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Mineral Composition of the Edible Muscle Tissue of Seven Species of Fish from the Northeast Pacific

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The edible muscle tissue of Pacific cod, Dover sole, walleye pollock, Pacific whiting, pomfret, Atka mackerel, and American shad was analyzed for its mineral content. Of 25 elements determined, 10 elements—Ag, B, Cd, Co, Mo, Ni, Pb, Sc, V, and Y—were below quantifiable levels and 15 elements—Al, Ba, Ca, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Na, P, Sr, and Zn—were at or above quantifiable levels. Iron and copper concentrations in Atka mackerel and American shad were at least 2 times higher than in any of the other five species. Manganese level in walleye pollock from Shelikof Strait was at least 5 times greater than that in pollock from the Bering Sea or Cape Ommaney, AK. Fish held in refrigerated seawater had significantly higher Na content than fish held in ice. The nape sections of Pacific cod had slightly higher levels of Ca, Hg, Mg, and Mn and slightly lower levels of Cu, Fe, and Zn than the tail sections; no difference was observed for Al, Ba, Cr, K, Li, Na, P, and Sr. The data extend the available information of the mineral composition of the various species of fish from both a nutritional and a health hazard point of view.

In recent years, there has been much interest in the study of trace metal composition of fish, especially after the discovery of widespread mercury pollution in the marine environment (Holden, 1973). It was suspected that other potentially toxic metals may similarly be widespread environmental contaminants. Because of a lack of information on the trace metal content of fish and fishery products intended for human consumption, the National Marine Fisheries Service initiated a series of surveys to determine the trace element content (toxic and essential) in fishery resources. The most comprehensive of these surveys covered 15 elements in 204 species of finfish, mollusca, and crustacea taken from 198 sites around the coastal United States including Alaska and Hawaii (Hall et al., 1978). To date, 20 elements are known to be essential in human/animal nutrition (NRC, 1980), and seafoods are a good dietary source of many of them (Stansby and Hall, 1967).

The study reported here extends the available information on the amount of Al, Ba, Ca, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Na, P, Sr, and Zn in the edible muscle tissue of seven species of fish, Pacific cod (*Gadus macrocephalus*), Dover sole (*Microstomus pacificus*), walleye pollock (*Theragra chalcogramma*), Pacific whiting (*Merluccius productus*), pomfret (*Brama japonica*), Atka mackerel (*Pleurogrammus monopterygius*), and American shad (*Alosa sapidissima*), caught in various locations in the northeast Pacific Ocean. These species are currently under study for expansion of our domestic food fisheries; thus, it is important to know their mineral composition from both a nutritional and a health hazard point of view.

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MATERIALS AND METHODS

The fish were obtained from fish-processing companies and research vessels of the National Oceanic and Atmospheric Administration. Most specimens were caught in nearshore waters off the states of Alaska, Washington, Oregon, and California. Pomfret, a pelagic species, were caught in the Gulf of Alaska.

The specimens were washed briefly with tap water to remove slime or ice, drained, weighed, and then filleted by hand with stainless steel knives. Analytical samples consisted of the entire fillets of each fish with the exception of the fillets used for the distribution study, where only the nape and tail sections of the fillets were utilized. The muscle tissue was ground in a Waring blender, packed in plastic containers, and stored at 0 °C until analyzed, normally within 2–3 days.

For all elements except mercury, tissue samples of approximately 10 g each were weighed into acid-washed Vycor crucibles and placed under infrared heat lamps for about 4 h to dry and char. The crucibles were transferred to a muffle furnace, which was allowed to gradually rise (no less than 2 h) to 450 °C, and allowed to remain in the furnace for 24–48 h to obtain a white ash. After cooling, 10 mL of 4% nitric acid was added to each crucible and the crucibles were covered with watch glasses and heated at low heat to near boiling. After cooling to room temperature, each sample was filtered through Whatman No. 40 filter paper into a 25-mL volumetric flask, followed by several rinsings of both the crucible and the filter paper with 4% nitric acid, and made to volume with 4% nitric acid.

The various elements, excluding Hg, were determined by emission spectroscopy (Jarrell-Ash Model 975 inductively coupled argon plasma emission spectrometer). Calibration of the instrument and analysis of the samples were performed with background and interelement corrections. Total mercury was determined by the Official

Table I. Limit of Quantitation[a] for 25 Elements

element	concentration, μg/mL	element	concentration, μg/mL
Ag	0.020	Mg	0.009
Al	0.110	Mn	0.021
B	0.018	Mo	0.100
Ba	0.008	Na	0.100
Ca	0.065	Ni	0.042
Cd	0.026	P	0.220
Co	0.025	Pb	0.250
Cr	0.018	Sc	0.005
Cu	0.014	Sr	0.016
Fe	0.018	V	0.035
Hg	0.005	Y	0.007
K	0.900	Zn	0.047
Li	0.006		

[a] Limit of quantitation = 5 × limit of detection. Limit of detection = 2 × standard deviation of background noise.

Food and Drug Administration Vanadium Pentoxide Method (Munns and Holland, 1977). Mercury vapor was measured with a Perkin-Elmer Model 403 atomic absorption spectrophotometer.

Results are stated in micrograms per gram (μg/g) or milligrams per 100 g (mg/100 g) on a wet weight basis. Control samples of fish were analyzed routinely to verify both accuracy and precision of the methods.

RESULTS AND DISCUSSION

Analysis of the National Bureau of Standards (NBS), Standard Reference Material SRM 1570 by the procedure described in this paper gave results that were very comparable to those reported by NBS for Ca, Cu, K, Mn, P, and Zn. Gorsuch (1970) and Smith (1965) reported that after the destruction of organic matter by either wet or dry oxidation techniques, recoveries of 94–100% were obtained for Al, Ba, Ca, Cr, Cu, K, Li, Mg, Mn, Mo, Na, Ni, Sc, Sr, V, and Y. Similar recoveries were obtained for Ag, Cd, Co, Fe, Hg, Pb, and Zn by wet oxidation, whereas dry oxidation gave recoveries of 65–99% for Ag, 80–100% for Cd, 75–100% for Co, 81–100% for Fe, 0–1% for Hg, 70–100% for Pb, and 50–100% for Zn. Using our procedure with fish samples as the test material, we obtained slightly higher recoveries than those listed above.

Of the 25 elements determined, 10 elements—Ag, B, Cd, Co, Mo, Ni, Pb, Sc, V, and Y—were at levels below our limits of quantitation (Table I). No attempt was made to concentrate these elements and determine their levels. These elements are therefore excluded from further discussion. The remaining 15 elements were at levels equal to or higher than our limits of quantitation.

The mineral composition of the samples for each species and for each geographical area of catch are presented in Table II. In those cases where more than one group of specimens of a species was caught on different dates from the same location, the data were combined. One exception to this was a lot of Pacific whiting that was held in refrigerated seawater rather than in ice. In Table III is presented the summary data for the 15 elements for each species, irrespective of area of catch. Of these 15 elements, 5 elements—Al, Ba, Hg, Li, and Sr—have little or no evidence of dietary essentiality for humans whereas 10 elements—Ca, Cr, Cu, Fe, K, Mg, Mn, Na, P, and Zn—are known to be essential for human nutrition (NRC, 1980). In Table IV are presented the summary mean values of the 10 essential elements for all 7 species combined and

Table II. Mineral Composition of the Edible Muscle Tissue of Several Species of Fish from Northeast Pacific

species, area of catch (no. of samples)	level	wt, g	μg/g (wet weight)														
			Al	Ba	Ca	Cr	Cu	Fe	Hg	K	Li	Mg	Mn	Na	P	Sr	Zn
Pacific cod																	
Cape Flattery,	mean	2623	0.239	0.010	108	0.106	0.346	2.099	0.129	4735	0.033	276	0.061	746	2207	0.430	4.160
WA (50)	SD	1174	0.142	0.008	24	0.025	0.115	0.789	0.050	623	0.017	27	0.026	143	220	0.257	0.492
Cape Sarichef, AK	mean	1148	0.182	0.007	113	0.089	0.195	1.650	0.031	3463	0.029	292	0.070	891	2017	0.367	3.627
(12)	SD	649	0.099	0.002	26	0.005	0.047	0.422	0.020	458	0.002	28	0.023	124	96	0.115	0.169
Cape Ommaney,	mean	798	0.035	0.022	133	0.114	0.289	1.580	0.058	4155	0.020	302	0.090	898	2115	0.525	3.731
AK (11)	SD	497	0.024	0.007	42	0.006	0.088	0.241	0.032	186	0.004	15	0.017	127	83	0.184	0.217
Dover sole																	
Newport, OR (29)	mean	660	0.203	0.007	115	0.081	0.160	1.984	0.121	1735	0.099	194	0.046	656	1547	0.502	3.428
	SD	326	0.231	0.007	24	0.019	0.072	0.554	0.059	606	0.044	28	0.023	211	202	0.142	0.752
Cape Ommaney,	mean	506	0.045	0.023	119	0.107	0.190	1.795	0.128	3081	0.035	247	0.083	1457	1576	0.640	3.179
AK (11)	SD	214	0.105	0.006	13	0.031	0.041	0.413	0.069	181	0.003	16	0.023	112	87	0.076	0.339
Santa Cruz, CA	mean	212	0.354	0.015	202	0.092	0.184	2.560	0.101	1970	0.103	265	0.063	1201	1840	0.907	5.056
(10)	SD	68	0.266	0.006	36	0.031	0.052	0.641	0.059	602	0.037	44	0.026	334	211	0.180	0.638
walleye pollock																	
Bering Sea, AK	mean	965	0.175	0.019	130	0.087	0.303	1.658	0.030	2245	0.107	254	0.047	1021	1493	0.697	3.086
(20)	SD	352	0.138	0.008	35	0.018	0.095	0.497	0.042	352	0.058	49	0.014	242	231	0.147	0.410
Shelikof Strait,	mean	1300	0.177	0.020	99	0.087	0.215	2.017	0.030	2282	0.073	281	0.526	603	1999	0.367	4.396
AK (10)	SD	488	0.157	0.009	22	0.015	0.049	0.388	0.018	568	0.032	32	0.163	211	198	0.148	0.684
Cape Ommaney,	mean	323	0.041	0.024	142	0.107	0.307	2.074	0.018	3938	0.031	324	0.077	1032	2028	0.542	4.179
AK (12)	SD	223	0.046	0.005	34	0.005	0.031	0.313	0.009	102	0.006	12	0.006	92	50	0.110	0.531
Pacific whiting																	
Astoria, OR (20)	mean	873	0.102	0.009	92	0.106	0.275	2.579	0.115	1979	0.108	283	0.103	436	2077	0.348	3.969
	SD	246	0.154	0.008	18	0.029	0.084	0.720	0.048	644	0.029	48	0.028	206	255	0.177	0.497
Astoria, OR (32)[a]	mean	937	0.173	0.009	104	0.086	0.226	2.437	0.113	2438	0.048	333	0.093	1214	1848	0.418	3.052
	SD	227	0.138	0.002	24	0.011	0.046	0.416	0.028	486	0.010	40	0.015	520	145	0.117	0.569
pomfret																	
Gulf of	mean	1088	0.060	0.013	88	0.097	0.325	2.930	0.114	3115	0.030	287	0.072	624	2174	0.264	3.635
Alaska, AK (24)	SD	162	0.047	0.008	25	0.009	0.085	0.578	0.032	619	0.007	27	0.015	101	186	0.082	0.390
Atka mackerel																	
Kodiak Island,	mean	461	0.110	0.008	141	0.122	0.643	6.159	0.014	3495	0.072	297	0.111	518	2569	0.316	5.067
AK (20)	SD	156	0.142	0.008	30	0.030	0.173	1.729	0.004	1724	0.045	17	0.020	155	151	0.109	0.857
Americal shad																	
Seaside, OR (13)	mean	1039	0.137	0.008	144	0.100	0.746	9.444	0.051	2443	0.023	306	0.146	692	2231	0.315	3.792
	SD	251	0.065	0.002	36	0.006	0.129	2.161	0.012	387	0.003	27	0.024	229	148	0.118	0.359

[a] These samples were held in refrigerated seawater for 2 days.

Table III. Mineral Composition of Several Pacific Coast Species of Fish

element	Pacific cod	Dover sole	walleye pollock	Pacific whiting	pomfret	Atka mackerel	American shad
			μg/g (Wet Weight)				
Al	0.199 ± 0.117	0.198 ± 0.210	0.135 ± 0.116	0.102 ± 0.154	0.060 ± 0.047	0.110 ± 0.142	0.137 ± 0.065
Ba	0.011 ± 0.001	0.012 ± 0.007	0.021 ± 0.007	0.009 ± 0.008	0.013 ± 0.008	0.008 ± 0.008	0.008 ± 0.002
Hg	0.102 ± 0.042	0.118 ± 0.061	0.027 ± 0.027	0.115 ± 0.048	0.114 ± 0.032	0.014 ± 0.004	0.051 ± 0.012
Li	0.030 ± 0.012	0.086 ± 0.034	0.077 ± 0.037	0.108 ± 0.029	0.030 ± 0.007	0.072 ± 0.045	0.023 ± 0.003
Sr	0.434 ± 0.223	0.613 ± 0.135	0.574 ± 0.137	0.348 ± 0.177	0.264 ± 0.082	0.316 ± 0.109	0.315 ± 0.118
			mg/100 g (Wet Weight)				
Ca	11.3 ± 2.70	13.3 ± 4.70	12.6 ± 3.2	9.20 ± 2.10	8.80 ± 2.50	14.1 ± 2.95	14.4 ± 3.60
Cr	0.010 ± 0.002	0.009 ± 0.002	0.009 ± 0.001	0.011 ± 0.003	0.010 ± 0.001	0.012 ± 0.003	0.010 ± 0.001
Cu	0.031 ± 0.010	0.017 ± 0.006	0.028 ± 0.007	0.028 ± 0.008	0.032 ± 0.008	0.064 ± 0.017	0.075 ± 0.013
Fe	0.195 ± 0.065	0.206 ± 0.054	0.186 ± 0.042	0.258 ± 0.072	0.293 ± 0.058	0.616 ± 0.173	0.944 ± 0.216
K	444 ± 53.0	208 ± 51.2	274 ± 33.2	198 ± 64.4	312 ± 61.9	349 ± 172	244 ± 38.7
Mg	28.2 ± 2.5	22.0 ± 2.90	28.0 ± 3.40	28.3 ± 4.80	28.7 ± 2.70	29.7 ± 1.70	30.6 ± 2.69
Mn	0.007 ± 0.002	0.006 ± 0.002	0.017 ± 0.005	0.010 ± 0.003	0.007 ± 0.002	0.011 ± 0.002	0.015 ± 0.002
Na	79.3 ± 13.7	94.1 ± 21.4	92.5 ± 19.2	43.6 ± 20.6	62.4 ± 10.1	51.8 ± 15.5	69.2 ± 22.9
P	216 ± 17.9	161 ± 17.8	177 ± 17.1	208 ± 25.5	217 ± 18.6	257 ± 15.1	223 ± 14.8
Zn	0.401 ± 0.040	0.370 ± 0.064	0.371 ± 0.051	0.397 ± 0.050	0.364 ± 0.039	0.507 ± 0.086	0.379 ± 0.036

Table IV. Percentage of U.S.-Recommended Daily Dietary Allowance (RDA) for Ca, Fe, Mg, P, and Zn and of Estimated Safe and Adequate Daily Dietary Intakes (EDI) for Cr, Cu, K, Mn, and Na Supplied by a 100-g Serving of Fish Muscle

element	mineral concentration in muscle, mg/100 g			recommended intake, mg		% of RDA or EDI
	mean	SD	rel SD, %	RDA	EDI	
Ca	12.0	2.26	18.8	800		1.5
Cr	0.010	0.001	10.0		0.05–0.20	5.0–20.0
Cu	0.039	0.021	53.8		2.0–3.0	1.3–2.0
Fe	0.385	0.288	74.8	10		3.8
K	290	86.8	29.9		1875–5625	5.2–15.5
Mg	27.9	2.78	10.0	350		8.0
Mn	0.01	0.004	40.0		2.5–5.0	0.2–0.4
Na	70.4	19.4	27.6		1100–3300	2.1–6.4
P	208	31.5	15.1	800		26.0
Zn	0.398	0.050	12.6	15		2.6

the recommended daily allowances and estimated daily intakes for adults (NRC, 1980).

Nonessential Elements. The concentrations of the nonessential elements—Al, Ba, Hg, Li, and Sr—were found at relatively low levels (Table II). Mean mercury levels ranged between 0.014 and 0.129 μg/g, and these levels were well below the Food and Drug Administration action level of 1.0 μg/g (*Fed. Regist.*, 1979).

Essential Elements. The mean Ca concentration of the 7 species was 12.0 mg/100 g (Table IV), which was in very good agreement with 12.4 mg/100 g for 10 species reported by Gordon and Roberts (1977) but in disagreement with 53 mg/100 g for 13 species reported by Sidwell et al. (1973). The Gordon and Roberts study included four of the species named in our study—Pacific cod, Dover sole, Pacific whiting, and American shad—whereas the Sidwell et al. study included only one species—Pacific whiting—reported in our study. Pacific whiting contained 9.2 mg of Ca/100 g compared to 8.7 mg/100 g reported by Gordon and Roberts (1977) and 28 mg/100 g reported by Sidwell et al. (1973). In our study, American shad contained 14.4 mg of Ca/100 g compared to 47.2 mg/100 g reported by Gordon and Roberts. The difference in Ca levels between the two studies may be due to contamination of the sample by bones since American shad is an extremely bony fish.

Levels of Cr, Mg, P, and Zn varied slightly from species to species and from one area of catch to another (Table II). Atka mackerel had higher levels of P and Zn than any other species. Additionally, Atka mackerel and American shad contained at least 2–3 times as much Cu and Fe as any of the other five species. The high Fe content may be due to the high amount of dark meat in these two species (Parks and Rose, 1933; Namiki, 1934).

Potassium levels ranged between 198 and 444 mg/100 g and averaged 290 mg/100 g. American shad was reported to contain 437 mg/100 g by Gordon and Roberts (1977) and 330 mg/100 g by Thurston (1958a), which are higher than our findings of 244 mg/100 g.

Manganese levels averaged 0.010 mg/100 g. The manganese level in walleye pollock from Shelikof Strait was at least 6 times greater than that in pollock from the Bering Sea or Cape Ommaney. This suggests that geographical location may affect the trace element content of fish. This phenomenon has definitely been shown to occur with Hg in halibut, sablefish, and pike (Hall et al., 1976a,b; Johnels and Westermark, 1969).

Sodium levels averaged 70.4 mg/100 g. These values were in close agreement with the 68 mg/100 g reported by Thurston (1958a). A 100-g portion of fish (fish that has not previously been held in refrigerated seawater or in brine) consumed by an adult who is on a low-Na diet would provide approximately 2–6% of the estimated adequate daily dietary intake of Na (NRC, 1980; Table IV). It appears that even the species with the highest Na content are suited for low-sodium diets.

Effect of Refrigerated Seawater (RSW) on Sodium Level. The use of RSW has been shown to be a good method for holding fish prior to processing. During the course of our studies, we measured the Na content of 32 Pacific whiting held in refrigerated seawater (RSW) for 2 days. Results (Table II) show that the high Na content in Pacific whiting held in RSW for 2 days as compared to those held in ice quite obviously is attributable to Na diffusion into the fish muscle during storage. Similar observations were made by Reppond et al. (1979), Lemon and Regier (1977), and Longard and Regier (1974). The high Na content found in Pacific whiting flesh held in RSW will obviously have serious dietetic implications on the use of RSW as a method of preserving fish for processing.

Distribution of Metals in Various Parts of the Fish. Because there was a scarcity of information on the distribution of metal in different parts of the edible muscle tissue of these species, we chose Pacific cod and analyzed the nape and tail sections of one fillet from each of 30 fish for their metal content. The mean metal concentration and standard deviation of the elements are presented in Table V. Analysis of the data by a paired Student's "*t*" test showed no difference in the levels of Al, Ba, Cr, K, Li, Na, P, and Sr between the nape and tail sections. Similar

Table V. Mean Values and Standard Deviations of 15 Elements in Nape and Tail Sections of Pacific Cod (n = 30)

element	nape, μg/g	tail, μg/g
Al	0.265 ± 0.151	0.261 ± 0.123
Ba	0.010 ± 0.007	0.011 ± 0.006
Ca	118 ± 14	107 ± 13
Cr	0.111 ± 0.028	0.105 ± 0.021
Cu	0.319 ± 0.099	0.483 ± 0.125
Fe	2.052 ± 0.799	2.730 ± 0.699
Hg	0.144 ± 0.057	0.127 ± 0.046
K	4736 ± 386	4625 ± 290
Li	0.031 ± 0.014	0.031 ± 0.014
Mg	279 ± 26	250 ± 26
Mn	0.068 ± 0.027	0.053 ± 0.016
Na	822 ± 131	866 ± 141
P	2058 ± 203	2070 ± 185
Sr	0.427 ± 0.166	0.484 ± 0.157
Zn	4.057 ± 0.498	4.555 ± 0.486

observations were made by Thurston (1958b) on Alaska pink salmon analyzed for the Na and K content of the nape and tail sections of fillets. For the remainder of the elements, the nape sections had slightly higher levels of Ca, Hg, Mg, and Mn and slightly lower levels of Cu, Fe, and Zn than the tail sections.

In summary, this work provided needed information on the levels of 10 essential and 5 nonessential elements found in the edible muscle tissue of 7 species of fish common to the North Pacific region. Such information is especially useful to those evaluating the nutritional aspects of foods and formulating special diets.

Registry No. Ag, 7440-22-4; Al, 7429-90-5; B, 7440-42-8; Ba, 7440-39-3; Ca, 7440-70-2; Cd, 7440-43-9; Co, 7440-48-4; Cr, 7440-47-3; Cu, 7440-50-8; Fe, 7439-89-6; Hg, 7439-97-6; K, 7440-09-7; Li, 7439-93-2; Mg, 7439-95-4; Mn, 7439-96-5; Mo, 7439-98-7; Na, 7440-23-5; Ni, 7440-02-0; P, 7723-14-0; Pb, 7439-92-1; Sc, 7440-20-2; Sr, 7440-24-6; V, 7440-62-2; Y, 7440-65-5; Zn, 7440-66-6.

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