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## Seafood consumption and blood mercury concentrations in adults aged 20 y, 2007–2010

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### Abstract

**Background:** Seafood is part of a healthy diet, but seafood can also contain methyl mercury—a neurotoxin.

**Objective:** The objective was to describe seafood consumption in US adults and to explore the relation between seafood consumption and blood mercury.

**Design:** Seafood consumption, obtained from a food-frequency questionnaire, and blood mercury data were available for 10,673 adults who participated in the 2007–2010 NHANES—a cross-sectional nationally representative sample of the US population. Seafood consumption was categorized by type (fish or shellfish) and by frequency of consumption (0, 1–2, 3–4, or 5 times/mo). Linear trends in geometric mean blood mercury concentrations by frequency of seafood consumption were tested. Logistic regression analyses examined the odds of blood mercury concentrations  $\geq 5.8 \mu\text{g/L}$  (as identified by the National Research Council) based on frequency of the specific type of seafood consumed (included in the model as continuous variables) adjusted for sex, age, and race/Hispanic origin.

**Results:** In 2007–2010,  $83.0\% \pm 0.7\%$  ( $\pm\text{SE}$ ) of adults consumed seafood in the preceding month. In adults consuming seafood, the blood mercury concentration increased as the frequency of seafood consumption increased ( $P < 0.001$ ). In 2007–2010,  $4.6\% \pm 0.39\%$  of adults had blood mercury concentrations  $\geq 5.8 \mu\text{g/L}$ . Results of the logistic regression on blood mercury concentrations  $\geq 5.8 \mu\text{g/L}$  showed no association with shrimp ( $P = 0.21$ ) or crab ( $P = 0.48$ ) consumption and a highly significant positive association with consumption of high-mercury fish (adjusted OR per unit monthly consumption: 4.58; 95% CI: 2.44, 8.62;  $P < 0.001$ ), tuna (adjusted

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The findings and conclusions in this report are those of the authors and not necessarily those of the Centers for Disease Control and Prevention.

OR: 1.14; 95% CI: 1.10, 1.17;  $P < 0.001$ ), salmon (adjusted OR: 1.14; 95% CI: 1.09, 1.20;  $P < 0.001$ ), and other seafood (adjusted OR: 1.12; 95% CI: 1.08, 1.15;  $P < 0.001$ ).

**Conclusion:** Most US adults consume seafood, and the blood mercury concentration is associated with the consumption of tuna, salmon, high-mercury fish, and other seafood.

## INTRODUCTION

The *Dietary Guidelines for Americans* (DGA)<sup>5</sup> 2010 and the FAO and WHO highlight the benefits of consuming seafood (1, 2). Seafood is a good source of protein and omega-3 (n-3) fatty acids (1, 2). Seafood includes both fish and shellfish. Seafood, however, can contain methyl mercury, a neurotoxin, and certain species of fish have higher concentrations of methyl mercury (1); consequently, the DGA 2010 recommends that pregnant and breastfeeding women limit their consumption of certain fish (1). Mercury, however, also may be linked to cardiovascular disease and specifically to an increased risk of myocardial infarction (3, 4) in adults, although studies have been inconsistent, especially with respect to hypertension (5–8). Because developing fetuses are most sensitive to the neurodevelopmental effects of mercury (9–11), many studies have analyzed the association between fish consumption and blood mercury concentrations in children and women of childbearing age (12–19). The relation between seafood consumption and blood mercury has rarely been analyzed in all US adults. The purpose of this study was to describe the consumption of seafood among US adults aged  $\geq 20$  y and to explore the relation between seafood consumption and blood mercury concentrations by using the most recent nationally representative data.

## SUBJECTS AND METHODS

### Sample design

NHANES 2007–2010 is a nationally representative survey conducted by the CDC's National Center for Health Statistics to assess the health and nutritional status of the civilian, non-institutionalized US population. The sample is selected based on a complex, multistage design with oversampling of certain groups. Beginning in 1999, public-use data files have been released every 2 y. This study is based on data from 2007 to 2010. In 2007–2010, non-Hispanic blacks, Hispanics, and persons aged  $\geq 60$  y were oversampled. The National Center for Health Statistics Research Ethics Review Board approved NHANES, and written informed consent was obtained from all participants.

The survey combines information from an in-home interview and a standardized physical examination at a mobile examination center (MEC). During the in-home interview, race and Hispanic origin were self-reported with open-ended questions, including the option of reporting multiple races. During the MEC examination, participants were eligible for a blood draw and were asked about their fish and shellfish consumption in the past 30 d (20, 21). The unweighted NHANES examination response rate for ages  $\geq 20$  y was 71.0% in 2007–2008 and 72.2% in 2009–2010 (22).

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<sup>5</sup>Abbreviations used: DGA, *Dietary Guidelines for Americans*; EPA, Environmental Protection Agency; MEC, mobile examination center.

## Blood mercury measurements

Blood specimens were collected at the MEC and sent to the Division of Laboratory Sciences, National Center for Environmental Health, CDC for analysis. Specimens were analyzed by using inductively coupled plasma mass spectrometry for total mercury concentration with a limit of detection of 0.33 mg/L. Total mercury measurements were validated by using the National Institute of Standards and Technology Standard Reference Material 966 as a bench quality-control material and 3 levels of in-house blood pools traceable to the Standard Reference Material for daily quality control. Detailed information about the blood specimens and processing are available (23).

## Seafood consumption

During the MEC examination, NHANES participants completed a limited food-frequency questionnaire focusing on fish and shellfish consumption during the previous 30 d. No information on portion size was collected in this food-frequency questionnaire. Participants were given a list of fish/shellfish and asked, "During the past thirty days, did you eat any types of fish (shellfish) listed on this card? Include any foods that had fish (shellfish) in them such as sandwiches, soups or salads." The fish list included breaded fish, tuna, bass, catfish, cod, flatfish, haddock, mackerel, perch, pike, pollock, porgy, salmon, sardines, sea bass, shark, swordfish, trout, walleye, other fish, and other unknown fish. The shellfish list included clams, crabs, crayfish, lobsters, mussels, oysters, scallops, shrimp, other shellfish, and other unknown shellfish.

The types of seafood consumed during the previous 30 d were categorized as shellfish and fish. Frequency of seafood consumption was categorized as 1–2, 3–4, or 5 times/mo. This was based on categorization observed in the literature (14, 17) and the frequency of distribution in this population.

Seafood was further categorized into 6 specific types. Seafood species that were consumed by >10% of the population (shrimp, tuna, salmon, and crabs) were grouped separately, and a category for high-mercury fish, consisting of shark and swordfish (as defined by the DGA 2010) (1), was also created. All other seafood were included in the final category (breaded fish, bass, catfish, cod, flatfish, haddock, mackerel, perch, pike, pollock, porgy, sardines, sea bass, trout, walleye, other fish, other unknown fish, clams, crayfish, lobsters, mussels, oysters, scallops, other shellfish, and other unknown shellfish).

## Covariates

Sex, age, race/Hispanic origin, and education were included in the analysis because differences in blood mercury have been seen by these covariates (11, 12, 17, 24, 25). Age was categorized into 3 groups (20–39, 40–59, or 60 y), which were chosen to be consistent with the NHANES sample design. Race and Hispanic origin were defined as non-Hispanic white, non-Hispanic black, and Hispanic (which includes Mexican American and other Hispanic persons). All other persons were classified as "other." Education was used as a surrogate for socioeconomic status. Education was categorized as less than a high school education, a high school education, and more than a high school education.

## Statistical methods

The percentage of adults consuming seafood by sex, type of seafood (including the specific types if consumed by 5% of adults), and frequency of consumption was presented. Geometric mean blood mercury was presented because the distribution of blood mercury is skewed. Means were presented by type of seafood and frequency of consumption. Analyses of differences in blood mercury concentrations by frequency of seafood consumption were conducted by using linear trend tests. Multiple logistic regression adjusted for race/Hispanic origin, age, sex, and education was used to examine association between the frequency of specific types of seafood consumption and blood mercury concentrations  $5.8 \mu\text{g/L}$ . This is the concentration that the National Research Council panel identified as the level below which “is likely to be without an appreciable risk of deleterious effects during a lifetime” and was adopted by the Environmental Protection Agency (EPA) (10, 11). In this model, consumption of the 6 aforementioned seafood categories (shrimp, tuna, salmon, crabs, high-mercury fish, and all other seafood) were included as continuous variables. In this model, all of these seafood categories were consumed by 10% of the population, except for high-mercury fish.

All statistical analyses were performed by using SAS version 9.3 (SAS Institute Inc) and SUDAAN version 10.0 (RTI International). Examination sample weights were used for all analyses to account for differential probabilities of selection, nonresponse, and noncoverage. The logit transformation was used to model the binary outcome and to construct CIs. A significance level of 0.05 was used for all statistical testing.

## RESULTS

In NHANES 2007–2010, there were 11,766 adults aged  $\geq 20$  y. Exclusion of persons with missing information on seafood consumption ( $n = 592$ ) and an additional 501 persons with missing mercury values resulted in a sample size of 10,673, 8661 of whom consumed any seafood (Table 1). Sample sizes by sex, type, and frequency of seafood consumption are shown elsewhere (see Supplemental Table 1 under “Supplemental data” in the online issue).

More than 80% ( $83\% \pm 0.7\%$ ;  $\pm\text{SE}$ ) of adults reported consuming seafood (Table 1). Almost 25% ( $24.5\% \pm 0.7\%$ ) consumed seafood 1–2 times/mo,  $18.4\% \pm 0.4\%$  consumed seafood 3–4 times/mo, and  $40.2\% \pm 1.0\%$  consumed seafood  $\geq 5$  times/mo. Just  $>9\%$  ( $9.2\% \pm 0.5\%$ ) of adults reported consuming only shellfish,  $28.0\% \pm 0.9\%$  reported consuming only fish, and  $45.8\% \pm 1.1\%$  reported consuming both fish and shellfish.

The geometric mean blood mercury concentration was  $0.99 \pm 0.04 \mu\text{g/L}$  among all adults (results not tabulated). The trends in geometric mean blood mercury concentrations as the frequency of seafood consumption increased are shown in Figure 1. The geometric mean blood mercury concentration among adults who consumed no seafood was  $0.45 \pm 0.01 \mu\text{g/L}$  and was  $1.16 \pm 0.04 \mu\text{g/L}$  among adults who consumed any seafood. In adults consuming any seafood, an increase in blood mercury was found as the frequency of seafood consumption increased ( $P < 0.001$ ). In adults who consumed 1–2 times/mo, the geometric blood mercury concentration was  $0.70 \pm 0.02 \mu\text{g/L}$ . In those who consumed seafood  $\geq 5$  times/mo, the geometric mean blood mercury concentration was  $1.70 \pm 0.06 \mu\text{g/L}$ . Trends

were also significant for consumers of fish only, shellfish only, and both fish and shellfish ( $P < 0.001$ ).

Now that seafood has been examined by the broad categories of shellfish and fish consumption, specific species of seafood will be analyzed. The percentage of the population consuming specific fish and shellfish if >5% of the population consumed that item is shown in Figure 2. Shrimp was the most commonly consumed seafood;  $47.4\% \pm 1.1\%$  of adults consumed shrimp in the previous 30 d. About one-third of adults ( $34.3\% \pm 0.9\%$ ) consumed tuna and  $26.9\% \pm 1.2\%$  of adults consumed salmon. Approximately 2% ( $1.8\% \pm 0.3\%$ ) of adults consumed high-mercury fish, shark, or swordfish (results not in figure).

After the specific species of seafood consumed was examined, the association with a blood mercury concentration  $5.8 \mu\text{g/L}$  was analyzed. Almost 5% ( $4.6\% \pm 0.39\%$ ) of US adults had blood mercury concentrations  $5.8 \mu\text{g/L}$  (results not tabulated). Logistic regression results showed a significantly higher odds of blood mercury concentrations  $5.8 \mu\text{g/L}$  with increasing frequency of specific fish, including tuna, salmon, and all other seafood but especially with high-mercury fish (Table 2). Shrimp and crab consumption was not associated with a higher odds of blood mercury concentrations  $5.8 \mu\text{g/L}$ . A unit increase in monthly consumption of tuna was associated with a 1.14-fold increase in the odds of blood mercury concentrations  $5.8 \mu\text{g/L}$  (95% CI: 1.10, 1.17). For salmon consumption, the corresponding difference was 1.14-fold (95% CI: 1.09, 1.20). A unit increase in monthly consumption of high-mercury fish was associated with a 4.58-fold increase in the odds of blood mercury concentrations  $5.8 \mu\text{g/L}$  (95% CI: 2.44, 8.62).

## DISCUSSION

In 2007–2010, >80% of US adults consumed seafood in the previous 30 d, and shrimp was the most common type of seafood consumed. Although the percentage of the population with blood mercury concentrations  $5.8 \mu\text{g/L}$  was low (4.6%), elevated blood mercury was associated with tuna, salmon, other seafood, and, especially, high-mercury fish consumption. The association between elevated mercury and consumption of specific fish, including tuna, has been reported (14). In the current analysis, the OR of a blood mercury concentration  $5.8 \mu\text{g/L}$  was approximately the same for tuna and salmon. This may have been because the consumption of tuna in our data represents 2 kinds of tuna: one with a high concentration and the other with a relatively low concentration of mercury. Bluefin and albacore tuna are high in mercury, whereas light canned tuna is low in mercury (1) and the food-frequency questionnaire used did not distinguish between the 2. In addition, the food-frequency questionnaire did not account for portion size. Finally, information about the body of water in which the seafood was caught was not obtained in the questionnaire.

The DGA states that 4 seafood varieties should not be consumed by pregnant women: shark, tilefish, swordfish, and king mackerel (1). Our high-mercury fish category consisted of shark and swordfish; data on tilefish was not collected as part of the limited food-frequency questionnaire. Furthermore, no distinction was made between king mackerel (high in mercury) and Atlantic and Pacific mackerel (low in mercury). A sensitivity analysis was conducted to examine the effects of altering the categorization of mackerel. When mackerel

was included in the “high mercury” category instead of the “all other” category, the OR estimate for high-mercury fish decreased (from 4.58 to 1.71) with no change in the OR estimate for “all other seafood.” On the basis of these observations, mackerel was included in the “all other” category.

Our results add to previous analyses of blood mercury concentrations in US women of childbearing age and children (12–17). In a previous study of US women of childbearing age using NHANES 1999–2000 data, shellfish consumption and fish consumption were independently associated with blood mercury concentrations (17). Similarly, Mahaffey et al (14) found that, in US women in NHANES 1999–2000, blood mercury concentrations in women who consumed fish or shellfish 9 times in the past 30 d were 7 times those in women who consumed no fish or shellfish in the past 30 d. A recent study by the EPA showed that geometric mean blood mercury concentrations in women of childbearing age decreased between 1999 and 2010 (19). The EPA study, and another study from CDC, also showed that most women of childbearing age have blood mercury concentrations that are “below levels of concern” (18, 19).

Previous local studies have examined blood mercury values for both men and women. For example, the 2004 New York City HANES study reported a higher geometric mean blood mercury concentration than we estimated (2.73  $\mu\text{g/L}$  compared with 0.99  $\mu\text{g/L}$ ). Approximately one-quarter of the New York City adult population had a blood mercury concentration 5  $\mu\text{g/L}$ . Although the referent point is slightly lower than what we used in our analysis, a much greater percentage of adults had a higher blood mercury concentration than in our study [based on a cutoff of 5  $\mu\text{g/L}$ , only 5.8% (results not tabulated) of adults in our study had a high blood mercury concentration]. Increased frequency of consumption of fish or shellfish was associated with increased blood mercury concentrations (24). In a survey based in San Francisco, 89% of men and women who were high fish consumers had high blood mercury concentrations (>5.0  $\mu\text{g/L}$ ) (26).

In comparison with a study of women of childbearing age in 10 countries, the geometric mean blood mercury concentration of the adult population in the United States (0.99  $\mu\text{g/L}$ ) and of women of childbearing age in the United States (0.87  $\mu\text{g/L}$ , results not tabulated) was within the range of geometric means in 7 European countries (0.40–1.38  $\mu\text{g/L}$ ) and at the low end of the range of 3 non-European countries (1.01–2.73  $\mu\text{g/L}$ ) (27). Many international studies are not easily compared with the current analysis, either because mean blood mercury concentrations were calculated (28, 29) rather than geometric mean blood mercury concentrations or total mercury was measured in the seafood rather than in the blood (30, 31).

The primary way that individuals in the United States are exposed to mercury is as methylmercury (organic mercury) found in fish and shellfish (13). Coal-burning plants and other manufacturing processes emit primarily inorganic mercury into the environment. This inorganic mercury is then converted into methylmercury by bacteria, which is consumed by fresh water and sea animals. Fish and shellfish accumulate methylmercury by consuming these animals. This bioaccumulation of methylmercury is hard to predict because it is affected by many factors, including the temperature and pH of the water as well as the

amount of mercury and other chemicals present in the water. However, in general, larger fish that eat other fish contain higher concentrations of methylmercury (10). The blood mercury concentration is a good measure of recent exposure to mercury and is suitable for assessing the association between recent seafood consumption and mercury body burden (11). In this study, only mercury exposure from seafood consumption was analyzed; other sources of mercury exposure may include dental amalgams and thimerosal among other sources (10). Contributions of these sources to blood mercury concentrations are likely to be small, considering that mercury released from dental amalgams are primarily inorganic, whereas blood mercury is largely organic and thimerosal has a short half-life (5.6 d) (32).

This study had some limitations. The portion size consumed, which was not considered in our study, affects the amount of mercury consumed by an individual. Another important limitation was that NHANES was not designed for detailed analysis by geographic variation. Because of anthropogenic sources of mercury, the exact location of a body of water affects the mercury concentration in seafood (10, 28, 29, 33).

This study had many strengths. This analysis focused on all US adults, not just women of childbearing age. Seafood consumption was analyzed by both type and frequency. In addition, this study helped elucidate the associations between specific seafood varieties and blood mercury concentrations in a nationally representative sample. This study had a large sample size sufficient for accurately estimating associations between relatively scarce dietary behavior, eg, consumption of high-mercury fish, and blood mercury concentrations 5.8  $\mu\text{g}/\text{L}$ . Finally, because the half-life of blood mercury is ~50 d (11) and the food frequency used to measure fish consumption was based on the last 30 d, both the outcome and exposure are based on similar time periods.

Seafood is an important part of a healthy diet, providing protein and important nutrients, including omega-3 fatty acids, which help to prevent heart disease (1). These results show that most US adults do consume seafood and that shrimp is the most common selection. Increased frequency of seafood consumption, and particularly high-mercury fish (swordfish and shark)—but also to a lesser extent tuna and salmon—are associated with blood mercury concentrations 5.8  $\mu\text{g}/\text{L}$ . Future research might help to identify the geographic variability for each specific fish species (eg, salmon, tuna) and how consumption of fish from specific bodies of water may affect blood mercury concentrations differently. Future research could also examine the association of blood mercury concentrations with actual amounts of seafood consumed.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

## Acknowledgments

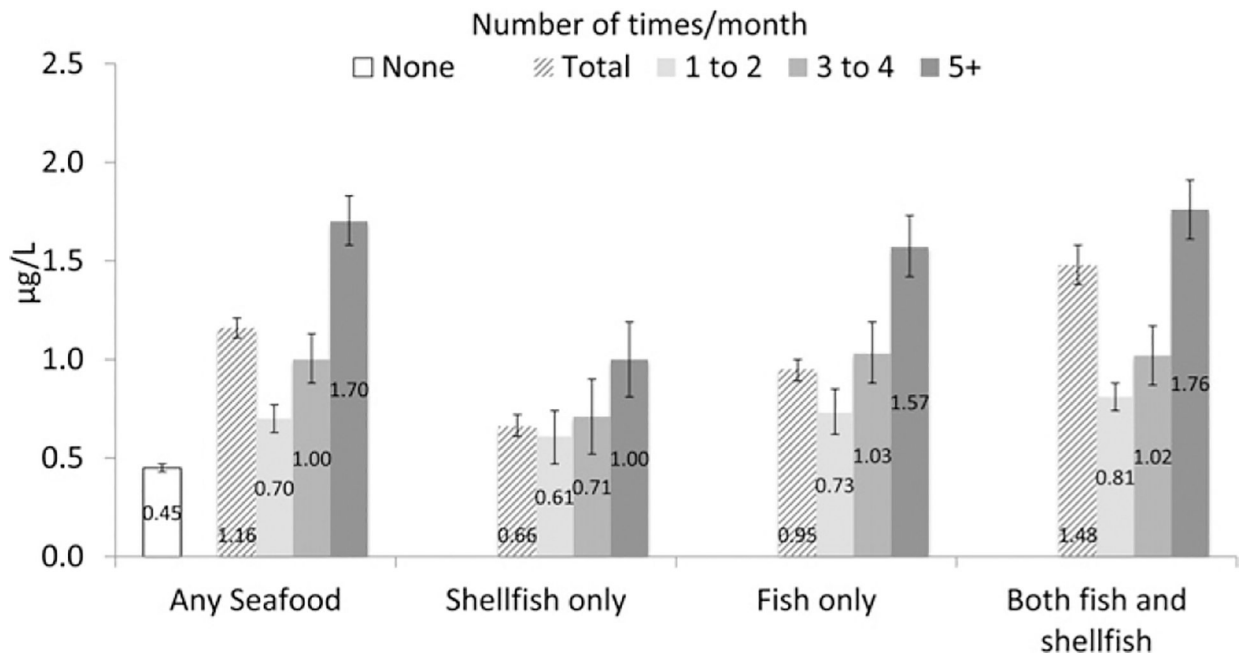
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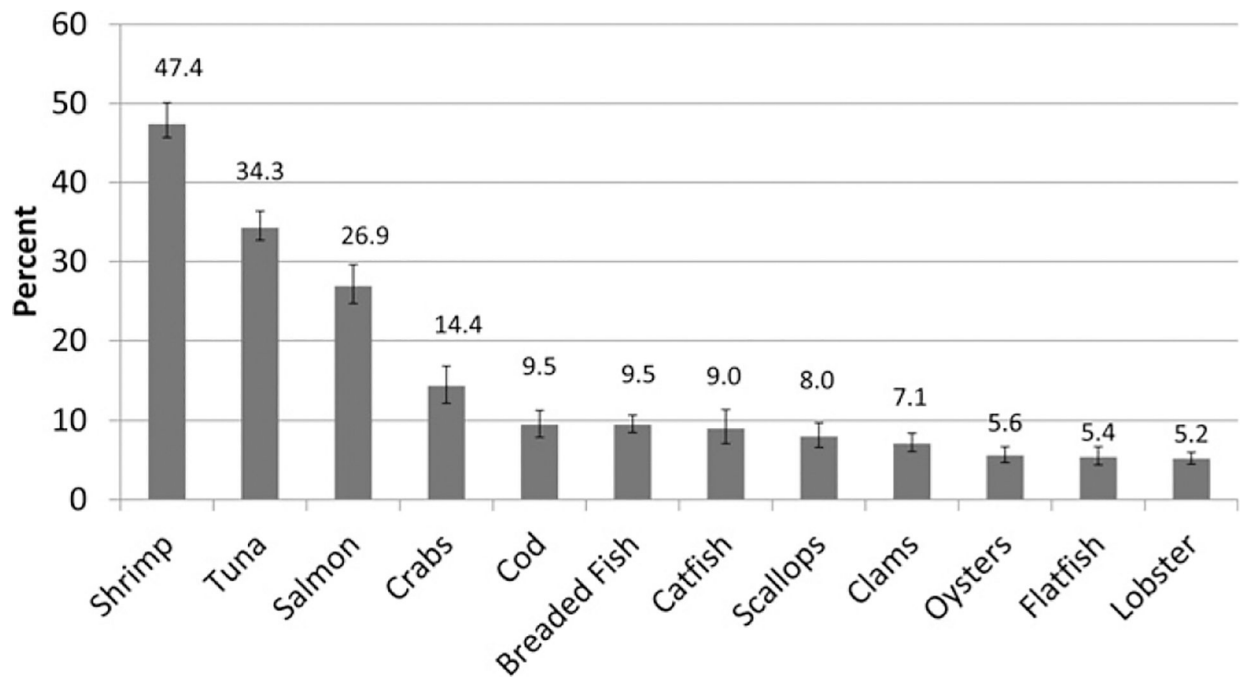


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**FIGURE 1.**

Geometric mean (95% CI) blood mercury concentrations by frequency of seafood consumption: adults aged  $\geq 20$  y, United States, 2007–2010 ( $n = 10,673$ ). All categories show a significant linear trend by number of times/mo,  $P < 0.001$ . Source: CDC/National Center for Health Statistics, NHANES (20).



**FIGURE 2.**

Percentage (95% CI) of the population consuming specific fish and shellfish: adults aged 20 y, United States, 2007–2010 ( $n = 10,673$ ). Fish and shellfish consumed by <5% of the population are not shown. Source: CDC/National Center for Health Statistics, NHANES (20).

TABLE 1

Percentage of adults who consumed seafood, by sex, type, and frequency: 20 y, United States 2007–2010<sup>1</sup>

	Any seafood (n = 8661)	Shellfish only	Fish only	Both fish and shellfish
All (n = 10,673)				
Total	83.0 ± 0.7	9.2 ± 0.5	28.0 ± 0.9	45.8 ± 1.1
1–2 times/mo	24.5 ± 0.7	6.9 ± 0.4	14.5 ± 0.6	3.1 ± 0.2
3–4 times/mo	18.4 ± 0.4	1.3 ± 0.2	6.8 ± 0.3	10.3 ± 0.3
5 times/mo	40.2 ± 1.0	1.0 ± 0.2	6.8 ± 0.4	32.4 ± 1.0
Male				
Total	83.9 ± 0.6	9.9 ± 0.6	27.4 ± 1.1	46.6 ± 1.2
1–2 times/mo	24.6 ± 0.9	7.0 ± 0.5	14.1 ± 0.8	3.5 ± 0.3
3–4 times/mo	18.8 ± 0.6 <sup>2</sup>	1.5 ± 0.2	6.8 ± 0.3	10.6 ± 0.6
5 times/mo	40.5 ± 1.2	1.4 ± 0.3	6.6 ± 0.6	32.5 ± 1.2
Female				
Total	82.2 ± 0.9	8.6 ± 0.6	28.6 ± 1.0	45.0 ± 1.1
1–2 times/mo	24.4 ± 0.7	6.8 ± 0.4	14.9 ± 0.7	2.7 ± 0.3
3–4 times/mo	18.0 ± 0.7	1.2 ± 0.2	6.8 ± 0.6	10.0 ± 0.4
5 times/mo	39.8 ± 1.0	0.6 ± 0.1	6.9 ± 0.4	32.3 ± 1.0

<sup>1</sup>All values are percentages ± SEs. All categories contained a sample size of 32. Seafood consumption (past 30 d) is based on data from a food-frequency questionnaire. Data are from NHANES (20). All pairwise comparisons between 1–2 times/mo and 5 times/mo are statistically significant ( $P < 0.001$ ).

<sup>2</sup>Value does not exactly represent the sum of the “Shellfish only,” “Fish only,” and “Both fish and shellfish” values because of a rounding error. For all other rows, “Shellfish only,” “Fish only,” and “Both fish and shellfish” values do sum to the “Any seafood” value.

**TABLE 2**Adjusted ORs (95% CIs) of blood mercury concentrations  $\geq 5.8 \mu\text{g/L}$  among adults: United States, 2007–2010<sup>1</sup>

Seafood consumption	Total sample (n = 10,658)
Shrimp	0.95 (0.88, 1.03)
Tuna	1.14 (1.10, 1.17)
Salmon	1.14 (1.09, 1.20)
Crabs	1.06 (0.90, 1.23)
High-mercury fish <sup>2</sup>	4.58 (2.44, 8.62)
All other seafood	1.12 (1.08, 1.15)

<sup>1</sup>Adjusted for race/Hispanic origin, sex, age, and education. Seafood consumption (past 30 d) is based on data from a food-frequency questionnaire. Data are from NHANES (20).

<sup>2</sup>Includes swordfish and shark.

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