for by using the method of additions. In the determination of cadmium and zinc, no interferences were noted and comparison with aqueous standards is satisfactory.

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LITERATURE CITED

Clarke, M. A., Morris, N. M., Tripp, V. W., Carpenter, F. G., *Proc. Sugar Ind. Technol.* 32, 160 (1973).
Clarke, M. A., Morris, N. M., Tripp, V. W., Carpenter, F. G., *Proc. Sugar Ind. Technol.* 33, 91 (1974).
Huffman, H. L., Jr., Caruso, J. A., *J. Agric. Food Chem.* 22, 824 (1974).
Kahn, H. L., *Int. J. Environ. Anal. Chem.* 3, 121 (1973).
Laitinen, H. A., "Chemical Analysis", McGraw-Hill, New York, N.Y., 1960, p 541.
Manning, D. C., *Am. Lab.* 5(8), 37 (1973).
Morriss, A. C., Nicol, W. M., *Proc. Tech. Sess. Cane Sugar Refin. Res. 1974*, in press.
Pommez, P., Clarke, M. A., *Proc. Tech. Sess. Cane Sugar Refin. Res. 1972* 5, 40 (1975).
Roberts, E. J., Rowland, S. P., *Can. J. Chem.* 47, 1571 (1969).
Roschnik, R. K., *Analyst* 98, 596 (1973).

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National Marine Fisheries Service Preliminary Survey of Selected Seafoods for Mercury, Lead, Cadmium, Chromium, and Arsenic Content

Elizabeth G. Zook,* John J. Powell, Betty M. Hackley,[1] John A. Emerson,[1] James R. Brooker,[2] and George M. Knobl, Jr.[3]

A preliminary screening study was conducted on mercury, lead, cadmium, chromium, and arsenic contents of 34 commonly consumed seafoods. A total of 334 samples were analyzed and, in general, 10 samples per species were obtained from a location. More than 96% of the samples fell below the FDA guideline of 0.5 ppm for mercury, with a mean level of 0.13 ppm. Mean lead values among species tended to be rather uniform and only a few species averaged higher than 0.6 ppm. No species mean exceeded 1 ppm. Cadmium content of most seafoods averaged less than 0.2 ppm. Chromium was present at less than 0.4 ppm in all species. Arsenic levels showed the widest variation and were higher for some species than the other elements tested. Some possible relationships between elements within each species were encountered, but the data were too limited to draw firm conclusions.

Historically, the levels of trace elements found in foods have been reported and, with few exceptions, accepted as natural constituents of the foods. Within the past 30 years, however, evidence has been obtained to support the conclusion that the trace element content of certain foods, especially fish, is often directly related to man-induced wastes discharged into streams, lakes, and the oceans.

One of the first indications was provided in the early 1950's by Japanese scientists who reported the deaths of 43 people who had consumed fish caught in Minimata Bay. These fish were found to contain abnormally high levels of mercury which had been discharged into the Bay by a chemical manufacturing plant (Irukayama et al., 1961). Swedish scientists (Westoo, 1967) also noted the buildup of mercury in freshwater fish with the result that in the 1960's their Government banned the use of alkyl mercury in agriculture and restricted other uses of mercury.

In 1969 Canadian scientists (Wobeser et al., 1970) announced that some of their freshwater fish were contaminated with mercury. Subsequently, Lake St. Clair, then other lakes and areas in the St. Lawrence system, and a few scattered areas were closed to commercial fishing.

Later that year, an announcement was made to the press that some canned tuna fish was found to exceed the Food and Drug Administration's interim guideline of 0.5 ppm of methylmercury. Public concern in the United States mounted and this concern led inevitably to some misleading statements and erroneous allegations. It became clearly important that a study be performed to determine the trace element contents of fish consumed in the United States. Accordingly, this paper reports the mercury, lead, cadmium, chromium, and arsenic contents of frequently consumed seafoods.

SAMPLES

Sampling Plan. This survey was conducted to obtain data on mineral concentrations in fish eaten in the United States; therefore, no attempt was made to follow a formal statistical sampling plan. Preferably, the fish were to be collected over a narrow time span; however, all were not to be harvested at the same time.

Collectors at four National Marine Fisheries Service Technology Centers or Laboratories were requested to obtain eight lots of each of the seafoods assigned to them in quantities sufficient to yield eight 2-lb samples of edible

Southeast Utilization Research Center, National Marine Fisheries Service, National Oceanic & Atmospheric Administration, U.S. Department of Commerce, College Park, Maryland 20740.

[1]Present address: Fishery Products Research Division, NMFS, NOAA, U.S. Department of Commerce, Washington, D.C. 20235.

[2]Present address: Fishery Products Inspection & Safety Division, NMFS, NOAA, U.S. Department of Commerce, Washington, D.C. 20235.

[3]Present address: Office of Associate Administrator for Marine Resources, NOAA, U.S. Department of Commerce, Rockville, Md. 20852.

muscle. A ninth lot was to be of sufficient size to subdivide into two 2-lb samples, to provide for analytical duplication within each species. In many cases, not enough sample was provided for this laboratory to subdivide. Consequently, seven seafoods (cultivated and wild catfish, spiny lobster, calico scallops, white shrimp from the Gulf and South Atlantic, and red snapper) were not duplicated. Data are given for 13 samples of calico scallops, 11 samples of red snapper, and 5 samples each of cultivated and wild catfish. Spiny lobster and white shrimp from the Gulf and South Atlantic are each composed of 10 individual samples. The remaining seafoods contain nine individual samples, the tenth sample being a within species duplicate. King crab leg and body meat taken from the same animals were analyzed separately.

Sample Preparation. Finfish were filleted and skinned if possible. The fillets were finely macerated in either a stainless steel Hobart Silent Cutter or Waring Blendor (reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA). Oysters, scallops, and clams were obtained shucked. Only the abductor muscle of the scallops and hearts and tongues of the surf clam were analyzed. All other mollusk samples were the entire edible animal. Crab, both blue and king, were edible cooked muscle commercially picked. Shrimp imported from Mexico and Asia and those caught in Alaskan waters were commercially peeled and deveined tails. Other shrimp were raw peeled tails. Spiny lobsters were split cooked tails. Shellfish samples were also finely macerated. For canned fish (tuna and salmon), the entire contents of each can were ground. All equipment was rinsed with double distilled water prior to use. The finely ground fish was packed into 4-oz plastic food containers and placed in frozen storage. Samples prepared and frozen at other NMFS laboratories were packed in dry ice, and shipped via air freight to the College Park Laboratory.

Sample Distribution. Mercury analysis was conducted at this laboratory. Analyses of the other four elements were conducted under contract by Analytical Consulting Services, Inc., Kensington, Md. Samples were delivered, packed in dry ice, to the contractor every 3 weeks. A maximum of five samples of a seafood was analyzed at the same time. The majority were limited to two or three samples per product. Samples designated as within species duplicates were generally analyzed on different days.

ANALYTICAL PROCEDURES

All five minerals (Hg, Pb, Cd, Cr, and As) were determined by atomic absorption spectroscopy.

Mercury. Mercury was determined, in triplicate, on a Varian Techtron AA5 atomic absorption spectrometer equipped with an R106 photomultiplier tube, a Mercury hollow cathode lamp, 100-μ slits, a 250 × 12.5 mm open ended absorption cell set in the quartz lenses of the instrument, and a strip-chart recorder operated at 5 mV. The analytical procedure was based on the Canadian Fresh Water Institute method of Uthe et al. (1970) and Armstrong and Uthe (1971) with the following modifications in sample preparation: (1) digestion flasks, 125-ml standard taper Erlenmeyer flasks; (2) sample size, 0.3 ± 0.1 g weighed on glassine paper; (3) digestion reagents, 5 ml of concentrated H_2SO_4 except mollusks; for mollusks (oysters, clams, and scallops), 5 ml of concentrated H_2SO_4 plus 1 ml of concentrated HNO_3; (4) digestion time, overnight in a covered shaking or stationary water bath held at 55 ± 5°C; (5) 6% w/v $KMnO_4$, freshly prepared on the day of use; filtered prior to use; (6) reaction time after $KMnO_4$ addition, 30 to 60 min, optimum 60 min with occasional shaking; (7) final volume, 35 ml; (8) standards, Johnson-Matthey Specpure $HgCl_2$; three levels of mercury (0.2–0.4 and 0.6 μg) and a reagent blank, each in triplicate, carried through the identical procedure with every set of samples.

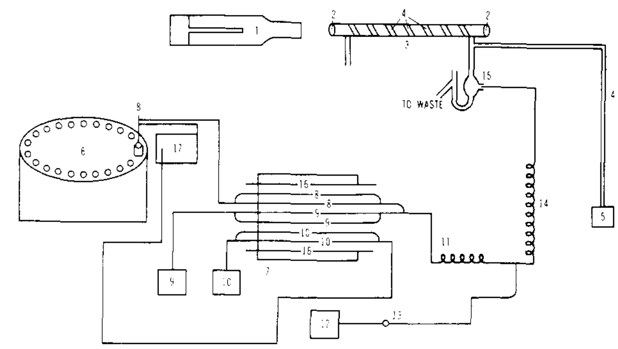

Figure 1. Automated "cold vapor" atomic absorption procedure for mercury: (1) Hg hollow cathode lamp; (2) Techtron quartz lens; (3) Techtron Hg Cell 250 × 12.5 mm; (4) heating tape (35°C); (5) rheostat for heating tape; (6) Technicon sampler II; (7) Technicon proporting pump, eight orange-purple lines (0.10 in. i.d.); (8) sample; (9) reductant; (10) H_2SO_4 wash; (11) 14-turn mixing coil; (12) "Silent Giant" fish tank air pump; (13) gang valve; (14) 28-turn mixing coil; (15) debubbler; (16) unused filler lines; (17) H_2SO_4 reservoir.

The semiautomated instrumental portion of the analysis (Figure 1) also differed slightly. The 250 × 12.5 mm absorption cell used with the Varian Techtron is almost twice the length and volume of the cell used by the Canadian Fresh Water Institute. Therefore, the temperature of the cell became important and it was held between 35 and 40°C by wrapping heating tape around the cell. Other differences in the automated cold vapor AA procedure were: (1) Technicon sampler II, operated at 20 samples per hr using a 1:6 ratio cam (30-sec sample–150-sec H_2SO_4 wash) and 4-ml sample cups; (2) Technicon manifold, six purple-orange lines (0.1 in. i.d.); two for sample and two for reductant each pair delivering 2.88 ± 0.04 ml/min—the remaining two for 1 N H_2SO_4 wash; (3) flow of Hg vapor through cell, sample and reductant (Uthe, 1971; stannous sulfate preparation) were allowed to react in a 14-turn mixing coil; the resulting Hg vapor was mixed with air, from an aquarium pump, and forced through a 28-turn mixing coil and debubbler into the absorption cell. The cell was cleared of Hg vapor during the 150-sec rinse cycle.

Mercury absorption was measured at 253.7 nm. Samples, standards, and blanks were randomized throughout the run. The concentration of mercury in the samples was calculated from a standard curve derived from $HgCl_2$ standards digested, oxidized, and diluted in the identical manner and at the same time as the samples.

Lead, Cadmium, and Chromium. Lead, cadmium, and chromium were determined on a Perkin-Elmer 403 atomic absorption instrument, equipped with single element hollow cathode tubes, a background corrector, and a recorder. Single 5 g or larger samples were treated with excess $Mg(NO_3)_2$ and dry-ashed in Vycor crucibles at 500°C according to the method of Dalton and Malanoski (1969). The atomic absorption spectrometer was run using conditions found optimum by the contractor. The following wavelengths were used for analysis by the contractor: lead, 283.3 nm; cadmium, 228.8 nm; chromium, 357.9 nm.

Samples were read against graduated levels of a mixed standard composed of salts of lead, cadmium, and chromium in 20% (v/v) HNO_3. Twenty percent HNO_3 was

Table I. Comparison of Values Obtained on Three Samples Using Various Analytical Procedures

Sample	Laboratory	Hg	Pb	Cd	Cr	As
Orchard	NBS	0.16	45	0.11	2.3	14
leaves	Lab I[b]		44	0.17		13
dried[a]	This study	0.16	43	0.10	5.9	9
Swordfish	Gulf Atomic[c]	1.27				0.8
raw	Lab I[b]		0.20	0.12	0.21	0.9
	This study	1.36	0.57	0.10	0.13	0.7
Halibut	Gulf Atomic[c]	0.28				1.2
raw	Lab I[b]		0.58	0.10	0.12	1.5
	Lab II[b]	0.35	0.39	0.07	0.11	
	This study	0.36	0.40	0.08	0.06	0.8

[a] National Bureau of Standards, Department of Commerce, reference standard. [b] Atomic absorption spectroscopy procedures. [c] Activation analysis, data obtained under purchase from Gulf General Atomic. No quantitative values received for Pb, Cd, and Cr, only computer-derived upper detection limits.

used for extracting the samples. Reagent blanks were carried through the entire analytical procedure, including the ashing step. The Perkin-Elmer spectrometer was operated using the background corrector for lead and cadmium analysis.

Arsenic. Arsenic was determined using a second subsample of approximately 1 g also dry-ashed according to Dalton and Malanoski (1969). Arsenic was read at 193.7 nm using a single element standard, prepared in the same extractant as the samples, by measuring the arsine produced from samples and standards in an argon protected hydrogen flame (Dalton and Malanoski, 1971).

RESULTS AND DISCUSSION

Three samples for which we had analytical data from other laboratories were available for comparison. The results on these samples are given in Table I. In general, the agreement was reasonable. Good agreement was obtained with NBS orchard leaf values for mercury, lead, and cadmium whereas chromium values were higher and arsenic values lower. Results obtained with two raw fish used routinely as standard samples in this laboratory did not always follow the analytical pattern observed with the NBS standard. Lead, chromium, and arsenic values in the fish standards fell in a much lower range than the same elements in the orchard leaves, however, and in this respect more closely resembled the seafoods under survey. In two collaborative assays, recoveries of mercuric chloride added to different fish averaged 99.7 ± 7.1% with five species and 99.8 ± 8.4% with nine species. Recovery data were not required of the contractor.

Day-to-day reproducibility was measured by analyzing duplicate samples on different days. The average coefficients of variation (CV) of these analyses for the minerals tested were (mineral, CV, %): Hg, 18.0; Pb, 33.4; Cd, 28.1; Cr, 40.5; As, 16.2. The results of the elemental analysis (334 samples) together with all pertinent information available on the 34 seafoods (29 species) are summarized in Table II. Mean mineral values and standard deviations are given with the range of the data obtained on the individual samples. At the start of this study little data were available on the five elements sought and there still is a paucity of microconstituents data on seafoods in the literature. Sidwell and Loomis (1976) have reviewed 223 references covering the literature from 1896 through 1974. The values reported by them for the five elements tested in this study are assembled by fish families in Table III. Except for the mercury content of perch and brown shrimp, lead in oysters, and cadmium in sea scallops, all of which had markedly higher mean values than any found in our study, the data appear to be similar to values found in the present survey. Arsenic values reported in the literature tend to be lower in finfish and higher in shellfish than the arsenic values found in this study.

Mercury. The overall mercury content of the 32 fresh fish and shellfish (314 samples) was 0.12 ppm. The 10 samples each of canned tuna and salmon averaged 0.33 and 0.07 ppm, respectively. Of the 334 samples of fish analyzed in this survey, only three species—halibut (*Hippoglossus stenolepis*), rockfish (mixed species), and red snapper (*Lutjanus campechanus*)—had any individual lots which exceeded the 0.5-ppm guideline for mercury of the United States Food and Drug Administration.

A single halibut weighing 196 lb (headed and gutted weight) had 0.52 ± 0.05 ppm of Hg. The next highest value was 0.46 ppm, found in two fish. The lowest value was 0.15 ppm. Data on mercury obtained by National Marine Fisheries Pacific Utilization Research Center and Southeastern Utilization Research Center laboratories on 1227 Pacific Halibut are given in Table IV. The samples analyzed in this survey are included among the Gulf of Alaska samples. Hall et al. (1976) concluded from this in-depth survey on mercury in halibut that a relationship existed between mercury level and area of catch, and size of fish.

The rockfish in this survey were purchased from San Francisco Bay boats and species are unknown. The highest samples had values of 0.65 and 0.85 ppm and the two lowest had mercury values of 0.13 and 0.16 ppm. Recent data (National Marine Fisheries Service, unpublished data) on 132 samples from 12 species of rockfish averaged less than 0.20 ppm. It is apparent that not all rockfish have a high mercury content, and that the mercury content may be related to the area of catch.

The 11 samples of red snapper reported in this survey had higher mercury levels than any other fish tested. Seven values exceeded 0.50 ppm and the lowest value found was 0.28. Additional data are being obtained on both these species.

One-hundred eighty-three samples of shellfish—oysters, clams, scallops, shrimp, and crabs—were analyzed in this study. The overall average was 0.05 ppm and only 10 samples were above 0.10 ppm, the highest being a king crab leg meat sample with 0.13 ppm. Certainly oysters, clams, scallops, shrimp, crab, and nearly all species of finfish are relatively low in mercury, and these results should assure consumers as to their safety as far as mercury content is concerned.

Lead. Lead was present at a higher level in fish than was mercury. The overall mean lead content for the fresh fish was 0.49 ppm and for the canned fish 0.84 ppm. Bay scallops, hard shell clams, and cod (both from Iceland and the Gulf of Maine) had the lowest mean lead values found in this study—0.24, 0.28, 0.32, and 0.33 ppm, respectively. The highest mean lead values were found in blue crab (0.79 ppm) and oysters from Long Island (0.74 ppm). Oysters from Maryland and Virginia oyster beds averaged 0.45 ppm. Mean lead values tended to be rather uniform with no special pattern discernible.

Cadmium. The cadmium content of most seafoods was less than 0.2 ppm. Three species had higher cadmium levels. These were oysters from Long Island (2.06 ppm), oysters from Maryland and Virginia (0.61 ppm), and calico scallops (2.34). The 29 remaining fresh fish had a mean cadmium content of 0.068. Clams, both hard and soft shell, spiny lobster, blue crab, king crab body meat, and sea scallops had average values of more than 0.100 ppm of cadmium. These six species averaged 0.133 ppm and the remaining 23 species averaged 0.051 ppm. Clams, scallops,

Table II. Microconstituent Content of Edible Portion of Selected Seafoods

Seafood, common name, scientific name, area and site[a] of catch	No. of samples and information on samples	Microconstituent, ppm				
		Hg	Pb	Cd	Cr	As
		Finfish				
Catfish, channel, cultured (*Ictalurus punctatus*), ponds, Miss. and Ark.	5 >1[b] 3-4/71[c]	0.13 ± 0.03[d] 0.05-0.23[e]	0.68 ± 0.41 0.39-1.35	0.079 ± 0.052 0.020-0.152	0.23 ± 0.14 0.08-0.42	2.2 ± 1.3 0.2-3.1
Catfish, channel, wild (*Ictalurus punctatus*), Lake Verett, La.	5 ⩾2[b] 24.1-33.0 cm[f] 284-652 g[g]	0.12 ± 0.04 0.08-0.19	0.59 ± 0.52 0.29-1.50	0.046 ± 0.044 0.000-0.091	0.12 ± 0.08 0.02-0.21	0.1 ± 0.1 0.0-0.3
Cod, Atlantic (*Gadus morhua*), Atlantic: Middle Bank, 7; Jeffery's Bank, 2; Cultivater Shoals, 1	10 6/10-8/30/71[c] 20-80 f[h]	0.19 ± 0.08 0.08-0.33	0.33 ± 0.14 0.18-0.60	0.048 ± 0.051 0.000-0.155	0.07 ± 0.05 0.00-0.16	3.5 ± 1.7 1.2-7.4
Cod, Atlantic, Icelandic (*Gadus morhua*), Atlantic: Iceland waters	10 ⩾2[i] 10 lots, 4 plants[j]	0.08 ± 0.03 0.04-0.14	0.32 ± 0.17 0.00-0.52	0.043 ± 0.035 0.000-0.119	0.12 ± 0.06 0.00-0.20	0.8 ± 0.4 0.3-1.6
Flounder, yellowtail (*Limanda ferruginea*), Atlantic: S. E. Georges Bank, 9; Middle Bank, 1	10 7/27-8/12/71[c]	0.07 ± 0.05 0.02-0.15	0.53 ± 0.21 0.27-0.91	0.028 ± 0.023 0.000-0.059	0.09 ± 0.09 0.00-0.29	4.5 ± 3.0 2.1-10.3
Haddock (*Melanogrammus aeglefinus*), Atlantic: Middle Bank, 7; Jeffery's Bank, 2; Cultivater Shoals, 1	10 6/30-9/19/71[c] 20-80 f[h]	0.17 ± 0.09 0.07-0.37	0.59 ± 0.26 0.10-0.95	0.046 ± 0.030 0.000-0.083	0.12 ± 0.07 0.00-0.22	6.6 ± 2.8 1.8-9.5
Hake, Pacific (*Merluccius productus*), Pacific: Gray's Harbor, 4; Winchester Bay, 3; Columbia River, 2; S. Willipa Bay, 1	10 7/17-8/25/71[c] 35-56 f[h]	0.12 ± 0.02 0.08-0.14	0.38 ± 0.22 0.12-0.76	0.020 ± 0.019 0.000-0.059	0.09 ± 0.07 0.00-0.23	0.6 ± 0.2 0.2-1.0
Hake, Silver (Whiting) (*Merluccius bilinearis*), Atlantic: Ipswich Bay, 4; Gulf of Maine, 2; Middle Bank, 1; Jeffery's Bank, 1; Isle of Shoals, 1; Cultivater Shoals, 1	10 6/15-9/1/71[c] 20-80 f[h]	0.14 ± 0.07 0.04-0.21	0.51 ± 0.15 0.33-0.74	0.047 ± 0.061 0.000-0.200	0.09 ± 0.09 0.00-0.26	3.7 ± 0.9 2.3-5.4
Halibut, Pacific (*Hippoglossus stenolepis*), Pacific: Gulf of Alaska, 10	10 1[b] 1970[e] 185 ± 10 cm, 167-203 cm[f] 158 ± 30 lb, 110-206 lb[g]	0.34 ± 0.13 0.14-0.52	0.56 ± 0.31 0.00-0.97	0.046 ± 0.020 0.009-0.080	0.18 ± 0.11 0.05-0.47	1.8 ± 1.0 0.8-3.9
Perch, ocean (Redfish) (*Sebastes marinus*), Atlantic: Gulf of Maine, 9; S. E. Nova Scotia, 1	10 4/19-4/27/71[c] NMFS Research Vessel[k]	0.18 ± 0.07 0.07-0.31	0.55 ± 0.33 0.17-1.26	0.069 ± 0.056 0.000-0.200	0.10 ± 0.08 0.00-0.23	1.3 ± 0.8 0.7-3.2
Pollock (*Pollachius virens*), Atlantic: Middle Bank, 7; Jeffrey's Bank, 1; Gloucester, Mass., 1	10 7/7-9/19/71[c] 3-80 f[h]	0.23 ± 0.11 0.10-0.45	0.63 ± 0.23 0.28-1.13	0.048 ± 0.036 0.000-0.110	0.08 ± 0.07 0.00-0.18	2.4 ± 1.1 1.1-4.7
Rockfish, mixed species, Pacific: California Coast from Fort Bragg to Santa Cruz	10 1 or 2[b] 6/3-14/71[c] 55 ± 8 cm, 47-69 cm[f] 1947 ± 742 g, 1083-3085 g[g]	0.41 ± 0.25 0.11-0.85	0.36 ± 0.22 0.00-0.81	0.031 ± 0.027 0.000-0.074	0.14 ± 0.03 0.00-0.21	0.3 ± 0.2 0.1-0.6
Snapper, red (*Lutjanus campechanus*), Gulf of Mexico: E. Baffin Bay to Galveston, 4; Morgan City, La. to Galveston, 7	11 1[b] 4/12-6/26/71[c] 53 ± 18 cm, 32-84 cm[f] 4251 ± 3757 g, 766-12258 g[g]	0.60 ± 0.32 0.28-1.46	0.45 ± 0.23 0.16-0.82	0.057 ± 0.044 0.000-0.119	0.12 ± 0.13 0.00-0.50	0.4 ± 0.1 0.2-1.0
		Shellfish				
Clams, hard (Quahog) (*Mercenaria mercenaria*), Atlantic: Upper Chincoteague Bay, 10	10 11/22-12/20/71[c] Little necks (sm.), 3[l] Cherrystones (med.), 2 Chowder (lg.), 5	0.05 ± 0.02 0.02-0.07	0.28 ± 0.18 0.00-0.63	0.122 ± 0.020 0.098-0.159	0.17 ± 0.17 0.06-0.64	1.8 ± 0.6 1.0-2.5
Clams, soft (*Mya arenaria*), Atlantic: Kent Island Area, Chesapeake Bay, Md., 10	10 7/1-12/2/71[c]	0.03 ± 0.02 0.01-0.05	0.40 ± 0.29 0.00-0.87	0.184 ± 0.082 0.059-0.293	0.23 ± 0.12 0.00-0.43	1.2 ± 0.5 0.6-2.1

Table II (*Continued*)

Seafood, common name, scientific name, area and site[a] of catch	No. of samples and information on samples	Microconstituent, ppm Hg	Pb	Cd	Cr	As
Clams, surf (*Spisula solidissima*), Atlantic: Ocean City, Md., 9; Chincoteague, Va., 1	10 11/16-12/6/71[c] Hearts & tongues, 9[m] Hearts only, 1	0.05 ± 0.02 0.01-0.07	0.52 ± 0.25 0.16-0.80	0.061 ± 0.030 0.000-0.098	0.39 ± 0.15 0.20-0.69	1.6 ± 0.3 1.2-2.2
Crab, blue (*Callinectes sapidus*), Atlantic: Chesapeake Bay, Md. & Va., 10	10 6/27-8/17/71[c] Backfin, 3[m] Lump, 2; regular, 5	0.07 ± 0.02 0.04-0.10	0.79 ± 0.33 0.38-1.50	0.101 ± 0.047 0.020-0.158	0.18 ± 0.09 0.07-0.35	1.3 ± 0.4 0.5-1.8
Crab, king (body meat) (*Paralithodes camschatica*), Pacific: Alaska, Cook Inlet or Kachenmak Bay, 5; Dutch Harbor, 5	10 12/16/70-2/8/71[c] Processed Seldovia and Sand Point, Alaska[j]	0.07 ± 0.02 0.05-0.11	0.45 ± 0.34 0.00-0.96	0.121 ± 0.047 0.020-0.189	0.10 ± 0.09 0.00-0.24	3.8 ± 1.2 2.6-7.0
Crab, king (leg meat) (*Paralithodes camschatica*), Pacific: Alaska, Cook Inlet or Kachenmak Bay, 5; Dutch Harbor, 5	10 Leg meat from above crabs	0.08 ± 0.03 0.05-0.11	0.38 ± 0.22 0.02-0.70	0.072 ± 0.049 0.000-0.158	0.13 ± 0.09 0.00-0.30	4.3 ± 1.5 2.3-6.7
Lobster, spiny (Atlantic) (*Panulirus borealis*), Atlantic: Florida, 10	10 Purchased as cooked split tails	0.19 ± 0.02 0.15-0.23	0.55 ± 0.41 0.04-1.57	0.133 ± 0.054 0.059-0.233	0.14 ± 0.08 0.06-0.31	7.2 ± 1.9 3.2-9.6
Oysters (*Crassostrea virginica*), Atlantic: Chesapeake Bay, Md., 6; Tangier Island, Va., 2; Chincoteague Bay, Va., 2	10 11/7-12/2/71[c]	0.03 ± 0.01 0.01-0.05	0.45 ± 0.28 0.00-0.84	0.621 ± 0.317 0.375-1.29	0.09 ± 0.06 0.00-0.15	0.8 ± 0.3 0.6-1.6
Oysters (*Crassostrea virginica*), Atlantic: Long Island Sound, Norwalk-Westport line, 3; inside Norwalk Isle, 3; Grassy Hummucks, 4	10 9/17-9/20/71[c]	0.06 ± 0.02 0.04-0.09	0.74 ± 0.30 0.31-1.28	2.06 ± 0.23 1.60-2.37	0.19 ± 0.12 0.12-0.54	1.0 ± 0.5 0.6-2.5
Scallops, Atlantic, bay (*Aequipecten irradians*), Nantucket Island, Mass., 10	10 1970[c] From frozen storage	0.04 ± 0.01 0.02-0.05	0.24 ± 0.19 0.00-0.48	0.035 ± 0.031 0.000-0.100	0.05 ± 0.05 0.00-0.15	0.7 ± 0.2 0.5-1.1
Scallops, calico (*Aequipecten gibbus*), Atlantic: within 15 miles of Cape Canaveral, Fla., 13	13 6/28/71[c]-10 12/17/71[c]-2 2/7/72[c]-1	0.04 ± 0.01 0.01-0.07	0.45 ± 0.28 0.18-1.05	2.34 ± 0.41 1.57-3.19	0.10 ± 0.06 0.00-0.23	4.2 ± 0.4 3.5-5.0
Scallops, sea (smooth) (*Placopecten magellanicus*), Atlantic: west side of South Channel, 10	10 8/13/71[c]	0.05 ± 0.01 0.03-0.08	0.47 ± 0.21 0.23-0.75	0.136 ± 0.053 0.040-0.234	0.06 ± 0.04 0.00-0.12	1.6 ± 0.3 1.3-2.4
Shrimp, Asian (unknown species), Pacific: India, 6; Thailand, 3; Philippines, 1	10 9.6 ± 6.9 g, 1.2-19.7 g[g] Packers, 6[j] Peeled and deveined, 8[j] In shell, 2[j]	0.05 ± 0.03 0.01-0.09	0.54 ± 0.41 0.09-1.21	0.046 ± 0.022 0.018-0.078	0.11 ± 0.06 0.00-0.18	1.0 ± 0.8 0.4-2.7
Shrimp, Alaskan (mixed species), Pacific: Alaska S. of Marmot Island, 8; Two Headed Island, 2	10 5/25-7/14/71[c] Sidestripe and coon-stripe, 9; pink, 1[n] Cooked, peeled, vacuum packed, Kodiak, Alaska[j]	0.06 ± 0.03 0.01-0.11	0.50 ± 0.40 0.17-1.24	0.069 ± 0.035 0.018-0.114	0.15 ± 0.03 0.09-0.19	3.1 ± 1.2 0.9-5.1
Shrimp, brown (*Penaeus aztecus*), Gulf of Mexico: S.E. of Sabine Pass, Tex., 10	10 8/11/71[c] 12-13 f[h]	0.07 ± 0.02 0.04-0.10	0.48 ± 0.36 0.10-1.19	0.045 ± 0.044 0.000-0.119	0.10 ± 0.06 0.00-0.19	4.4 ± 0.7 3.1-5.2
Shrimp, pink (Northern) (*Pandalus borealis*), Atlantic: Middle Bank, 8; Jeffrey's Bank, 1; Stillwagon Bank, 1	10 4/25-9/13/71[c] 20-75 f[h]	0.06 ± 0.01 0.04-0.08	0.39 ± 0.15 0.10-0.61	0.069 ± 0.066 0.000-0.200	0.10 ± 0.07 0.00-0.25	6.0 ± 1.9 3.6-9.4
Shrimp, Mexican (unknown species), Pacific: Gulf of California, 7; no info., 2; Matazian, 1	10 16.0 ± 3.8 g, 10.0-25.2 g[g] Packers, 5	0.06 ± 0.03 0.03-0.12	0.40 ± 0.36 0.10-1.18	0.040 ± 0.031 0.000-0.097	0.10 ± 0.07 0.01-0.23	1.9 ± 0.8 0.5-2.9
Shrimp, white (*Penaeus setiferus*), Gulf of Mexico: off Mississippi, 10	10 6/17/71[c] 10 ± 1.1 g[g] 17 f[h]	0.07 ± 0.03 0.04-0.12	0.56 ± 0.49 0.18-1.44	0.079 ± 0.022 0.056-0.112	0.19 ± 0.04 0.15-0.25	3.0 ± 0.8 1.7-4.4
Shrimp, white (*Penaeus setiferus*), Atlantic: within 5 miles of Cape Canavaral, Fla., 10	10 6/28/71[c]	0.13 ± 0.04 0.08-0.18	0.47 ± 0.33 0.16-1.20	0.049 ± 0.023 0.000-0.076	0.05 ± 0.01 0.00-0.11	4.6 ± 1.3 2.8-7.7

Table II (*Continued*)

Seafood, common name, scientific name, area and site[a] of catch	No. of samples and information on samples	Microconstituent, ppm				
		Hg	Pb	Cd	Cr	As
		Canned Fish				
Salmon, sockeye (*Oncorhynchus nerka*), Pacific: Naknek River, 4; Egegik River, 3; Togiak River, 2; Ugashik River, 1	10 6/30-7/16/71[c]	0.07 ± 0.03 0.04-0.13	0.94 ± 0.36 0.24-1.41	0.067 ± 0.038 0.038-0.159	0.16 ± 0.06 0.10-0.28	0.3 ± 0.1 0.2-0.4
Tuna, yellowfin (*Thunnus albacares*), Pacific: Costa Rica, 6; Baja, Calif., 2; Mexico, 1; Panama, 1	10 3/1-5/15/71[c] Packs, 9[j] Oil pack, 6 Brine pack, 4	0.33 ± 0.08 0.21-0.44	0.74 ± 0.56 0.13-1.99	0.047 ± 0.043 0.000-0.139	0.07 ± 0.05 0.00-0.14	0.3 ± 0.01 0.1-0.9

[a] Number of samples per site. [b] Number of fish per sample. [c] Time of capture (range). [d] Mean ± standard deviation. [e] Range. [f] Fish length (range). [g] Fish weight (range). [h] Depth of capture (range). [i] One-pound packages (frozen). [j] Inspection service information. [k] Boat of capture. [l] Commercial size designation. [m] Tissue analyzed. [n] Species.

Table III. Literature Values[a] for Seafoods from Fish Families Surveyed in This Study

Seafood	Microconstituent, ppm				
	Hg	Pb	Cd	Cr	As
		Finfish			
Catfish	11[b]	2	3	1	2
(*Ictaluridae*)	0.17 ± 0.13[c]	0.64 ± 0.06	0.06 ± 0.02	0.23	1.15 ± 1.46
	0.04-0.50[d]	0.59-0.68	0.05-0.08		0.12-2.18
Cod	0	3	3	0	3
(*Gadus morhua*)		0.28 ± 0.07	0.04 ± 0.02		2.14 ± 1.26
		0.20-0.34	0.03-0.06		0.86-3.37
Flounder	27	3	3	5	5
(*Pleuronectidae*)	0.22 ± 0.20	0.36 ± 0.17	0.03 ± 0.01	0.09 ± 0.08	2.45 ± 1.92
	0.02-0.80	0.20-0.53	0.03-0.04	0.01-0.18	0.11-4.51
Haddock	9	3	3	4	2
(*Melanogrammus*	0.07 ± 0.06	0.33 ± 0.17	0.05 ± 0.03	0.11 ± 0.12	2.56 ± 2.77
aeglefinus)	0.02-0.17	0.20-0.53	0.03-0.08	0.02-0.30	0.60-4.51
Hake	10	2	2	2	0
(*Merluccius*)	0.25 ± 0.13	0.44 ± 0.10	0.04 ± 0.03	0.09 ± 0.00	
	0.09-0.45	0.38-0.51	0.02-0.05	0.09-0.09	
Perch	56	2	4	1	2
(*Percidae*)	1.18 ± 2.32	0.55 ± 0.07	0.55 ± 0.62	0.07	0.31 ± 0.26
	0.08-15.70	0.50-0.60	0.02-1.24		0.05-0.57
Pollock	4	1	2	1	1
	0.12 ± 0.08	1.64	0.26 ± 0.29	0.08	2.35
	0.05-0.23		0.05-0.46		
Snapper	2	1	1	1	1
(*Lutjanidae*)	0.44 ± 0.23	0.48	0.41	0.12	0.06
	0.28-0.60				
Whiting	0	0	1	0	1
(*Sillaginidae*)			0.01		0.73
Tuna	35	0	0	0	0
(*Thunnus*)	0.51 ± 0.30				
	0.12-1.39				
		Shellfish			
Crab, blue	6	5	13	2	8
	0.16 ± 0.15	0.54 ± 0.18	3.62 ± 6.31	0.14 ± 0.06	12.16 ± 11.79
	0.07-0.48	0.30-0.81	0.01-22.40	0.10-0.17	3.81-35.62
Clams,	22	9	12	6	11
all species	0.08 ± 0.05	1.60 ± 2.28	0.22 ± 0.17	0.33 ± 0.12	3.13 ± 3.85
	0.01-0.26	0.15-7.37	0.03-0.58	0.17-0.44	0.90-12.72
Oysters	9	12	11	2	10
(*Virginica*)	0.10 ± 0.06	24.92 ± 38.97	1.88 ± 1.29	0.12 ± 0.04	9.12 ± 15.59
	0.03-0.23	0.20-100.00	0.11-3.60	0.09-0.14	0.45-42.74
Scallops, sea	5	6	5	5	7
	0.04 ± 0.008	0.32 ± 0.12	2.77 ± 4.45	0.09 ± 0.02	8.76 ± 12.80
	0.03-0.05	0.15-0.47	0.03-10.55	0.05-0.11	0.39-33.56
Shrimp, brown	13	4	8	7	8
	0.70 ± 2.02	0.46 ± 0.06	0.09 ± 0.06	0.07 ± 0.05	8.71 ± 7.63
	0.02-7.36	0.39-0.52	0.04-0.24	0.01-0.12	1.77-23.75

[a] From Sidwell and Loomis (1976). [b] Number of means (references) averaged. [c] Mean ± standard deviation. [d] Range.

oysters, and lobster were higher in cadmium than the other species tested in this survey.

Chromium. Mean chromium values were less than 0.4 ppm in all products tested, the overall mean of fresh fish samples being 0.13 ppm. Surf clams had the highest mean chromium content—0.39 ppm. Soft shell clams and cultured catfish were next with 0.23 ppm. Nine seafoods, cod from the Gulf of Maine, yellowtail flounder, Pacific hake, oysters from Maryland and Virginia, pollock, bay scallops, sea scallops, white shrimp from Florida, and silver

Table IV. Summary of Mercury Levels[a] of Pacific Halibut (*Hippoglossus stenolepis*) by Weight and by Area of Catch

Weight range, lb[b]	Total no. of fish	Mercury, ppm Mean	Range	No. ≥0.5
		Bering Sea		
5-60	88	0.11	0.02-0.78	4
61-80	33	0.15	0.06-0.42	0
81-100	16	0.19	0.09-0.55	1
101-125	10	0.32	0.08-1.00	2
126-150	5	0.27	0.22-0.35	0
		Gulf of Alaska		
5-60	378	0.11	0.01-0.50	1
61-80	92	0.18	0.05-0.47	0
81-100	76	0.25	0.05-1.10	2
101-125	92	0.29	0.03-0.74	3
126-150	67	0.38	0.12-1.28	14
Over 151	56	0.45	0.14-1.05	18
		Southeast Alaska		
5-60	33	0.12	0.04-0.34	0
61-80	10	0.33	0.09-1.30	2
81-100	9	0.28	0.09-0.59	1
101-125	13	0.46	0.22-0.95	5
126-150	3	0.31	0.26-0.36	0
Over 151	2	0.80	0.50-1.10	2
		British Columbia		
5-60	122	0.19	0.04-1.04	12
61-80	20	0.69	0.12-1.23	15
81-100	11	0.66	0.10-1.22	8
101-125	7	0.96	0.50-1.46	7
126-150	3	0.52	0.25-0.77	2
		Washington-Oregon		
5-60	75	0.42	0.10-1.43	23
61-80	6	0.88	0.70-1.13	6

[a] From Hall et al., 1976. [b] Headed and gutted weight.

hake (whiting), had mean values less than 0.1 ppm, the lowest being bay scallops and white shrimp from Florida with 0.05 ppm. Chromium is known to be an essential nutrient, although exact daily requirements have not yet been established (Mertz and Cornatzer, 1971).

Arsenic. Arsenic was present in a higher concentration and varied more than the other elements tested in this study. Relatively high levels of arsenic in fish are a matter of record and have been known for a considerable time. Both Chapman (1926) and Coulson et al. (1935) demonstrated that arsenic occurs in shrimp in a form not readily assimilated by animals or man. The overall arsenic mean was 2.6 ppm. The lowest mean arsenic value was found in wild catfish—0.1 ppm. Interestingly, cultured catfish averaged much higher—2.2 ppm. Rockfish and red snapper, both species with rather high mercury levels, had low arsenic levels, less than 0.5 ppm. Seven species had mean values of less than 1.0 ppm of arsenic. In addition to the rockfish, red snapper, and wild catfish, these were cod from Iceland waters, Pacific hake, oysters from Maryland and Virginia, and bay scallops.

Canned Fish. Salmon and tuna were the only canned fish covered in this survey. Arsenic was low and of the same magnitude in both species. The mean value for mercury in tuna was well below the 0.5-ppm guideline at 0.33 ppm and lower still in salmon—0.07 ppm; lead, cadmium, and chromium were present at higher levels in the canned salmon.

MINERAL-ELEMENT RELATIONSHIPS

Although the data were very limited, rank correlation values (Litchfield and Wilcoxon, 1955) were determined within each species for all possible mineral–element relationships. The following mineral–element pairs show a possible relationship only in the species listed: mercury to lead—sea scallops; mercury to cadmium—surf clams, Pacific hake; mercury to chromium—sea scallops; mercury to arsenic—oysters from Long Island, canned salmon; lead to cadmium–shrimp from Alaska and Asia, white shrimp from the Gulf of Mexico, and red snapper; lead to chromium—soft shell clams, white shrimp from the Gulf, oysters from Long Island, and canned salmon; cadmium to chromium—calico scallops; and cadmium to arsenic—yellowtail flounder, soft shell clams, and pollock.

LOCATION DIFFERENCE

The five samples each of cultivated catfish raised in Mississippi and Arkansas ponds and the wild catfish caught in Lake Verett, Louisiana, showed a difference in cadmium, chromium, and arsenic data with higher average levels of all these metals in the cultured fish. Neither the lead nor mercury data showed this relationship in these catfish.

The cod from Iceland was similar in lead, cadmium, and chromium content to the cod caught on the banks in the North Atlantic. However, cod from Iceland was somewhat lower in mercury content and considerably lower in arsenic content. The white shrimp from the Gulf of Mexico was higher in cadmium and chromium than the same species caught off Cape Canaveral, Florida; otherwise, mineral content was similar.

Compared to oysters from Maryland and Virginia the oysters from the Long Island beds averaged higher in all metals tested. With cadmium, no overlap of values occurred.

The king crab leg and body meat were from the same crabs and although the averages for lead and cadmium content were lower in the leg samples, the data overlapped.

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LITERATURE CITED

Armstrong, F. A. J., Uthe, J. F., *At. Absorpt. Newsl.* **10**, 101 (1971).
Chapman, A., *Analyst* **51**, 548 (1926).
Coulson, E. J., Remington, R. E., Lynch, K. E., *J. Nutr.* **10**, 255 (1935).
Dalton, E. F., Malanoski, A. J., *J. Assoc. Off. Anal. Chem.* **52**, 1035 (1969).
Dalton, E. F., Malanoski, A. J., *At. Absorpt. Newsl.* **10**, 92 (1971).
Hall, A. S., Teeny, F. M., Lewis, L. G., Hardman, W. H., Gauglitz, E. J., Jr., *Fish. Bull.*, submitted for publication (1976).
Irukayama, K., Fujiki, M., Kai, F., Kondo, T., *Kumamoto Med. J.* **14**, 159 (1961).
Litchfield, J. T., Jr., Wilcoxon, F., *Anal. Chem.* **27**, 299 (1955).
Mertz, W., Cornatzer, W. E., Ed., "Newer Trace Elements in Nutrition", Marcel Dekker, New York, N.Y., 1971, pp 1–16.
Sidwell, V. D., Loomis, K. L., *Mar. Fish. Rev.*, submitted for publication (1976).
Uthe, J. F., "International Symposium on Identification and Measurement of Environmental Pollutants", National Research Council of Canada, Ottawa, Canada, 1971, pp 207–212.
Uthe, J. F., Armstrong, F. A. J., Stainton, M. P., *J. Fish. Res. Board Canada* **27**, 805 (1970).
Westoo, C., *Var Foeda* (1), 1 (1967); Fisheries Research Board of Canada Translation Series No. 1350 (1969).
Wobeser, G., Nielson, N. O., Dunlop, R. H., Atton, F. M., *J. Fish. Res. Board Canada* **27**, 830 (1970).

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