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NUTRITION ADVISORY GROUP HANDBOOK

FEEDING CAPTIVE PISCIVOROUS ANIMALS: NUTRITIONAL ASPECTS OF FISH AS FOOD [a]

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Piscivory is a term which specifically refers to the consumption of fish, but for the purposes of this document also encompasses a variety of organisms including marine invertebrates. Fish and marine invertebrates are prevalent constituents in the diets of a diversity of captive animals. Appropriate selection, purchase, storage, and thawing of these products is critical to the successful husbandry and nutritional management of captive piscivores. The nutritional status of captive zoo and aquarium animals which rely entirely on fish as food is dependent on the quality and composition of the fish they consume. The nutrient composition of fish may vary immensely.[2,7,11] Concentrations of fat and protein, as well as many vitamins and minerals, differ depending upon species, age and gender, stage of life cycle, and season and location of catch. In migratory fish, such as salmon, the fat composition of spawning fish differs markedly from that of non-reproductively active salmon.

[a] Adapted in part from Allen, M.E., O.T. Oftedal, and D.J. Baer. 1996. The feeding and nutrition of carnivores. Pp. 139-147 *in* Kleiman, D.G., M.E. Allen, K.V. Thompson, and S. Lumpkin (eds). Wild Mammals in Captivity. University of Chicago Press, Chicago, IL; and Bernard, J.B., and D.E. Ullrey. 1989. Evaluation of dietary husbandry of marine mammals at two major zoological parks. J. Zoo. Wildl. Med. 20:45-52.

Composition of Marine Products

Existing data on the composition of fish relate primarily to edible portions, since most food tables were established for assessing dietary intakes of humans. Humans typically consume only fish muscle whereas piscivorous animals generally consume entire fish, including bones, skin, scales, and viscera. Bones and scales are the primary sources of calcium in whole fish and are not taken into account in most fish analyses. Therefore, tables of composition of fish used in human nutrition would not reflect actual calcium concentrations consumed by a piscivore.

Whole fish are relatively good sources of most nutrients (Tables 1-4), and similar to other whole prey items, typically contain a substantial concentration of protein (40-80% on a dry matter basis (DMB)). Ether extract, an estimate of fat, is highly variable within and among fish species, ranging from about 2-50% (DMB), depending upon physiological stage, diet, and season. Generally, anchovies, herring, and mackerel have consistently high fat content. Most fish species are a valuable source of major and trace minerals. Some trace minerals, such as selenium, are present in fairly high concentrations in whole fish, ranging to nearly 5 ppm. In this instance, much of the selenium is in a complex with relatively low bioavailability. Sufficient selenium is available to meet the needs of piscivores but without danger of selenium toxicity.

Hyponatremia has been reported in marine mammals, primarily pinnipeds, maintained in fresh water. A need for NaCl supplements, at the rate of 3 g per kg fish (wet basis), has been suggested.[6,7] Sea lions, however, have been successfully kept in fresh water environments with out supplements of NaCl. Sodium is present in fish and marine invertebrates at 0.2-5.5% (DMB). The level of supplemental NaCl recommended, coupled with the sodium already present in marine products, results in unreasonably high concentrations of sodium in dietary dry matter. Without further evidence, it is difficult to justify NaCl supplementation for piscivorous animals, although, it is desirable to maintain a saltwater environment for aquatic marine animals.

Some species of fish may contain very high concentrations of the fat-soluble vitamins A and D. Vitamin E probably also occurs in ample amounts in fresh fish; however, since it is a natural antioxidant and fish oils oxidize readily, much of the vitamin E originally present may be destroyed prior to feeding.[1,11] These vitamin concentrations, however, are quite variable with vitamin A ranging from 7,000 to 336,000 IU/kg (DMB), vitamin D ranging from 450 to 16,800 IU/kg (DMB), and vitamin E ranging from 23 to 433 IU/kg (DMB)(Table 4). Many zoos and aquariums utilize nutritional supplements for piscivorous animals that contain substantial amounts of vitamins A and D. At high dietary levels, both of these vitamins are potentially toxic, and the addition of vitamins A and D to a diet of whole fish may not be advisable.[1]

Wild pinnipeds and cetaceans, as well as piscivorous birds, reptiles, amphibians, and fish, feed on a wide variety of fish species, which likely satisfy their specific nutrient requirements. When feeding captive piscivores, we are often limited to feeding a few species of fish and marine invertebrates, which may vary considerably in nutrient content. In zoos and aquariums, therefore, the recommended method of feeding most piscivorous animals is to feed at least three, and preferably more, species of fish. These should include fin fish and invertebrates, which complement each other in nutrient concentrations and, to the extent possible, represent the types of items the animals may consume in the wild.

Knowledge of the specific fish species consumed by wild piscivorous animals may aid in selecting the most appropriate fish to purchase. Free-ranging northern fur seals, for instance, consume large quantities of invertebrates, such as squid, in comparison to the quantity of fin fish consumed. One of the characteristics of squid is that they appear to have higher concentrations of copper than do fin fish. This may reflect a higher requirement for copper or simply a higher tolerance. In this case, given these compositional differences, the feeding of squid, in addition to fin fish, may deserve serious consideration.

Thiamin and vitamin E

Thiamin and vitamin E are nutrients that are known to be limiting or problematic in fish and marine invertebrates. Both of these vitamins are relatively quickly degraded in killed fish, even when fish are frozen under ideal conditions, which necessitates supplementation for piscivorous animals. Thiaminases, enzymes that destroy or inactivate thiamin,[4] are naturally present in the tissue of many marine animals.[8] Consumption of fish and marine invertebrates without supplementation may result in deficiency.[5,12,13] Species that are known to contain discernible amounts of thiaminase are clams, herring, smelt, and mackerel.[9] The recommended supplementation is 25-30 mg of thiamin per kg of fish (wet basis).[5,7]

Animals fed thawed frozen fish are particularly susceptible to vitamin E deficiency. Destruction of vitamin E occurs in fish as polyunsaturated oils undergo peroxidation. Much of the vitamin E present in fresh fish may be destroyed even after only a few weeks of frozen storage. The peroxidative process consumes vitamin E in the fish, and the potential deficiency problem may be further confounded because the ingested unsaturated oils increase the vitamin E requirements of the piscivorous animal.[10] The recommended level of supplementation is 100 IU of vitamin E per kg of fish (wet basis).[3,7]

Shipping, Handling and Storage

The nutritional value and composition of fish is greatly dependent upon proper shipping, storage and handling. Even under ideal freezer conditions, denaturation of proteins, rancidity of fats, destruction of vitamins, and dehydration may occur. Fish lipids have a lower freezing point than do mammalian lipids. Degradation of proteins and oxidative changes in fish lipids, resulting in rancidity, can be accelerated by inappropriately high freezer temperatures. Fish should be stored with an average product temperature of -18° to -30° C.[7,10] Additionally, to protect against potential spoilage, stock should be rotated so that fish are stored no longer than 4-6 months.

Generally, the shorter time between catching and freezing fish, the better the quality. Fish may be purchased as sea-frozen or shore-frozen. Sea-frozen fish are usually more expensive and not all species are available. Fish are also available as bulk-frozen or individually-quick-frozen (IQF). The shorter the period to completely freeze fish, the better the quality. Bulk-frozen fish are usually packed in cartons and the cartons placed in blast freezers. Fish in the center of the cartons may not freeze for several hours. Conversely, IQF fish undergo much more rapid freezing. Fish are placed on belts, in chambers, with coolants that reduce temperatures to freezing in a matter of minutes, and are therefore more expensive. When feeding large piscivorous animals, where multiple 20 kg cartons may be used in one day, good quality bulk-frozen fish are appropriate and cost effective. When feeding a small group of fish-eating birds that may consume only 5 kg of fish per day, the use of IQF fish is warranted. These can be picked one by one from the carton without having to entirely or partially thaw the carton. This results in less waste, but more importantly, assures that fish remain totally frozen until ready for thawing. Repeated thawing and freezing should be avoided since cell rupture, fluid loss, tissue damage, and oxidative changes will be accelerated.

Thawing fish for food

Nutrient losses may result, and fish may serve as a medium for bacterial growth if improperly thawed. The nutritional integrity of the fish is best maintained during thawing when they are placed loosely covered in a refrigerated area and thawed as close in time to feeding as possible. Fish may be safely thawed under refrigeration at 2 to 3½ C. Other thawing methods (microwave, running water) should be used in emergency situations only. Thawing at room temperature is not advised and will hasten microbial growth and oxidative tissue damage, adversely affecting quality and palatability.

Establishing vendor specifications

Many problems associated with improper shipping, handling, and storage may be avoided by providing vendors with written specifications, via a purchase agreement or contract, and by enforcing compliance. These specifications should not only describe species, size requirements, and acceptable quality characteristics, but should include requirements for packaging and shipping.

Fish may be considered acceptable if eyes are clear and not sunken, gills are red, flesh is firm and not broken, and if there is little or no odor.[10] Characteristic signs of previous thawing include presence of ice crystals, opaque corneas, and flesh that does not return to its normal shape when touched. It is not always possible to adequately examine fish while frozen. The day of receipt, bulk-frozen fish can be randomly examined by using a band saw to cut out several sections of several cartons from various locations within the shipment. These sections can be rapidly thawed under running water to facilitate examination. IQF fish are easily thawed upon receipt. Purchaser and vendor should have a previously established method of shipment evaluation and problem resolution to preclude misunderstandings.

Fish should be packed in thick plastic bags and be contained in thick, plastic coated boxes. Boxes should identify species and contain information regarding date of catch and vendor or distributor name and address. Delivery trucks should be monitored for correct temperature with specifications denoting that frozen conditions must be maintained from origin to delivery. Storage freezers should also be electronically monitored and have temperature-sensitive alarms to alert support staff to problems. Some zoos and aquariums ask keepers to monitor fish use by animals, since not all poor quality fish can be detected upon arrival of the shipment. Feed refusals by animals, or by keepers who can evaluate the thawed fish may be recorded. If excessive discards are noted, arrangements may be made with vendors to obtain credit. Good relationships with vendors are also important in assuring good quality fish.

Seasonal availability

Most species of fish are caught on a seasonal basis. However, suppliers often store large quantities making them continually available. It is critical to ascertain approximate catch dates from suppliers to avoid purchasing fish that may have already deteriorated in quality and exceeded recommended storage times. To efficiently accommodate the seasonal availability of fish and marine invertebrates, it may be necessary to systematically alter the diet composition of captive piscivorous animals. For additional information, the National Oceanic and Atmospheric Administration (NOAA, U.S. Department of Commerce, Washington, D.C.) issues information on the months each species is available on a fresh-caught basis.

Sampling Techniques and Nutrient Analyses

Monitoring nutritional quality of fish begins with collecting a representative sample from a batch or lot of fish when it is delivered and accepted, prior to use as food. The objective in sampling is to obtain a homogenous sample that is identical to the bulk of the lot from which it was taken. Frozen samples should consist of at least 3 kg of fish. For IQF fish, random samples should be taken from at least five, randomly selected cases from varied locations within the shipment. Bulk-frozen fish should be sampled by cutting sections from both the center and edge of at least five, randomly selected cases from varied locations within the shipment. All sampled fish should be stored in the freezer, in pre-labeled, heavy, plastic bags with excess air evacuated. Samples should be shipped and maintained frozen until analyses are completed. Sample preparation methods which involve thawing of fish samples is not appropriate for analysis of any heat- or oxygen-sensitive nutrients such as vitamins or fatty acids.

Known variation in composition of fish and marine invertebrates and seasonal variation in availability necessitate routine sampling and analysis. It is, likewise, important that data on nutrient content be accurate. For instance, without appropriate data on the nutrient content of the whole fish, zoos and aquariums that feed piscivorous species based only on a prescribed number or unit weight of fish may see tremendous fluctuations in appetite and ultimately in body mass of piscivores. Many factors can influence the accuracy of analytical data including sampling technique and variations among laboratories. Whole fish are often difficult to analyze properly because either the entire fish must be analyzed or it must be thoroughly homogenized for the sample to be representative. Differences in laboratory technique may also influence results of nutrient analyses. Laboratories chosen to analyze fish should use Association of Official Analytical Chemists (AOAC, Arlington, VA) procedures and should use the same methodologies consistently over time to allow for appropriate comparisons. Monitoring nutrient composition should, at the very least, include analyses for dry matter, protein, fat, and gross energy. Data on nutrient composition is critical for appropriate adjustments in quantities fed of alternate species or different lots of fish without altering the overall nutrient content of the diet.

Summary

Nutritional characteristics of different species of fish and different lots of fish are inherently variable. Purchasing fish that have been recently caught and frozen will help ensure a minimal loss to spoilage. A good quality diet, properly stored and thawed, representing a mixture of fish and marine invertebrate species, should be provided to captive piscivorous animals, in order to compensate for nutrient variability and seasonal variation in fish composition. However, supplementation may be necessary to insure a proper nutrient balance. It is essential to supplement with both thiamin and vitamin E.

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Table 1. Proximate analysis and energy content of whole fish and marine invertebrates (DMB).[abcd]

Item	No. of samples	DM	CP	EE	ASH	GE
		-----------------------------------%-------	----------------------------	----------------------------	----------------------------	kcal/g
Anchovies	10	25.8 - 36.9	43.1 - 66.3	16.8 - 33.3	10.2 - 24.5	4.43 - 5.71
Butterfish	1	31.0	46.2	38.2	7.7	*
Capelin	16	14.6 - 22.8	56.0 - 76.5	7.0 - 23.3	8.6 - 12.8	4.94 - 5.92
Clams	1	20.6	48.5	5.5	7.41	4.73
Goldfish	1	19.4	58.8	8.5	23.0	4.15
Herring	10	23.9 - 32.1	46.8 - 69.0	13.3 - 43.0	7.5 - 14.8	5.13 - 6.73
Herring, Atlantic	5	20.6 - 28.6	44.2 - 70.2	16.4 - 38.3	7.3 - 11.9	5.45 - 6.41
Krill	3	14.4 - 26.2	47.9 - 60.2	2.0 - 22.8	11.1 - 16.5	5.12 - 5.33
Krill, dry	1	95.3	47.9	17.4	12.5	*
Krill, pacifica	1	18.9	59.6	10.4	15.3	5.33
Krill, superba	1	19.2	57.0	15.0	16.5	5.12
Mackerel, Atlantic	3	31.2 - 36.9	41.8 - 50.1	42.3 - 48.4	6.2 - 6.4	6.43 - 6.84
Mackerel, Pacific	3	23.7 - 33.4	43.4 - 79.2	3.7 - 37.5	7.0 - 13.8	4.46 - 5.94
Mackerel, Spanish	1	33.8	33.4	41.4	5.2	6.54
Minnows	1	18.6	64.6	14.1	14.5	4.97
Plankton, ocean	1	9.0	54.7	7.5	14.8	*
Salmon	1	22.3	73.0	*	*	*
Shrimp, brine	4	9.7 - 13.3	44.6 - 59.8	5.9 - 14.6	10.1 - 17.1	4.49 - 5.04
Shrimp, brine, dry	1	93.9	44.8	4.4	19.6	*
Shrimp, meat	2	17.8 - 19.9	86.5 - 89.9	3.1 - 3.5	6.2 - 6.5	5.05 - 5.20
Shrimp, shell	1	22.7	52.5	1.5	23.5	3.66
Shrimp, whole	2	18.8 - 23.3	71.1 - 81.9	3.3 - 3.4	9.9 - 14.4	4.51 - 4.90
Silversides	4	26.7 - 29.3	53.5 - 57.3	23.5 - 28.3	10.5 - 11.9	5.48 - 5.80
Smelt	11	15.8 - 24.3	51.9 - 73.6	12.7 - 39.5	6.1 - 11.2	5.20 - 6.50
Smelt, Columbia River	9	18.9 - 28.8	45.3 - 58.5	31.0 - 43.6	5.6 - 7.3	6.01 - 7.04
Smelt, fresh water	10	15.8 - 34.4	56.2 - 73.2	15.9 - 28.9	7.2 - 10.2	5.45 - 6.05
Smelt, ocean	2	20.4 - 25.4	63.6 - 65.2	17.0 - 19.3	9.0 - 9.4	5.36 - 5.77
Squid	2	15.4 - 18.8	65.4 - 77.3	8.3 - 11.4	4.8 - 6.4	5.42 - 5.44
Trout, rainbow	5	27.7 - 30.7	54.7 - 68.5	27.2 - 33.9	7.0 - 9.2	5.68 - 6.15
Whitebait	1	20.4	67.7	10.0	12.3	4.94

[a] Data provided by Joni B. Bernard and Duane E. Ullrey, Comparative Nutrition Laboratory, Michigan State University and Allen and Baer Associates.
[b] Numbers of samples of some species are small, and data should be used with caution.
[c] Scientific names of fish species provided in Table 5.
[d] Abbreviations and methods of analysis described in Table 6.
* Value not determined.

Table 2. Major mineral content of whole fish and marine invertebrates (DMB).[abcd]

Item	No. of samples	Ca	P	Mg	Na	K
		----------------	----------------	%	----------------	----------------
Anchovies	10	1.84 - 2.80	1.55 - 2.52	0.14 - 0.28	1.06 - 5.56	0.87 - 1.63
Butterfish	1	1.46	1.06	0.14	0.44	1.15
Capelin	16	1.19 - 2.20	1.34 - 2.33	0.08 - 0.23	0.39 - 1.74	0.78 - 1.96
Clams	1	0.17	0.61	0.29	1.11	0.96
Goldfish	1	6.99	4.36	0.17	0.65	1.22
Herring	6	1.62 - 6.41	1.29 - 2.34	0.09 - 0.24	0.36 - 1.08	1.15 - 1.78
Herring, Atlantic	5	1.56 - 1.85	1.00 - 2.13	0.10 - 0.24	0.35 - 0.85	0.94 - 1.94
Krill	3	1.24 - 2.01	0.71 - 1.10	0.29 - 0.47	1.84 - 2.96	0.97 - 1.07
Krill, dry	1	2.53	0.83	0.48	2.18	0.31
Krill, pacifica	1	1.84	1.29	0.17	3.02	0.72
Krill, superba	1	2.11	1.35	0.53	2.76	1.25
Mackerel, Atlantic	3	0.73 - 1.16	1.09 - 1.23	0.10 - 0.14	0.38 - 0.48	0.77 - 1.03
Mackerel, Pacific	3	1.55 - 3.08	1.21 - 2.65	0.09 - 0.23	0.35 - 1.17	0.75 - 1.60
Mackerel, Spanish	1	1.20	1.13	0.05	0.24	0.82
Minnows	1	3.71	3.01	0.19	0.59	1.38
Plankton, ocean	1	4.28	0.89	0.54	1.57	1.02
Salmon	1	1.06	0.79	*	*	*
Shrimp, brine	4	0.14 - 0.30	0.90 - 1.22	0.13 - 0.41	0.47 - 3.86	1.10 - 1.47
Shrimp, brine, dry	1	5.21	0.82	0.55	1.14	0.53
Shrimp, meat	2	0.33 - 0.75	0.89 - 1.05	0.15 - 0.25	0.77 - 0.89	0.95 - 1.20
Shrimp, shell	1	7.63	3.25	0.67	0.49	0.65
Shrimp, whole	2	1.89 - 3.26	1.41 - 1.53	0.23 - 0.26	0.69 - 0.86	0.86 - 1.11
Silversides	4	2.29 - 2.89	1.69 - 2.36	0.11 - 0.18	0.59 - 1.58	0.66 - 1.02
Smelt	11	0.97 - 2.88	1.16 - 2.10	0.07 - 0.13	0.18 - 0.51	0.36 - 1.70
Smelt, Columbia River	9	0.93 - 1.88	1.03 - 1.63	0.05 - 0.14	0.29 - 0.50	0.82 - 1.21
Smelt, fresh water	10	1.64 - 2.56	1.62 - 2.01	0.10 - 0.15	0.24 - 0.58	0.95 - 1.41
Smelt, ocean	2	1.74 - 2.81	1.57 - 1.71	0.11 - 0.15	0.36 - 0.63	0.93 - 1.42
Squid	2	0.11 - 0.17	1.12 - 1.21	0.21 - 0.23	0.84 - 0.90	0.66 - 1.17
Trout, rainbow	5	1.54 - 1.82	1.54 - 1.78	0.10 - 0.11	0.22 - 0.27	1.33 - 1.60
Whitebait	1	2.32	1.95	0.18	0.46	1.47

[a] Data provided by Joni B. Bernard and Duane E. Ullrey, Comparative Nutrition Laboratory, Michigan State University and Allen and Baer Associates.
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* Value not determined.

Table 3. Trace mineral content of whole fish and marine invertebrates (DMB).[abcd]

Item	No. of samples	Cu	Fe	Zn	Mn	Se
		ppm				
Anchovies	10	5 - 17	98 - 2060	57 - 113	6 - 34	0.70 - 1.77
Butterfish	1	15	147	156	9	1.13
Capelin	16	3 - 10	36 - 140	41 - 87	2 - 5	0.52 - 1.25
Clams	1	12	135	27	6	0.95
Goldfish	1	14	307	225	64	1.22
Herring	6	3 - 14	64 - 274	55 - 101	4 - 10	0.94 - 2.13
Herring, Atlantic	5	4 - 6	64 - 132	44 - 80	3 - 7	0.93 - 4.48
Krill	3	47 - 85	96 - 138	46 - 48	5 - 7	1.04 - 1.55
Krill, dry	1	66	59	41	4	1.30
Krill, pacifica	1	39	19	45	4	1.53
Krill, superba	1	89	432	53	12	1.61
Mackerel, Atlantic	3	5 - 10	63 - 100	39 - 46	2 - 3	2.09 - 2.67
Mackerel, Pacific	3	4 - 8	153 - 184	41 - 82	0 - 2	2.90 - 4.67
Mackerel, Spanish	1	2	83	32	3	1.26
Minnows	1	13	225	165	17	0.82
Plankton, ocean	1	68	225	82	8	0.73
Salmon	1	*	*	*	*	*
Shrimp, brine	4	7 - 16	155 - 848	54 - 155	7 - 44	1.46 - 1.96
Shrimp, brine, dry	1	25	1335	55	33	1.21
Shrimp, meat	2	10 - 27	75 - 107	60 - 82	4 - 11	1.12 - 1.38
Shrimp, shell	1	13	78	89	20	0.65
Shrimp, whole	2	18 -180	82 - 293	57 - 97	12 - 53	1.57 - 1.59
Silversides	4	3 - 10	32 - 54	75 - 99	4 - 8	1.18 - 1.38
Smelt	11	2 - 6	32 - 113	45 - 129	0 - 10	0.45 - 1.21
Smelt, Columbia River	9	4 - 13	56 - 114	35 - 83	2 - 5	0.56 - 1.26
Smelt, fresh water	10	2 - 8	26 - 87	78 - 113	4 - 19	0.73 - 1.29
Smelt, ocean	2	2 - 3	29 - 36	80 - 94	7 - 14	0.55 - 1.00
Squid	2	106 - 245	12 - 29	63 - 87	0 - 2	2.42 - 2.71
Trout, rainbow	5	5 - 9	41 - 62	96 - 130	0 - 1	0.69 - 1.03
Whitebait	1	4	112	75	10	0.80

[a] Data provided by Joni B. Bernard and Duane E. Ullrey, Comparative Nutrition Laboratory, Michigan State University and Allen and Baer Associates.
[b] Numbers of samples of some species are small, and data should be used with caution.
[c] Scientific names of fish species provided in Table 5.
[d] Abbreviations and methods of analysis described in Table 6.
* Value not determined.

Table 4. Fat-soluble vitamin content of whole fish and marine invertebrates. [abcd]

Item	No. of samples	Vitamin A (IU/kg)		Vitamin D_3[e] (IU/kg)		Vitamin E (IU/kg)	
		Wet	DMB	Wet	DMB	Wet	DMB
Anchovies	9	2,197 - 11,855	7,087 - 38,242	*	*	13 - 83	33 - 241
Capelin	12	1,665 - 35,498	8,904 - 189,829	463	3,171	5 - 66	23 - 360
Herring	5	2,997 - 9,400	10,704 - 31,864	2,240	7,593	8 - 36	25 - 129
Krill	1	11,500	56,372	100	490	32	157
Mackerel, Atlantic	1	15,900	59,108	4,520	16,800	9	33
Mullet	15	2,477 - 20,253	9,365 - 69,217	*	*	43 - 139	161 - 433
Shrimp, whole	1	68	286	*	*	78	335
Smelt	1	2,458	12,265	*	*	33	165
Smelt, Columbia River	3	23,543 - 75,300	98,096 - 336,160	100	446	33 - 67	138 - 299
Smelt, fresh water	10	2,331 - 18,848	9,287 - 75,091	100	633	14 - 63	85 - 282
Smelt, ocean	2	4,500 - 5,300	17,717 - 25,980	121	476	8 - 13	39 - 49
Whitebait	1	3,000	14,706	512	2,510	5	25

[a] Data provided by Joni B. Bernard, Comparative Nutrition Laboratory, Michigan State University and Allen and Baer Associates.
[b] Numbers of samples of some species are small, and data should be used with caution.
[c] Scientific names of fish species provided in Table 5.
[d] Abbreviations and methods of analysis described in Table 6.
[e] Vitamin D analysis available for only one sample per species.
* Value not determined.

Table 5. Scientific names of fish and marine invertebrates in Tables 1 and 2.

Common Name	Genus species
Anchovies	*Engraulis mordax*
Butterfish	*Peprilus* sp.
Capelin	*Mallatus villosus*
Clams	*Spisula solidissima*
Goldfish	*Cyprinus carpio*
Herring	Species not indicated
Herring, Atlantic	*Clupea harengus*
Krill	*Euphasia* sp.
Krill, pacifica	*Euphasia pacifica*
Krill, superba	*Euphasia superba*
Mackerel, Atlantic	*Scomberomorus scrombrus*
Mackerel, Pacific	*Scomberomorus japonicus*
Mackerel, Spanish	*Scomberomorus maculatus*
Minnows	*Cyprinidae*
Mullet	*Mugil* sp.
Plankton, ocean	Species not indicated
Salmon	*Oncorynchus* sp.
Shrimp, brine	*Artemia salina*
Shrimp, whole	*Penaeus* sp.
Silversides	*Menidia andens*
Smelt	*Species not indicated*
Smelt, Columbia River	*Thaleichthys pacificus*
Smelt, fresh water	*Osmerus mordax*
Smelt, ocean	*Osmerus* sp.
Squid	*Ilex and Loligo* sp.
Trout, rainbow	*Salmo gairdneri*
Whitebait	*Clupea harengus or sprattus*

Table 6. Nutrient abbreviations used in Tables 1 and 2, and methods of analysis.

	Abbreviation	Description	Method of Analysis
Proximate analysis	DM	dry matter	Freeze-dried & vacuum oven (60°C)
	CP	crude protein	Nitrogen by Kjeldahl x 6.25
	EE	ether extract (crude fat)	Extraction with diethyl ether
	Ash	total minerals	Combustion overnight at 600°C
	GE	gross energy	Bomb calorimetry
Macro minerals	Ca	calcium	Atomic absorption spectrophotometry
	P	phosphorus	Light spectrophotometry
	Mg	magnesium	Atomic absorption spectrophotometry
	Na	sodium	Atomic emission spectrophotometry
	K	potassium	Atomic emission spectrophotometry
Trace minerals	Cu	copper	Atomic absorption spectrophotometry
	Fe	iron	Atomic absorption spectrophotometry
	Zn	zinc	Atomic absorption spectrophotometry
	Mn	manganese	Atomic absorption spectrophotometry
	Se	selenium	Fluorometry
Vitamins	Vitamin A	all-*trans*-retinol	High-pressure liquid chromatography
	Vitamin D_3	cholecalciferol	High-pressure liquid chromatography
	Vitamin E	D-α-tocopherol	High-pressure liquid chromatography