EFFECTS OF REGULATORY GUIDELINES ON THE INTAKE OF MERCURY FROM FISH—THE MECCA[1] PROJECT

ROLAND FINCH[2]

ABSTRACT

The MECCA program applies a survey of the fish consumption habits of a sample of over 4,500 individuals, representative of the U.S. population, to build a computer model, which uses known levels of microconstituents in 52 kinds of fish to predict the distribution of the daily intakes of the microconstituents from fish among the survey participants. The model was applied to mercury levels in fish to estimate the effects of guidelines (maximum permitted levels) for fish in protecting the population against excessive intake. The study indicated that, for the sample population, intakes of mercury from fish would remain safe if the guideline for mercury in fish were raised from the present level of 0.5 ppm to 1.5 ppm. The effect of such an increase would be of benefit to both the consumer and the fishing industry. This model can be used to predict the distribution of consumer intakes from fish of any constituent present in the fish, whether nutritious or potentially hazardous, for which the levels in the edible portion of the 52 kinds of fish used in the model are known.

Following incidents of methyl mercury poisoning reported from Japan and Sweden, the U.S. Food and Drug Administration (FDA) in 1970 established an interim guideline permitting a maximum level of 0.5 part per million (ppm) for methylmercury in fish, determined in practice through total mercury. This level was based on a careful review of the limited information available to the FDA at that time, but it was noted that this was an interim action and the level would be subject to amendment if subsequent information indicated this should be done. The level was based on the following assumptions:

1. Fish is the sole significant contributor of methylmercury in the U.S. food supply. Traces of mercury are sometimes found in other foods but are present in the substantially less toxic inorganic form.
2. Almost all of the mercury present in marine fish, which compose most of the U.S. supply, is present in the form of methylmercury.
3. Man can safely consume up to 30 μg methylmercury daily (see Peterson, Klawe, and Sharp, 1973). Continued consumption of larger average intakes increases his body burden and can result in harmful effects.
4. An average high consumption level of fish in the United States does not normally exceed 60 g (just over 2 oz) daily. This figure can be compared with the calculated national average of approximately 14 g daily.
5. Limiting the methylmercury level of fish to 0.5 ppm would limit the intake provided by 60 g fish to 30 μg/day.

It was pointed out at the time that the greater part of the fish supply in the United States contains considerably less than 0.5 ppm mercury and suggested that it would be more realistic to use a weighted average of the mercury levels of all species consumed in calculating a guideline. This average, calculated to be below 0.20 ppm, would give a guideline of 1.2 ppm or higher. Such an approach was not regarded as acceptable by the FDA, since

[1] MECCA is an acronym for Model for the Estimation of the Consumption of Contaminants from Aquatic Foods.

[2] Fishery Products Research and Inspection Division, National Marine Fisheries Service, NOAA, Washington, DC 20235.

Manuscript accepted February 1973.
FISHERY BULLETIN: VOL. 71, NO. 3, 1973.

some consumers can be expected to eat disproportionately large amounts of species which they prefer and which in some cases will contain more than this average. This interim level is still in effect.

The application of the 0.5 mercury interim guideline has led to serious operational and economic hardship for some segments of the fishing industry. The swordfish industry has been virtually eliminated, at least for the present. The tuna and halibut industries are operating voluntary self-regulation schemes involving extensive testing, elaborate and expensive handling procedures, and product loss. Press reports on other species have alarmed consumers and adversely affected sales. It is therefore worth examining this present guideline level to see if evidence exists that would provide a basis for upward modification which, while ensuring adequate consumer protection, would alleviate the burden on the fishing industry.

Apart from reexamination of the assumptions, such as the proportion of total mercury present as methylmercury in fish, two key figures can be reviewed which together establish the basis for the 0.5-ppm level. The first of these, the so-called acceptable daily intake (ADI) of 30 μg methylmercury/day, has been reviewed recently by the World Health Organization (WHO)/Food and Agriculture Organization of the United Nations (FAO) Expert Committee of Food Additives, but no information has thus far emerged which will permit a modification of this figure. The second figure is the high average consumption level of 60 g fish daily.

In order to examine the second assumption more carefully, a computer program was written to apply the results of a survey of fish consumption patterns of over 1,500 families to estimate the distribution of individual intakes of any microconstituent for which the levels in different species of fish are known. This was then applied to predict the effect of alternative regulatory guidelines (maximum permitted levels) on reducing the mercury intake of consumers. The same program is directly applicable to estimating the distribution of individual intakes of any microconstituent, whether nutritious or potentially toxic, provided that the levels are known in all the species of fish consumed.

The following report details the procedures used and discusses the results as applied to methylmercury.

MARKET FACTS INC. SURVEY

Commencing February 1969, Market Facts Inc. of Chicago, Ill., under contract with the National Marine Fisheries Services (NMFS), carried out a 1 yr survey of fish consumption patterns of 1,586 U.S. households with a total of 4,864 persons. The participants were selected at random from a large panel designed to parallel census data for the United States with respect to population density and degree of urbanization, geographic region, household income, and age of panel members, providing a reasonable cross section of other demographic characteristics.

The head of each household completed a diary of fish purchases twice monthly for 12 mo. These diaries reported purchases of fish and shellfish products by item, weight and cost, numbers of fish meals eaten away from home by item, and the number of meals consumed at home prepared from sport fish by species. Purchases of meat, meat products, and meat substitute foods were also recorded.

This survey was undertaken to provide information for economic analysis. Results have been reviewed by Nash (1971) and by Miller and Nash (1971).

APPLICATION OF THE SURVEY TO INTAKE ESTIMATES

General Procedure

In order to organize the data in the Market Facts survey to enable intakes to be estimated, they were first transformed into a data base which lists for each family, estimates of the total weights of each kind[3] of fish consumed

[3] The term kind of fish is used here rather than species since, although most of the kinds of fish in the data base are identifiable species in the biological sense, some refer to common names representing mixed species

for the period reported. A computer model was then constructed to scan the data base, using for each run a given set of microconstituent levels for the 52 kinds of fish reported in the data base, and to calculate the average daily intake of the microconstituent for each family in turn, based upon its consumption by species. From this a distribution of the estimated intake levels of all the individuals in the survey was calculated and printed out, with other data to be described. This model was applied to calculate mercury intakes from fish of individuals in the sample on the basis of average levels of mercury for the 52 kinds of fish in the data base. Further computer runs were then made using alternative input mercury levels. These were calculated assuming the effects of different regulatory guidelines upon the mercury levels in the available supply. The program readouts enabled the mercury intakes of the population average, or of any given fraction of the population, to be estimated under any of the input conditions. By comparing results, the extent to which different guidelines reduced the intakes of mercury was estimated. This process is described in detail in the following sections of the report.

Transformation of Survey Information to Data Bases

The estimates of consumption of kinds of fish which comprised the data base were developed as follows:

1. Records were selected from those families who reported for a minimum of 12 periods (6 mo). The number of reporting periods was noted for each family.
2. The purchases of each item by each family during all reporting periods were totaled.
3. These amounts were transformed into corresponding figures for weights of each kind of edible fish consumed by multiplying the total for each item by an appropriate factor for that item. Table 1 lists these factors and provides a note on their derivation.
4. The next step was to estimate the amounts of fish items consumed in meals away from home. The records showed for each item the number of times it was consumed in the reporting period, and how many family members participated in each meal out. From this, the total number of servings of each item for each family was determined for the total reporting period.
5. This number of servings was then converted to the weight consumed, using a factor for the item representing the average weight in ounces usually provided in one serving. Table 1 lists the factors used.
6. The estimated weights for each kind of sport fish consumed by each family was obtained by multiplying the number of events for each kind by the number in the family and then by a factor representing the estimated average weight of the edible portion of this kind usually consumed by an average individual. These factors shown in Table 1 are the same as those used for meals away from home.
7. The total weight of each kind of fish consumed by each family was obtained by adding the edible weights purchased to the weights provided by meals away from home and the sports catch consumption. In a number of cases, several separately reported items were aggregated to provide total estimates of the consumption of a given kind of fish from all sources. For example, the total for the light meat tuna category included canned light meat tuna, tuna sandwiches, tuna salad, and tuna pies. In this way over 150 different classes of fish and products, many of them specialty items, were reduced to 52 kinds. The finished data base displays the estimated amounts of each of these 52 kinds of fish consumed from all sources by each family during the reporting period, the length of reporting period, the number in in the family, and coded socioeconomic data provided by the original survey.

used in the survey and better understood by the average consumer. For example, light meat tuna can legally consist of several species, although in the United States it commonly includes yellowfin tuna, *Thunnus albacares*; bluefin tuna, *Thunnus thynnus*; and skipjack tuna, *Katsuwonus pelamis*. Also for convenience of calculation, some fish products, such as fish sticks, were identified as kinds of fish in the data base rather than reassigning them to component species.

TABLE 1.—Factors used to convert purchased weight, events of meals away from home and home consumption of sport catch to weight of edible portion consumed.[1]

Original item code	Name of item	Purchase/ consumed	Meals away from home and sport catches (oz/event)
001	Tuna pie	0.18	—
002	Clam chowder	.13	—
003	Oyster stew	.30	—
004	Shrimp creole	.14	—
005	Shrimp, stuffed	.90	—
006	TV or prepared fish dinners	.25	—
007	Smoked fish (not canned)	.75	—
008	Cured fish (not canned)	1.00	—
009	Kippered fish (not canned)	.35	—
010	Salted fish (not canned)	1.00	—
011	Pickled fish (not canned)	1.00	—
012	Other specialty items	.50	—
014	Shrimp — size unspec.	.70	3.00
015	Shrimp — jumbo size	.70	3.00
016	Shrimp — large size	.70	3.00
017	Shrimp — medium size	.70	3.00
018	Oysters	1.00	4.00
019	Alaska king crab, unspec.	.20	2.25
020	Alaska king crab, hard	.20	2.25
021	Alaska king crab, soft	.20	2.25
022	Alaska king crab, other	.20	2.25
023	Dungeness crab, unspec.	.24	4.00
024	Dungeness crab, hard	.24	4.00
025	Dungeness crab, soft	.24	4.00
026	Dungeness crab, other	.24	4.00
027	Blue crab, unspec.	.15	4.00
028	Blue crab, hard	.15	4.00
029	Blue crab, soft	.55	4.00
030	Blue crab, other	.15	4.00
031	Deviled crab	1.00	4.00
032	Other crabs, unspec.	.15	4.00
033	Lobster (not Crayfish)	.25	6.00
034	Lobster tail (rock lobster)	.50	6.00
035	Clams (excluding clam chowder)	1.00	4.00
036	Scallops	1.00	4.00
037	Fish sticks	.50	2.00
038	Other	1.00	4.00
039	Haddock	1.00	5.00
040	Flounder and/or sole	1.00	4.00
041	Halibut (Pacific)	1.00	5.00
042	Ocean perch	1.00	4.00
043	Cod	1.00	6.00
044	Salmon	.90	5.50
045	Red snapper	.40	8.00
046	Catfish	.90	5.00
047	Whiting	.40	6.00
048	Scup, porgy	.40	6.00
049	Mullet	.50	6.00
050	Bullhead	.80	6.00
051	Herring	.40	6.00
052	Mackerel	1.00	6.00
053	Buffalo fish	1.00	6.00
054	Yellow perch, Lake perch	.90	4.00
055	Striped bass	.35	6.00
056	Swordfish	1.00	6.00
057	Carp	.40	6.00
058	Crappie	.40	6.00
059	Shad	.40	6.00
060	Alewife	.35	6.00
061	Pollock	1.00	6.00
062	Lake trout	.90	6.00
063	Lake whitefish	.90	6.00
064	Smelt	.80	6.00
065	Jack mackerel	.40	6.00
066	Rockfish (Pacific)	1.00	6.00
067	Pompano	.40	6.00
068	Pike	.80	6.00
069	Butterfish	.50	6.00
070	Trout (other than lake)	.50	6.00

Original item code	Name of item	Purchase/ consumed	Meal away from home and sport catches (oz/event)
071	Perch (other than yellow or lake)	.50	4.00
072	Bass (other than striped)	.50	6.00
073	Fish sticks	.50	2.00
074	All other	1.00	6.00
075	Canned pink salmon	1.00	—
076	Canned red or sockeye	1.00	—
077	Canned silver or coho	1.00	—
078	Canned chum	1.00	—
079	Canned chinook	1.00	—
080	Canned salmon, unspec.	1.00	—
081	Canned other	1.00	—
082	Canned white meat, unspec.	1.00	—
083	Canned white meat, chunk	1.00	—
084	Canned white meat, solid	1.00	—
085	Canned light meat, unspec.	1.00	—
086	Canned light meat, chunk	1.00	—
087	Canned light meat, solid	1.00	—
088	Canned dark meat, unspec.	1.00	—
089	Canned dark meat, chunk	1.00	—
090	Canned dark meat, solid	1.00	—
091	Canned grated tuna	1.00	—
092	Canned tuna chunk, unspec.	1.00	—
093	Canned other	1.00	—
094	Canned tuna, unspec.	1.00	—
095	Canned Maine	1.00	—
096	Canned Imported	1.00	—
097	Canned Pacific	1.00	—
098	Other sardines, other unspec.	1.00	—
099	Canned shrimp	1.00	—
100	Canned oysters	1.00	—
101	Canned mackerel	1.00	—
102	Canned anchovies	1.00	—
103	Canned clams (minced)	1.00	—
104	Canned lobster	1.00	—
105	Canned crab/crabmeat, unspec.	1.00	—
106	Canned Alaska king crab	1.00	—
107	Canned crab dungeness	1.00	—
108	Herring	.90	—
109	Gefilte fish	1.00	—
110	Shrimp, unspec.	—	3.00
111	Fried shrimp	—	3.00
112	Shrimp cocktail	—	1.50
113	Stuffed shrimp	—	4.00
114	Shrimp royale	—	3.00
115	Other shrimp	—	4.00
116	Lobster, unspec.	—	6.00
117	Lobster tail	—	6.00
118	Other lobster (boiled, etc.)	—	6.00
119	Clams, unspec/fried	—	4.00
120	Clam chowder	—	1.50
121	Other clams	—	2.00
122	Crab/crabmeat, unspec.	—	4.00
123	Crab dungeness	—	4.00
124	Crab Louis	—	2.00
125	Alaska/king crab	—	2.25
126	Other crabs (soup)	—	1.50
127	Perch, unspec.	—	4.00
128	Ocean perch	—	4.00
129	Fried perch	—	4.00
130	Other perch	—	4.00
131	Oysters	—	4.00
132	Scallops	—	4.00
133	Other oysters	—	4.00
134	Flounder	—	5.00
135	Haddock	—	5.00
136	Catfish	—	5.00
137	Halibut	—	5.00
138	Trout	—	6.00

TABLE 1.—*Continued.*

Original item code	Name of item	Purchase/ consumed	Meal away from home and sport catches (oz/event)
139	Red snapper	—	8.00
140	Tuna	—	2.50
141	Tuna casserole/salad/ a la king	—	2.50
142	Salmon, all	—	5.50
143	Swordfish	—	6.00
144	Fish sticks	—	2.00
145	Fish & chips	—	3.00
146	Fish & fries	—	3.00
147	Seafood plate/platter Fish dinner	—	4.00
148	Fish sandwich	—	2.00
149	Fish croquettes	—	2.00
150	Sole	—	4.00
151	Chinese dinners	—	0.75
152	Fish fry	—	4.00
153	Fish, unspec.	—	6.00
154	Other	—	6.00
155	Mackerel	—	6.00
156	Herring	—	5.00
157	Whitefish	—	6.00
158	Cod	—	6.00
159	Pike	—	6.00

[1] These data were derived by reviewing the commonly sold forms of the species involved, available data on the yield of edible portions from purchased forms, and amounts used in standard recipes. For meals away from home, data on amounts of fish served in various dishes was obtained from major institutional caterers. All these figures are somewhat variable, and the factors used represent best estimates of the averages in each case.

A review was made of the defective records in the survey, i.e., those with incomplete data. It was decided that these might be compensated in two ways. One would be to eliminate all defective records. This would give a smaller base but one which might be atypical since more records were defective in some categories. The second approach would be to include all records and develop a recovery procedure for these. It was decided to develop two data bases, one using each procedure. If these compared well, it would indicate the acceptability of both treatments. A detailed description of the consideration, the procedures used, and a comparison of results using the two data bases, are shown in the Appendix. Both methods gave comparable results, thus adding confidence that the methods used were valid. Runs were usually made using Data Base 1.

Application of Data Bases to Estimate Mercury Intakes

The computer program is designed to use the data base to estimate the intake of a microconstituent, in this case mercury, for each family in turn and to display the distribution of these estimated intakes among families and individuals. This is accomplished as follows:

1. The input for each run is a set of microconstituent levels for each of the 52 kinds of fish.
2. Using this set of levels, the program calculates the estimated average microconstituent intake of each family in micrograms per day (I_f) by aggregating the intakes calculated for each kind of fish, and prorating from the number of periods reported (P) to 24 (1 yr, semimonthly) as follows:

$$I_f = \frac{24}{P} \Sigma\ W_s \times L_s \times 0.0777$$

where: W_s = estimated total weight (ounces) consumed of species s.

L_s = level of microconstituent (ppm) in species s.

3. The intake for each family is divided by the number in the family to give individual daily intake levels.
4. The results from all families and individuals are ranked in intervals of 1 μg/day. The results are printed out in two forms. One shows the number and percentage of individuals and families falling into each interval. The second is a histogram which displays the percentage of individuals by tenths falling into each interval.
5. The program also prints out the coded identity of each of the families in the five highest intake intervals occurring and the level of their individual intakes.
6. In addition, the average daily intake for all individuals is calculated and printed out.

Mercury Levels in Fish

In order to apply methylmercury data to the program, a review was made of analytical results available for total mercury on different species of fish, including results obtained by the NMFS, and those made available by the FDA and the Canadian Government Inspection Service. The data were all obtained using variations of the following procedures: Armstrong and Uthe (1971); Uthe (1971) and Uthe, Armstrong, and Stainton (1970). Difficulty was experienced in cross referencing in some cases since the Market Facts survey used common names for fish which did not always represent unique species. For example, the survey lists mackerel. This could include Spanish mackerel, *Scomberomorus maculatus*; king mackerel, *Scomberomorus cavalla*; or Atlantic mackerel, *Scomber scombrus*. It would not refer to jack mackerel, *Trachurus symmetricus*, which would appear under canned mackerel. In this case, average mercury levels were calculated for mackerel by weighting levels for each of the three species referred to above according to the 1969 U.S. landings (Riley, 1970).

In the case of mixed categories, levels were calculated for each, making assumptions on their frequency of use. Thus in the case of fish sticks, it was assumed that these consisted of 40% cod, 40% haddock, and 20% sole. The risk of introducing serious errors by this somewhat arbitrary procedure was not considered high since all the species likely to be involved in these grouped categories have relatively low mercury levels (0.1 ppm) and do not differ greatly from each other. The case of light meat tuna presents a particular problem since the consumption is relatively high and the levels both within and between species vary considerably.

In other cases also it is difficult to be sure of the extent to which the analytical data for particular kinds of fish is representative of mercury levels in the corresponding commercial supply since methylmercury levels in fish may vary substantially with biological and environmental factors and since there are practical limits to the number and range of samples which may be obtained and analyzed and to their application to the market supply. Moreover, sampling for regulatory purposes may be concentrated on those segments of the catch whose size and catch location may give reason to believe they are most likely to exceed the guideline, e.g., large fish, so that the results obtained in the course of regulatory activities may be unrepresentative of the whole catch. For this study the sources of all available data for each species were reviewed and, to the extent possible, data believed to be unrepresentative were eliminated. The mercury data used also reflect that in the fishery resource, not that in the market place, since FDA controls have eliminated much, if not all, of the high level fish. The figures used cannot therefore be regarded as indicators of levels found in the present supply, but rather that which would exist under various guideline conditions.

To assess the effects of possible errors in the mercury levels used, the sensitivity of the estimates produced by the program to variations in input levels of each species in the program was tested. Preliminary runs were made in which the input mercury levels were increased for each kind of fish in turn. In the case of kinds of fish having low levels initially, the level was increased by 100%. Where the initial levels were over 0.20 ppm, the levels were increased by 25-70% with actual increases no less than 0.10 ppm. Sensitivity was judged by differences from the standard run in the level of intake not exceeded by 99% of the sample (99% level), by changes in the intakes of the highest family. The preliminary runs showed that increases in 40 of the kinds of fish in the survey had no measurable effect on the higher intake levels. This means that relatively large errors in the mercury input data for these kinds of fish data would not be critical to the reliability of the end result. Of the remainder, only variations in the input data of white meat tuna, light meat tuna, and swordfish showed marked effects on the end results. These were subjected to further sensitivity testing using revised data as were also mackerel, red snapper and the "all other fish" category since mercury data available for these was limited. The results of these tests, shown in Table 2, confirms that only the input levels of light meat tuna, white meat tuna, and swordfish markedly affect the end results.

Finally, in order to estimate the effects of guidelines on the mercury consumption pattern, average mercury levels were calculated for each kind of fish, under five assumptions:

1. All the commercial catch is marketed (base line).
2. Fish containing over 1.5 ppm mercury are removed from the market (guideline 1.5 ppm).
3. Fish containing over 1.0 ppm mercury are removed from the market (guideline 1.0 ppm).
4. Fish containing over 0.75 ppm mercury are removed from the market (guideline 0.75 ppm).
5. All fish containing over 0.5 ppm mercury are removed from the market (present FDA guideline).

For most kinds of fish no sample exceeded 0.5 ppm, and the averages were the same under different assumptions. A list of the levels used under the assumptions is given in Table 3. It is reiterated that these are not intended in all cases to represent levels in fish now available in the market.

TABLE 2.—Sensitivity test.[1]

Run identity	Mercury level input (ppm)		Readouts (μg/day)[2]			
	Standard	Test	0.1%	1.0%	Highest reading	Average
Standard run	—	—	30	17	31.8	2.57
Light meat tuna	0.31	0.41	30	18	32.7	2.85
White meat tuna	0.30	0.35	30	18	31.8	2.69
Swordfish	1.10	0.00	.19	12	20.8	1.94
Mackerel	0.51	0.71	30	17	31.8	2.58
Red snapper	0.43	0.54	30	17	31.8	2.58
All other fish	0.15	0.30	30	17	31.8	2.62

[1] The tests were run using Data Base 2 and preliminary data. They may therefore differ slightly from the final run data. Sensitivity to the increase or decrease in mercury level input shown in the test column may be seen by comparing the corresponding readouts with the standard run.
[2] Columns marked 0.1% and 1.0% refer to the level of daily intake in μg/day exceeded only by 0.1% and 1.0%, respectively, of the individuals in the sample.

TABLE 3.—Mercury levels[1] used in MECCA runs.

Code	Kind of fish	Alternative guideline levels (ppm)				
		none	1.5	1.0	0.75	0.5
01	Tuna — light	0.31	0.26	0.26	0.26	0.22
02	Tuna — white	0.30	—	—	—	—
03	Clam	0.04	—	—	—	—
04	Oyster	0.03	—	—	—	—
05	Shrimp	0.06	—	—	—	—
06	Whitefish	0.05	—	—	—	—
07	Herring	0.07	—	—	—	—
08	Cod	0.10	—	—	—	—
09	King crab	0.06	—	—	—	—
10	Dungeness crab	0.16	—	—	—	—
11	Blue crab	0.08	—	—	—	—
12	Lobster	0.24	0.24	0.24	0.19	0.19
13	Lobster tail	0.09	—	—	—	—
14	Scallops	0.03	—	—	—	—
15	Other shellfish	0.06	—	—	—	—
16	Haddock	0.05	—	—	—	—
17	Flounder/sole	0.10	—	—	—	—
18	Halibut	0.23	0.21	0.21	0.20	0.17
19	Ocean perch	0.08	—	—	—	—
20	Salmon	0.03	—	—	—	—
21	Snapper	0.42	0.37	0.37	0.36	0.32
22	Catfish	0.14	—	—	—	—
23	Whiting	0.07	—	—	—	—
24	Scup porgy	0.19	—	—	—	—
25	Mullet	0.14	—	—	—	—
26	Bullhead	0.30	0.30	0.30	0.30	0.14
27	Mackerel	0.51	0.44	0.37	0.33	0.25
28	Buffalo fish	0.23	0.21	0.21	0.21	0.21
29	Yellow, lake perch	0.35	0.35	0.26	0.24	0.21
30	Striped bass	0.35	0.35	0.26	0.23	0.21
31	Swordfish	1.10	0.92	0.80	0.63	0.49
32	Carp	0.31	0.31	0.22	0.19	0.17
33	Crappie	0.11	—	—	—	—
34	Shad	0.12	—	—	—	—
35	Alewife	0.10	—	—	—	—
36	Pollock	0.22	—	—	—	—
37	Lake trout	0.35	—	—	—	—
38	Smelt	0.07	—	—	—	—
39	Jack mackerel	0.04	—	—	—	—
40	Rockfish (Pacific)	0.20	0.20	0.20	0.19	0.19
41	Pompano	0.41	0.25	0.25	0.25	0.25
42	Pike	0.56	0.56	0.43	0.37	0.25
43	Butterfish	0.05	—	—	—	—
44	Trout	0.16	0.16	0.15	0.15	0.13
45	Bass	0.44	0.44	0.37	0.33	0.27
46	Fish sticks	0.06	—	—	—	—
47	All other fish	0.15	—	—	—	—
48	Seafood plate	0.06	—	—	—	—
49	Other specialties	0.06	—	—	—	—
50	Sardine, not Maine	0.02	—	—	—	—
51	Anchovies	0.04	—	—	—	—
52	TV dinners	0.05	—	—	—	—

[1] Figures are only shown for guidelines where there are differences from the unconstrained averages.

PROGRAM RUNS AND READOUTS

Following a number of preliminary experiments, including data base comparisons and sensitivity tests, the computer program was run using Data Base 1 with the following mercury levels:

1. Base-line level, i.e., average calculated for each species assuming no guidelines.
2. Average levels calculated for each species assuming each of the guidelines referred to above (Table 3).
3. Base-line level with the level for swordfish set at zero (to simulate the effect of removing swordfish from the fish supply).

From the printouts for each run, the following figures were tabulated:[4]

1. The estimated daily intake level exceeded by only 1% of the individuals in the sample (referred to as the 1% level).
2. The estimated daily intake level exceeded by only 0.1% of individuals in the sample (referred to as the 0.1% level).
3. The coded identity and estimated daily intake level of the four families with the highest intakes.
4. The average estimated daily intake of all individuals in the survey.

SUMMARY OF RESULTS

The results are summarized in Table 4. They show:

1. Based on the input levels used, 99.9% of the sample population had an intake of less than 30 μg/day, the acceptable daily intake (ADI) which forms the basis of FDA's present 0.5 ppm guideline (99.9% level).
2. The maximum intake was 31.7 μg/day, and this level was reached by one family comprising four individuals, the only family which exceeded 30 μg/day.
3. Ninety-nine percent of the test group had intakes below 17 μg/day, just over one-half of the present ADI (1% level).
4. The average intake was 2.48 μg/day, around 8% of the present ADI.
5. The application of guidelines reduced the higher estimated intakes substantially but reduced the average intake by a proportionately smaller amount.
6. The application of the present 0.5 ppm guideline reduced the highest intake to 21.3 μg/day, the 99.9% level to 20 μg/day, and the average level to 1.99 μg/day.
7. The application of a 1.0 ppm guideline reduced the highest intake to 24.6 μg/day, the 0.1% level to 25.0 μg/day, and the average level to 2.23 μg/day.
8. The application of a 1.5 ppm guideline reduced the highest intake to 27.2 μg/day, the 0.1% level to 26 μg/day, and the average level to 2.28 μg/day.

[4] Preliminary runs had shown that one family consisting of a single individual had a mercury intake around 50% higher than the next highest family under all conditions. This individual had reported for a period of 6 mo a total consumption of lake trout of 891 oz (equivalent to 4.9 oz/day). Review of the associated data showed him to have an annual income of $500, a 4th-grade education, and to have purchased 62 lb during a single 2-week reporting period, and none at other times. His total expenditure for the lake trout was given as $8.00, which is much less than the usual retail value of this amount. This report was judged to be returned or entered erroneously and was omitted.

TABLE 4.—Summary of intake estimates using Data Base 1 (μg/day).[1]

Guideline base	0.1% level	1.0% level	Average level	Intake levels of individuals in the four highest families			
None	30	17	2.48	31.7	29.2	26.6	26.4
1.5 ppm	26	15	2.28	27.2	25.5	24.1	23.0
1.0 ppm	25	15	2.23	24.6	24.0	23.4	23.0
0.75 ppm	21	15	2.17	23.5	22.9	20.9	20.6
0.5 ppm	20	14	1.99	21.3	20.1	20.0	19.0

[1] Intake levels in μg/day exceeded by only 0.1% and 1.0% of the test group.

Swordfish are found to have mercury levels considerably higher than those of other common marine food species. This species has in consequence been largely eliminated from the U.S. market. The effect of this upon mercury intakes was investigated by making a run in which swordfish was eliminated by putting a level of zero into the program. The results are shown in Table 5.

It may be seen that elimination of swordfish gives intake levels which are substantially lower.

This reflects the substantial contribution that swordfish makes to the mercury intake in the diets of high fish consumers. These estimates indicate that if swordfish were to be eliminated from the diet, and no guideline applied, 99.9% of the sample would have a daily intake not exceeding 19 μg/day and the highest intake

TABLE 5.—Effect of eliminating swordfish in intakes (μg/day).[1]

Basis	0.1% level	1.0% level	Average level	Intake levels of individuals in the four highest families			
No guideline	30	17	2.48	31.7	29.2	26.6	26.4
As above but eliminate swordfish	24	15	2.22	26.6	26.4	23.5	23.2

[1] Intake levels in μg/day exceeded by only 0.1% and 1.0% of the test group.

would be 26.3 ppm, less than 90% of the present ADI.

CONCLUSIONS AND DISCUSSION

These results provide evidence which would permit FDA to raise the present interim guideline for mercury in fish to 1.5 ppm without compromising public safety.

At the higher level, it would still be necessary to monitor some fisheries such as swordfish, and perhaps big eye tuna, but the expensive controls on tuna, halibut, and other species would be unnecessary. The benefits of such an action would be:

1. To assist in price stabilization or possible reduction of the affected products.
2. To remove a heavy cost and administrative burden from the processors. While no precise estimate is available, this is believed to run into several millions of dollars of unproductive costs annually.
3. To increase the fish supply by avoidance of rejection, with the corresponding nutritional benefits which this unique food supplies to the U.S. consumer.
4. To offer a probability of restoring the swordfish industry, since an FDA's market survey on swordfish made in 1971, showed that nearly 90% of swordfish samples taken then did not exceed 1.5 ppm. Swordfish at a higher mercury level might be exported to countries which, because of their differing consumption patterns, may not have limiting mercury requirements.

In order to justify the application of the results of the MECCA program to modify present regulatory guidelines, several limitations of the program must be considered. These include:

1. There are limitations on the accuracy of returns received for any survey involving over 40,000 mailed returns. Since families at all levels of education participate, errors in entries will be numerous. When entries are missing, the error is apparent and may be treated, but otherwise there is not usually any way to check. This is especially true in this case where the survey was performed for a different purpose than the present application and was completed 2 yr previously. In addition, there may be key punch errors in transcribing the written report forms received to cards.
2. It is assumed that all the fish purchased was consumed. Any errors in this respect would mean real levels lower than those shown by the program, and so provide a safety factor.
3. The transposition of common names understood by the consumer to particular species with identified mercury levels can give rise to error.
4. In some cases available mercury data are limited.

However, even with these potential shortcomings, we believe that the results of this program present a much more realistic concept than can be obtained from the present simple assumption of a high level daily intake of 60 g/day fish. Particularly it may be noted that, while the absolute values of intakes may be in some error, the relative figures showing the effects of guidelines are likely to be considerably more precise since the same errors in each run will tend to cancel in comparisons. Thus it may be noted in the data base comparison that, while the average intake level estimated for each type of run shown in Table 2 varies from 1.79 to 2.66 μg/day, the difference between the figures produced from the two bases for the same runs varies only from 0.15 to 0.19 μg/day with Data Base 2 being always higher. It may further be noted that the daily consumption of fish in the United States averages 14 g/day. Assuming a weighted average mercury content of around 0.15 ppm for U.S. species, this would provide 2.10 μg/day, which is less than the unconstrained average of 2.48 μg/day predicted by the model. The model figure includes consumption of sport catch but, although no figures exist, this is considered to be relatively small compared with consumption of commercial catch. The model results then are consistent with the national average derived externally and may indeed show a measure of conservatism, further strengthening the model solidity.

Probably the most important consideration is philosophical. How much of the population can be protected? While it seems likely that the Market Facts survey covers the broad fish purchase pattern in the United States there may be people who for reasons of religion, diet, ethnic considerations, etc. do not fall into the Market Facts pattern. Their interests, if threatened, may best be protected by an education program. It is hard to see how abnormal consumers, i.e., those outside the typical broad fish consumption pattern reviewed, such as weight watchers, can be protected realistically by any guideline that does not seriously restrict the food fish supply and the considerable nutritional benefits it has to offer the U.S. consumer. This is probably true of other guidelines based on a normal consumption pattern. For example, it should be noted that the MECCA results demonstrate that adequate protection would be provided to the entire population using a 1.5 ppm guideline. Applying the more simplistic basis of a 60-g high daily consumption originally used by FDA to the same population demonstrates less protection since 1.8% of the participants in the survey consumed an average of more than 60 g/day, and therefore on a 0.5 ppm guideline, which assumes all fish are at least at this level, these consumers could have exceeded 30 μg/day. In fact, 1% of the participants in the survey consumed 77 g daily, and 0.1% consumed 165 g daily. The MECCA program therefore demonstrates that a greater degree of protection would actually exist using a 1.5 ppm guideline than was planned for in the original calculation which established the present guideline. But in no case under the 1.5 ppm guideline did any participant exceed 27.2 μg/day, nearly 90% of the ADI.

A final note is that the MECCA program is applicable to estimating the distribution of intakes from fish of any nutritional or potentially toxic microconstituent for which the levels in the fish are known. However, its application to potential toxins is limited to mercury since other elements and compounds occur in the whole food supply. The development of a wider survey is now being considered covering the full food spectrum. Participation by FDA and U.S. Department of Agriculture is being investigated. Such a survey could be addressed to any nutrient or constituent in the same manner as MECCA to determine the distribution of the intakes of, say, available iron, vitamin A, DDT, radionuclides, etc.

ACKNOWLEDGMENT

The substantial and willing assistance of David Weiss of NOAA Computer Division and many other staff members of the College Park Fishery Products Technological Laboratory and the Economics Research Laboratory of NMFS and NOAA Computer Division, is gratefully acknowledged.

LITERATURE CITED

ARMSTRONG, F. A. J., AND J. F. UTHE.
1971. Semi-automated determination of mercury in annimal tissue. At. Absorpt. Newsl. 10:101-103.

MILLER, M. M., AND D. A. NASH.
1971. Regional and other related aspects of shellfish consumption—some preliminary findings from the 1969 consumer panel survey. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ. 361, 18 p.

NASH, D. A.
1971. A survey of fish purchases by socio-economic characteristics, fourth quarterly report November and December 1969 and January 1970. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Data Rep. 61, 148 p. on 3 microfiche.

PETERSON, C. L., W. L. KLAWE, AND G. D. SHARP.
1973. Mercury in tuna: A review. Fish. Bull., U.S. 71:603-613.

RILEY, F.
1970. Fisheries of the United States, 1969. U.S. Fish Wildl. Serv., Curr. Fish. Stat. 5300, 87 p.

UTHE, J. F.
1971. Determination of total and organic mercury levels in fish tissue. *In* B. Westley (editor), International symposium on identification and measurement of environmental pollutants, p. 207-212. National Research Council of Canada, Ottawa, Canada.

UTHE, J. F., F. A. J. ARMSTRONG, AND M. T. STAINTON.
1970. Mercury determination in fish samples by wet digestion and flameless atomic absorption spectrophotometry. J. Fish. Res. Board Can. 27:805-811.

APPENDIX

TECHNIQUES USED TO RECOVER DEFECTIVE RECORDS

While editing the Market Facts data, in preparation for creating the MECCA data base, 13,377 records were identified which qualified for inclusion, but which had critical information missing. The missing information was found to be confined to four data elements:

1. Number of individuals in family.
2. Number of meals eaten away from home.
3. Weight of fish purchased.
4. Item code (species identification).

The majority of the 13,377 records had two or more of these items missing. Because of certain redundant information in each record it was felt that many of these records could be recovered without substantial distortion of the true distribution of fish consumption.

The most easily recoverable data item was "number of individuals in family." For each record with this defect, the file of good records was searched until a match on family identity was obtained. The number of individuals shown in the good record was then inserted into the defective record.

Records of meals eaten away from home were supposed to contain the number of meals eaten on that occasion (not necessarily equal to number in family). To recover records in which this information was missing, the file of good records was read. A tally was kept of the number of "meals away from home" records, and the total number of meals eaten on those occasions was tallied. From those two figures the average number of meals eaten away from home on each occasion was computed (1.7). This value was then inserted into the defective records.

Records which had only the above two defects were reintroduced into the file of good records following recovery. The two remaining types of defects presented a more difficult problem of recovery. Not only was there no redundant information of any use, but also it was determined that nearly all of the remaining defective records had neither purchase weight nor species identification. The only usable data in the record, other than family-specific items, was an indication of fish category such as "fresh or frozen finfish," "specialty items," etc. There were 10 such categories. Balancing the desire to account for all fish products consumed against the possibility of introducing distortion of the distribution of consumption, it was decided to create two separate data bases: one with only good records and the records already recovered and the other to include all records, following the recovery of these more serious defects.

These remaining records were recovered in the following manner:

1. The file of good records was first sorted by fish category.
2. The percentage of each category represented by each item code (species identification) was calculated.
3. A cumulative percentage table was constructed for each category, giving the relative frequencies of each item code among the good records on a scale of 1 to 10,000.
4. Each defective record without an item code was read sequentially. A random number in the range 1 to 10,000 was generated and used as the subscript to the appropriate cumulative percentage table. The corresponding item code was then assigned to the record.

This processing resulted in the random assignment of item codes to the defective records with essentially the same relative frequency found in the good records.

The final phase of the recovery process involved assigning a "consumption weight" to each record without a "purchase weight" entry. The good records had already been processed to convert "weight purchased" to "weight consumed" by use of ratio figures supplied by NMFS. The good records were sorted by item code, and the average consumption weight for each item was calculated. These average weights were placed in an array in item code order. The records which were defective in purchase weight were then read sequentially, and the item code in each record was used as a subscript to access the proper average weight figure in the array. The average weight figure thus located was inserted into the defective record, completing the recovery process.

A comparison of results obtained on different types of runs using both data bases shows little difference (Appendix Table 1).

APPENDIX TABLE 1.—Comparison of data bases using four indices (all figures in μg/day).[1]

Run	0.1% level		1.0% level		Average level		Maximum individual level	
	[2]DB1	[2]DB2	DB1	DB2	DB1	DB2	DB1	DB2
Standard run	29	30	17	17	2.39	2.57	31.7	31.8
Sensitivity LM tuna	30	30	18	18	2.66	2.85	32.6	32.7
Guideline 1.0	26	26	15	15	2.18	2.34	26.9	27.0
Guideline 0.5	21	21	13	14	1.94	2.10	20.7	20.8
Swordfish 0	21	21	14	14	2.13	2.30	26.2	26.3
Guideline 0.5 + swordfish 0	17	19	12	12	1.79	1.94	20.7	20.8

[1] Intake levels in μg/day exceeded only by 0.1% and 1.0% of the test group.
[2] DB1—using Data Base 1. BD2—using Data Base 2. These figures were obtained using preliminary mercury data and may differ slightly from the final results, but the comparative data will not be significantly different.