

# **A Review of Mercury in the Environment (Its Occurrence in Marine Fish)**



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**prepared by  
Charles J. Moore**

**South Carolina Department of Natural Resources**

**Marine Resources Division**

**Office of Environmental Management**

**P.O. Box 12559, Charleston, South Carolina 29422-2559**



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**Charles J. Moore**

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**OFFICE OF ENVIRONMENTAL MANAGEMENT**

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**SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES**

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## INTRODUCTION

A recent mercury advisory on consumption of king mackerel in South Carolina has resulted in numerous questions and concerns by the fishing public as well as the general public. To address these questions and concerns, the Department of Natural Resources (DNR) determined that a workshop for regional managers, biologists, the fishing public and the general public should be convened in early 2001. This document is a first step in planning that workshop. This paper is intended to collect facts and to objectively state the issues in terms that the layman can understand. Additionally, this report will serve as a guide for DNR and South Carolina Department of Health and Environmental Control (DHEC) in selecting the workshop's topics and speakers. Workshop proceedings including conclusions and recommendations will be published.

This report summarizes available information concerning the level and sources of mercury in the environment, particularly in marine fish; its transformation to methylmercury; its ability to bioaccumulate in the food chain; and its toxicity to man. A primary issue of concern addressed in this report is the adequacy and level of safety being provided to the American seafood consumer by federal and state agencies concerning mercury contamination in marine fish.

The Clean Water Act (Amendment 112(n)(1) B of 1990) required the United States Environmental Protection Agency (EPA) to conduct and report to Congress a study concerning: the rate and mass of mercury emissions from electrical utility steam generating units and other sources; the health and environmental effects of such emissions and the available technologies and the potential costs to control such emissions. This report, Mercury Study Report to Congress (EPA, 1997a), provides up-to-date information concerning mercury and emphasizes that "the typical U.S. consumer of fish is not in danger of consuming harmful levels of methylmercury and is not being advised to reduce fish consumption".

In March 1999, the U.S. Department of Health and Human Services, in accordance with guidelines

developed by the Agency for Toxic Substance and Disease Registry (ATSDR) and EPA, published an updated Toxicological Profile for Mercury (Risher and Woskin, 1999). This report increased the minimal risk level (MRL) of 0.1 microgram per kilogram of body weight per day (ug/kg/d) established in 1994 for ingestion of methylmercury to 0.3 ug/kg/d. This increase, however, did not result in a change in advice provided by the Food and Drug Administration (FDA) regarding consumption of commercially caught fish. An individual of average weight is still advised to consume no more than about 7 ounces of fish containing 1 ppm or 14 ounces of fish containing 0.5 ppm per week. The report states: "Commercial fish sold through interstate commerce that are found to have levels of methylmercury above an "action level" of 1 ppm (established by FDA) cannot be sold to the public".

A subsequent report, prepared by the Mercury Policy Project and cosponsored by the Sierra Club and Clean Water Action entitled "The One That Got Away" (Bender and Williams, 2000), concludes that the FDA seafood mercury monitoring program is severely inadequate; that some commercially sold fish are above the FDA action limit; the health of the American consumer, particularly women and children, is being threatened; and that the American people are not being made aware of the risks associated with methylmercury in seafood.

In July 2000, the National Research Council (National Academy of Sciences) published a report (NRC, 2000) endorsing EPA's MRL or reference dose (RfD) for MeHg of 0.1 ug/kg per day as a scientifically justifiable level for the protection of public health. Congress requested the study be conducted prior to the establishment of the new, more stringent levels for mercury emissions from coal-burning power plants. This report concludes that American children of women that consume large amounts of fish and seafood during pregnancy may be at special risk of brain and nerve damage resulting in neurological problems, including learning disabilities.

The key points presented in the following pages of this review are:

- 1) Methylmercury is a worldwide pollutant originating largely from the burning of fossil fuels,

- primarily in the generation of electrical power;
- 2) It is estimated that should all anthropogenic sources of mercury pollution be eliminated, it would require more than 50 years for methylmercury in fish to return to pre-industrial levels;
  - 3) Methylmercury is a potent neurotoxin that can cause birth defects, learning disabilities, blindness, paralysis, loss of muscular control and death;
  - 4) Methylmercury bioaccumulates through the food chain with the primary source of risk to human health being the consumption of fish (freshwater and marine);
  - 5) Methylmercury in many freshwater and marine fish has been documented at levels that exceed those generally agreed upon by federal agencies (EPA and FDA), state agencies and recently by the National Academy of Sciences (National Research Council) and methylmercury constitutes a health risk that should be limited or avoided by man;
  - 6) Pregnant women, women of child bearing age (15-44 years of age), and children aged 12 and under are of special concern. Eating ten grams (a quarter cup) of fish a day with an average mercury concentration of 0.1 to 0.15 ppm is up to twice the average EPA recommended reference dose; at a 1.0 ppm level the mercury intake range could be 6 to 12 times the exposure recommended by EPA;
  - 7) There is a general misconception that commercially harvested fish and seafood can not be sold (seafood markets, restaurants, etc.) in this country if it contains more than the FDA action limit of 1.0 ppm of mercury;
  - 8) South Atlantic states do not have a program to examine and document methylmercury contamination in marine fish and other wildlife such as exists in the San Francisco Bay region and the Gulf of Mexico,
  - 9) No effective national education campaign exists for focusing on a factual and realistic evalu-

ation of the dangers in consuming certain types of freshwater and marine fish and seafood, particularly in regards to that consumed by children under 12 years old and by women of child-bearing age.

## **SOURCES AND MOVEMENT OF MERCURY**

### **Mercury - What Is It?**

Mercury is a basic chemical element of which there is a fixed amount on earth. It is a heavy, silvery-white liquid that vaporizes quickly at ambient temperatures. It exists in three oxidation states: metallic, mercurous and mercuric. Most mercury occurring in the atmosphere is in the form of elemental vapor. Most mercury in water, soil, sediments or biota is in the form of inorganic salts or organic (methylmercury) forms (EPA, 1997a).

### **Uses of Mercury**

Mercury is utilized in the electrical industry (switches, thermostats, batteries etc.), dentistry (dental amalgams), numerous industrial processes including the production of chlorine and caustic soda, in nuclear reactors, as an anti-fungal agent for wood processing, a solvent for reactive and precious metal, and as a preservative of pharmaceutical products. Industrial demand for mercury peaked in 1964 and fell 74% between 1980 and 1993 and by another 75% between 1988 and 1996. This decline was largely a result of federal bans on mercury additives in paint and pesticides and the reduction of mercury in batteries (EPA, 1997a).

### **Sources of Mercury in the Environment**

Mercury emissions into the environment can be characterized by three sources. These are: the natural release and cycling of geologically bound mercury, anthropogenic releases, and, thirdly, the re-emission of mercury to the atmosphere from that deposited to earth's surface in the past by the other two sources. Recent EPA estimates place the annual amount of mercury released into the air by human activities at 50 to 75 percent of the yearly total (EPA, 1997a). Of approximately 200,000 tons of mercury emitted to the atmosphere since 1890, about 95 percent resides in terrestrial soils, about 3 percent in ocean surface waters and 2 percent in the atmosphere. The amount of

mercury in the atmosphere is estimated to have increased by 200 % to 500 % since the beginning of the industrial revolution (EPA, 1997a). Whereas mercury deposition rates have decreased in the vicinity of some localized sources in the western United States during the 1990s, measurements continue to increase in remote sites in northern Canada and Alaska indicating that the global atmospheric burden is continuing to increase (Monterio and Furness, 1997).

Between 1990 and 1996, atmospheric mercury levels have risen between 5.5% and 17% in the upper Midwest, depending on the season, with an average annual increase of 8% (Glass and Sorenson, 1999). Studies conducted in the Atlantic Ocean estimate a rise in mercury levels of 1.2 % – 1.5 % per year since 1970 (Mason et al. 1994). Recent studies indicate that mercury contamination in the marine environment is increasing at a rate of up to 4.8% a year (Monterio and Furness, 1997). Mercury concentrations in the feathers of seabirds breeding in the Azores, Madeira and Salvages islands, a tropical sector of the northeast Atlantic remote from mercury emissions due to human activity, were compared to preserved museum specimens dating back to 1886. Birds that typically feed on fish within the epipelagic layer (upper 100m of the ocean) showed an increase of an average of 1.1%-1.9%. Feathers from birds that fed primarily on fish from the mesopelagic zone (below the epipelagic layer) showed average increases of 3.5% to 4.8% per year (Monterio and Furness, 1997).

### **Anthropogenic Sources of Mercury in the United States**

Of the estimated 158 tons of mercury emitted annually into the atmosphere by human activities in the United States, approximately 87 percent is from combustion point sources, 10 percent from manufacturing, and 3 percent from all other sources (EPA, 1997a). Of this total, about one-third (52 tons) is deposited within the lower 48 states and two-thirds (107 tons) is transported outside of U.S. borders. An additional 35 tons is deposited within US borders from the global reservoir for a total annual mercury deposition of 87 tons. Four specific source categories (all high temperature waste combustion of fossil fuel processes) account for approximately 80 percent of total mercury emissions in the U.S.: coal-fired utility boilers (33 percent), municipal combustion (19 percent), commercial /industrial boilers (18 percent) and medical

waste incinerators (10 percent). When fully implemented, current EPA emission limits established during recent years will reduce mercury emission by waste combustion and medical waste incinerators by 90 percent over 1995 levels (EPA, 1997a).

**Electrical power plants built in the 1940s to 1970s are the largest industry source of mercury emitted into the environment.** In 1994, such plants emitted a total of 91,422 pounds of mercury (Stanfield and Lopez, 2000). The vast majority (95%) came from coal-burning plants, and most of that was from those plants built prior to 1977 (77%). These plants have been and continue to be unregulated in regard to mercury emissions. The Clean Air Act passed by Congress in 1970, and amended in 1977 and 1990, exempted such plants from new air pollution standards. In fact, until 2000, all electrical utilities emitting less than 25,000 pounds of mercury a year were exempt from reporting (Sandfield and Lopez, 2000). As this was 12 times the annual emission level of the highest emitting plant in the U.S., all plants were therefore exempt. This reporting threshold was changed for the 2000 reporting year (report not due until 2002) to require that facilities that release 10 or more pounds of mercury annually must now report their releases.

### **Reduction and Associated Costs of Anthropogenic Mercury**

Mercury emissions at 129 municipal waste combustion facilities could be reduced by 90% (26 tons) annually by material separation, product substitution, carbon filter beds, etc. at an estimated national annual cost between \$11 and 47 million (EPA, 1997a). Fifteen tons of mercury emissions could be eliminated (a 95% reduction) at approximately 2,400 medical waste incinerators at a cost of \$60 to 120 million. Seven tons of mercury could be eliminated at 14 chlor-alkali plants at a cost of \$65 million. It will require an estimated national annual cost of \$5 billion to remove 48 tons of mercury emissions per year (a 90% reduction) at 426 coal-fired utility facilities (EPA, 1997a).

### **Movement of Mercury in the Environment**

Mercury in the form of vapor and/or inorganic salts may be transported great distances over several months in the atmosphere prior to falling out or being deposited by precipitation. It may be emitted back into the atmosphere as a gas or associated with dust particles to be re-deposited elsewhere. Thus, mercury is dis-

tributed to even the most remote areas of the earth. Mercury in soils has a long retention time, possibly hundreds of years and may continue to be released into the air and surface waters for many years to come. An expert panel on mercury and atmospheric processes concluded that if all mercury releases were stopped today it could **take at least 50 years for the methylmercury levels in fish to return to pre-industrial levels** (Standfield and Lopez, 2000).

## THREATS TO WILDLIFE

### Movement of Mercury into the Food Chain

Plants and animals, including man, are exposed to mercury as it cycles between the air, water and land by direct contact and by ingesting mercury-contaminated food. Elemental and inorganic forms of mercury are poorly absorbed in the digestive tract of higher animals. Very large quantities of inorganic mercury would have to be swallowed to cause toxicity in man. Less than 0.01% of any inorganic mercury that passes through the digestive system is absorbed and even that is rather quickly eliminated (EPA, 1997a). However, inorganic forms of mercury are efficiently bio-transformed by bacteria and other chemical processes to methylated forms that are almost completely absorbed within the digestive system and move efficiently through the food chain from the smallest organisms to top predators, including man. Methylmercury is eliminated from living tissue very slowly. Several months to years are required to reduce only half the mercury contaminant level within living tissue. **Thus, nearly 100% of the mercury that bioaccumulates at various trophic levels of the food chain is methylmercury (EPA, 1997a).**

### Bioaccumulation

Mercury accumulates in living tissue when the rate of uptake exceeds the rate of elimination. Top aquatic predators such as freshwater largemouth bass, pike and walleye and marine fish such as king mackerel, sharks, and swordfish may contain concentrations of mercury 10,000 to 100,000 times greater than that found in the surrounding water (EPA, 1999). The bioaccumulation factor of methylmercury for all fish may be nearly 3 million and may approach more than 7 million for top predators. High levels of mercury contamination have been found in fish-eating birds such as the wood stork, loon, osprey and bald eagle, and mammals such as minks, otters, and the endan-

gered Florida panther (EPA, 1997a). Similarly, the primary source of mercury contamination in man is through eating fish.

### Toxic Impacts on Plants and Animals

Methylmercury concentrations in plant and animal tissue have been associated with sublethal effects and death (Risher and DeWoskin, 1999). Sublethal effects to plants include inhibition of growth, decreased chlorophyll, and leaf and root damage. Sublethal effects in animals include impaired growth and development, reduced reproductive success, liver and kidney damage and behavioral abnormalities. Laboratory studies have been utilized to assess the effects of methylmercury from fish to mink, otter and several avian species (EPA, 1997a). Effects can occur at a dose of 0.25 ug/g of body weight / per day with death occurring in some species at 0.1 to 0.5 ug/g body weight/ per day. Smaller animals, such as mink and monkeys are generally more susceptible to mercury poisoning than are larger animals, such as mule deer or harp seals (EPA, 1997a). Mercury is a known human toxicant (Mad Hatters Disease) with neurotoxic effects ranging from decreased motor skills, tremors, the inability to walk and convulsions to death (EPA, 1997a).

### Mercury Levels in Fish

When an organism contaminated with methylmercury is ingested by a predatory fish (bird, man etc.) it is quickly absorbed and circulated by the animal's circulatory system. Methylmercury readily attaches to protein sodium ions throughout the fish's musculature (Minnesota Department of Health, 2000). **Skinning and trimming fish does not significantly reduce the mercury concentration in fillets, nor is it removed in the cooking process.** In fact, as cooking removes moisture, mercury concentrations are higher in fish flesh after cooking (EPA, 1999).

### Mercury in Freshwater Fish

As part of the 1984-85 National Contaminant Biomonitoring Program, the U.S. Fish and Wildlife Service sampled freshwater fish for mercury contamination from 109 random stations nationwide. The maximum, geometric mean, and the 85<sup>th</sup> percentile concentrations for mercury were 0.37, 0.10 and 0.17 ppm (wet weight), respectively (Kidwell et al, 1995). In EPA's 1987 National Study of Chemical Residues in Fish, mercury was detected in fish at 92% of the



374 sites sampled (EPA, 1999). Maximum, arithmetic mean and median concentrations in fish tissue were 1.77, 0.26 and 0.17 ppm (wet weight). Freshwater sport fish (walleye, chain pickerel, largemouth and smallmouth bass) analyzed during the 1980s to 1996 in Canadian provinces consistently contained mean mercury concentrations greater than 0.5 ppm with individual fish exceeding 2.0 ppm. One largemouth bass was found to contain 8.94 ppm of mercury (EPA, 1999). In a separate study, largemouth bass in Florida measured as high as 4.4 ppm (Dukes, 98).

Most (68%) of all health advisories issued in the United States are the result of mercury contamination in freshwater fish (EPA, 1999). Mercury advisories in fish increased 115% from 1993 (899 advisories issued by 27 states) to 1998 (1,931 advisories issued by 40 states). Ten states have issued statewide advisories for mercury in their freshwater lakes and rivers. Eleven states have issued more than 90% of all mercury advisories: Minnesota (821), Wisconsin (402), Indiana (126), Florida (97), Georgia (80), Massachusetts (58), South Carolina (49) New Jersey (30), New Mexico (26), and Montana (22) (EPA, 1997a). The greater number of advisories concerning mercury in Minnesota and Wisconsin result from an active mercury sampling program of freshwater lake-fish in the 1970s and do not necessarily reflect greater levels of mercury contamination within their waterways.

### **Mercury in Marine Fish**

Between 1963 and 1970 the average annual commercial catch (domestic and international fleet) of north Atlantic swordfish was about 22 million pounds. In 1969, FDA, in response to mercury poisonings in Japan, set an administrative guideline of 0.5 ppm for mercury in fish and shellfish moving in interstate commerce. In December 1970, as a result of the publication that most swordfish contained mercury in excess of this limit, what had been a flourishing swordfish fishery went into a period of decline (Booz et al., 1979). From 1971 to 1978, some U.S. fishermen continued to fish for swordfish in spite of the threat that their catches would be confiscated by the FDA for sampling and testing, and that most fish would not pass the 0.5 ppm restriction (SAFMC, 1985). Landings data for this period were considered unreliable (SAMFC, 1985).

In 1978, FDA's mercury content control was chal-

lenged in court (U.S. District Court, North District of Florida - Anderson vs. FDA and FDA vs. Anderson). Based on more detailed analysis of seafood consumption patterns prepared by the National Marine Fisheries Service, the allowable mercury content level was raised to 1.0 ppm (SAFMC, 1985). From 1978 to 1982, as consumers' fear of mercury contamination waned and consumption increased, the annual swordfish catch increased to 26 million pounds in 1983 and to 37 million pounds in 1989 (NMFS, 1997).

FDA currently advises that pregnant women and women of childbearing age who may become pregnant limit their consumption of shark and swordfish to no more than one meal per month. FDA further advises that persons other than pregnant women and women of child bearing age in the general population limit their regular consumption of shark and swordfish (which typically contains methylmercury around 1.0 ppm) to about 7 ounces per week (about one serving) to stay below the acceptable daily intake for methylmercury.

According to EPA's Report to Congress (EPA, 1997a), "mercury levels in marine fish have been monitored for more than 20 years by the National Marine Fisheries Service (NMFS) and have remained relatively constant in various species." However, the only NMFS data concerning mercury in marine fish which could be located by this author was a survey of trace elements in the fishery resources in mid 1970s (Hall et al., 1978). This comprehensive survey, initiated in 1971, examined the occurrence of 15 trace elements (including mercury) in 204 species of finfish, mollusca and crustaceans from 198 coastal United States sites. Those species reported as having a mean mercury level of 0.4 to 0.5 ppm or greater are listed below (Table 1.) The only marine species of commercial importance not sampled by this survey was swordfish, which, according to the authors, was not sampled in this study for "policy reasons" (Ahmed, 1991). The midpoint of the mean range for mercury within swordfish tissue from FDA surveillance samples during the 1970s was 0.95 ppm (Ahmad, 1991).

FDA sampling data, obtained in a 1999 Freedom of Information request and reported by Bender and Williams (2000), indicates that 36% of the swordfish, 33% of the shark and nearly 4 % of large tuna sold commercially in the United States between 1992 and

Table 1. Species reported in 1978 by the National Marine Fisheries Service - Survey of Trace Elements in the Fishery Resource (Hall et al., 1978) as having a mean mercury level of 0.4 to 0.5 ppm or greater.

Species	# in Sample	Range of mean mercury content in muscle, ppm
Atlantic barracuda	7	2.0 – 3.0
Atlantic bonito	15	1.0 – 2.0
Gaftopsail catfish	34	0.5 – 0.6
Smooth dogfish shark	95	1.0 – 2.0
Black grouper	33	0.7 – 0.8
Bluestriped grunt	16	0.6 – 0.7
Scalloped hammerhead shark	12	2.0 – 3.0
Smooth hammerhead shark	10	2.0 – 3.0
Jack crevalle	49	0.6 – 0.7
Ladyfish	2	2.0 – 3.0
Shortfin mako shark	3	2.0 – 3.0
Blue marlin	33	4.0 – 5.0
Striped marlin	40	1.0 – 2.0
White marlin	52	0.7 – 0.8
Sand perch	1	0.6 – 0.7
Red pogy	22	0.5 – 0.6
Sailfish	43	0.5 – 0.6
Atlantic sharpnose shark	1	0.8 – 0.9
Blacktip shark	16	0.7 - 0.8
American lobster (leg meat)	2	0.5 - 0.6
American lobster (tail meat)	2	1.0 - 2.0

1998 exceeded the 1.0 ppm action level for methylmercury. Approximately three-quarters of the sharks and swordfish and one-third of the large tunas sampled exceeded 0.5 ppm mercury. According to Bender and Williams (2000), FDA posed “detention” alerts for these three species in 1996 and 1997 but discontinued sampling these species for mercury, taking no samples in 1998 or 1999, and is no longer conducting a domestic monitoring program for these fish. Canned tuna (39 cans) sampled in 1992 revealed nearly 20% contained 0.3 to 0.5 ppm and ten percent exceeded 0.5 ppm mercury. The last testing of canned tuna (13 cans) by FDA for mercury was done in 1995 with 15% percent containing 0.3 to 0.5 ppm. Canned tuna is the most commonly consumed fish in the United States, averaging 10 cans per person per year (Johnson, 1999).

EPA studies also detected mean concentrations of methylmercury in muscle tissue of nine species of Atlantic sharks of 0.88 ppm (EPA, 1999). Mercury concentrations in these samples ranged from 0.06 to

2.87 ppm. Bluefin tuna from the northwest Atlantic Ocean were found to contain mercury at a mean concentration of 3.41 ppm (EPA, 1999). In 1994, EPA issued a chemical hazard alert for bonito, halibut, Spanish mackerel, king mackerel, shark, marlin and bluefin tuna based on a federal action level of 1 ppm mercury in the edible flesh of food fish bound for market. In 1998, Florida advisories for mercury included gafftopsail catfish, jack crevalle, spotted seatrout, ladyfish, sharks, and west coast king mackerel (Dukes, 1998).

EPA funded a program in 1988 to develop and implement voluntary, incentive-based management strategies to protect, restore, and maintain the health and productivity of the Gulf of Mexico ecosystem. The program is a partnership of Florida, Alabama, Mississippi, Louisiana, and Texas and 18 different Federal agencies, as well as numerous public and private organizations. A program report, while not making an evaluation or drawing conclusions about mercury-as-

sociated human health risks, provides existing knowledge of the mercury concentrations present in fish and shellfish within the Gulf of Mexico (Gulf of Mexico Program Report, 1999). Utilizing 6,620 records representing samples from 121 species (federal and state mercury monitoring samples) collected on or after January 1, 1990, mercury concentrations were mapped and made available on the internet (<http://www.duxbury.battelle.org/gmp/newExecSum.htm>). The report concludes that mercury is common in edible tissues of estuarine/marine fish and shellfish harvested from the Gulf of Mexico. Approximately 77 percent of the 24 species/species groups (including three size classes of king mackerel) analyzed in the study had a Gulfwide mean mercury concentration between 0.2 and 1.0 ppm. Species reported as containing mercury levels greater than 0.4ppm Gulfwide are listed in Table 2. No species or species/group had a Gulfwide mean mercury concentration greater than 1.0 ppm.

Tissues from seven fish species from San Francisco Bay were analyzed for mercury in 1994 and 1997 (Davis, 1997). More than half of the fish showed concentrations above 0.23 ppm. An overall average level of mercury for the seven species examined was 0.3 ppm with the highest levels occurring in leopard sharks, which exceeded 1.0 ppm, and in individual striped bass samples (0.9 ppm). A positive correlation of increasing mercury concentrations with increasing fish length (age) was noted in several species. Based

on these studies, the California Office of Environmental Health and Hazard Assessment (1998) issued health advisories warning that: adults should eat no more than two eight-ounce meals per month of San Francisco Bay sport fish, including sturgeon and striped bass caught in the Delta; striped bass over 35 inches should not be eaten; and women who are pregnant or may become pregnant, nursing mothers and children under the age of six should not eat more than one meal of fish per month. No striped bass over 27 inches or any shark over 24 inches should be eaten.

### Mercury in King Mackerel

Health advisories concerning the consumption of large king mackerel (over 43 inches total length) taken from the Gulf of Mexico were issued by all Gulf states during 1997-98 (Dukes, 1998). In response to the detection of high levels of mercury in Gulf Coast king mackerel, North Carolina sampled the mercury content of king and Spanish mackerels in November 1998 (Hale, 1999). The 22 Spanish mackerel samples ranged from 0.06 to 0.84 ppm mercury and the 30 king mackerel fillets ranged from 0.36 to 3.0 ppm. **In 1999, king mackerel examined by Florida, Georgia, South Carolina and North Carolina were found to contain mercury levels as high as 3.5 ppm and health advisories were issued by each state (DHEC, South Carolina, 2000).**

The 1999 king mackerel fillets were collected and independently analyzed for mercury concentration by

Table 2. Species and species groups reported as having Gulfwide mean mercury levels of 0.4 or greater in edible fish tissue collected since 1990 (Gulf of Mexico Program Report, 1999).

Species	Number of Samples	Mean of mercury in edible tissue (ppm)	Maximum site value (ppm)
Blacktip shark	73	0.86	2.0
Bonnethead shark	76	0.51	1.4
Groupers ( <i>Mycteroperca</i> )	64	0.43	1.4
Jack crevalle	68	0.63	3.1
Sand seatrout	93	0.57	0.9
Largemouth bass	723	0.46	1.6
King mackerel (>39")	58	0.96	1.7
King mackerel (33-39")	89	0.69	1.1
King mackerel (<39")	77	0.60	1.7
Spanish mackerel	179	0.57	1.7
Common snook	190	0.50	1.5

North Carolina (112 fish), South Carolina (28 fish), Georgia (20 fish) and Florida (21 fish). Mercury levels were similar in each state's samples and were correlated with fish length (Figure 1). Health advisories were jointly issued by each state and were based on fish length:

- 1) No consumption limits were placed on king mackerel less than 33 inches (fork length);
- 2) Individuals should eat no more than four 8-ounce servings of king mackerel from fish between 33 and 39 inches (fork length) per month;
- 3) Children (up to 12 years of age) and women of child bearing age should consume no more than one 8-ounce serving per month from fish between 33 and 39 inches;
- 4) King mackerel more than 39 inches in fork length should not be eaten.

To determine the possible consequences of mercury levels in large king mackerel exceeding the 1.0 ppm FDA action level, fisheries representatives contacted FDA for guidance as to their possible future

actions to restrict the distribution and /or sale of such fish (Gregory M. Cramer, Center for Food Safety and Applied Nutrition, FDA, pers. comm. 2000). Information provided to FDA indicated that king mackerel landed commercially average 27-34 inches, only 10 to 15% fish exceed 39 inches and overall mercury level of commercially landed fish of around 0.6ppm. States were advised that FDA's policy for MeHg focused on time weighted exposures rather than on exposures from an individual meal or individual fish. FDA concluded that the information provided showed that there is only a 10 to 15 percent chance that commercially harvested king mackerel will have MeHg levels exceeding 1 ppm and that the average contamination level is 0.6 ppm. Since FDA's 1 ppm limit focuses on a lot average and there is little likelihood of exceeding that limit, FDA would not prohibit the sale of king mackerel over 39 inches.

The mean mercury level by size category for the 181 king mackerel sampled by all four states is given in Table 3. The length frequency of king mackerel caught commercially between 1995 and 1999 in South Carolina is provided in Figure 2. The length frequency of king mackerel taken recreationally from North Carolina, South Carolina, Georgia and Florida based upon

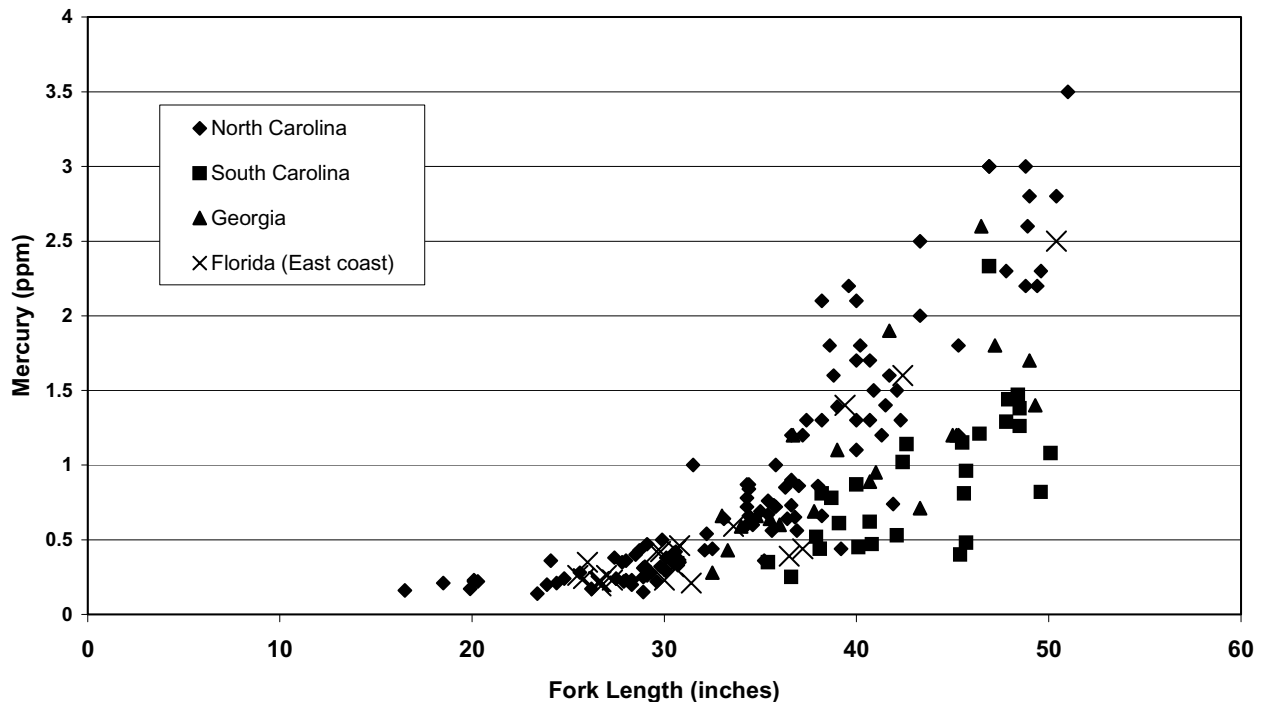


Figure 1. Mercury concentrations in the edible tissue of king mackerel collected in North Carolina, South Carolina, Georgia and Florida (East Coast).

the NMFS Marine Recreational Fishing Survey (1999) is presented in Figure 3.

## THREATS TO HUMANS

### Methylmercury Poisoning

Two major cases of methylmercury poisoning through fish consumption have been documented, both in Japan (EPA, 1997a). The first occurred in Minamata, Kyushu, Japan during the late 1950s and 1960s. Methylmercury in waste sludge from a chemical factory that used mercury as a catalyst drained into Minamata

Bay. Mercury concentrations in fish, which were a primary diet item of local residents, were between 10 and 30 ppm wet weight. Thousands of individuals complained of symptoms, now known as Minamata disease, including impairment of: peripheral vision, speech, hearing, and walking; a feeling of “pins and needles” in the hands and feet; uncoordination of movements as in writing; and mental disturbances. Many people (adults and children) died. It was recognized that nervous system damage could occur to the fetus if the mother ate fish contaminated with high concentrations of methylmercury during pregnancy.

Table 3. The mean methylmercury level in 181 king mackerel sampled in 1999 by North Carolina, South Carolina, Georgia and Florida, by size category:

Size Category (Fork length)	(Number of fish)	Average MeHg	Range
< 27 inches (legal size limit)	19	0.22 ppm	0.14 – 0.36 ppm
27 to 32 inches	43	0.34 ppm	0.15 – 1.00 ppm
33 to 39 inches	53	0.80 ppm	0.25 – 2.10 ppm
> 39 inches	66	1.54 ppm	0.40 – 3.50 ppm

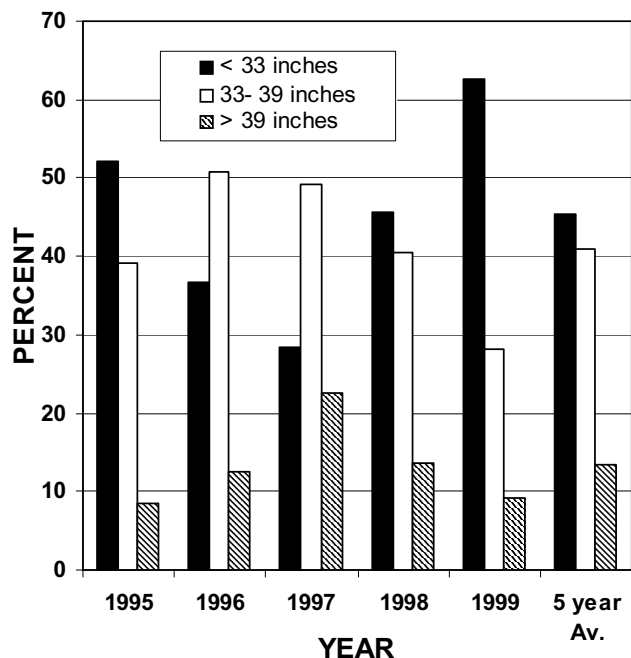


Figure 2. Length frequency of king mackerel caught commercially in South Carolina (SCDNR Marine Resources Statistics Program Annual Reports 1995-1999).

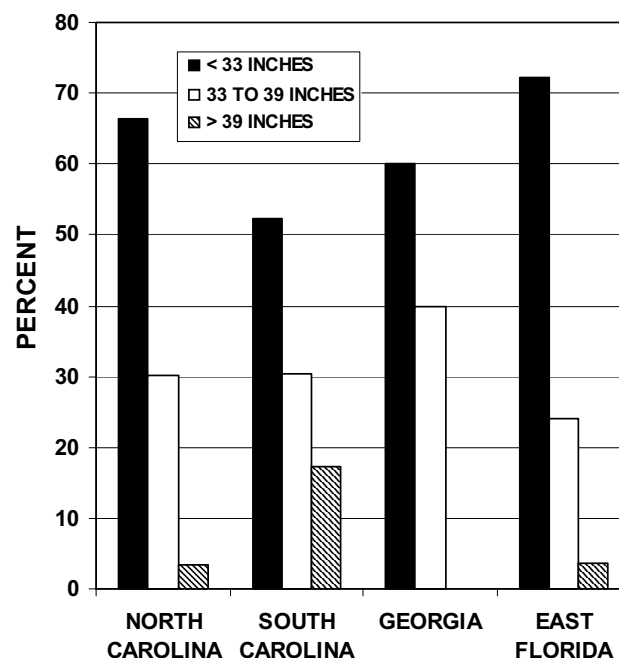


Figure 3. King mackerel length frequency distributions (NMFS Marine Recreational Fisheries Survey, 1999).

In 1965, a second methylmercury-poisoning outbreak was traced to a chemical factory releasing methylmercury into the Agano River in Japan (EPA, 1997a).

Two additional poisoning incidents have been documented from the consumption of seed grain treated with a fungicide containing methylmercury. Severe human poisoning occurred in Iran in 1960, and again in Iraq in 1970, which was estimated to have hospitalized approximately 6,500 people with 459 fatalities reported (EPA, 1997a).

### **Characterization of Risk to Human Populations**

The characterization of risk to U.S. human populations focuses on exposure to methylmercury over time. Ingestion of fish tissue is the dominant exposure pathway. The critical elements in estimating the risk of methylmercury exposure from fish are: the species of fish consumed, the concentration of methylmercury in the fish, the quantity and frequency of consumption, and the sex and age of the individual eating the fish (EPA, 1997a). There has been a 25 % increase in fish consumption in the United States since 1980 (Bender and Williams, 2000). On average, Americans eat about 19 pounds of fish each year and approximately 15 pounds (75%) is marine (Bender and Williams, 2000).

### **MeHg Reference Dose**

A reference dose (RfD) is defined as an estimate of a daily exposure to the human population (including sensitive subpopulations) that is likely to be without an appreciable risk of deleterious effects during a lifetime (Risher and DeWoskin, 1999). The RfD for methylmercury has been determined by EPA to be 0.0001 mg per kg of body weight per day, meaning a person could consume 0.1 microgram (ug) methylmercury for every kg of his/her body weight every day for a lifetime without anticipation of risk of adverse effect. A recent study mandated by the U.S. Congress, including an evaluation of three large epidemiological studies in the Seychelles Islands, Faroe Islands and New Zealand by the National Academy of Sciences, endorsed EPA's RfD for MeHg and found it to be scientifically justifiable for the protection of public health (NCR, 2000).

### **General Population**

The FDA advises the general population to limit their consumption of fish species which have methylmercury levels around 1.0 ppm to about 7 ounces or about one serving per week (Risher and DeWoskin, 1999). Fish consumed with levels averaging around 0.5 ppm should be limited to 14 ounces per week or two servings. The most recent U.S. Department of Health and Human Services toxicological profile for mercury (Risher and DeWoskin, 1999) states the following:

“The Food and Drug Administration (FDA) estimates that most people are exposed on average to about 50 ng of mercury per kilogram of body weight per day (50 ng/kg/day) in the food they eat. This is about 3.5 micrograms (ug) of mercury per day for an adult of average weight. This level is not thought to result in any harmful effects. A large part of this mercury is in the form of methylmercury and probably comes from eating fish. Commercial fish sold through interstate commerce that are found to have levels of methylmercury above an “action level” of 1 ppm (established by the FDA) cannot be sold to the public. This level itself is below a level associated with adverse effects. However, if you fish in contaminated waters and eat the fish you catch, you may be exposed to higher levels of mercury. Public health advisories are issued by state and federal authorities for local waters that are thought to be contaminated with mercury. These advisories can help noncommercial (sport and subsistence) fishermen and their families avoid eating fish contaminated with mercury.”

EPA recommendations are based on an integrated risk information system. EPA recommends that an individual of average weight (158 pounds) in order to not surpass an RfD of 0.0001 mg/kg of body weight / day not to consume more than: one meal (8 oz. portion) of fish containing more than 0.5 ppm MeHg per month; or one meal every other month of fish containing 1.0 ppm or more. Fish contaminated with more than 1.9 ppm MeHg should never be eaten (Table 4).

Table 4. EPA recommended monthly fish consumption limits (number of 8 ounce portions) of fish containing various levels of MeHg for an individual weighting 72kg(158 pounds) in order to not exceed the recommended RfD of 0.0001mg/kg of body weight/d (EPA, 1999).

Concentration in fish tissue MeHg (ppm)	Fish meals/month (8 ounce portions)
>0.03 - 0.06	16
>0.06 - 0.08	12
>0.08 - 0.12	8
>0.12 - 0.24	4
>0.24 - 0.32	3
>0.32 - 0.48	2
>0.48 - 0.97	1
>0.97 - 1.9	0.5
>1.9	NONE

### Subpopulations of Concern

**Pregnant women, women of child bearing age (15-44 years of age), and children aged 14 and under are of special concern.** EPA advises that anyone in this group who is eating ten grams (a quarter cup) of fish a day with an average mercury concentration of 0.1 to 0.15 ppm is at or up to twice the average EPA recommended RfD for mercury. Should the fish have a mercury concentration of 0.5 ppm, it may expose them to three to six times the interim RfD and at a 1.0 ppm level the mercury intake range could be at 6 to 12 times the recommended exposure (EPA, 1997a). Bender and Williams (2000) point out that EPA’s Mercury Study to Congress (EPA, 1997b) estimates that 7 million women and children are at risk of mercury poisoning due to consumption of fish. Because swordfish, sharks and other large predatory fish may contain methylmercury levels which exceed the FDA 1.0 ppm limit, that agency’s advice to consumers warns pregnant women and those of child bearing age to limit their consumption of such fish to no more that one meal a month (FDA, 1995). Four states (Vermont, Minnesota, Michigan and New Jersey) recommend that expectant mothers and children not eat swordfish or shark and limit consumption of canned tuna to 7 ounces per week. Seven states (Texas, Alabama, Mississippi, Florida, Georgia, South Carolina, and North Carolina) recommend that the public, and especially women and children, should limit consumption or not eat larger king mackerel because of their high mercury content.

### Jurisdiction and Action Limits

The United States Food and Drug Administration (FDA) has jurisdiction of fish sold in commerce and has set an action level of 1.0 mg/kg body weight (ppm) (Federal Register 44:3990, January 19,1979). EPA reports the concentration of methylmercury in the ten most commercially important marine species (tuna, shrimp, pollack, salmon, cod, catfish, clam, flounder, crab, and scallop), on the average, to be close to ten times lower than the action limit. FDA originally set an administrative guideline of 0.5 ppm for mercury in 1969 for both fish and shellfish in interstate commerce. This was converted to an action level in 1974, increased to 1.0 ppm in 1979 and converted from a mercury standard to one based on methylmercury in 1984 (EPA, 1997a).

FDA public information concerning Action Limits indicates:

- 1) “Action levels and tolerances represent limits at or above which FDA will take legal action to remove products from the market. The blending of a food or feed containing a substance in excess of an action level or tolerance with another food or feed is not permitted.” (FDA, 1998)
- 2) “FDA works with state regulators when commercial fish, caught and sold locally, are found to contain methyl mercury levels exceeding 1 ppm. The agency also checks imported fish at ports and refuses entry if methylmercury levels exceed the FDA limits.” (FDA, 1995)

According to Bender\* and Williams \*\* (2000), FDA is using guidance developed in the 1970s for protecting the public from mercury levels in seafood and the 1.0 ppm action level for mercury, established in 1979, is not legally enforceable and only serves as discretionary guidance to FDA and states. Public awareness of mercury exposure is significantly lacking. **Guidelines, programs and practices established by FDA are seldom implemented and provide the American public with a false sense of safety about the consumption of mercury contaminated seafood (Bender and Williams, 2000).** Whereas, 75% of the public responding to a recent survey in the Northeast indicated that they eat fish on a regular basis, only about one-half were aware of FDA or state advisories and only one-third knew their meaning (NESCAUM, 1999).

FDA and EPA state that each state has the primary responsibility for protecting its residents from the health risks of consuming contaminated, non-commercially caught fish. They do this by issuing recommendations to the public to either limit or avoid consumption of certain fish from specific waterways, or in some cases, from all state waters (EPA 1997a). However it is also acknowledged “that not all anglers heed such advice”.

Southeastern states (North Carolina, South Carolina, Georgia, and Florida) each utilize different approaches for developing fish advisories for mercury in state waters (Manning, 2000). Florida bases its recommendations on 1976 toxicity criteria for mercury reported by the World Health Organization. The general public should not consume more than one meal a week of fish containing approximately 0.5 ppm mercury. More sensitive individuals (women of child bearing age and children 12 years old and younger) should not consume more than one meal of such fish a month. Fish containing up to 1.5 ppm should not be eaten more than once a month and fish with greater amounts

of mercury should not be consumed. South Carolina and Georgia set similar consumption guidance levels for fish containing mercury – fish containing 0.23 – 0.25 to 0.6 – 0.7 ppm should be limited to one meal per week, fish with 0.6 – 0.7 to 2.3 – 3.0 ppm should not be consumed more than once a month and fish with 2.0 to 3.0 ppm should never be consumed. North Carolina has utilized a level of 1 ppm for issuing fish consumption advisories in the past but is currently recommending a mercury toxicity criteria of 0.2 ug/kg/day for sensitive populations and 0.5 ug/kg body weight /day for non-sensitive populations (Manning, 2000).

## SUMMARY

The National Academy of Science’s National Research Council (NRC) report (2000) concerning the toxicological effects of methylmercury (MeHg) recently endorsed EPA studies concerning its toxicological effects. The report states, “On the basis of its evaluation, the committee’s consensus is that the value of EPA’s current RfD for MeHg, 0.1 ug/kg (body weight) per day, is a scientifically justifiable level for the protection of public health”. The Committee found that high-dose MeHg exposure effects included mental retardation, cerebral palsy, deafness, blindness and dysarthria. Low-dose prenatal exposure to MeHg from maternal consumption of fish has been associated with poor performance on neurobehavioral tests, particularly on tests of attention, fine motor function, language, visual-spatial abilities and verbal memory. They also found evidence in humans and animals that MeHg levels even lower than those associated with neurodevelopmental effects can have adverse effects on the developing and adult cardiovascular system (blood pressure regulation, heart-rate variability, and heart disease).

The NRC report (2000) confirms that public health concerns expressed by both federal and state agen-

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\* Michael Bender is executive director of the Mercury Policy Project (Montpelier, Vt.). He has a BA degree from State University of New York and a MS degree in Resource Management and Administration from Antioch New England, New Hampshire. He has 10 years experience in the municipal hazardous waste management field and currently represents the Abenaki, a Native American tribe, on the Vermont Advisory Committee on mercury pollution.

\*\*Jane Williams is the executive director of California Communities Against Toxics. She has a degree in economics from the University of California and serves on the board of the California Environmental Research Group, the Clean Air Network, the Mercury Policy Project, and the Nonstockpile Chemical Weapons Forum.



cies during the past forty years about the level of MeHg in fish and seafood are real and justified. More stringent requirements of mercury emissions from coal-burning power plant are needed. An obvious need for additional sampling exists for long term monitoring of MeHg in freshwater and marine fish as well as other types of seafood at both a state and federal level.

From a public health standpoint, the greatest need is to provide the American public with an effective education campaign focusing on a factual and realistic evaluation of the dangers in consuming certain types of freshwater and marine fish and seafood. This is particularly true in regards to fish and seafood consumed by children under 12 years old and by women of childbearing age. Federal and state mercury advisories that have been issued are poorly reported, generally ignored by the public and fail to adequately warn of the combined effects of consuming various types of meals containing mercury contamination. State mercury advisories (including South Carolina's) are primarily based on river systems and the number of meals that should not be exceeded for various types of fish. Few, if any, advisories indicate that if an individual eats a meal of contaminated fish or other food containing methylmercury, such as a tuna-fish sandwich, that all other foods which may also contain methylmercury should be avoided.

There is a general misconception that commercially sold (seafood markets, restaurants etc.) fish and seafood can not be sold in this country if it contains more than the FDA action limit of 1.0 ppm of MeHg. FDA's lack of sampling methylmercury content in marine fish and seafood as well as the policy of focusing on time weighted exposures rather than on exposures from an individual meal or fish makes it impossible for an individual to determine his level of exposure. All state and federal advisories recommend that more sensitive sub-populations not consume a single meal containing MeHg concentrations greater than 2.0 ppm.

Federal and state agencies in the Southeastern United States need to combine efforts and resources to develop a program similar to those being carried out by the California Regional Water Quality Control Board in the San Francisco Bay Region and by the Gulf of Mexico Program in the Gulf to examine and document environmental issues such as MeHg con-

tamination in estuarine and marine fish as well as other seafood.

Program efforts are needed to:

- 1) establish an effective public education program particularly aimed at parents of young children and women of childbearing age as to the occurrence of mercury in fish and seafood and safe consumption levels;
- 2) identify primary species (size classes or sub-populations) that, based on feeding habits and life expectancy, should be analyzed and monitored for MeHg;
- 3) determine the level of MeHg contamination in water, sediments, fish and other aquatic organisms in the regions fresh and marine waterways;
- 4) and establish a long-term regional MeHg monitoring program.

## LITERATURE CITED

- Ahmed, F.E. (editor). 1991. Seafood Safety committee on evaluation of the safety of fishery products. National Academy Press, Washington, DC.
- Bender, M. and J. Williams. 2000. The one that got away: FDA fails to protect the public from high mercury levels in seafood. Mercury Policy Project Report 19p.
- Booz, Allen and Hamilton Inc. 1979. Description of the swordfish fishery. For: South Atlantic Fishery Management Council. Charleston, S.C.
- California Office of Environmental Health and Hazard Assessment. 1998. Interim Fish Consumption Health Advisory.
- Cramer, Gregory M. 2000. Guidance (FDA) to the State of North Carolina re: the sale of king mackerel with > 1ppm MeHg. Center for Food Safety and Applied Nutrition, FDA, email dated March 30, 2000).
- Davis, J.A. 1997. Contaminant concentrations in fish from San Francisco Bay. Richmond, California, San Francisco Estuarine Institute. 99p.
- DHEC (South Carolina Department of Health and Environmental Control). 2000. King Mackerel advisory issued. Press Release March 23, 2000 Columbia, SC. 2p.
- Dukes, C. 1998. Heavy metal blunder. Texas Fish and Game Magazine. March 1998 2p.
- EPA (U.S. Environmental Protection Agency). 1997. A Mercury Study Report to Congress, Washington DC Volume 1: Executive summary.
- EPA (U.S. Environmental Protection Agency). 1997b. Mercury Study Report to Congress, Washington DC Vol. IV: An assessment of exposure to mercury in the United States.
- EPA (U.S. Environmental Protection Agency). 1999. Fact Sheet - Mercury Update: Impact on fish advisories. 13p.
- FDA (U.S. Food and Drug Administration). 1998. Action levels for poisonous or deleterious substances in human food and animal feed. Industry Activities Staff Booklet, March 1998.
- FDA (U.S. Food and Drug Administration). 1995. Mercury in fish. Cause for concern?. In U.S. Consumer, Revised May 1995.
- Glass, G. and J. Sorenson. 1999. Six year trend ( 1990-1996) of wet mercury deposition in the upper Midwest, USA. Jour. Environ. Sci. Techn. September 1999.
- Gulf of Mexico Program. 1999. The Occurrence of Mercury in the Fishery Resources of the Gulf of Mexico. Executive Summary. <http://www.duxbury.battelle.org/gmp/new/ExecSum.htm>
- Hale, T.F. 1999 . Results of tissue mercury analysis for period 1 mackerel samples. State of North Carolina Department of Environment and Natural Resources: Inhouse Report 7p.
- Hall, R.A., E.G. Zook and G. M. Meaburn. 1978. National Marine Fisheries Service survey of trace elements in the fishery resource. NOAA Tech. Rep. NMFS SSRF-721.
- Johnson, H.M. 1999. Annual report on the U.S. seafood industry, 7<sup>th</sup> ed. Bellevue (WA): H. M. Johnson & Associates; 1999.
- Kidwell, J.M., L.J. Phillips, and G.F. Birchard. 1995. Comparative analyses of contaminate levels in bottom feeding and predatory fish using the National Contaminant Biomonitoring Program Data. Bulletin Environmental Contamination and Toxicology. 54:919-923.
- Mason, R., W. Fitzgerald and F. Morgan 1994 Gecehemico Cosmochinm Acta. 58(15):3191-3194.
- Manning, R.O. 2000. Briefing for the South Atlantic Fishery Management council – Mercury assessment in king mackerel and resulting consumption advisory. Environmental Protection Division, Georgia DNR, 11p.

- Minnesota Department of Health. 2000. Mercury in the Environment. Fish Facts.
- Monteiro, L.R. and R.W. Furness. 1997. Accelerated increase in mercury contamination in North Atlantic mesopelagic food chains as indicated by time series of seabird feathers. *Journal of Environmental Toxicology and Chemistry* 16 (12): 2489-2493.
- NESCAUM ( Northeast States for Coordinated Air Use Management.) 1999 Preliminary findings from the northeast fish consumption and mercury awareness survey. May 1999.
- NRC (National Research Council -Academy of Natural Sciences and Engineering ). 2000. Toxicological effects of methylmercury (Executive Summary) National Academy Press 9p.
- NMFS (National Marine Fisheries Service). 1997. Draft Amendment 1 to the Fishery Management Plan for Atlantic Swordfish including an environmental assessment and regulatory impact review. Highly Migratory Species Division (NMFS), NOAA. January 28, 1997. 107p.
- NMFS (National Marine Fisheries Service). 1999. Marine Recreational Fishery Survey. N.O.A.A. (NMFS) Washington, DC. *Cur. Fish. Stat.*
- Risher, J.R. and R. DeWoskin. 1999. Toxicological profile for mercury (update). U.S. Dept. Health & Human Services. 617p.
- South Atlantic Fishery Management Council (SAFMC). 1985. Fishery Management Plan, Regulatory Impact Review, Initial Regulatory Flexibility Analysis and Final Environmental Impact Statement for Atlantic Swordfish. Southpark Circle, Suite 306, Charleston, South Carolina, February, 1985.
- South Carolina Department of Natural Resources (Marine Resources Division –Office of Fisheries Management) Commercial Fisheries Statistics Program. 1995-1999. Annual reports.
- Stanfield, R. and C. Lopez. 2000. Lethal legacy - the dirty truth about the Nation's most polluting power plants. U.S. Public Interest Research Group (U.S. PIRG), the National Campaign Against Dirty Power 42p.