Chapter 1
Basic facts and figures

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1.1 Introduction

With more than 30,000 known species, fish form the biggest group in the animal kingdom that is used for the production of animal-based foods. Only about 700 of these species are commercially fished and used for food production. Further, some 100 crustacean and 100 molluscan species (for example mussels, snails and cephalopods) are used as food for humans. The amount captured worldwide is registered annually by the Food and Agriculture Organization of the United Nations (FAO).

Fish and other seafood are very important in covering a part of the protein demand for humans. In 2000, food fish contributed 15.9% to the human diet on a worldwide basis (fish as a percentage of total animal protein intake). There are, however, great differences between continents and countries. In low-income, food-deficient countries (LIFDC) fish contributes 20.6%, in Asia 23.3%, in China 21.1%, whereas in South America the contribution amounts only to 5.7%, in North and Central America to 7.1% and in Europe to 10.3%. The average contribution in developed countries is 12% whereas it is 18.8% in developing countries (FAO).

1.2 World fishery production

World fishery production has been developing rapidly since 1950 (Table 1.1). In 1948 only 22 million metric tonnes of fish were captured, whereas in 2004 the world production amounted to more than 140 million tonnes. The dramatic increase of captured fish from 1950 to 1975 was followed by a somewhat more moderate increase between 1975 and 1990, and stagnation since then. Today, most fish stocks are fully exploited and a few are even overexploited. The growth in world fishery production in the past 10–15 years is based on a steadily growing aquaculture. The proportion of species farmed by aquaculture of the total world fishery production amounts today to more than 40%.

The countries contributing most to total world fishery production of 140,457 million tonnes in 2004 are listed in Table 1.2. In Table 1.3 the major captured fish species are listed, and in Table 1.4 the major species farmed by aquaculture. Of this world fishery production of 140,457 million tonnes, 105,632 million tonnes (75.2%) were used for human consumption. Of these 75%, 39% were marketed fresh, 19% frozen, 8% cured and 9% canned.

Table 1.1 Development of world fish production (catch and aquaculture) since 1900.

Year	1900	1948	1958	1968	1978	1988	1995	1998	2004
Million tonnes	4	22	40	67	73	99	117	118	140

Table 1.2 World fishery production: top 10 countries in 2004.

Country	Capture	Aquaculture	Total (tonnes)
China	16,892,793	30,614,968	47,507,761
Peru	9,613,180	22,199	9,635,379
India	3,615,724	2,472,335	6,088,059
Indonesia	4,811,320	1,045,051	5,856,371
Chile	4,935,376	674,979	5,610,355
USA	4,959,826	606,549	5,566,375
Japan	4,401,341	776,421	5,177,762
Thailand	2,845,088	1,172,866	4,017,954
Norway	2,522,225	637,993	3,160,218
Vietnam	1,879,488	1,198,617	3,078,105

Table 1.3 World fishery production in 2004: fish species captured (greater than 1 million metric tons).

Species	Taxonomic name	Amount captured (tonnes)
Peruvian anchovy	*Engraulis ringens*	10,679,338
Alaska pollock	*Theragra chalcogramma*	2,691,939
Blue whiting	*Micromesistius poutassou*	2,427,862
Skipjack tuna	*Katsuwonus pelamis*	2,092,356
Atlantic herring	*Clupea harengus*	2,019,933
Chub mackerel	*Scomber japonicus*	2,017,276
Japanese anchovy	*Engraulis japonicus*	1,795,844
Chilean jack mackerel	*Trachurus murphyi*	1,778,777
Largehead hairtail	*Trichiurus lepturus*	1,587,452
Yellowfin tuna	*Thunnus albacares*	1,384,358
European pilchard	*Sardina pilchardus*	1,062,432

Table 1.4 World aquaculture production of fish, crustaceans and molluscs in 2004 (greater than 1 million metric tonnes).

Species	Taxonomic name	Quantity (tonnes)
Pacific oyster	*Crassostrea gigas*	4,429,337
Silver carp	*Hypophthalmichthys molitrix*	3,979,292
Grass carp	*Ctenopharyngodon idellus*	3,876,868
Carp	*Cyprinus carpio*	3,387,918
Japanese carpet shell	*Ruditapes philippinarum*	2,860,152
Bighead carp	*Hypophthalmichthys nobilis*	2,101,688
Crucian carp	*Carassius carassius*	1,949,758
Nile tilapia	*Oreochromis niloticus*	1,495,744
Whiteleg shrimp	*Penaeus vannamei*	1,386,382
Atlantic salmon	*Salmo salar*	1,244,637
Japanese scallop	*Patinopecten yessoensis*	1,126,159

Part of the world fishery catch is processed into fish meal, which is used as a fertiliser or as animal (mainly fish) feed. For this, some target fish species such as sand eel and anchoveta (so-called 'industry fish') are caught. The fish oil recovered during the fish meal process is to some extent also used for human nutrition.

The stagnation of the world fish catch has led to an intensive discussion about better use and management of the resources. Also, quality aspects that have been neglected for many years are back on the agenda (careful handling of the the catch, prolonged shelf life of ice- and frozen-stored fish, optimisation of yield in fish processing machines, etc.).

1.3 Categories of fish species

Fish species can be divided into categories, for example according to their habitat as marine and freshwater species. Some species such as European eel and most salmon can live in both

Table 1.5 Categories of marine and freshwater fish species according to their total fat content in edible tissue (fillet).

Category	Total fat content (%)	Common names	Taxonomic names
Lean fish species	<1	Cod, saithe, haddock, whiting, ling, cusk, grenadier, blue whiting, blue ling, pike, perch, pikeperch, monkfish or angler, lemon sole, Alaska pollack	*Gadus morhua*, *Pollachius pollachius*, *Pollachius virens*, *Melanogrammus aeglefinus*, *Molva molva*, *Brosme brosme*, *Coryphaenoides rupestris*, *Macrourus berglax*, *Micromesistius poutassou*, *Molva dypterygia*, *Esox lucius*, *Perca fluviatilis*, *Stizostedion lucioperca*, *Lophius piscatorius*, *Microstomus kitt*, *Theragra chalcogramma*
Species with low fat content	>1–5	White halibut, wolffish, plaice, hake, dab, grey mullet, red mullet, redfish, whitch, sole, turbot, brill, trout, tench, whitefish	*Hippoglossus hippoglossus*, *Anarhichas lupus*, *Anarhichas minor*, *Pleuronectes platessa*, *Merluccius merluccius*, *Limanda limanda*, *Mugil cephalus*, *Mullus surmuletus*, *Sebastes marinus*, *Sebastes mentella*, *Glyptocephalus cynoglossus*, *Solea solea*, *Psetta maxima*, *Scophtalmus rhombus*, *Trutta trutta*, *Tinca tinca*, *Coregonus* sp.
Medium fatty fish species	>5–10	Redfish, sardine, swordfish, Bream, catfish, albacore, dogfish, tuna, conger, salmon	*Sebastes marinus*, *Sebastes mentella*, *Sardina pilchardus*, *Xiphias gladius*, *Abramis brama*, *Silurus glanis*, *Squalus acanthias*, *Thunnus thynnus*, *Conger conger*, *Salmo salar*
Fatty fish species	>10	Sprat, black halibut, mackerel, herring, eel	*Sprattus sprattus*, *Hippoglossoides platessoides*, *Scomber scombrus*, *Clupea harengus*, *Anguilla anguilla*

environments. Typical representatives of freshwater fish are: carp, pike, perch, pikeperch, tench; examples of marine fish are: cod, saithe, redfish, mackerel and herring. Often, their anatomical shape is also used for categorisation: roundfish such as saithe, cod and hake; flat fish species such as plaice, dab and flounder; and snake-shaped fish such as eel, lamprey and moray.

Also, the categories groundfish and swarmfish are used. Groundfish are those species that search for their prey close to the bottom of the sea (cod, flat fish); swarm fish are those that gather in big schools, mainly the small, pelagic, fatty species such as herring, sprat and sardine.

Most species belong to the group of bony fish (Osteichthyes), which means that they have a fully developed bony skeleton. Some fish species have so-called real bones which are not attached to the backbone or to other bones but are located free in the muscle tissue. These bones are formed by hardened connective tissue. Sharks, rays and chimaeras belong to the group of cartilagenous fish (Chondrichthyes). They have no bones, but a cartilaginous tissue which is enforced by calcium carbonate.

Fish species can also be divided into four classes (Table 1.5) based on their nutritional properties, for example their fat content, which can vary in some species depending on their state of maturity from 1% to 30%.

1.4 Fish muscle

Fish flesh, fish muscle or fish fillet is the name for the body musculature of fish reaching from head to tail: this muscle forms the major part of the edible portion of fish. This side muscle consists of segments (myomers) lying between connective tissue layers (myocommata). The muscle fibres within the myomers are longitudinally orientated.

The proportion of fish flesh to total body weight varies between 40% and 65%, depending of species, shape, age and the physiological status of the fish. Fish with more elliptical cross sections (tuna, herring and salmon) exhibit a much higher proportion of the edible part than flatfish species or species with very big heads such as monkfish.

Fish flesh consists of light and dark musculature. Both types can be differentiated by chemical composition, physiological importance and nutritional value. Most species have more light than dark muscle. Herring and mackerel have approximately equal amounts of light and dark muscle. The dark muscle occurs just below the skin in the area of the lateral line, and continues as a wedge shape to the backbone.

The light musculature is used for rapid, sudden movements and obtains energy mainly from anaerobic glycolysis. For continuous swimming, fish use their dark musculature. This type of muscle is therefore well developed in pelagic species (herring, mackerel, tuna), well supplied with blood and rich in myoglobin. The metabolism of dark muscle is aerobic; energy is provided by lipids and carbohydrates.

1.5 Nutritional composition

The nutritional composition of fish (Tables 1.6 and 1.7) is comparable to that of warm-blooded animals; in relation to essential elements such as selenium and iodine, it is superior.

Table 1.6 Compositional data of edible part (fillet) of marine and freshwater fish species. Data are average values calculated or estimated and rounded from several food composition tables as well as from our analyses and can be subject to great variations depending on intrinsic fish parameters such as state of maturity, sex, age, season, nutritional status, etc.

Components	Fish species									
	Anchovy	Sea bass	Bluefish	Burbot	Common carp	Channel catfish	Cod	Pacific cod	Cusk	Eel
	Engraulis encrasicolus	*Morone saxiatilis*	*Pomatomus saltatrix*	*Lota lota*	*Cyprinus carpio*	*Ictalurus punctatus*	*Gadus morhua*	*Gadus macrocephalus*	*Brosme brosme*	*Anguilla anguilla*
Moisture (g/100 g)	73	79	71	79	67	80	81	81	76	68
Raw protein (g/100 g)	20	18	20	19	18	16	18	18	19	18
Total lipids (g/100 g)	5	2	4	1	6	3	0.5	0.4	0.7	12
Ash (g/100 g)	1.4	1	1	1.2	1.5	1	1.2	1.2	1.3	1.4
Energy (kcal/100 g)	131	97	124	90	127	95	82	82	87	184
Energy (kJ/100 g)	548	406	519	377	531	397	343	343	364	770
Calcium (mg/100 g)	147	15	7	50	41	14	16	7	10	20
Magnesium (mg/100 g)	41	40	33	32	29	23	32	24	31	20
Phosphorus (mg/100 g)	174	198	227	200	415	209	203	174	204	216
Potassium (mg/100 g)	383	256	327	404	333	358	413	403	392	272
Sodium (mg/100 g)	104	69	60	97	49	43	54	71	31	51
Zinc (mg/100 g)	1.7	0.4	0.08	0.8	1.5	0.5	0.5	0.4	0.3	1.6
Copper (mg/100 g)	0.2	0.03	0.05	0.2	0.06	0.03	0.03	0.03	0.02	0.02
Manganese (mg/100 g)	0.07	0.12	0.2	0.7	0.04	0.03	0.02	0.01	0.02	0.04
Selenium (µg/100 g)	37	375	375	136	13	13	33	37	37	7
Iodine (µg/100 g)							187			
20:5 (*n* – 3) (g/100 g)	0.538	0.169	0.252	0.07	0.238	0.13	0.064	0.08	Total PUFA	0.084
22:6 (*n* – 3) (g/100 g)	0.911	0.585	0.519	0.096	0.114	0.234	0.12	0.135	0.28	0.063
Cholesterol (mg/100 g)	30	80	59	60	66	58	39	37	41	51

Table 1.6 *Continued*

Components	Fish species								
	Haddock	White halibut	Greenland halibut	Herring	Ling	Mackerel	Monkfish	Mullet	Redfish
	Melanogrammus aeglefinus	*Hippoglossus hippoglossus*	*Rheinhardtius hippoglossoides*	*Clupea harengus*	*Molva molva*	*Scomber scombrus*	*Lophius piscatorius*	*Mugil cephalus*	*Sebastes marinus*
Moisture (g/100 g)	78	78	70	72	80	64	83	77	79
Raw protein (g/100 g)	19	21	14	18	19	19	15	19	19
Total lipids (g/100 g)	0.7	2.3	14	9	0.6	14	1.5	3.8	1.6
Ash (g/100 g)	1.2	1.4	1	1.5	1.4	1.4	1.2	1.2	1.2
Energy (kcal/100 g)	87	110	186	158	87	205	76	117	94
Energy (kJ/100 g)	364	460	778	661	364	858	318	490	393
Calcium (mg/100 g)	33	47	3	57	34	12	8	41	107
Magnesium (mg/100 g)	39	83	26	32	63	76	21	29	30
Phosphorus (mg/100 g)	188	222	164	236	198	217	200	221	216
Potassium (mg/100 g)	311	450	268	327	379	314	400	357	273
Sodium (mg/100 g)	68	54	80	90	135	90	18	65	75
Zinc (mg/100 g)	0.3	0.4	0.4	1	0.3	0.6	0.3	0.5	0.5
Copper (mg/100 g)	0.06	0.03	0.03	0.09	0.1	0.07	0.03	0.05	0.03
Manganese (mg/100 g)	0.03	0.02	0.01	0.04	0.03	0.02	0.02	0.02	0.02
Selenium (µg/100 g)	30	37	37	36	36	44	36	36	43
Iodine (µg/100 g)	186	22	74	41	175	109	27		70
20:5 ($n-3$) (g/100 g)	0.059	0.071	0.526	0.709	Total	0.898	Total	0.217	0.08
22:6 ($n-3$) (g/100 g)	0.126	0.292	0.393	0.862	PUFA	1.401	PUFA	0.108	0.211
					0.22		0.61		
Cholesterol (mg/100 g)	36	45	42	31	31	33	33	49	42

Components	Pike *Esox lucius*	Saithe *Pollachius virens*	Alaska Pollack *Theragra chalcogramma*	Orange roughy *Hoplostetus atlanticus*	Bluefin tuna *Thunnus thynnus*	Skipjack *Euthynnus pelamis*	Yellowfin tuna *Thunnus albacares*	Turbot *Psetta maxima*	Wolffish *Anarhichas lupus*
Moisture (g/100 g)	79	78	82	76	68	71	71	77	80
Raw protein (g/100 g)	19	19	17	15	23	22	23	16	18
Total lipids (g/100 g)	0.7	1	0.8	0.7	5	1	15	3	2
Ash (g/100 g)	1.2	1.4	1.2	0.9	1.2	1.3	1.3	2	1.2
Energy (kcal/100 g)	88	92	81	69	144	103	168	95	96
Energy (kJ/100 g)	368	385	339	289	602	431	452	397	402
Calcium (mg/100 g)	57	60	5	30	8	29	16	18	6
Magnesium (mg/100 g)	31	67	57	30	50	34	50	51	30
Phosphorus (mg/100 g)	220	221	376	200	254	222	191	129	200
Potassium (mg/100 g)	259	356	326	300	252	407	444	238	300
Sodium (mg/100 g)	39	86	99	63	39	37	37	150	85
Zinc (mg/100 g)	0.67	0.37	0.44	0.75	0.6	0.82	0.52	0.22	0.78
Copper (mg/100 g)	0.05	0.05	0.04	0.1	0.09	0.09	0.06	0.04	0.03
Manganese (mg/100 g)	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Selenium (µg/100 g)	12	36	22	36	36	36	36	36	36
Iodine (µg/100 g)		121	46					180	
20:5 (*n* – 3) (g/100 g)	0.033	0.071	0.15		0.283	0.071	0.037	Total PUFA	0.307
22:6 (*n* – 3) (g/100 g)	0.074	0.35	0.22		0.890	0.185	0.181	0.88	0.316
Cholesterol (mg/100 g)	39	31	71	20	38	47	45	39	43

Continued

Table 1.6 *Continued*

Components	Fish species				
	Salmon	Chinook	Keta	Coho	Swordfish
	Salmo salar	*Oncorhynchus tschawytscha*	*Oncorhynchus keta*	*Oncorhynchus kisutch*	*Xiphias gladius*
Moisture (g/100 g)	69	73	75	73	76
Raw protein (g/100 g)	20	20	20	22	20
Total lipids (g/100 g)	6	10	4	6	4
Ash (g/100 g)	2.5	1.4	1.2	1.2	1.5
Energy (kcal/100 g)	142	180	120	146	121
Energy (kJ/100 g)	594	753	502	611	506
Calcium (mg/100 g)	12	22	11	36	4
Magnesium (mg/100 g)	29	95	22	31	27
Phosphorus (mg/100 g)	200	289	283	262	263
Potassium (mg/100 g)	490	394	429	423	288
Sodium (mg/100 g)	44	47	50	46	90
Zinc (mg/100 g)	0.6	0.4	0.5	0.4	1.2
Copper (mg/100 g)	0.3	0.04	0.06	0.05	0.1
Manganese (mg/100 g)	0.02	0.02	0.02	0.01	0.02
Selenium (µg/100 g)	37	36	35	36	48
Iodine (µg/100 g)	45				
20:5 ($n-3$) (g/100 g)	0.32	0.788	0.233	0.429	0.108
22:6 ($n-3$) (g/100 g)	1.12	0.567	0.394	0.656	0.531
Cholesterol (mg/100 g)	26	66	74	45	39

Table 1.7 Compositional data of edible part (fillet) of marine crustacean and molluscan shellfish species. Data are average values calculated or estimated and rounded from several food composition tables as well as from our analyses and can be subject to great variations depending on intrinsic fish parameters such as state of maturity, sex, age, season, nutritional status, etc.

	Crustacean and molluscan shellfish species								
	Pacific oyster	American oyster	Common octopus	Blue mussle	American lobster	Snow crab	Dungeness crab	Blue crab	King crab
Components	*Crassostrea gigas*	*Crassostrea virginica*	*Octopus vulgaris*	*Mytilus edulis*	*Homarus americanus*	*Chionoectes opilio*	*Cancer magister*	*Callinectes sapidus*	*Paralithodes camtschatica*
Moisture (g/100 g)	82	85	80	81	77	81	79	79	80
Raw protein (g/100 g)	9.5	7	15	12	19	19	17	18	18
Total lipids (g/100 g)	2	2	1	2	1	1	1	1	0.6
Ash (g/100 g)	1.2	1.4	1.6	1.6	2.2	2	1.7	1.8	1.8
Energy (kcal/100 g)	81	68	82	86	90	90	86	87	84
Energy (kJ/100 g)	339	285	343	360	377	377	360	364	351
Calcium (mg/100 g)	8	45	53	26	48	26	46	89	46
Iron (mg/100 g)	5	6.7	5.3	4	0.3	2.5	0.4	0.7	0.6
Magnesium (mg/100 g)	22	47	30	34	27	49	45	34	49
Phosphorus (mg/100 g)	162	135	186	197	144	133	182	229	219
Potassium (mg/100 g)	168	156	350	320	275	173	354	329	204
Sodium (mg/100 g)	106	211	230	286	296	539	295	293	836
Zinc (mg/100 g)	17	91	1.7	1.6	3	2.8	4.3	3.5	6
Copper (mg/100 g)	1.6	4.5	0.4	0.1	1.7	0.6	0.7	0.7	0.9
Manganese (mg/100 g)	0.6	0.4	0.03	3.4	0.06	0.03	0.08	0.2	0.04
Selenium (µg/100 g)	77	64	45	45	41	35	37	37	36
Iodine (µg/100 g)			25	99					
20:5 ($n-3$) (g/100 g)	0.438	0.268	0.076	0.188	Total PUFA	0.259	0.219	0.17	Total PUFA
22:6 ($n-3$) (g/100 g)	0.25	0.292	0.081	0.253	0.15	0.113	0.088	0.15	0.13
Cholesterol (mg/100 g)	50	53	48	28	95	55	59	78	42

The protein of fish muscle is rich in essential amino acids, has a high biological value and can be digested easily. The amount of connective tissue is low (1–2%) compared with warm-blooded animals (10–13%).

The content of non-protein nitrogen (NPN) components in fish flesh is high. The main components are creatine (200–700 mg/100 g), trimethylamine oxide (100–1000 mg/100 g), adenosine nucleotides (200–400 mg/100 g), free amino acids and dipeptides. Chondrichthyes contain high amounts of urea. The average sum of NPN amounts to 420 mg/100 g and contributes to 15% of raw protein content (nitrogen content × 6.25).

The fat content of fish varies greatly in quantity and fatty acid composition. The protein content is almost constant. The fat content is mainly dependent on biological state of maturity, but also on nutritional status, age, catching ground and season. The fat is not homogeneously distributed in the body. In lean fish species, it is located in the liver as an energy reservoir; in fatty species, it is deposited in the muscle tissue, as a subcutaneous layer under the skin or in the intestines. In many fatty fish species, a linear correlation exists between the fat and water content of muscle tissue.

Lean fish species have a higher proportion of polar lipids (phosphatidylcholine and phosphatidylethanolamine) than fatty fish species, in which the fat consists mainly of neutral lipids (triacylglycerols). The polar lipids are mainly located in the lipid bilayer of the cell membranes, whereas the neutral lipids are located in the fat cells of the energy reservoirs (liver, muscle). The cholesterol content of fish muscle is generally low (35 mg/100 g).

Fish lipids differ from those of terrestrial animals mainly in their high content of long-chain, highly unsaturated fatty acids of the *n*–3 series (eicosapentaenoic acid, 20:5 and docosahexaenoic acid, 22:6), often referred to as polyunsaturated fatty acids (PUFAs). The content of these PUFAs in fatty fish species can be high: dogfish 3 g/100 g, herring 2.3 g/100 g, mackerel 4.6 g/100 g, salmon 2.3 g/100 g and tuna 2.1 g/100 g. The highly unsaturated character of these fatty acids is the reason why they are susceptible to lipid oxidation and oxidative degradation. Fatty fish species therefore have a tendency to exhibit rancid tastes and odours after limited storage time.

1.6 Vitamins

The vitamin contents in fish are species specific. They can vary considerably within one species with age, size, sex, season, diet, state of health and geographic location. In fish farmed by aquaculture, the contents of vitamins reflect the composition of the corresponding components in the fish feed. Therefore, the vitamin content of wild and farmed fish can be different.

From different food composition tables, the mean vitamin contents in raw muscle are summarised in Table 1.8a, b for several marine fish and in Table 1.9a, b for freshwater fish.

1.6.1 Fat-soluble vitamins

The liver of fish is a rich source of fat-soluble vitamins (A, D, E and K). In fish flesh, dark muscle contains more fat-soluble vitamins than white muscle because of its higher fat content.

Table 1.8a Fat-soluble vitamins in marine fish species (µg/100 g edible portion).

Species	Taxonomic name	Fat (g/100 g)	Vitamin A	Vitamin D	Vitamin E	Vitamin K_1
Anchovy	*Engraulis encrasicolus*	2.3	19	20	500	
Anglerfish	*Lophius piscatorius*	0.1–1.5	8–80	1–2	500–1000	n.d.
Atlantic halibut	*Hippoglossus hippoglossus*	1.6–10.4	<2–33	5–18	700–1000	
Catfish (wolffish)	*Anarhichas lupus*	2.0–2.5	18–27	0.5–1.8	1100–2150	
Cod	*Gadus morhua*	0.3–0.7	2–11	1.2–1.5	449–1100	0.02–0.05
Dab	*Limanda limanda*	1.0–1.6	14	1.5	400	0.01
Flounder	*Platichthys flesus*	0.7–3.2	9–10	0.8	360–1000	0.2
Greenland halibut	*Rheinhardtius hippoglossoides*	9.8–14.1	5–50	11–15	850–2200	
Haddock	*Melanogrammus aeglefinus*	0.2–1.0	2–17	1	390–500	0.03
Hake	*Merluccius merluccius*	0.4–2.5	15	1	600	0.01
Herring (Atlantic)	*Clupea harengus*	14.0–17.8	6–38	11–27	600–1800	0.04
Herring (Baltic Sea)	*Clupea harengus membras*	9.2	9.7	7.8	2000	0.08
Horse mackerel	*Trachurus trachurus*	3.9–5.6	12–40	0.5	700	
Ling	*Molva molva*	0.6–2.8	2–10	1–3.4	300	
Mackerel	*Scomber scombrus*	3–30	51–214	1–13	600–1550	5.0 0.6
Mullet	*Mugilidae* spp.	4.2–4.3	45–47	3	1000	
Plaice	*Pleuronectes platessa*	1.4–1.9	0–16	3.0–9.0	600–800	0.05
Redfish (ocean perch)	*Sebastes marinus*	0.9–3.6	13–14	2.3	900–1300	
Saithe	*Pollachius pollachius*	0.2–0.9	2–20	1–2.2	200–700	0.04
	Pollachius virens	0.3–0.9	2–11	0.7–0.8	360–600	
Sardine (pilchard)	*Sardina pilchardus*	4.5–5.2	19–20	8.5–11	465	
Skate (ray)	*Raja* spp.	1.26	3.0			
Smelt	*Osmerus eperlanus*	1.7–1.8	11	1	100	
Sole	*Solea solea / Solea vulgaris*	1.1–7.1	<2–4	8	600–800	
Sprat	*Sprattus sprattus*	10.5–17.6	100–150	18.7–20	1200–2500	1.0
Swordfish	*Xiphias gladius*	4.0–4.4	20–36	2	1000	
Tuna	*Thunnus spp.*	15.1–15.5	450–464	4.5–5.0	1171	
	Thunnus thynnus	1.1–4.9	370	2.9–5.0	1200	
	Thunnus alalunga	10.0	370	5.4	1200	
Turbot	*Psetta maxima*	1.7–3.0	1–12	1.7–2	600	n.d.
Tusk	*Brosme brosme*	0.2–0.5	2–10	1	100–300	
Whiting	*Merlangius merlangus*	0.6–0.7	3–15	0.2	200–230	0.03
Witch	*Glyptocephalus cynoglossus*	1.1	1	0.01	800	

n.d., No data.

Table 1.8b Water-soluble vitamins in marine fish species (µg/100 g edible portion).

Species	Thiamin B_1	Riboflavin B_2	Niacin B_3	Vitamin B_6	Pantothenic acid B_5	Biotin B_7	Folic acid B_9	Vitamin B_{12}	Vit. C
Anchovy	10–70	120–270	3100–20,000	143–180	773	7	4–12.3	0.6–3.3	500
Anglerfish	24	60	1683	165	225	2.0	11	2.0	1000
Atlantic halibut	40–78	45–80	4000–6000	354–500	250–400	3.1–5	2.6–12	0.8–1.1	1
Catfish (wolffish)	70–200	60–80	2200–2400	300–357	570–600	2.0	1	2–2.2	1000
Cod	50–56	46–110	2000–2300	200–230	200–256	2.2	8.0–12	0.6–1.2	2000
Dab	100–103	80–84	2300	190–257	860	1.2	5.0	1.5	1000
Flounder	150–220	200–210	3000–3500	250	680–1000	1.2	5–15	1.0–3.0	857–1000
Greenland halibut	46–65	70–80	1300–1500	430–600	250–300	2.0	12	1.0	1000
Haddock	50–70	100–170	3100–4000	120–500	200–300	2.4–5.0	0.8–13	0.7–2	2000
Hake	90–100	80–200	1600–2900	230–880	190	4.3	14	2.1	1583
Herring	40–60	200–300	3756–4500	346–500	940–1000	4.5–10	5–10	8.5–14	500–667
Horse mackerel	140–180	140–421	3400–8320	310–700	350–500	2	1	4.4–12.7	1000
Ling	50–70	80	2300–2500	260–304	300–320	4.2–6.4	11	0.5–0.6	2000
Mackerel	100–140	314–360	7500–9400	426–800	460–1000	1.5–7	1–8	8.4–12	0–800
Mullet	60–65	138–150	3800–4033	424	300	3	14	2.2	600
Plaice	150–259	90–220	3500–4000	220–347	767–800	1.2–90	11–14	1.5–10	1500–1633
Redfish	50–110	50–90	1200–2500	230–372	360	1–11	13	1–3.8	800–829
Saithe: *P. pollachius*	50–170	100–350	1290–4000	100–400	140–300	3.2–7	10	1–3.5	1500
P. virens	47–100	185–200	3270–3500	287–500	380–400	7–7.2	10	3.2–4	1000
Sardine (pilchard)	10–20	250–300	7400–12933	270–960	660–758	8.4	4	0.1–17	400
Skate (ray)	20–30	10–400	2000–2500	750				1	
Smelt	50–100	120–140	1450–1900	120–183	640–920	30	5–37	1.8–3.4	3000
Sole	60–72	50–100	3000–3500	259–314	300–322	1.2–4.4	10	0.8–1.0	2000
Sprat	40–80	150–260	4167–5000	200–230	600–1000	6	5	7	200
Swordfish	36–50	80–82	7600–7947	330	412	1.5	2	0.6–1.8	850
Tuna	160–176	160–166	8500–8519	460–612	660–739	1.5	15	4.3–4.5	1000
Thunnus thynnus	163–241	80–251	8500–8640	450–1000	500–1054	1.5–5	15	3.4–9.4	2000–2600
Thunnus alalunga	50–160	110–160	1200–8500	440–460	420–660	1.5–3	15	1.7–4.3	5000
Turbot	20–50	80–150	1100–6100	152–300	250–1000	3.2	8–16	0.8–1.7	Trace
Tusk	30–50	60–150	2300–2800	300–387	120–300	0.1	2	0.3–1	3000
Whiting	40–100	50–200	2000–6100	240	190	4.3	14	2.1	1500
Witch	89	79	3424	249	325	5	11	1.1	1

Table 1.9a Fat-soluble vitamin content in edible part of freshwater fish species (µg/100 g edible portion).

Species	Taxonomic name	Fat (g/100 g)	Vitamin A	Vitamin D	Vitamin E	Vitamin K_1
Brook trout	*Salvelinus fontinalis*	2.1	10	1	100	
Carp	*Cyprinus carpio*	4.8–4.9	44	0.5	500	0.2
Eel	*Anguilla anguilla*	24.5–32.5	600–1800	20–30	2800–8000	0.7–2.8
Perch	*Perca fluviatilis*	0.80–1.3	6.5–7	0.2–0.8	1200–1500	
Pike	*Esox lucius*	0.9	14–15	2	850–910	
Pike-perch	*Stizostedion lucioperca*	0.7	1	0.2–0.7	1350–1450	0.08
Pollan	*Coregonus* spp.	3.0–3.2	21–22	1	2678–2700	
Salmon	*Salmo salar*	7–23	15–41	8–30	600–4000	
Tench	*Tinca tinca*	0.7	1	0.2	100	
Trout	*Salmo trutta*	2.7–3.3	12–32	2.1	650–1700	
Rainbow trout	*Oncorhynchus mykiss*	3.3–10.2	10–18	13.0–32.9	1600–2700	0.07

The flesh of fatty fish still contains moderate amounts of vitamin A, but lean fish contain only trace amounts.

Fish and fish products are commonly regarded as the most important natural food sources of vitamin D. Vitamin D contents differ greatly between species. In general, the higher the fat content of the fish meat, the higher is the vitamin D content.

Vitamin E functions as a natural antioxidant to prevent lipids from becoming rancid. Fish flesh is only a low to modest source of vitamin E.

Relatively few values for the vitamin K content of fish are available. The highest concentrations are found in muscle of marine and freshwater fish with high fat content, and in the liver. Lean fish contain only very small amounts of vitamin K. Fish muscle, compared with some green vegetables, represents only a minor source of vitamin K.

1.6.2 Water-soluble vitamins

Most fish species cannot synthesise vitamin C (ascorbic acid). The average vitamin C content of fish ranges from 1 to 5 mg per 100 g. These small amounts are without any nutritional significance for humans.

The natural thiamin (vitamin B_1) content of most fish and fishery products is relatively low. A special problem with some fresh- and seawater fish species is the occurrence of thiaminases. These enzymes cleave the thiamin molecule. They occur especially in the viscera of fish. For example, carp, mackerel and mussels have high thiaminase activity. The enzymes can act during food storage, but they are inactivated by heat, so cooking and smoking destroy them.

All plant and animal cells contain riboflavin (vitamin B_2), but there are few rich sources. Fish is a modest source. Only the dark muscle, the roe and the liver of several fish species contain higher concentrations of riboflavin.

Table 1.9b Water-soluble vitamin content in edible part of freshwater fish species (μg/100 g edible portion).

Species	Thiamin B_1	Riboflavin B_2	Nicotinamid B_3	Pyridoxin B_6	Pantothenic acid B_5	Biotin B_7	Folic acid B_9	B_{12}	C
Brook trout	100	70	4000	980	1000	3.0	26	3.0	3000
Carp	68–110	52–80	1863–3000	70–156	150–592	8.5	22–70	1.5–3.2	1000–1086
Eel	150–180	40–320	2600–3800	244–300	140–200	5.1	12–14	1.0–4.4	1000–1800
Perch	70–75	70–120	1700–4000	230	190	4.3	14	1.0	2000
Pike	81–90	55–70	1600–1700	140–150	240	2	6–13	2	3725
Pike-perch	160	250	2300	240	170	2.1	10	1.6	1000
Pollan	88	108	3168	367	658	10	9–23	3.2	900
Salmon	170–230	100–170	6000–8200	811–980	1000–2000	5–7.4	3.4–26	2.9–6.2	1000
Tench	75	180	4000	290	670	4.3	21	2.1	1000
Trout	84–100	76–140	3400–3500	539	1700–1950	4.5	9.4–16	5	1100
Rainbow trout	90–100	80–210	3666–5500	258–700	970–2000	4.5	8–22	3–5	3400

Seafood is rich in niacin. Lean fish contain lower levels than fatty fish like mackerel, salmon and tuna. Although niacin is equally spread throughout the fish body, liver, roe and sperm can contain higher amounts.

With the exception of salmon and trout, fish generally contain only small amounts of pantothenic acid. In fish, the highest concentrations are found in the ovaries and the lowest in the flesh.

Fish and shellfish are very good sources of vitamin B_6. Mackerel, herring, tuna, sardine and salmon are especially rich in this vitamin. A 200 g portion of fish fillet contains on average approximately 30–60% of the daily requirement of a human. Fish liver contains particularly high concentrations.

Fish organs like liver and kidneys contain more folic acid than the flesh. Fish are poor sources compared with plant products. These small amounts are without any nutritional significance for humans.

Biotin is found only in small amounts in most fish. One fish meal (200 g) covers 10–20% of the daily requirement of a human.

Vitamin B_{12} originates from synthesis by microorganisms. It is only found in animal foods. Seafood is an important food source. In particular, organs like liver and heart are very rich sources. Dark-fleshed fish like herring and mackerel contain more vitamin B_{12} than white-fleshed fish like cod and flatfish.

The dark muscle of fish usually contains higher levels of the water-soluble vitamins than the white meat.

In general, fish meat is a rich source of vitamin D and B_{12}. Many species like Atlantic halibut, herring, mackerel, swordfish, tuna, trout and salmon also contain considerable amounts of niacin and vitamin B_6. The higher the fat content of the fish meat, the higher is the content of fat-soluble and some water-soluble vitamins.

1.7 Minerals

There are numerous minerals in fish. The two most important, found predominantly in marine fish species, are the essential elements selenium and iodine. Fish is the only major natural source for these elements. The regular intake of these elements through food is of great importance because the population in many European countries is not sufficiently supplied with these elements. Insufficient iodine can lead to goitre and other diseases. Also, lack of selenium leads to numerous diseases. The iodine content in marine fish varies, according to species, between 50 and 800 µg/100 g. Fish skin is extremely rich in iodine. Freshwater species contain only 5 µg iodine/100 g on average. The selenium concentration in marine fish is 0.35–0.60 mg/kg. The daily requirement of these essential elements can be met by eating a 200 g portion of marine fish.

1.8 *Post mortem* changes in fish muscle

Directly after death of the fish, a series of biochemical reactions starts, which is of paramount importance for the quality and shelf life of products. These reactions depend on several different factors: the type of fish species, the physiological condition of the fish, as well as environmental influences (for example water temperature, salinity) the living fish has been exposed to, may influence quality loss and spoilage. In addition, catching and harvesting methods, killing procedures and the performance of slaughtering have a great effect on the biochemical reactions related to disintegration of the fish fillet by gaping for example, or to the so-called ‘tuna burn’, which is a term describing pale and soft flesh of tuna.

Details of *post mortem* metabolism are discussed in most of the following chapters of this book, as changes in the metabolome (for example in nucleotide concentrations) can be used to follow quality loss and spoilage of fish. This introductory chapter only gives an overview of the important biochemical reactions related to quality changes.

Even during the catching process, the concentration of ammonium ions in the fillet increases and glycogen stores are reduced. When the fish has been killed, anaerobic glycolysis continues, increasing the concentration of L-lactate in the fillet with a concomitant decrease in the pH value. The concentration of creatine phosphate and adenosine triphosphate (ATP) decreases, and the onset of *rigor mortis* starts when the concentration of ATP is no longer sufficient to remove the connection between thick (myosin) and thin (actin) filaments of the myofibrils.

Freezing of fish or fish fillet directly after catch more or less halts most of the enzymatic reactions, depending on the temperature of the frozen fish. However, during later thawing, chilled storage or further processing of the fish, glycolysis, proteolysis, lipolysis and other enzymatic reactions continue and may result in quality losses. Decrease of water-binding capacity and texture deterioration are examples of the effects of ‘thaw rigor’.

The start, extent and length of *rigor mortis* vary considerably between different fish species. *Rigor mortis* may last for several days before the fish flesh becomes tender due to the action of endogenous proteases, without, however, reaching the same elasticity as before *rigor*. Several proteolytic systems, consisting of enzymes and inhibitors, are involved in the degradation of the structural proteins of fish muscle: these are the acid cathepsins located in lysosomes, alkaline proteinases, proteosomes (multicatalytic proteinase complexes), calpains, aminopeptidases, collagenases and elastases.

Enzymes bound in cell organelles or located in the cell membranes are gradually released during storage of fish in melting ice or at higher temperatures in the refrigerator. Fish muscle lysosomes contain a multitude of hydrolytic enzymes apart from cathepsins, which may influence metabolite changes of fresh fish. Mitochondrial enzymes are involved in ATP degradation and the increase of calcium ions (Ca^{2+}) in the sarcoplasma. The heavy destruction of cell organelles during freezing and thawing has been used to develop methods of distinguishing fresh from thawed fish (see Chapter 16).

Storage of fish being *in rigor* at elevated temperatures (for example 17 °C for Atlantic cod, *Gadus morhua*) results in heavy shortening of the muscle. The connective tissue becomes partly denatured, and the connections between the myocommata and the muscle fibres are removed. The result is ‘gaping’, which is characterised by fissures and cracks in the fillet.

As the muscle tissue of living marine fish is sterile, the quality of fish stored in melting ice is initially mainly influenced by autolytic reactions. ATP is degraded in several steps into hypoxanthine and ribose or ribose phosphate. Formation of hypoxanthine can be used as a freshness indicator, as discussed in detail in Chapter 4.

Gadoid fishes, like cod, hake (*Merluccius* spp.) or Alaska pollack (*Theragra chalcogramma*), contain the enzyme trimethylamine oxide demethylase (TMAOase), which catalyses the cleavage of trimethylamine oxide (TMAO) into dimethylamine (DMA) and formaldehyde (FA). Gadoid fish produce DMA and FA during processing (for example filleting) or in the first days of storage in melting ice. Later TMAOase activity is inhibited by oxygen, and the reaction ends after a few days. Later (±10 days after catch), bacterial reduction of TMAO to trimethylamine (TMA) starts, a process that dominates during further storage of the fish or fillet. TMA is responsible for the fishy flavour of spoiled marine fish.

TMA and ammonia are the main components of the 'total volatile basic nitrogen' (TVBN) fraction of chilled stored fish. The TVBN fraction is obtained by steam distillation of alkalised fish muscle or fish muscle extract. Fish exceeding certain limits of the TVBN value is considered unsuitable for human consumption when sensory assessment leads to the same conclusion. Ammonia is the main component of the TVBN fraction in the first phase of storage lasting 1 to 2 weeks, depending on species and storage conditions, whereas the rise of TMA is correlated to spoilage of the fish (see Chapter 2).

Directly after the catch, the muscle tissue of healthy marine fish is free from bacteria, but not the gills, skin and intestines. The bacteria penetrate into the fillet mainly through the gills and body cavity during storage and processing, accompanied by changes in the composition of the bacterial flora. Gram-negative psychrotrophic rods (*Shewanella* spp., *Pseudomonas* spp., *Vibrio* spp. and *Aeromonas* spp.) are important spoilage bacteria (see Chapter 15).

Bacteria are also responsible for the formation of biogenic amines from precursor amino acids in spoiling fish by decarboxylation. Histamine is produced from histidine, cadaverine from lysine, putrescine from ornithine, tryptamine from tryptophane, tyramine from tyrosine and agmatine from arginine. Dark-fleshed fish species, like scombroids (for example tuna, mackerel) or some clupeids (for example anchovy), which contain high concentrations of histidine, are especially important histamine formers if stored at higher temperatures (see Chapter 3).

Fish lipids are not stable during storage at any temperature. Lipolysis and lipid oxidation may occur in chilled or frozen fish, leading to unpleasant flavours and tastes caused by carbonyl compounds and short-chain carbonic acids. Binding of free fatty acids to fish muscle proteins may result in texture deterioration.

Speed and extent of lipolysis and of oxidation of unsaturated fatty acids are higher in dark muscle than in white muscle, like many other biochemical reactions in the fillet *post mortem*. The activity of enzymes (for example lysosomal enzymes, TMAOase) and other proteins like myoglobin, as well as the concentration of metal ions (for example $Fe^{2+/3+}$), relevant to spoilage is higher in red than in white muscle.

During frozen storage, lipid degradation by lipolysis (lipases, phospholipases) is not completely stopped but continues at a lower rate, leading to increased concentrations of free fatty acids, which can be used as quality indicators.

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