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ORIGINAL ARTICLE

Estimated long-term fish and shellfish intake—national health and nutrition examination survey

Nga L. Tran[1], Leila M. Barraj[1], Xiaoyu Bi[1], Laurie C. Schuda[2] and Jacqueline Moya[2]

Usual intake estimates describe long-term average intake of food and nutrients and food contaminants. The frequencies of fish and shellfish intake over a 30-day period from National Health and Examination Survey (NHANES 1999–2006) were combined with 24-h dietary recall data from NHANES 2003–2004 using a Monte Carlo procedure to estimate the usual intake of fish and shellfish in this study. Usual intakes were estimated for the US population including children 1 to <11 years, males/females 11 to <16 years, 16 to <21 years, and adults 21+ years. Estimated mean fish intake (consumers only) was highest among children 1 to <2 years and 2 to <3 years, at 0.37 g/kg-day for both age groups, and lowest for females 11 to <16 years, at 0.13 g/kg-day. In all age groups, daily intake estimates were highest for breaded fish, salmon, and mackerel. Among children and teenage consumers, tuna, salmon, and breaded fish were the most frequently consumed fish; shrimp, scallops, and crabs were the most frequently consumed shellfish. The intake estimates from this study better reflect long-term average intake rates and are preferred to assess long-term intake of nutrients and possible exposure to environmental contaminants from fish and shellfish sources than 2-day average estimates.

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INTRODUCTION

The term usual intake refers to the long-term average intake of a food or nutrient by an individual.[1] Estimation of usual intake distributions is generally the measurement of interest to public health officials. Usual intake, however, cannot be observed in short-term dietary recall studies and is difficult to collect because it is costly and burdensome to the respondent.[1–3] Estimation of the long-term average daily intake of a food on the basis of short-term survey data, such as the 24-h dietary recall, can be problematic particularly when foods of interest are consumed only occasionally, as in the case of fish and shellfish.[4,5] An approach for dealing with this problem by combining food consumption frequency data with 24-h recall data using probability-based methods to estimate long-term average daily intake is described by Tran et al.[6] This paper describes the application of the 2004 procedure explained in Tran et al[6] that uses the complementary NHANES dietary data sets on 24-h recall and food consumption frequency to estimate the long-term average (or usual) daily intake of fish and shellfish in the US population and selected populations of children.

MATERIALS AND METHODS

Data

NHANES is a complex multistage probability sample designed to be representative of the civilian US population.[7] The NHANES data sets provide nationally representative nutrition and health data and prevalence estimates for nutrition and health status measures in the United States. The NHANES over-samples minorities, low-income groups, adolescents aged 12–16 years, and adults 60+ years of age and older. Statistical weights are provided by the National Center for Health Statistics (NCHS) for the surveys to adjust for the differential probabilities of selection. The dietary component of the survey is conducted as a partnership between the US Department of Agriculture (USDA) and the US Department of Health and Human Services (DHHS). DHHS is responsible for the sample design and data collection, and USDA is responsible for the survey's dietary data collection methodology, maintenance of the databases used to code and process the data, and data review and processing.

The dietary interview component of NHANES collects information on the foods that were consumed during the 24-h period before the interview (24-h dietary recall) and about the frequency of fish and shellfish consumptions during the past 30 days (the food frequency questionnaire (FFQ)). The 24-h dietary recall survey includes questions to assess the amounts consumed at an eating occasion (EO). As part of the examination, trained dietary interviewers collect detailed information on all foods and beverages consumed by respondents in the previous 24 h time period (midnight to midnight). In NHANES 2003–2004 and 2005–2006, a second dietary recall is administered by telephone 3–10 days after the first dietary interview, but not on the same day of the week as the first interview.

The FFQ data are included in the "Dietary Interview (Total Nutrients)" data file in the NHANES 1999–2000 and 2001–2002 and in the "Dietary Interview (Total Nutrient Intakes—First Day)" data file in the NHANES 2003–2004 and 2005–2006 NHANES. FFQ data are available for all participants (>1 year) in the NHANES 1999–2000 and 2005–2006, and only for children aged 1 to <6 years and females aged 16 to <50 years in the 2001–2002 and 2003–2004 surveys.[8–11] The FFQ data from all 4 years (NHANES 1999–2006) were combined in this study analysis. Survey participants reporting consumption of at least one of the fish or shellfish FFQ categories were identified as "consumers." The total frequency of consumption for 21 fish and 10 shellfish FFQ categories are listed in Table 1.

This analysis uses the 24-h dietary recall data from the NHANES 2003–2004 survey. As food consumption in the NHANES surveys are reported "as consumed", for example, tuna salad sandwich, USDA recipes were used to estimate the fish/shellfish portions. In several occasions where USDA recipes are missing, other recipes (e.g., previously compiled recipes from cookbooks) were used. Over 300 NHANES food codes were mapped to 21 fish and 10 shellfish FFQ categories.

[1]Exponent, Washington, DC, USA and [2]US EPA, Washington, DC, USA. Correspondence: Dr. Nga L. Tran, Exponent, 1150 Connecticut Avenue NW, Suite 1100, Washington, DC 20036, USA.
Tel.: +1 202 772 4915. Fax: +1 202 772 4979.
E-mail: ntran@exponent.com
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Monte Carlo Model

The frequency of intake of fish and shellfish over a 30-day period from 4 years (NHANES 1999–2006) were combined with the 24-h dietary recall data from NHANES 2003–2004 using the Latin Hypercube sampling procedure provided in Crystal Ball[12] to estimate the long-term average daily intake of fish and shellfish for the US population stratified by life stages and sex. The Latin Hypercube sampling procedure divides the input distributions into intervals of equal probability and samples from each interval according the interval's probability distribution, so that the entire range of the distribution is sampled in an even consistent manner. Estimates of long-term daily intake of fish and shellfish for 12 different age and gender groups including children 1 to <2, 2 to <3, 3 to <6, 6 to <11 years; males and females 11 to <16, 16 to <18, 18–21 years; and adult males and females 21 years and older were derived. The children's age groups were chosen based on the EPA's Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants.[13] The following procedure was applied:

1. The fish and shellfish foods in NHANES 2003–2004 24-h dietary recall were mapped with the FFQ fish/shellfish categories (F_j).
2. Amounts consumed per EO for each fish/shellfish FFQ category (A_j) were derived from the NHANES 2003–2004 24-h dietary recall database using the Foods and Residue Evaluation Program (FARE), a proprietary data processing software that was developed to facilitate the mining of the thousands of individual intake records in the NHANES database. FARE is used by the US FDA, the USDA, the California Office of Environmental Health Hazard Assessment, and by Health Canada Pest Management Regulatory Agency to derive estimates of food, nutrient, and contaminant intakes based on consumption data from NHANES and USDA's Continuing Survey of Food Intakes by Individuals (CSFII).[14] FARE was used to process consumption data for several peer-reviewed publications.[6,15,16] A version of the software that uses preprocessed data from the CSFII was also reviewed by the US EPA Scientific Advisory Panel in 2000. The weighted distribution of A_j were derived for several age/gender groups, including children 1, 2, 3 to <6, 6 to <11, 11 to <16 years, males 16+ years, and females 16+ years. Sample sizes were, however, too small in the children's group (<16 years) for the following fish types: flatfish, haddock, mackerel, pike, pollock, porgy, sardines, sea bass, shark, swordfish, and trout; hence these fish types were combined to derive a distribution of grams per EO. Similarly, owing to small sample sizes, crayfish, lobster, mussel, scallop, other shellfish, and unknown shellfish were also combined in the derivation of the distribution of amount consumed per EO.
3. Eight-year statistical weights were derived using the approach recommended by NHANES. Namely, the 4-year statistical weights (WTMEC4YR) for participants in the 1999–2000 and 2001–2002 surveys were multiplied by 0.50, and the 2-year statistical weights (WTMEC2YR) for the participants in the 2003–2004 and 2005–2006 surveys were multiplied by 0.25. In addition, as in NHANES 2001–2002 and 2003–2004 the fish FFQ was only available for children 1 to <6 years and women 16 to <50 years, the statistical weights for these groups were further multiplied by 0.5 to avoid over-representing these age groups in the combined database.
4. Crystal Ball was used to combine randomly sampled individual records of fish/shellfish 30-day frequency of consumption from the NHANES "consumers" database with serving size values randomly sampled from the corresponding distribution of intake amount per EO. In combining the two sets of distributions, the within-person correlations were maintained in the frequency of consumption. The following algorithm was applied:

   i Select a person (i) from the list of NHANES participants.
   ii Identify his/her frequency of consumption of the various NHANES fish/shellfish categories (F_{ij}) in a 30-day period, and
   iii For each NHANES fish/shellfish category (F_j), randomly select an EO amount ($A_{j,F_{ij}}$) from the amount distribution A_j corresponding to the fish/shellfish category.
   iv Derive the 30-day total amount of fish/shellfish (j) consumed by individual (i) as:

$$T_{ij} = (F_{ij} \times A_{j,F_{ij}})$$

Thus, for each selected NHANES individual, the algorithm produced a total fish/shellfish consumed over the 30 days (T_{ij}) and a 30-day average daily intake was then derived by dividing T_{ij} by 30.

As the data generated by the Monte Carlo procedure were used to estimate fish intake by various populations of interest as well as the total US population, a stratified approach was used to conduct the Monte Carlo procedure in order to ensure that the populations were sampled with comparable frequencies. Specifically, the FFQ "consumers" database was split into five age strata and the Monte Carlo model was run independently for each of the strata. The number of iterations used for each stratum was set at 10 × the number of subjects in the stratum. This ensured that the number of records for each stratum in the combined output from all the individual strata runs was proportional to the initial number of records in the strata (i.e., pre-Monte Carlo). Note that despite the fact that Latin Hypercube sampling was used, some subjects were sampled more frequently than others owing to the random sampling nature of the Monte Carlo procedure.

Derivation of Summary Statistics and Statistical Weights

The output of the Monte Carlo procedure consisted of 170,070 records for fish and/or shellfish consumers. These records were combined with the data from the NHANES participants who had reported that they did not consume any fish or shellfish in the past 30 days to regenerate the total US population. Estimates of the mean, SEM, percentage consumers, selected percentiles (5th, 10th, 25th, 50th, 75th, 90th, 95th, and 99th), and maximum intakes were derived for the total US population and select age/gender groups. Statistical weights were used in the derivation of all summary statistics, and the estimates of the SEM were also adjusted for the complex NHANES survey design.

As the Monte Carlo procedure was applied only to consumers of fish and/or shellfish, each consumer appears on average about 10 times, while every non-consumer of fish or shellfish appears once in the final output database. Also, as the random sampling in the Monte Carlo procedure resulted in different number of "draws" for the various consumers of fish and or shellfish, an adjusted weight was derived as the ratio of the 8-year statistical weight to the number of times the particular individual was sampled in the Monte Carlo procedure. This approach not only adjusted for the different probabilities of selection in the Monte Carlo procedure, but also ensured that the weighted proportion of consumers was not distorted in the total output database that consisted of the records generated by the Monte Carlo procedure for the fish and shellfish consumers and the records for non-consumers.

Adjustment for the Design Effect

NHANES uses a complex, multistage, probability sampling design and guidance provided by NCHS, indicating that analytic approaches designed for data from simple random samples are not appropriate. Ignoring the complex sampling design can lead to biased estimates and underestimate the SE. The stratification and clustering of the design must be incorporated into the analysis to get proper estimates of the SE. NCHS lists three approaches for estimating the SE for complex surveys such as the NHANES survey.[17] These include the Taylor series (linearization) method, the average design effect method, the balance repeated replication methods, or the jackknife methods. We used the stratum variable (SDMVSTRA) and the sampling using (PSU) variable (SDMVPSU) in STATA[18] to estimate sampling errors by the Taylor series method. However, when deriving SE estimates on a per user basis, there were multiple cases where the number of consumers of fish and shellfish in specific populations was too small, and thus several strata consisted of a single PSU. The design-adjusted SE could not be estimated in that case as it requires that at least two PSU be present in each stratum. Thus in these cases, application of the Taylor's series method would have required redefining the stratum and PSU variables (by combining multiple strata) on an analysis by analysis and population by population basis to ensure that there were no strata with single sampling units. Therefore, in the per user analyses, the SEs were estimated using an alternative approach, namely the average design effect (DEFF) method. The average DEFF method combines an average design effect ($DEFF_{avg}$) with estimates of the SE derived assuming simple random sampling (SE_{SRS}) to estimate a "design-adjusted" SE:

$$\text{Design} - \text{Adjusted SE} = SE_{SRS} \times \sqrt{DEFF_{avg}}$$

However, as outlined by Scott and Holt, Skinner, and STATA[18–20], the DEFF is the ratio of the complex design-based variance estimate divided by the estimate of the true variance that would be derived from a hypothetical simple random sample. As it is not possible to estimate the true variance for the hypothetical simple random sample, and hence the DEFF, the design-adjusted SEs were derived by combining an average

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Table 1. Total frequency of fish and shellfish consumed over a 30-day period, US population.

Type	*Unweighted no. of users*	*Total frequency*
Fish		
Tuna	6833	18,337
Salmon	3157	7317
Breaded fish	2952	6024
Other fish	2336	5606
Catfish	2379	4570
Unknown fish	1010	2230
Cod	1002	1897
Flatfish	904	1871
Sardines	570	1213
Trout	612	1150
Perch	487	954
Pollock	442	931
Haddock	481	930
Bass	282	541
Mackerel	174	375
Swordfish	197	302
Walleye	158	279
Sea bass	156	244
Porgy	72	137
Shark	49	64
Pike	37	57
Shellfish		
Shrimp	8692	18,061
Crab	2185	3901
Clam	1123	1850
Scallop	975	1547
Oyster	755	1303
Lobster	835	1139
Other shellfish	555	951
Mussel	375	603
Crayfish	235	488
Unknown shellfish	62	110

misspecification effect (MEFF). The MEFF (the ratio of the complex-design-based variance estimate to the variance estimate derived by ignoring the sample weights, stratification, and clustering) was derived for each population using the consumers only FFQ data for total shell fish, total fish, and total fish + shell fish. An average MEFF was calculated for each population and combined with the misspecified estimates of the SE (SE_{MIS}) to estimate "design-adjusted" SE:

$$\text{Design} - \text{Adjusted SE} = SE_{MIS} \times \sqrt{MEFF_{avg}}$$

RESULTS

Summary estimates of the consumption distributions generated in this study are presented below. No formal statistical tests were conducted to assess whether the relative differences observed between various life stages and sex are "significantly different" or not.

Frequency of Consumption

The fish most often consumed, in descending order, by the US population over a 30-day period were tuna, salmon, breaded fish, other fish, and catfish (Table 1). The shellfish most often consumed, in descending order, by the US population over a 30-day period were shrimp, crab, clam, scallop, and oyster (Table 1).

Amount Consumed per EO

Table 2 presents the estimated amount of fish and shellfish consumed per EO for the overall US population and select age groups. The average amount of fish consumed is higher for males 16+ years (112 g/EO) than for females 16+ years (81.6 g/EO). Among children, the average fish amount consumed is 24.8, 42.6, 45.6, and 83.0 g/EO for children <2, 2 to <3, 3 to <6, and 6 to <11 years, respectively. As would be expected, the average amount of shellfish consumed per EO is well below that of fish. Nevertheless, the average amount of shellfish consumed remains higher for males 16+ years (72.0 g/EO) than for females 16+ years (50.9 g/EO). The per serving (g/EO) estimates derived from the NHANES data are similar to those derived by Smiciklas-Wright et al.[21] from the CSFII 1994–1996 data.

Per Capita Fish and Shellfish Intake

The daily intake of fish (all types combined) and shellfish (all types combined) among all NHANES subjects (i.e., intake from all consumers divided by the total population of fish consumers and non-consumers) is referred to as *per capita* intake. The estimated mean *per capita* daily fish and shellfish intake are 8.78 g/day (SE = 0.27 g/day) and 3.06 g/day (SE = 0.14 g/day), respectively. Tuna, salmon, and breaded fish have the highest *per capita* daily intake estimates and contribute 24%, 19%, and 11%, respectively, to the total mean *per capita* fish intake. The estimated shrimp daily intake is the highest and represents 48% of the total mean *per capita* shellfish intake. The mean *per capita* estimates and SE for select age groups in g/day and g/kg bw/day are summarized in Table 3 for fish and shellfish. Detailed *per capita* percentile intake estimates can be found in the Supplementary Data section.

Fish Consumers' Daily Intake

Subjects with reported consumption of at least one of the fish categories in the FFQ over the last 30 days are considered fish consumers in this study. Based on this definition, 69% of the overall NHANES subjects are fish consumers. Over 50% of the children <11 years of age are fish consumers, and the highest percentage of consumers (≥75%) is among the adult males and females in the 21+ year age group. Among the fish consumers, the estimated usual average daily intake of fish (all types combined) on a g/kg-day basis is highest among children 1 to <2 years and 2 to <3 years, both at 0.37 g/kg-day. The lowest fish intake estimate is 0.13 g/kg-day for females aged 11 to <16 years. Usual daily fish intakes and SE for the US population and select life stages and sex in g/day and g/kg-day are presented in Table 4. More detailed percentile intake estimates can be found in the Supplementary Data section.

Among all fish consumers, tuna is the most frequently consumed type (35%), followed by salmon (18%), breaded fish (14%), catfish (10%), and other fish (10%). The average daily intakes on a g/kg-day basis are the highest for salmon, mackerel, and breaded fish (all three at 0.14 g/kg-day) and flat fish (0.13 g/kg-day). Usual daily fish intakes and SE by fish types for the US population are presented in Table 5. More detailed percentile intake estimates can be found in the Supplementary Data section.

Among fish consuming children and teenagers, tuna, breaded fish, and salmon are the three most frequently consumed fish, in descending order. While tuna is the top consumed type of fish, usual daily intake estimates for tuna are well below the breaded fish and salmon estimates. Among children aged <11 years, the usual daily intakes for breaded fish are the highest (ranging from 4 to 6.7 g/day) and usual daily intakes of salmon are the highest among older children and teenagers aged 11 to <18 years (ranging from 6 to 10.4 g/day). Usual daily intakes and SE for these three top consumed fish types by children and teenagers are presented in Table 6. More detailed percentile intake estimates can be found in the Supplementary Data section.

Shellfish Consumers' Daily Intake

Subjects with reported consumption of at least one of the shellfish categories in the FFQ over the last 30 days are considered

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Table 2. Fish and shellfish consumed per EO, NHANES 2003–2004.

Population	*g per eating occasion (g/EO)*							
	No. EO[a]	*Mean*	*10th*	*25th*	*50th*	*75th*	*90th*	*95th*
All fish								
Children 1 to <2 years	685,964	24.8	2.7	3.1	13.7	34.2	73.5	85.1
Children 2 to <3 years	601,086	42.6	7.3	22.2	33.9	54.9	101	102
Children 3 to <6 years	1,867,554	45.6	8.1	22.4	33.8	53.3	94.1	137
Children 6 to <11 years	2,254,487	83.0	22.8	47.7	56.4	121	195	196
Males 11 to <16 years	1,241,885	85.5	12.5	30.7	63.2	114	190	253
Females 11 to <16 years	1,588,949	72.6	15.8	31.3	53.3	94.2	170	210
Males 16+ years[b]	27,963,264	112	26.1	52.2	93.1	149	236	265
Females 16+ years[b]	30,720,077	81.6	17.6	38.6	62.7	105	159	215
US population	66,923,266	92.3	18.3	42.4	68.5	122	203	254
All shellfish								
Children 1 to <2 years	141,632	7.3	—	—	—	—	—	—
Children 2 to <3 years	144,975	15.7	—	—	—	—	—	—
Children 3 to <6 years	477,026	42.1	8.4	13.8	40.3	50.4	100	101
Children 6 to <11 years	1,531,852	38.2	4.0	8.4	34.2	46.1	75.8	114
Males 11 to <16 years	357,600	48.0	7.6	7.8	16.2	58.2	123	252
Females 11 to <16 years	635,432	53.5	12.4	16.3	24.2	89.8	130	148
Males 16+ years[b]	18,545,624	72.0	9.3	21.6	45.3	107.1	168	244
Females 16+ years[b]	15,062,415	50.9	8.2	19.0	34.7	65.0	108	149
US population	36,896,556	60.6	8.1	18.1	37.3	78.4	134	220

[a]Weighted number of EOs.
[b]The serving size distributions of seafood among the older adolescent and adult populations (adolescents 16 to <18 years, adolescents 18 to <21 years, and adults 21 years and older) were comparable such that the serving size distributions by age/gender, males 16+ and females 16+ years old, were representative of the older adolescent and adult populations.

"shellfish consumers" in this study. Based on this definition, 48% of the overall NHANES subjects are shellfish consumers. Twenty-two percentage of the children aged 1 to <2 years are shellfish consumers, and the highest percentage of consumers is among the adult males and females 21+-year-old group (56% and 53%, respectively). Among the shellfish consumers, the average intake of shellfish (all types combined) on a g/kg-day basis is highest among children 3 to <6 years at 0.18 g/kg-day. The lowest estimated shellfish intake is 0.05 g/kg-day for children aged 1 to <2 years. Usual daily shellfish intake estimates and SE for the US population and select life stages and sex in g/day and g/kg-day are presented in Table 4. More detailed percentile intake estimates can be found in the Supplementary Data section.

Among all shellfish consumers, shrimp is the most frequently consumed shellfish (41%), followed by crabs (12%), scallops, and clams (both at 7%). The estimated usual daily intake of shrimp, crabs, and scallops are similar (0.06 g/kg-day) and the estimated clams intake is the lowest (0.03 g/kg-day). While not among the top consumed shellfish, the average daily intakes on a g/kg-day basis is the highest for crayfish and other shellfish (0.07 g/kg-day). Usual daily intake estimates and SE by shellfish types for the US population are presented in Table 7. More detailed percentile intake estimates can be found in the Supplementary Data section. The percentile estimates indicate a larger variability between subjects in a given age and sex group than between subjects in different age and sex groups.

Among the children and teenage shellfish consumers, shrimp is also the most frequently consumed shellfish. On a mean daily intake basis, the highest amount of shellfish consumed (in g/kg-day) is either for shrimp, scallop, or crabs depending on the age group. Usual daily intake estimates and SE for these three top consumed shellfish by children and teenagers are presented in Table 8. More detailed percentile intake estimates can be found in the Supplementary Data section. The percentile estimates indicate a larger variability between consumers in a given age and sex group than between consumers in different age and sex groups.

DISCUSSION

While the 24-h recall has been the most common method used to collect food intake information,[22] data from a limited number of recalls are the least ideal for estimating usual and longer term average daily food intakes owing to the intra-individual variation of consumption from day to day.[23] Intake distributions for consumers of foods that are not consumed on a daily basis, such as fish, based on 24-h recall tend to be skewed to the right.[24,25] Exposure estimates for fish consumers derived from rightly skewed food intake distributions tend to overestimate actual long-term exposure at the high end and thus could attenuate relationships that may exist between the dietary exposure and the studied effect. However, differences at the *per capita* mean are less accentuated. Lambe et al.[5] compared *per capita* mean intakes from 3-day and 14-day diary surveys and found that *per capita* intakes from the 14-day diary survey were on average 0.9 times the *per capita* mean from the 3-day diary survey. Table 9 compares the *per capita* mean usual intake estimates derived in this study to the *per capita* mean 2-day intakes from USDA's 1994–1996 and 1998 CSFII.[26] The same relative difference that was observed by Lambe et al.[5] is observed between the *per capita* mean intakes derived in this study and the *per capita* means based on the 2-day CSFII survey for most populations considered. However, the difference for children 11–16 years is much larger. While the reason for the larger difference in this population is not clear, it could be related to the fact that the estimates refer to two different studies and time periods, or that some FFQ respondents underestimated the frequency of consumption of fish or only reported consumption of fish "meals" or did not include consumption of fish in mixtures in their reported frequencies.

Other published estimates of fish consumption in the United States generally refer to specific populations from limited geographical locations (e.g., occupational or recreational fishermen and their families) or to specific ethnic groups or are representative of short-term intakes.[27–31] Hence, estimates from these studies would not be comparable to estimates derived in the current study. However, long-term fish intake estimates derived in this study are

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Table 3. *Per capita* (consumers and non-consumers) usual intake of fish and shellfish (usual reflects 30-day average).

Population	*% Consumers*	*Intake (g/day)*		*Intake (g/kg/day)*	
		Mean	*SE*	*Mean*	*SE*
All fish					
Children 1 to <2 years	53	2.22	0.16	0.19	0.013
Children 2 to <3 years	60	3.02	0.19	0.22	0.014
Children 3 to <6 years	59	3.56	0.18	0.20	0.010
Children 6 to <11 years	51	4.39	0.32	0.15	0.012
Males 11 to <16 years	48	3.76	0.36	0.07	0.007
Females 11 to <16 years	48	3.25	0.37	0.06	0.008
Males 16 to <18 years	49	6.32	0.95	0.09	0.014
Females 16 to <18 years	48	3.98	0.44	0.07	0.008
Males 18 to <21 years	55	8.66	1.19	0.11	0.012
Females 18 to <21 years	56	5.15	0.40	0.08	0.006
Males 21+ years	76	13.50	0.51	0.16	0.006
Females 21+ years	75	9.16	0.33	0.13	0.005
Total US	69	8.78	0.27	0.14	0.005
All shellfish					
Children 1 to <2 years	22	0.12	0.01	0.011	0.001
Children 2 to <3 years	26	0.38	0.04	0.029	0.003
Children 3 to <6 years	29	0.91	0.07	0.051	0.004
Children 6 to <11 years	33	1.10	0.11	0.038	0.004
Males 11 to <16 years	33	1.52	0.23	0.028	0.004
Females 11 to <16 years	35	1.36	0.13	0.026	0.002
Males 16 to <18 years	39	2.16	0.36	0.030	0.005
Females 16 to <18 years	39	1.88	0.29	0.032	0.005
Males 18 to <21 years	48	3.53	0.48	0.047	0.007
Females 18 to <21 years	42	2.07	0.21	0.032	0.003
Males 21+ years	56	4.88	0.27	0.058	0.003
Females 21+ years	53	3.17	0.15	0.046	0.002
Total US	48	3.06	0.14	0.046	0.002

Table 4. Usual intake of fish and shellfish among consumers by age group (usual reflects 30-day average).

Population	*% Consumers*	*Intake (g/day)*		*Intake (g/kg/day)*	
		Mean	*SE*	*Mean*	*SE*
All fish					
Children 1 to <2 years	53	4.16	0.10	0.37	0.009
Children 2 to <3 years	60	5.03	0.11	0.37	0.008
Children 3 to 6 years	59	6.00	0.09	0.33	0.005
Children 6 to <11 years	51	8.64	0.17	0.30	0.006
Males 11 to <16 years	48	7.85	0.22	0.15	0.005
Females 11 to <16 years	48	6.80	0.20	0.13	0.004
Males 16 to <18 years	49	12.83	0.63	0.18	0.009
Females 16 to <18 years	48	8.29	0.29	0.14	0.005
Males 18 to <21 years	55	15.88	0.86	0.20	0.011
Females 18 to <21 years	56	9.25	0.24	0.15	0.004
Males 21+ years	76	17.86	0.20	0.21	0.003
Females 21+ years	75	12.27	0.14	0.18	0.002
Total US	69	12.80	0.28	0.20	0.005
All shellfish					
Children 1 to <2 years	22	0.56	0.02	0.05	0.002
Children 2 to <3 years	26	1.48	0.05	0.11	0.004
Children 3 to 6 years	29	3.15	0.07	0.18	0.004
Children 6 to <11 years	33	3.33	0.12	0.12	0.005
Males 11 to <16 years	33	4.61	0.23	0.09	0.004
Females 11 to <16 years	35	3.90	0.18	0.08	0.003
Males 16 to <18 years	39	5.49	0.29	0.08	0.004
Females 16 to <18 years	39	4.77	0.28	0.08	0.005
Males 18 to <21 years	48	7.29	0.32	0.10	0.005
Females 18 to <21 years	42	4.93	0.16	0.08	0.003
Males 21+ years	56	8.71	0.12	0.10	0.002
Females 21+ years	53	5.97	0.09	0.09	0.001
Total US	48	6.38	0.15	0.10	0.002

similar to recent estimates of usual intake of fish and seafood based on the data from NHANES 2001–2004 from the National Cancer Institute (NCI) (Table 10).[32]

The NCI model is based on the same general premise as the approach used in the current study, namely that usual intake is equal to the probability of consumption times the amount consumed. The current study combined the empirical distribution of the number of EOs per day with the empirical distribution of amounts consumed per EO, while the NCI approach uses more complex statistical methods to estimate the probability of consumption and the distribution of daily consumption amounts. Specifically, the NCI method consists of two parts.[33] The first part of the NCI approach uses logistic regression with a person-specific random effect to model the probability of consumption on a given day. The probability of consumption is estimated from the 24-h dietary recall data. The second part of NCI's model specifies the consumption-day amount of a food using the 24-h recall data on a transformed scale. It includes a person-specific effect as well as within-person variability owing to day-to-day variation in an individual's intake and other sources of random error. The NCI

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summary tables do not specify whether the estimates are for consumers only or *per capita* estimates. A recent publication showed a larger association between serum mercury levels and estimates of long-term intake of fish derived using the NCI method, than between serum mercury levels and the simple 2-day average intake estimates.[34]

Carrington and Bolger[35] derived estimates of long-term fish intake by women aged 18–44 years using consumption data from the 1994 to 1996 and 1998 CSFII, adjusted to reflect the proportion of household reporting fish consumption over a 12-month period. The estimated median, 75th, 90th, and 95th percentile intake estimates derived by Carrington and Bolger[35], expressed in oz/day were 0.23, 0.57, 1.38, and 2.09, which are comparable to the estimates derived in the current study.

The usual intake distributions were generated using a Monte Carol procedure that combined the frequency of fish and shell fish consumption with gram per EO values randomly selected from age- and sex-specific gram per EO distributions derived from short-term intake data. These gram per EO distributions do not distinguish between individual variation and temporal (i.e., within individual) variation. Also as the same gram per EO distributions were used for subjects in the same age and sex group, the approach used is implicitly assuming that the variation observed in the gram per EO is entirely temporal (i.e., that there is no individual variation for subjects in the same age and sex group).

Table 5. Usual intake by fish types among all fish consumers (usual reflects 30-day average).

Fish type	*% Consumer*	*Intake (g/day)*		*Intake (g/kg/day)*	
		Mean	*SE*	*Mean*	*SE*
Tuna	35	5.87	0.13	0.09	0.00
Salmon	18	8.80	0.36	0.14	0.01
Breaded fish	14	7.26	0.21	0.14	0.00
Other fish	10	6.72	0.44	0.12	0.01
Catfish	10	7.17	0.19	0.11	0.00
Cod	7	7.74	0.33	0.11	0.00
Flat fish	6	8.06	0.31	0.13	0.01
Unknown fish	4	6.94	0.38	0.10	0.01
Haddock	3	6.40	0.34	0.09	0.00
Trout	3	5.84	0.26	0.09	0.00
Pollock	3	6.96	0.52	0.11	0.01
Perch	2	7.94	0.68	0.11	0.01
Sardine	2	7.22	0.38	0.12	0.01
Bass	1	7.94	1.10	0.11	0.01
Swordfish	1	4.87	0.27	0.07	0.01
Walleye	1	7.54	0.66	0.10	0.01
Seabass	1	4.96	0.39	0.07	0.01
Mackerel	1	8.48	0.08	0.14	0.04
Shark	0.3	3.79	0.21	0.07	0.00
Pike	0.3	4.78	0.35	0.07	0.01
Porgy	0.2	5.56	0.46	0.10	0.01

Table 7. Usual shellfish intake by type among all shellfish consumers (usual reflects 30-day average).

Shellfish types	*% Consumers*	*Intake (g/day)*		*Intake (g/kg/day)*	
		Mean	*SE*	*Mean*	*SE*
Shrimp	41	3.63	0.08	0.06	0.00
Crab	12	4.14	0.12	0.06	0.00
Clam	7	2.12	0.08	0.03	0.00
Scallop	7	4.43	0.13	0.06	0.00
Lobster	5	3.83	0.15	0.06	0.00
Oyster	4	2.48	0.13	0.04	0.00
Other shellfish	3	4.76	0.20	0.07	0.00
Mussel	2	4.29	0.18	0.06	0.00
Crayfish	1	4.45	0.36	0.07	0.01
Unknown shellfish	0.2	4.52	0.96	0.06	0.01

Table 6. Usual intake of top three fish types among consuming children (usual reflects 30-day average).

Population	*Fish type*	*% Consumers*	*Intake (g/day)*		*Intake (g/kg/day)*	
			Mean	*SE*	*Mean*	*SE*
Children 1 to <2 years	Tuna	24	0.78	0.04	0.07	0.004
	Breaded fish	18	4.13	0.18	0.36	0.02
	Salmon	11	3.72	0.18	0.33	0.02
Children 2 to <3 years	Tuna	30	2.93	0.10	0.22	0.01
	Breaded fish	20	4.19	0.14	0.31	0.01
	Salmon	11	2.51	0.17	0.18	0.01
Children 3 to <6 years	Tuna	27	2.84	0.05	0.16	0.003
	Breaded fish	21	4.12	0.12	0.24	0.01
	Salmon	10	4.83	0.14	0.27	0.01
Children 6 to <11 years	Tuna	25	4.99	0.12	0.17	0.004
	Breaded fish	15	6.74	0.30	0.25	0.01
	Salmon	10	4.02	0.18	0.14	0.01
Females 11 to <16 years	Tuna	22	5.39	0.23	0.10	0.004
	Breaded fish	11	4.83	0.48	0.09	0.01
	Salmon	9	6.55	0.41	0.13	0.01
Females 16 to <18 years	Tuna	26	5.02	0.22	0.09	0.004
	Salmon	12	7.45	0.61	0.13	0.01
	Breaded fish	7	6.74	0.80	0.11	0.01
Males 11 to <16 years	Tuna	17	5.24	0.23	0.10	0.004
	Salmon	12	5.98	0.43	0.11	0.01
	Breaded fish	9	4.99	0.44	0.10	0.01
Males 16 to <18 years	Tuna	19	6.47	0.56	0.09	0.01
	Salmon	13	10.38	1.00	0.14	0.01
	Breaded fish	8	9.72	1.63	0.13	0.02

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Table 8. Usual intake of top three shellfish types among consuming children (usual reflects 30-day average).

Population	*Shellfish type*	*% Consumers*	*Intake (g/day)*		*Intake (g/kg/day)*	
			Mean	*SE*	*Mean*	*SE*
Children 1 to <2 years	Shrimp	19	0.48	0.02	0.04	0.001
	Crab	4	0.40	0.03	0.04	0.003
	Scallop	1	0.45	0.05	0.04	0.004
Children 2 to <3 years	Shrimp	21	1.57	0.06	0.12	0.005
	Crab	5	0.48	0.02	0.04	0.002
	Scallop	1	0.31	0.02	0.02	0.002
Children 3 to <6 years	Shrimp	25	1.98	0.03	0.11	0.002
	Crab	4	3.43	0.16	0.20	0.010
	Scallop	1	3.46	0.26	0.19	0.016
Children 6 to <11 years	Shrimp	28	1.96	0.06	0.07	0.002
	Crab	6	3.12	0.27	0.11	0.011
	Scallop	1	3.26	0.55	0.12	0.023
Females 11 to <16 years	Shrimp	28	3.21	0.17	0.06	0.003
	Crab	7	2.30	0.18	0.04	0.004
	Scallop	2	2.19	0.34	0.04	0.006
Females 16 to <18 years	Shrimp	32	2.83	0.22	0.05	0.004
	Crab	10	3.63	0.37	0.06	0.006
	Scallop	2	10.92	2.55	0.18	0.042
Males 11 to <16 years	Shrimp	27	3.23	0.19	0.06	0.003
	Crab	6	2.76	0.27	0.05	0.005
	Scallop	2	3.86	0.72	0.07	0.012
Males 16 to <18 years	Shrimp	33	3.95	0.26	0.06	0.004
	Crab	7	3.45	0.44	0.04	0.006
	Scallop	3	3.10	0.46	0.04	0.005

Table 9. Comparison with other *per capita* intake estimates.

Population	*Fish type*	*Mean (g/day)*	*CSFII estimate (g/day)*[26]
	All fish	3.56	
Children 3 to <6 years	All shellfish	0.91	Children 3–5 years
	All fish and shellfish	4.47	5.2
	All fish	4.39	
Children 6 to 11 years	All shellfish	1.10	Children 6–10 years
	All fish and shellfish	5.49	6.3
	All fish	3.76	
Males 11 to <16 years	All shellfish	1.52	
	All fish and shellfish	5.28	M and F 11–15 years
			8.5
	All fish	3.25	
Females 11 to <16 years	All shellfish	1.36	
	All fish and shellfish	4.61	
	All fish	6.32	
Males 16 to <18 years	All shellfish	2.16	
	All fish and shellfish	8.48	M and F 16–17 years
			8.1
	All fish	3.98	
Females 16 to <18 years	All shellfish	1.88	
	All fish and shellfish	5.86	
	All fish	13.50	
Males 21+ years	All shellfish	4.88	
	All fish and shellfish	18.38	M and F 18+ years
			15.3
	All fish	9.16	
Females 21+ years	All shellfish	3.17	
	All fish and shellfish	12.33	

Allowing for inter-individual variation in the amount consumed per EO would be expected to result in larger long-term individual variation in fish consumption.

A potential limitation of the approach used in this study stems from applying one EO amount to a person's frequency of consumption, and thus not allowing for potential within-person

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Table 10. Comparison of usual intake estimates of fish and shell fish (oz/day)

Study	*Age (years)*	*Mean*	*Percentile*						
			5	*10*	*25*	*50*	*75*	*90*	*95*
Children									
NCI	1–3	0.20	0.02	0.03	0.06	0.12	0.23	0.41	0.56
Current study	1–2	0.13	<0.01	0.01	0.02	0.07	0.17	0.30	0.46
NCI	4–8	0.20	0.03	0.04	0.08	0.16	0.30	0.52	0.71
Current study	3–6	0.23	0.02	0.03	0.06	0.13	0.27	0.50	0.72
Males									
NCI	9–13	0.20	0.01	0.02	0.05	0.12	0.28	0.55	0.80
Current study	11–16	0.29	0.01	0.02	0.06	0.15	0.32	0.65	1.05
NCI	14–18	0.20	0.01	0.02	0.06	0.14	0.30	0.59	0.86
Current study	16–18	0.44	0.02	0.04	0.09	0.23	0.50	1.13	1.70
NCI	19–30	0.50	0.03	0.06	0.12	0.28	0.58	1.06	1.51
Current study	18–21	0.56	0.03	0.05	0.12	0.29	0.64	1.23	1.80
NCI	19+	0.70	0.05	0.09	0.19	0.42	0.87	1.56	2.17
Current study	21+	0.73	0.04	0.08	0.20	0.45	0.92	1.66	2.32
Females									
NCI	9–13	0.20	0.03	0.04	0.07	0.12	0.22	0.35	0.47
Current study	11–16	0.25	0.01	0.02	0.05	0.14	0.30	0.59	0.87
NCI	14–18	0.30	0.04	0.06	0.11	0.19	0.33	0.53	0.69
Current study	16–18	0.31	0.02	0.03	0.07	0.17	0.36	0.70	1.09
NCI	19–30	0.30	0.05	0.08	0.13	0.23	0.39	0.62	0.80
Current study	18–21	0.35	0.02	0.03	0.08	0.20	0.44	0.83	1.13
NCI	19+	0.50	0.09	0.12	0.22	0.39	0.67	1.04	1.31
Current study	21+	0.49	0.03	0.06	0.13	0.30	0.61	1.10	1.55
All persons									
NCI	1+	0.50	0.04	0.07	0.14	0.31	0.62	1.10	1.52
Current study	1+	0.51	0.03	0.05	0.12	0.29	0.62	1.18	1.69

EO-to-EO variability. However, the process was repeated multiple times per person (an average of 10 times), hence allowed for different EO amounts to be applied to the same person at each iteration. The approach used in this study could result in more variability in the usual intake distribution at the population level than if different EO amounts were selected for each of the EO.

Another potential limitation of the approach used in this study is the assumption of independence between the distributions of the number of servings of fish consumed per month and the amount of fish consumed per serving. Tooze et al.[33] analyzed data from four 24-h dietary recalls from the Eating at America's Table Study (EATS) and showed a positive association between the amount of food consumed per day and the number of days the food was reported consumed. Based on their results, Tooze et al.[33] indicate that ignoring the potential positive association between the two distributions could result in overestimation of the usual amount of food consumed at the lower percentiles and underestimation at the upper percentiles. We estimated the Pearson correlation coefficient between the reported frequency of consumption per month and the amount consumed per day for tuna, the fish reported to be most frequently consumed in the FFQ. The correlation was 0.11 for consumers of tuna on day 1, -0.16 for consumers of tuna on day 2, and -0.02 for consumers on day 1 or day 2. These results appear to contradict the correlations reported by Tooze et al.[33] It is not possible to determine whether this apparent contradiction is due to the difference between the reference periods for the frequency distribution (30 days in the NHANES FFQ *versus* 4 days in EATS) or to generalize the current finding for tuna to other types of fish.

This study combines data from several NHANES data sets spanning a period of 7 years (from 1999 to 2006). It is possible that fish consumption patterns may have changed over this period. Further, there were methodological differences between the various NHANES included in this assessment. The approach included an adjustment to the statistical weights assigned to participants in the various NHANES, but did not address other potential differences between the various NHANES. Further, the weight adjustment approach used owing to the differences in the targeted age groups in the various NHANES survey years may have distorted the weighting procedure recommended by NHANES. As a result, the total population counts and estimates may not be entirely representative of the overall US population (all ages combined) and of age groups that overlap with females 16 to <50. Our tabulated results include the following age cohorts: children 1 to <2, 2 to <3, 3 to <6, 6 to <11 years, and M/F 11 to <16, 16 to <18, 18 to <21, 21+ years, as well as total US. Hence, results for females 21+ years and total US may be affected by this weight adjustment.

Conclusion

Estimation of the long-term average daily intake of a food on the basis of short-term survey data, such as the 24-h dietary recall, can be problematic particularly when foods of interest are consumed only occasionally, as in the case of fish and shellfish. This study uses empirical distributions of long-term frequency of fish consumption and fish intakes per EO derived from several NHANES databases to estimate long-term fish intake for the US population. The intake estimates from this study better reflect long-term average intake rates and are preferred to assess long-term intake of nutrients and possible exposure to environmental contaminants from fish and shellfish sources than 2-day average estimates.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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