The Benefits and Costs of Fish Consumption Advisories for Mercury

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Abstract

Mercury contamination of the Chesapeake Bay is a concern to health authorities in the region. We evaluate the economic and health effects of postulated recreational and commercial fishing advisories for striped bass on the Maryland portion of the bay. Awareness of and response to the advisory is estimated using a meta-analysis of the literature. Three values are estimated: welfare losses to recreational anglers, welfare losses in the commercial striped bass fishery, and health benefits. An estimate of percentage of consumer surplus loss is applied to the value of all fishing days in the bay to estimate recreational welfare loss. Welfare losses to the commercial fishery are estimated based on a model of supply and demand. Health benefits are estimated using estimated exposure and epidemiological relationships, and while potentially large, are highly uncertain. Results also suggest most individuals are below advisory standards ex ante, such that advisories should target high-frequency consumers.

Key Words: fisheries, mercury, advisories, recreation, health benefits
JEL Classification Numbers: I18, Q22, Q25, Q26

Executive Summary

Mercury contamination of the Chesapeake Bay is a concern to health authorities in the region. Authorities are considering issuing fish consumption advisories (FCAs) to warn people about the health dangers of consuming contaminated fish. Prior to December 2001, Maryland had issued only four fish consumption advisories. On December 12, 2001, the state issued several advisories concerning contamination by polychlorinated biphenyls (PCBs) and mercury. Currently, there is no advisory on consumption of fish from the Chesapeake Bay. We evaluate the economic and health effects of potential recreational and commercial fishing advisories in the Maryland portion of the Chesapeake Bay, counting effects experienced by or through all users of this portion of the bay. Because the Maryland Department of Natural Resources indicates that striped bass (*Morone saxatilis*) is the species of greatest concern for mercury contamination in the Chesapeake Bay, we assume that advisories are limited to this species. Based on 1992–1994 weighted average tissue concentration levels of 0.205 mg/kg in Chesapeake Bay striped bass from Gilmour (1999), and the current oral reference dose for methylmercury from the Environmental Protection Agency (EPA), we postulate a recreational FCA suggesting restricted consumption for the general population (< four meals per month) and restricted consumption for sensitive subpopulations (< two meals per month for children and women of childbearing age). Furthermore, we postulate that the state may issue “Commercial Health Advice” consistent in severity with the projected FCAs for the recreational fishery, since the fisheries occupy essentially the same area.

A review of the literature assesses the degree to which anglers are aware of advisories and engage in consumption-related averting behaviors, based on estimates from *ex post* analysis of fisheries with characteristics similar to the bay. The mean percentage of estuarine anglers who are aware of advisories is estimated to be 48% (95% confidence interval, CI: 46%–50%). Anglers who are aware of advisories are 26.1% less likely to consume listed species than anglers who are not (95% CI: 22.1%–30%).

We estimate three endpoints: welfare losses to recreational anglers, welfare losses to consumers and producers of commercial striped bass, and health benefits to recreational anglers due to reduced consumption of contaminated striped bass. Under a recreational FCA, aware anglers will undertake some combination of behavioral adjustments that may range from ignoring the advisory to altogether ceasing trips to the affected water body. Such behavioral modification results in economic losses to anglers. Applying an estimate of the percentage of consumer surplus lost due to an advisory from the literature to consumer surplus estimates for a fishing day in the Chesapeake Bay, we estimate an annual consumer surplus loss over all Maryland saltwater fishing days of $8.83 million ($2000). For the commercial striped bass fishery, we estimate a very simple model of supply and demand that predicts equilibrium price and quantity with reasonable accuracy. Using parameter estimates from this model, we estimate annual consumer and producer surplus losses of $215,800 and $304,500, respectively, under commercial consumption advice, for a total annual surplus loss of $520,300.

In our analysis of health effects, we estimate changes in methylmercury uptake for recreational anglers and their families as a result of the advisory, and quantify changes in three primary endpoints: paresthesia (prickling, tickling, or itching sensation, and an initial symptom of methylmercury disease), abnormal scores on tests of childhood neurological development, and cardiovascular health and mortality effects. Additionally, we estimate the number of individuals exceeding both the Chesapeake Bay advisory and EPA's reference dose (RfD). Although there is no evidence of either paresthesia or childhood neurological development delays at current exposure levels, we do predict reductions in acute myocardial infarction (AMI) and all-cause mortality under an advisory because of a lower mercury exposure threshold for these effects. However, these estimates are surrounded by much uncertainty, and because the study used to estimate this relationship has not been replicated, our confidence in them is even further attenuated.

We find that most anglers are in compliance with the advisory standards, even before the advisory is announced. About 3% of anglers exceed advisory standards before it is implemented, and only 2% do so afterward. Furthermore, we find that approximately 9% of exposed women of childbearing age exceed EPA's RfD, and 7% do so once the advisory has been implemented. The finding that most individuals are already in compliance with advisory guidelines suggests that advisories are likely to be relevant to only a small percentage of angler families at the high end of the consumption distribution, and that compliance might be further increased if educational efforts are directed at this segment of the population.

Finally, based on our mortality estimate, we estimate annual health benefits from an advisory to be approximately $14 million. The value of further information for this mercury-mortality relationship is quite high, as it suggests that significant health benefits may accrue at lower mercury levels than has been suggested by the research focusing on neurological development effects from fetal exposure, the health endpoint that has been the focus of policy discussion to date.

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The Benefits and Costs of Fish Consumption Advisories for Mercury

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1. Introduction

Mercury (periodic table element Hg) is found in the environment in a wide variety of forms. It generally appears in its elemental form (Hg^0) or as divalent mercury (Hg^{2+}) and can be found in the atmosphere, in rocks and soils, and in water (U.S. EPA 2000). Surface waters are contaminated by mercury from both naturally occurring releases and industrial emissions. Sources of mercury include emissions from power plants, paper and pulp mills, and wastewater treatment plants; depositions from the atmosphere; and soil runoff. Some 85% of mercury emissions in the United States are believed to come from power plants as a result of fossil fuel combustion (U.S. EPA 2001a). Fish encounter mercury in the aquatic environment. Biological processes of animal species convert elemental and divalent mercury into an organic form called methylmercury (MeHg). Nearly all (>90%) mercury found in fish tissues is MeHg.

Consumption of mercury-contaminated fish can cause serious health problems in humans. MeHg is rapidly absorbed by the gastrointestinal tract and binds itself to all tissues. In

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humans the greatest concentrations of MeHg are found in the kidneys, although MeHg easily crosses the blood/brain and placental barriers. The estimated lethal dose of MeHg is 10–60 mg/kg. Methylmercury does vacate the body, with an estimated half-life of 44–80 days (U.S. EPA 2000).

Two major MeHg contamination episodes have been associated with eating fish, both occurring in regions of Japan where average per capita consumption of fish, a food staple, was very high, about 300 g/day (U.S. EPA 2000; U.S. EPA 2001a).[1] The symptoms of mercury contamination are called Minamata disease, after the region of Japan where it was first recognized. Those with the disease suffer from impaired peripheral vision, paresthesia (prickling, tickling, or itching sensation), and some loss of motor control.[2] In addition to these effects, recent studies have highlighted abnormal scores on tests of childhood neurological development as a result of fetal exposure, and cardiovascular health and mortality effects.

To manage the risks associated with eating contaminated fish, federal and state authorities have issued fish consumption advisories (FCAs) to reduce the probability of health effects, and in the case of commercial FCAs, to alter the behavior of the fishing industry affected. Assuming such FCAs are perfectly effective, in theory, there would be no mercury-related health effects, but there would be economic losses associated with the FCAs themselves and perhaps on ancillary fishing markets. In reality, many people ignore advisories, which lessens the costs associated with the FCA but also reduces health benefits.

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[1] In the United States, about 3% to 5% of the population regularly consumes in excess of 100 g/day.

[2] A major contamination episode in Iraq was associated with mercury-contaminated seed grain. This population suffered similar symptoms to the Japanese populations.

In this study, we evaluate the economic costs and health benefits associated with potential recreational and commercial fish consumption advisories in the Chesapeake Bay.[3] Health benefits are calculated for two endpoints: changes in children's IQ score due to prenatal mercury exposure, and mercury-related all-cause mortality in middle-aged men. Our model is applied to a specific case study area (the Maryland portion of the Chesapeake Bay) and a specific species (striped bass, *Morone saxatilis*), which the Maryland Department of Natural Resources considers the species of greatest concern for mercury contamination in the Chesapeake Bay.

This project is designed to provide information useful to analyses of the benefits of reducing mercury emissions. A primary benefit of reducing mercury emissions is the reduced likelihood of fish consumption advisories and the resulting welfare losses from changes in anglers' behavior associated with advisory compliance. In addition, of course, reduced mercury emissions will lead to a reduction in mercury-related health effects, assuming that baseline mercury levels in fish (and other exposure pathways) are above those found to cause health effects. However, health improvements may be mitigated if, with the lifting of a fish advisory, consumption of fish containing methylmercury increases. Because we do not have information linking mercury emissions to concentrations in the environment, our report focuses not on mercury emissions reductions, but rather on the costs and benefits associated with fish consumption advisories themselves.

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[3] Prior to December 2001, Maryland had issued only four fish consumption advisories. On December 12, 2001, the state issued several consumption advisories for freshwater anglers concerning contamination by PCBs and mercury. As of July 2002, there was no fish consumption advisory for the Chesapeake Bay.

We develop three modules within the Maryland Externalities Screening and Valuation Model, or "Maryland Model," developed for Maryland Department of Natural Resources by Resources for the Future. These are the Recreational Angler and Commercial Fishery Response Modules, and the Mercury Health Effects Module. The basis for the Maryland Model is the Tracking and Analysis Framework (TAF) model, a peer-reviewed probabilistic model that was used by the National Acid Precipitation Assessment Program to estimate costs and benefits associated with reductions in acid precipitation in the United States. For descriptions of TAF and the Maryland Model, see Bloyd et al. (1996) and Austin et al. (1999).

1.1. Plan of the Report

Section 2 of the report provides background on FCAs, briefly reviewing the mechanisms by which mercury concentrates in fish tissues. The current state of consumption advisories in the United States and in Maryland is then outlined, followed by a description of the Environmental Protection Agency (EPA) methodology for calculating safe levels of fish consumption and appropriate advisory levels. Mercury concentration levels of Chesapeake Bay striped bass are then evaluated within the context of EPA's FCA methodology to establish the likely FCA outcome for the Chesapeake Bay.

Section 3 of the report presents the model for estimating consumer surplus losses from an FCA for recreational fishing of striped bass in the Chesapeake. This section has two parts: first, a literature review and evaluation of behavioral choices made by anglers in response to an advisory, and second, an economic analysis and model for estimating welfare losses associated with these behaviors. Section 4 presents the model and results for an economic analysis of an advisory on commercial striped bass fishing in the bay. Section 5 presents a literature review and analysis of the human health effects of methylmercury and describes the model used to quantify and value such effects under a recreational advisory. Finally, Section 6 presents results of sensitivity analyses.

2. Background

2.1. Current Fish Consumption Advisories

Fish consumption advisories are a standard risk management tool in the United States. The goal of advisories is to warn the public about contamination of wildlife species, the adverse health affects associated with consumption of these species, and the methods to avoid or minimize potential contamination. The populations most at risk for MeHg exposure are those who tend to have high fish consumption rates relative to the general public, so much of the effort at publicizing advisories has been aimed at those who consume sport-harvested fish—that is, anglers and their families. Fish consumption advisories generally come in one of five forms, four of which recommend consumption levels for specific segments of the population; the fifth is associated with commercial species (Table 2.1; U.S. EPA 2001b). If "restricted" consumption of a particular species is recommended, consumption levels are communicated in the form of "meals per month" for either the general population or a subpopulation. These consumption levels are based on a standard portion, or "meal size," and the level of contaminant concentration found in the species at that site.

Table 2.1. Types of Consumption Advisories

Type of Advisory (Abbreviation)	*Definition*
No Consumption: General Population (NCGP)	Issued when levels of chemical contamination in fish or wildlife pose a health risk to the general public. The general population is advised to avoid eating certain types of locally caught fish or wildlife.
No Consumption: Sensitive Subpopulation (NCSP)	Issued when levels of contamination in fish or wildlife pose a health risk to sensitive subpopulations, such as pregnant women or and children. The sensitive subpopulation is advised to avoid eating certain types of locally caught fish or wildlife.
Restricted Consumption: General Population (RGP)	Issued when levels of contamination in fish or wildlife pose a health risk if too much fish or wildlife is consumed. The general population is advised to limit eating of certain types of locally caught fish or wildlife.
Restricted Consumption: Sensitive Subpopulation (RSP)	Issued when levels of contamination in fish or wildlife pose a health risk if too much fish or wildlife is consumed. The sensitive subpopulation is advised to limit eating of certain types of locally caught fish or wildlife.
Commercial Fishing Ban (CFB)	Issued when high levels of contamination are found in fish caught for commercial purposes. These bans prohibit the commercial harvest and sale of fish, shellfish, and/or wildlife from a designated water body.

In addition to the advisory types listed above, ten states also issue “Commercial Health Advice” (U.S. EPA 2001c).[4] The advice falls well short of a commercial fishing ban and is closely aligned with the information included in many consumption advisories. “Advice” is generally targeted at sensitive subpopulations (children, pregnant women, women who may soon be pregnant) and recommends restricted consumption of specified commercial species.

In 2000 almost 6,500 advisories were issued, a 124% increase over 1993 (Figure 2.1; U.S. EPA 2001b). This increase was due to more intensive monitoring by federal and state agencies rather than an increase in the general contaminant level (U.S. EPA 2001b, 2). A simple count of advisories, however, obscures the extent to which they vary. A single advisory issued by, say, a state agency may cover a single species at a single site for a single pollutant. Alternatively, an advisory may cover multiple species and pollutants at multiple sites.

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[4] These are Connecticut, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, Rhode Island, Vermont, and Washington.

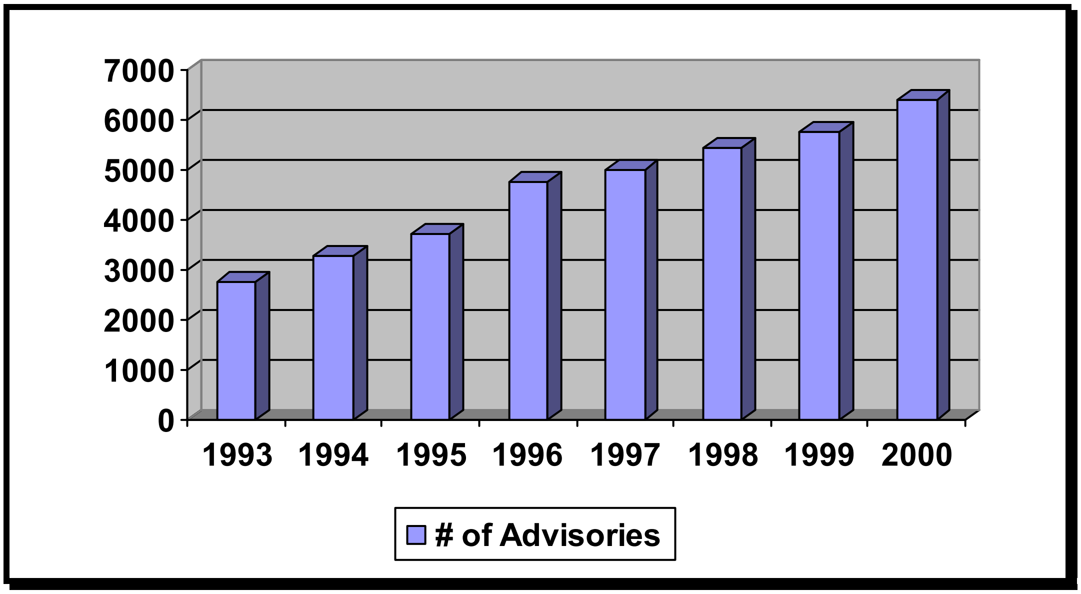

Figure 2.1. Number of Advisories, by Year. Source: U.S. EPA 2001b

By early 2001, approximately 9% of the nation's river miles and 23% of its lake acreage were under some form of consumption advisory. As of July 2002, the Chesapeake Bay was not under any type of advisory, but many of its tributaries (including the Potomac, James, Back, and Anacostia Rivers) have had fish consumption advisories issued. Although there are different ways of counting advisories, EPA reports that by 2001, some 2,259 advisories had been issued by 41 states for mercury contamination of a wide variety of fish species (U.S. EPA 2001c). Twenty-six of these advisories have been issued by 12 states for mercury contamination of coastal or estuarine regions. Six of the 12 states are located along the Atlantic coast (Delaware, Florida, Georgia, Maine, North Carolina, and South Carolina). In addition, 3 states in the immediate vicinity of Maryland—Delaware, Pennsylvania, and Virginia—have issued fish consumption advisories for mercury (Figure 2.2).

All states that share a border with Maryland, including the District of Columbia, have issued FCAs. Delaware has issued 20 advisories covering a wide variety of fish species and contaminants, including dioxins, polychlorinated biphenyls (PCBs), Dieldrin, arsenic, and pesticides. One advisory was issued for the Chesapeake and Delaware Canal, which links the Chesapeake Bay and the Delaware River; the FCA recommends no consumption by the general population for any fish harvested from this water body because of PCB contamination. Five Delaware FCAs address mercury contamination: Beck's Pond (RGP, all species), the Delaware River (NCGP, all species), Silver Lake Dover (RGP, all species), lower Delaware River and Bay (RGP, striped bass), and the St. Jones River (RGP, all species). The last 2 FCAs cover estuarine waters.

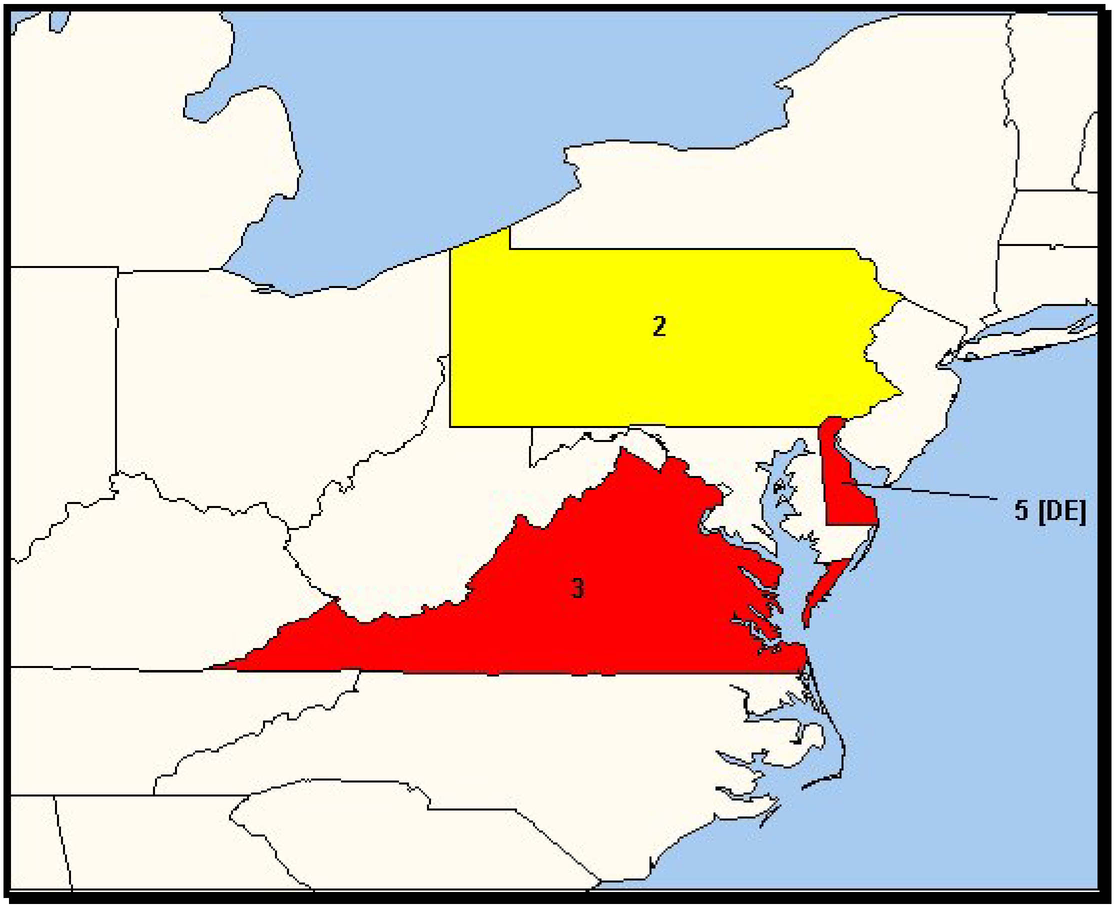

Figure 2.2. Mercury Advisories Issued by States Bordering Maryland.

Source: U.S. EPA 2001c

Pennsylvania has issued 36 advisories, 2 for mercury contamination. Other advisories have been issued for PCBs, chlordane, and mirex. The first mercury advisory, issued in 1993, covers Lake Wallenpaupack and recommends NCGP for walleye greater than 19 inches. The second mercury advisory was issued in 2001 and covers all freshwater rivers and lakes in the state. This broad advisory recommends RGP for all species caught in any of Pennsylvania's freshwaters.

West Virginia has issued 11 advisories for dioxin, PCBs, and chlordane contamination. There have been no FCAs for mercury. Two advisories have been issued for tributaries of the Chesapeake Bay, the Potomac River, and the North Branch of the Potomac. Both advisories are for dioxin contamination of nonsportfish species, with a recommendation of NCGP.

Virginia has issued 10 advisories because of contamination by three chemicals: mercury, PCBs, and kepone. Mercury advisories have been issued for the North Fork of the Holston River (NCGP, all species), the South Fork of the Shenandoah River (NCGP, all species), and the South River (NCGP, all species). Tributaries of the Chesapeake are also under an advisory. The James River has a kepone-related advisory recommending restricted consumption by the general population of all species. The Potomac River has an FCA for PCB contamination of channel catfish greater than 18 inches (RGP).

The District of Columbia has issued a single advisory covering all its lakes and rivers, including the Potomac and Anacostia Rivers, both tributaries of the Chesapeake Bay. This FCA recommends no consumption by the general population of carp, catfish, or American eel, and it also extends an RGP advisory on all other fish species.

Prior to December 2001, Maryland had issued only four fish consumption advisories. Three FCAs involved chlordane contamination; the fourth was due to PCB contamination. Two of the chlordane advisories were issued for tributaries of the Chesapeake. Restricted consumption by the general population has been recommended for channel catfish and American eel on the Back River and for Baltimore Harbor. On December 12, 2001, however, the Maryland Department of the Environment issued new FCAs covering a wide variety of water bodies and fish species because of PCB, pesticide, and mercury contamination (Huslin 2001; Maryland

Department of the Environment 2001). The species under FCAs for PCB and pesticide contamination now include channel catfish, white perch, striped bass, blue crab, American eel, white catfish, brown bullhead, black crappie, spot, common carp, and yellow perch. Yellow perch is also under an FCA because of mercury contamination, as are smallmouth bass, largemouth bass, pickerel, northern pike walleye, and bluegill. The advisories for all species but yellow perch are statewide advisories for all publicly accessible lakes and impoundments. The bass advisory extends to all rivers and streams in Maryland. The yellow perch advisory covers Piney Dam, Deep Creek Lake, and the main stem of the Susquehanna River. All advisories are RGPs and RSPs, recommending limited meals for the general population and sensitive subpopulations.

Finally, personal communications with Maryland Department of Natural Resources personnel indicate that the primary Chesapeake Bay species for which there is concern regarding MeHg contamination is striped bass, *Morone saxatilis* (Sherwell and Miller 2001). Some 43 advisories have been issued nationwide for striped bass, the majority due to PCB or dioxin contamination. Fifteen of these advisories have been issued for estuarine waters, of which 11 cover the Newark–New York City region, including Newark Bay, New York Harbor, and the Hudson River. Three of the advisories were issued for mercury contamination. Maine included striped bass in its statewide mercury advisory. The other 2 mercury-related striped bass advisories covered the San Francisco Bay and the Lower Delaware River and Delaware Bay.

2.2. Calculating Fish Consumption Limits

EPA has established a methodology for determining whether advisories for fish consumption should be issued (U.S. EPA 2000), based on assessed risks of contamination. The variable needed is simply the contaminant concentration in the local fish population. Calculations are sufficiently straightforward that a local agency with more information (e.g., details such as meal size and average body weight of consumers) can adjust the EPA recommendations to fit local conditions.

To understand this procedure, a few preliminaries are in order. The first concerns how mercury gets into fish tissue. Fish draw oxygen from water via thin membranes of the gill tissues. As water is pumped across the gills, mercury and other contaminants cross the gill membrane and enter directly into the blood (Reinert et al. 1996). Contaminants thus achieve a concentration within a single fish that is greater than the surrounding aquatic environment. Fish may also bioaccumulate contaminants from their food. Generally, the concentration of mercury in tissues increases with the age and size of the fish. Finally, fish that are higher in the aquatic food chain accumulate higher concentrations than fish or other organisms lower in the food chain, a process known as biomagnification. Fish are relatively more susceptible to contaminant concentration than terrestrial species because they accumulate contaminants not only through the food they consume but also through their constant contact with water. In some cases, fish species have MeHg concentrations 1,000 to 10,000 times greater than the surrounding aquatic environment (U.S. EPA 2001a). In contrast, terrestrial species accumulate little mercury contamination from airborne (vaporized) forms of mercury or from food sources.

Mercury taken up by fish is deposited into muscle tissues (fillets) as well as skin and fatty tissues, so it is difficult to remove the contaminant prior to consumption by humans.[5] Further, there are no cooking practices that reduce potential contaminant consumption; in fact, as cooking reduces the moisture content of the fillet, mercury actually becomes more concentrated per unit of fish.

The other crucial concept is the oral reference dose (RfD), an estimate of the lifetime daily exposure to a contaminant above which harmful health effects will occur (U.S. EPA 2001d). The calculation of an RfD also includes an "uncertainty factor" that adjusts the dose downward to reflect uncertainties about the accuracy of the calculated exposure level. In 2001 EPA established the RfD for mercury at 1×10^{-4} mg/kg/day. The RfD is based on the "critical effect" of developmental neuropsychological impairment, which is measured using several evaluative endpoints. The EPA RfD does not take into account potential carcinogenic impacts of MeHg contamination because of inadequate data for humans and limited evidence from animal studies (U.S. EPA 2001d).

The calculation consists of two parts. The first part calculates the maximum daily allowable consumption of contaminated fish for humans, expressed in kilograms of fish per day,

$$CR_{lim} = (RfD \times BW) \div C_m \qquad (2.1)$$

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[5] Other contaminants, such as PCBs, bind primarily to fatty tissues, making contaminant reduction prior to consumption much easier.

where CR_{lim} is the allowable daily consumption limit, RfD is the established reference dose (mg/kg/day) of the contaminant, BW is body weight (kg), and C_m is the estimated contaminant concentration (mg/kg) in the fish species.

The reference dose is based on chronic exposure studies and assumes that a threshold exists for toxic effects (U.S. EPA 2001d). It is an estimate of the daily exposure level below which the risk of toxic effects in humans is “acceptable.” The unit of measurement expresses the level of uptake per kilogram of weight in the subject; thus RfD measures the milligrams of contaminant that can be consumed per kilogram of weight of the person. The body weight (BW) variable in equation (2.1) adjusts for consumption by persons of different size. Thus, the allowable daily consumption limit for a heavier adult is greater than that for a small child, all else equal. The final portion of the equation adjusts for the contaminant concentration in the species of interest (C_m). All else equal, as the contaminant concentration in the species increases, the allowable daily consumption limit falls.[6]

CR_{lim} represents a maximum average daily consumption level that is “safe.” That is, average daily consumption at this level over a lifetime would not result in adverse, noncarcinogenic health effects. Exceeding this dose during a single day would not necessarily cause either chronic or acute health effects, but exceeding the limit over a long period of time would likely produce symptoms of contamination.

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[6] Equation (2.1) is the standard EPA calculation. One can modify the equation such that the contaminant concentration is on the left side of the equation, as in $C_m = (RfD \times BW) \div C_{lim}$ where C_{lim} measures average daily consumption of fish in a given time period. This form of the equation allows one to calculate the maximum allowable contaminant concentration in a species at a fixed consumption rate.

The daily limit can be converted to meals per unit of time, a measure that is more easily communicated to a target audience. The recommended consumption depends upon an assumed meal size and is calculated as

$$CR_{mm} = (CR_{lim} \times T_{ap}) \div MS \qquad (2.2)$$

where CR_{mm} is recommended consumption (meals per month), CR_{lim} is the maximum allowable daily consumption limit, T_{ap} is a time averaging period (1 month = 30.44 days), and MS is meal size. EPA recommendations are based on a standard meal size of 227 g of fish (about 8 ounces). Those who consume more than this amount are at greater risk of developing symptoms, whereas those who consume less than this amount are at less risk. In the case of extremely low allowable daily consumption limits, the calculation may yield a value for CR_{mm} equal to zero—that is, no consumption.

2.3. Design of Advisories for Chesapeake Bay

To date, the Maryland Department of Environment (MDE) has not issued any advisories for the Chesapeake Bay, pending analysis of fish samples from the bay (Huslin 2001). For the purposes of this project, it is necessary to project the likely advisories for the bay. As noted above, state Department of Natural Resource officials anticipate mercury advisories to be issued for striped bass. Mercury contamination concentrations vary by the size of fish, so projecting the potential set of advisories will first require an estimate of the relationship between MeHg concentrations and fish size. Second, the predicted concentration levels must be related to the size of striped bass kept by Chesapeake Bay anglers. This will allow us to estimate the mean concentration levels of MeHg in striped bass that are consumed. Finally, the predicted mean concentration can be used in the EPA recommended consumption equations (equations 2.1 and 2.2) to predict the recommended consumption advisories to be issued by MDE.

2.4. Relating MeHg Concentration to Fish Size

The only available data on which a preliminary analysis of potential Chesapeake estuary FCAs can be conducted are provided by Gilmour (1999). The Gilmour data consist of 18 samples of striped bass from the upper bay, 10 samples from the midbay, near Annapolis, and 14 samples from the Potomac River, a tributary of the bay, all collected from 1992 to 1994. The upper bay and midbay striped bass samples (n=28) showed a mean concentration of 0.182 mg/kg, with a median concentration of 0.155 mg/kg and a maximum concentration of 0.521 mg/kg.[7] When the Potomac sample is included, the mean, median, and maximum concentrations are 0.201 mg/kg, 0.164 mg/kg, and 0.607 mg/kg, respectively. Regression analysis shows a positive relationship between the fish weight and Hg concentrations (Table 2.2). The models indicate that for every 1% increase in weight, Hg concentrations increase by 0.6% to 0.9%.

New data will be available soon. The state collected striped bass from several regions of the bay during fall 2001 and spring 2002 to ascertain a temporally relevant, comprehensive, fish-length-based assessment of mercury levels before issuing an FCA, should one be deemed necessary.

Table 2.2. Regression Analysis of the Gilmour Data[a]

Variable	Potomac River[b]	Upper Bay[b]	Midbay[b]
Intercept	-2.275	-2.180	-3.198
	(-9.303)	(-10.508)	(-4.774)
ln(Weight)	0.876	0.636	0.890
	(3.154)	(2.529)	(1.758)
Adjusted R^2	0.408	0.241	0.188
N	14	18	10

Dependent Variable*: ln(Hg concentration).*
[a] t-ratios in parentheses .
[b] Specification from Gilmour (1999, 16).

2.5. Estimating Mean MeHg Concentration Levels for "Kept" Fish

The mean length of Chesapeake Bay fish in the Gilmour data was 64.4 cm, or a little over 25 inches, with a maximum length of 84 cm (33 inches); the mean weight of the sampled fish was 2.76 kg. The Gilmour sample may not be representative of the size and number of fish kept by Chesapeake anglers, however. Over the 1997–2000 period, anglers participating in the state's Cooperative Striped Bass Survey reported keeping approximately 5,300 striped bass. Using the distribution of kept fish to calculate mean fish lengths and fish weights, the average "kept" striped bass was 64 cm long and weighed approximately 2.75 kg, very close to the means from the Gilmour sample.[8] The data also showed, however, that 12% of kept fish were larger than the largest fish in the Gilmour sample. Because the Gilmour data did not include relatively large fish, the mean concentration level using the Gilmour data alone may be underestimated.

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[7] Samples measured total mercury, not just MeHg. This is fairly common, given the cost of MeHg measurement relative to total Hg measurement costs and the fact that nearly all mercury in fish is MeHg.

[8] The survey data reported only the fish length. Predicted weights for the cooperative survey data were predicted using a model based on the Gilmour data. The weight-length relationship was modeled using a simple linear model, *Weight* = -4.706 + 0.116 *Length,* where the intercept and the length variables were highly significant. The model explained nearly 94% of the variation in weight.

The distribution for “kept fish” using the 1997–2000 Cooperative Striped Bass Survey data is given in Table 2.3, along with predicted values for fish weight and Hg concentration levels. The weight-length relationship given in footnote 8 and in the Gilmour mercury concentration models was used to predict Hg concentrations found in larger fish. For example, consider a 36-inch (91.4 cm) fish caught in the upper bay. The weight-length model predicts that such a fish would weigh 5.90 kg. Using Gilmour’s upper bay mercury concentration model (column 3 of Table 2.2), a fish of this weight is predicted to have a mercury concentration of 0.35 mg/kg.

2.6. Projecting Probable Fish Consumption Advisories

Given the distribution estimated from the 1992–1994 Gilmour data and the 1997–2000 striped bass survey, the probability-weighted estimate of mercury concentration of fish consumed from the upper Chesapeake Bay is 0.205 mg/kg. This concentration value can be used in EPA equations (2.1) and (2.2) to estimate the recommended number of meals per month for consumers of striped bass. EPA standards assume an average adult body weight of 60 kg and an RfD of 1×10^{-4} mg/kg/day. Given a contaminant concentration level (C_m) of 0.205 mg/kg, equation (2.1) yields a maximum allowable daily concentration limit of 0.034 kg per day. Assuming an 8-ounce meal size (0.227 kg), equation (2.2) indicates that an adult should consume no more than four meals per month, .and a child of 35 kg, no more than two meals per month. Given the advisory actions of other states, it is likely that the recommendation for women of childbearing age will match that for children.

Table 2.3. Distribution of Chesapeake Bay Striped Bass Kept by Anglers (1997–2000), Predicted Weight, and Mercury Concentration Levels

Length (in.)	Fish (n)	Percentage of Fish	Cumulative Distribution	Weight (kg)[a]	Upper Bay Hg (mg/kg)[b]	Midbay Hg (mg/kg)[c]
18	252	4.8%	4.8%	0.60	0.0815	0.0258
19	610	11.5%	16.3%	0.89	0.1051	0.0369
20	550	10.4%	26.7%	1.19	0.1261	0.0476
21	466	8.8%	35.5%	1.48	0.1452	0.0579
22	483	9.1%	44.6%	1.78	0.1629	0.0681
23	299	5.7%	50.3%	2.07	0.1796	0.0781
24	315	6.0%	56.2%	2.37	0.1955	0.0879
25	187	3.5%	59.8%	2.66	0.2106	0.0976
26	203	3.8%	63.6%	2.95	0.2252	0.1071
27	115	2.2%	65.8%	3.25	0.2392	0.1166
28	208	3.9%	69.7%	3.54	0.2528	0.1260
29	226	4.3%	74.0%	3.84	0.2660	0.1352
30	212	4.0%	78.0%	4.13	0.2788	0.1444
31	207	3.9%	81.9%	4.43	0.2913	0.1536
32	202	3.8%	85.7%	4.72	0.3035	0.1626
33	125	2.4%	88.1%	5.02	0.3154	0.1716
34	161	3.0%	91.1%	5.31	0.3270	0.1806
35	112	2.1%	93.2%	5.61	0.3384	0.1895
36	104	2.0%	95.2%	5.90	0.3497	0.1983
37	60	1.1%	96.3%	6.20	0.3607	0.2071
38	50	0.9%	97.3%	6.49	0.3715	0.2158
39	29	0.5%	97.8%	6.78	0.3821	0.2245
40	42	0.8%	98.6%	7.08	0.3926	0.2332
41	22	0.4%	99.0%	7.37	0.4029	0.2418
42	18	0.3%	99.4%	7.67	0.4131	0.2504
43	11	0.2%	99.6%	7.96	0.4231	0.2589
44	11	0.2%	99.8%	8.26	0.4330	0.2675
45	6	0.1%	99.9%	8.55	0.4427	0.2759
46	3	0.1%	100.0%	8.85	0.4524	0.2844
48	2	0.0%	100.0%	9.44	0.4713	0.3012

Source: Chesapeake Bay Cooperative Striped Bass Survey, conducted by the Maryland Department of Natural Resources.

[a] Calculated using the weight-length model in footnote 8.

[b] Calculated using Gilmour's (1999) upper bay mercury concentration model (Table 2.2).

[c] Calculated using Gilmour's (1999) midbay mercury concentration model (Table 2.2).

2.7. Summary

Given the scope of the most recent advisories issued by the state of Maryland and the Hg concentration levels found in Chesapeake Bay striped bass tissues, the most likely consumption advisories can be hypothesized (Table 2.4). At mean concentration levels, the advisory for recreational anglers would most likely suggest that the general population restrict consumption of striped bass to no more than four meals per month; the likely advisory for children and women of childbearing age would be no more than two meals per month. Given the concentration levels found in Chesapeake Bay striped bass, a commercial fishing ban is very unlikely. Instead, MDE would likely follow other coastal states and issue "Commercial Health Advice" consistent with the recommendations given to recreational anglers.

Table 2.4. Most Likely FCA Scenario for Chesapeake Bay Striped Bass

Population	Recommendation
General population	Restricted consumption, four meals per month
Children and women of childbearing age	Restricted consumption, two meals per month
Commercial fisheries	Issue "Commercial Health Advice"

The FCA scenario summarized in Table 2.4 is based upon assumptions about how MDE might implement EPA's FCA methodology. Should MDE choose a different set of default parameters, such as meal size or body weight, recommended consumption restrictions may change. A smaller meal size will increase the recommended consumption rates; a larger meal size will decrease the recommended consumption rate, all else equal. Similarly, larger body weights would relax consumption restrictions; smaller weights would tighten them.[9] It is unlikely, however, that different parameter values for these variables will change the recommendation by more than one meal per month in either direction. Finally, the recommended restrictions are based on a contaminant concentration of 0.205 mg/kg, the mean of the concentration levels in upper Chesapeake Bay fish based on the "kept fish" distribution in Table 2.3. The Chesapeake midbay fish have lower concentration levels. If the state agency bases its recommendation on fish caught from all portions of the Chesapeake, the mean contaminant concentration level would be lower, and those lower estimates would loosen recommended consumption restrictions.

3. Recreational Fishing Losses from an FCA

3.1. Awareness, Compliance, and Averting Behaviors Associated with FCAs

When a fish consumption advisory is issued, anglers have a number of potential responses:

1. ignore the advisory and continue current fishing practices;
2. follow advisory consumption limits or change target species (or both);
3. cease consumption of listed species and change target species;
4. cease consumption of all species from the affected water body; and
5. take fewer fishing trips, or none, to the affected water body.

In the absence of an original study designed to elicit the potential responses of Chesapeake anglers, it is necessary to review the literature on advisories and make an educated guess regarding their awareness and their potential responses. This section and Section 3.2

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[10] In some cases one study may have reported a number of estimates, each of which is based on an independent sample of a different population. Where possible, each independent estimate is reported. The source for each

attempt to distill and synthesize the literature related to FCAs. As such, these sections should be viewed as a meta-analysis of the literature.

The same parameter of interest—say, the proportion of anglers who are aware of fish consumption advisories—may have many estimates, each of which comes from a different study or study region. Each estimate of the parameter of interest is initially treated with equal weight, in that all estimates from all studies are reported.[10] This allows the reader to make an informed judgment with respect to the subsequent treatment of the data. The information gathered from the literature is then subjected to two filters. First, all estimates are evaluated with respect to applicability to the Chesapeake Bay region. Where a sufficient number of estimates are identified for regions that share many attributes in common with the Chesapeake Bay region (e.g., estuarine waters located near major urban populations), only this subset of estimates is retained for analysis. For other parameters of interest, the literature yields so few estimates that this is not possible; subsequent analysis is based on all estimates gleaned from the literature. The rationale for each approach is explained in detail.

A second filter is used to incorporate the statistical properties of each estimate. A Bayesian weighting procedure, described below, is applied to the data. Essentially, this method gives greater weight to parameters based on larger sample sizes (i.e., more precise estimates) than those estimates based on smaller sample sizes. Admittedly, this is only one of many ways in which a meta-analysis may be conducted.

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estimate is always identified.

Although the fish consumption advisory literature is not very extensive, it is adequate to make reasonable assumptions regarding the potential behavioral impacts of any FCA issued for the Chesapeake. In all, some 20 advisory-related studies were reviewed to assess the following recreational anglers' behaviors:

1. awareness of fish consumption advisories;
2. probability of consuming species caught from waters under advisory, given an angler's awareness of the advisory;
3. the degree to which other averting behaviors are adopted; and
4. probability of exceeding advisory limits.

Analysis of advisory awareness and changes in consumption behavior are used to assess the degree to which mercury uptake by Chesapeake Bay anglers will change under an advisory. This is done by relating the results of the literature review to data provided by the Chesapeake Bay Cooperative Striped Bass Survey.

3.1.1. Percentage of Recreational Anglers Aware of Advisories

The probability of an angler's awareness of advisories is the most frequently encountered statistic in the advisory literature. Table 3.1 summarizes the studies used to estimate the probability an angler will be aware of an advisory. Many studies report on more than one region; here, these are treated as separate samples where appropriate and where the data permit. Fourteen studies provide 22 estimates of the probability that an angler is aware of advisories. The vast majority of the studies reported in Table 3.1 are intercept surveys conducted at contaminated sites.[11]

The estimates of angler awareness range widely, from 19% to 96%. Regression analysis does not reveal a statistically significant relationship with the length of time an advisory is in place. Thus, angler awareness is more likely a function of advisory severity, angler characteristics, and state efforts to make anglers aware of advisories. Treating all studies equally, the mean of all the estimates suggests that 71% of anglers were aware of advisories, indicating that very high levels of angler awareness are possible. In particular, the ten estimates from the Great Lakes states and states that border the Ohio River show exceptionally high levels of advisory awareness, with a mean awareness of 87%.

Three of the studies concern freshwater anglers in southern states (the Tennessee studies are not intercept surveys and include awareness of anglers who do not fish a contaminated site). Two reports examine freshwater anglers from the New England states, and another examines subsistence anglers in Puerto Rico. This leaves six estimates (from four studies) of interest: those for estuarine and coastal waters. These are highlighted in bold italicized text in Table 3.1.

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[11] This type of study surveys people at the site where they recreate. As such, it is not a random sample even of recreators, since the most frequent recreators are more likely to be "intercepted." To the extent more frequent recreators behave differently than less frequent recreators, the results of such studies may be biased with respect to all recreators.

Table 3.1. Percentage of Anglers Aware of an Advisory

Authors	Location	Survey Date	Sample Size	Percentage Aware
Belton et al. (1986)	***New York Harbor***	1983–85	1900	***50%***
Burger and Gochfeld (1991)	Puerto Rico	1988	25	96%
Burger et al. (1993)	***Jamaica Bay, NY***	1990	154	***19%***
Krieger and Hoehn (1998)	Michigan waters	1991	951	86%
Connelly and Knuth (1995)	Lake Champlain, NY and VT	1992	744	84%
Connelly et al. (1996)	Lake Ontario	1992	366	95%
Knuth et al. (1993)	Ohio River	1992	839	87%
Knuth et al. (1993)	Ohio River, PA	1992	123	79%
Knuth et al. (1993)	Ohio River, WV	1992	233	80%
Knuth et al. (1993)	Ohio River, OH	1992	250	86%
Knuth et al. (1993)	Ohio River, IN	1992	265	90%
Knuth et al. (1993)	Ohio River, KY	1992	278	92%
Knuth et al. (1993)	Ohio River, IL	1992	119	87%
MacDonald and Boyle (1997)	Maine open waters	1994–95	999	63%
May and Burger (1996)	***Arthur Kill, NJ***	1994	168	***60%***
May and Burger (1996)	***Raritan Bay, NJ***	1994	60	***28%***
May and Burger (1996)	***New Jersey Shore***	1994	44	***30%***
Phlugh et al. (1999)	***Newark Bay, NJ***	1995	300	***60%***
Burger (1998)	Savannah River, SC	1997	258	62%
Jakus et al. (1998)	Tennessee lakes	1997	222	65%
Jakus and Shaw (2002)	Tennessee lakes	1997–99	457	70%
Breffle et al. (1999)	Green Bay, WI	1998	647	85%

Bold italic type indicates estimate for estuarine or coastal region.

All of the estuarine and coastal estimates are derived from intercept surveys of anglers at contaminated waters in the New York–New Jersey region. As with the Chesapeake Bay region, the waters are near a major metropolitan area. Further, it seems likely that many of the characteristics of New York–New Jersey's recreational anglers are shared by Chesapeake anglers: they may be diverse in ethnicity, first language, and angling experience. A big difference between the two regions is that the New York–New Jersey estuarine region has a "no consumption" advisory, a recommendation more severe than that anticipated for the Chesapeake Bay.

The four estuarine and coastal studies were conducted over a 13-year period (1983–1995) and revealed a wide range of estimates for angler awareness, from 19% to 60%. Table 3.2 shows the calculated standard error for each study, along with a 95% confidence interval (CI) for the estimate. Treating all the estimates equally, the mean probability that an angler was aware of advisories was 41%.

Table 3.2. Standard Errors and Confidence Intervals for Advisory Awareness Estimates, Estuarine and Coastal Regions

Authors	Location	Percentage Aware	Standard Error	95% CI
Belton et al. (1986)	New York Harbor	50%	1.1%	47.7%–52.2%
Burger et al. (1993)	Jamaica Bay, NY	19%	3.2%	12.8%–25.2%
May and Burger (1996)	Arthur Kill, NJ	60%	3.8%	52.6%–67.4%
May and Burger (1996)	Raritan Bay, NJ	28%	5.8%	16.6%–39.4%
May and Burger (1996)	New Jersey Shore	30%	6.9%	16.5%–43.5%
Phlugh et al. (1999)	Newark Bay, NJ	60%	2.8%	54.5%–65.5%

Some of the estimates (e.g., Raritan Bay and New Jersey Shore) are based on relatively small sample sizes, so it is advisable to take into account the error associated with each study estimate. Similarly, one might not wish to assign the studies equal weight, instead giving greater weight to studies with larger sample sizes. One method to accomplish both goals is a Bayesian weighting methodology, in which the weights are based upon the inverse of the variance of each estimate. In this case the estimate with the smallest variance (Belton et al.) receives the most weight, and the estimate with the largest variance (May and Burger, New Jersey Shore) receives the least. Desvousges et al. (1998, 34) provide the formulas to calculate the updated mean and variance,

$$E[\beta \mid b] = \frac{((\beta / \sigma_\beta) + (b / \sigma_b))}{(1 / \sigma_\beta) + (1 / \sigma_b)}$$

$$Var\ [\beta \mid b] = \frac{1}{(1 / \sigma_\beta) + (1 / \sigma_b)}$$

where β and σ_β are the prior estimate of the mean and variance, respectively, and b and σ_b are "new" estimates of the mean and variance. The equations from Desvousges et al. provide estimates for the mean and variance of the posterior distribution. Ordering the estimates chronologically, the Belton et al. mean-variance estimates become the basis for the subsequent Bayesian calculations. Based upon this analysis, the mean percentage of anglers aware of advisories is predicted to be 48%, with a 95% CI of 46%–50%.

3.1.2. Percentage of Recreational Anglers Consuming Sport-Caught Fish

Ten studies provided 12 estimates of the percentage of anglers consuming some or all of their sport-caught fish. Table 3.3 presents these data.[12] The estimates range from 39% in Tennessee to 100% among subsistence anglers of Puerto Rico. The mean proportion of anglers keeping some or all of their catch is 0.69, or 69%. If the estimate for subsistence anglers is dropped, the mean percentage falls to 66%. If the data are restricted to the New York–New Jersey harbor region, the estimated proportion of anglers consuming sport-caught fish is 71%.

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[12] The sample size for the Knuth et al. (1993) study changed from Table 3.2 to Table 3.3. This study comprises several independent samples, but the consumption estimate is reported only for the combined dataset.

Table 3.3. Percentage of Anglers Consuming All or Some of Their Catch

Authors	Location	Survey Date	Sample Size	Percentage Consuming
Belton et al. (1986)	New York Harbor	1983	1900	58%
Burger and Gochfeld (1991)	Puerto Rico	1988	25	100%
Diana et al. (1993)	Lake Ontario	1988	256	70%
Burger et al. (1993)	Jamaica Bay, NY	1990	154	85%
Connelly and Knuth (1995)	Lake Champlain, NY and VT	1992	744	66%
Knuth et al. (1993)	Ohio River	1992	2110	43%
MacDonald and Boyle (1997)	Maine open waters	1994–95	999	41%
May and Burger (1996)	Arthur Kill, NJ	1994	168	70%
May and Burger (1996)	Raritan Bay, NJ	1994	60	88%
May and Burger (1996)	New Jersey Shore	1994	44	82%
Burger (1998)	Savannah River, SC	1997	258	82%
Jakus et al. (1998)	Tennessee lakes	1997	222	39%

The consumption estimates presented in Table 3.3 do not account for the influence of advisory knowledge. How awareness of an advisory affects the probability of consumption is of interest because changing propensity to consume is a key averting behavior in response to an advisory. Some percentage of anglers will choose not to consume listed species (or perhaps any species) from the water body under advisory. What we need is a statistic that gauges the response of consumption to the presence of an advisory. To do this, it is necessary to completely characterize the sample of consumption anglers by knowledge of fish consumption advisories. The following probability relationship must hold:

$$P(Consume) = P(Consume \cap Aware) + P(Consume \cap Not\ Aware)$$

Conditional estimates of the probability of consumption can be recovered according to

$$P(Consume \mid Aware) = P(Consume \cap Aware) \div P(Aware)$$

$$P(Consume \mid Not\ Aware) = P(Consume \cap Not\ Aware) \div P(Not\ Aware)$$

The two conditional probability estimates then can be used to gauge the degree to which anglers will cease consumption of sport-caught fish when an advisory is in place. This will, in turn, affect the overall probability (percentage) of consumption by anglers.

Unfortunately, only three studies (offering five estimates) provide the necessary information. Table 3.4 shows the data from each of the studies and the estimates of the conditional probabilities.

Table 3.4. Estimating Conditional Consumption Probabilities[a]

Study	$P(A)$	$P(NA)$	$P(C)$	$P(C \cap A)$	$P(C \cap NA)$	$P(C \mid A)$	$P(C \mid NA)$
Belton et al. (1986)	***0.580***	0.420	***0.500***	***0.205***	0.295	0.353	0.702
May and Burger (1996), Arthur Kill	***0.600***	0.400	***0.700***	0.396	0.304	***0.660***	0.760
May and Burger (1996), Raritan Bay	***0.280***	0.720	***0.880***	0.280	0.600	***1.000***	0.833
May and Burger (1996), New Jersey Shore	***0.300***	0.700	***0.820***	0.210	0.610	***0.700***	0.871
MacDonald and Boyle,(1997), All	***0.630***	***0.370***	***0.413***	***0.236***	***0.177***	0.375	0.478

[a] Abbreviations for Probabilities:
A = Aware of Advisories
NA = Not Aware of Advisories
C = Consume Fish from Contaminated Waters
Numbers in bold italics are provided in study documents.

The two estimates of interest are shown in the last two columns of Table 3.4, the consumption probabilities conditional on knowledge of advisories. The probability that an angler would consume fish from a contaminated water body given knowledge of advisories ranges from 0.35 to 1.00. Denote this probability as *P(Consume | Aware)*. If the 100% probability is not included (it was based on a very small sample), the estimates of *P(Consume | Aware)* range from 0.35 to 0.70. The conditional estimates of the probability an angler would consume fish from a contaminated water body given no awareness of advisories, denoted *P(Consume | Not Aware)*, range from 0.48 to 0.87. In all cases except the 100% conditional probability estimate, *P(Consume | Aware)* is less than *P(Consume | Not Aware)*. This suggests that anglers who are aware of advisories are less likely to consume fish than anglers who are not aware of advisories. Applying the Bayesian equations cited by Desvousges et al., the mean and variance for the conditional consumption probabilities can be estimated. The mean *P(Consume|Aware)* is 0.493, with a 95% CI of 0.473–0.51.3. The mean *P(Consume|Not Aware)* is 0.667, with a 95% CI of 0.642–0.692.[13]

These estimates can now be evaluated to gauge the degree to which anglers will cease consumption of listed species. For example, the Belton et al. (1986) study shows that anglers who were aware of advisories were only half as likely to consume fish from the contaminated water as anglers who were unaware of advisories. The degree to which aware anglers are less likely to consume from contaminated waters is given by

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[13] The standard error for the conditional consumption probabilities is likely underestimated because they themselves are a product of random variables. Not all the variance was accounted for, such that the 95% CIs are likely too narrow.

$$\%\text{Reduction} = \frac{\text{P(Consume} \mid \text{Aware)} - \text{P(Consume} \mid \text{Not Aware)}}{\text{P(Consume} \mid \text{Not Aware)}} \times 100$$

Evaluated at the means for *P(Consume|Aware)* and *P(Consume|Not Aware)*, the percentage reduction in the probability of consumption is 26.1%. An empirical distribution for this value was formed by taking 1,000 random draws from the distributions of *P(Consume|Aware)* and *P(Consume|Not Aware)* and calculating the percentage reduction for each draw. The empirical distribution yields a 95% CI for the percentage reduction of 22.1%–30.0%.

3.1.3. Other Averting Behaviors

Anglers can respond to advisories in several ways. The change in consumption probability calculated in Section 3.1.2 may occur because they target a different species for consumption or, more simply, because they avoid *all* species from a water body with under an FCA for *any* species. Anglers may also respond to an advisory by eating fewer meals of the listed species or reducing the number of trips to contaminated water bodies. With many chemical contaminants, consumption risks may be reduced by changing fish preparation or cooking methods, thus making listed species safer to eat. But cooking and preparation methods do little to reduce the risk of eating fish species contaminated by mercury because unlike other contaminants, mercury does not concentrate in specific bodily tissues.[14] This section focuses on averting actions that are relevant to mercury contamination.

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[14] For example, PCBs concentrate in the fatty tissues of fish. Removal of these tissues greatly reduces PCB contamination of those who consume these fish. Unlike PCBs, mercury is more evenly distributed throughout a fish, binding to the proteins in muscle tissues.

Table 3.5 presents consumption-related averting behaviors as reported in the literature. Behaviors are presented slightly differently from study to study, with different conditions governing each response. Sometimes the response is based on behavior given the advisory, other times it is based on contingent behavior if the advisory were not in place.

The roughly 26% decrease in consumption of listed species calculated using conditional probability rules described in Section 3.1.2 is supported by the consumption reductions noted by the five studies reported in Table 3.5. Between 13% and 25% of those surveyed reported not eating any fish from contaminated waters; 23% to 26% reported changing the species targeted for consumption; and 15% to 54% reported adjusting overall fish consumption.

Table 3.5. Consumption-Related Behaviors Due to Fish Consumption Advisories

Question/Behavior	Location	Authors
If advisory were not in place…		
54% would eat more fish	Lake Champlain	Connelly and Knuth (1995)
15% would consume more fish	Maine	MacDonald and Boyle (1997)
In response to present advisory…		
42% reduced fish consumption	Ohio River	Knuth et al. (1993)
13% stopped eating all fish	Ohio River	Knuth et al. (1993)
26% changed target species	Ohio River	Knuth et al. (1993)
23% changed target species	Green Bay	Breffle et al. (1999)
45% changed species for consumption	Green Bay	Breffle et al. (1999)
If favorite site had an FCA…		
25% would not eat any fish	Michigan	Kreiger and Hoehn (1998)
14% would eat fewer fish	Michigan	Kreiger and Hoehn (1998)

In addition to changing consumption behaviors in response to advisories, anglers may also change trip-related behavior. For example, an angler may choose not to visit a contaminated site. This, in turn, may affect the total number of fishing trips taken during a season. Table 3.6 reports trip-related averting actions.

Table 3.6. Trip-Related Behaviors Due to Fish Consumption Advisories

Question/Behavior	Location	Authors
If advisory were not in place…		
10% would fish more days	Maine	MacDonald and Boyle (1997)
5% would fish more waters	Maine	MacDonald and Boyle (1997)
5% would fish different waters	Maine	MacDonald and Boyle (1997)
In response to present advisory…		
7% do not fish contaminated water body	Lake Champlain	Connelly and Knuth (1995)
7% do not fish contaminated water body	Green Bay	Breffle et al. (1999)
37% take fewer trips	Ohio River	Knuth et al. (1993)
30% fish fewer days	Green Bay	Breffle et al. (1999)
26% change fishing site	Ohio River	Knuth et al. (1993)
31% change fishing site	Green Bay	Breffle et al. (1999)
If favorite site had an FCA…		
36% change fishing site	Michigan	Kreiger and Hoehn (1998)

In addition to the studies cited in Table 3.6, a number of articles in the economics literature examine the impact of advisories on the probability a site is visited and on the number of trips taken over the course of the season. These studies support the general findings reported in Table 3.6—that FCAs cause anglers to choose other locations to fish and take fewer overall fishing trips during any given time period. Jakus et al. (1997) examined the site location preferences of freshwater Tennessee anglers, finding that the removal of an advisory at any one site would increase the probability that site would be visited on any given occasion by 0.1% to 2.55%. Parsons et al. (1999) examined fishing in middle Tennessee lakes (2 of 14 sites were contaminated) and predicted that total seasonal trips would increase by more than 0.3 trips per person if advisories were removed from both lakes (approximately a 2% increase). Employing a different dataset for Tennessee anglers, Jakus et al. (1998) use a site-choice-only model to find that anglers are less likely to visits lakes with advisories than lakes without advisories, all else equal. Other studies confirm a similar effect (e.g., Montgomery and Needelman 1997; Chen and Cosslett 1998; Parsons and Hauber 1998; and Shaw and Shonkwiler 2000). Unfortunately, none of these last five studies report the estimated change in seasonal trips due to advisories. The welfare effects of changing trip-related behavior are examined in Section 3.2 of this report.

3.1.4. Percentage of Anglers Exceeding Recommended Consumption Limits

Thus far, this report has examined the degree to which anglers will eliminate or reduce consumption of species under an FCA. Despite FCAs, some anglers will continue to consume listed species at current consumption rates, possibly in excess of recommended consumption limits. Several authors measure the degree to which anglers exceed limits. Table 3.7 summarizes this information.[15]

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[15] The Knuth et al. (1993) study consisted of independent samples conducted either at different times (the first estimate in Table 3.7) or in different locations (the next six estimates). Data were reported in such a way that each estimate can be calculated independent of the others.

Table 3.7. Percentage of Anglers Exceeding Recommended Consumption Limits

Authors	Location	Survey Year	Sample Size	Percentage Who Exceed Limit
Diana et al. (1993)	Lake Ontario	1988	256	57.0%
Knuth et al. (1993)	Ohio River	1992	839	11.1%
Knuth et al. (1993)	Ohio River, PA	1992	123	1.9%
Knuth et al. (1993)	Ohio River, WV	1992	233	6.6%
Knuth et al. (1993)	Ohio River, OH	1992	250	1.7%
Knuth et al. (1993)	Ohio River, IN	1992	265	4.8%
Knuth et al. (1993)	Ohio River, KY	1992	278	36.1%
Knuth et al. (1993)	Ohio River, IL	1992	119	0.0%
Connelly and Knuth (1995)	Lake Champlain	1992	744	8.0%
May and Burger (1996)	Arthur Kill, NJ	1994	168	30.0%

The Illinois estimate is 0% only because the state had not issued an Ohio River FCA at the time of the survey. Even so, the estimated percentage of anglers exceeding advisory limits ranges widely, from 1.7% to 57%. The Desvousges et al. Bayesian calculations can be applied to estimate the degree to which Chesapeake Bay anglers may exceed consumption limits. Eliminating the Illinois estimate, these calculations yield a mean percentage of anglers exceeding the limit of 9.6%, with a 95% CI of 7.7% to 11.5%.

3.1.5. Assessing Changes in Consumption-Related Behavior by Chesapeake Bay Anglers

The analysis of this section can be combined with recreational trip and consumption information to assess consumption-related behavior by anglers and see how this behavior might change under an advisory. In particular, we need to know how both the propensity to consume and the number of trips for striped bass change under an advisory, so that we can estimate pre- and post-advisory per capita mercury uptake. Although the per capita change in exposure under an advisory depends upon the behavioral changes estimated in this section, this value is the primary input to the Health Effects Module, and these calculations are discussed in detail in Section 5. The change in consumption can be calculated using the results of Sections 3.1.1 and 3.1.2, if one assumes that the current number of trips per angler is independent of anglers' current propensity to consume fish. With this assumption, the current probability that any given angler will consume striped bass is 0.674.

Table 3.8 displays our pre-advisory estimates of participation and consumption behaviors for anglers from any state who use the Maryland portion of the Chesapeake Bay. Note, then, that these estimates ignore benefits and costs associated with use by anglers of the Virginia portion of the Chesapeake Bay. In particular, the costs of an FCA and the health benefits associated with an FCA would both be larger if use of the Virginia portion were counted.

Table 3.8. Current Participation and Consumption by Chesapeake Bay Recreational Anglers

Row	Measure	Value	Source
(1)	Total Maryland saltwater fishing trips (2000)	3,722,018	MRFSS
(2)	Inland (Chesapeake Bay) fishing trips (92% of row 1)	3,406,647	MRFSS
(3)	Percentage of trips for striped bass fishing	24.6%	1996 FHWAR-MD
(4)	Trips for striped bass fishing (row 2 × row 3)	836,672	
(5)	Percentage of trips on which striped bass are kept for consumption	67.4%	1997–2000 MD CSBS
(6)	Trips on which striped bass are kept for consumption (row 4 × row 5)	563,917	

MRFSS = Marine Recreational Fishing Statistics Survey.
FHWAR-MD = National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, Maryland.
MD CSBS = Maryland Cooperative Striped Bass Survey.

When FCAs have been issued in other areas, studies have shown that anglers who are aware of the advisory are less likely to consume listed species than those who are not aware of the advisory. The conditional consumption probability estimates of Table 3.4 depict this effect.

Under the assumption that anglers who are unaware of the advisory will not change their consumption propensity, then *P(Consume | Not Aware of Advisories)* is equal to the current consumption probability. An estimate of *P(Consume | Aware of Advisories)* is given by the following relationship,

$$\text{Reduction} = \frac{P(\text{Consume} \mid \text{Aware}) - P(\text{Consume} \mid \text{Not Aware})}{P(\text{Consume} \mid \text{Not Aware})}$$

The left-hand side of this equation is given by the mean percentage reduction in probability of consumption from Table 3.4, or 0.261. Given *P(Consume|Not Aware)* = 0.674, *P(Consume | Aware)* is estimated to be 0.498. The overall consumption probability following an advisory can be estimated using the following probability relationship,

P(Consume) = P(Aware of Advisories) × *P(Consume | Aware)* +

P(Not Aware of Advisories) × *P(Consume|Not Aware)*

where *P(Aware of Advisories)* = 0.48 and *P(Not Aware of Advisories)* = 0.52. These values were estimated in section 3.1.1. Thus the overall consumption probability after advisories is estimated to be *P(Consume)* = (0.48 × 0.498) + (0.52 × 0.674) = 0.590.

The second parameter of interest is the reduction in the total number of trips under an advisory. In the presence of an advisory, anglers may choose not to visit a contaminated site, or reduce their number of trips to the site. We apply the Parsons et al. (1999) estimate of a 2% reduction in trips to all saltwater trips in Maryland, and assume that this reduction occurs uniformly throughout the population. This estimate, along with the estimates of changes in consumption behavior discussed above, are used to estimate the change in per capita mercury uptake under an advisory in Section 5. Table 3.9 displays our postadvisory estimates of participation and consumption behaviors.

Table 3.9. Participation and Consumption by Chesapeake Bay Recreational Anglers under a Striped Bass Fish Consumption Advisory

Row	Measure	Value	Source
(1)	Total Maryland saltwater fishing trips (2000)	3,722,018	MRFSS
(2)	Percentage reduction in total trips due to FCA	2%	Parsons et al. (1999)
(3)	Total Maryland saltwater fishing trips with FCA (row 1 × (1 – row 2))	3,647,578	
(4)	Inland (Chesapeake Bay) fishing trips (row 3 × 0.92)	3,359,771	MRFSS
(5)	Percentage of trips for striped bass fishing	24.6%	1996 FHWAR-MD
(6)	Trips for striped bass fishing (row 4 × row 5)	825,520	
(7)	Percentage of trips on which striped bass are kept for consumption	59.0%	This study
(8)	Trips on which striped bass are kept for consumption (row 6 × row 7)	486,661	

MRFSS = Marine Recreational Fishing Statistics Survey.
FHWAR-MD = National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, Maryland.
MD CSBS = Maryland Cooperative Striped Bass Survey.

3.1.6. Summary

The advisory literature has been reviewed with respect to the consumption-related averting behaviors. Conditional consumption probability estimates show that the propensity to consume sport-caught fish is related to advisory awareness. These estimates will be used in Section 5 to estimate the change in total Hg uptake by anglers. Table 3.10 summarizes the parameters estimated for the Chesapeake Bay.

Table 3.10. Summary of Parameters Estimated for Chesapeake Bay

Parameter	Mean	95% CI
P(Aware of Advisories)	0.48	0.46–0.48
P(Consume | Aware)	0.498	0.478–0.518
P(Consume | Not Aware)	0.674	0.649–0.699
Percentage reduction in probability of consumption (Aware vs. Not Aware)	26.1%	22.1%–30.0%
P(Exceed Consumption Limits)	0.096	0.077–0.115

A number of assumptions were required in the estimation of angler behavioral changes under an advisory. Table 3.11 outlines the critical assumptions and the probable direction of bias in the estimate of the change in angler striped bass consumption. The various assumptions suggest that in all likelihood, we are underestimating reductions in consumption and mercury uptake resulting from anglers' behavioral response to an advisory.

Table 3.11. Assumptions and Limitations of Angler Behavior Estimates

Parameter, Limitations	**Probable Bias in Estimate of ΔConsumption**
P(Aware of Advisories)	
• No control for severity of advisories, angler characteristics, or state efforts to publicize advisories • Advisory awareness based upon awareness in Northeast estuaries, which is low compared with other regions; advisory awareness maybe greater in the Chesapeake, especially if state educational efforts are extensive	Bias Δconsumption downward
P(Consume), P(Consume|Aware) and P(Consume|Not Aware)	Unknown
• Based on only three studies • Standard errors do not fully reflect all sources of random error • For "not aware" anglers, P(Consume) before FCA equals P(Consume) after FCA	
Average Consumption ("Kept" Fish) per Trip	Bias Δconsumption downward
• Assumed constant after advisory; literature suggests that those who are aware of advisories yet still consume fish tend to reduce consumption	
Reduction in Trips	
• Quantitative estimate based on only one study	Unknown

3.2. Economic Analysis of Fish Consumption Advisories and Chesapeake Bay Recreational Fishing

Economic losses are expected to result from the behavioral adjustments undertaken by anglers who respond to a recreational advisory. The size of the total consumer surplus loss from an advisory is proportional to the magnitude of the average angler behavioral response at the margin. This marginal response is from a baseline angler behavior that reflects any preexisting advisories. For example, if there were already a consumption advisory in place for Chesapeake Bay striped bass for a contaminant other than mercury, anglers would have already undertaken some level of behavioral adjustment before the announcement of a mercury advisory. It is possible, then, that the behavioral adjustment under a mercury advisory might be negligible, such that the consumer surplus loss from that specific advisory would be close to zero. In reality, however, some incremental behavioral adjustment is likely as a result of such factors as the increased severity implied by the existence of multiple advisories, increased awareness due to the additional advisory, or possibly greater aversion to mercury contamination than to other contaminants for some individuals. The size of this marginal response is also a function of several other factors, such as advisory severity, agency outreach and information efforts, and the availability of noncontaminated substitute species or sites, among others.[16]

Economists have only recently begun to publish reports on the economic value of behavioral changes induced by fish consumption advisories. Most frequently, researchers have applied standard versions of recreational site-choice models to the problem, treating the presence or absence of an FCA as a site attribute. In general, these models have found that, all else equal, anglers are less likely to visit fishing sites under an advisory than sites not under an advisory. The models can then be used to estimate the dollar value of lost consumer surplus associated with FCAs.

Although the major portion of the applicable literature uses the approach noted in the previous paragraph (and reported in detail below), economists have also used other techniques and value measures to estimate the effects of an FCA. Four studies, in particular, stand out. Kreiger and Hoehn (1998, 1999) have published a pair of papers that examine the value of information provided by an advisory. They note that an angler may use advisory information *ex*

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[16] Because there are currently no FCAs for fish caught in the Chesapeake Bay, we assume that anglers in this

ante, prior to making site-choice decisions, and thus such information may have value to that individual; they therefore estimate the value of "partial" versus "full" disclosure programs. Partial disclosure programs report only those sites that have been tested and found contaminated, whereas a full disclosure program reveals the outcome—whether contaminated or safe—for all sites that have been tested. By implication, the full disclosure program also reveals which sites have not been tested. The payment vehicle in the contingent valuation scenario is increased license fees; anglers are willing to pay an additional $5.63 annually for full disclosure on all sites that had been tested to that date, with an additional $0.005 for full disclosure on each additional site tested (Kreiger and Hoehn 1998); in 2000 dollars ($2000), the values are $6.97 and $0.006. The *ex ante* value of the information estimate is not directly applicable to this study because we are interested in potential losses of consumer surplus by Chesapeake anglers.

MacDonald and Boyle (1997) use contingent valuation to measure the impact of a statewide mercury advisory for all open-water fishing in Maine. One of the authors' goals is estimating the economic losses to anglers using a contingent valuation question. Respondents were presented with a dichotomous choice question asking whether they would have been willing to pay *X* dollars more for fishing during the season. Questions were designed for the "with" and "without" FCA scenarios. Empirical models showed that the presence of the advisory was statistically insignificant; that is, the data suggest that the advisory does not significantly change the net economic value of fishing in Maine.

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analysis have not undertaken any prior behavioral adjustment.

Johnson and Desvousges (1997) use conjoint analysis to measure the value of advisories (among a variety of other environmental goods). Advisories are directly linked to the reduction of pollutants emitted by power plants, although it is not clear whether the survey instrument explicitly references mercury contamination of fish. The payment vehicle is an increase in the price of electrical power reflected in the respondent's utility bill. The valuation scenario asks willingness to pay (WTP) to decrease the number of fish consumption bans (the base number of lakes was 200, although it is not clear how many were under an advisory). The valuation model is linear in the number of lakes from which advisories would be lifted. The model indicates that respondents are willing to pay approximately 1.1% higher utility bills to reduce emissions enough to cancel an advisory on a single lake. The study does not name the location of the survey, nor is the percentage of the electrical bill converted to a dollar value.

Finally, in a study of the Lavaca Bay region of the Gulf Coast of Texas, MacNair et al. (1998) use a combined revealed preference–stated preference site-choice model to estimate the impact of a coastal consumption advisory. The authors find a statistically significant effect on site choice, with anglers less likely to visit the contaminated site relative to other sites, all else equal. The model is unconventional in the sense that it does not include a travel cost variable; instead, the authors use only the distance traveled to the site as an explanatory variable. Thus, the report does not state a monetized estimate of economic losses, instead stating that anglers suffered a 3.2% loss in the expected utility index.

3.2.1. Economic Losses Due to Fish Consumption Advisories

A number of economists have examined the angler's economic losses due to the presence of contaminants in sufficient quantity that an FCA must be issued. Ten studies are summarized in

Table 3.12, which presents the estimates for Great Lakes sites first, followed by the Northeast and concluding with the southern United States. As noted in the table, the studies often differ by modeling approach. Most use some form of a linked site-choice–trips model, generally a multinomial logit site-choice model linked to a trips model using either the Morey, Rowe, and Watson (MRW) or the Hausman, Leonard, and McFadden (HLM) version of the utility index. Shaw and Shonkwiler's (2000) seasonal model differs considerably from the MRW and HLM indices, relying on an index related to the total distance traveled during the fishing season as opposed to the usual formulation based on the number of trips taken during a season. Other authors used FCA-related data to examine different model formulations. For example, Jakus et al. (1997) estimated a simple site-choice model but linked this model to an equation explaining other aspects of angler behavior (e.g., anglers' catch rates), whereas Chen and Cosslett (1998) evaluated different forms of the site-choice model, comparing multinomial logit models to multinomial probit results.

The "seasonal" value models range from the March–August season of the Tennessee models and the April–October season of the New York State model to the full-year model of the Green Bay study. Because the seasonal estimates are not strictly comparable, the focus of this section is on per trip estimates of lost economic surplus. The range of estimates for these losses from the site-choice models is relatively narrow, from \$2.04 per trip to \$5.51 per trip (\$2000).[17] The lowest values in the range are given by the middle Tennessee studies, which are just over \$2

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[17] In a paper not reported in Table 3.12, Jakus and Shaw (2002) use a dummy variable to indicate the presence of an advisory at a given site. This model, which predicts relatively large per trip losses, represents a significant departure from previous studies in that the site-choice model uses a site-specific "perceived hazard" index that is related to the probability an angler will keep fish at a given site.

per trip. The choice set for these models includes 14 sites, 2 of which are contaminated. Jakus et al. (1997) report losses in middle Tennessee representing about 8% of total per trip consumer surplus. The lowest estimate of lost per trip consumer surplus in middle Tennessee ($2.04) is matched by the estimate for New York State (Montgomery and Needelman 1997). The choice set for this study also includes very few contaminated sites relative to the number of uncontaminated sites (only 23 of nearly 2,600 sites had toxic species).

Table 3.12. Estimates of Lost Consumer Surplus Due to Fish Consumption Advisories

Authors	Model	Location	Lost Economic Value per Trip	Lost Economic Value per Season	Value per Trip ($2000)	Value per Season ($2000)
Chen and Cosslett (1998)	MNL	41 Great Lakes sites	$3.06		**$4.93**[c]	
Chen and Cosslett (1998)	MNP	41 Great Lakes sites	$3.42		**$5.51**[c]	
Breffle et al. (1999)	MNL	Green Bay, WI	$4.17	$55.00	**$4.40**[c]	$58.04 (12 months)
Montgomery and Needelman (1997)	MNL MRW	2,586 New York ponds, lakes	$1.51	$63.25	$2.04	$85.29 (7 months)
Parsons and Hauber (1998)	MNL	2,029 Maine lakes, rivers	$1.67		$2.25	
Jakus et al. (1997)	MNL MRW	14 middle Tennessee lakes[a]	$1.85[b]	$21.96	**$2.13**[c]	$25.28 (6 months)
Jakus et al. (1997)	MNL MRW	14 east Tennessee Lakes	$2.86	$47.40	**$3.29**[c]	$54.56 (6 months)
Jakus et al. (1998)	MNL with catch rate model	12 east Tennessee lakes	$2.33		$2.49	
Parsons et al. (1999)	HLM	14 middle Tennessee lakes[a]	$1.77	$21.55	**$2.04**[c]	$24.80 (6 months)
Parsons et al. (1999)	MRW	14 middle Tennessee lakes[a]	$1.84[b]	$23.62	$2.12	$27.19 (6 months)
Shaw and Shonkwiler (2000)	SS	14 middle Tennessee lakes[a]		$10.67		$12.28 (6 months)

MNL = Multinomial logit model.
MNP = Multinomial probit model.
HLM = Hausman, Leonard, and McFadden index.
MRW = Morey, Rowe, and Watson index.
SS = Shaw and Shonkwiler "distance" index.

[a] All 14 middle Tennessee lakes studies used the same dataset.

[b] Jakus et al. (1997) and Parsons et al. (1999) welfare estimates differ slightly due to the bootstrap process used in calculations.

[c] Estimates in boldface are used in subsequent analysis.

In general, larger welfare estimates are obtained for regions with a large proportion of contaminated sites. For example, Chen and Cosslett (1998), with 14 of 41 sites contaminated, obtain loss estimates of $4.93 (MNL) and $5.51 (MNP) per trip.[18] The two Jakus et al. east Tennessee lakes models have choice sets of 14 (1997) and 12 (1998) sites each, of which 6 sites have contaminated species. These models, using different datasets, yield economic surplus loss estimates of $3.29 (1997) and $2.49 (1998) per trip ($2000). The first estimate represents approximately 6% of per trip consumer surplus. The second estimate is restricted to consumption anglers who were aware of the advisory.

Only a few of the estimates reported in Table 3.12 have an accompanying confidence interval or standard deviation. Adjusted to $2000, the lost economic surplus estimates for which a variance is reported or could be estimated are shown in boldface in Table 3.12. The studies selected for further analysis are quite comparable to one another, relying upon revealed preference data to estimate a site-choice model. The only exception to this rule is the Breffle et al. dataset, which augments revealed preference data with stated preference data. Following the Desvousges et al. Bayesian equations presented in Section 3.1, the mean and a 95% confidence interval for per trip losses can be estimated.

The Bayesian approach assumes that a "true" fixed value for per trip loss of consumer surplus exists and is invariant to the other factors that affect recreational fishing. This may not be the case, especially if the attributes and conditions under which the losses are estimated (say, for freshwater fishing in the relatively small lakes of Tennessee) differ substantially from those found in the Chesapeake Bay. One could hypothesize that the attributes and conditions of

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[18] Chen and Cosslett also estimate a varying-parameters version of the MNP model. The per trip welfare loss estimated by this model is $0.73 per trip. Given that this estimate is derived from a model that has no benchmark

recreational fishing of the Great Lakes are more closely akin to the attributes and conditions found in the Chesapeake. Thus, the Bayesian estimates of the mean and variance are first calculated using just the three Great Lakes estimates (Chen and Cosslett 1998; Breffle et al. 1999). For recreational anglers on the Great Lakes, the estimated per trip loss of consumer surplus is \$5.24 per trip, with a 95% CI of \$4.87–\$5.62. In contrast, using all six welfare estimates for which the variance is provided, the mean per trip loss is \$2.55, with a 95% CI of \$2.20–\$2.90.

3.2.2. Economic Studies of Recreational Fishing in the Chesapeake Bay

Two studies, in particular, examine recreational angling in the Chesapeake Bay. Bockstael et al. (1989) measure the aggregate value of water quality improvements in the bay. Their study includes not only recreational angling but beach use and swimming as well. The angling portion of the research focuses on striped bass anglers fishing in Maryland. Data were gathered from the 1980 National Fishing, Hunting, and Wildlife Associated Recreation (FHWAR) survey. Rather than measure the demand for striped bass fishing in terms of trips, the FHWAR data provide information only on the number of days of fishing by individual anglers at three aggregate sites in Maryland. The statistical analysis of demand for fishing finds that trips are positively related to the striped bass catch rate. With respect to welfare measures, the authors do not report per day measures of consumer surplus. Rather, aggregate welfare measures are provided for a water quality improvement scenario based on a 20% increase in the striped bass catch rate. The aggregate annual increase in consumer surplus is estimated at \$1.37 million with

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against which to gauge its validity, it was decided to use the authors' estimates from their fixed-parameter MNL and a range of $0.66 million to $2.07 million, or $2.73 million with a range of $1.31 million to $4.12 million ($2000).

McConnell and Strand (1994) use 1988–1989 National Marine Fisheries Service data to evaluate recreational fishing in the mid- and south- Atlantic sport fisheries. The authors use both stated preference and revealed preference models to estimate the value of access to these fisheries. In the first value-of-access model, a dichotomous choice question asked anglers their willingness to sell the right to fish in the state in which they were interviewed. For example, people interviewed in Maryland were asked about their willingness to relinquish the right to fish in Maryland, leaving the respondents open to fish in other states. The statistical model shows that willingness to sell access is negatively related to the small-game catch rate (the small-game species category includes striped bass and 11 other fish). For those anglers interviewed in the Chesapeake region (Maryland and Virginia), mean willingness to sell the right to fish for a year is $573 with a 95% CI of $555–$591, or a mean of $769 with a 95% CI of $725–$813 ($2000). This value can be considered the total annual consumer surplus associated with fishing in saltwater regions of the Chesapeake.

A second value-of-access model is based on a willingness-to-pay framework, implying a different property rights perspective. This question is limited to those anglers who had taken a multiple-day trip on which they had spent at least one day fishing. Anglers were asked how much the cost of fishing would have had to increase to make them give up one day of fishing on that multiple-day trip. The statistical model indicates that WTP for the day of fishing is

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MNP models.

positively related to the small-game catch rate. The mean value for a day of Maryland fishing is $20, with a median of $32, or $28 and $44 ($2000), respectively. Results for Virginia show a mean of $31 and a median of $53, or $43 and $73 ($2000), respectively. No confidence intervals or standard errors are provided for these daily fishing values.

Finally, McConnell and Strand (1994) estimate a nested multinomial logit model for mid- and south-Atlantic sport fishing. The model includes a nest for mode and target species choice and another for site choice, conditional on mode and species choice.[19] The revealed preference data indicate that, across all modes, some 32.1% of angler trips were taken with the goal of targeting striped bass.[20] The models estimate that the value for a day of saltwater fishing in Maryland is roughly $27, or $37 ($2000), whereas a day of fishing in Virginia saltwater has a value of approximately $42, or $58 ($2000). Again, no confidence intervals or standard errors are provided. Still, the revealed preference values arising from the nested multinomial logit model, which are based on single-day trips, are remarkably similar to the WTP estimates for a day of fishing arising from the stated preference models.

The McConnell and Strand (1994) estimates of access value (total per day consumer surplus) can be linked to the consumption advisory literature via the Jakus et al. (1997) study. This is the only study that compared welfare losses associated with FCAs to total consumer surplus. In the two Tennessee study regions on which Jakus et al. report, the losses associated with FCAs represent 6%–8% of total per trip consumer surplus. Given that the data on which the

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[19] The different modes include party/charter boat, private/rental boats, or shore fishing.

[20] This figure is reasonably close to the estimate from the 1996 FHWAR, which indicated that 24.6% of all saltwater fishing days were for striped bass (Table 3.8).

MNL models are based consist of single-day trips, this percentage can be directly applied to the McConnell and Strand estimates. Assuming the midpoint of the Jakus et al. loss range (i.e., 7%), Table 3.13 presents potential losses associated with an FCA. The average per day surplus loss, using just the estimates of the mean, is $2.42.

Table 3.13. Potential Consumer Surplus Losses for Chesapeake Anglers

McConnell and Strand (1994) Estimates with Jakus et al. (1997) Percentage FCA Loss

Location	Type of Data	Measure	Consumer Surplus ($2000)	7% Loss
Maryland	SP	Per day WTP (mean)	$28	**$1.96**
Maryland	SP	Per day WTP (median)	$44	$3.08
Maryland	RP	Per day WTP (mean)	$37	**$2.59**
Virginia	SP	Per day WTP (mean)	$31	**$2.17**
Virginia	SP	Per day WTP (median)	$53	$3.71
Virginia	RP	Per day WTP (mean)	$42	**$2.94**
Chesapeake	SP	Annual WTP (mean)	$769	$53.83

SP = stated preference.
RP = revealed preference.
WTP = willingness to pay.
Boldfaced values were used to calculate average per day loss.

The per day loss estimates are quite similar to the loss estimates presented in Table 3.12. The per day range for the Chesapeake Bay region lies almost wholly within the range reported in Table 3.1, $2.04–$5.51. The annual estimate of loss due to FCAs is also quite close to the Breffle et al. (1999) measure ($58.04).

3.2.3. Estimating Consumer Surplus Losses to Chesapeake Bay Anglers

The congruity between the estimated losses in Table 3.12 and Table 3.13 is remarkable. The application of the Jakus et al. (1997) percentage loss estimate to the McConnell and Strand (1994) per day consumer surplus estimates results in an average loss to Chesapeake Bay anglers of $2.42, which lies well within the 95% confidence interval implied by the boldfaced estimates in Table 3.12 for which some measure of dispersion is reported. Thus, the $2.42 per day loss for Chesapeake Bay anglers seems a reasonable place to begin the welfare calculation.

The per unit losses reported in Table 3.12 are not restricted to those anglers who targeted listed species. Rather, the estimates represent *ex post* losses in consumer surplus—that is, losses accruing to all anglers after they respond to FCAs. Conceptually, then, the surplus estimates represent the monetized impact on utility of such averting behaviors as changing fishing sites, changing target species, and reducing consumption of listed species. As such, the loss should be applied to all fishing days for all potential Chesapeake Bay anglers. This figure is not available, but a conservative estimate would be to apply the $2.42 loss to all Maryland saltwater fishing days. If one applies the per day loss after anglers have adjusted total seasonal trips to saltwater areas, the total annual surplus loss is $2.42 per day × 3,647,578 days (Table 3.9, row 3), or $8.83 million.[21]

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[21] This loss estimate (as well as our health benefit estimates) would be greater if trips in the Virginia portion of the bay were included in the analysis.

3.2.4. Summary

This section of the report summarized the recreational fishing literature. A comprehensive review of the literature associated with consumption advisories yielded two estimates of the per trip loss in consumer surplus (Table 3.14). A major study of Atlantic coast fishing by McConnell and Strand (1994) yielded per day and seasonal estimates of the value of saltwater fishing in the Chesapeake region. The percentage loss in per day consumer surplus estimated by Jakus et al. (1997) applied to the McConnell/ and Strand (1994) estimates results in estimates of daily losses in the Chesapeake. The per day loss is estimated to be $2.42 (range $1.96–$2.94), with an annual loss of approximately $8.83 million.

Table 3.14. Summary of Consumer Surplus Losses Due to Chesapeake FCAs

Measure	Mean	95% CI
Per trip loss (Great Lakes only)	$5.24	$4.87–$5.62
Per trip loss (all studies)	$2.55	$2.20–$2.90
Per trip loss: Apply 7% consumer surplus loss to McConnell and Strand daily consumer surplus estimate	$2.42	$1.96–$2.94
Aggregate annual loss	$8.83 million	

The results of this section must be interpreted within the context of the assumptions and limitations of the analysis (Table 3.15). First, the per trip consumer surplus loss estimates are averaged over all anglers. “Complete averters,” those who do not eat contaminated fish, are not at risk yet may engage in unnecessary defensive actions, such as ceasing consumption of all fish or never fishing a site under an advisory. These unnecessary actions are included in the consumer surplus loss estimates. Second, FCAs may have effects that in turn affect different anglers in different ways. For example, Jakus et al. (1998) hypothesized that recreational welfare losses may differ across those anglers who consume (or had planned on consuming) fish relative to those who fish primarily for catch-and-release. Reductions in harvest rates by consumption anglers in response to FCAs may increase the overall biomass in the estuary. Increased biomass may mean that catch-and-release anglers benefit from catching more, and larger, fish. Such effects may cause the consumer surplus losses, which are estimated over all anglers, to be smaller in the long run. Finally, the recreational losses do not include any health-related benefits or losses associated with (a) reduced Hg uptake by those anglers heeding the advisory or (b) the health effects of continued Hg uptake by those anglers who do not know about the advisory or choose to ignore it.

Table 3.15. Assumptions and Limitations of Consumer Surplus Estimates

Assumption, Limitation	Effect on Consumer Surplus Estimates
"Complete averters" may engage in unnecessary actions to avoid Hg contamination. These actions are included in loss estimate.	Bias consumer surplus loss upward.
Does not include possible impacts of reduced harvest on fish stocks, which may be viewed positively by some catch-and-release anglers.	Bias consumer surplus loss upward.

3.3. The Recreational Angler Response Module

Within the Maryland Model, the Recreational Angler Response Module uses the parameters described in this section to estimate two major endpoints: the consumer surplus loss due to an advisory, and the per capita average change in methylmercury uptake under an advisory, compared with a baseline of no advisory. When possible, uncertain parameters from either data or the literature are specified as probability distributions, and this uncertainty is propagated throughout the model. The model allows the user to vary angler awareness as well as consumption preferences (explained in more detail in Sections 5 and 6). Additionally, the user can choose between two options to estimate consumer surplus loss. Consumer surplus loss can be estimated using the Jakus et al. (1997) and Chesapeake Bay value of a fishing day estimates, as reported in Table 3.14, or the combined Great Lakes estimates of per trip welfare loss under an advisory, described earlier in this section.

4. Commercial Fishing Losses from FCAs

As noted in previous sections of this report, mercury contamination and consumption advisories are a concern for striped bass. Not only is striped bass caught by recreational anglers, it is also a major commercial species. Two studies from the literature are of interest. The first (Kahn and Kemp 1985) estimates a supply-and-demand system for commercial striped bass fishing in the Chesapeake Bay, and the second (Buerger and Kahn 1989) estimates a supply-and-demand system for Hudson River, New York, striped bass. The model specifications used in each of these reports ("the Kahn studies") will be reviewed below. These specifications then will be used to help specify an "original" model of the Chesapeake Bay striped bass fishery using a more up-to-date dataset, which is used to estimate losses under both a commercial fishing ban and a fish consumption advisory.[22]

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[22] Ancillary costs to a fishing ban or advisory, such as employment losses, are beyond the scope of this analysis.

4.1. Commercial Striped Bass Fishing Models

The Kahn and Kemp commercial striped bass model is only a portion of a larger study aimed at estimating losses associated with submerged aquatic vegetation in the Chesapeake Bay.[23] The supply equation is specified as a function of the ratio of the striped bass price to the price of two substitute species (oysters and clams), the price of fishing effort, the adult population of striped bass, and a time trend. The price of fishing effort is described as "an index of labor opportunity costs and energy costs." Details regarding the construction of the index are not provided. The demand equation is specified as a function of the price of striped bass, the price of substitute goods (given by the consumer price index, CPI, for meat, poultry, and fish), the regional population, regional per capita income, and a time trend.

The log-linear supply-and-demand model is estimated using two-stage least squares on a dataset covering the 1965–1979 period. Exogenous variables include all the variables listed above (except, of course, the endogenous price and quantity of striped bass), the lagged price of striped bass, and an index of submerged aquatic vegetation in the bay. Table 4.1 shows the sign and statistical significance of the variables in each equation.

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[23] In addition to the commercial fishing model, the authors also estimated a sport fishing model and linked submerged aquatic vegetation to an equilibrium catch equation.

Table 4.1. Kahn and Kemp Chesapeake Bay Striped Bass Commercial Fishing Model[a]

Variable	Supply	Demand
Intercept	+	–
$ln(P_{Striped\ Bass}/P_{Oyster})$	+	
$ln(P_{Striped\ Bass}/P_{Clams})$	+*	
$ln(P_{Effort})$	–*	
Ln(Adult Striped Bass Population)	+*	
Ln(Time Trend)	+*	–
$ln(P_{Striped\ Bass})$		–*
$ln(CPI_{Substitutes})$		+
ln(Population)		+
ln(Income)		+

Dependent variable: *ln(Striped Bass Catch).*
[a]Statistical significance at α=0.10.

All of the key coefficients have the correct signs as predicted by economic theory. The price of striped bass, the price of substitutes, and the "technology" variable of the supply equation, as measured by the population of striped bass, all have the proper signs. The demand equation, however, has only one significant variable (the price of striped bass). The price coefficient can be interpreted as an elasticity, with a value of –1.28.

With respect to welfare analysis, the authors do not provide aggregate measures of producer or consumer surplus. Instead, welfare estimates are restricted to the reduction in submerged aquatic vegetation and include welfare losses to sport anglers as well as commercial fisheries. An aspect of the study worth noting is that the stocks of striped bass in the Chesapeake were declining over much of the period covered by the data. Following the Kahn and Kemp study, Chesapeake Bay stocks declined to the point where the fishery was closed to commercial fishing in the late 1980s. In response, many commercial anglers switched species or were engaged by the state of Maryland in other fishing activities. After striped bass stocks had recovered, the commercial fishery was reopened. Given the unsettled nature of the striped bass fishery during the period subsequent to the Kahn and Kemp study, using the Kahn and Kemp equations for a direct function transfer to estimate commercial losses due to a striped bass FCA may not be desirable.

The second investigation of commercial striped bass fishing was conducted for the Hudson River in New York State (Buerger and Kahn 1989). As in the Kahn and Kemp Chesapeake Bay study, these authors link the supply-and-demand analysis to an equilibrium catch equation. The striped bass fishery in the Hudson depends not only on the population of striped bass in the river but also on the population of striped bass migrating from the Chesapeake Bay.[24] In this model, the supply equation is specified as a function of the price of striped bass, indices of Hudson Bay (adult) and Chesapeake Bay (juvenile) striped bass populations, and the price of flukes, porgies, yellowtail flounder, bluefish, and lobsters. The demand equation is specified as a function of the price of striped bass, income, New York State population, a time trend, and the CPI for meat, poultry, and fish.

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[24] In this study of the Chesapeake Bay striped bass fishery, we do not consider the implications of migration between the Chesapeake and the Hudson in the economic analysis. It is possible that FCAs imposed on the Chesapeake affect fishing on the Hudson, and vice versa.

The supply-and-demand model is estimated using two-stage least squares for the 1964–1985 period. Table 4.2 shows the sign and statistical significance of each variable in the model. Similar to the Chesapeake Bay model of Table 4.1, nearly all the important economic variables have a coefficient with a sign corresponding to economic theory. Evaluated at mean values for the independent variables, the demand elasticity for Hudson River striped bass is estimated to be –1.32.

Table 4.2. Buerger and Kahn Hudson River Striped Bass Commercial Fishing Model

Variable	Supply	Demand
Intercept	–*	+
$P_{Striped\ Bass}$	+*	–*
Hudson Bay Striped Bass Population Index	+	
Chesapeake Bay Striped Bass Population Index	+*	
P_{Fluke}	+*	
$P_{Porgies}$	+*	
$P_{Yellowtail\ flounder}$	+*	
$P_{Bluefish}$	+*	
$P_{Lobster}$	–*	
$CPI_{Substitutes}$		+*
Income		+*
New York State Population		–*
Time Trend		–*

Dependent variable: *Striped Bass Catch.*
[a]Statistical significance at α=0.10.

4.2. Modeling the Commercial Striped Bass of Chesapeake Bay

In their econometric review of commercial fishery demand elasticities, Roy et al. (1991) note the extremely wide range of demand elasticities in the literature. For example, a variety of fish products have demands that range from the extremely inelastic (–0.05) to the extremely elastic (–22.73)., a range that the authors cannot attribute fully to poor data or poor statistical analysis. Monte Carlo analysis is used to evaluate the modeling decisions of an analyst and the subsequent impact on elasticity estimates. The authors find that a two-stage least squares approach leads to an accurate estimate of the demand elasticity relative to an ordinary least squares approach. In the presence of a highly overidentified model or model misspecification (e.g., excluded exogenous variables), a quantity-dependent demand model is preferred to an inverse demand model.

Given the results from Roy et al. and the Kahn studies cited in the previous section, a quantity-dependent, two-stage least squares approach is used to model supply and demand of the commercial Chesapeake Bay striped bass fishery. Further, the Kahn studies can help specify the supply-and-demand models. Data on Chesapeake Bay commercial landings in Maryland and value of landings were obtained from the Maryland Department of Natural Resources Web page. These data provide quantity and value of landings for a variety of commercial species. Agency personnel supplied further information useful in the modeling process, including the number of commercial licenses used in any given year and the number of striped bass by age group.

Unfortunately, these data are not available for the full time period. License data are available only for 1980–2000, with 1991 license data missing. Striped bass population data are available only for 1982–2000. In addition, the striped bass fishery was closed for five years, from

1985 through 1989. During this time the quantity of landings was zero, such that price could not be defined as an equilibrium outcome of supply and demand. Thus, we have complete data for only 13 years (1982–1984, 1990 , and 1992–2000). Given these data shortcomings, the supply-and-demand model must be estimated with parsimony to conserve degrees of freedom.

In light of the Kahn commercial striped bass models cited above, the supply equation is specified using the price of striped bass, the number of commercial licenses, and the total population of three-, four-, and five-year-old striped bass in the bay.[25] In addition, Maryland personnel indicate that oysters and catfish were the primary alternative species sought by commercial operations during the striped bass fishery closure of the late 1980s; thus, the equilibrium prices for oysters and catfish are also included in the supply equation. On the demand side, the specification includes the price of striped bass, household income for mid-Atlantic states, a price index for substitute goods (the CPI for meat, poultry, and fish), and the regional population (Maryland, Virginia, and the District of Columbia). The results are shown in Table 4.3.[26]

The three statistically significant variables in the supply equation all have the expected sign. The price of striped bass is positive, the price of oysters is negative, and the sign of the technology variable—the striped bass population—is also positive. Neither of the remaining variables (the price of catfish and the number of commercial licenses) is statistically significant.

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[25] This is akin to the juvenile recruitment index of Buerger and Kahn.

[26] Durbin-Watson statistics are reported. The data consist of fewer than 15 observations, however, making it difficult to draw definitive conclusions regarding potential autocorrelation problems.

Evaluated at mean values for price and quantity, the own price supply elasticity is 1.13, or slightly elastic.

Table 4.3 Two-Stage Least Squares Model of Supply and Demand for the Commercial Chesapeake Bay Striped Bass Fishery[a]

Variable	Supply	Demand
Intercept	–250.51 (–0.22)	–18,709.92 (–1.82)
$P_{Striped\ bass}$	643.49 (2.38)	–911.73 (–1.50)
$P_{Oysters}$	–507.3 (–2.32)	
$P_{Catfish}$	–749.82 (–1.29)	
# Commercial licenses	–0.06 (–0.09)	
Striped Bass Population	0.18 (4.69)	
Household Income		0.17 (1.15)
$CPI_{Substitutes}$		–229.1 (–1.61)
Regional Population		0.003 (1.63)
R^2	0.77	0.34
Durbin-Watson	2.32	1.34
Observations	13	13

Dependent variable: *Striped Bass Landings (1,000 lbs.).*
[a] t-ratios in parentheses.

The demand equation has only one variable (the intercept) statistically significant at conventional levels. Many of the remaining variables are reasonably close to significance at the 0.10 level, however. The most important variable for this analysis is the own price effect. The P-value for this variable is 0.14, suggesting that price is an important influence on the demand for striped bass even if it is not significant at conventional test levels. The price of substitute goods is also close to significance (P=0.11) but has the wrong sign. Evaluated at mean price and quantity, the own price elasticity of demand is elastic, at a value of –1.60, very close to the estimates obtained by Buerger and Kahn (–1.32) and Kahn and Kemp (–1.28).

In 2000, landings of Chesapeake Bay striped bass totaled 2.26 million pounds with an equilibrium price of $1.53 per pound. Evaluated at year 2000 values of the explanatory variables, the predicted quantity of landings using the supply equation overestimates actual landings by 0.3%. Although the statistical significance of the estimated demand parameters is not ideal, the model predicts quantity reasonably well, overestimating landings by 11.3%.[27] The equilibrium price and quantity given by the statistical models at year 2000 values for the explanatory variables are $1.69 per pound (10.4% error) and 2.37 million pounds (4.9% error), respectively. Thus, the models appear to do a reasonable job of prediction. Further, an important economic property of the model—the demand elasticity—appears to be in line with demand elasticity estimates appearing in the recent literature (Table 4.4). Note that the demand elasticities for narrowly defined, single-species commodities tend to be greater in absolute value than the elasticity estimates for more broadly defined commodity groups, a result predicted by economic theory.

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[27] In addition to the linear specifications reported in Table 4.3, log-linear and semilog forms were also estimated. These models had inferior predictive capabilities relative to the linear specification.

Table 4.4. Recent Estimates of Demand Elasticity for Fish

Study	Location	Demand Elasticity	Species or Commodity
This study	Chesapeake Bay	–1.60	Striped bass
Kahn and Kemp (1985)	Chesapeake Bay	–1.28	Striped bass
Burger and Kahn (1989)	Hudson Bay	–1.32	Striped bass
Wessells et al. (1995)	Montreal	–1.98	Mussels
Eales et al. (1997)	Japan	–1.18	Medium-value fresh fish
Salvanes and DeVoretz (1997)	Canada	–0.98	Fresh fish
Eales and Wessells (1999)	Japan	–0.72 to –1.00	Medium-value fresh fish
Angrist et al. (2000)	Boston	–0.85 to –1.24	Whiting

4.3. Welfare Analysis for the Commercial Striped Bass Fishery

Evaluated at the equilibrium price and quantity predicted by the statistical models ($1.69 per pound and 2.37 million pounds, respectively), annual consumer surplus is estimated to be $3.08 million, whereas annual producer surplus is estimated to be $3.09 million, for a total surplus value of $6.17 million. When estimated at the actual 2000 equilibrium price ($1.53 per pound) and quantity (2.26 million pounds), annual consumer surplus is $2.80 million, annual producer surplus is $2.71 million, and total surplus is $5.51 million.[28] These estimates can be interpreted as the loss that would be incurred by market participants under a commercial fishing ban.

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[28] This approach essentially adjusts the intercept of each linear equation to force supply and demand curves through the observed equilibrium price and quantity, but maintains the estimated price slopes.

The statistical insignificance of many demand equation parameters, however, suggests that the estimate of consumer surplus may be associated with a substantial amount of error. Using the delta method to calculate the variance of the consumer surplus estimate (Greene 2000), the 95% confidence interval includes the value $0 (95% CI for consumer surplus is –$1.44 million to $7.60 million). A similar calculation for the variance of producer surplus in the striped bass fishery yielded a much narrower 95% confidence interval, $2.41 million to $3.78 million. The welfare analysis for the commercial fishery should be evaluated in light of the wide variance of the consumer surplus estimate.

Given the Hg concentration levels in striped bass as estimated based on Gilmour (1999), a complete ban on commercial striped bass fishing is unlikely. Instead, we assume the state is likely to issue "Commercial Health Advice" recommending restricted consumption by both the general population and subpopulations (children and women of childbearing age). Theoretically, this can be modeled as a shift "to the left" of the demand curve as sensitive subpopulations restrict their consumption of striped bass. Unfortunately, the literature does not provide any guidance for evaluating the magnitude of the shift in commercial demand. We can, however, crudely model the impact of commercial advice by assuming that consumer surplus loss in the commercial fishery is of equal proportion to the losses incurred by recreational anglers. The only estimates of percentage losses in consumer surplus are those given by Jakus et al. (1997) and used in Section 3.2: approximately 6% to 8%.

If commercial advice is issued, it is assumed that consumer surplus losses will amount to 7% (SD = 0.5) of initial consumer surplus, a reduction in annual consumer surplus from $3.08 million to $2.87 million ($215,800). Figure 4.1 shows the leftward shift in demand such that the loss in consumer surplus is equal to $215,800. It is seen that the equilibrium price falls to $1.56, a 7.7% drop from the initial equilibrium value of $1.69 per pound. Equilibrium quantity falls from 2.37 million to 2.29 million pounds, a 3.4% reduction. The demand shift and subsequent changes in equilibrium price and quantity result in an annual net loss of producer surplus of $304,500, or 9.9% of initial producer surplus. Aggregate annual surplus losses in the commercial striped bass market are estimated to be the sum of the changes in consumer and producer surpluses, or $520,300.[29]

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[29] As in the recreational analysis, these estimates are specific to the Maryland portion of the bay. Extending this analysis to include Virginia anglers would increase estimated losses (as well as health benefits).

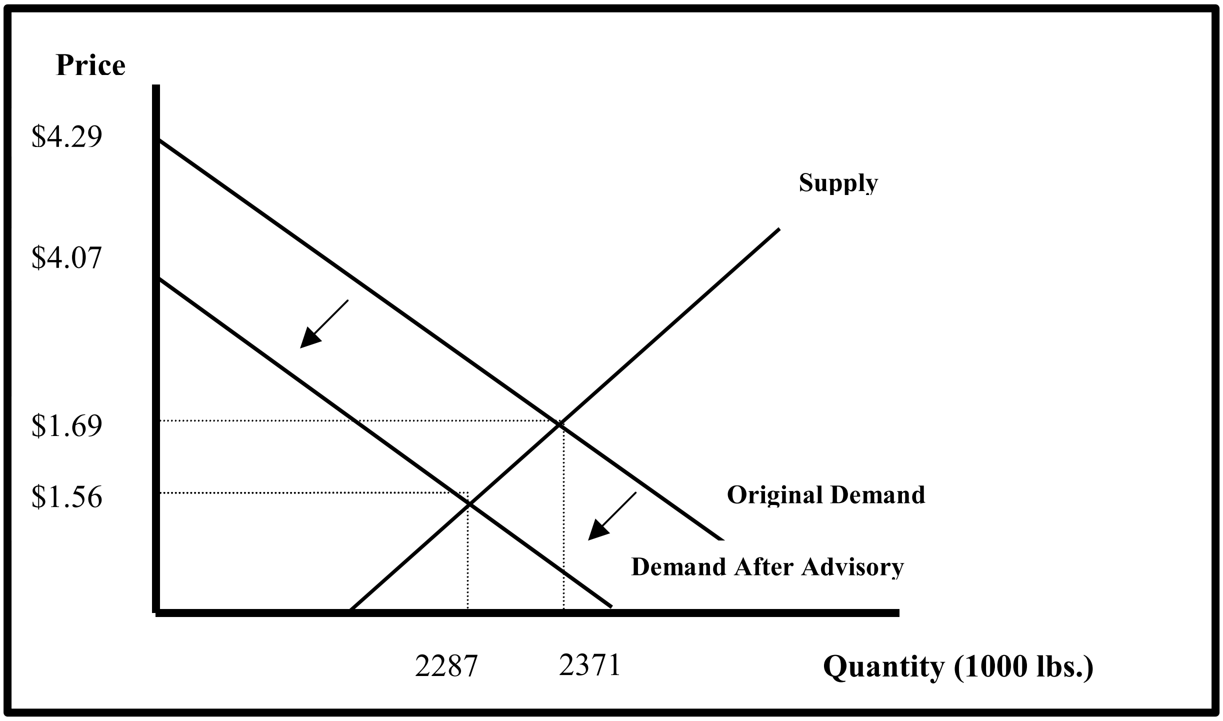

Figure 4.1: Shift in Demand Following Commercial Advice

4.4. Summary

This section has reviewed models of the supply and demand for commercial striped bass. Two articles were identified in the literature. Although both models have drawbacks that prevent direct use for a function transfer exercise, they do provide benchmarks against which to compare the original modeling effort for the Chesapeake Bay striped bass fishery. The empirical properties of the supply-and-demand models for the Chesapeake are not ideal (particularly for the demand equation), but the predictive capability of each model appears acceptable. Given conditions in 2000, the total annual economic surplus in the commercial striped bass fishery is estimated to be about $6.2 million. The section closed with an estimate that under a notice of

Commercial Health Advice, total annual losses in the market for commercially caught Chesapeake Bay striped bass would be just over $520,000.

The limitations of this portion of the analysis stem from two sources. First, because of the lack of any estimate of the change in commercial demand due to FCAs, it was necessary to make an assumption based on changes in demand found in the literature on recreational fishing. Unfortunately, only one estimate of the percentage consumer surplus loss could be found, so it is difficult to assess transferability of this estimate to the Chesapeake Bay commercial striped bass fishery. Second, whereas some properties of the demand equation suggest that the commercial demand model is acceptable (e.g., its predictive ability and the point estimate of the demand elasticity), the price parameter was not estimated with a great degree of precision. That lack of precision leads to an estimated consumer surplus loss with a very wide confidence interval. When the 7% loss in consumer surplus is applied to the endpoints of the confidence interval, annual losses could range from $0 to $530,000. In contrast, the producer surplus estimate is relatively precise. Applying the 9.9% producer surplus loss to the endpoints of the producer surplus CI suggests that annual losses range from $239,000 to $374,000.[30] Given uncertainty regarding the 7% consumer surplus loss assumption, the actual confidence intervals are likely to be even larger.

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[30] The 2SLS model generates two variance-covariance matrices, one for each equation. CS and PS depend on the equilibrium outcome and thus depend on the parameters on both the supply equation and the demand equation. This dependence is not accounted for in the reported CS and PS confidence intervals, which are based only on the covariance matrix for the appropriate equation. Further, the percentage losses in CS and PS are assumed constant when they are, in fact, random variables. In light of these simplifications, the range of CS and PS losses is likely to be narrower relative to an than if the random nature of all parameters were fully incorporated.

4.5. Commercial Fishing Response Module

In the Maryland Model, the Commercial Fishing Response Module replicates the calculations described in this section. The model first replicates the consumer and producer surplus calculations based on the parameters discussed in this section. Both estimated and actual equilibrium price and quantity for the commercial striped bass fishery are used as inputs to the module. The module simultaneously applies consumer and producer surplus reductions for both a ban and the more likely scenario, a commercial consumption "advice."

5. Health Benefits of Mercury Exposure Reductions

This section reviews the epidemiological literature on the relationship between methylmercury exposure and three broadly defined health endpoints: adult central nervous system effects, childhood neuropsychological development, and cardiovascular health and mortality. The quantification of these endpoints in the Maryland Model for a recreational fish consumption advisory is also described, and results and benefits estimates are reported.[31]

5.1. Health Effects of Methylmercury

Popular awareness of the health effects of mercury poisoning was first raised by a high-dose exposure from consumption of contaminated fish near Minamata Bay in Japan during the 1950s and resulting in the coining of the term "Minamata disease." In particular, the danger of prenatal exposure was made apparent by the prevalence of congenital Minamata disease in

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[31] Health benefits would also likely accrue under the issuance of commercial consumption advice. However, given an absence of commercial consumption data for the region as well as the reduced probability of such an advisory relative to a recreational advisory, we do not attempt to estimate any potential health effects or benefits.

children born to exposed mothers, which manifested itself in the form of mental retardation as well as several other signs and symptoms. Akagi et al. (1998) estimate that the mean maternal hair Hg concentration of patients with congenital Minamata disease was 441 mg/kg (range: 3.8, 133 mg/kg). A second mass poisoning occurred during the 1970s in Iraq, when seed grain treated with a fungicide containing MeHg was ground into flour and consumed by the public. It is believed that this poisoning episode involved higher and more acute exposures than did the Minamata episode (NRC 2000). Data from these two studies provided the basis for the first human dose-response studies for MeHg uptake.

A large body of literature describes the relationship between MeHg exposure and a number of health endpoints, such as cancer and immunological, reproductive, renal, cardiovascular, and neurological effects. Within this study, we focus specifically on cardiovascular and neurological effects due to adult and prenatal exposure, which currently appear to be the most robust health endpoints for chronic low-dose MeHg exposure given the existing literature. This section reviews the epidemiological literature pertaining to those broad endpoints. (For a more comprehensive review of the literature, see NRC 2000.)

5.1.1. Central Nervous System Effects in Adults

Minamata disease encompasses the combination of central nervous system effects that adults may experience in the event of mercury poisoning. Although there is no specific test to confirm a diagnosis of Minamata disease, it has historically been identified based on a characteristic combination of symptoms. One initial symptom, and a commonly relied upon indicator of methylmercury disease, is paresthesia, or an itching, prickling, or tickling sensation in the extremities. Based on evaluation of data from the Minamata and Iraqi poisonings, the

World Health Organization (WHO, IPCS 1990) suggests that 5% of adults with a blood Hg concentration at or above 200 ppb will exhibit paresthesia.

However, further research has suggested that deleterious effects may occur at exposure levels below this threshold. Kosatsky and Foran (1996), in a review of 13 studies of long-term fish consumers, conclude that at a blood concentration level of 200 ppb, neurological effects may be present in as few as 11% and as many as 31% of the exposed population. As a result, they suggest a need to better define the portion of the dose-response curve below that threshold (NRC 2000). Additional studies have suggested neurological and sensory impairments for adults with chronic low-dose exposures, though at this point there appears to be no strong evidence of ubiquitous, well-defined effects.[32]

5.1.2 Central Nervous System Effects in Children

Since the Minamata and Iraqi poisoning episodes, it has become widely accepted that the fetus is at a particularly high risk for mercury poisoning. Although much of the attention initially focused on mental and psychomotor retardation, recent studies of chronic low-dose prenatal consumption have provided evidence for more subtle neuropsychological endpoints. The most valid and promising endpoint for analysis appears to be childhood neuropsychological development. Three large epidemiological studies attempt to evaluate the relationship between childhood neuropsychological development and prenatal methylmercury exposure. These studies evaluate cohorts in the Faroe Islands (Grandjean et al. 1997), New Zealand (Kjellström et al. 1989), and the Seychelles Islands (Davidson et al. 1998). Moreover, Crump et al. (1998) and

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[32] See, for example, Lebel et al. (1996, 1998) and Beuter and Edwards (1998).

Budtz-Jørgensen et al. (1999) have performed benchmark analyses of the New Zealand and Faroe Islands studies, respectively.

Of the three studies, the Faroe Islands study is considered the most robust: it has the largest cohort and was subjected to significant peer review and reanalysis. The study administered a battery of neuropsychological tests at age 7 to 917 surviving members of a 1986–1987 birth cohort of 1,022 children. These tests focused on language, attention, memory, mood, and visuospatial and motor functions. Mercury exposure, which occurred largely through maternal consumption of whale meat and was quantified in both maternal hair and cord blood concentrations, was found to be significantly associated with increased dysfunction in language, attention, memory, and to a lesser extent, visuospatial and motor functions. The associations remained when children with maternal hair mercury concentrations exceeding 10 mg/kg were excluded. Overall, the authors estimated that a tenfold increase in cord blood mercury concentration was associated with delays of approximately four to seven months in these developmental indicators.

In the New Zealand study, Kjellström et al. (1989) evaluated a cohort of 237 at 6 years of age, administering a battery of 26 tests for psychological and scholastic development, 5 of which were analyzed further in multiple regressions. In the study each child considered “high Hg” was matched with three controls of varying maternal hair mercury concentration and fish consumption based on a number of potential confounding factors. In weighted regressions, Hg concentrations in maternal hair were associated with reduced scores on full-scale IQ, language development, perceptual performance, and motor skills.[33] Unweighted regressions produced similar results, though generally at reduced statistical significance. Although the New Zealand cohort has the strength of population heterogeneity, it suffers from a small cohort and less extensive reanalysis compared with the Faroe Islands study.

Table 5.1 describes the tests subjected to further analysis from both the Faroe Islands and the New Zealand studies.

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[33] Observations were given a weight of 0 to 1, depending on the extent to which an observation was an outlier.

Table 5.1. Description of Administered Tests from the Faroe Islands and New Zealand Studies

Study	Test	Domain
Faroe Islands	Neurobehavioral Evaluation System (NES): finger tapping	Manual motor ability
	NES Continuous Performance Test (CPT): reaction time	Vigilance, attention
	Bender Copying Test	Visuospatial ability
	Boston Naming Test	Naming, association
	California Verbal Learning Test (CVLT): children	Short-term memory
New Zealand	Test of Language Development, spoken language quotient (TOLD-SL)	Language development
	Weschler Intelligence Scale for Children, Revised: performance IQ (WISC-RP)	Intelligence
	Weschler Intelligence Scale for Children, Revised: full-scale IQ (WISC-RF)	Intelligence
	McCarthy Scales: perceptual performance (MCC-PP)	Intelligence
	McCarthy Scales: motoric (MCC-MOT)	Fine and gross motor coordination

Sources: Crump et al. (1998); Grandjean et al. (1997).

In the Seychelles child development study, 711 children were evaluated at about 5 to 6 years of age for general cognitive ability, language skills, reading, arithmetic, visual-spatial ability, and social and adaptive behavior, using maternal hair mercury concentration as the exposure metric. The majority of tests administered in the Seychelles study were global tests of neuropsychological development rather than domain-specific tests, as in the Faroe Islands study. Unlike the Faroe Islands and New Zealand studies, the Seychelles study did not find evidence of an adverse effect of either prenatal or postnatal MeHg exposure.

Several plausible explanations surface for the difference in findings between the Faroe Islands study and the Seychelles study. Among these are differences in exposure metric, types of tests administered, age of subjects at testing, and sources of exposure (whale meat versus fish). However, considering these two studies in conjunction with the New Zealand results further complicates their comparison because although the New Zealand and Seychelles studies are similar in design, the New Zealand results are in agreement with those from the Faroe Islands. It is possible that the divergent results are attributable to between-sample variability in the expression of neurotoxicity at low doses, as studies with a large cohort may fail to adequately capture an adverse response if it is limited to the upper ranges of the exposure distributions (NRC 2000). Ultimately, of the three studies, the National Research Council (NRC 2000) suggests that the Faroe Islands results warrant the most confidence because of the large cohort size and the robustness of results when subjected to reanalysis.

Two recent studies (Crump et al. 1998; Budtz-Jørgensen et al. 1999) have performed benchmark analyses for the New Zealand and Faroe Islands studies, respectively, in the hopes of eliciting safe levels of exposure. The benchmark dose (BMD) is the dose of a substance that results in an increased probability of an abnormal test performance by a predetermined benchmark response (BMR). In other words, the probability of an abnormal test score increases from P_0 for an unexposed child to P_0 + BMR for a child at or in excess of the BMD. The default probability of an abnormal test score is typically assumed to be 5% in an unexposed population. However, this default is chosen strictly for statistical purposes and may not reflect the true frequency of abnormal scores in an unexposed population.[34] The lower 95% limit on the BMD, or BMDL, is also reported and is intended to be an alternative to the "no observed adverse effects level" (NOAEL).[35] The BMDL, then, necessarily depends on the number of observations. All else equal, a higher number of observations will tighten the confidence interval and thus result in a higher BMDL. In addition to the benchmark analyses of Crump (1998) and Budtz-Jørgensen et al. (1999), NRC (2000) conducts an integrative analysis of the major endpoints of all three studies as a basis for comparison. Table 5.2 summarizes the benchmark estimates from the three benchmark studies.

Table 5.2. Summary of Estimates from Benchmark Analyses

Approach	BMD mg/kg hair	BMDL
Most sensitive endpoint, New Zealand (McCarthy Scales: perceptual performance)	8	4
Median endpoint, New Zealand	12	6
Most sensitive endpoint, Faroe Islands (Neurobehavioral Evaluation System Continuous Performance Test)	15	10
Median endpoint, Faroe Islands	20	12
NRC integrative analysis	21	8

Source: NRC (2000).

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[34] A number of functional forms are explored in these analyses, with preference being given to the K-power model, in the form $\mu(d)=\beta \, x \, d^k$. k is restricted to be greater than or equal to 1, to prevent supralinear models, which are though to be less biologically plausible (NRC 2000).

[35] The NOAEL has been defined as the highest experimental dose that does not produce a statistically or biologically significant increase in adverse effects relative to control groups. Several statistical drawbacks, such as the fact that the NOAEL must be an observed experimental dose and thus can vary considerably across studies, have made its use somewhat controversial (NRC 2000).

5.1.3. Cardiovascular Effects

A significant body of research has found suggestions of a positive relationship between fish consumption and cardiovascular health. Fish consumption is thought to reduce cardiovascular risk because of the implicit intake of omega-3 fatty acids and selenium. Furthermore, a diet high in fish consumption may indicate eating habits that are associated with low risk of cardiovascular disease, such as infrequent consumption of red meat.

However, the presence of mercury in fish tissue confounds this apparent relationship. MeHg has been associated with adverse cardiovascular effects, such as increased blood pressure and abnormal cardiac function. Two recent studies focus specifically on the relationship between low-level dietary exposure to MeHg and cardiovascular health, one of which finds evidence of a link between mercury uptake and all-cause mortality. Such findings suggest a potential risk-risk trade-off under a fish consumption advisory because averting anglers who reduce fish consumption to avoid mercury contamination will be sacrificing, to some extent, the potential protective effects of fish consumption.

Salonen et al. (1995) compared the association between fish consumption and mercury concentrations in hair and urine, and then examined the relationship between these concentrations and the occurrence of acute myocardial infarction (AMI) and chronic mortality from coronary heart disease (CHD), cardiovascular disease (CVD), or any cause over a five-year period. These relationships were evaluated in a cohort of 1,833 Finnish men between the ages of 42 and 60, all of whom were free of heart disease, stroke, claudication (muscle pain due to insufficient blood flow), and cancer at the study’s inception. Mean hair concentration for the sample was 1.92 mg/kg, with a standard deviation of 1.98 mg/kg. In Cox proportional hazards models, with a number of cardiovascular risk factors as covariates, dietary intakes of fish and mercury were associated with a significantly increased risk of AMI and death from CVD or any cause. The study found that men in the highest third (tertile) of the sample for hair mercury content (>2.0 μg/g) had a 2.0-fold increased risk of AMI relative to the other two tertiles when controlling for age and coronary heart disease. For the same tertile, the relative risk of death from CVD was 2.9, and from any cause, 3.3.

In addition, cardiovascular health in adulthood can be linked to the development of risk factors in childhood that ultimately may result from prenatal exposure to methylmercury. Blood pressure in childhood is an important determinant of hypertension risk later in life, and prenatal methylmercury exposure has been linked to increased blood pressure in children. Sørensen et al. (1999), in a study of 1,000 children from the Faroe Islands, found an association between prenatal methylmercury exposure and cardiovascular function at 7 years of age. An increase in maternal cord blood concentration from 1 to 10 μg/L was significantly associated with a 14.6 and 13.9 mmHg increase in systolic and diastolic blood pressures, respectively. Furthermore, in boys, heart rate variability, an indicator of cardiac autonomic control, decreased by 47% as cord blood concentrations increased over this same range.

5.2. Methodology

This section describes the calculation of pre- and postadvisory methylmercury uptake based on catch and consumption data and behavioral parameters estimated in Section 2, and the modeling and quantification of health effects from methylmercury exposure.

5.2.1. Estimating Striped Bass Consumption and Mercury Uptake

The first step in quantifying the human health effects of a mercury fish consumption advisory is the estimation of mercury uptake, and more importantly the change in mercury uptake once an advisory has been implemented. Human mercury uptake occurs primarily via three pathways: inhalation, dietary intake, and the leaching of mercury from dental amalgams. Human exposure from inhalation is predominantly elemental mercury, though inhalation is also a source of human exposure to small quantities of inorganic and methylmercury. Dietary intake is primarily methylmercury.[36] All uptake from dental amalgams is in the form of elemental mercury.

It is methylmercury uptake that has been most explicitly linked to human health, and to which humans are primarily exposed to through fish consumption.[37] Almost all methylmercury from dietary uptake is through fish consumption, and for the consuming anglers in this study, the most significant source of methylmercury exposure is striped bass from the Chesapeake Bay. Using data on striped bass fishing trips and fish tissue methylmercury concentration in the Chesapeake Bay, we calculate average per capita striped bass consumption and methylmercury uptake for anglers and their families. Additionally, we calculate the per capita reduction in these parameters based on the behavioral responses to a fish consumption advisory quantified in Section 3.

We derive estimates of striped bass consumption from data from the Chesapeake Bay Cooperative Striped Bass Survey for the years 1997–2000. This voluntary survey, taken online

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[36] Average methylmercury uptake rates from food consumption are estimated at 2.00 µg/day and 1.52 µg/day for males and females aged 25 to 30, respectively, the majority of which is from fresh and canned seafood (Rowe et al. 1995).

[37] Analysis of the health effects of MeHg is somewhat complicated by the fact that MeHg transforms into mercuric mercury (Hg^{++}) in the brain, which has a longer half-life and probable—though not well understood—health risks (NRC 2000). NRC suggests that future risk assessment for MeHg consider exposure to all species of Hg. This issue is important because the literature shows that the health effects of MeHg are subject to a threshold of exposure. If other forms of mercury in the body are not counted, this threshold is less likely to be exceeded.

or by mail, reports the total number of anglers, the number of fish caught, and for each individual fish, its length and whether it was kept or released. We calculate the weight of each kept fish using the formula from Gilmour (1999), discussed in Section 2, and calculate a per trip total weight of kept fish.[38] Incorporating the average meal size (0.25 kg, as assumed in EPA analyses) and the edible percentage of caught striped bass, we are able to calculate the number of meals caught per trip.[39] From the behavioral model we know the average number of anglers keeping striped bass for consumption (186,800 pre-advisory; 165,100 postadvisory) as well as the average number of trips on which striped bass are being kept for consumption (563,917 pre-advisory; 486,661 postadvisory). We assume that an angler's catch is shared and distributed evenly among the average number of anglers per trip (2.89, SD = 1.5, estimated from survey data) and the average Maryland household size of 2.61 (U.S. Census 2000a).[40] This information allows for calculation of a distribution of per capita meals per month.

We estimate pre-advisory average per capita meals of striped bass per month to be 1.31 (SD = 0.77). Comparison with other estimates suggests that this estimate is reasonable. A survey of recreational anglers at Lake Roosevelt in Washington (Mariën and Patrick 2001) finds that anglers consume an average of 1.67 (SD = 1.17) meals of bass per month. Moreover, although

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[38] One shortcoming of our data from the Maryland Cooperative Striped Bass Survey is that although an angler reports the total catch for the trip, actual data for only 20 of these fish are recorded. To compensate, we assume that the average weight of fish and the percentage of kept fish were the same for the remainder of caught fish.

[39] We use conversion factors from NMFS (1981) to determine what percentage of the weight of a given fish can actually be consumed. For striped bass, a fillet is 35% of the total fish weight; although no value is reported for steaks, we assume 50%, such that 85% of a given fish is consumed.

[40] Although we assume that fish are distributed equally among the household, we do not have sufficient information to fully quantify the composition of the consuming population in terms of age and gender. For the quantification of health effects, then, we estimate the size of the population at risk based on information we know or can estimate with reason.

Rowe et al. (1995) report data from the Angler Cohort Study of Lake Ontario fishermen suggesting that 20% of anglers consume 1 meal or more per month, and about 3% of anglers consume more than 10 meals per month, these numbers appear to be for multiple species of freshwater fish.

From Gilmour (1999) we apply a probability-weighted average mercury concentration in fish (mg/kg) in the upper Chesapeake Bay, in order to calculate an average per person daily mercury exposure from striped bass using the estimated distribution of per capita meals per month. The meals per month and exposure distributions most closely resemble a lognormal distribution, and the exposure distribution is shown in Figure 5.1.

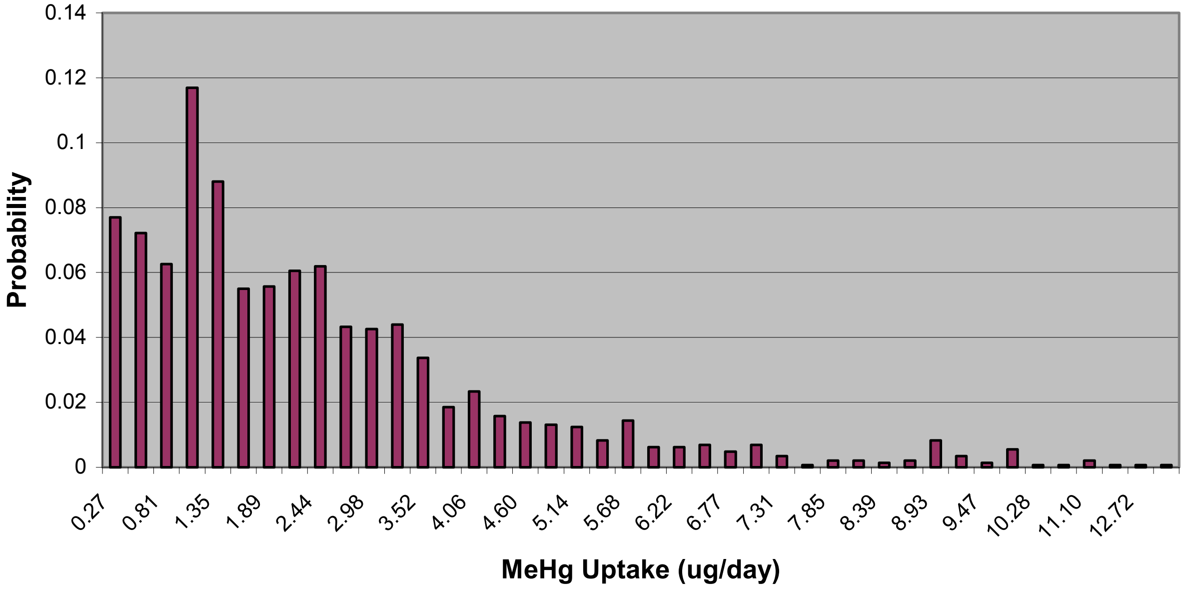

Figure 5.1. Pre-advisory Distribution of Estimated per Capita Mercury Uptake from Striped Bass by Chesapeake Bay Angler Families

Because we assume that, on average, all individuals consuming at the same level before the advisory reduce consumption by the same amount, the shape of the distribution remains the same after an advisory,[41] and the entire distribution is shifted to the left.[42] Reductions are calculated based on two parameters from the behavioral analysis in Section 2: a 2% reduction in total trips under an advisory, and a mean reduction in the probability of consumption of 26.1%. Across the population, we estimate an average reduction in daily per capita MeHg uptake from striped bass of 11% to 14%.[43]

To estimate the implications of striped bass consumption for mercury-related health effects, daily methylmercury uptake from striped bass must be converted into blood and hair concentrations. To convert daily mercury uptake to blood concentration, we use the following equation (described in U.S. EPA 2001e):

$$C = \frac{d \times a \times f}{b \times v} \tag{5.1}$$

where C is the concentration in blood, measured in μg/L; d is the daily dietary intake of methylmercury, measured in μg/day; a is the absorption factor (0.95, unitless), f is the fraction of daily intake taken up by blood (0.05, unitless), b is the elimination constant (0.014 days^{-1}), and v

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[41] This is a simplifying assumption made because we lack data regarding the distribution of the behavioral response across consumption levels. It is possible that an advisory could instead change the shape of the consumption distribution. For example, people at the low end of the distribution may value fish consumption less than people at the high end, and reduce consumption disproportionately under an advisory. Or, people at the high end might be more likely to be aware of and heed the advisory, giving them a higher propensity to reduce consumption.

[42] Not all individuals actually reduce mercury uptake, however, as was described in Section 2. Thus we calculate an average reduction by "consumption group," which is represented by an individual bar in Figure 5.1. This implicitly assumes that an averting angler maintains the pre-advisory level of fish consumption by catching and consuming fish from noncontaminated substitute sites, or by catching and consuming Chesapeake Bay fish with insignificant mercury concentrations.

[43] A variation to the assumptions behind this estimate is presented in Section 6.

is the assumed volume of blood in the body (5L).[44] To convert blood concentration to hair concentration (mg/kg), we assume a factor of 4 (U.S. EPA 2001e).

However, additional sources of mercury exposure must be considered. Chesapeake Bay anglers are unlikely to be consuming striped bass exclusively, making it necessary to account for other potential sources of methylmercury exposure, such as other fish products and inhalation. Furthermore, it is also important to account for the fact that although the health effects we examine in this study are associated with methylmercury, and thus, fish consumption, epidemiological studies typically use blood or hair total Hg concentrations as a proxy for methylmercury exposure. These total Hg measurements may reflect other sources of inorganic mercury or elemental mercury leached from dental amalgams that may confound the relationship between methylmercury from fish consumption and certain health endpoints. To account for other sources of exposure, we add a background blood concentration of 1.2 µg/L (CDC 2001) to the exposure from striped bass consumption calculated above.[45] Finally, because MeHg vacates the body rather quickly (a half-life of 40 to 80 days) (U.S. EPA 2000), and individuals are assumed to consume fish (and thus expose themselves to MeHg) at a constant rate, we assume that an individual's exposure level (and thus blood and hair mercury concentrations) are

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[44] We assume that maternal blood and umbilical cord blood concentrations are the same. This is consistent with the findings of Kuntz et al. (1982) and Sikorski et al. (1989), although a handful of other studies (Dennis and Fehr 1975; Pitkin et al. 1976; and Kuhnert et al. 1981) have found cord blood concentrations to be about 20% to 30% higher than maternal blood concentrations (NRC 2000).

[45] This background rate is based on preliminary analysis of the 1999 National Health and Nutrition Examination Survey data for U.S. women of childbearing age. The study is touted as the "first nationally representative tissue measures of the U.S. population's exposure to Hg," and thus should be representative of average uptake levels from fish and other sources of exposure. We assume that consuming anglers eat fish more frequently than the average population and thus add mercury uptake from Chesapeake Bay striped bass to this background rate. Furthermore, because comparable data are not available for males, we apply this background rate to the entire population.

constant, barring any behavioral change. Table 5.3 reports summary statistics for estimated exposure variables.

Table 5.3. Summary Statistics for Estimated Mercury Exposure Variables

Variable	Mean	SD	Minimum	Maximum
Number of exposed anglers	186,700	19,000	136,000	260,500
Number of exposed women of childbearing age	79,710	8112	58,070	111,200
Number of potentially at-risk births	2617	266.3	1906	3651
Average per capita daily methylmercury intake from striped bass, no advisory (μg)[1]	1.78	2.15	0.05	13.82
Average per capita daily methylmercury intake from striped bass, advisory (μg)	1.53	1.84	0.04	13.1
Average per capita blood concentration, no advisory (μg/L)	2.63	1.46	0.91	13.15
Average per capita blood concentration, advisory (μg/L)	2.44	1.24	0.89	11.02
Average per capita hair concentration, no advisory (mg/kg)	0.66	0.36	0.23	3.29
Average per capita hair concentration, advisory (mg/kg)	0.61	0.31	0.22	2.76

[1] All mercury-related variables are reported as geometric means and standard deviations because of the lognormal nature of the distribution.

5.2.2. Estimating Female Exposure

The estimation of health effects requires estimates of the size of specific subpopulations to which the endpoints from the epidemiological literature apply. In particular, we need to estimate the number of exposed females of childbearing age and the number of potential births to these women. Unfortunately, Maryland Department of Natural Resources does not record gender information for licensed anglers. However, we obtained an estimate of female participation from the 1996 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation data for Maryland, which reports that 26% (approximately 48,500) of Maryland recreational anglers are female. We assume that the remaining exposed females are spouses of anglers. Thus, using the marriage rate for males over 15 years of age in Maryland (55%), we estimate approximately 76,000 additional exposed females, for a total of about 124,500. Given that all recorded anglers are over 15, we assume the same for their spouses; based on current population data, about 64% of these women are between 15 and 49, what we consider childbearing age. We thus estimate the total number of exposed females of childbearing age to be 79,710. Using 2000 birthrates for Maryland, for both married and unmarried women, we calculate 2,617 potentially affected births.[46] Estimating female exposure based on assumptions from these data surely adds error to our estimates of health effects. However, the model allows these assumptions to be modified with better information.

5.3. Modeling Health Effects

Within the Maryland Model, the Mercury Health Effects Module uses MeHg uptake and demographic data to quantify three general health endpoints: adult central nervous system effects, effects on childhood neuropsychological development, and cardiovascular health and

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[46] We use a combination of two birthrates to estimate this number. We assume that female anglers marry at the same rate as the general population, and that all other exposed women are married and exposed via their husbands. For Maryland, the birthrates are 23.06 births per 1,000 unmarried women, and 46.37 births per 1,000 married women (U.S. Census 2000b).

mortality effects. Generally, the model quantifies the change in the number of cases of an effect under an advisory, using the common dose-response equation:

$$\Delta C = DR \times RATE \times POP \times (I_0 - I_t) \tag{5.2}$$

where C is the number of cases; DR is the dose-response coefficient, which represents a percentage change in the baseline rate of occurrence for a given level of MeHg exposure; $RATE$ is the baseline rate of occurrence of the effect in the population; POP is the exposed population; and I is some measure of MeHg exposure, which could be µg/day of consumption, mg/kg of hair, or µg/L of blood, with I_0 being baseline exposure and I_t being exposure at time t. For effects for which an exposure threshold, T, exists, if $I_0 < T$ then the total number of cases is zero, unless I_t exceeds both I_0 and T. Some epidemiological studies report a dose-response coefficient or percentage change in risk; others report the risk increase in percentage points associated with a given exposure or increase in exposure, circumventing the dose-response coefficient entirely. When the latter is the case, the equation appears as follows:

$$\Delta C = (RATE_0 + \Delta RATE) \times POP \tag{5.3}$$

where $\Delta RATE$ is the percentage point increase to the baseline rate specified for a given dose or dose increase, and is equal to zero if this dose or dose increase does not occur.

Finally, a few additional health endpoints are quantified as an average change in a given variable (e.g., blood pressure) across the population. In these cases the model utilizes the following linear relationship:

$$\Delta V = \beta(I_0 - I_t) \tag{5.4}$$

where ΔV is the average change in the given health variable, I is a measure of MeHg exposure as discussed above, and β is an estimated coefficient representing the change in V per unit change in I.

In addition to the endpoints discussed above, the model estimates the number of individuals who exceed the assumed advisory guidelines for Maryland, as well as the number of individuals who exceed EPA's reference dose (RfD). The remainder of this section provides a brief description of the design of the Mercury Health Effects Module, as well as an explanation of the parameters used in the estimation of health effects.

5.3.1. Central Nervous System Effects in Adults

One of the earliest signs of mercury poisoning in adults is paresthesia, or a prickling, tickling, or itching sensation in the extremities. Although the WHO (IPCS 1990) characterization of the dose-response relationship for paresthesia has been criticized, at this point there has been no research to further define the lower portion of the dose-response curve, and thus we include the WHO relationship in our model. This relationship assumes a 5 percentage point increase in the occurrence of paresthesia above a threshold of about 200 μg/day. We limit the population at risk for paresthesia in our study to exposed male and female anglers and male anglers' wives aged 15 and over, which corresponds to the age range of the licensed angler population.

5.3.2. Childhood Neuropsychological Development

Our primary method of estimating the effects of reduced mercury consumption on childhood neuropsychological development is the use of the benchmark analyses described in

Section 5.1.[47] Following the rationale of NRC (2000), we choose the Faroe Islands study as our preferred analysis of the effects of prenatal methylmercury consumption. Of the Faroe Islands endpoints that are benchmarked, the Continuous Performance Test is the most sensitive. However, because this test is administered to only about half of the cohort, the Boston Naming Test, the second most sensitive endpoint, is chosen by NRC as the point of departure for calculating the RfD for methylmercury (NRC 2000). Because of this, we choose the Boston Naming Test from the Faroe Islands as our preferred indicator of adverse neuropsychological effects in children.

Within the model, however, all endpoints for which benchmark doses were derived in Crump et al. (1998) and Budtz-Jørgensen et al. (1999) can be estimated. Furthermore, we also allow childhood neuropsychological effects to be estimated using the benchmark derived by NRC (2000) in its integrative analysis. For each benchmarked test, one can calculate the number of exposed women of childbearing age who exceed the BMD, as well as the reduction in abnormal births (births of children who would be expected to score in the abnormal range at age 6 or 7, when the test is administered) due to a mercury advisory. We assume that the BMD is normally distributed and apply the estimated BMDL as the lower 95% limit. We also allow for the calculation of abnormal births using a BMD for the Boston Naming Test from Budtz-Jørgensen et al. (1999) under the assumption of a 16% baseline risk, instead of 5%. Table 5.4 displays the complete set of benchmark doses included in the model. To facilitate comparison,

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[47] We chose to quantify these effects using benchmark analyses rather than the original studies based on our notion that reporting the number of children facing an increased risk of abnormal scores is more meaningful from a policy standpoint than the average change in individual scores at a given average exposure.

benchmark doses for the Faroe Islands are reported in mg/kg of maternal hair mercury, though they are in terms of blood concentration in the model.

Table 5.4. Tests and Benchmark Doses Included in the Maryland Model (mgHg/kg of Hair)

Study	End Point	BMD	BMDL
Faroe Islands	Neurobehavioral Evaluation System: finger tapping	20	11
	Neurobehavioral Evaluation System Continuous Performance Test: reaction time	18	9
	Bender Copying Errors	29	14
	Boston Naming Test	15	10
	California Verbal Learning Test: delayed recall	27	13
	Boston Naming Test (p_0=0.16)	8	5
New Zealand	Test of Language Development	12	6
	Weschler Intelligence Scale for Children, Revised: performance IQ	12	6
	Weschler Intelligence Scale for Children, Revised: full-scale IQ	13	6
	McCarthy Scales: perceptual performance	8	4
	McCarthy Scales: motoric	13	6
NRC integrative analysis	Multiple, across 3 main studies	21	8

Sources: Budtz-Jørgensen et al. (1999); NRC (2000). Benchmark doses represent a 5 percentage point increase in the baseline risk.

Finally, the model includes one endpoint for childhood neuropsychological development with the potential for valuation. From the New Zealand study, we model the average reduction in Weschler Intelligence Scale for Children, Revised full-scale IQ score. Kjellström et al. (1989)

estimated a 4.41 reduction in IQ score for an increase in maternal hair mercury level of 1 mg/kg, above a threshold of 6 mg/kg. Below this threshold, however, no significant relationship was observed. Using the average change in maternal hair mercury concentration data for the population, the model estimates an average change in IQ score for individuals above the threshold. Furthermore, this endpoint is an input to the Health Benefits Module, which assigns a dollar value to health effects when possible.

5.3.3. Cardiovascular Effects

The model currently estimates three cardiovascular-related endpoints: acute myocardial infarction (AMI), all-cause mortality, and average change in systolic and diastolic blood pressure in children 7 years of age. The parameter estimates for AMI and all-cause mortality are from Salonen et al. (1995). We use their risk factor–adjusted estimates in the model. For AMI, the study estimates an increase in risk of 69% at a threshold of 2 μg/g methylmercury in hair when adjusting for risk factors, with an additional increase in risk of 6.8% for each additional 1 μg/g thereafter. The increase in risk for all-cause mortality at the same threshold is 93%, with a further increase of 9.0% for each additional 1 μg/g. As was noted earlier, the cohort in Salonen et al. (1995) is 1,833 Finnish males aged 42 to 60. Thus, a prudent estimate on our part would limit the application of these coefficients to males within the same age range. Because our population data do not correspond exactly to those age groups, we apply these coefficients to males aged 40 to 59.[48] Our estimate of the change in mercury-related mortality for males is used to obtain an

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[48] We extend this relationship to women in Section 6. The mortality rate in the Maryland Model is 803/100,000 deaths per person per year, and the baseline occurrences of AMI in 1999 for men and women are 0.0049 and 0.0031,

estimate of mortality benefits in the Benefits Valuation Module. Benefits estimates are reported in Section 5.4.

The last cardiovascular endpoint we estimate is an average change in systolic and diastolic blood pressure at age 7 due to prenatal exposure to methylmercury from maternal consumption. High blood pressure in childhood is believed to be a risk factor for the development of hypertension in adulthood. Sørensen et al. (1999) estimate an increase of 14.6 mmHg (95% CI = 8.3, 20.8) and 13.9 mmHg (95% CI = 7.4, 20.4), respectively, for systolic and diastolic blood pressures for an increase in cord blood mercury concentration from 1 to 10 µg/L. Above this level, no increase in blood pressure is observed. Thus, in our model, the application of these estimates is limited to that portion of the dose-response curve.

5.3.4. Number of Individuals Exceeding Advisory and RfD

Finally, using the estimates of consumption and mercury uptake from the model, the Health Module calculates the number of individuals who exceed the assumed striped bass consumption advisory for the Chesapeake Bay—four meals per month for the general population and two meals per month for sensitive subpopulations—as well as EPA's RfD of 0.1 µg/kg-day. For the general Maryland advisory, the model estimates the number of male anglers, female anglers, and anglers' wives not of childbearing age who are consuming in excess of the advisory. For the advisory for sensitive subpopulations, the model estimates only the number of women of childbearing age who exceed the recommended guidelines, because we lack data on other

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respectively. Furthermore, it should be noted that because AMIs are often fatal (almost 40% of the time for men and 60% of the time for women), there is significant overlap between these two endpoints (NRMI 2001).

sensitive subpopulations. Lastly, the model calculates the number of male and female anglers and anglers' wives exposed to methylmercury in excess of EPA's RfD.

5.3.5. Health Effects Valuation

The Health Valuation Submodule of the Benefits Valuation Module relies primarily on estimates of willingness-to-pay (WTP) from revealed and stated preference studies. When WTP estimates are not available, proxies, such as estimated medical or treatment costs, are used. The module is explained in greater detail in Bloyd et al. (1996) and Austin et al. (1999).

The Mercury Benefits Valuation Module is set up to value two endpoints from the Mercury Health Effects Module: the average reduction in IQ score due to prenatal exposure, and mortality for men aged 42 to 60. Currently, the Benefits Valuation Module assigns a value of $10,420 ($2000) per IQ point lost to a child at age 7, as is reported by Rowe et al. (1995) in their valuation of health effects from lead.[49] Total benefits, then, would equal that amount multiplied by both the average reduction in IQ score and the number of births to women of childbearing age who exceed the hair concentration threshold for IQ effects.

We evaluate the model for mortality benefits using three equally weighted estimates of the value of a statistical life (VSL). For a low estimate, we use a value of $700,000 ($2000, SD = $48,000) from Krupnick et al. (2002). Our central estimate comes from Mrozek and Taylor (2002), who in their meta-analysis of 33 wage-risk studies suggest that VSL estimates from most revealed preference studies have tended to overestimate willingness to pay for risk reduction by not accounting for interindustry wage differentials. They estimate a VSL of $2.32 million (SD =

$212,376). Finally, our high VSL assumption is from U.S. EPA (1999), which pooled 26 value-of-statistical-life studies to derive a Weibull distribution with a mean of $6.37 million (SD = $4.31 million). EPA uses this value in its Section 812 Retrospective and Prospective Studies (U.S. EPA 1997, 1999). Each of these values is given an equal probability weight. These weights result in a weighted mean of approximately $3.11 million (SD = $3.37 million).

5.4. Results

This section quantifies the changes in the health endpoints described above, as well as the number of individuals who exceed both the assumed Chesapeake Bay recreational advisory and EPA's RfD. It also reports estimated health benefits resulting from avoided methylmercury-related mortality. Variations to the assumptions made in the quantification of health effects are explored in Section 6.

5.4.1. Paresthesia

The WHO study (IPCS 1990) reports a methylmercury uptake threshold for paresthesia in the range of 190 to 210 μg/day. However, the maximum methylmercury uptake observed in our study before a consumption advisory is approximately 14 μg/day, far short of this level. Therefore, we do not predict any cases of paraesthesia. At current fish consumption levels, paraesthesia from methylmercury uptake remains unlikely, unless fish tissue concentrations increase considerably. However, as was mentioned earlier, criticism of the WHO analysis suggests that more work is needed on the lower portion of the dose response curve (Kosatsky and

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[49] This value represents a 1.98% reduction in potential lifetime earnings per IQ lost. Its derivation is explained in more detail in Rowe et al. (1995).

Foran 1996; NRC 2000). Furthermore, it is a general belief that children are a population at greater risk of developing mercury disease (Rowe et al. 1995). However, to date, epidemiological research on children and methylmercury exposure has focused almost entirely on neuropsychological effects. There are currently no dose-response analyses specific to children for the manifestation of physical effects of methylmercury disease. Such analysis is difficult because consumption data for children—particularly children in angler families—are essentially nonexistent.

5.4.2. Childhood Neuropsychological Development

Our analysis suggests no evidence of childhood neuropsychological developmental effects at current fish consumption and mercury fish-tissue concentration levels. Our preferred method is to rely upon the Boston Naming Test benchmark estimates to indicate the presence of abnormal effects. However, our maximum estimated blood concentration of approximately 13 µg/L falls far short of the benchmark dose of 85 µg/L suggested by Budtz-Jørgensen et al. (1999) for a 5 percentage point increase in the baseline risk. In fact, the maximum concentration level falls far short of even the lowest BMD for the Faroe Islands study, which is 71.75 µg/L for the Continuous Performance Test (BMDL = 48.37 µg/L).

For the sake of comparison, we evaluate neuropsychological effects with both the New Zealand and the National Research Council integrative benchmark doses. However, the selection of benchmark doses is of little importance to our results. No abnormal test scores are predicted either under the NRC integrative BMD assumption or when any of the BMDs from the New Zealand benchmark study are assumed. Benchmark doses for both the NRC integrative and the New Zealand studies are denominated in mg/kg Hg in maternal hair. The lowest of the BMDs is

8 mg/kg (BMDL = 4 mg/kg) for the McCarthy Perceptual Performance scale from the New Zealand study, which still exceeds the maximum estimated hair concentration for the Chesapeake Bay population of 3.29 mg/kg. For further sensitivity analysis, we apply the BMD for the Boston Naming Test modeled under the assumption of a 16% baseline risk (Budtz-Jørgensen et al. 1999). The estimated BMD (in blood concentration) for a 5% increase in this case is 43.98 µg/L (BMDL = 29.74), still far in excess of our maximum estimated concentration for the exposed Chesapeake Bay population.[50]

Finally, we evaluate the average reduction in child IQ score at age 7, based on the relationship specified for the Weschler Intelligence Scale for Children, Revised full-scale IQ and maternal hair mercury concentration in the original New Zealand study (Kjellström et al. 1989). However, once again the concentration levels estimated for the exposed Chesapeake Bay population fall short of the threshold above which this relationship is found to be significant. Thus, we observe no reduction in child IQ scores for statistical births to exposed females of childbearing age in our study.

5.4.3. Cardiovascular Effects

The threshold for cardiovascular effects reported by Salonen et al. (1995) (2 mg/kg hair mercury) is lower than those for childhood neuropsychological development and falls within our estimated distribution of hair mercury concentrations. As a result, we predict cases of AMI and all-cause mortality, and subsequent reductions under an advisory, as reported in Table 5.5. The

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[50] Budtz-Jørgensen et al. (1999) found that logarithmic benchmark models fit the Faroese data well, and because the logarithmic model allows the dose-response curve to assume a supralinear form, it produced benchmark doses low enough to result in neuropsychological damages in our model. However, because current epidemiological literature suggests that a supralinear curve is unrealistic, we do not include these estimates in our model.

Salonen et al. estimates are for men aged 42 to 60, and we limit the application of this relationship accordingly. However, in Section 6 we extend the relationship to women and estimate AMI and mortality cases for both genders.

Table 5.5. Reduction in Mercury-Related AMI and Mortality to Middle-Aged Males Due to a Recreational Advisory

Endpoint	Result	Mercury-Related Cases (SD)
Acute myocardial infarction	Pre-advisory	6.85 (17.30)
	Reduction due to advisory	2.03 (4.59)
All-cause mortality	Pre-advisory	14.53 (34.94)
	Reduction due to advisory	4.37 (9.48)

The 90% CIs are (0, 11.95) and (0, 22.69) for AMI and mortality, respectively. Over the full distribution, the possibility of a negative value occurs because the original coefficients from the study have confidence intervals allowing them to assume slightly negative values. Although these results suggest, on average, an approximately 30% reduction in the occurrence of mercury-related AMI and all-cause mortality as the result of a mercury fish consumption advisory, the large standard deviations imply an inability to say anything conclusive regarding the strength of this effect. Our confidence in these results is even further attenuated by the fact that the Salonen et al. results have yet to be replicated for other samples. Thus, although the link between methylmercury uptake and cardiovascular health is generally accepted, there is not sufficient research to confirm the specific relationships evaluated here.

We also estimate average systolic and diastolic blood pressure changes at age 7 due to an advisory, for children born in the current year to exposed females. These results are reported in Table 5.6.

Table 5.6. Blood Pressure Change at Age 7 Due to a Reduction in Fetal Exposure

Endpoint	Mean Reduction Due to Advisory (mmHg) (SD)
Systolic blood pressure	0.36 (0.42)
Diastolic blood pressure	0.34 (0.39)

Under an advisory, children born to women exposed at current levels will experience an average reduction in systolic blood pressure of 0.36 mmHg and an average reduction in diastolic blood pressure of 0.34 mmHg. As was the case with AMI and mortality, the large confidence intervals surrounding these estimates prevent us from saying anything conclusive about this effect. Furthermore, given that average systolic and diastolic blood pressures at this age are approximately 101 mmHg and 64 mmHg, respectively, our results suggest a percentage change in blood pressure of along the lines of 0.5%.[51] We are uncertain of the implications of a change of this magnitude on the future cardiovascular health of children exposed prenatally.

5.4.4. Uncertainty Pertaining to Cardiovascular and Mortality Results

Insight into the uncertainty surrounding the results of cardiovascular and mortality effects can be achieved using the importance analysis feature in Analytica. For all four endpoints, this analysis suggests the same three predominant sources of uncertainty. These are, in order of importance, the number of anglers per trip, the number of saltwater fishing trips in Maryland, and the number of anglers aware of the advisory. The contributions of these variables to the uncertainty in these endpoints are not surprising. The three variables have implications for the extent to which catch is shared, total catch and consumption, and the size of the consuming population, respectively. In the model all of these variables are particularly uncertain because the number of anglers per trip varies considerably, and estimates of the number of trips and awareness are derived from a survey of relatively few anglers. The uncertainty surrounding these estimates leads to significant uncertainty for both average exposure levels and the size of the population being exposed. Although surveys are the only way to gain a true sense of total participation and awareness, survey data of consumption habits, rather than the derivation of consumption levels through the distribution of total catch among anglers, would likely reduce uncertainty.

An additional point to consider is the finding that chronic all-cause mortality is the most prevalent quantified health effect from methylmercury. Mortality, being the most severe endpoint, would be expected to be the least prevalent; other health endpoints that are insufficiently severe to cause mortality would be more frequently observed and associated with lower doses. Along the neurotoxic pathway, for example, subtle neurological effects, such as reduced intelligence or motor skills, are observed at thresholds lower than those that cause severe mercury poisoning and death. A similar result would be expected along the cardiovascular pathway investigated by Salonen et al. AMI and other less severe health effects that potentially

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[51] Brotons et al. (1989) suggest this average based on a review of previous studies.

precede mortality should be observed more frequently. These results suggest, then, that additional endpoints along this cardiovascular pathway remain to be identified and quantified.

5.4.5. Number of Individuals Exceeding the Advisory and RfD

In addition to the health effects estimated above, the Health Module also calculates the number of individuals who exceed the consumption advisory and EPA's RfD for methylmercury based on striped bass consumption. These results are reported in Table 5.7.

Table 5.7. Number of Individuals Exceeding Chesapeake Bay Advisory and EPA's RfD

Guideline	Number Exceeding Guideline[1] (SD)	Minimum	Maximum
Chesapeake Bay Advisory: General Population	6,352 (10,530)	0	52,860
Chesapeake Bay Advisory: Sensitive Subpopulations	11,690 (12,440)	0	45,220
EPA RfD	18,090 (31,070)	0	170,200

[1] The estimate for the general advisory includes male anglers and exposed females not of childbearing age; the estimate for the sensitive advisory includes only exposed females of childbearing age; and the estimate for the EPA RfD includes male anglers and all exposed females.

We estimate that slightly more than 6,300 individuals will exceed consumption guidelines of the general FCA for the Chesapeake Bay, about 5,400 of whom are anglers. This implies that only approximately 4% of consuming anglers will exceed the advisory recommendation, or about 2% of total anglers—a high rate of compliance relative to most other studies.[52] As was discussed in Section 3.1, the mean percentage of anglers who exceed advisory

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[52] Because we estimate that only about 26% of consuming anglers avert, this result suggests that the majority of those who do not avert are consuming at levels within advisory guidelines.

consumption recommendations is 9.6%, with a 95% CI of 7.7%–11.5%. However, we have no information about the severity of the advisories in these studies, or the number of species involved. Presumably, anglers are more likely to be in compliance with an advisory that is limited to one species, as is assumed for the advisory in this study. Furthermore, according to our model, only about 5% of consuming anglers, or roughly 3% of all anglers, are consuming in excess of these guidelines before they are announced, suggesting that advisory guidelines are likely to be relevant to only a small percentage of the population at the high end of the consumption distribution. This finding may have implications for advisory-related educational efforts by the state, as outreach efforts targeting these high-consumption anglers might do more to further compliance than more generalized efforts.

Our results suggest that women of childbearing age are less likely to be in compliance with their relatively more restrictive advisory (no more than two meals per month). We estimate that about 15% of mercury-exposed females of childbearing age will consume in excess of advisory guidelines. However, this result is likely more indicative of a weakness in our data than of an actual behavioral pattern. Because we have no separate data for consumption patterns of males and females, we are restricted to the assumption that males and females consume the same percentage of fish from a given trip, which implies that on a high-catch trip, women of childbearing age will be eating exactly the same amount of fish as their husbands. A more realistic assumption might be the existence of some threshold at which a woman of childbearing age will limit her fish intake. In the absence of consumption data for recreationally caught fish for women in this age range, however, it is difficult to guess where this threshold might be set.

Finally, we estimate that about 18,000 individuals will be in excess of EPA’s reference dose of 0.1 µg/kg/day based on consumption of striped bass alone. Of these individuals, about

5,490 are women of childbearing age. This represents about 7% of exposed females of childbearing age and slightly more than 4% of total exposed females in Maryland. Before the advisory, these numbers are approximately 9% and 6%, respectively. These estimates, however, are likely biased by two countervailing forces. The first is that estimates of RfD compliance consider only daily intake from striped bass, thus underestimating daily exposure. However, our estimates for females of childbearing age are also likely subject to the upward bias discussed in the preceding paragraph, namely that they assume women of childbearing age are consuming fish at the same rate as male anglers.

Estimates of female compliance with the RfD vary. EPA estimates that about 7% of women nationwide exceed the RfD (NRC 2000). Stern et al. (1996), using fish consumption data from a survey in New Jersey, estimate that 21% of women of childbearing age exceed the RfD. In comparing their estimates with those from this study, one must consider (in addition to the potential sources of error discussed above) that the percentages we report are only for females known to be exposed through their own or their husbands' participation in recreational angling in the Chesapeake Bay. Although freshwater female anglers and anglers' wives in Maryland might be expected to exceed these guidelines at rates similar to or higher than those from the Chesapeake Bay, incorporating compliance by females of childbearing age in the population at large into the calculation of this percentage will almost certainly drive our estimate of noncompliance downward.

5.4.6. Health Benefits Estimates

Given that we estimate no change in IQ score from reduced prenatal methylmercury exposure, we are able to value only mortality benefits from the estimated reduction in statistical deaths under an advisory. We quantify mortality benefits only for mortality among men aged 40 to 59, though women of the same age range are included in benefits calculations in the sensitivity analysis in Section 6. Assuming that this mercury-mortality relationship exists, it would likely be similar for both genders and among other age ranges, such that the benefits estimate reported here is almost certainly conservative. For middle-aged males, we estimate mean benefits from mortality reduction to be $14.36 million (95% CI: 0, $74.66 million).

The information content of these benefits estimates is limited as a result of the tremendous uncertainty surrounding them. However, the estimates do suggest that mortality benefits may figure prominently in an analysis of a mercury fish consumption advisory, particularly because Salonen et al. (1995) suggest that these benefits are likely to come at lower concentration levels than some of the other health benefits estimated in this study, most notably childhood neuropsychological development. Should further research corroborate the existence of the relationship between mercury uptake and chronic mortality, the health benefits from a mercury consumption advisory may outweigh the recreational and consumer surplus losses, given sufficiently large populations and fish tissue concentration levels. For example, in our study, we estimate a recreational surplus loss of $8.83 million ($2000). In the absence of a commercial advisory, mortality benefits exceed this recreational surplus loss by almost 70%.

Thus, while our results suggest that consumption advisories at the concentration and consumption levels for the Chesapeake Bay may not be economically justified based on potential neurotoxicity to the fetus, they may be warranted for the potential cardiovascular and mortality effects. However, because the study on which we base these results has not been replicated, this insight is fraught with uncertainty. Given the magnitude of potential benefits, further epidemiological research on this relationship will be of substantial value.

5.5. Summary

This section reviewed the epidemiological literature summarizing the relationship between methylmercury exposure and human health, discussed the quantification of three broadly defined health endpoints in the Maryland Model, and estimated changes in these endpoints and health benefits from a recreational mercury fish consumption advisory. Although we estimate no adult central nervous system effects (as manifested in paresthesia incidences) or childhood neuropsychological development effects, we do estimate small reductions in the occurrence of acute myocardial infarction and all-cause mortality as the result of an advisory. We also predict, on average, a small decrease in systolic and diastolic blood pressures at age 7. However, all of these estimates are surrounded by large confidence intervals, largely because of uncertainty in exposure levels and the size of the exposed population. Furthermore, our finding of chronic mortality as the most prevalent endpoint suggests that there are other, less severe health effects associated with methylmercury exposure that remain to be identified and quantified.

In general, angler compliance with the advisory is quite high, with only 2% of total anglers consuming in excess of advisory recommendations. Although females of childbearing age are more likely to exceed consumption guidelines in our model, we attribute this finding more to the assumptions made and the limitations of our data rather than to an actual behavioral pattern. In addition, our estimate of females of childbearing age who exceed the EPA RfD for methylmercury suggests that the percentage of women in Maryland exceeding the RfD is lower than in other parts of the country.

Finally, our mean estimate of mortality benefits from a mercury advisory for males aged 40 to 59 is $14.36 million (95% CI: 0, $74.66 million). Although estimated health benefits are uncertain, surplus losses are more certain and likely to be sizable. Policymakers should attempt to minimize these costs by targeting high-quantity consumers and communicating a precise message to these anglers. Additionally, because there is so much uncertainty surrounding our estimate of mortality benefits, the potential for such benefits from a mercury fish consumption advisory warrants further epidemiological research on this relationship.

6. Sensitivity Analysis

A number of sources of potential error arise in our analysis of changes in welfare as a result of some of the simplifying assumptions made in the model. This section presents results from selected sensitivity analyses that were conducted to determine the magnitude of the effect of various assumptions or restrictions on estimates of changes in welfare. In particular, this section addresses assumptions that could potentially have a large impact on estimated health benefits. Additionally, this section discusses the potential for incorporating other policy and behavioral scenarios into the Maryland Model.

In this section, we alter five assumptions made in our earlier analysis that are expected to have significant implications for health benefits estimates, and compare benefits estimates for these alternative scenarios with our original estimates. We examine the following alternative scenarios:

1. Perfect information, such that all consuming anglers are aware of the current advisory.
2. Perfect compliance, such that all mercury-related health effects are eliminated.
3. Averting anglers continue to be exposed to mercury through other sources of fish consumption.
4. The absence of a maternal hair mercury concentration threshold for IQ effects.
5. The mercury-mortality relationship is applied to both males and females.

6.1. Perfect Awareness and Perfect Compliance

As discussed in Section 3, we derive an estimate of angler awareness for Chesapeake Bay anglers using a Bayesian-weighted mean estimate of anglers' FCA awareness of based on estimates from the literature. The applicability of parameter estimates from other sites to this analysis of the Chesapeake Bay is somewhat uncertain because angler characteristics and outreach and education efforts by the state may vary by location, and the characteristics at the locations examined may differ from those of the Chesapeake Bay. However, we can estimate the magnitude of the effect of angler awareness on health benefits by estimating health benefits under a scenario of perfect awareness. An assumption of perfect awareness implies that state education and outreach efforts are sufficient to ensure that every consuming angler is aware of the advisory. The probability that an aware angler will continue to consume striped bass, however, remains the same as in our original analysis (0.498). An assumption of perfect awareness more than doubles the number of aware anglers in our analysis. Because more anglers will avert under this scenario, average methylmercury intake and concentration estimates under an advisory are reduced relative to our original analysis, by approximately 14%. We also estimate maximum total potential mortality benefits under original assumptions, the equivalent of perfect advisory compliance.

Under perfect awareness, greater average reductions in mercury intake across the angler population result in an increased reduction of excess mortality to men aged 40 to 59, such that mortality benefits under our central assumptions increase by approximately 87%. Table 6.1 reports mortality benefits estimates for this scenario and compares these results with our original estimate and estimated benefits for a scenario of perfect compliance. Mortality-related benefits under a scenario of perfect awareness are approximately 55% of total potential mercury-related mortality benefits, given our original assumptions regarding consumption levels and angler propensity to consume.

Table 6.1. Comparison of Estimated Mortality Benefits under an Assumption of Perfect Awareness, with Original Estimates (million $2000)

Scenario	Reduction in Number of Cases	Benefits from Estimated Mortality Reduction (SD)
Original	4.37 (9.48)	$14.36 ($45.12)
Perfect awareness	7.98 (16.10)	$27.87 ($88.35)
Perfect compliance	14.53 (34.94)	$45.30 ($157.20)

6.2. Averting Anglers Are Exposed to Mercury from Substitute Sources of Fish

We assume in the main analysis that consuming anglers who avert under an advisory maintain their original level of consumption of recreationally caught fish, but do so by catching their fish from noncontaminated substitute sites or by consuming Chesapeake Bay species with negligible mercury concentrations. By allowing for a full elimination of mercury exposure from the Chesapeake Bay for averting anglers, this assumption also allows for the possibility that many anglers will avert by ceasing consumption of recreationally caught fish altogether, rather than seeking such fish from a substitute site or source.[53] A variation of this original assumption is that all averting anglers switch to alternative sources of fish but expose themselves to new sources of mercury in the process. Thus, methylmercury exposure is reduced only to the extent that the mercury tissue concentrations of the substitute fish are lower than those of striped bass.

Absent data on Chesapeake anglers' behavior under an advisory, it is difficult to estimate the extent to which anglers might be limiting their exposure reduction by consuming other contaminated fish. However, one means of addressing this potential effect is to assume that averting anglers, in the presence of an advisory, replace their methylmercury uptake from Chesapeake Bay striped bass with the average per capita daily mercury uptake from canned and other commercial seafood products. This assumption will likely overestimate mercury exposure to anglers under an advisory, however, because in theory background blood concentrations should already be accounting for average fish consumption levels.

Once an advisory has been announced, using our original assumptions for awareness and compliance, we estimate that approximately 15,990 of 165,000 consuming anglers avert, or cease consumption of recreationally caught striped bass from the bay. These anglers and their spouses are assigned the background FDA uptake rate from commercial seafood products, which averaged over the population is 1.76 µg/day (Rowe et al.1995). Consuming anglers who do not

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[53] Although this extension to the assumption can be made in terms of mercury exposure, it should be noted that we are actually assuming that these individuals are holding their total fish consumption levels constant. This implies that these averting individuals are still retaining the protective health benefits of fish consumption and thus are not really making a trade-off in terms of health risks.

avert in the presence of an advisory continue to consume striped bass from the Chesapeake Bay at pre-advisory levels.

Under this scenario, baseline all-cause mortality rates are the same as in our original analysis, but the reduction in methylmercury-related mortality under an advisory is smaller because of a smaller average reduction in methylmercury uptake across the exposed population. Table 6.2 compares benefits estimates from this scenario with our original benefits and potential benefits estimates. When averting anglers are assumed to substitute canned and other commercial seafood products rather than switching to recreationally caught fish from noncontaminated substitute sites, mortality benefits are about 30% as large as our original estimates.

Table 6.2. Comparison of Estimated Mortality Benefits If Averting Anglers Are Exposed to Mercury through Substitute Fish, with Original Estimates (million $2000)

Scenario	Reduction in Cases	Benefits from Estimated Mortality Reduction (SD)
Original	4.37 (9.48)	14.36 (45.12)
This scenario	1.53 (3.90)	4.30 (17.55)
Perfect compliance	14.53 (34.94)	36.90 (105.00)

Furthermore, although our estimates of compliance with a striped bass advisory remain the same as in our original analysis under this assumption, a smaller per capita reduction in mercury exposure implies that more individuals will be exceeding EPA’s RfD. In this scenario, we estimate that 21,200 (SD = 32,600) individuals, 6,603 (SD = 9,891) of whom are women of childbearing age, will be exposed to mercury through fish consumption in excess of EPA guidelines, compared with 18,000 and 5,490, respectively, in our original analysis. These new estimates represent about 8% of exposed women of childbearing age and slightly more than 5% of total exposed females in Maryland, about a 1 percentage point increase in both values from our original analysis.

6.3. Removal of the Threshold for IQ Effects

In this scenario, we eliminate the threshold for IQ effects from the New Zealand study, which in the main analysis was set at a maternal hair mercury concentration of 6 mg/kg. Although Kjellström et al. (1987) did not find a significant relationship between prenatal methylmercury exposure and IQ score below this level, we apply the relationship for the entire dose-response curve for sensitivity purposes.

Elimination of this threshold, with all other original assumptions intact, results in a per capita average increase in IQ score of 0.52 points (SD = 0.50) under an advisory, or about a 0.5% increase in an average score of 100 points. This average is over total births to exposed females of childbearing age (2,617), and an IQ point is valued at $10,420 ($2000); thus we estimate total benefits from avoided intelligence loss to be $10.57 million (SD = $9.91 million). Although research currently does not support the changing of this threshold, if it were reduced or eliminated, sizable gains from avoided reductions in intelligence due to prenatal methylmercury exposure would be expected under a fish consumption advisory.

6.4. Application of the Mercury-AMI and Mercury-Mortality Relationships to Women

The cohort in the Salonen et al. (1995) study is limited to males aged 42 to 60. As a result, in the main analysis, we limit the application of their estimated relationship accordingly.

However, it is plausible that a similar relationship exists for females of the same age range. In this scenario we calculate increased AMI and mortality cases for both males and females and sum benefits over both genders. Table 6.3 reports mortality and AMI for both males and females, given all other original assumptions.

Table 6.3. Reduction in Mercury-Related AMI and Mortality for Both Genders Due to Advisory

Endpoint	Result	Mercury-Related Cases (SD)		
		Males	Females	Total
Acute myocardial infarction	Pre-advisory	6.85 (17.30)	3.38 (8.53)	10.23 (25.83)
	Reduction due to advisory	2.03 (4.59)	1.00 (2.26)	3.03 (6.85)
All-cause mortality	Pre-advisory	14.53 (34.94)	11.40 (27.42)	25.93 (62.36)
	Reduction due to advisory	4.37 (9.48)	3.43 (7.44)	7.80 (16.92)

Occurrences of AMI and all-cause mortality are lower for females than for males because of the relatively smaller size of the exposed female population and the lower baseline risk of AMI for females. However, the inclusion of females in an analysis of cardiovascular and mortality risk increases our central estimate of mortality benefits by approximately 78%, as is seen in Table 6.4. Because of the magnitude of potential benefits with the addition of females, research should explore the existence of these relationships for women.

Table 6.4. Comparison of Estimated Mortality Benefits When Females Are Included in the Analysis, with Original Estimates ($2000)

Scenario	Benefits from Estimated Mortality Reduction (SD)
Original (males only)	14.36 (45.12)
Males and females	25.63 (80.53)
Perfect compliance (males and females)	80.85 (280.6)

6.5. Potential Implications of Alternative Assumptions for Recreational Consumer Surplus Loss

Estimates of consumer surplus loss due to a recreational fish consumption advisory in the Chesapeake Bay are also likely to be sensitive to the assumptions made in our model. For example, altering such parameters as angler awareness via outreach and education efforts or changing anglers' propensity to heed an advisory will change the magnitude of their behavioral response, and thus should affect consumer surplus accordingly: a greater behavioral change should imply greater economic losses. The magnitude of this relationship will depend primarily on the availability and proximity of noncontaminated substitute sites. However, given that there is no literature linking per trip consumer surplus loss to advisory severity or educational efforts, we have no obvious means of adjusting per trip consumer surplus losses for a given change in awareness or compliance.

Incorporating dynamic stock effects into the analysis may also have implications for consumer surplus loss. As discussed in Section 2, an averting response by consuming anglers may, over time, reduce the per trip consumer surplus losses borne by catch-and-release anglers: reductions in harvest by consuming anglers may increase biomass in the estuary, improving catch rates—and consequently per trip value—for catch-and-release anglers. This effect will to some extent attenuate the present value of overall consumer surplus loss from an advisory, though the magnitude of this effect is quite uncertain. Any change in average per trip consumer surplus loss will affect total welfare losses under an advisory proportionally.

6.6. Additional Opportunities for Sensitivity Analysis

Currently, the Maryland Model allows the user to alter several types of input parameters, all of which have been discussed either in this chapter or in the main analysis. Table 6.5 lists the parameters that can be altered.

Table 6.5. Options for Sensitivity Analysis Provided in the Maryland Model

Option	Choices
Choose angler awareness	Bayesian weighted mean from literature (default) Perfect awareness
Choose mercury exposure scenario	Averting anglers eliminate mercury uptake from striped bass (default) Averting anglers are exposed to mercury from other fish sources
Choose method of estimating recreational surplus loss	Percentage loss applied to Maryland fishing day estimates (default) Consumer surplus estimates from Great Lakes
Choose a study for assessing childhood neuropsychological development effects	Faroe Islands (default) New Zealand NRC integrative analysis
Choose an assumption for IQ effects	Threshold (default) No threshold

The user can also directly change other input parameters or data in the model to facilitate the analysis of different populations or fisheries, simulate a variety of policy or behavioral scenarios, or incorporate new parameter estimates from the literature. To do so, however, the user must open the edit function in Analytica and change the input values. An advisory of increased severity, for example, might be modeled by increasing the percentage reduction in trips taken as well as the percentage of anglers complying with consumption guidelines. Various levels of education and outreach efforts by the state could be modeled by altering the percentage of anglers aware of the advisory. Although the literature may not provide specific estimates for adjusting these variables, one could postulate reasonable adjustments to our original assumptions. Additionally, modification of relevant demographic variables could allow for the examination of effects on selected or altogether different populations. Further variations to the original assumptions could certainly be explored.

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Appendix: The Maryland Model

This section highlights some of the major features of the Mercury Fish Advisories version of the Maryland Model, showing major endpoints and options provided to the user and discussed in this study. Figure A.1 depicts the top-level screen of the model. The Atmospheric Transport Module is not included in our analysis, so this appendix focuses on features of the Anglers' Response, Health Effects, and Benefits Modules.[54]

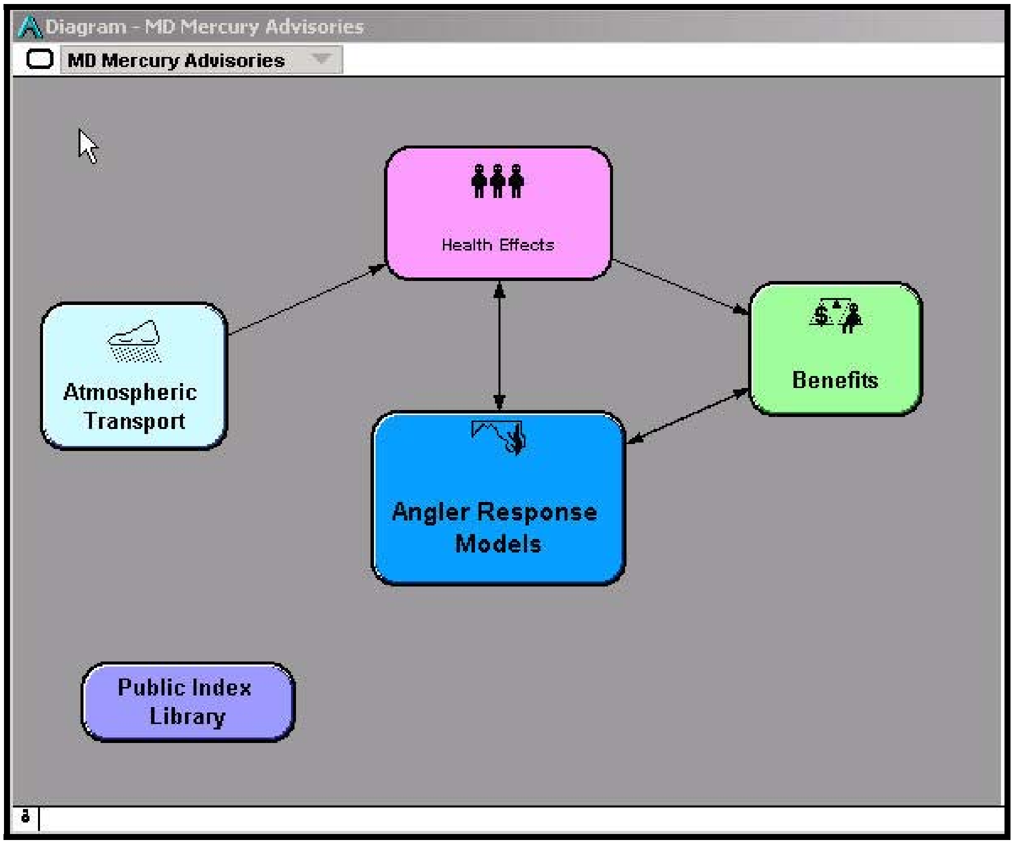

Figure A.1. The Mercury Fish Consumption Advisory Model

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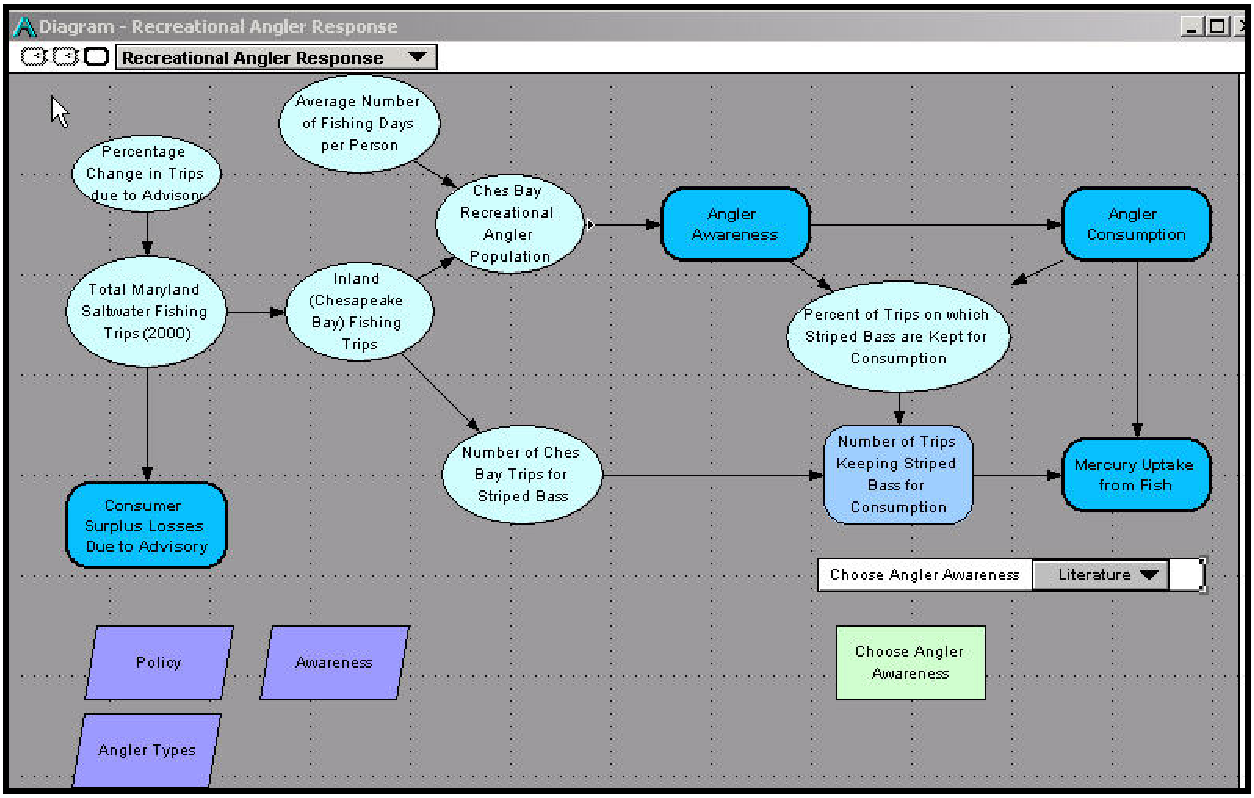
[54] A number of the modules shown contain seemingly superfluous nodes, which are generally indexes, such as "Policy" or "Awareness," that are used to characterize the data and results throughout the model.

A.1. The Recreational Angler Response Module

The Recreational Angler Response Module is depicted in Figure A.2. It allows the user to select an assumption for anglers' awareness, either an estimate representative of the literature or perfect awareness.[55] Two important parameters are calculated in submodules within this module: recreational consumer surplus loss under an advisory, and methylmercury uptake from Chesapeake Bay striped bass both before and after an advisory.



Choose Angler Awareness: Literature

Figure A.2. The Recreational Angler Response Module

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[55] Such choices are often represented by both a rectangular choice node and a pop-up menu. The choice node defines the available options and allows the user to make a selection. The pop-up menu is added for convenience, so that a user familiar with the choices can make a decision upon entering the module without having to go into the choice node.

The submodule for calculating consumer surplus losses under an advisory is shown in Figure A.3. The user is provided with two options for estimating consumer surplus losses, which are described in Section 2.

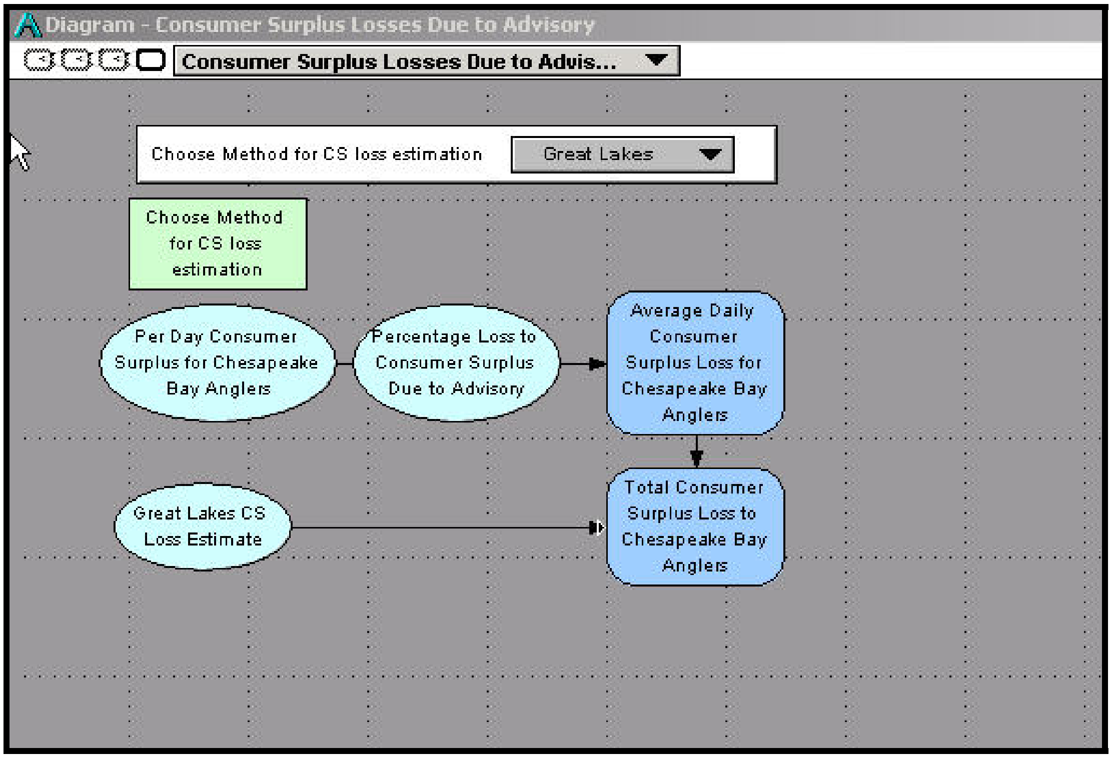


Figure A.3. Consumer Surplus Loss Calculation Submodule

Within the Recreational Angler Response Module, the Mercury Uptake Submodule quantifies per capita daily methylmercury exposure both before and after an advisory using striped bass catch and consumption data, striped bass fish tissue mercury concentration estimates, and the estimated behavioral parameters. The module converts raw catch into meals, distributes this catch among anglers and their families, and using fish tissue concentration data, calculates a per person daily mercury uptake and the change in uptake under an advisory. This estimate serves as the primary input to the Health Effects Module. The Mercury Uptake Calculation Submodule is depicted in Figure A.4.

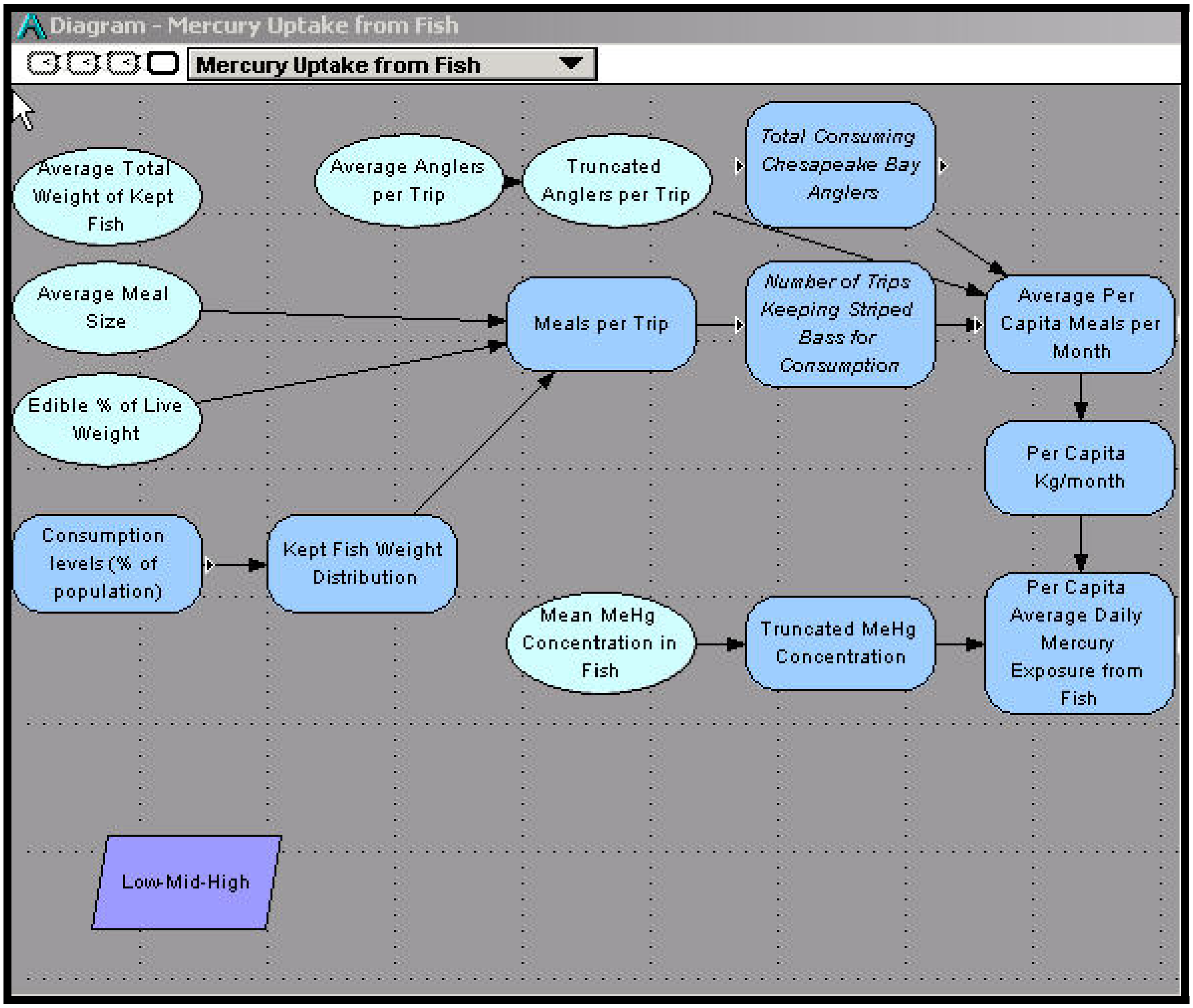


Figure A.4. Mercury Uptake Calculation Submodule

A.2. Commercial Fisheries Response Module

The Commercial Fisheries Response Module calculates consumer and producer surplus losses under both a ban on commercial fishing and the issuance of commercial fish consumption advice by the state. The basis for these calculations is parameter estimates from an original supply-and-demand model of the Chesapeake Bay commercial striped bass fishery, which are used as inputs to the module. Currently, options are not included in the model for altering the assumptions made in estimating these parameters. However, the size of reductions in consumer and producer surplus can be modified in the model with better information. Figure A.5 depicts the top level of the Commercial Fisheries Response Module.

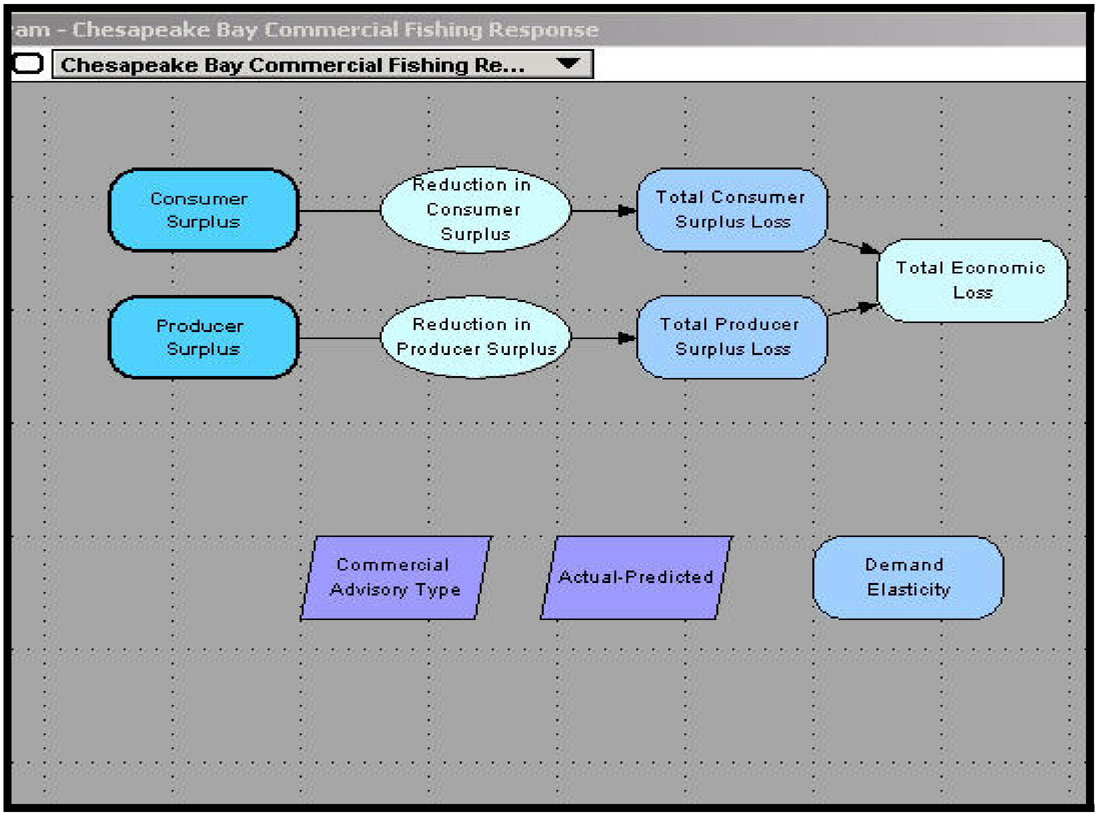


Figure A.5. Commercial Fisheries Response Module

A.3. Mercury Health Effects Module

Figure A.6 shows the uppermost level of the Mercury Health Effects Module. The user chooses the assumption for determining anglers' exposure—that is, whether averting anglers are exposed to mercury from new sources of fish consumption. Total human exposure and all five health endpoints are calculated in submodules within this module.

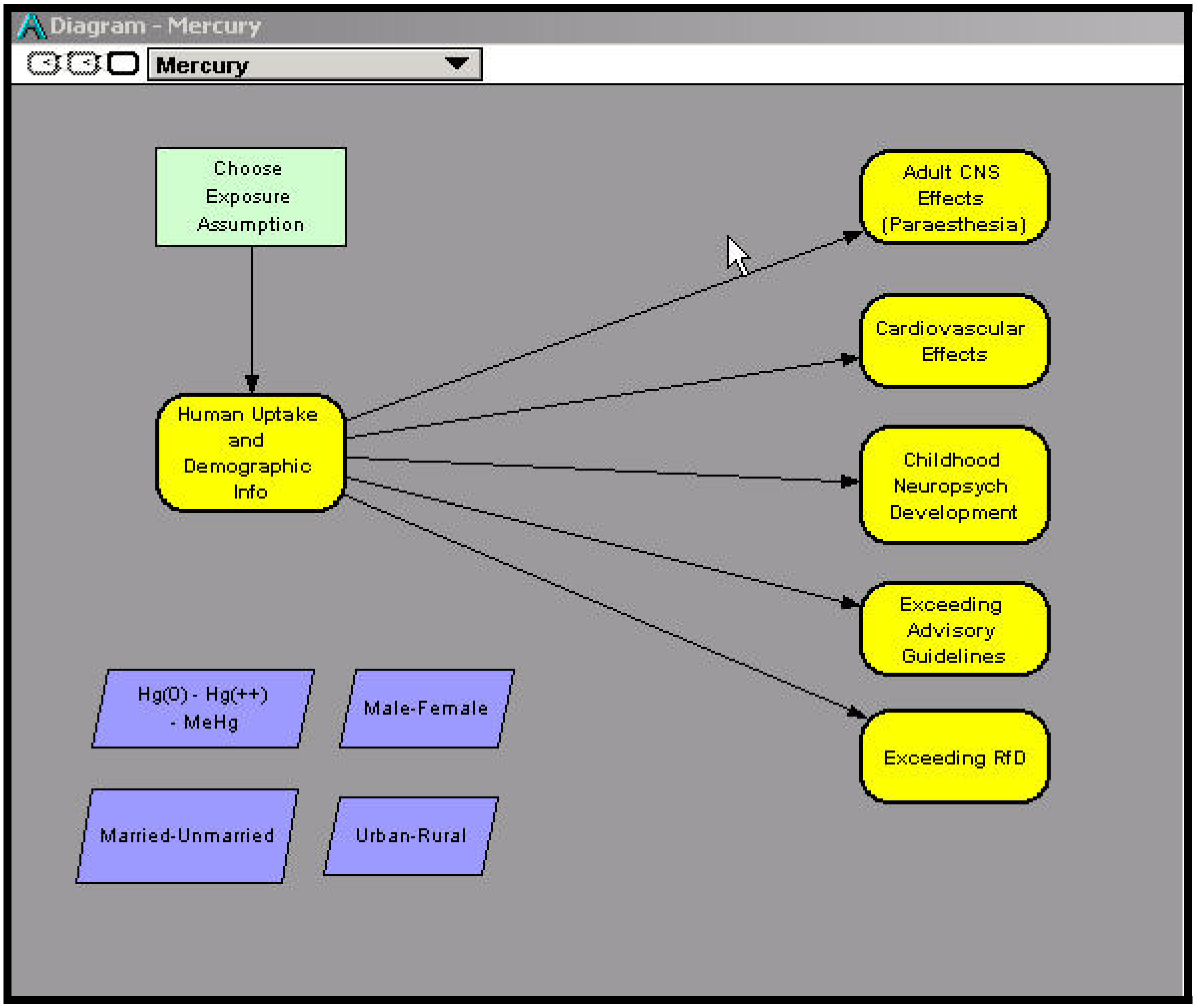


Figure A.6. Mercury Health Effects Module

The Human Uptake Submodule, shown in Figure A.7, combines mercury uptake from fish with other sources of MeHg exposure, namely inhalation, to determine total exposure. However, the submodule inventories all forms of mercury to which humans are exposed. Depending on the assumptions chosen by the user, average background MeHg uptake from commercially caught fish may or may not be included in the calculation. Mercury from dental amalgams is never included because mercury exposure from dental amalgams is in the form of elemental mercury. The node labeled Total Human Uptake (ALT) reports human uptake for the alternative exposure scenario discussed in Section 6. In the Intake Conversions Submodule, human uptake data is combined with baseline blood mercury concentration levels, and final blood and hair concentrations are calculated.

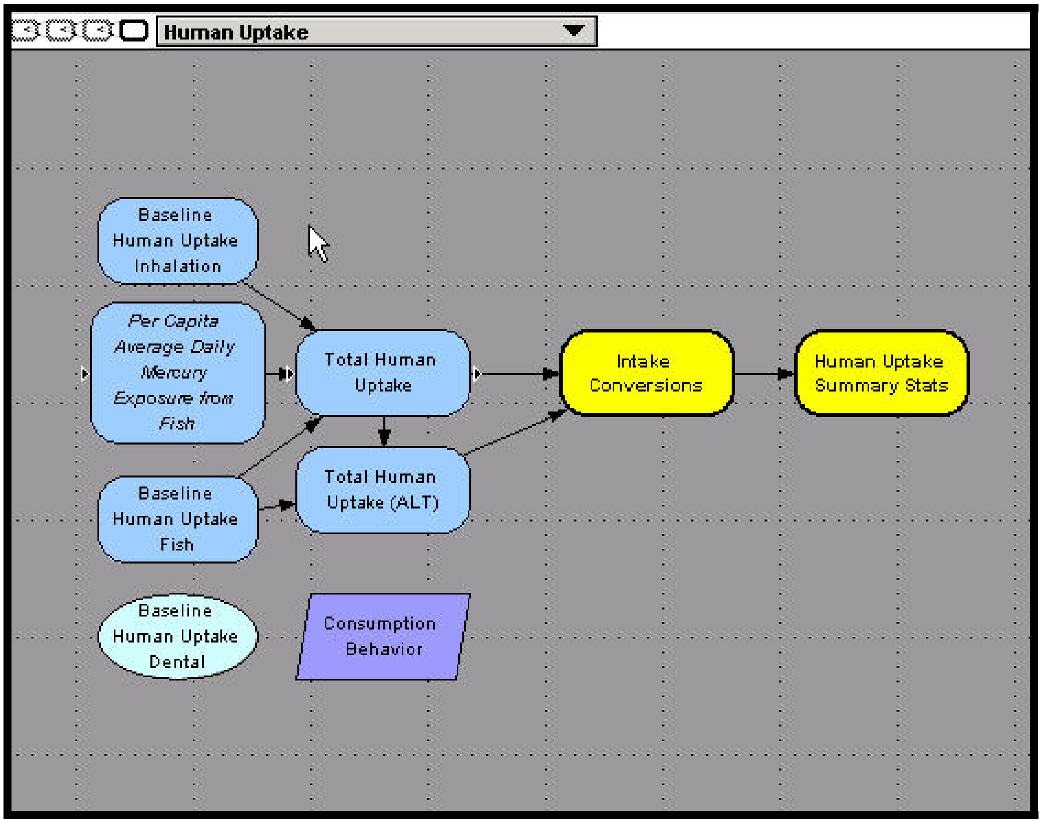
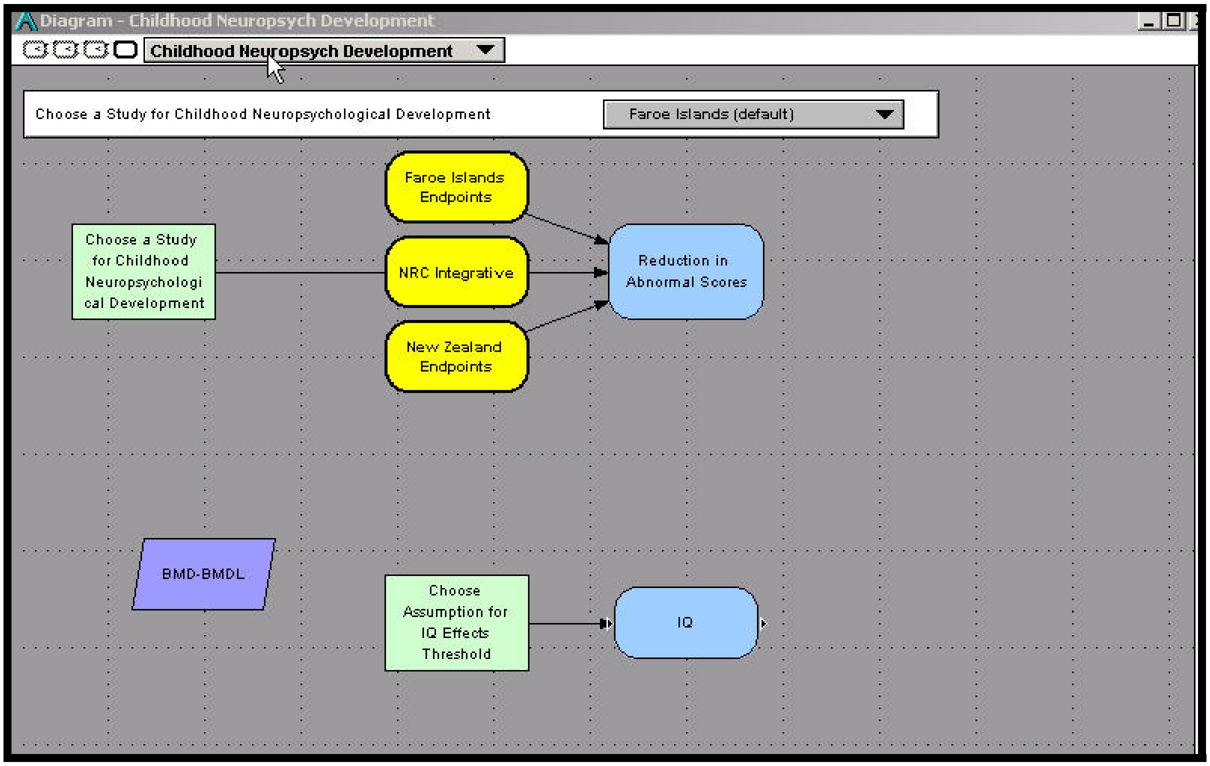


Figure A.7. Human Uptake Submodule

Figures A.8 and A.9 display the two layers of complexity within the Childhood Neuropsychological Development Submodule. The user selects a study to quantify the reduction in abnormal test scores under an advisory. Furthermore, the user can decide to remove the threshold in calculating average change in IQ score under an advisory. Within the submodule for each study, the user can quantify any particular neuropsychological development test, as is depicted for the Faroe Islands study in Figure A.9. The submodule quantifies the number of women who exceed any benchmark dose, as well as the number of abnormal test scores.



Choose a Study for Childhood Neuropsychological Development: Faroe Islands (default)

Figure A.8. Childhood Neuropsychological Development Submodule

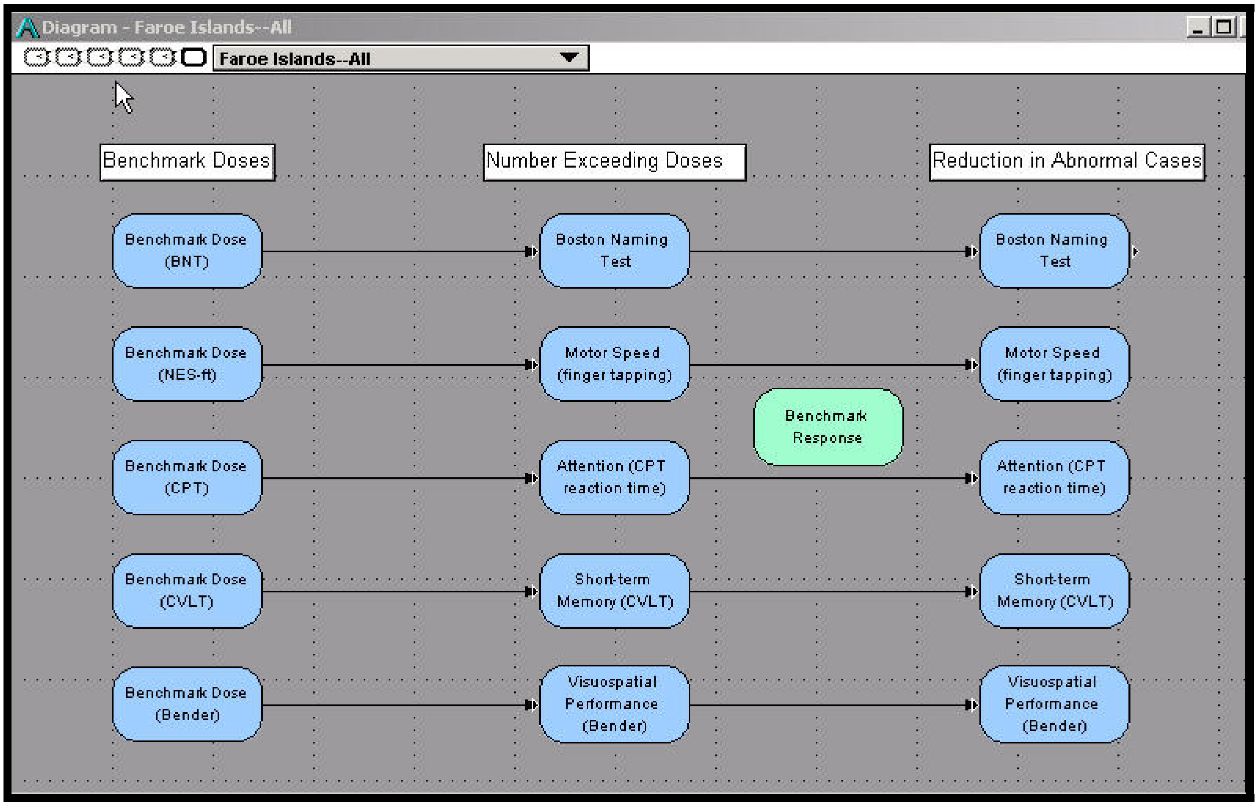
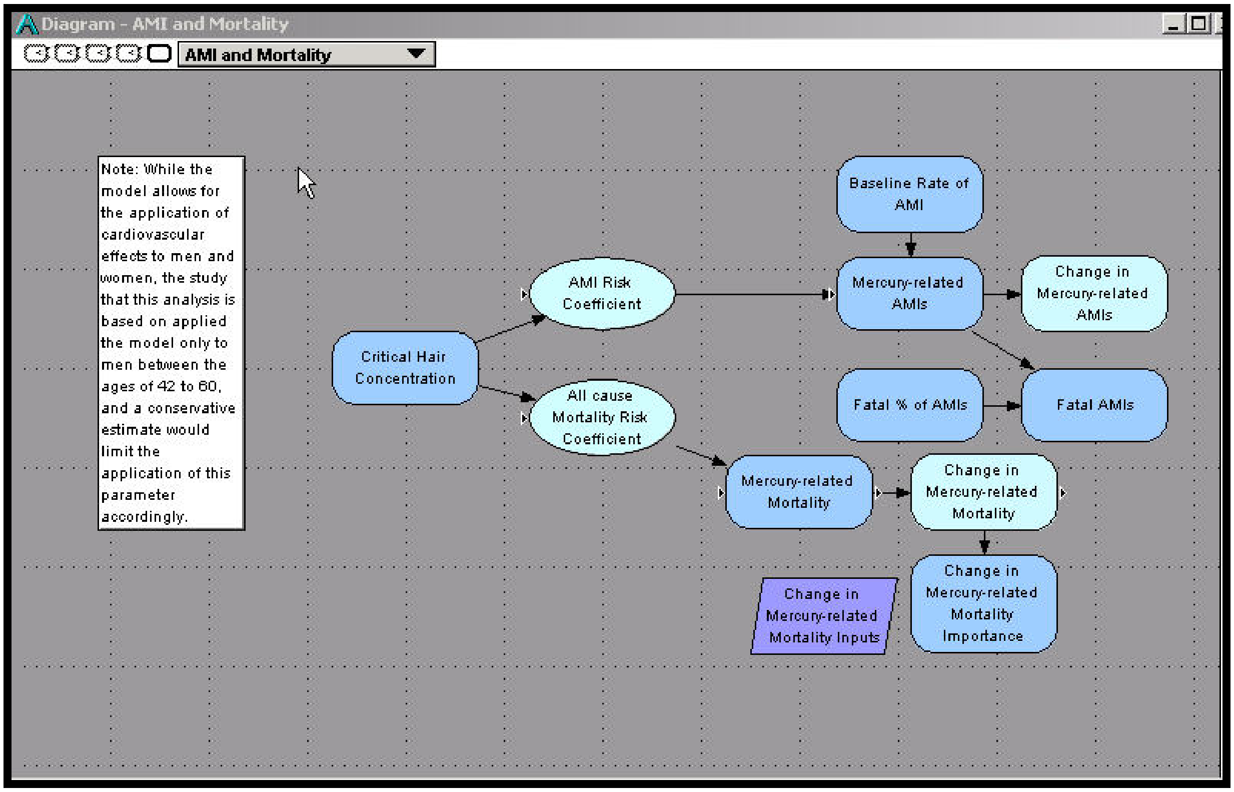


Figure A.9. Faroe Islands Submodule

The Cardiovascular Effects Submodule of the Mercury Health Effects Module is presented in Figure A.10. This submodule estimates cases of mercury-related AMI and mortality and the reductions in these two endpoints under a fish consumption advisory. It also allows for the calculation of fatal AMIs so that the extent of overlap between these two endpoints can be examined. The submodule calculates these endpoints for both men and women. The nodes labeled Importance perform importance analysis on the results to determine the primary sources of uncertainty.



Note: While the model allows for the application of cardiovascular effects to men and women, the study that this analysis is based on applied the model only to men between the ages of 42 to 60, and a conservative estimate would limit the application of this parameter accordingly.

Figure A.10. AMI and Chronic Mortality Effects Submodule

A.4. Health Benefits Valuation

The Mercury Health Valuation Module is capable of reporting the value of reductions in cases of paresthesia (though cases of paresthesia are not predicted in the analysis), chronic mortality, and the value of the average improvement in children's IQ score under an advisory. The VSL can be varied for mortality benefits calculation, within the Health Values Library in the larger Health Benefits Module.

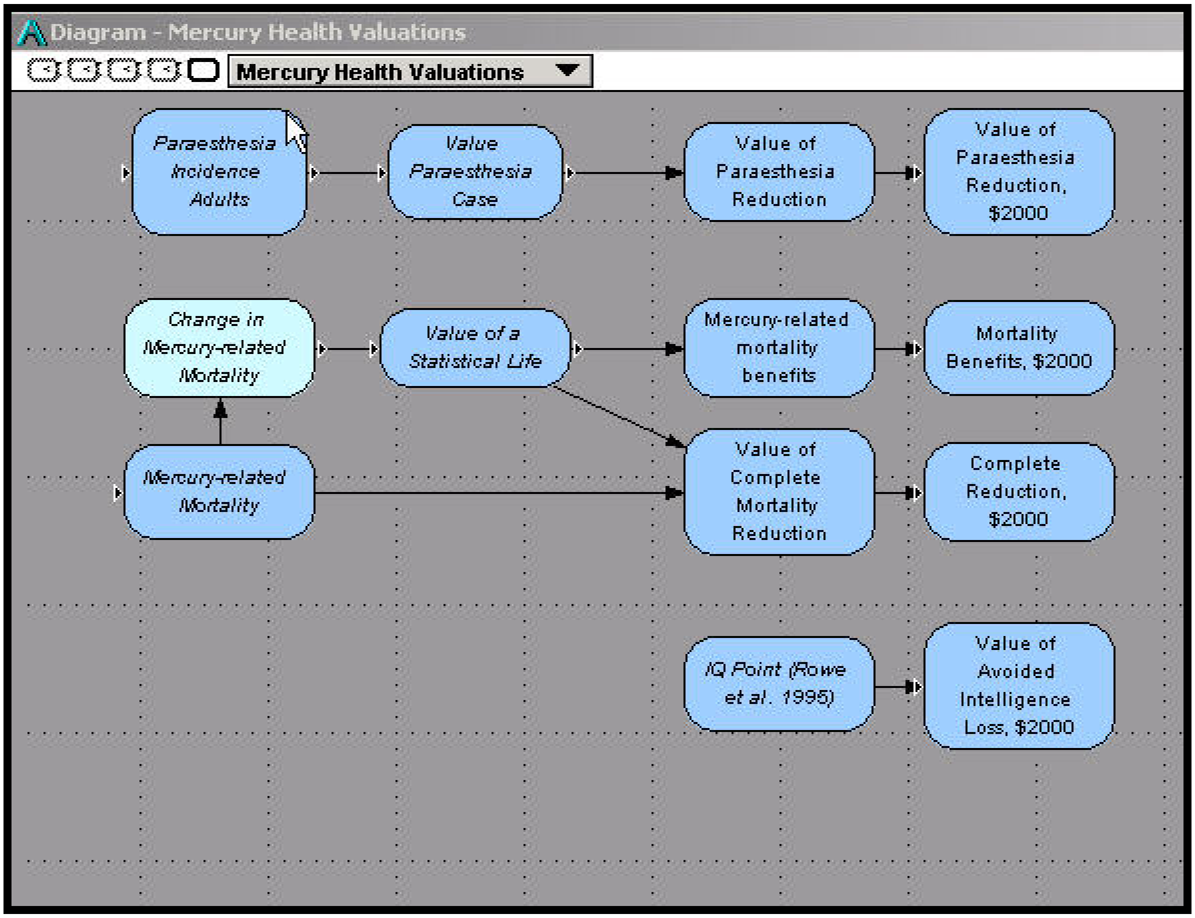


Figure A.11. Mercury Health Valuation Module