0.3 ppm (Appendix A).

The estimated mean monthly Hg exposure for all study participants was 1.53 $\mu\text{g Hg per kg consumer body weight per month}$ ($\mu\text{g kg}^{-1} \text{ month}^{-1}$). Of this total, the mean monthly contributions of different sources included 0.27 $\mu\text{g kg}^{-1} \text{ month}^{-1}$ of Hg from restaurant meals, 0.43 $\mu\text{g kg}^{-1} \text{ month}^{-1}$ from store-bought fish meals, 0.29 $\mu\text{g kg}^{-1} \text{ month}^{-1}$ from fish sport-caught from preserve waters, and 0.54 $\mu\text{g kg}^{-1} \text{ month}^{-1}$ from fish sport-caught from other sources (Table 2.1). By combining the mean reported Hg concentration (MeHg or T-Hg as proxy when MeHg values were not available) for particular fish species consumed with the portion sizes reported for each fish meal, the overall mean monthly exposure for summer 2007 for four out of 17 participants (23.5%) exceeded the USEPA monthly reference dose for MeHg (i.e., 3.1 $\mu\text{g kg}^{-1} \text{ month}^{-1}$, assuming a 31-day month). However, the mean monthly Hg exposure for six out of 17 participants (35.3%) exceeded the threshold recommended by the USEPA for at least one month; of these participants, the mean monthly Hg exposure exceeded the monthly reference dose twice. In July and August 2007 (i.e., months for which complete consumption records were available), the number of days that participants' Hg exposure exceeded the daily reference dose ranged from 0 to 10, with a mean of 2.8 days and 1.8 days for July and August, respectively.

Table 2.1. Mean (\pm one standard deviation) number of monthly fish meals (meals month⁻¹), monthly fish intake (oz month⁻¹), and monthly Hg exposure ($\mu\text{g kg}^{-1}$ month⁻¹) for all meals ($N=182$) recorded by all study participants ($N=17$) in June, July, and August 2007. Fish meals were obtained commercially from restaurants or stores, sport-caught from fishing preserves, or sport-caught from other sources. The range of observed values is indicated parenthetically.

Source	Mean fish meals (meals month ⁻¹)	Mean fish intake (oz month ⁻¹)	Mean Hg exposure ($\mu\text{g Hg kg}^{-1}$ month ⁻¹)
Restaurant	1.32 \pm 1.36 (0 – 4.5)	8.82 \pm 9.91 (0 - 32)	0.27 \pm 0.41 (0 - 1.6)
Store	1.86 \pm 2.53 (0 – 9)	8.29 \pm 9.16 (0 - 31)	0.43 \pm 0.56 (0 - 1.66)
Sport-caught, Preserve	0.92 \pm 1.03 (0 – 3)	4.87 \pm 6.81 (0 - 20)	0.29 \pm 0.46 (0 - 1.42)
Sport-caught, Other	0.4 \pm 0.92 (0 – 3)	3.6 \pm 7.69 (0 - 22)	0.54 \pm 1.14 (0 - 3.2)
All fish meals	4.5 \pm 3.36 (0.33 - 11)	25.57 \pm 19.28 (2.67 – 59.5)	1.53 \pm 1.68 (0.01 - 5.08)

Table 2.2. Ten most frequently consumed species of fish from all meals ($N=182$) reported by 17 study participants, including source of meal, number of meals, percentage of total meals, mean and maximum measured Hg concentration (MeHg or T-Hg as available, in ppm) for each species, and source of fish Hg data (AFRP unpublished data, NYSDEC 2007, USTFA 2008; for NERC data see Kamman et al. 2005; for USFDA data see USDDHHS and USEPA 2006). Tuna (both albacore and yellowfin), walleye, and lobster (indicated in bold) were also among the fish species with the ten highest Hg concentrations of all species consumed by participants (Table 2.3).

Species	Source	Meals	% Total Meals	Mean [Hg] (ppm)	Max [Hg] (ppm)	Data Source
1. Tuna		23	13			
Albacore	Commercial, Sport-caught	21	12	0.353	0.853	USFDA
Yellowfin	Commercial	2	1	0.325	1.079	USFDA
2. Salmon		22	12			
Alaskan Wild Landlocked Atlantic	Commercial	5	3	0	0	USFDA
Other	Sport-caught	2	1	0.135	0.285	AFRP
Other	Commercial	15	8	0.014	0.19	USFDA
3. Haddock	Commercial	17	9	0.031	0.041	USFDA
4. Lake trout	Sport-caught	17	9	0.219	1.376	AFRP
5. Brook trout	Sport-caught	14	8	0.196	0.420	AFRP
6. Shrimp	Commercial	11	6	0	0.05	USFDA
7. Walleye	Sport-caught	9	5	0.447, 0.818	0.749, 4.9	NERC, NYSDEC
8. Lobster	Commercial	6	3	0.31	1.31	USFDA
9. Rainbow trout	Sport-caught	6	3	0.014	0.04	USTFA
10. Clams and mussels	Commercial	6	3	0	0	USFDA

Table 2.3. Fish species with the ten highest mean Hg concentration of all species ($N=30$) consumed by 17 participants, including source of meal, number of meals, percentage of total meals, mean and maximum measured Hg concentration (MeHg or T-Hg as available, in ppm) for each species, and source of fish Hg data (AFRP unpublished data, MEDEP 2008, NYSDEC 2007; for NERC data see Kamman et al. 2005; for USFDA data see USDDHHS and USEPA 2006). Walleye, tuna (both albacore and yellowfin), and lobster (indicated in bold) were also among the ten most frequently consumed fish species (Table 2.2).

Species	Source	Meals	% Total Meals	Mean [T-Hg] (ppm)	Max [T-Hg] (ppm)	Data Source
1. Swordfish	Commercial	2	1	0.976	3.22	USFDA
2. Walleye	Sport-caught	9	5	0.447, 0.818	0.749, 4.9	NERC, NYSDEC
3. Largemouth bass	Sport-caught	1	1	0.5	2.13	NYSDEC
4. Tuna, Albacore	Commercial, Sport-caught	21	12	0.353	0.853	USFDA
5. Smallmouth bass	Sport-caught	2	1	0.335	0.806	AFRP
6. Tuna, Yellowfin	Commercial	2	1	0.325	1.079	USFDA
7. Striped bass	Sport-caught	3	2	0.318	0.783	MEDEP
8. Lobster	Commercial	6	3	0.310	1.31	USFDA
9. Halibut	Commercial	1	1	0.252	1.52	USFDA
10. Sea bass	Commercial	1	1	0.219	0.96	USFDA

Of the 182 fish meals consumed by 17 participants in summer 2007, 29% were purchased from restaurants, 40% were store-bought, 23% were fish sport-caught from preserve waters, and 8% were fish sport-caught from other sources (Figure 2.1a). However, restaurant and store-bought fish meals contributed only 16% and 24%, respectively, of participants' total Hg intake. Meals of fish caught from preserve waters contributed 20% of participants' total Hg intake, while meals of fish sport-caught from other sources contributed 40% of participants' total Hg intake (Figure 2.1b). The source of fish meals had a significant effect on both the mean portion size ($F_{3, 163} = 6.505$, $p = 0.0003$) and mean Hg concentration ($F_{3, 104} = 21.679$, $p < 0.0001$) after controlling for the random effects of individual and household. Both the mean portion size (Figure 2.2) and mean Hg concentration (Figure 2.3) of meals of fish sport-caught from sources other than preserve waters were significantly larger than the

mean portion size and mean Hg concentration of fish meals from other sources, however, the mean portion size and Hg concentration did not differ significantly for meals from the other three sources based on available data.

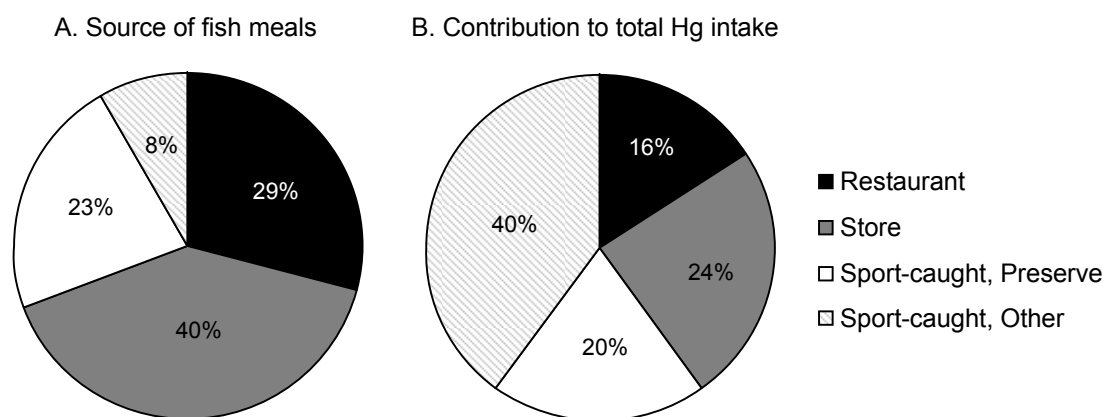


Figure 2.1. a) Source of all fish meals ($N=182$) recorded by 17 study participants in June, July, and August 2007, and b) the relative contribution of each source to participants' total Hg intake. Fish meals were purchased from restaurants or stores, sport-caught from private fishing preserves, or sport-caught from other waters. Note that the number of fish meals does not account for portion size.

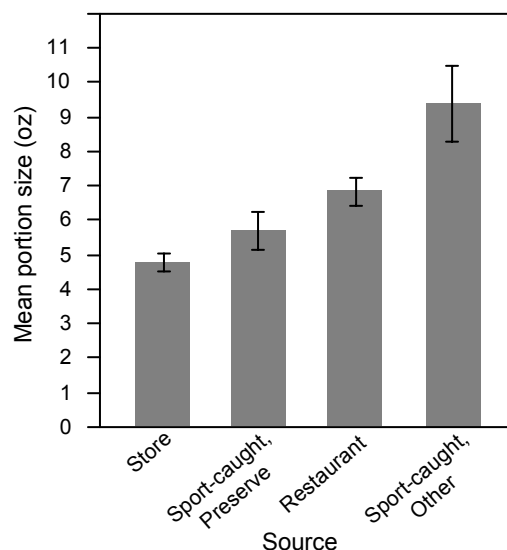


Figure 2.2. Mean portion size (oz) of fish meals purchased from stores (S; $N=73$), sport-caught from waters of private fishing preserves (SC; $N=41$), purchased from restaurants (R; $N=53$), and sport-caught from other waters (SCO; $N=15$). Error bars represent \pm one standard error of the mean.

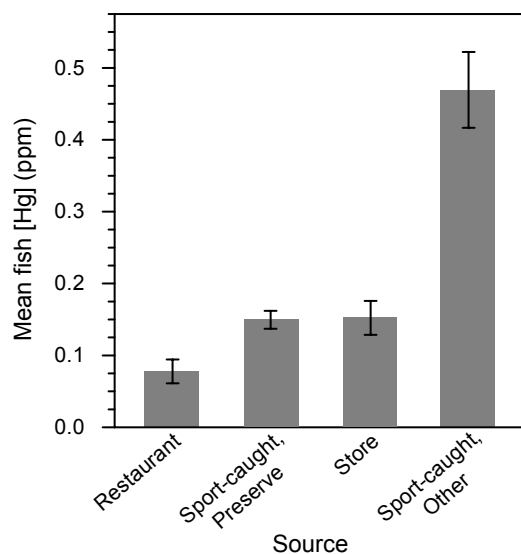


Figure 2.3. Mean Hg concentration (ppm) of fish purchased from restaurants ($N=53$), sport-caught from waters of private fishing preserves ($N=41$), purchased from stores ($N=73$), and sport-caught from other waters ($N=15$). Error bars represent \pm one standard error of the mean.

Hair mercury analysis

The mean value of measured hair T-Hg concentrations was 1.03 ppm, and concentrations from 11 out of 17 participants (64.7%) were below 1 ppm, the threshold recommended by the USEPA and the National Academy of Sciences (NRC 2000). Hair T-Hg concentrations in six out of 17 participants (35.3%) were above 1 ppm, with a maximum value of 4.4 ppm (Figure 2.4). No participant reported having occupational exposure to Hg. Six out of 17 participants (35.3%) reported having had a flu shot in the last 12 months; of these participants, two had hair T-Hg concentrations above the recommended threshold. Most participants reported having amalgam dental fillings; 13 out of 17 participants (76.5%) had at least one amalgam filling, and reported having as many as 18. Two participants reported having had fillings removed in the last 12 months, but hair T-Hg concentrations in both individuals were below recommended levels. Data characterizing other possible sources of Hg exposure were not available for two participants, one of whom had measured hair T-Hg concentrations above 1 ppm.

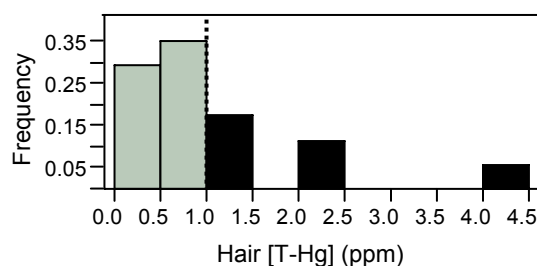


Figure 2.4. Frequency distribution of measured T-Hg concentration (ppm) in hair samples of participating Adirondack anglers and family members ($N=17$). Hair T-Hg concentrations of 35% of participants exceeded the threshold concentration of 1.0 ppm (shown in black); the USEPA and the National Academy of Sciences (NRC 2000) recommend that hair mercury concentrations remain below this level.

The estimated mean monthly Hg exposure of participants with hair T-Hg concentrations below the 1.0 ppm threshold concentration was significantly lower than

the mean monthly exposure of participants with hair T-Hg concentrations exceeding this threshold, with values of 0.72 and 3.02 $\mu\text{g kg}^{-1} \text{ month}^{-1}$, respectively ($t = -3.02$, $p = 0.02$; Figure 2.5a). Additionally, the mean monthly fish intake of participants with hair T-Hg concentrations below the 1.0 ppm threshold was significantly lower than that of participants with hair T-Hg concentrations exceeding 1.0 ppm, with mean monthly fish consumption of 17.7 and 40.1 oz month⁻¹ ($t = -2.61$, $p = 0.03$; Figure 2.5b). Similarly, the mean hair T-Hg concentration of participants whose estimated monthly Hg exposure was below the USEPA monthly reference dose of 3.1 $\mu\text{g kg}^{-1} \text{ month}^{-1}$ was lower than that of participants whose monthly Hg exposure for at least one month exceeded the reference dose, with mean hair T-Hg concentrations of 0.66 and 1.72 ppm, respectively (Figure 2.6); the difference between the log transformed mean hair T-Hg concentrations for the two groups was nearly significant ($t = -2.18$, $p = 0.06$).

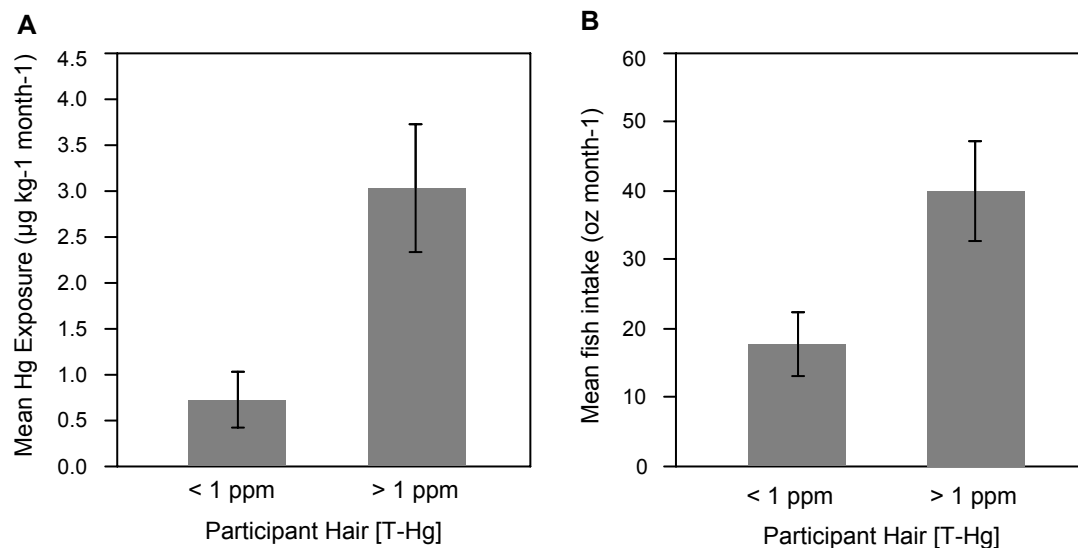


Figure 2.5. Comparison of: a) mean Hg exposure ($\mu\text{g kg}^{-1} \text{ month}^{-1}$) and b) mean fish intake (oz month⁻¹) of participants with measured hair T-Hg concentrations less than ($N=11$) and greater than ($N=6$) the 1.0 ppm threshold recommended by the USEPA and National Academy of Sciences (NRC 2000). Error bars represent \pm one standard error of the mean.

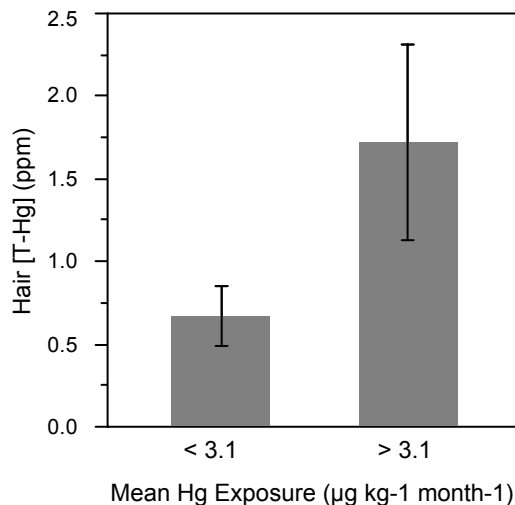


Figure 2.6. Comparison of mean measured hair T-Hg concentration (ppm) of participants with calculated mean Hg exposure less than ($N=11$) and greater than ($N=6$) the $3.1 \mu\text{g kg}^{-1} \text{ month}^{-1}$ USEPA reference dose. Error bars represent \pm one standard error of the mean.

Of the 26 multilevel models in the model set, the two models predicting log transformed participant hair T-Hg concentration with the most support from the data included two fixed effects (i.e., predictor variables): estimated participant Hg exposure for the month of August (exp_8), as well as this parameter with its quadratic term (exp_8, exp_8*exp_8; Table 2.4). Six other models had considerably less support from the dataset (i.e., $\Delta\text{AICc} < 7$; Burnham and Anderson 2004). The fixed effects in these models included the number of days participant Hg exposure exceeded the USEPA reference (days), participant Hg exposure for the month of July (exp_7), the mean participant Hg exposure for summer 2007 (exp_s); three additional models included each of these parameters along with its respective quadratic term (i.e., days, days*days; exp_7, exp_7*exp_7; and exp_s, exp_s*exp_s; Table 2.4). The remaining 18 models had essentially no support from the dataset compared to the other models. All 10 models in this model set containing the fixed effect of participant body weight (bw) had essentially no support from the data; additionally, the effect of body weight

on log transformed hair T-Hg concentration was also not significant in any of the 10 model combinations in which it was included as a variable. For the model best supported by the dataset (with fixed effects exp_8, exp_8*exp_8), approximately 10% of the variation explained by the fixed effect was accounted for at the household level; while for the model ranked second (with fixed effect exp_8), approximately 33% of the variation explained by the fixed effect was accounted for at the household level.

Table 2.4. Empirical model selection showing all models with a $\Delta AIC_c < 7$ for predicting log transformed participant hair T-Hg concentration, including values of AIC_c , ΔAIC_c , AIC_c weight (ω_i) and the model likelihood (\mathcal{L}). Fixed effects include participant estimated Hg exposure for July, August, and the overall summer mean (“exp_7”, “exp_8”, “exp_s”), the number of days estimated Hg exposure exceeded the USEPA reference dose (“days”); * indicates an interaction. All models included the random effect of household.

Model	AIC_c	ΔAIC_c	ω_i	\mathcal{L}
exp_8, exp_8*exp_8, hh	44.4	0	0.49	1.00
exp_8, hh	46.3	1.9	0.19	0.39
days, hh	47.1	2.7	0.13	0.26
days, days*days, hh	49.0	4.6	0.05	0.10
exp_s, hh	49.1	4.7	0.05	0.10
exp_7, hh	49.4	5	0.04	0.08
exp_s, exp_s*exp_s, hh	50.4	6	0.02	0.05
exp_7, exp_7*exp_7, hh	50.8	6.4	0.02	0.04

Historical angling data

Based upon 50 years of data reported from angler diaries and cards (AFRP unpublished data), the overall total catch of sport-fish species most targeted by anglers (i.e., brook trout, lake trout, landlocked salmon, rainbow trout [*Oncorhynchus mykiss*], and smallmouth bass) on privately-owned Adirondack fishing preserves has remained fairly consistent from 1960 to 2007, with a mean total annual catch of over 4300 fish of these five species (Figure 2.7). However, the percentage of fish creelied rather than caught and subsequently released has decreased over time. In the 1960s, an average of

99% of brook trout, 100% of lake trout, and 97% of smallmouth bass were creeled, whereas in 2007 only 16% of brook trout, 22% of lake trout, and 9% of smallmouth bass were creeled – and the remainder of the total catch released (Figure 2.8). Nearly 95% of all reported angling trips took place in the months of May-September.

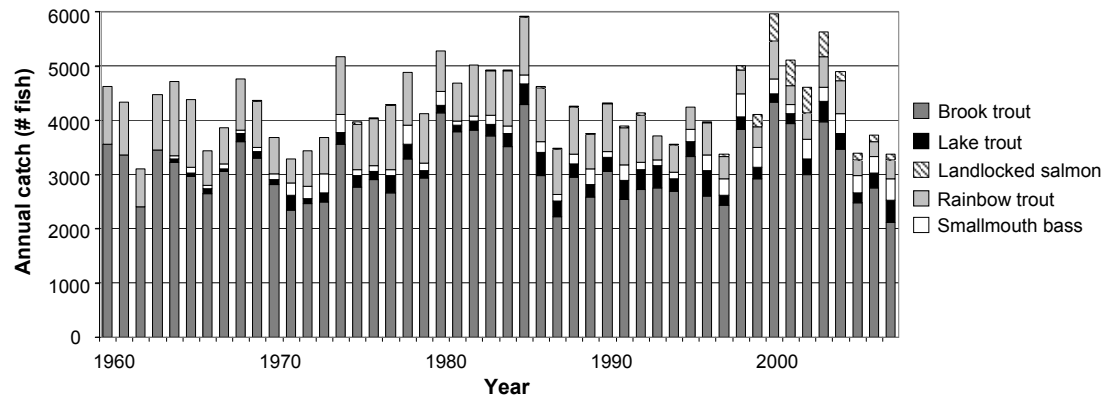


Figure 2.7. Annual reported catch of brook trout, lake trout, landlocked salmon, rainbow trout, and smallmouth bass from waters of privately-owned Adirondack fishing preserves. Smallmouth bass and lake trout data are not available for the years 1960-1962 and 1960-1963, respectively.

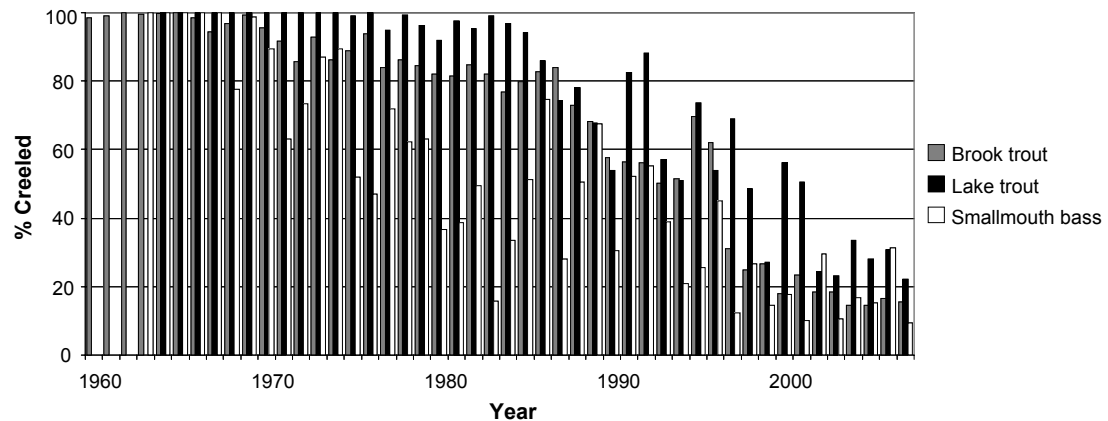


Figure 2.8. Annual percent of the total reported catch of brook trout, lake trout, and smallmouth bass from waters of privately-owned Adirondack fishing preserves that were creeled (and presumably kept for consumption) rather than released. Smallmouth bass and lake trout data are not available for the years 1960-1962 and 1960-1963, respectively.

By comparison with estimated levels of Hg exposure in 2007, the estimated mean monthly participant Hg exposure from fish sport-caught from preserve waters alone would have been one and half times greater in 2000, more than four times greater in 1980, and over six times greater in 1960 as calculated by adjusting current exposure estimates by the proportion of fish creeled in previous years. In the years 1960, 1970, 1980, and 1990, the estimated Hg exposure of 18% of participants exceeded the USEPA monthly reference dose due to Hg intake from fish sport-caught from preserve waters alone and excluding other sources. By accounting for both the decreased percentage of fish creeled from private fishing preserves over time and the increased per capita consumption of commercial fish consumption over time, the overall mean estimated Hg exposure of participants in 1960 was 1.8 times higher than of the overall mean level of exposure in 2007 (Figure 2.9). In 1960, when an average of 99% of fish were creeled (Figure 2.8) and the estimated per capita commercial fish consumption was only 10.3 pounds as compared to 16.3 pounds in 2007 (USDA ERS 2008), the estimated mean monthly Hg exposure from fish meals from all sources of 35% of participants exceeded the USEPA monthly reference dose, as compared to only 24% in summer 2007. However, the estimated mean Hg exposure of all participants from all meal sources does not exceed the USEPA reference dose in any year (Figure 2.9).

Angler surveys

Nine households participated in the angler survey component of our study. All survey participants were adults, 44 to 83 years old, with a mean age of 63.6 years. No female participants were pregnant or breastfeeding. Study participants exceeded national average educational levels; every respondent and spouse completed a

minimum of a high school education, and on average completed an additional five years of college, technical, or vocational training. Ninety-four percent of participants had at least two additional years of college, technical or vocational training, while 82% earned at least a bachelor's degree.

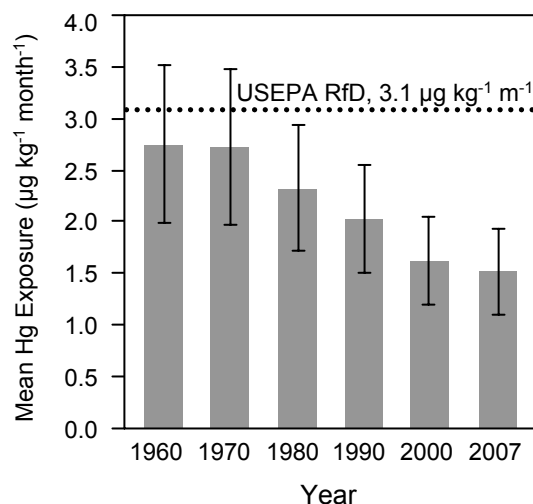


Figure 2.9. Comparison of estimated mean Hg exposure ($\mu\text{g kg}^{-1} \text{ month}^{-1}$) from participant fish consumption records in summer 2007 with estimates of exposure in past summers using historical angling data and commercial fish consumption data. Mean monthly Hg exposure for 1960, 1970, 1980, 1990, and 2000 was estimated by adjusting the summer 2007 Hg exposure by the proportion of fish creel from waters of private Adirondack fishing preserves over time (and presumably kept for consumption; AFRP unpublished data), and by changes in per capita commercial fish consumption over time (USDA ERS 2008) The consumption of fish sport-caught from other waters was assumed to have remained constant over time. Error bars represent \pm one standard error of the mean.

Anglers spent between 10 and 40 days per year angling on waters of private Adirondack fishing preserves, with a mean of 24 days per year. Responses indicated that no angler regularly (i.e., at least once per month) shared fish caught from preserve waters with other individuals outside of their household. When asked to indicate the importance of different factors when making decisions about consuming sport-caught fish, the following were reported as most important: 1) “Taste” (96% of possible

points); 2) “Whether fish may contain Hg” (87% of points); 3) “Whether fish may contain other contaminants” (84% of points); 4) “Health benefits of eating fish” (82% of points); and 5) “Sustainability of fishery” (80% of points). However, the following factors were most important to respondents when making decisions about consuming fish obtained from commercial sources (i.e., purchased from stores or restaurants): 1) “Taste” (96% of possible points); 2) “Health benefits of eating fish” (87% of points); 3) “Which species are available” (82% of points); 4) “Cost” (80% of points); and 5) “Whether fish may contain Hg” (78% of points).

Participants were very interested in learning about their own hair Hg concentrations and those of their spouses and children (if applicable). When asked how the results of hair Hg analysis may change their household’s fish consumption; participants responded as follows: 1) If family hair Hg levels were found to be below recommended levels, most participants would not change their current fish consumption behaviors; several would eat more fish or eat different species; and 2) If family hair Hg levels were found to be above recommended levels, all participants would eat less fish; several would also eat different species of fish. Respondents also reported being very interested in efforts to learn more about Hg in fish from waters of private fishing preserves, including a variety of fish species (including species not tested such as rainbow trout, forage fish such as white suckers and smelt, and endangered or rare species) from a variety of lakes (including waters both included and not included in testing efforts to date). While eight out of nine households claimed to be familiar with the NYS health advisory, only half (48%) of the responses to three questions about consumption recommendations were correct, and only three of the nine households answered all three questions correctly.

Discussion

Fish consumption and mercury exposure

In summer 2007, 17 participating Adirondack anglers and their families consumed an average of approximately 26 oz of fish each month (Table 2.1) – a rate of consumption just below the fish intake of 26.6 oz per month recommended by health professionals. In 2003, per capita fish consumption in the U.S. was approximately 16.3 pounds per year (Institute of Medicine 2007), equivalent to 21.7 oz per month. This national average is 15% lower than the mean rate of fish consumption among participants in this study, although the national data include only commercial fisheries products and do not account for fish sport-caught by recreational anglers. Additionally, data from the 1999-2000 National Health and Nutrition Examination Survey show that mean fish consumption of U.S. residents age two and older was approximately 15.5 oz per week, while the mean fish consumed by the upper quartile was more than 126 oz per week (Institute of Medicine 2007).

The mean monthly fish consumption of study participants ranged from less than 3 oz to nearly 60 oz; 65% of participants consumed less fish than the amount recommended by health professionals. In the future, should these individuals decide to increase their fish consumption per health recommendations, their monthly Hg exposure will likely correspondingly increase as well, and the rate of increase will be dependent upon the Hg concentrations in species chosen for consumption. Of the ten fish species consumed most frequently in the U.S. in 2004 (Institute of Medicine 2007), four of these species (i.e., shrimp, tuna, salmon, and clams) were also among the ten species most frequently consumed by Adirondack participants in summer 2007 (Table 2.2). Of these four species, only tuna (including albacore and yellowfin) had Hg concentrations above 0.3 ppm, the level at which the USEPA (2001b) recommends limiting fish consumption.

Of the ten fish species most frequently consumed by study participants, sport-caught species, including brook trout, lake trout, landlocked salmon, rainbow trout, and walleye, accounted for approximately 26% of all meals consumed. Of these species, walleye was the only one with a mean Hg concentration exceeding 0.3 ppm. However, given that meals of sport-caught fish comprised a significant portion of study participants' overall fish intake, and therefore their Hg exposure (Figure 2.1), we calculate consumption guidelines for fish of different Hg concentration – and reported as being consumed in this study – using the USEPA reference dose (Table 2.5). The recommendations for walleye are the most illustrative in that they highlight how greatly the recommended number of meals per month for a given fish consumer will vary with greater variability in fish Hg concentration data, particularly when high Hg concentrations are found in a particular species. For example, the mean Hg concentration of walleye from one regional dataset was 0.447 ppm (NYSDEC 2007); at this concentration, a 60 kg (132 lb) individual could consume nearly two 8 oz meals in a month and not exceed the USEPA reference dose. However, the mean Hg concentration of walleye from another region was 0.818 (from a subset of the NERC dataset; see Kamman et al. 2005), and at this concentration, the same individual could consume only one 8 oz meal per month without exceeding the reference dose. Additionally, using the maximum measured walleye Hg concentrations from each dataset, 0.749 ppm and 4.9 ppm, the same fish consumer could only consume just over one 8 oz meal per month, and only one 8 oz meal in nearly six months, respectively, without exceeding the reference dose. In contrast, the mean Hg concentration in landlocked salmon from private Adirondack waters was only 0.135 ppm (AFRP unpublished data). The same 60 kg individual could therefore consume more than six 8 oz meals per month of this species without exceeding the reference dose, or nearly 3 meals of salmon with the maximum measured Hg concentration of 0.285 ppm.

Table 2.5. The estimated number of 8 oz meals that 60 kg (132 lb) and 70 kg (154 lb) individuals can consume in a month before exceeding the USEPA reference dose (RfD) of $3.1 \mu\text{g MeHg kg}^{-1} \text{ month}^{-1}$, assuming: (A) mean fish Hg concentration and (B) maximum fish Hg concentration from available datasets. *Walleye Hg concentration data are from two datasets, see Kamman et al. 2005 (NERC dataset) and NYSDEC 2007. Other measures of fish Hg are from AFRP unpublished data.

Species	Number of 8 oz meals consumed before exceeding USEPA RfD (meals month ⁻¹)			
	(A) Mean fish [Hg] values		(B) Maximum fish [Hg] values	
	60 kg consumer	70 kg consumer	60 kg consumer	70 kg consumer
Brook trout	4.2	4.9	2.0	2.3
Lake trout	3.7	4.8	0.6	0.7
Landlocked salmon	6.1	7.1	2.9	3.4
Smallmouth bass	2.4	2.8	0.8	1
Walleye*	1.8, 1.0	2.1, 1.1	1.1, 0.2	1.3, 0.2

Although maximum Hg concentration values from a comprehensive dataset would represent the upper bound of possible exposure and therefore a worst-case scenario, it is important to note that consumption recommendations would change drastically using these data. Consuming a large amount of a fish high in Hg concentration will therefore affect an individual's mean Hg exposure for a long period of time, particularly if that individual is also consuming other fish meals. It is important to note that the number of meals that can be consumed without exceeding the reference dose will vary with the consumer's body weight. Larger individuals can consume more meals without exceeding the reference dose, however, women and children – who may be well below 60 kg in body weight – would be advised to consume fewer meals of a given fish species in order to keep their overall Hg intake below the USEPA reference dose (NRC 2000).

Estimates of Hg exposure must therefore account for the rates of consumption of particular fish species – which correspond to rates of Hg intake as determined by

the Hg concentration in those species – and also assess the relative risk by considering the gender, age, and weight of a particular fish consumer. Additionally, any assessment of the risk of possible health effects must also consider the nutritional benefits of fish consumption. Ideally, fish consumers' Hg exposure should not exceed the USEPA reference dose, yet the total intake of fish should meet the minimum recommended consumption rates. In order to obtain the nutritional benefits of fish, the Dietary Guidelines Advisory Committee and the American Heart Association recommend the consumption of at least six oz of fish week, or 26.6 oz per month (Institute of Medicine 2007). The USEPA and USFDA (2004) further clarify that children and women of childbearing age – particularly those that are pregnant, nursing, or planning to become pregnant (i.e., those populations that are most sensitive to the health effects of MeHg) should consume up to 12 oz per week, or 53.2 oz per month, of fish with lower Hg concentrations. No participant in our study reported being a member of these sensitive populations; however, it is likely that many anglers in the U.S. do share their catch with women of childbearing age or young children.

When assessing relative levels of risk from fish consumption, it is useful to consider a particular fish consumer's mean Hg exposure over time. Given that the human body is able to excrete Hg, exposure on a particular day is not a concern – even if it exceeded the daily reference dose – if the overall pattern of exposure remained below recommended levels. The overall monthly mean Hg exposures of 76% of study participants for summer 2007 were below the USEPA MeHg reference dose of $3.1 \mu\text{g kg}^{-1} \text{ month}^{-1}$. However, the estimated Hg exposure of 35% of participants exceeded the reference dose for at least one month, as did the estimated overall mean summer Hg exposure of 24% of participants, with a maximum estimated monthly Hg exposure of approximately $5 \mu\text{g kg}^{-1} \text{ month}^{-1}$ (Table 2.1). We emphasize that there is no scientific consensus regarding the expected health effects of these levels of Hg

exposure, which resulted from relatively moderate fish consumption. Additionally, our study participants did not include any children or women who were pregnant, nursing, or planning to become pregnant; restricting Hg exposure to below the reference dose would be particularly important for fish consumers among these sensitive groups (USEPA 1997).

A previous study conducted by Flaherty et al. (2003) estimated the Hg exposure of Wisconsin ice anglers using a MeHg toxicity model that incorporated consumption information obtained via interviews and fish Hg concentration data from the Wisconsin Department of Natural Resources. Using a model based on rates of fish consumption, the measured mean Hg concentrations in those fish, and rates of uptake and excretion by the human body, the authors determined that the Hg exposure of the majority of anglers (95%) did not exceed the USEPA reference dose for MeHg. This type of modeling approach may be a useful tool for community-level risk assessment, particularly when more detailed consumption data are not available. By contrast, our study instead collected detailed fish consumption data throughout the study period that allowed for a direct comparison of estimated Hg exposure through fish consumption with the USEPA reference dose, and in addition compared estimated exposure levels in humans with T-Hg values measured in hair samples.

Hair tests provide a means of ground-truthing Hg exposure estimates from fish consumption records, and similar to such estimates, measures of hair T-Hg concentration are most informative when interpreted as a measure of average exposure over time. Because it takes approximately 40 to 50 days for Hg from a given fish meal to accumulate in hair, and because hair grows at an average rate of approximately 1.1 cm each month (NRC 2000), the portion of hair clipped from nearest the scalp (approximately 1 cm) by participants on 15 September 2007 would be expected to most closely reflect fish consumption in July 2007. However, although

41% of participants collected their hair samples within two days of 15 September as instructed, on average samples were collected five days later – and two participants collected their samples 25 days late. Therefore, given average rates of Hg excretion and hair growth and the actual timing of hair sample collection, it would be expected that the measures of hair T-Hg would correspond most closely to participant estimated Hg exposure in late July and early to mid August. These inconsistencies in the date of hair sample collection, along with the inherent variability in the rates of Hg uptake and excretion and hair growth of individual participants, make it difficult to correlate measured hair Hg concentrations with fish consumption and corresponding Hg exposure estimates at a specific point in time.

Despite these limitations, it is informative to focus on comparisons of measured hair T-Hg values with estimates of mean Hg exposure in summer 2007. The results from an empirical model selection analysis using AIC indicated that the log transformed values of participant hair T-Hg concentration were best explained by multilevel models accounting for the random effect of household and including one primary fixed effect: the estimated Hg exposure in August (and its respective quadratic term; Table 2.4). Additional models that included alternate estimates of Hg exposure, including the number of days that estimated exposure exceeded the USEPA reference dose, the mean estimated exposure for the summer, and the mean estimated exposure for July (along with respective quadratic terms), were ranked relatively highly within the model set. Given the timing of hair sample collection, the variability in rates of individual hair growth and Hg excretion, and perhaps more importantly, the variability in measures of fish Hg concentrations used for exposure estimates, these results are not surprising. These six models with ΔAIC_c values of less than seven received some support from the data relative to the first two models, although the probability that these models would be the best model in the set is considerably less

than the two models with ΔAIC_c values of less than two (Burnham and Anderson 2004; Table 2.4).

Models including estimated Hg intake (which unlike Hg exposure, did not take into account participant body weight) for July, August, and the overall summer mean received essentially no support from the data. These results indicate that, as expected, Hg exposure estimates that accounted for participant body weight better predicted hair T-Hg concentration, likely because the amount of Hg that can be safely consumed and efficiently excreted will vary with an individual's body size. Models that included body weight as a separate parameter were not supported by the dataset, nor were models that included participant's mean monthly fish consumption. If participant fish consumption had been a better predictor of hair T-Hg concentration than estimated Hg exposure, the accuracy of the fish Hg concentration values used to estimate exposure would have been questionable. The amount of fish consumed will influence overall Hg exposure, but the Hg concentration of fish consumed – which in this study were not measured directly – will more directly predict the actual level and timing of exposure.

As with calculated exposure estimates, the measured hair T-Hg concentrations of 65% of study participants were below 1.0 ppm (Figure 2.4), which is the hair Hg concentration that would be expected in an individual exposed to an amount of Hg corresponding to the USEPA reference dose. The USEPA and the National Academy of Sciences recommend that hair Hg concentrations do not exceed this threshold; body Hg concentrations corresponding to or below this level are not expected to result in health effects over an individual's lifetime (NRC 2000). The maximum measured hair T-Hg concentration in our study was 4.4 ppm, which is still well below 11 ppm – the hair Hg concentration that corresponds to the benchmark dose exposure level set by the USEPA. The benchmark dose is based on data indicating that at this level of

exposure, 10 percent of births would be expected to show neurological defects (NRC 2000). As with the reference dose, it is particularly important that women who are pregnant, nursing a baby, or planning to become pregnant do not exceed this threshold. Individuals in these sensitive groups are advised to follow recommendations from the USEPA and state consumption advisories to avoid fish with higher levels of Hg. After carefully considering the benefits of fish consumption, it may be appropriate for these individuals to reduce their consumption of other fish as well.

The range (0.14 ppm to 4.44 ppm) and mean (1.03 ppm) of hair T-Hg concentrations measured in our study participants are comparable to those observed in other studies, although previous data collection efforts have largely focused on measurements of the hair Hg concentration of women and children. For example, the 90th percentile hair Hg concentration of women of childbearing age was 1.4 ppm in the 1999 National Health and Nutrition Examination Study (CDC 2001). Additionally, the results of a statewide Hg monitoring program in Alaska indicated that the mean hair Hg concentrations of pregnant women and other women of childbearing age were 0.72 ppm and 1.12 ppm, respectively; hair Hg concentrations in 77% of women of childbearing age were below 1.0 ppm (Arnold et al. 2005). In another study, hair Hg concentrations in women of childbearing age ranged from 0.005 to 4.62 ppm, with an overall mean of 0.29 ppm, and were correlated with rates of fish consumption (Knobeloch et al. 2005). Still other studies found mean hair Hg concentrations ranging from 0.3 to 1.0 ppm (Smith et al. 1997, USEPA 1997, Stern et al. 2001).

All hair Hg data in our study – and nearly all data from other studies – are well below the World Health Organization’s (WHO) “No Observed Effect Level” of 14 ppm Hg calculated from available epidemiological data; at this level, no appreciable adverse effects in fetuses would be expected (FAO and WHO 2003). It is worth

noting, however, that the USEPA weekly reference dose of $0.7 \mu\text{g kg}^{-1} \text{ week}^{-1}$ is considerably more conservative than the WHO Permitted Tolerable Weekly Intake level of $1.6 \mu\text{g kg}^{-1} \text{ week}^{-1}$; this threshold adjusts the level of continual exposure at which no appreciable health effects in children would be expected in order to be sufficiently protective of developing fetuses (FAO and WHO 2003).

Considerations for risk interpretation and decision making

The measured hair T-Hg concentrations of 35% of study participants exceeded the 1.0 ppm threshold recommended by the USEPA and the National Academy of Sciences; similarly, the estimated Hg exposure of 35% of participants exceeded the USEPA reference dose for at least one month in summer 2007. Multilevel models that included estimates of Hg exposure as independent variables received the most support from the data within the model set as the strongest predictors of measured hair T-Hg concentration. Furthermore, the mean hair T-Hg concentration of participants whose estimated Hg exposure exceeded the USEPA reference dose was significantly greater than that of participants with Hg exposure below the reference dose, and the estimated mean Hg exposure of participants with hair T-Hg concentrations above the recommended 1.0 ppm threshold was significantly higher.

Of the six participants whose estimated Hg intake exceeded the USEPA reference dose, measured hair T-Hg concentrations in five of these six individuals also exceeded 1.0 ppm. This discrepancy is informative and highlights how the availability of fish Hg data or consumption data can limit risk assessment. One participant had a hair T-Hg concentration of 2.33 ppm, but this individual's exposure estimate did not exceed the USEPA reference dose based on available consumption data. However, this participant did not keep comprehensive records during the study period; therefore, it is only known that the participant did not consume any sport-caught fish and

consumed supermarket fish (of unknown species) twice per month. Given that the particular species consumed were not recorded, monthly Hg intake was estimated using the mean Hg values for the ten species of fish purchased most frequently in the U.S. (Institute of Medicine 2007). This approach clearly is less likely to have reflected the actual Hg intake from the meals consumed than if appropriate species-specific Hg data had been used – emphasizing the need for complete consumption records to accurately assess risk.

Similarly, another participant had a relatively low hair T-Hg concentration of 0.3 ppm, despite their estimated Hg intake for the month of June having exceeded the USEPA reference dose by nearly threefold. There are two probable scenarios to explain this discrepancy, both of which illustrate the need for consumption records containing sufficient detail about not only the species of fish consumed, but also the timing, size, and source of meals. This participant's estimated Hg exposure was primarily elevated due to three large (16 oz each) meals of walleye sport-caught from the Canadian province of Quebec and consumed in late June. A mean Hg concentration of 0.818 ppm was obtained from existing data from the northeastern U.S. (from a subset of the NERC dataset; see Kamman et al. 2005). Given that this concentration is quite high, well above the 0.3 ppm threshold at which the USEPA (2001b) recommends limiting fish consumption, and that the 16 oz portions for each meal were quite large, these three meals alone greatly elevated this participant's monthly exposure for June, as well as this individual's overall mean summer exposure.

However, we have no way of ascertaining whether the Hg concentration in the particular walleye consumed by this participant were in fact 0.818 ppm; available data indicated that measured Hg concentrations from walleye in Quebec ranged from as low as 0.08 ppm to as high as 4.9 ppm ($N=1028$ samples). The actual Hg

concentration in the fish consumed could therefore have been nearly an order of magnitude lower – or nearly six times greater – than the values used for exposure calculations. Furthermore, given that all other meals consumed by this participant were relatively low in Hg, the pulse dose of Hg from these walleye meals may not have been reflected in the hair sample due to individual variability in rates of Hg uptake and excretion and hair growth. This example again illustrates that in most situations, it is appropriate to assess relative risk through estimates of mean Hg exposure over longer periods of time; the relative risk of sustained elevated Hg intake is typically higher than that of occasional meals resulting in periodic elevated Hg intake. However, a pulse dose of Hg – even if the elevated level of exposure is not sustained for more than a very brief period of time – could increase the risk of health effects if women who are pregnant, nursing, or planning to become pregnant, infants, or young children are exposed to Hg levels that exceed the USEPA reference dose during critical periods of development (NRC 2000).

It is important to note that participant monthly Hg exposures were estimated using the mean Hg concentration data available for a particular species (and from a particular lake or region, if available) in order to obtain the best estimate of mean exposure over time. To provide a basis for comparison, if the maximum Hg concentration values for particular species from existing datasets were instead used in the same exposure calculations for our study participants, the mean monthly Hg exposure of 59% of study participants (instead of 35%) would have exceeded the USEPA reference dose for at least one month in summer 2007. Risk assessments, and subsequently risk communication efforts, will therefore be fundamentally limited by the availability of data quantifying Hg concentrations in fish, as well as by the variability of measures of fish Hg concentration as described above. These calculations clearly indicate the need to continue to develop datasets quantifying Hg

concentrations in fish consumed by humans at particular locations (i.e., specific to particular bodies of water) – while also accurately characterizing the consumption behaviors of fish consumers. Additionally, given that the older, larger predatory fish targeted by anglers tend to bioaccumulate higher concentrations of Hg, it is important to target both the species and sizes of fish consumed (Lepak et al., *Submitted*).

Comprehensive fish Hg datasets, together with detailed characterizations of fish consumption – including the source, portion size, and timing of fish meals – are therefore essential for accurately assessing and interpreting the relative risks to a particular population of fish consumers. Such data would assist professionals involved in risk assessment and risk communication in fostering more informed, science-based decision making about fish consumption. Recent research on Hg in fish has focused on identifying and categorizing regions of particular concern using specific fish species as indicators of Hg contamination (Driscoll et al. 2007, Evers et al. 2007) and additional efforts have synthesized Hg data from fish tissue monitoring networks across northeastern North America (Kamman et al. 2005, NEIWPCC 2007). Efforts such as these are useful for identifying regions with the highest levels of Hg contamination; however, once such areas have been identified, it is essential to select appropriate indicator species and locations for future data collection.

By selecting target or indicator species of fish that are harvested and consumed by humans – and have the highest Hg concentrations relative to other species within that region, thereby posing the greatest risks to fish consumers – public health agencies can more effectively identify areas where the consumption of Hg-contaminated sport fish poses threats to human health (Lepak et al. *Submitted*). However, the relative risk of a given level of Hg exposure to a particular fish consumer is also dependent upon the sensitivity of that individual to possible health effects (e.g., the developing nervous systems of fetuses and young children are

particularly susceptible to harm). Targeted risk assessments and subsequent risk communication efforts will be more appropriate – and informative – for a particular group of fish consumers if relevant data are interpreted comprehensively within the context of how available data can inform decision making by fish consumers to reduce their Hg exposure.

Consumption advisories issued by state agencies currently comprise the most comprehensive risk communication effort for disseminating information about contaminants in non-commercial fisheries. As such, it is essential that research and monitoring efforts provide sufficient data for state and federal public health agencies to make informed decisions while developing fish consumption advisories. Data indicating the presence of potential threats to human health should be clearly communicated in order to provide consumers with the resources to make informed decisions about fish consumption. Consistency is an important consideration for scientists, public health agencies, resource managers, and policymakers responsible for identifying and managing areas where Hg contamination is a concern. Currently, all states within the northeastern U.S. have issued statewide advisories that recommend limiting the consumption of fish from all freshwaters, and in some cases also provide additional advice for particular species, regions or listed water bodies. The advisories for all seven of the northeastern states are consistent with the USEPA and USFDA recommendation that individuals most sensitive to the toxicological effects of MeHg (i.e., women who are pregnant, nursing, or may become pregnant, and children) should further limit their fish consumption (USEPA 2001a, USEPA and USFDA 2004). However, given the need to clearly communicate information about Hg in fish, it is important to note several discrepancies between the fish consumption advisories issued from these northeastern states alone.

Fish species, water bodies, and regions of particular concern have been identified independently in each of the northeastern states, and disparate advisories have been developed to reflect these specific concerns. Yet inconsistencies in data collection have led to situations in which one state may have data showing that a species should be listed in the state advisory, while a neighboring state may not have sufficient data to include that particular species in its advisory. For example, the Vermont fish advisory recommends that sensitive groups limit their consumption of lake trout to one meal per month – the same advice offered for other predatory fish species such as smallmouth bass and chain pickerel (VTDOH 2008). By contrast, the New York State health advisory recommends that sensitive groups avoid consuming pickerel and smallmouth bass entirely (NYSDOH 2008), but makes no specific mention of lake trout in the general advisory despite the fact that this large, predatory species would be expected to have higher Hg concentrations based on data collected previously (Kamman et al. 2005, see Figure 1). Furthermore, the state of Connecticut advises unlimited consumption of “most trout” – thus offering the same advice for species such as lake trout that would be expected to be relatively high in Hg concentration and species such as brook trout and brown trout (*Salmo trutta*) that are generally lower in Hg concentration due to differences in diet and faster growth (CTDPH 2008). Additionally, many water bodies do not have specific advisories regarding fish known to be contaminated and consumed, as is again the case in New York, where no general advice is provided regarding the consumption of lake trout from the state’s waters despite the availability of broad regional data from the eastern U.S. showing relatively high Hg concentrations within this species (Kamman et al. 2005, AFRP unpublished data).

These types of inconsistencies between neighboring states may cause great confusion among interested anglers and highlight the need to gather sufficient data

characterizing Hg concentrations in the fish species consumed by humans, and to synthesize and communicate this information consistently. A generalized advisory will not always be suitable for all water bodies due to the inherent variability of fish Hg concentration across aquatic ecosystems. However, carefully selecting appropriate indicator species to develop more complete datasets and fully utilizing the data that are currently available can minimize many of these inconsistencies. This is similar to the more broadly recognized need – orchestrated by federal agencies such as the USEPA – to develop consistent criteria for risk assessment, advisory development, and communicating which sensitive populations are most at risk. Differences in consumption advisories reflect the inherent complexity and variability of dietary exposure to MeHg and the uncertainty regarding the negative health effects of MeHg intake through moderate fish consumption. Sensitive populations are defined differently in all seven northeastern state advisories, as are the thresholds of fish tissue Hg concentration used to develop consumption advisories (Table 2.6). Federal agencies offer additional recommendations regarding fish consumption, and further confusion may result from an incomplete understanding of these guidelines (Institute of Medicine 2007).

Although consistency in recommendations is important to avoid confusion on the part of fish consumers, the value of issuing blanket advisories throughout a state (e.g., NY) or geographic region (e.g., the Adirondack and Catskill Mountain region) may be limited if the demographics and fish consumption behaviors of fish consumers in a particular locale are not taken into account (Burger et al. 2007). Other researchers have discussed the influences of economic status, education level, cultural beliefs, appreciation of taste, ethnicity, health concerns, income, age, and gender on decision making about fish consumption (Strauss 2004, Verbeke and Vackier 2005). Respondents to angler surveys in our Adirondack study ($N=9$ households) reported

similar influences and indicated that taste, whether fish may contain Hg or other contaminants, health benefits, and fishery sustainability were most important for making decisions about consuming sport-caught fish. When making decisions about consuming fish obtained from commercial sources (i.e., purchased from stores or restaurants), respondents in our Adirondack study also deemed taste, health benefits, and whether fish may contain Hg as the most important factors; considerations of cost and the commercial availability of particular species were important as well.

Table 2.6. Summary of sensitive populations and fish tissue mercury concentrations considered when developing fish consumption advisories for seven states in the northeastern United States (NEIWPCC 2007).

State	Sensitive population	Fish [Hg] (ppm)
CT	Pregnant and nursing women, women who plan to become pregnant within one year, children under 6	0.1
MA	Pregnant and nursing women, women of child-bearing age, children under 12	0.2
ME	Pregnant and nursing women, women who may get pregnant, children under 8	0.3
NH	Pregnant and nursing women, women who may get pregnant, children under 7	0.3
NY	Women of childbearing age, infants, children under 15	1.0
RI	Pregnant and nursing women, women who plan to become pregnant within one year, young children	0.3
VT	Women of childbearing age (particularly pregnant and nursing women, women planning to get pregnant), children under 6	0.3

Participants in our study are relatively affluent (e.g., are affiliated with private fishing preserves) and well-educated (e.g., 82% of study participants have at least a bachelor's degree, as compared to the national average of 27%; USCB 2008) and are therefore less likely to be constrained by food costs and arguably more likely to have access to resources to facilitate more informed health decisions. However, fish consumers in lower socioeconomic demographics are more likely to purchase more lower-cost foods, including fish, regardless of the Hg content of that fish. It is also interesting to note that study participants considered the sustainability of a particular

fishery as more important for decision making about sport-caught fish, which is representative of the balance that managers must try to achieve between maintaining fisheries for recreational angling with preserving the ecological integrity of aquatic systems.

Future directions

This analysis illustrates how a comprehensive approach to data collection can characterize the Hg exposure of fish consumers and thereby provide information for more informed decision making about fish consumption, particularly about sport-caught fish. By ground-truthing Hg exposure estimates from consumption records with measured hair T-Hg values, comparing rates of Hg exposure to recommended thresholds, and characterizing angling and consumption patterns over time, we provide a more complete perspective of how Hg contamination affects fish consumers. Given that the estimated Hg exposure of 35% of study participants exceeded the USEPA reference dose, and 35% of participant hair T-Hg concentrations exceeded the recommended threshold, we conclude that Hg exposure can be accurately estimated from fish consumption records. This approach requires measures of Hg concentration in fish consumed by humans, along with detailed information about the portion size and rate of consumption of meals of particular fish species from both sport-caught and commercial sources. The relative risk of possible health effects of a given level of Hg exposure will depend on the sensitivity of a particular fish consumer; risk assessment and risk communication professionals can then develop targeted risk communication materials to provide recommendations for appropriate fish consumption behaviors to foster informed decision making to reduce Hg exposure if needed (Figure 2.10).

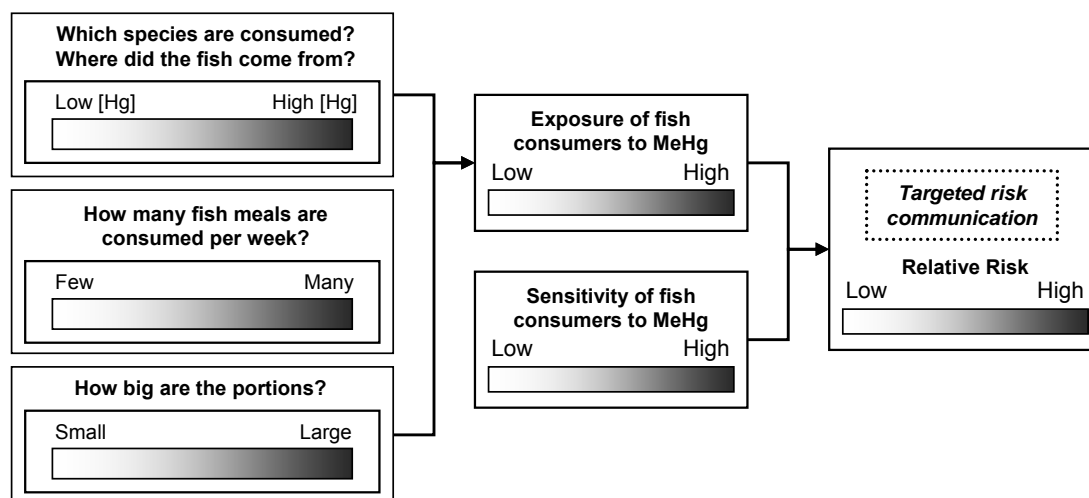


Figure 2.10. Quantifying the species and source (and the Hg concentration), consumption rate, and portion size of fish meals allows for estimates of Hg exposure. The relative risk of possible health effects of a given level of Hg exposure will depend on the sensitivity of a particular fish consumer; targeted risk communication materials can then provide recommendations for appropriate fish consumption behaviors to reduce Hg exposure if needed.

Although the scope of this study was limited to a subset of anglers and families affiliated with privately-owned Adirondack preserves, the approach to data collection and interpretation used in this analysis is applicable to any community where there are concerns about the relative risks of Hg exposure from fish consumption. Sport and subsistence anglers typically consume more fish than the general population (Burger 2000), yet no comprehensive nationwide information regarding rates of sport fish consumption are available, largely due to the difficulty of determining whether fish caught by anglers are actually consumed. Our Adirondack study provides both present-day and historical perspectives of how Hg exposure is affected by both angling and fish consumption practices. Specifically, Hg exposure is estimated to have decreased with the notable decline in the percentage of fish creel and kept for consumption from the waters of private Adirondack fishing preserves, likely due to a

shifting cultural norm among the angling community to catch and release fish in order to maintain a sustainable fishery. By contrast, Hg exposure from fish meals purchased from stores and restaurants is estimated to have increased over time as per capita consumption rates of commercial fisheries products have increased. These types of community-level or national-level data provide a broader framework for interpreting individual fish consumption patterns and can improve risk communication efforts. Information about Hg concentrations in fish and other research findings, as well as consumption recommendations from state and federal advisories, will be more salient to consumers when presented in a context relevant to the fish consumption patterns of particular communities.

Therefore, it is important for future efforts to identify those individuals who would most benefit from a more complete characterization of risk (e.g., due to a higher sensitivity to the health effects of Hg, or high levels of Hg exposure) to foster more informed decision making about fish consumption, thereby minimizing Hg exposure, and to also consider how risk information can be presented to best address the concerns of a given fish consumer. The responses of study participants to open-ended questions about what additional information they would like to know about Hg in Adirondack waters provided examples of such concerns. Some participant questions may be answered with existing resources, such as how Hg accumulates in fish tissue, whether the amount of Hg in a given fish meal is affected by cooking method, and whether certain parts of the fish (e.g., fatty belly meat) may have higher Hg concentrations than other parts. However, other participant concerns reflect the need for future research, such as continued data collection to characterize both current Hg concentrations in particular fish species and trends in Hg concentration over time, the need for scientific consensus regarding the long-term health effects of consuming fish with moderate to high Hg levels, and the reasons for discrepancies in health advisories

among different agencies; such information must also then be communicated clearly and consistently.

Presently, limited datasets, uncertainty about health effects, and inconsistent consumption recommendations challenge the ability of fish consumers to make informed decisions about how best to reduce their exposure to Hg while still obtaining the nutritional benefits of fish consumption. Achieving this balance between known health benefits and potential health risks is particularly difficult for anglers and families consuming sport-caught fish. Datasets characterizing Hg concentrations in the species and sizes of fish consumed are often incomplete, and this information is often presented inconsistently by neighboring states due to different policy decisions about how to develop health advisories and communicate information to fish consumers, particularly those most sensitive to the potential health effects of Hg exposure (e.g., women of childbearing age, infants, and young children).

Despite these limitations, science-based decision making about fish consumption can likely be facilitated using dialectical risk messages that assist fish consumers in evaluating pertinent research findings to obtain information appropriate for their particular situation. For groups of fish consumers most sensitive to health effects, risk communications with more persuasive message structures, such as the USEPA and USFDA (2004) joint advisory for commercial fish, are arguably appropriate in order to take a precautionary approach to preventing health effects resulting from Hg exposure during key developmental stages. However, even persuasive message structures require fairly complex decision making in order for fish consumers to effectively select fish species that are low in Hg concentration yet still provide nutritional benefits. By presenting risk information within a context appropriate for the demographics and social norms of the target audience – namely the fish consumption behaviors and preferences of particular groups of fish consumers –

an individual fish consumer will be able to interpret available data within the context of his or her existing knowledge structures and social influences, and will be better equipped to weigh the benefits and risks of fish consumption.

More importantly, health advisories should strive to present consumption recommendations to fish consumers using “best practices” from risk communications research (see Williamson 2007); however, these communication strategies are contingent upon the availability of data characterizing Hg concentrations in the fish consumed by humans in particular locations. Ideally, in order for an individual to make an informed decision about the species they choose to consume, how often, and in what quantities, health advisories and other risk communications efforts would provide consumption guidelines based on measures of Hg concentration in the sizes and species of fish from sources preferred by and available to particular groups of fish consumers. Although it will likely never be feasible to know the Hg concentration in any particular fish meal, it is arguably important to continue to augment existing datasets to include sufficient information (i.e., sufficient for informed advisory development and decision making about fish consumption) for those species consumed by humans for which data are limited or nonexistent, and for species with high or variable Hg concentration. Additionally, risk communications efforts will be most effective at reducing Hg exposure if they are targeted at those individuals who are most susceptible to the health risks of Hg exposure, and at subpopulations such as anglers that consume more fish than the general population.

Future assessments of the risks of Hg exposure can therefore be improved by continuing to discuss the limitations of existing data and characterizing – and minimizing – sources of variability and uncertainty (Table 2.7). By measuring Hg concentrations in fish species consumed by humans, and surveying the patterns of fish consumption among particular communities, we can better characterize the levels of

Table 2.7. Sources of uncertainty and variability that influence assessment of the relative risks of Hg exposure, and subsequent decision making about fish consumption.

Source of uncertainty:	Suggested solutions:
<i>Limited fish [Hg] data</i>	Targeted data collection to quantify [Hg] in fish species consumed in particular regions
<i>Variable fish [Hg] data</i>	Research to better characterize and model Hg bioaccumulation in fish; continued data collection to augment existing datasets and characterize variability
<i>MeHg vs. T-Hg</i>	Research to characterize relative proportions of MeHg and T-Hg in different fish species
<i>Unknown fish consumption patterns</i>	Quantify the source, portion size, species, and timing of fish meals consumed through surveys or fish consumption records of targeted populations for whom fish Hg intake is a concern (e.g., women of childbearing age, subsistence fishers, recreational anglers)
<i>Dose response</i>	Assessment of existing and future studies to characterize the variability in individual rates of Hg uptake, excretion, and hair growth
<i>Health effects</i>	Research into the effects of both moderate and high Hg exposure on fish consumers, particular sensitive subpopulations
<i>Inconsistent consumption guidelines</i>	Use consistent guidelines for advisory development in neighboring states, ensure that health advisories comprehensively address recommendations for species consumed by humans in particular regions
<i>Inconsistent sensitive consumers</i>	Consistently define subpopulations of fish consumers that are most sensitive to the health effects of MeHg exposure (e.g., fetuses, women of childbearing age, young children)
<i>Efficacy of health advisories</i>	Evaluation of existing risk assessment tools and exploration of alternative means of communicating information to foster informed decision making about behaviors that reduce risk

Hg exposure through fish consumption. The relevance of these exposure estimates will become increasingly meaningful to individual fish consumers with improved understanding of the true health effects of Hg exposure, and science-based decision making can thereby be facilitated through clear and consistent communications of relevant risk information.

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CHAPTER 3

MERCURY CONTAMINATION IN SPORT FISH IN THE NORTHEASTERN UNITED STATES: CONSIDERATIONS FOR FUTURE DATA COLLECTION

Abstract

The northeastern United States is influenced by high rates of atmospheric deposition of mercury. Subsequent integration of methylmercury into aquatic food webs results in contamination levels in fish high enough to present concerns for human health. Resource and sampling limitations have hindered comprehensive understanding of mercury in the environment and relative levels of methylmercury exposure through fish consumption. Because of these limitations, data collection should maximize the benefits of information gained by monitoring programs. Here we review recent efforts to collect and integrate fish mercury data and provide suggestions to improve and focus future research and monitoring efforts to better address threats to human health. By selecting appropriate target species – those species and sizes of fish harvested for consumption and those with the highest and most variable mercury concentrations in a given location – health and fisheries professionals can more comprehensively advise fish consumers and inform the protection of human health.

Introduction

Despite two decades of mercury (Hg) research and monitoring efforts, no consensus has been reached regarding the selection of appropriate target fish species for monitoring efforts or the criteria used to issue fish consumption advisories. This lack of consensus has resulted in the development of disparate consumption advisories

in different states, as well as inconsistent definitions of consumer groups at risk from Hg exposure. The scope of Hg testing is inherently limited by financial and logistical constraints, therefore it is particularly important to identify fish species, sizes and testing locations that will provide the most beneficial and relevant information to safeguard human health. The most important factors to consider when determining the species of fish and locations from which to collect data for the development of consumption advisories are: 1) the rate at which a given fish species is consumed by humans in a given location, 2) the concentration and variability of methylmercury (MeHg) in the fish consumed, and 3) the minimum length a fish must exceed to be legally harvested for consumption. We recommend that these three factors be considered for the planning and implementation of future data collection efforts if the ultimate goal is to inform the protection of human health – and present our rationale for these priorities in this forum.

Mercury contamination and bioaccumulation in freshwater systems in northeastern North America have been of concern for the last two decades, prompting many scientists to pursue studies of factors leading to high Hg concentrations in biota consumed by humans, particularly sport fish. Statewide fish consumption advisories have been developed in all states of the northeastern United States in order to protect consumers from potential health threats. Additionally, the issue of Hg contamination continues to be salient with policymakers, as evidenced by federal legislation proposed in 2007 to establish a comprehensive national Hg monitoring program (US House 2007, US Senate 2007). Recent efforts by researchers, state and federal agencies, and various governmental authorities emphasize the ongoing need to address the issue of Hg contamination at both the national scale and in regions with particularly high Hg levels in biota, such as the northeastern United States.

Here we suggest criteria that researchers, agencies and governments can use to select appropriate target species for Hg testing to ensure that the data sets used to develop fish consumption advisories are as complete as possible and relevant to consumers. We emphasize that from the standpoint of risk assessment and the protection of human health, it is especially important to collect data for the species and sizes of fish that are consumed by humans in particular locations. We provide a brief background of Hg contamination in fish, then focus on three related initiatives: (1) an effort to identify areas of high Hg concentration in fish and other biota through monitoring programs in northeastern North America (Driscoll et al. 2007, Evers et al. 2007), (2) an effort to establish a uniform Total Maximum Daily Load (TMDL) methodology across states in the northeastern United States (NEIWPCC 2007), and (3) an effort to develop a comprehensive national Hg monitoring network (Harris et al. 2007, US House 2007, US Senate 2007). By clearly synthesizing and communicating available information, and by identifying and understanding the strengths and limitations of recent efforts, scientists, policymakers, public health agencies, resource managers and fish consumers can more comprehensively address the challenges presented by Hg contamination.

Mercury in the Environment and Subsequent Human Health Effects

Many aspects of Hg contamination have been evaluated during recent decades. For example, it has been shown that the northeastern United States is strongly influenced by atmospheric deposition of Hg (NADP 2008), and subsequent integration into aquatic food webs results in high Hg concentrations in aquatic biota (Driscoll et al. 1994, Chen et al. 2005, Kamman et al. 2005). Fish and other aquatic organisms accumulate Hg in their tissues primarily through bioaccumulation as contaminants move throughout food webs (USEPA 2001a, Power et al. 2002). The characteristics

of the fish itself (i.e., its diet, age, and size), the Hg input to a particular area, and biogeochemical dynamics influenced by a suite of watershed characteristics all affect the MeHg concentration within a particular individual fish (Driscoll et al. 1994, Power et al. 2002, Johnston et al. 2003). In general, larger, older, piscivorous fish (those that eat other fish) tend to have elevated Hg concentrations, thereby representing an increased risk to human consumers relative to younger, smaller fish that are herbivorous or omnivorous (Bahnick et al. 1994, Power et al. 2002). It is generally assumed that MeHg – the most toxic form of mercury – comprises more than 95% of the total Hg (T-Hg) in sport fish (Bloom 1992), but T-Hg is often measured as a proxy for MeHg due to the higher expense of MeHg analyses. The terms used in this paper include: “MeHg” (when the methylated form of mercury is being discussed), “T-Hg” (when total mercury is being discussed) and “mercury” (when more than one form of mercury is being discussed).

Management actions – such as stocking fish and regulating harvest rates – can alter the structure of lake food webs and thereby influence Hg concentrations of resident fish (Göthberg 1983, Verta 1990, Rask et al. 1996). Natural variation in food webs (e.g., fish die-offs) and lake characteristics (e.g., pH and total phosphorus) can also result in unexpected changes in Hg dynamics (Rask et al. 1996, Driscoll et al. 2007). These types of changes can occur rapidly and as such, it is important to recognize lake and food web characteristics that influence Hg bioaccumulation in fish and therefore affect human exposure to Hg through fish consumption. Despite ongoing attention to Hg pollution and potential impacts upon consumers, the degree and variability of contaminant levels in many water bodies and popular sport fish within them remains uncharacterized.

Methylmercury is a potent neurotoxin and a known concern for human health, particularly with regard to the developing nervous systems during fetal and early child

development (For a complete review of health effects, see USEPA 1997, NRC 2000, Institute of Medicine 2007, Mergler et al. 2007). Although MeHg is gradually eliminated from the body, it can accumulate in the blood stream over time if consumption levels exceed the body's capacity for excretion (USEPA 2001a, USEPA and USFDA 2004). The USEPA (2001b) therefore recommends that Hg concentrations in fish should not exceed 0.3 parts per million (ppm), or 0.3 micrograms (μg) MeHg per gram (g) fish, given assumptions about fish consumer body weight and fish intake. In other words, the amount of fish that can be consumed without exceeding the USEPA reference dose varies with the individual's body weight and the concentration of mercury found in the fish (NRC 2000). Despite the health concerns associated with MeHg, the nutritional benefits of fish consumption are well documented and may outweigh the health risks (Knuth et al. 2003, Institute of Medicine 2007, Mergler et al. 2007). As such, the USEPA and USFDA (2004) recommend that women and children consume up to 12 ounces per week of fish with low levels of MeHg, and the Dietary Guidelines Advisory Committee and the American Heart Association recommend the consumption of at least six ounces of fish per week to maintain a healthy and balanced diet (Institute of Medicine 2007). Weighing the nutritional benefits of consuming fish with possible negative health effects from MeHg exposure requires the collection and dissemination of detailed information about patterns of fish consumption and MeHg concentrations in species consumed by humans.

Development of Data Collection and Monitoring Efforts

Driscoll et al. (2007) and Evers et al. (2007) identified, predicted and classified areas with high concentrations of Hg in freshwater biota in the northeastern United States and southeastern Canada. Their efforts used a subset of the data compiled

throughout the northeastern United States during a four-year effort that included more than 30,000 observations of Hg levels in biota representing 40 fish and 44 wildlife species (Evers and Clair 2005). Specifically, Driscoll et al. (2007) used measurements of standard-age (~4.5 years) and standard-length (200 mm) yellow perch (*Perca flavescens*) Hg concentrations to evaluate the utility of using four simple and common measures of water quality – dissolved organic carbon, acid neutralizing capacity, pH and total phosphorus – to predict which aquatic systems supported yellow perch with levels of Hg that exceed the EPA human health criterion of 0.3 ppm MeHg in fish tissue. Evers et al. (2007) relied upon measurements of Hg concentrations in standard-length (200 millimeters [mm]) yellow perch to identify “biological Hg hotspots”, then used data for both yellow perch, and to a lesser extent, largemouth bass (*Micropterus salmoides*), to identify additional “areas of concern” for human health.

Efforts such as these are useful for identifying regions with the highest levels of Hg contamination, and it is important to locate regions where MeHg concentrations in fish may pose the greatest risk to humans. However, measures of MeHg concentration in these species do not provide information most directly pertinent to assessing human health risks because they do not consider which species are most frequently harvested and consumed by anglers, as discussed later in this manuscript. By assessing fish consumption and subsequently monitoring MeHg concentrations in fish species that are harvested and consumed by humans from a particular location, public health agencies can more effectively identify areas where the consumption of sport fish poses threats to human health and prioritize testing in those areas where fish consumers are exposed to the highest levels of MeHg.

Other efforts are assessing Hg concentrations across the northeastern United States using fish species that are more sensitive to Hg contamination. In December 2007, the USEPA approved the Northeast Regional Hg Total Maximum Daily Load

(TMDL) as presented by state agencies of Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont in cooperation with the New England Interstate Water Pollution Control Commission. This plan outlines steps to reduce Hg concentrations in fish in freshwater systems throughout the Northeast in order to meet water quality standards and eventually eliminate the need for fish consumption advisories (NEIWPCC 2007). The Northeast Regional Hg TMDL is based on a compilation of data from monitoring programs conducted by state and provincial governments, as well as other large-scale research initiatives, in order to establish a baseline from which to assess future reductions in fish Hg concentrations. Smallmouth bass (*Micropterus dolomieu*) were chosen as the indicator species for this effort to assess improvements in water quality because this species bioaccumulates MeHg at relatively high levels and is ubiquitously distributed across the northeastern states. The Northeast Regional Hg TMDL aims to reduce mercury concentrations in 90% of smallmouth bass to 0.3 ppm, thereby reducing Hg levels in nearly all other species to below this threshold as well. However, the extent of human consumption was not a primary criterion considered in the selection of smallmouth bass as a target species.

In the future, the collection of regional data may also be facilitated by efforts at the national level, including federal policy initiatives. Collaborations among researchers from academia, government agencies and other organizations have led to recommendations for a comprehensive monitoring program to determine whether Hg concentrations in air, watersheds, waters, soils and aquatic biota are changing over time as a result of regulatory policies to reduce Hg emissions (Harris et. al 2007). These recommendations have been incorporated into legislation proposed in March 2007 to establish a comprehensive national Hg monitoring network in order to collect field data from various ecoregions across the United States (US House 2007, US

Senate 2007). But as before, the initiation of data collection by a new level of government may again lead to choosing fish species for evaluation that are not directly relevant to angler consumption.

Fish are important and appropriate indicators of Hg deposition as they represent the main pathway by which humans and wildlife are exposed to MeHg (Harris et al. 2007). If the proposed federal monitoring program is established, it would provide data concerning: 1) MeHg concentrations in yearling fish, and 2) Hg concentrations in commercially and recreationally important fish (US House 2007, US Senate 2007). However, it is unclear how the proposed monitoring program would determine which fish species are “commercially and recreationally important” at the national scale or at a given monitoring site, or whether the fish tested would be of a size consumed by humans (e.g., complying with state minimum length regulations). We emphasize that the objective of the proposed monitoring program is to comprehensively monitor changes in atmospheric deposition and corresponding changes in biotic indicators, rather than to directly assess the exposure of fish consumers to MeHg. However, given that the ultimate goal of reducing Hg emissions and subsequent deposition is to protect human health, we argue that it is also fundamentally important that researchers, state and federal agencies and policymakers collectively consider the criteria described below. Specifically, we ask whether such a Hg monitoring program should also provide data to directly inform the development of comprehensive fish consumption advisories and other appropriate public policy in the short term, in addition to achieving the desired long-term monitoring goals.

Criteria for Selecting Target Species for Data Collection Efforts

Criterion 1 – Patterns of fish consumption by humans:

Methylmercury concentrations in fish are inherently variable within and across species and freshwater systems, therefore it is essential to collect data for the fish species harvested and subsequently consumed by humans at particular locations. The fish consumption patterns and species preferences of particular groups of consumers vary regionally and even locally, and depend on cultural factors, including taste preferences, economic status, education level, cultural beliefs, ethnicity, health awareness, income, age and gender (Strauss 2004, Verbeke and Vackier 2005). In the northeastern United States large native sport fish species, such as northern pike (*Esox lucius*), walleye (*Sander vitreus*), and salmonids including lake trout (*Salvelinus namaycush*) and landlocked Atlantic salmon (*Salmo salar*) are generally widespread in their distribution and heavily targeted by anglers, according to a 2001 survey conducted by the US Census Bureau (Figure 3.1). A survey of over 4,000 adults living in the states that border the Great Lakes conducted between June 2001 and June 2002 found that among respondents who ate sport-caught fish, approximately 64% of fish consumed were a combination of walleye and salmonids. Yellow perch and rainbow smelt (*Osmerus mordax*) together constituted only 21% of fish consumed, while smallmouth bass were not listed individually and made up some smaller proportion of “other sport-caught fish” that together constituted approximately 10% of fish consumed (Imm et al. 2005).

Detailed and comprehensive angler harvest data analogous to that available from the Great Lakes are lacking from most other regions, including the northeastern United States. Nevertheless, obtaining some information about the rates at which particular sport fish species are consumed by anglers and their families or other consumer groups in a given location is necessary to provide a better foundation for targeted Hg testing, limiting unnecessary testing of fish species that are rarely consumed. However, local knowledge can provide insights to inform the development

of future data collection efforts. For example, in areas of New York and Vermont, fisheries biologists have observed that some smallmouth bass fisheries may be largely catch-and-release (Scott Krueger, Department of Natural Resources, Cornell University, personal communication, 27 February 2008, Richard Kirn, VT Fish and Wildlife Department, personal communication, 6 December 2007). Furthermore, the New Hampshire Fish and Game Department (NHFG) voiced concerns about the use of smallmouth bass as an indicator species for the Northeast Regional Hg TMDL, stating that smallmouth and largemouth bass have high catch-and-release rates and are therefore not frequently consumed (it is the general belief of the NHFG Department that approximately 95% of all bass caught are released; Michael Racine, NHFG, personal communication, 28 December 2007).

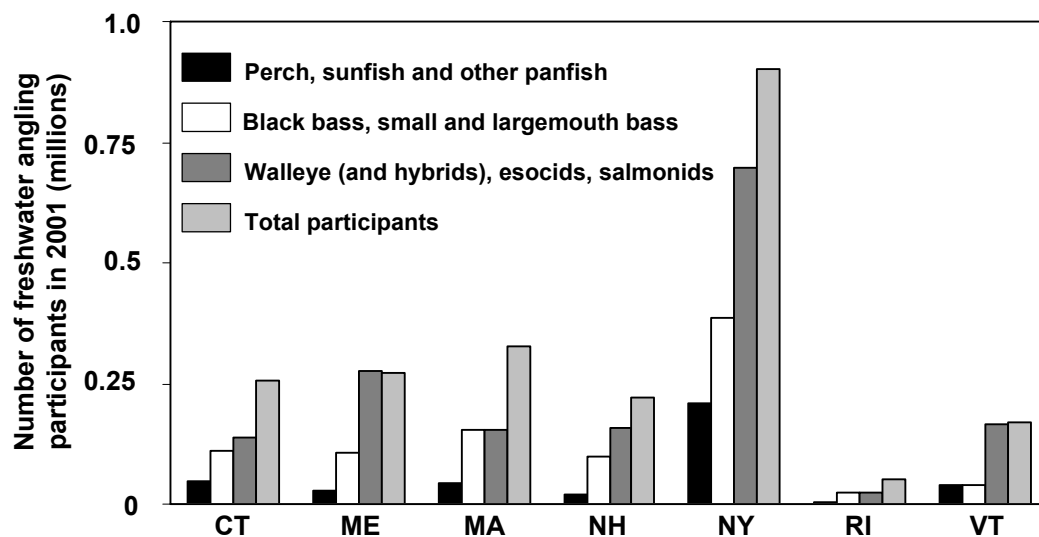


Figure 3.1. Groups of fish species targeted by resident and non-resident freshwater anglers in the northeastern states in 2001, using data compiled from the USCB (2001). Esocids include pike, pickerel and muskellunge hybrids. Groups of species not shown because they are not addressed here include: 1) crappie, 2) bullhead and catfish, 3) white bass, striped bass and hybrids (potentially marine), and groups designated as 4) anything and 5) other. Each of these groups represented no more than 30% of the total participants in any state. Note that these data reflect species targeted by anglers and may not necessarily be harvested for consumption; black bass in particular are primarily caught and released. Additionally, because anglers may target multiple species, the sum of participants for all species may exceed the total.

Though some consumer groups may harvest smallmouth bass and yellow perch, available information suggests that it is more important – from a human health perspective – to have information regarding Hg concentrations in other fish species that are consumed more frequently in the northeastern United States. Determining which fish species are most frequently consumed in particular regions (e.g., the Adirondack region of New York) or more specific locations (e.g., communities with a large number of anglers who depend on self-caught fish for part of their family's food supply) will identify those species of primary importance for Hg testing in those areas. In order to assess how Hg contamination may affect human health, we contend that fish consumption must be evaluated – both quantitatively (through consumption surveys) and qualitatively (through the experiences of agencies and fisheries biologists) – and considered as the primary criterion when selecting which fish species and locations to monitor.

Criterion 2 – Variability in fish methylmercury concentrations:

Diet is the most important factor contributing to Hg concentration in fish (Harris and Bodaly 1998, Johnston et al. 2003). Large predatory fish targeted by anglers are particularly likely to have elevated Hg concentrations due to their higher trophic level and old age (Bahnick et al. 1994, Power et al. 2002) and therefore represent an increased risk to fish consumers. Although non-native yellow perch and smallmouth bass are ubiquitous in the study area examined by Driscoll et al. (2007) and Evers et al. (2007), as well as the area encompassed by the Northeast Regional Hg TMDL (NEIWPCC 2007), these species are not representative of entire fish communities. Freshwater systems, such as lakes, often support a nearshore (littoral) and offshore (pelagic) food web that overlap to varying degrees depending on food web structure (Vander Zanden et al. 1999, Lepak et al. 2006). For example,

smallmouth bass are closely associated with nearshore or littoral habitats. Thus, obtaining information about Hg concentrations in smallmouth bass may provide little to no information about species – such as walleye and lake trout – that rely largely on offshore, or pelagic, food sources.

In water bodies where yellow perch MeHg concentrations exceed the 0.3 ppm criterion, MeHg concentrations in larger predatory fish will typically be high enough to pose concerns for human health (Driscoll et al. 2007, Evers et al. 2007, NEIWPCC 2007). Similarly, if MeHg concentrations in smallmouth bass exceed 0.3 ppm, MeHg concentrations in other large predatory species are likely to exceed this threshold as well. A subset of the NERC data set from northeastern North America (see Kamman et al. 2005) indicates that the top predator species (e.g., walleye, northern pike, and lake trout) with the highest concentrations of T-Hg also have the greatest variability in T-Hg concentration, despite relatively large sample sizes (Figure 3.2). Kamman et al. (2005) attribute much of the variability in T-Hg concentration in fish to the water bodies sampled. This variability likely also results from differences in food web structure within a given body of water (Vander Zanden and Rasmussen 1996). Littoral and pelagic food webs are typically distinct, therefore measures of T-Hg concentrations in yellow perch or smallmouth bass sampled from nearshore areas do not directly provide information about the MeHg concentrations of sport fish species – such as walleye and salmonids, which are most often targeted for consumption by humans – that rely primarily on offshore food webs.

Criterion 3 – Fish length:

Most state angling regulations provide minimum length limits for sport fish that can be legally harvested. For example, in 2008 the statewide minimum length limit for landlocked salmon and walleye in New York is 15 inches (381 mm), while

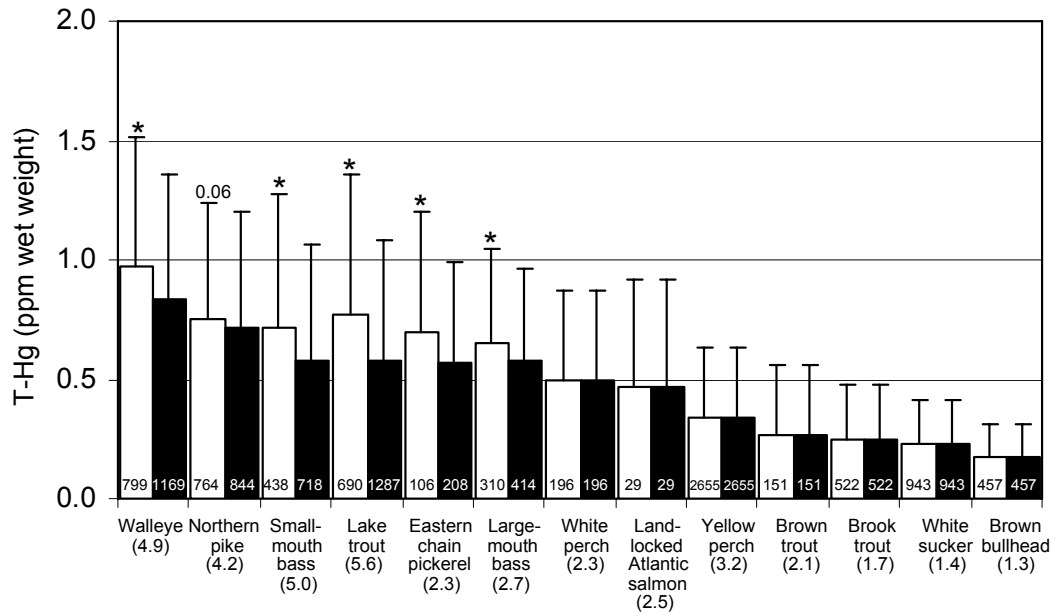


Figure 3.2. Mean (\pm SD) T-Hg concentration (ppm wet weight) in sport fish species from eastern North America computed with data for only fish at or exceeding legal length (white bars) as compared to the mean T-Hg concentration of all fish in the data set regardless of length (black bars) based on the New York State 2006-2008 General Statewide freshwater angling regulations. Mean values that differ significantly ($p \leq .01$) are indicated by “*”; $p = .06$ for northern pike. Only fish for which total length measurements were available were included in the analysis. Sample sizes associated with each mean are shown at the base of the respective bar, and the maximum value of T-Hg measured in that species in the data set is indicated below the species name. Figure produced from subset of the NERC data set (see Kamman et al. 2005).

northern pike and lake trout must be 18 and 21 inches (457 and 533 mm) in length respectively, and black bass (large and smallmouth bass) must be 12 inches (305 mm) to harvest legally (NYSDEC 2006). These regulations promote the harvest of large fish in an attempt to protect and sustain naturally reproducing fish populations, yet these same regulations encourage the harvest of fish that present a disproportionately high risk of MeHg exposure to anglers and their families. Driscoll et al. (2007) specifically acknowledge that using small yellow perch as an indicator species helps identify the most polluted lakes. Although this approach is useful for locating regions that are heavily influenced by Hg contamination, using small fish as a proxy for the level of contamination within water bodies is insufficient for developing appropriate fish consumption advisories. For example, if data sets used to develop consumption advisories include fish shorter than current minimum length limits, the mean Hg concentrations will likely be artificially low relative to the mean Hg concentration in fish people can legally harvest and consume.

We analyzed a subset of the NERC data set (provided by N. Kamman, 21 December 2007) to determine how the mean T-Hg concentrations in the predatory sport fish species most often consumed by humans changed when only fish of legal length were included in data analysis. The mean T-Hg concentrations of fish with known total lengths that met or exceeded the New York State minimum legal-length limit for harvest were significantly higher (two-sample t-tests assuming equal variance; p 's $\leq .01$) in walleye, smallmouth bass, lake trout, eastern chain pickerel and largemouth bass relative to the T-Hg concentrations when all data for fish of known lengths were considered (Figure 3.2). The mean T-Hg concentration of northern pike with total length at or above legal length did not differ significantly (two-sample t-test assuming equal variance; $t_{1606} = 1.55$, $p = .06$) from the mean T-Hg concentration for all fish of known total length. Analyses for the remaining species

only included data for fish of legal length, either because all fish measured were above legal length (e.g., landlocked Atlantic salmon) or because there is no New York State minimum length limit for that species (e.g., white perch, yellow perch, brown trout, brook trout, white sucker, and brown bullhead). Although this analysis applies New York State length regulations limits to a data set including samples collected throughout the Northeast, it illustrates the need to collect data from fish of legal length – in other words, fish that will be consumed by humans – to inform the development of fish consumption advisories.

Further Considerations for Human Health

Consumption advisories issued by state agencies constitute comprehensive risk communication efforts regarding levels of contaminants in sport-caught fish and the recommended levels of fish consumption for different consumer groups. Currently, however, sensitive populations (i.e., the women of childbearing age and young children who would potentially benefit most from limiting their exposure to Hg) are defined differently in all seven northeastern state advisories, as are the thresholds of fish tissue Hg concentration used to develop consumption advisories (Table 3.1). To make matters even more confusing for potential consumers of sport fish, in situations where localized Hg data are available some of these state advisories offer different consumption advice for specific fish species, sizes, water bodies or regions. Considering fish consumption information from a given region and consistently defining particular groups of fish consumers will allow for the development of recommendations appropriate to local consumption practices that will be more protective of human health than blanket regional advisories (Burger et al. 2007).

Assessing potential health risks resulting from MeHg exposure through fish consumption necessitates consistent benchmarks of unacceptable exposure. As

described above, the Hg concentration in fish tissue that warrants a consumption advisory currently differs in all seven of the northeastern states (Table 3.1). With this in mind, we note that recent efforts by Driscoll et al. (2007) and Evers et al. (2007) and the Northeast Regional Hg TMDL (NEIWPCC 2007) have taken an important step towards consistency by choosing to use the USEPA threshold Hg concentration in fish tissue of 0.3 ppm (USEPA 2001b) as an initial benchmark to identify potential human health risks. In order to communicate information to particular groups of fish consumers clearly and unambiguously, consistency should be an important consideration for scientists, public health agencies, resource managers, and policymakers responsible for identifying and managing areas where Hg contamination is a concern.

Table 3.1. Summary of sensitive populations and fish tissue mercury concentrations considered when developing fish consumption advisories for seven states in the northeastern United States (NEIWPCC 2007).

State	Sensitive population	Fish [Hg] (ppm)
CT	Pregnant and nursing women, women who plan to become pregnant within one year, children under 6	0.1
MA	Pregnant and nursing women, women of child-bearing age, children under 12	0.2
ME	Pregnant and nursing women, women who may get pregnant, children under 8	0.3
NH	Pregnant and nursing women, women who may get pregnant, children under 7	0.3
NY	Women of childbearing age, infants, children under 15	1.0
RI	Pregnant and nursing women, women who plan to become pregnant within one year, young children	0.3
VT	Women of childbearing age (particularly pregnant and nursing women, women planning to get pregnant), children under 6	0.3

Conclusions

Although research to date has made notable strides towards understanding the processes affecting the bioaccumulation of MeHg in freshwater fish, the MeHg concentration present in a particular fish will always be dependent on a number of

site-specific factors. Understanding the inherent variability in fish MeHg concentrations, characterizing MeHg concentrations in fish consumed by humans and consistently communicating results from monitoring efforts are essential for developing effective fish consumption advisories and public policy. Localized information about which fish species are harvested and consumed, and in what quantities, by anglers and their families and other groups of fish consumers will directly inform assessments of the relative risk of MeHg exposure for different individuals, and will subsequently lead to the development of more targeted fish consumption advisories (Figure 3.3). Continuing to consider legal harvest sizes for particular species when developing consumption guidelines from fish MeHg data will allow for a more focused view of MeHg contamination in fish as it directly relates to human health. Maximizing the integration of data collected by different entities – and for different purposes – should remain a priority in order to fully utilize valuable information regarding Hg levels in fish. By appropriately targeting future efforts, we will greatly improve our ability to protect human health with limited resources.

In summary, when collecting data with the intent to develop consumption advisories to directly protect human health, it is most important to measure contaminant levels in fish that:

1. Anglers and their families frequently harvest and consume from a given location;
2. Represent a disproportionately high risk to human health due to high concentrations and variability of MeHg;
3. Are equal to or greater than the minimum length limit required for harvest.

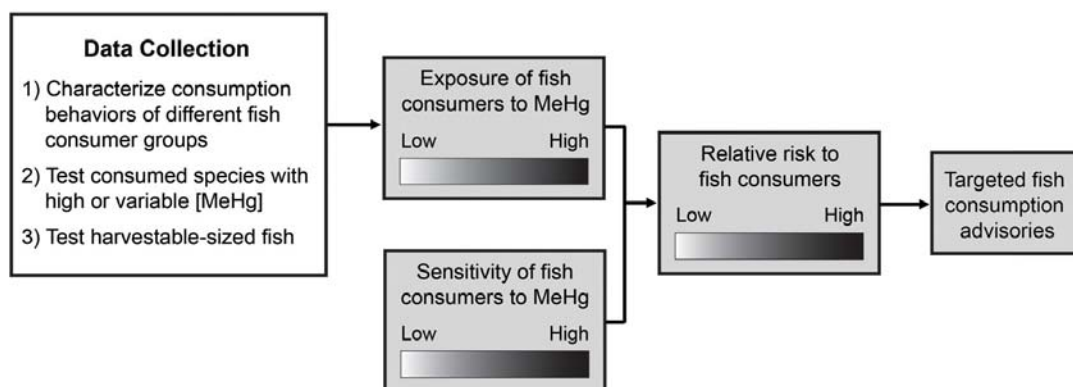


Figure 3.3. An approach to targeted data collection (open box) to best inform the protection of human health. The shaded boxes represent areas for further consideration beyond the scope of this manuscript. The relative risk to fish consumer groups is determined by a combination of the level of exposure (i.e., rate of consumption of a given species with a given methylmercury concentration) and the sensitivity of an individual consumer to the health effects of methylmercury (i.e., developing fetuses and young children are most sensitive). Characterizing the relative risks to different groups of fish consumers in particular locations will allow for targeted fish consumption advisories to more comprehensively protect human health.

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APPENDICES

APPENDIX A
FISH MERCURY DATA USED FOR EXPOSURE ESTIMATES

Mercury data for fish meals obtained commercially (i.e., from restaurants and stores), including: fish species consumed, number of meals, mercury concentration data (methylmercury or total mercury as available, in ppm or $\mu\text{g g}^{-1}$, including mean, median, minimum, maximum, and standard deviation), sample size (N), and data source (for USFDA data see USDDHHS and USEPA 2006).

Species	# Meals	Mean [Hg] (ppm)	Median [Hg] (ppm)	Min [Hg] (ppm)	Max [Hg] (ppm)	SD	N	Data
Clams*	4	ND	ND	ND	ND	ND	6	FDA
Clams, mahogany* ¹	4	ND	ND	ND	ND	ND	6	FDA
Clams, mussels* ¹	1	ND	ND	ND	ND	ND	6	FDA
Cod	3	0.095	0.087	0.08	ND	0.42	39	FDA
Crab	2	0.06	0.03	0.112	ND	0.61	63	FDA
Flounder* ²	3	0.045	0.035	0.049	ND	0.18	23	FDA
Haddock	17	0.031	0.041	0.021	ND	0.041	4	FDA
Halibut	1	0.252	0.2	0.233	ND	1.52	46	FDA
Lobster	6	0.31	N/A	N/A	0.05	1.31	88	FDA
Mahi mahi ³	1	0.19	0.18	0.104	0	0.45	22	FDA
Oysters	2	0.013	ND	0.042	ND	0.25	38	FDA
Pollock	3	0.041	ND	0.106	ND	0.78	62	FDA
Salmon*	15	0.014	ND	0.041	ND	0.19	34	FDA
Salmon, canned*	5	ND	ND	ND	ND	ND	23	FDA
Scallops	3	0.05	N/A	N/A	ND	0.22	66	FDA
Sea bass ⁴	1	0.219	0.13	0.227	ND	0.96	47	FDA
Shrimp*	11	ND	ND	ND	ND	0.05	24	FDA
Sole* ²	4	0.045	0.035	0.049	ND	0.18	23	FDA
Swordfish	2	0.976	0.86	0.51	ND	3.22	618	FDA
Tilapia*	5	0.01	ND	0.023	ND	0.07	9	FDA
Tuna, yellowfin	2	0.325	0.27	0.22	ND	1.079	87	FDA
Tuna, canned albacore	21	0.353	0.339	0.126	ND	0.853	399	FDA
"Seafood salad" ⁵	3	0.041	ND	0.106	ND	0.78	62	FDA
"Supermarket fish" ⁶	6	0.067	N/A	N/A	N/A	0.347	N/A	FDA
"Sushi" ⁷	2	0.383	0.322	0.269	ND	1.3	228	FDA

ND = measured value below detection limit

* indicates measure of methylmercury (in ppm, or $\mu\text{g g}^{-1}$), remaining values are measures of total mercury (in ppm, or $\mu\text{g g}^{-1}$).

¹ Used mercury data for “clams”.

² Included in “flatfish”.

³ Used data from www.cfsan.fda.gov/~frf/seamehg2.html; Accessed 1 Sep 2007.

⁴ Includes data for sea bass, striped bass, and rockfish.

⁵ Used data for pollock.

⁶ Species unspecified; used mean of ten most frequently purchased species (see Institute of Medicine 2007).

⁷ Used data for “tuna, all”.

Mercury data for meals of fish sport-caught from waters of private Adirondack fishing preserves, including: fish species consumed, water from which fish were caught, number of meals, total mercury concentration data (in ppm or $\mu\text{g g}^{-1}$, including mean, median, minimum, maximum, and standard deviation), sample size (N), and data source (AFRP unpublished data, USTFA 2008).

Species	Water	# Meals	Mean [Hg] (ppm)	Median [Hg] (ppm)	Min [Hg] (ppm)	Max [Hg] (ppm)	SD	N	Data
Brook trout	Green Lake	2	0.067	0.067	0.014	0.057	0.076	2	AFRP
Brook trout	Goose Lake	1	0.196	0.196	0.092	0.057	0.42	18	AFRP, all waters
Brook trout	Jones Lake	1	0.196	0.196	0.092	0.057	0.42	18	AFRP
Brook trout	Canachagala Lake	10	0.196	0.196	0.092	0.057	0.42	18	AFRP
Lake trout	First Bisby Lake	1	0.202	0.193	0.12	0.081	0.513	13	AFRP
Lake trout	Little Moose Lake	16	0.16	0.147	0.064	0.063	0.374	94	AFRP
Landlocked salmon	Little Moose Lake	2	0.06	0.06	0.035	0.036	0.085	2	AFRP
Rainbow trout	First Bisby Lake	6	0.014	N/A	0.007	N/A	0.04	65	USTFA
Smallmouth bass	Second Bisby Lake	2	0.335	0.299	0.195	0.082	0.806	12	AFRP

Mercury data for meals of fish sport-caught from other waters (i.e., not preserve waters), including: fish species consumed, water and location from which fish were caught (if known), number of meals, total mercury concentration data (in ppm or $\mu\text{g g}^{-1}$, including mean, median, minimum, maximum, and standard deviation), sample size (N), and data source (NYSDEC 2007, MEDEP 2008; for NERC data see Kamman et al. 2005, for USFDA data see USDDHHS and USEPA 2006).

Species	Water	# Meals	Mean [Hg] (ppm)	Median [Hg] (ppm)	Min [Hg] (ppm)	Max [Hg] (ppm)	SD	N	Data
Cusk ¹	Unknown, southern Maine	1	0.095	0.087	0.08	ND	0.42	39	FDA
Largemouth bass	Cazenovia Lake, Cazenovia, NY	1	0.499	N/A	N/A	0.02	2.13	539	NYSDEC, all waters
Striped bass	Kennebec River, Bath, ME	3	0.318	0.314	0.13	0.096	0.783	38	MEDEP
Walleye	Canadarago Lake, Richfield, NY	6	0.447	N/A	0.151	0.226	0.749	10	NYSDEC
Walleye	Unknown, Quebec, Canada	3	0.818	0.69	0.527	0.08	4.9	1028	NERC

¹ Used USFDA data for cod; cusk data not available.

Protocol to determine appropriate Hg concentration data

1. Commercial fish:

Used available USFDA data for commercial fish (see USDDHHS and USEPA 2006); assumptions made as needed for records of fish meals with insufficient information (e.g., species designated as “supermarket fish”; see notes above).

2. Fish sport-caught from waters of private Adirondack fishing preserve:

Lake and species-specific data used whenever available (e.g., total mercury values measured in lake trout from Little Moose Lake); if necessary used overall mean and maximum measured total mercury concentration values for a particular species from all waters for which data are available (e.g., the mean total mercury concentration in brook trout from all waters; data source designated as “AFRP, all waters”).

3. Fish sport-caught from other waters:

Lake and species-specific data used whenever available (e.g., striped bass from the Kennebec River, Maine); if necessary used overall mean and maximum mercury concentration values for a particular species from all waters in a particular state (e.g., largemouth bass from New York State) or region (e.g., walleye from Quebec, Canada). No cusk data were available; USFDA data for cod were used as an approximation.

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APPENDIX B

STUDY INSTRUMENTS: ANGLER SURVEY, FISH CONSUMPTION RECORD,
HAIR SAMPLE COLLECTION INSTRUCTIONS

**MERCURY IN ADIRONDACK FISH:
MAKING DECISIONS ABOUT FISH CONSUMPTION**

**Angler Survey
Summer 2007**

**Research conducted by the Adirondack Fishery Research Program
Department of Natural Resources, Cornell University**

The purpose of this study is to learn more about what type of information about mercury in sport fish would be most useful to anglers and their families for making decisions about fish consumption.

Please take a few minutes to complete this survey to tell us what you know about mercury in fish in the Adirondacks, as well as what else you would like to know in order to make informed decisions about your family's fish consumption. The information you provide will remain strictly confidential and will never be associated with your name.

Please contact us with any questions. We greatly appreciate your participation!

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MERCURY IN SPORT FISH

1. In August 2005 the Adirondack League Club and Cornell Adirondack Fishery Research Program researchers began testing the mercury concentrations of fish from Club waters.

How interested are you in learning more about the mercury levels in fish from Club waters?

1
Not Interested

2

3

4

5

Very Interested

- 2. What are you hoping to learn from the efforts to test mercury levels in fish from Club waters?**

a) More about mercury levels in specific lakes (check all that apply):

- | | |
|--|--|
| <input type="checkbox"/> East Lake | <input type="checkbox"/> Sand Lake |
| <input type="checkbox"/> First Bisby Lake | <input type="checkbox"/> Second Bisby Lake |
| <input type="checkbox"/> Green Lake | <input type="checkbox"/> Third Bisby Lake |
| <input type="checkbox"/> Honnedaga Lake | <input type="checkbox"/> Woodhull Lake |
| <input type="checkbox"/> Little Moose Lake | <input type="checkbox"/> Other: _____ |
| <input type="checkbox"/> Panther Lake | |

b) More about mercury levels in specific species of fish (check all that apply):

- ☐ Brook trout
- ☐ Lake trout
- ☐ Landlocked salmon
- ☐ Smallmouth bass
- ☐ Other: _____

c) More about how mercury in fish in Club waters may affect (check all that apply):

- ☐ Your health
- ☐ Your spouse's health (if applicable)
- ☐ Your children's health (if applicable)
- ☐ The health of others who share your catch (if applicable)
- ☐ Other: _____

a) How interested would you be in knowing your own hair mercury level?

b) How interested would you be in knowing the hair mercury level of your spouse (if applicable)?

c) How interested would you be in measuring the hair mercury level of your children, or other children with whom you share your catch (if applicable)?

4. Based on hair test results, which of the following actions might your family consider?

☐ Eat more fish

☐ Eat less fish

☐ Eat different species of fish

☐ Not alter fish consumption habits

☐ Other: _____

☐ Eat more fish

☐ Eat less fish

☐ Eat different species of fish

☐ Not alter fish consumption habits

☐ Other: _____

5. How important are the following factors when you and your family make decisions about eating sport-caught fish?

	Not Important				Very Important
	1	2	3	4	5
Taste	1	2	3	4	5
Cost	1	2	3	4	5
New York State advisory recommendations	1	2	3	4	5
U.S. EPA and FDA advisory recommendations	1	2	3	4	5
Health benefits of eating fish	1	2	3	4	5
Whether fish may contain mercury	1	2	3	4	5
Whether fish may contain other contaminants	1	2	3	4	5
Which species you catch	1	2	3	4	5
Which species you want to catch	1	2	3	4	5
Advice from others in your community	1	2	3	4	5
Sustainability of fishery	1	2	3	4	5
Other: _____	1	2	3	4	5

6. How important are the following factors when you and your family make decisions about eating fish purchased from a store or restaurant?

	Not Important				Very Important
	1	2	3	4	5
Taste	1	2	3	4	5
Cost	1	2	3	4	5
New York State advisory recommendations	1	2	3	4	5
U.S. EPA and FDA advisory recommendations	1	2	3	4	5
Health benefits of eating fish	1	2	3	4	5
Whether fish may contain mercury	1	2	3	4	5
Whether fish may contain other contaminants	1	2	3	4	5
Which species are available	1	2	3	4	5
Advice from others in your community	1	2	3	4	5
Sustainability of fishery	1	2	3	4	5
Other: _____	1	2	3	4	5

7. Sport fish in a number of New York waters have been found to contain levels of chemical contaminants that may pose health risks to fish consumers. The New York Department of Environmental Conservation distributes health advisories written by the Department of Health that give advice about limiting consumption of fish from certain waters.

a) Are you familiar with the fish consumption recommendations outlined by the New York State Health Advisory for Adirondack waters?

☐ Yes

☐ No

b) The New York State Health Advisory considers the following Adirondack fish to have lower mercury levels: all sizes of bullhead, bluegill/sunfish, rock bass, crappie, and brook, brown and rainbow trout; yellow perch less than 10 inches.

What do you think New York State recommends as the maximum number of meals of these fish that women of childbearing age and children under 15 should eat?

☐ Eat no meals

☐ 1 meal per week

☐ 5-6 meals per week

☐ 1 meal per month

☐ 2 meals per week

☐ 1 meal per day

☐ 2-3 meals per month

☐ 3-4 meals per week

☐ No limit

c) The New York State Health Advisory considers the following Adirondack fish to have higher mercury levels: all sizes of northern pike, pickerel, walleye, and largemouth and smallmouth bass; yellow perch longer than 10 inches.

What do you think New York State recommends as the maximum number of meals of these fish that women of childbearing age and children under 15 should eat?

☐ Eat no meals

☐ 1 meal per week

☐ 5-6 meals per week

☐ 1 meal per month

☐ 2 meals per week

☐ 1 meal per day

☐ 2-3 meals per month

☐ 3-4 meals per week

☐ No limit

d) What do you think New York State recommends as the maximum number of meals of sport fish caught from Adirondack waters that all other individuals (i.e. not women and children) should eat?

☐ Eat no meals

☐ 1 meal per week

☐ 5-6 meals per week

☐ 1 meal per month

☐ 2 meals per week

☐ 1 meal per day

☐ 2-3 meals per month

☐ 3-4 meals per week

☐ No limit

- 1 2 3 4 5
Not clearly Very clearly

- 9. Do you have any other questions or concerns about mercury and fish consumption?**

10. Please describe all members of your family or household, starting with yourself. This information will be important to allow Cornell researchers to determine whether each member of your household eats more or less fish than recommended by established health guidelines.

Household Members	Age	Height	Weight (lbs)	Gender (male/female)	If female: Pregnant or breastfeeding? (Yes/No)
1 (Yourself)					
2					
3					
4					

11. Are there other people with whom you frequently (at least once a month) share your fish caught from Adirondack League Club waters? If so, please describe those individuals here to the best of your knowledge.

Age	Gender (male/female)	If female: Pregnant or breastfeeding? (Yes/No)

12. How many years of education have each of your family members completed? Count 12 years for high school graduation, and 1 year for each additional year of college, technical, or vocational training.

Yourself: _____ years Household member 5: _____ years
 Household member 2: _____ years Household member 6: _____ years
 Household member 3: _____ years Household member 7: _____ years
 Household member 4: _____ years Household member 8: _____ years

13. a) Where is your primary place of residence (where you spend the most days each year)?

City: _____ State: _____

- b) Approximately how many days each year do you typically spend at the Adirondack League Club?

_____ days per year

- c) Approximately how many days each year do you typically spend angling on Adirondack League Club waters?

_____ days per year

A few final questions:

Would you be interested in submitting hair samples from adult (age 18+) family members?

- ☐ Yes If yes, how many hair sampling kits would you like? _____
- ☐ No

If you would prefer to be contacted at a different address, please provide that address here.

If we may contact you by phone or email about project updates, please provide that information here.

Phone: _____

Email: _____

To return this questionnaire, simply mail it to us as soon as possible using the envelope and postage provided.

Please also include 1 copy of your signed consent form.

THANK YOU FOR YOUR PARTICIPATION!

HOUSEHOLD FISH CONSUMPTION RECORD

SUMMER 2007

Research conducted by the Adirondack Fishery Research Program
Department of Natural Resources, Cornell University

The purpose of this study is to learn more about what type of information about mercury in sport fish would be most useful to anglers and their families for making decisions about fish consumption. Together with information from the angler surveys, these records will allow us to learn more about the consumption of fish from Adirondack League Club waters, as well as what information would be most useful for members of the community who are making decisions about fish consumption. We will return this record to you when the study is completed.

Please take a few minutes to complete this record on each day that anyone in your family or household eats fish. The information you provide will remain strictly confidential and will never be associated with your name.

Please contact us with any questions. We greatly appreciate your continued participation!

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Dr. Clifford E. Kraft
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1. First, please describe all members of your family or household, starting with yourself. Please copy this information from Question #10 on the Angler Survey. This information will allow Cornell researchers to determine whether each household member eats more or less fish than recommended by established health guidelines.

NOTE: It is very important to consistently use the same number to refer to a particular member of your household to provide an accurate record of fish consumption.

Household Members	Age	Height	Weight (lbs)	Gender (male/female)	If female: Pregnant or breastfeeding? (Yes/No)
1 (Yourself)					
2					
3					
4					
5					
6					
7					
8					

2. Please complete the fish consumption record to the best of your ability for the months of June, July, and August.

Refer to the instructions on page 2 as needed, and contact Hannah Shayler at has34@cornell.edu or (774) 280-2096 with any additional questions.

3. In August 2007, AFTER you have completed this fish consumption record, please answer the brief questions on the last page of the survey.

HOUSEHOLD FISH CONSUMPTION RECORD

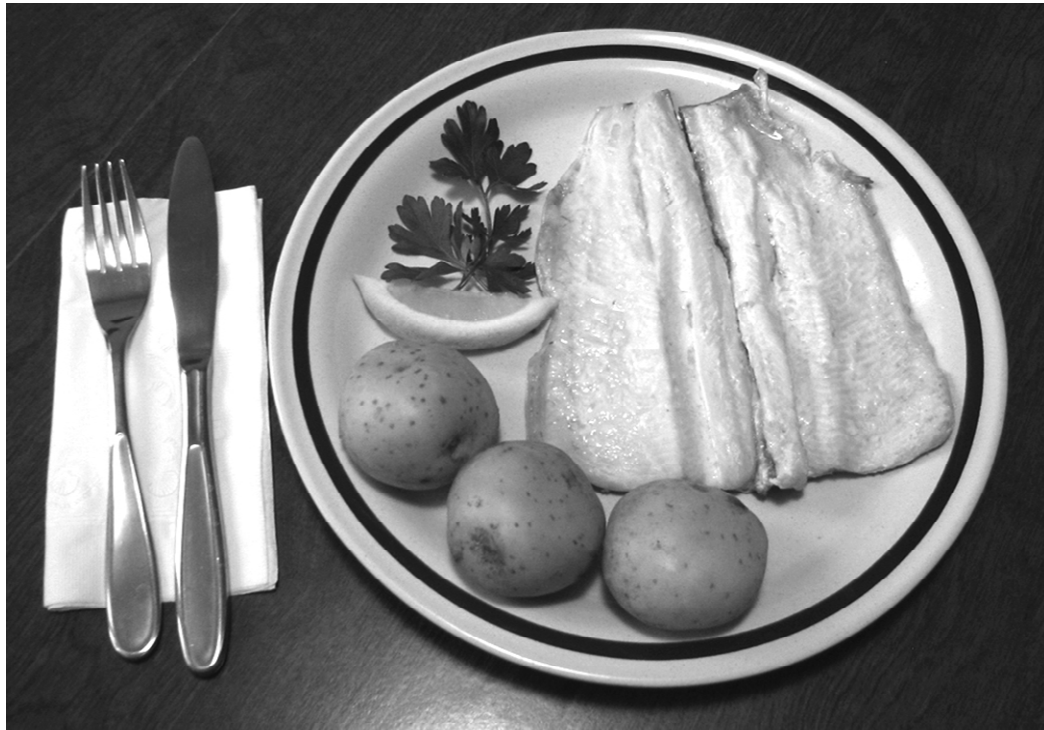
June, July, and August 2007

1. Record meals of all fish and other seafood (including shellfish such as lobster, shrimp, scallops, and clams): including sport-caught fish (regardless of who caught the fish), and fish or other seafood bought in restaurants or stores, eaten at home or away from home.
2. Record information for every fish meal eaten by any member of your household.
3. Record each meal on a separate line. If more than one household member eats a portion of a given meal, list each household member and portion size separately.
4. Record the species of fish eaten and the approximate size of the meals eaten by members of your household. Refer to the portion sizes (8 oz., or ½ pound) pictured on the next page. Were portion sizes less, more, or about the same as the amount shown?
For example, if you ate about half the amount shown, that would be about 4 oz., while a portion slightly smaller than the amount shown would be about 6 oz.
5. If the fish was sport-caught, please record the name of the lake from which it was caught, including the city and state for lakes not on the Adirondack League Club preserve. If the fish was purchased commercially, indicate if it came from a store or restaurant.
6. See the example entries below if you have any further questions.

Example:

Date	Species	Source			Household member	Portion (oz.)
		Caught from ALC waters (Lake)	Caught from non-ALC waters (Lake, City, State)	Purchased commercially (store-bought or restaurant)		
6/1	Brook trout	Little Moose			1	8
					2	4
6/5	Haddock			Restaurant	1	8
6/5	Swordfish			Restaurant	2	8
6/7	Landlocked salmon		Cayuga Lake, Ithaca, NY		1	8
					2	6
					3	6
6/10	Tilapia			Store-bought	1	6
					3	4
					4	4

Example:



About 8 ounces (1/2 pound) of thin fish fillet.



About 8 ounces (1/2 pound) of thick fish steak.

A few final questions:

1. a) **Would you consider the information in this record to be typical of your family's fish consumption during the summer months?**

☐ Yes

☐ No

- b) **If you answered "No", specify whether your family:**

☐ Usually eats more fish during the summer

☐ Usually eats less fish during the summer

☐ Usually eats different species of fish during the summer

Explain: _____

- c) **During the rest of the year (September – May), specify whether your family:**

☐ Usually eats more fish than during the summer

☐ Usually eats less fish than during the summer

☐ Usually eats different species of fish than during the summer

Explain: _____

2. **If you haven't already done so, would you be interested in submitting hair samples from adult (age 18+) family members?**

☐ Yes

If yes, how many hair sampling kits would you like? _____

☐ No

3. **Would you like us to return your fish consumption record to you at the end of this study?**

☐ Yes

If yes, please list any changes to your address:

☐ No

Once you have completed your household fish consumption record for the months of June, July, and August, simply mail it to us using the envelope and postage provided.

THANK YOU FOR YOUR PARTICIPATION!

HAIR SAMPLE COLLECTION INSTRUCTIONS

This kit includes:

Gloves
Plastic sample bag
Postage-paid envelope

You will also need:

Comb
Stainless steel scissors
Hair clip (may be helpful if you have long hair)
Thinning shears (may be helpful if you have short hair)

1) If they have not done so already, each family member who will be submitting a hair sample must read and sign a consent form. **The hair samples cannot be processed without a signed consent form from the family member submitting the sample. Only adult family members (age 18+) may submit a hair sample.**

2) Fill out the brief survey attached to your plastic sample bag to indicate whether you may have been exposed to mercury from other sources besides fish consumption. If you have not yet returned it, be sure to **fill in the identification number** from the inside front cover of your fish consumption record to be sure that your hair sample is linked to those records.

3) Wash, rinse, and thoroughly dry your hair. Make sure your hair is free of conditioners, styling products, or any other substance that might interfere with the analysis.

4) Thoroughly wash and dry your hands. If you prefer, you may use the gloves provided.

5) Using clean stainless steel scissors, cut off a small clump of hair from the back of your head as close to the scalp as possible. Trim the pieces of hair so that your sample will include only the ½ inch of hair that was closest to your scalp. This hair is the newest growth and will most closely reflect your fish consumption during the summer months. Discard the remaining hair.

6) Continue to collect hair samples from different locations at the back of your head until you have approximately 1 teaspoon (loosely packed) of cut hair. This will ensure that the laboratory conducting the analysis has a sufficient amount to process the hair sample.

7) If you collect hair from many small spots on the back of your head, it will be less noticeable. If you have short hair, you may wish to use thinning shears.

8) Place the hair sample into the plastic sample bag labeled with your name. Return the hair samples and consent forms to us using the postage-paid envelope provided. **Samples must be received by October 1 in order to be sent to the laboratory for processing.**