13 Fish, Whales, Crustaceans, Mollusks

13.1 Fish

13.1.1 Foreword

Fish and fish products fulfill an important role in human nutrition as a source of biologically valuable proteins, fats and fat-soluble vitamins. Fish can be categorized in many different ways, e. g., according to:

- The environment in which the fish lives: sea fish (herring, cod, saithe) and freshwater fish (pike, carp, trout), or those which can live in both environments, e. g., eels and salmon. Sea fish can be subdivided into groundfish and pelagial fish.
- The body form: round (cod, saithe) or flat (common sole, turbot or plaice).

Commercial fishing takes place in the open sea, coastal and freshwater areas. Conservation programs and hatcheries to rebuild stocks play important roles in the management of fresh and saltwater fish resources.

Table 13.1. Fish, crustaceans, mullusks (fished in 2001)

Continent	1000 t	Country	1000 t
World	129,943	China	44,063
		Peru	7996
Africa	7292	India	5965
America, North,		Japan	5521
Central	8885	USA	5405
America, South	15,817	Indonesia	5068
Asia	78,763	Chile	4363
Europe	17,875	Russian Fed.	3718
Oceania	1163	Thailand	3606
		Norway	3199
		Philippines	2380
		Korea	2282
		Vietnam	2010
		Iceland	1985
		∑ (%)[a]	75

[a] World production = 100%

Table 13.2. Catch of fish by German fishery in 2007

Name	Metric ton
Herring	24,515
Mackerel	11,043
Cod	8064
Haddock	136
Pollack	2247
Red fish	263
Crab	11,385
Mussel	5797
Others	18,317
Sum	81,767

Table 13.3. Average per capita consumption of fish and shellfish (2001–2003)[a]

Country	kg/year
Iceland	91.4
Japan	66.9
Portugal	57.1
Norway	49.5
Spain	44.5
France	33.5
Finland	32.1
Sweden	29.5
Luxembourg	28.6
China	25.7
Italy	24.3
Denmark	22.9
United States	22.6
Belgium	22.3
Greece	21.9
Netherlands	21.7
United Kingdom	20.4
Ireland	20.4
Switzerland	15.7
Germany	14.3; 15.5[b]
Ukraine	13.6
Austria	11.5
Czech Republic	10.2
Poland	8.9
India	4.8

[a] Source: FAO
[b] 2006.

The fishing industry catch has risen sharply in tonnage during this century. In 1900 the catch was approx. 4 million t, while it had increased to 129 million t by 2001. Table 13.1 shows the catch in tonnage of the leading countries engaged in fishing. This includes shellfish products, i. e. lobsters and crustaceans such as crabs, crayfish and shrimps, and mollusks such as clams, oysters, scallops, squid, etc., which are not true fish but are harvested from the sea by the fishing industry. Table 13.2 lists the catch of fish by the German fishery. Table 13.3 gives information on the per capita consumption of fish and shellfish. Because of the high nutritional value of ω-polyunsaturated fatty acids (cf. 3.2.1.3) fish consumption is recommended as an important part of the human diet.

13.1.2 Food Fish

Table 13.4 shows the important food fish. In general, a predatory fish is better tasting than a non-predaceous fish, a fatty fish better than a non-fatty fish. The fishbone-rich species, such as carp, perch, pike and fench, are often less in demand than fish with fewer bones.
Some important food fish will be described in more detail.

13.1.2.1 Sea Fish

13.1.2.1.1 Sharks

Dogfish (*Squalus acanthias*) about 1 m long are marinated or smoked before marketing. In North America fish of the family *Squalidae* are generally referred to as dogfish sharks. Other names are spiny, spring or piked dogfish and rock salmon. Trade names used in th U.K. are flake, huss or rig. In Germany the name used is Dornhai (Dornfisch), and the smoked dorsal muscle is sold as “Seeaal”, while the hot-smoked, skimmed belly walls are called “Schillerlocken”.
Mackerel sharks of the family *Lamnidae* are also in this group. The main species of this family are: (a) porbeagle, blue dog or Beaumaris shark (*Lamna nasus*); and (b) salmon, (c) mako and (d) white sharks. The blue shark is found in the Atlantic Ocean and the North Sea as an escort of herring schools. It possesses a meat similar to veal and is known in the trade as sea or wild sturgeon, or calf-fish. Due to a high content of urea (cf. 13.1.4.3.6), the meat of these fish is often tainted with a mild odor of ammonia. Endeavors to popularize shark and related fish meat are well justified since the meat is highly nutritious; however consumer acceptance would be hampered by the word “shark”, therefore other terms are commonly preferred in the trade. Shark fins are a favorite dish in China and are imported to Europe as a specialty food.

13.1.2.1.2 Herring

The herring (*Clupea harengus*) is a fatty fish (fat content >10%, cf. Table 13.5). It is one of the most processed and most important food fish and a source of raw materials for meal and marine oil. Herrings are categorized according to the season of the catch (spring or winter herring), spawning time or stage of development (e. g. matje, the young fatty herring with roe only slightly developed, is cured and packed in half barrels), or according to the ways in which the fish were caught: drag or drift nets, trawling nets, gill and trammel nets or by seining (purse seining), the most important form of snaring.
The herring averages 12–35 cm in length and migrates in large swarms or schools throughout the nothern temperate and cold seas.
Herring is marketed cold or hot smoked (kippers, buckling), frozen, salt-cured, dried and spiced, jellied, marinated and canned in a large variety of sauces, creams, vegetable oils, etc. Sprat (*Sprattus sprattus phalericus*), called brisling in Scandinavia and Sprotte in Germany, is processed into an “Appetitsild” (skinned fillets or spice-cured sprats packed in vinegar, salt, sugar and seasonings). Canned brisling is packed in edible oil, tomato and mustard sauces, etc. and is sold as brisling sardines. Brisling is often lightly smoked and marketed as such. Sprats are also processed into a delicatessen product called “Anchosen”, which consists mostly of small sprats, sometimes mixed with cured matje, and preserved in salt and sugar, with or without spices and sodium nitrate.
Anchovies (*Engraulis encrasicolus*; German term “Sardellen”; found in Atlantic and Pacific

Table 13.4. Major commercial fish species – quality and utilization

Name	Family	Genus, sp.	Comments on quality and processing
Sea fish			
Pleurotremata (sharks)			
Dogfish	Squalidae	*Squalus acanthias (Acanthias vulgaris)*	
Rajiformes (skates)			
Skates, e. g., thronback, common skate	Rajidae	*Raja clavata, R. batis*	Used are the wing shaped body widenings, the pectoral part and breast fins as a delicacy; it is fried, smoked or jellied
Acipenseriformes (sturgeons)			
Sturgeon	Acipenseridae	*Acipenser sturio*	Exceptionally delicate when smoked, caviar is made from its roe
Clupeiformes (herrings)			
Herring	Clupeidae	*Clupea harengus*	Valuable fish with fine white meat, fried and grilled; industrially processed, for example into Bismarck herrings, rollmops and brat-herring
Sprat	Clupeidae	*Sprattus sprattus*	Mostly cold or warm smoked; anchovies
Sardine	Clupeidae	*Sardina pilchardus*	Mostly steam cooked and canned in oil; along sea coast grilled and fried
Anchovy (Anchovis)	Engraulidae	*Engraulis encrasicolus*	Pleasant, aromatic fragrant, cured in brine, made into rings and paste
Lophiiformes (anglers)			
Angler, allmouth	Lophiidae	*Lophius piscatorius*	White, good and firm meat, poached
Gadiformes (cods)			
Ling	Gadidae	*Molva molva*	Tasty firm white meat
Cod	Gadidae	*Gadus morhua*	Meat is prone to fracturing, used fresh, filleted, salted and frozen, dried (stock- and klipfish), cooked, poached; oil is produced from liver
Haddock	Gadidae	*Melanogrammus aeglefinus*	Very fine in taste, processed as fresh, pickled, or marinated, smoked, fried, roasted, cooked or poached, or used for fish salad
Coalfish pollack, black coor or Boston bluefish	Gadidae	*Pollachius virens, P. pollachius*	Meat is lightly tinted grayish-brown, it is filleted, smoked, sliced as cutlets or chops and processed in oil (used forsalmon substitute)
Whithing	Merlangius	*Merlangius merlangius*	Good meat, easily digested, but very sensitive, fried or deep fried roasted or smoked, used for fish stuffings
Hake	Merluccidae	*Merluccius merluccius*	Fresh or frozen, all processing methods are used
Scorpaeniformes			
Red fish, ocean perch	Scorpaenidae	*Sebastes marinus*	Tasty meat, fattier than cod, it is filleted or smoked
Gurnard, sea robin (gray gurnard, red gurnard)	Triglidae	*Trigla gurnardus, T. lucerna*	White firm meat (red sp. is of higher quality), used fresh or smoked
Lumpfish, sea hen	Cyclopteridae	*Cyclopterus lumpus*	Smoked, its roe is processed into caviar substitute

Table 13.4. continued

Name	Family	Genus, sp.	Comments on quality and processing
Perciformes (percoid fishes)			
Red mullet	Mullidae	*Mullus barbatus*	White fine and a piquant delicius meat, mostly grilled
Catfish, wolffish	Anarhicha-didae	*Anarhichas lupus, A. minor*	Fine white fragrant meat, poached grilled, doughtype crust coated
Mackerel	Scombridae	*Scomber scombrus*	Highly valued fish, tasty reddish meat, fried, grilled, smoked or canned; its meat is not readily digestible
Tuna	Scombridae	*Thunnus thynnus*	Reddish meat of exceptional taste, it is fried, roasted, smoked, or canned in oil or processed into paste sausages or rolls
Pleuronectiformes (flat fishes)			
Turbot (butt or britt)	Scopthalmidae	*Psetta maxima (Rhombus maximum)*	Apart from common sole, the highest valued flat fish, meat is snow-white firm and piquant, it is cooked, grilled or poached
Halibut	Pleuronectidae	*Hippoglossus hippoglossus*	Tasty meat, it is poached, fried or smoked
Plaice	Pleuronectidae	*Pleuronectes platessa*	Tasty meat, fried or filleted and poached
Flounder	Pleuronectidae	*Platichthys flesus*	Good white meat, it is poached, fried or smoked
Common sole	Soleidae	*Solea solea*	It is the finest flat fish, it is poached, fried, grilled or roasted
Freshwater fish			
Petromyzones (lampreys)			
Lamprey	Petromyzoni-dae	*Lampetra fluviatilis*	It is industrially processed
Anguilliformes (eel sp.)			
Eel	Angullidae	*Anguilla anguilla*	Tasty meat, good quality when not exceeding 1 kg in weight, the fresh fish is fried, roasted, or it is smoked, marinated of jellied
Salmoniformes (salmons)			
Salmon	Salmonidae	*Salmo salar*	High quality fish (5–10 kg), it is poached, grilled, cured or smoked, also pickled
River trout	Salmonidae	*Salmo trutta*	High quality fish, no fishbone, bluish tinted when cooked, roasted a la meuniere
Rainbow trout (lake- or steelhead trout)	Salmonidae	*Salmo gairdnerii*	
Brook trout	Salmonidae	*Salvelinus fontinalis*	A worthy fish, meat is pale pinkish, processed as trout but mostly fried
Whitefish	Salmonidae	*Coregonus sp.*	Processed as trout
Coregonus, whitefish	Salmonidae	*Coregonus sp.*	White tender and tasty meat, though somewhat dry, it is fried or deep fried
Smelt	Osmeridae	*Osmerus eperlanus*	A fishbone rich meat which is mostly deep fried
Pike (jackfish)	Esocidae	*Esox lucius*	Young pikes (best quality 2–3 kg) are soft tender and tasty, the meat is well rated though it is bone rich, steam cooked, cooked or fried

Table 13.4. continued

Cypriniformes (carps)			
Roach	Cyprinidae	*Rutilus rutilus*	It has a tasty meat though fishbone rich
Bream	Cyprinidae	*Abramis brama*	Tasty meat but fishbone rich
Tench	Cyprinidae	*Tinca tinca*	Tender fatty meat, tasty, bluish when cooked, mostly steam cooked
Carp	Cyprinidae	*Cyprinus carpio*	Soft meat, readily disgestible, a valuable fish food, bluish when cooked
Crucian	Cyprinidae	*Carassim carassim*	A good food fish, but not as good as carp, the meat is bone rich
Perciformes (perchoid fishes)			
Perch	Percidae	*Perca fluviatilis*	Firm, white and very tasty meat, best quality is below 1 kg (25–40 cm), it is fried, filleted and/or steam cooked
Zander	Percidae	*Stizostedion lucioperca*	White, soft, juicy and tasty meat, 40–50 cm, fried or steam cooked, it is the best quality freshwater fish
Ruffle	Percidae	*Gymno-cephaluscernua*	Exceptionally tasty meat

Oceans) should also be included in the herring group. Anchovies are usually salted (cured in brine in barrels until the flesh has reddened). They are also canned in glass jars, marketed as a paste or cream, smoked or dried. Sardines (*Sardina pilchardus*), from the Mediterranean or Atlantic (France, Spain, Portugal) or from Africa's west coast, are often marketed steamed, fried or grilled, or canned in oil or tomato sauce. The fully grown sardine is known in the trade as pilchard (Californian, Chilean, Japanese). It is also salt-cured and pressed in barrels or canned in edible oil or in sauce. "Russian sardines" or "Kronsardine" are actually marinated small herrings or sprats caught in the Baltic Sea. Also in the herring group is the allis shad (*Alosa alosa* or *Clupea alosa*), which is sold fresh, smoked or canned.

13.1.2.1.3 Cod Fish

These nonfatty fish (fat content <1%, cf. Table 13.5) are usually marketed fresh, whole and gutted, and many have the head and/or skin removed or be filleted. The Atlantic cod (*Gadus morhua*) is considered the most important food fish of Northern Europe. Classified according to size, designations are: small codling, codling, sprag and cod in the U.K. and Iceland; and scrod in the United States.

Saithe is also known as coalfish or pollack (*Pollachius virens*) or by names such as black cod or Boston bluefish. After salt-curing and slicing, it is lightly smoked and packed in edible oil. Saithe is marketed in Germany as a salmon substitute called "Seelachs". Rolled in balls and canned, it is called "side boller" in Norway.

Whiting (*Merlangius merlangius*), known as merlan in France, is a North Atlantic, North Sea fish, marketed in many forms.

Haddock (*Melanogrammus aeglefinus*) is a North Atlantic and Arctic Sea fish. Small haddock are called gibbers or pingers, and large ones are jumbos. The annual haddock catch is lower than those of the above-mentioned fish, i. e. anchovy, herring, cod, sardine and pollack. Hake (*Merluccius merluccius*) is an Atlantic and North Sea fish. Its various subspecies are the Cape, Chilean, Northeast Pacific, Mediterranean and North American east coast white hake. The annual catch is somewhat higher than that of haddock. Even higher than both is the catch of menhaden (*Brevoortia tyrannus*), which accounts for almost 38% of the fish tonnage in the United States.

Table 13.5. Average chemical composition of fish

Fish	Moisture[a]	Protein[a]	Fat[a]	Minerals[a]	Edible portion[b]
Freshwater fish					
Eel	61	15	26	1.0	70
Perch	80	18	0.8	1.3	38
Zander	78	19	0.7	1.2	50
Carp	75	19	4.8	1.3	55
Tench	77	18	0.8	1.8	40
Pike	80	18	0.9	1.1	55
Salmon	66	20	14	1.0	64
River trout	78	19	2.7	1.2	50
Smelt	80	17	1.7	0.9	48
Sea fish					
Cod	82	17	0.64	1.2	75
Haddock	81	18	0.61	1.1	57
Ling	79	19	0.6	1.0	68
Hake	79	17	2.5	1.1	58
Red fish (ocean perch)	78	19	3	1.4	52
Catfish	80	16	2.0	1.1	52
Plaice	79	17	1.9	1.4	56
Flounder	81	17	0.7	1.3	45
Common sole	80	18	1.4	1.1	71
Halibut (butt)	75	19	1.7	1.3	80
Turbot (britt)	80	17	1.7	0.7	46
Herring (Atlantic)	63	17	18	1.3	67
Herring (Baltic Sea)	71	18	9	1.3	65
Sardine	74	19	5	1.6	59
Mackerel	68	19	12	1.3	62
Tuna	62	22	16	1.1	61

[a] As % of edible portion.
[b] As % of the whole fish weight.

13.1.2.1.4 Scorpaenidae

Red fish of the North Atlantic and arctic regions (*Sebastes marinus* and other species), which are known as red fish or ocean perch (U.K.) or rosefish or Norway haddock (U.S.A.), have gained in importance in recent decades. Red fish meat is rich in vitamins, firm and moderately fat (fat content 1–10%, cf. Table 13.5). It is marketed fresh or frozen, whole or as fillets; as cold or hot smoked steaks; and roasted or cooked.

13.1.2.1.5 Perch-like Fish

The bluefin tuna (*Thunnus thynnus*) is one of the several *Thunnus* spp. It has a red, beef-like muscle tissue and is caught primarily in the North and Mediterranean Seas and the Atlantic Ocean. It is a fatty fish (cf. Table 13.5), which is marketed salted and dried, smoked, or canned in edible oil, brine or tomato sauce. Tuna meat is also a common delicatessen item (tuna paste, sausages, rolls, etc.). The Atlantic mackerel (*Scomber scombrus*) is of great importance, as are the chub or Pacific mackerel (*S. japonicus*) and the blue Australian mackerel (*S. australasicus*). Mackerel are sold whole, gutted or ungutted; or filleted, frozen, smoked, salted, pickle-salted (Boston mackerel), etc.

13.1.2.1.6 Flat Fish

This group includes: plaice or hen fish (*Pleuronectes platessa*); flounder (*Platichthys flesus*, also known as fluke); Atlantic halibut or butt (*Hippoglossus hippoglossus*); common dab (*Pleuronectes limanda*); brill (*Rhombus laevis*); Atlantic and North Sea common sole (*Solea solea*, "Dover" sole); and turbot (*Psetta maxima*, also called butt or britt). These fish and haddock (cf. 13.1.2.1.3) are the sea fish most popular with consumers.

13.1.2.2 Freshwater Fish

Some important freshwater fish are; eels; carp; tench; roach; silver bream; pike, jackfish or pickerel; perch, pike-perch or blue pike; salmon; rainbow, river or brown trout; and pollan (freshwater herring or white fish). Unlike sea fish, the catch of freshwater fish is of little economic importance (cf. Table 13.2), although it does offer an important source of biologically valuable proteins.

13.1.2.2.1 Eels

Freshwater and sea eels (*Anguilla anguilla, A. rostrata, Conger conger*, etc.) are sold fresh, marinated, jellied, frozen or smoked as unripe summer (yellow or brown eel) or ripe winter eels (bright or silver eel). Due to their high fat content (cf. Table 13.5), eels are not readily digestible.

13.1.2.2.2 Salmon

Salmon (*Salmo salar*) and sea trout (*Salmo trutta*) are migratory. Salted or frozen fish are supplied to the European market by Norway and by imports from Alaska and the Pacific Coast of Canada. Also included in this group are: river trout (*Salmo trutta f. fario*) and lake trout (*Salmo gairdnerii*), which is commonly called steelhead trout in North America when it journeys between the sea and inland lakes.

13.1.3 Skin and Muscle Tissue Structure

As in other backboned animals, fish skin consists of two layers: the outer epidermis and the inner derma (cutis or corium). The outer epidermis is not horny but is rich in water, has numerous gland cells and is responsible for the slimy surface. Mucopolysaccharides are major components of this mucous, with galactosamine and glucosamine as the main sugars. The derma is permeated with connective tissue fibers and has various pigment cells, among them guanophores, which contain silverywhite glistening guanine crystals. Scales protrude from the derma. Their number, size and kind differ from species to species. This is of importance in fish processing since it determines whether a fish can be processed with or without skin. The nature and state of fish skin affects shelf life and flavor. The spreading of skin microflora after death is the main cause of the rapid decay of fish. The skin contains numerous spores resistant to low temperatures; they can grow even at $< -10\,^{\circ}C$ (psychrophiles or psychrotolerant microorganisms). The decay is also enhanced by bacteria present in fish intestines.

The fish body is fully covered by muscle tissue. It is divided dorsoventrally by spinous processes and fin rays and in the horizontal direction by septa. Corresponding to the number of vertebra, the rump muscle tissue is divided into muscle sections (myomeres) (Fig. 13.1), which are separated from each other by connective tissue envelopes. The transversal envelopes are called myocommata, the horizontal ones myosepta. While myosepta are arranged in a straight line, myocommata are pleated in a zig-zag fashion. Since cooking gelatinizes the connective tissue, the muscle tissue is readily disintegrated into flake-like segments.

The muscle fibers (muscle cells), which are enclosed by the sarcolemma, contain 1000–2000 myofibrils (Fig. 13.1), the cell nucleus, sarcoplasm, mitochondria and the sarcoplasmic reticulum. The myofibrils are divided into sarcomeres which, as in mammalian muscle (cf. 12.2.1), consists of thick and thin filaments. Depending on the myoglobin content (cf. 13.1.4.2.1), fish flesh is dark or light colored. The dark muscles are similar to the heart muscle. They lie directly under the skin (Fig. 13.1) and allow persistent swimming. In comparison, the light muscles allow sudden exertion. The proportion of dark muscles is correspondingly low in sea bed fish, e. g., flounder. On the other hand, it is relatively high in fish which constantly swim, e. g., herring and mackerel. Unlike the light muscles, the dark muscles

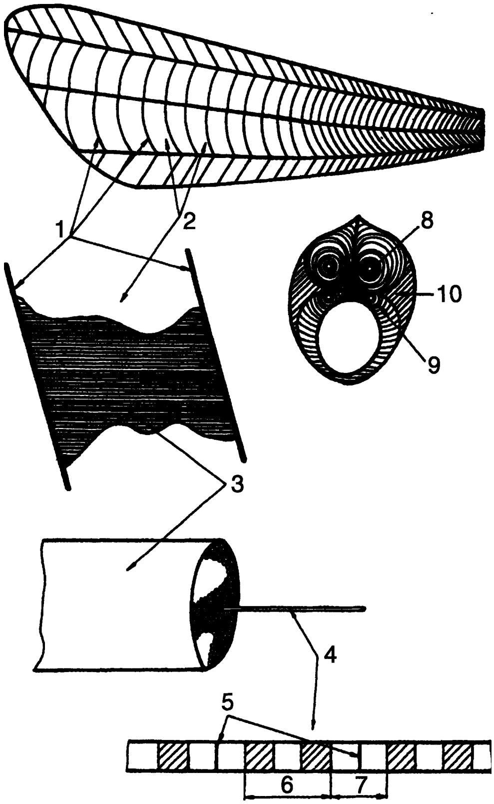


Fig. 13.1. Schematic representation of the muscle structure of fish (according to *Tülsner*, 1994) *1* myosepta, *2* myomeres, *3* muscle fibers, *4* myofibrils, *5* Z line, *6* A band, *7* I band, *8* light muscle (back part), *9* light muscle (stomach part), *10* dark side muscle

are richer in lipids, nucleic acids and B vitamins. The light muscles get their energy from glycolysis and exhibit a higher ATPase activity.

13.1.4 Composition

13.1.4.1 Overview

The edible portion of a fish body is less than in warm-blooded animals. The total waste might approach 50% and 10–15% after head removal. Fish meat and that of land animals are readily digestible, but fish is digested substantially faster and has therefore a much lower nutritive saturation value. The cooking loss is approx. 15% with fish, which is significantly less than that of beef. The biological value of fish proteins is similar to that of land animals. While the crude protein content of fish is about 17–20%, the fat and water contents vary widely. Some are distinctly nonfatty, with fat contents of only 0.1–0.4% (haddock or cod), while some are very fatty (eels, herring or tuna), with fat contents of 16–26%. Many fish species have fat contents between these extreme values. Table 13.5 provides data on the basic composition of fish.

13.1.4.2 Proteins

The protein-N content of fish muscle tissue is between 2–3%. The amino acid composition, when compared to that of beef or milk casein (Table 13.6), reveals the high nutritional value of fish proteins. The sarcoplasma protein accounts for 20–30% of the muscle tissue total protein. The contractile apparatus accounts for 65–75% protein; the connective tissue of teleosts is 3%; and of elasmobranchs, such as sharks and rays (skate or rocker), is up to 10%. The individual protein groups and their functions in muscle tissue of mammals (cf. 12.3.2) also apply to fish.

Table 13.6. Amino acid composition of fish muscle, beef muscle and casein (amino acid-N as % of total-N)

	Casein	Beef muscle	Cod muscle
Aspartic acid	4.7	4.0	6.8
Threonine	3.6	3.7	3.4
Serine	5.3	4.6	3.6
Glutamic acid	13.3	9.3	8.8
Proline	7.5	4.3	3.4
Glycine	3.2	6.0	5.8
Alanine	3.0	4.9	5.9
Cystine	0.2	0.8	2.5
Valine	5.4	3.7	2.5
Methionine	1.8	2.2	2.0
Isoleucine	4.1	4.2	2.7
Leucine	6.1	5.1	5.1
Tyrosine	3.0	2.1	1.7
Phenylalanine	2.7	2.7	2.1
Tryptophan	1.0	1.2	1.1
Lysine	9.8	9.8	11.7
Histidine	5.3	4.9	3.5
Arginine	8.2	14.5	13.2

13.1.4.2.1 Sarcoplasma Proteins

Fish sarcoplasma proteins consist largely of enzymes. The enzymes correspond to those of mammalian muscle tissue. When these proteins are separated electrophoretically, specific patterns are obtained for each fish species. This is a helpful chemical means of fish taxonomy. The pigments are concentrated in the dark muscle. For instance, 3.9 g/kg of myoglobin, 5.8 g/kg of hemoglobin and 0.13 g/kg of cytochrome C are present in the dark muscle of a type of mackerel (*Scomber japonicus*). The light muscles contain only 0.1 g/kg of hemoglobin and myoglobin. Hemoglobin is absent in some mollusks and in Antarctic fish with colorless blood. The amino acid composition of fish and mammalian myoglobins is clearly different. Fish myoglobin contains, e. g., a cysteine residue which is absent in mammals. In strongly pigmented fish (e. g. tuna), pigment degradation reactions can induce meat discoloration (e. g. observable "greening" in canned tuna meat).

13.1.4.2.2 Contractile Proteins

The proportion of myofibrillar proteins in fish total protein is higher than in mammalian muscle tissue, however the proportions among individual components (Table 13.7) are similar (cf. 12.3.2.1). The heat stability of fish proteins is lower than that of mammals, the protein denaturation induced by urea occurs more readily, and protein hydrolysis by trypsin is faster (Fig. 13.2). These properties provide additional evidence of the good digestibility of fish proteins. Mollusks contain paramyosin. The percentage of this protein in smooth muscles, e. g., of oysters, is 38%.

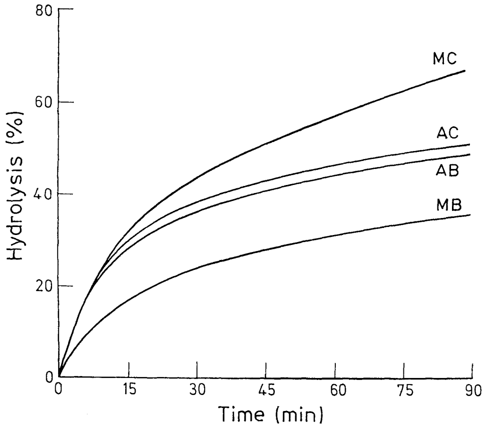


Fig. 13.2. Tryptic hydrolysis of myofibrils (M) and actin (A) from cod fish (C) and beef (B) under the same conditions. (according to *Connell*, 1964)

The amino acid composition shows relatively high amounts of Arg (12%) and Lys (9%) and little Pro. The paramyosin molecule consists of two peptide chains (M_r) 95,000–125,000), each of which is 120 nm long, has a helical structure and is twisted to a rod. In fact, two disulfide bonds contribute to the stability of the molecule. It forms the core in the thick filaments and is surrounded by myosin. In the production of gels, it influences the rheological properties and is the reason why gels made from mollusk meat are more elastic and more cohesive than gels made from fish protein.

13.1.4.2.3 Connective Tissue Protein

The content of connective tissue protein (1.3%) in fish muscle is lower than in mammalian mus-

Table 13.7. Myofibrillar proteins of fish

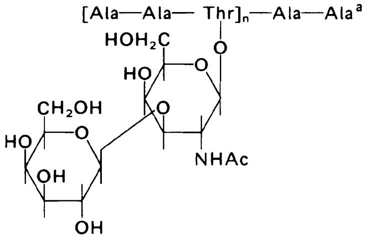
Protein	Content (%)	Molar mass
Myosin	50–58	Two long (200,000 and 240,000) and two short (15,000 and 28,000) peptide chains
Actin G	15–20	41,785
Tropomyosin	4–6	70,000
Troponin	4–6	72,000
Paramyosin	2–19[a]	200,000–258,000

[a] High percentages in the smooth muscle of mussels and squid.

cle. Collagen is the main component with a content of up to 90% and the remainder is elastin. The shrinkage temperature, T_s, is about 45 °C in fish collagen, i. e. much lower than in mammalian collagen (60–65 °C). These two factors make fish meat more tender than mammalian meat.

13.1.4.2.4 Serum Proteins

The congealing temperature of the blood serum of polar fish of Arctic or Antarctic regions (e. g. *Trematomus borchgrevinski, Dissostichus mawsoni, Boreogadus saida*) is about −2 °C and thus is significantly lower than that of other fish (−0.6 to −0.8 °C). Antifreeze gly-coproteins account for such low values. The amino acid sequence of this class of proteins is characterized by high periodicity:



[a] C-terminal has one or two alanine residues (13.1)

The molecular weight range is 10.5–27 kdal, while the conformation is generally stretched, with several *a*-helical regions. These glycoproteins are hydrated to a great extent in solution. The antifreezing effects are attributed to the disaccharide residues as well as to the methyl side chains of the peptide moiety.

13.1.4.3 Other N-Compounds

The nonprotein-N content is 9–18% of the total nitrogen content in teleosts and 33–38% in elasmobranchs.

13.1.4.3.1 Free Amino Acids, Peptides

Histidine is the predominant free amino acid in fish with dark-colored flesh (tuna, mackerel). Its content in the flesh is 0.6–1.3% fresh weight and can even exceed 2%. During bacterial decay of the flesh, a large amount of histamine is formed from histidine. Fish with light colored flesh contain only 0.005–0.05% free histidine. Free 1-methylhistidine is also present in fish muscle tissue. Anserine and carnosine contents are 25 mg/kg fresh tissue. Taurine content is high (500 mg/kg).

13.1.4.3.2 Amines, Amine Oxides

Sea fish contain 40–120 mg/kg of trimethylamine oxide, which is involved in the regulation of the osmotic pressure. After death, this compound is reduced by bacteria to "fishy" smelling trimethylamine (cf. 13.1.4.8). On the other hand, fresh-water fish contain only very low amounts of trimethylamine (0–5 mg/kg). On storage of fish, a part of the trimethylamine is enzymatically broken down to dimethylamine and formaldehyde. The latter then undergoes cross-linking reactions with proteins, which reduce the solubility (cf. 13.1.6.2) and make the fish tougher. In addition to trimethylamine, the amine fraction contains dimethyl- and monomethylamines and ammonia, and some other biogenic amines derived from amino acid decarboxylation. The concentration of volatile nitrogen bases increases after death, the increase being influenced by storage duration and conditions. The level of volatile amines can be used as an objective measure of fish freshness (Fig. 13.3).

13.1.4.3.3 Guanidine Compounds

Guanidine compounds, such as creatine, are 600–700 mg/kg fresh fish muscle tissue. In crustaceans, the role of creatine is taken over by arginine.

13.1.4.3.4 Quaternary Ammonium Compounds

Glycine betaine and γ-butyrobetaine are present in low amounts in fish flesh.

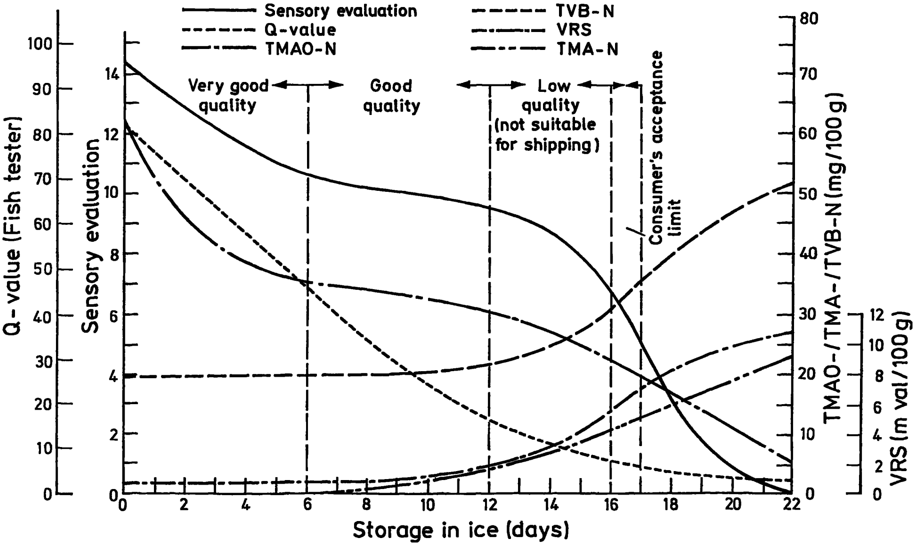


Fig. 13.3. Cod fish quality change during storage (according to *Ludorff*, 1973). Sensory evaluation: in total 15 points are given, 5 for visual appearance and 10 for odor, taste and texture; Q-value: electric resistance of the fish tissue as recorded by a "fish tester"; Q40: quality class S, Q = 30−40: A, Q = 20−30: B, Q20: C and worse; TMAO-N: trimethylamine oxide-N; TVB-N; total volatile base-N; VRS: volatile reducing substances, TMA-N: trimethylamine-N

13.1.4.3.5 Purines

The purine content in fish muscle tissue is about 300 mg/kg.

13.1.4.3.6 Urea

The fairly high content of urea in muscle tissue (1.3–2.1 g/kg) is characteristic of elasmobranchs (rays, sharks). The compound is decomposed to ammonia by bacterial urease during fish storage.

13.1.4.4 Carbohydrates

Glycogen is the principal carbohydrate. Its content (up to 0.3%) is generally lower than in mammalian muscle tissue.

13.1.4.5 Lipids

The fat (oil) content of fish is highly variable. It is influenced not only by the kind of fish but by the maturity, season, food availability and feeding habit. Fat deposition occurs in muscle tissue (e. g. carp, herring), in liver (cod, haddock, saithe) or in intestines (blue pike, pike, perch).

Fish is an important source of ω-3-polyenic acids with 5 and 6 double bonds (cf. Table 13.8), which are considered valuable from a physiological and nutritional viewpoint. In contrast to the high content of unsaturated fatty acids, the level of anti-

Table 13.8. The content of ω-3-fatty acids in fish (g/100 g of fillet)

Type of fish	EPA (20:5)[a]	DHA (22:6)[a]
Mackerel	0.65	1.10
Salmon (Atlantic)	0.18	0.61
Salmon (red)	1.30	1.70
Trout	0.22	0.62
Tuna	0.63	1.70
Cod	0.08	0.15
Flounder	0.11	0.11
Perch	0.17	0.47
Haddock	0.05	0.10
Sole	0.09	0.09

[a] Structure (cf. 3.2.1.2).

Table 13.9. Minerals in fish muscle

Element	Content (mg/kg)	Element	Content (mg/kg)
Ca	48–420	Fe	5–248
Mg	240–310	Cu	0.4–1.7
P	1730–2170	I	0.1–1.0

oxidatively active tocopherols is relatively low. Therefore, the lipids of fish represents a major problem in preservation because of its easy peroxidation (cf. 13.1.4.8).

13.1.4.6 Vitamins

Fish fat and liver (liver oil) are significant sources of fat-soluble vitamins, A and D. Also present are vitamins E (tocopherol) and K. The water-soluble vitamins, thiamine, riboflavin and niacin, occur in relatively high amounts, while others are present only in low amounts.

13.1.4.7 Minerals

The average content of major minerals in fish muscle tissue is compiled in Table 13.9.

13.1.4.8 Aroma Substances

Aroma substances are formed by the enzymatic oxidative degradation of the highly unsaturated fatty acids with the participation of lipoxygenases of varying specificity. These aroma substances contribute to the mild green-metallic-mushroom aroma of fresh fish. Dilution analyses have shown that these substances are acetaldehyde, propanal, 1-octen-3-one, (Z)-1,5-octadien-3-one, (E,Z)-2,6-nonadienal, (Z,Z)-3,6-nonadienal and (E,E)-2,4-decadienal.

Using salmon as an example, Table 13.10 (compare LO with LI) shows how the concentrations of important odorants change in the cooking process. The highly volatile substances acetaldehyde and propanal decrease and hexanal, (Z)-4-hep-

Table 13.10. Influence of the storage temperature of the raw material on the formation of odorants during cooking of salmon and cod[a]

Aroma substance	Salmon			Cod	
	LO[b]	LI[c]	LII[c]	KI[c]	KII[c]
Acetaldehyde	3700	2300	2500	1300	2400
Propanal	3500	1700	4700	n.a.	n.a.
2,3-Butandione	57	52	n.a.	200	596
2,3-Pentandione	141	234	318	86	26
Hexanal	35	58	148	n.a.	28
(Z)-3-Hexenal	2.6	3.9	50	1.3	4.3
(Z)-4-Heptenal	3.0	6.0	47	1.6	2.8
Methional	3.0	8.0	4.4	11	10
1-Octen-3-one	0.5	0.4	0.4	0.7	0.2
(Z)-1,5-Octadien-3-one	0.4	0.3	0.5	0.1	0.16
(Z,Z)-3,6-Nonadienal	n.a.	5.7	49	1.3	4.2
(E,Z)-2,6-Nonadienal	9.3	9.7	26	3.5	2.8
(E)-2-Nonenal	2.0	2.7	6.4	n.a.	n.a.
(E,E)-2,4-Nonadienal	2.2	2.6	3.7	3.2	2.0
(E,E)-2,4-Decadienal	4.8	6.0	18	3.5	2.2
Methanethiol	n.a.	n.a.	n.a.	100	130
2-Methylbutanal	n.a.	n.a.	n.a.	20	270
3-Methylbutanal	n.a.	n.a.	n.a.	51	620

[a] Concentrations given in µg/kg raw or cooked fish; n.a.: not analyzed.
[b] LO: raw salmon (*Salmo salar*), stored for 14 weeks at −60 °C.
[c] Salmon and cod (*Gadus morhua*) were each stored for 14 weeks at −60 °C (LI, KI) and −13 °C (LII, KII), then covered with aluminium foil and heated in a boiling water bath for 15 min.

tenal and methional increase. In the aroma profile of boiled cod, "mild fishy" and "boiled potato" notes can be detected. If methional and (Z)-1,5-octadien-3-one are dissolved in water in the concentrations that are formed during the cooking of cod (sample KI in Table 13.10), the mixture has a fishy and boiled-potato odor (Table 13.11). In addition, a geranium-like odor is detectable, which is produced by the pure octadienone. Consequently, these two carbonyl compounds are primarily responsible for the cooking aroma of this low-fat fish.

It is well known that on cold storage, aroma defects can appear faster in a high-fat fish than in a low-fat fish. This is clearly shown in an experiment in which salmon and cod were stored for 14 weeks at different temperatures and then boiled. While the aroma of the fish stored at $-60\,^{\circ}C$ was perfect, the relatively low temperature of $-13\,^{\circ}C$ had a negative effect on the aroma. The salmon had an intensive fatty/train oil odor and, in comparison, the low-fat cod had only a more intensively malty odor. The aroma defect of the fatty fish, which becomes very unpleasantly noticeable, is based on the peroxidation of polyunsaturated ω-3 fatty acids, which results in a 13 fold increase in (Z)-3-hexenal (compare LII with LI in Table 13.10), an 8 fold increase in (Z)-4-heptenal and a 9 fold increase in (Z,Z)-3,6-nonadienal. In low-fat cod, these aldehydes increased at most by a factor of 3.

The change in the aroma of cod was produced by an increase in malty smelling 2- and 3-methylbutanal, which had 12 to 13 times higher concentrations in KII than in KI (Table 13.10).

The compound 2,6-dibromophenol, which has a very low aroma threshold of 0.5 ng/kg, also contributes to the aroma of fresh sea fish. In higher concentrations, it produces an iodoform-like odor defect which has been observed in shrimps. The meaty aroma note of cooked tuna is caused by the formation of 2-methyl-3-furanthiol (cf. 12.9).

Trimethylamine also has a fishy odor. However, its odor threshold at the pH of fish meat is very much higher than that of the potent lipid peroxidation products, e. g., (Z)-1,5-octadien-3-one (cf. 3.7.2.1.8 and 11.2.4.4.4). Therefore, it plays a role as an off-flavor substance only on stronger bacterial infection of fish at temperatures $>0\,^{\circ}C$.

Table 13.11. Aroma profile of a mixture of methional (1) and (Z)-1,5-octadien-3-one (2) dissolved in water[a]

Odor quality	Intensity[b]
Fishy	2
Potatoes, boiled	1
Geranium-like	2.5

[a] Concentration: 1 (10 µg/kg), 2 (0.16 µ/kg).
[b] Scale: 0 (not detectable) – 3 (strong).

13.1.4.9 Other Constituents

More than 500 tropical fish species (barracuda, sting ray, fugu, globefish), including some valuable food fish, are known to be passively poisonous. Poisoning can occur as a result of their consumption. The toxicity can vary with the season, and can extend to the whole body or be localized in individual organs (gonads, i. e. ovaries and testicles, liver, intestines, blood). Cooking can destroy some of these toxic substances. They consist of peptides, proteins and other compounds. Some of their structures have been elucidated. There are also actively poisonous fish, with prickles or tiny needle-like spines used as the poisoning apparatus. These are triggered as a weapon in defence or attack. This group of fish includes the species *Dasytidae, Scorpaenidae* and *Trachinidae*. The latter, known as lesser weever (Trachinus viperd), is a fish of the Atlantic Ocean and the Mediterranean Sea.

13.1.5 Post mortem Changes

After death, fish muscle tissue is subjected to practically the same spontaneous reactions as mammalian muscle tissue (cf. 12.4.3). Due to the low glycogen content of fish muscle, its pH drop is small. Generally, pH values of 6.2 are obtained. The duration and extent of rigor mortis depend on the type and physiological condition of the fish. In some species, several days can pass before the rigor subsides as a result of the activity of endogenous fish proteinases. The enzymes hydrolyze the Z region of the myofibrils, releasing α-actinin and converting the high molecular α-connectin, which is arranged lengthwise along the myofibrils, to the β-form. Collagen is attacked by collagenase; myosin and actin are not degraded. Deep freezing inhibits the proteolysis, which starts again on thawing. This can cause water loss and undesirable changes in texture in the production of filets. Therefore, deep frozen filets should be made from killed off fish or fish which have passed through rigor mortis. In the case of fresh fish kept in ice, attempts are made to keep the fishing time short so that the fish are stabilized until consumption by rapid and continuous rigor mortis.

Because of the particular structure of fish muscle, the tendency to generate an alkaline pH reaction in muscle, and a high probability of microbial infection during fishing and fish dressing, conditions are highly favorable for rapid spoilage of fish. Therefore, bacteriological supervision and control, from the market to processing plants and during distribution, are of utmost importance.

There are various physical and chemical criteria for assessing fish meat freshness.

The pH of fresh fish is 6.0–6.5. The suitability limit for consumption is pH 6.8, while spoiled fish meat has a pH of 7.0 or above due to the formation of ammonia and amines (cf. 13.1.4.3.2).

The specific resistance of fish muscle changes with storage duration. Soon after catching it is 440–460 ohms, after 4-days approx. 280 ohms, and after 12 days it drops to 260 ohms. The suitability limit for consumption is reached after 16 days, when the resistance is 220 ohms.

The refractive index (n) of fish eye fluid is affected by storage duration. In cod of very good quality, n ranges from 1.3347 to 1.3366. Fish with a n of 1.3394 or higher is not suitable for marketing. The decrease in TMAO concentration and a concomitant increase in volatile N-containing substances, such as trimethyl-amine and several volatile reducing compounds, belong to the chemical criteria for fish quality assessment. Figure 13.3 provides data on the usefulness of some quality criteria, with cod stored in ice taken as an example. In addition to chemical and physical data, sensory evaluation data are included. Another method is based on the observation that the post mortem degradation of ATP, which gives ino-sine in some fish and hypoxanthine in others, proceeds analogously to the loss of freshness. The *K value* serves to objectify this development. It has been defined as the ratio of the concentrations of inosine plus hypoxanthine to the total concentration of the ATP metabolites. The nucleotides and their degradation products are determined by using HPLC. In practice, not only is the relatively elaborate analysis a disadvantage, but also the dependency of the K value on a series of variables, e. g., the fish species.

A promising development is the gas sensor which can quickly register off-flavor substances or at least indicate an increase in volatile compounds that accompany the decrease in quality on storage.

13.1.6 Storage and Processing of Fish and Fish Products

13.1.6.1 General Remarks

Today, the fishing grounds are not only further and further away and the fishing trips longer, but the fishing ships must also be economically utilized. Therefore, as a result of the easy deterioration of fish, it has become increasingly necessary to process the fish on accompanying factory ships. An overview of the steps involved in fish processing is given in Fig. 13.4. The manual operation steps of the past, such as bleeding, gutting, washing, cutting off the heads, skinning, and filleting, have now been replaced to a significant extent by machines.

The fish waste that accumulates on processing, which accounts for up to 50% of the whole fish, is economically utilized by processing into fish meal on board and on land (cf. 13.1.6.13).

The ready decomposition or spoilage of fish flesh is the result of the special structure of the muscle tissue and the diverse ways in which microbial contamination occurs while handling fish, from catching, through processing and during distribution. From the earliest times, fish handling methods, like those for land animals, have been designed to increase the shelf life or storage ability. Fish are usually initially cooled or frozen, or are dried, salted and smoked, followed by pickling in vinegar or in gelatin with vinegar added. They may also be deep fried in oil, or pickled with or without vinegar and soaked in a sauce in an airtight, sealed container. The expected shelf life of such products determines if they are consid-

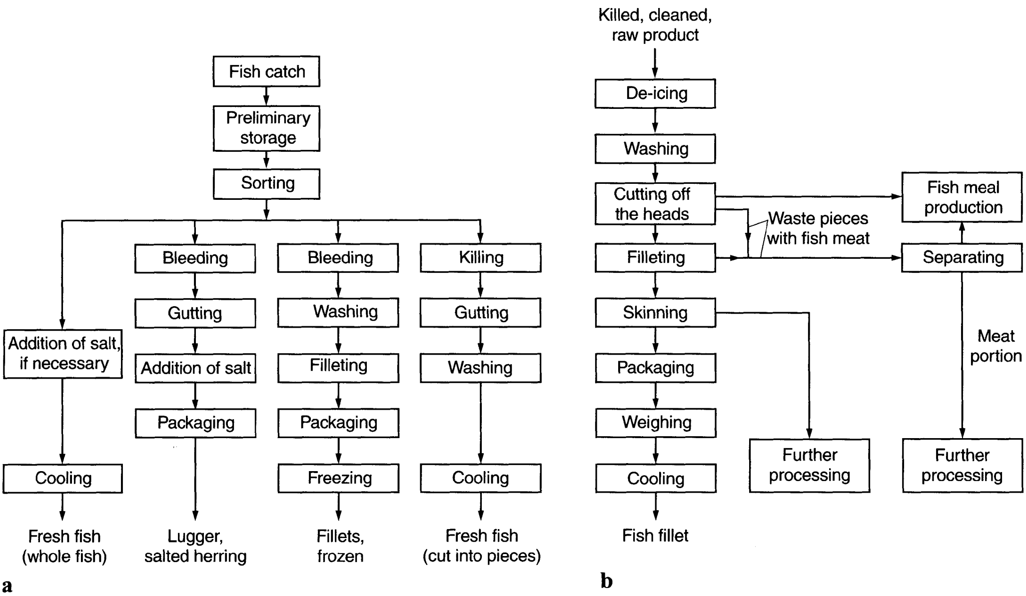


Fig. 13.4. Fish processing on board (**a**) and on land (**b**)

ered fully preserved, canned or semi-preserved products. Semi-preserves may contain additives against microbial spoilage. The compositions of some fish products are given in Table 13.12.

13.1.6.2 Cooling and Freezing

Preservation of freshness by refrigeration is the most modern and effective way to retain the wholesomeness and nutritional value of food. Refrigeration also enables fishing fleets to range the oceans for months in search of fish. Refrigeration permits stockpiling of fish, thus making fish processing plants more economical and better able to respond to market demand and supply.

Fish deteriorates rapidly at temperatures only slightly above 0 °C. Therefore, immediately after catching fish are packed in ice on board the ship. The ice used may be sprinkled with a bactericidal substance. Freezing, which may also be used on ships, is suitable for whole fish (gutted or ungutted, with or without head or skin removal), as is the case with flat fish, tuna, mackerel or herring, or for fish fillets (cod, haddock, saithe, red fish).

Only quick freezing is used (−30 to −40 °C; cf. Fig. 13.5), so the critical temperature range of −0.5 to −5 °C is rapidly passed over. Apart

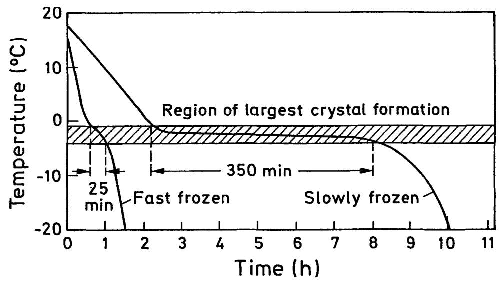


Fig. 13.5. Temperature course during fish fillet freezing process

from air and contact freezing processes, cryogen frosters are being increasingly used, especially for sensitive and high quality product (crustaceans).

In air freezing, freezing takes place in a cold current of air in differently arranged, usually continuously operated systems (tunnel, spiral band etc.). In the contact freezing processes used, the fish are pressed and frosted between two contact plates that are cooled by a flow of coolant. The blocks obtained by this process can be portioned into slabs or sticks using band saws. They can be sold to the consumer as such or breaded and prefried (170 °C, 20 s). Waste pieces (8–12%) are

Table 13.12. Average chemical composition of processed fish

Product	Moisture[a]	Protein[a]	Fat[a]	NaCl[a]	Edible portion[b]
Salted fish					
Matje herring	54	18	18	10	68
Salt cured herring	48	21	16	15	68
Dried fish					
Stockfish	15	79	2.5	3	64
Klipfish	34	45	0.7	13	99
Smoked fish					
Buckling	58	23	16	3	62
Smoked sprats	62	17	20	2	60
Eel	53	19	26	1	73
Mackerel	61	21	16	1	70
Schillerlocken (smoked haddock filet)	53	21	24		100
Semi-preserved fish					
Bismarck herring	60	20	17	3	95
Bratherring (fried and pickled herring)	62	17	15	4	92
Herring, jellied	56	29	13		55
Anchovies	69	13	5	1	100
Herring tidbit	62	15	10	3	100

[a] As % of edible portion.
[b] As % of the whole fish weight.

used for fishburgers and similar products. In comparison with conventional freezing systems, the food comes into direct contact with the refrigerant (liquid nitrogen or liquid carbon dioxide) in shock freezing. The spatial arrangement of the freezing systems essentially corresponds to those in air freezing.

During freezing of fish, problems associated with drip or sap losses, discoloration and rancidity due to lipid peroxidation and, consequently, fish weight loss, poor visual appearance and flat taste may arise and must be avoided by suitable processing. Cold storage should proceed at high air humidity (90%) and with stationary, noncirculating air. Data on the storage properties of some frozen fish are provided in Table 13.13.

Thawing is carried out in a stream of air saturated with water vapor at 20–25 °C or by spraying with water. Fish must be processed immediately after thawing because it loses juices rapidly and decays. Fish muscle enzymes have noticeable activity even at −10 °C. Excessively long storage or insufficient cooling, especially of fatty fish, results in a rancid off-flavor and an unattractive, yellow colored fish surface. Antioxidants and associated synergistic compounds, such as ascorbic and citric acids, are used to inhibit fat deterioration. Changes in muscle texture are primarily due to changes in protein solubility (Fig. 13.6).

Table 13.13. Shelf life of frozen fish, crustaceans and mollusks as influenced by storage temperature

Product	Shelf life (months) at		
	−18 °C	−25 °C	−30 °C
Fatty fish	4	8	12
Nonfatty fish	8	18	24
Lobsters, cray- and crawfish	6	12	15
Crabs	6	12	12
Oysters	4	10	12

13.1.6.3 Drying

Fish can be preserved by drying naturally in the sun or in drying installations.

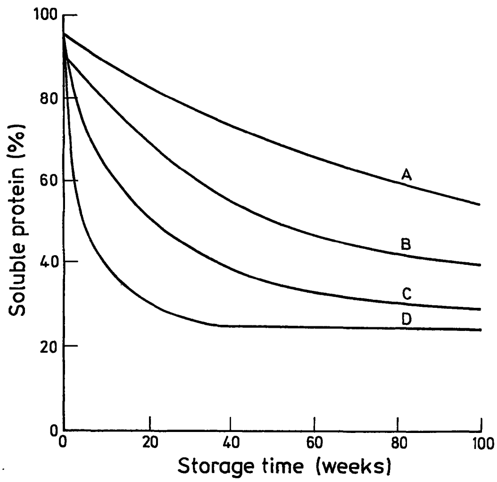


Fig. 13.6. Changes in fish muscle protein solubility as a result of cold storage (−14 °C). A: plaice, B: halibut, C: dogfish, D: cod. (according to *Connell*, 1964)

Stock fish, primarily nonfatty fish (cod, saithe, haddock, ling or tuck, which is often called cusk in North America) with head removed, split and gutted, is spread outdoors to dry in sea air (water content 12–18%). It is an unsalted fish product that is primarily produced in Norway and Iceland. Alternatively, machine-cut, headless and tailless fish which has been belly-clipped ("clipped" fish) is salted, either directly or in brine, and then put through a drying process (salt content 18–20%, water content < 40%). This is most often done with cod or other non-fatty fish species in Canada and Norway.

13.1.6.4 Salting

Salted fish (whole or parts) are obtained by salting fresh, deep frozen or frozen fish. Salt is the most important and oldest preservative for fish. Rubbing or sprinkling of fish with salt or immersion in brine, often followed by smoking, is called fish curing. Pickling in vinegar might be an additional preservation step. Salted products include: herring, anchovies, saithe, cod, salmon, tuna, and roe or caviar. It should be taken into account that if salting is used as the sole method of preservation without further processing (like matje, marinaded fish, smoked products etc.), complete bacterial protection is not provided because halophilic microorganisms can cause spoilage.

In dry salting, fish and salt are alternately stacked in open piles and the resulting brine can drain off. In wet salting, the fish are put into more or less concentrated salt solutions. In heavily salted fish there are at least 20 g of salt in 100 g tissue fluid; in a medium-salted fish the salt content is 12–20 g.

Salting of herring is of special importance. There are the mildly salted matje (8–10% NaCl), the medium-salted "scotch cure", and the heavily salted herring, i. e. dry salting up to 25% NaCl. Herrings are also dressed, salted and packaged, both at sea and on land. The shelf life of salted herring is several months. Matje herring (immature sea herring, often wrongly called "sardines") must be consumed soon after they are removed from refrigeration. Salting might provide a finished end-product, but it is often used as a form of fast, temporary preservation, yielding semi-finished products which are later to be processed further. After salting, herring pass through a maturation process which generates a typical flavor. The proteolytic enzyme of the fish are involved in such "gibbed" herring maturation. During gibbing (i. e. a process of removing gills, long gut and stomach), the milt (male fish) or roe (female fish) and some of the pyloric cacea are left in the fish. These organs release enzymes which contribute to the maturation of the fish. If all organs are removed, no maturation occurs. Salting causes cell shrinkage and denaturation of muscle proteins, which manifests itself in a decrease in solubility (Fig. 13.7). This is used to convert a finely ground mass of low-fat fish meat to firm products. Similar in importance to herring are salted cod (Atlantic, Pacific and Greenland cod), which are salted dry or in brine as split or boneless fillets, and salted saithe, pollack (Dover hake) and some other saltwater fish of the *Gadus* species. Salted achovies (Mediterranean or Scandinavian) are also of importance.

13.1.6.5 Smoking

Smoked fish are obtained from fresh, deep frozen, frozen or salted fish which have been dressed in various ways. The whole fish body or fish por-

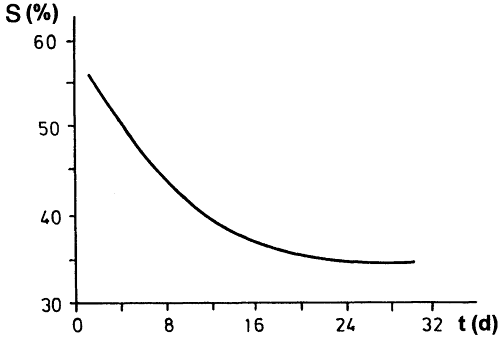


Fig. 13.7. Decrease in solubility of proteins during the salting of cod (according to *Tülsner*, 1994) *Ordinate*: S, solubility in % of total protein. *Abscissa*: duration of action of NaCl

tions are exposed to freshly generated sawdust smoke.

Cold smoking is performed for 1–3 days below 25 °C, generally at 18–25 °C, and is most often used with cooked and mature fatty fish (large size herring, salmon, cod, tuna). A product called "Buckling" is a large, fatty herring, sometimes nobbed (with head), that has been smoked. Delicatessen Buckling are made from gutted herring. Kippered herring (Newcastle Kipper) are obtained from fresh, fatty herring with the back split from head to tail. The dressed fish are then lightly brined and cold smoked. In the United States the term "kipper" corresponds to products hot smoked on trays (e. g. kippered black cod). Salted or frozen salmon are smoked in North America. The shelf life is 2 weeks.

Hot smoking is performed for 1–4 h at temperatures between 70 and 150 °C. It is used with whole, gutted or descaled fish such as herring (Buckling), sprat ("Kieler Sprotten" in Germany), plaice, flounder, halibut (with or without skin), eels, mackerel, tuna, haddock, whiting (merlan), saithe, cod, red fish (ocean perch), dog-fish, sturgeon and shad. In the process, the fish are cooked by air cooking. In some places, a minimum temperature of 85 °C is stipulated to kill microorganisms. Unlike cold-smoked fish, hot-smoked fish have only a limited shelf life, 3–10 days, which can be extended only by cold storage. Hot-smoked caviar (cod or saithe) is available. Smoking is conducted in smoking installations which consist of a smoke generator and a smoking chamber. In this chamber, the fish are dried and cooked and smoked.

13.1.6.6 Marinated, Fried and Cooked Fish Products

Marinade is vinegar or wine, or a mixture of both, usually spiced and salted, in which fish are soaked or steeped before use or before being pickled and stored for a longer time. The fish used might be fresh, deep frozen or frozen, or salted whole fish or fish portions. Marinating tenderizes muscle tissue without heat treatment. Fish preservation by pickling in this manner is based on the combined action of salt and vinegar. Vinegar-packed herring, called simply marinades, are a popular German fish food packaged in retail glass jars. Pickled fish can be packaged together with some plant extracts, sauces, gravy, creams, mayonnaise or related products, or they can be immersed in an edible oil (although oilpacked fish are not called pickled fish). Some of these products might contain chemical preservatives.

Marinated fish are packaged in cans, jars, etc., and may be handled without packaging. Fish marinades have only a limited shelf life (they are semi-preserves), and even chemical preservatives can not prevent their eventual decay. Marinated fish considered as delicatessen items are "Kronsardines", Bismarck herring, rollmops and pickled herring.

Fried fish products are prepared from variously dressed fresh, deep frozen or frozen whole fish or fish portions, with or without further dressing in eggs and bread crumbs (batter formulations, such as "shake and bake"). They are then made tender by frying, baking, roasting or barbecuing. These products may be packaged or canned in the presence of vinegar, sauces, gravy or an edible oil, often with a chemical preservative added. Examples of these products are fried marinated fish sticks, "Brathering", "Bratrollmops", balls, etc.

Cooked fish products are processed in a similar manner. Tenderization is achieved by cooking or steaming. Processing also involves the use of vinegar or wine, addition of salt and the use of a preservative. The cooked products can be solidified, with or without plant ingredients, into a jelly (herring in jelly) or packaged with other extracts, sauces or gravy. Cooked fish products include herring marinades, rollmops, bacon rollmops in jelly, sea eel (dogfish) in jelly, or broths made from disintegrated saltwater fish meat. The occasional liquefaction of cooked fish jelly ("jelly disease") indicates microbial proteolysis.

13.1.6.7 Saithe

Saithe, often called coalfish, coley, pollack or Boston bluefish (trade name "Dover hake"), are processed into fillets, saltcured, dyed or tinted, and smoked. They are then cut into slices or cutlets and covered with edible oil. The product has a good shelf life.

13.1.6.8 Anchosen

Anchosen are made from fresh, frozen or deep-frozen small sprats and herring, preserved with salt in the presence of added sugar or sugars derived from starch saccharification, spiced and biologically ripened with sodium nitrate. Flavors are also added. Proteinases are also used to accelerate ripening.
Anchosen can be packed in sauce (gravy), creams or in edible oils, garnished with plant ingredients and a chemical preservative may be added. Examples of anchosen are appetit-sild, cut spiced herring and spiced herring. Appetit-sild is a product consisting of skinned fillets of spice-cured sprats, cured and packed in vinegar, salt, sugar and spices.

13.1.6.9 Pasteurized Fish Products

Pasteurized fish products made of fresh, deep-frozen or frozen fish or fish portions have shelf lives, even without cold storage, of at least 6 months. These products are prepared by prolonged heat treatment of fish at temperatures below 100 °C. They are then tightly sealed in a container. Such products are salted or soaked in vinegar prior to pasteurization.

13.1.6.10 Fish Products with an Extended Shelf Life

Canned fish products of extended shelf life are products made from fresh fish, frozen or deep-frozen whole fish or fish portions. The shelf life without special cold storage of at least one year is achieved by adequate heat treatment in gas-tight containers.
These products with an extended shelf life can normally be kept indefinitely (in practice about 5 years). Special can materials have to be chosen when the fish is canned with corrosive ingredients such as tomato or mustard sauce, vinegar or lemon juice. The can is usually made of a lacquer-coated tinplate or inert aluminum.
Products with extended shelf lives are in their own juice or in added oil, or in some sauce or cream (e. g. "sardine" pilchards, *Sardina pilchardus*, packed in olive or soya oil, tomato mustard, or lemon juice). Also available are fish paste, meat balls or "Frikadellen" (Germany), i. e. flesh of white fish made into rissoles using flour, eggs and spices, which are then roasted, deep fried and used ready-to-serve, as hors d'oeuvres, and fish salad. The latter products are canned or packed in glass jars, and may be packed under controlled atmosphere.

13.1.6.11 Surimi, Kamboko

Surimi is a concentrate of insoluble muscle proteins (ca. 20%). It forms a solid cohesive gel with water (ca. 80%), which solidifies when warm. For production, lean fish meat is ground at 5–10 °C and extracted with water until basically only myosin, actin, actomyosin and small amounts of collagen remain. The addition of paramyosin (cf. 13.1.4.2.2) intensifies the structure of the gel. In the further processing of Surimi to Kamboko, starch (ca. 5%), egg white, flavor enhancers, colorants and aroma substances are added, whereby an attempt is made to imitate crab or mussel meat. The resulting mixture is solidified by denaturation of the proteins first at 40–50 °C and then at 80–90 °C. Fibrous structures are produced by extrusion.

13.1.6.12 Fish Eggs and Sperm

13.1.6.12.1 Caviar

Specially prepared sturgeon eggs (roe) are called caviar. The roe ("hard roe") are detached from the fish ovary gland. The roe are washed in cold water, salted and left to ripen until they become transparent. They are then drained from the brine slime and are marketed for the wholesale market in small metal or glass containers or in barrels. Occasionally, the caviar is pasteurized. Two basic types are marketed: grainy caviar, where eggs are readily detached from roe, and pressed caviar, where the ovarian membrane and the excess fluid are removed by gentle pressing. Caviar is made from various sturgeon species (beluga, stoer or sevruga). The roe of these sturgeon species caught in winter, when mildly salted (below 6% NaCl), give a high quality caviar called "Malossol". The beluga (the largest of the three sturgeons mentioned) provides the most valuable caviar.

Pressed caviar is obtained from all species. Salmon caviar (such as Amur and Keta caviars from Siberian salmon roe) is processed using less than 8.5% salt. American whitefish caviar is a mixture of roe from salmon, whitefish, carp and some other fish. Scandinavian caviar is from cod and lumpfish.

Sturgeon caviar is gray or brown to black in color. Salmon caviar is yellow-red or red. Most caviar is imported from the Russian Fed. and Iran (Caspian Sea caviars). It readily decays and so must be kept refrigerated. A medium-size beluga sturgeon can provide 15–20 kg caviar.

13.1.6.12.2 Caviar Substitutes

Caviar substitutes are made of roe of various sea and freshwater fish. Germany produces the dyed caviar of lumpfish (lumpsuckers), and also cod and herring caviars. The roe are soured, salted, spiced, dyed black, treated with traganth gum and, occasionally, a preservative is added.

13.1.6.12.3 Fish Sperm

Fish sperm are a product of the gonads of male fish and are often called milt or soft roe. Salted sperm from sea and freshwater fish, particularly herring, are most commonly marketed.

13.1.6.13 Some Other Fish Products

These include the nutritional products and seasonings derived from fish protein hydrolysates; insulin from shark pancreas; proteins recovered from saltwater fish fillet cutting; fish meal used as feed for young animals, poultry and pond fish; and, lastly, fish fat (oil), as mentioned in 14.3.1.2. Of increasing importance is the production of fish protein concentrates and, when necessary, their modified products (cf. 1.4.6.3.2 and Table 1.44).

13.2 Whales

Although a whale is in a true sense a mammal and not a fish, it will be covered here. The blue (*Balaenoptera muculus*) and the finback whale (*B. physalus*) are the two most important whales, each growing up to 30 m in length and up to 150 tons in weight. Also caught are the humpback (*Megaptera nodosa*), the sperm (*Physeter macrocephalus*) and the sei whale (*Balaenoptera borealis*). Whale meat is similar to big game meat or beef. It has long and coarse muscle fibers arranged in bundles and colored gray-reddish. The color of the meat is affected by the age of the whale, and may be bright red or dark red, while frozen whale meat becomes dark black-brown in color. Freezing imparts a rough, firm texture to the meat. The fresh meat has a pleasant flavor but, due to the fast rate of fat oxidation, the shelf life is very short. For this reason bulk whale meat is not readily accepted by food wholesalers and the retail market. Whale meat extracts are also produced (cf. 12.7.3.2).

13.3 Crustaceans

Crustaceans have no backbone; their body is divided into sections, each bearing a pair of jointlegs. An armor-like shell covers and protects the body. Included are shrimp, crayfish (also called crabfish), crabs (e. g. freshwater, edible green shore crab) and lobster. Compositional data are provided in Table 13.14.

13.3.1 Shrimps

The most important shrimps are the common or brown shrimp from the North Sea (*Crangon crangon*), the Baltic Sea shrimp (*Palaemon adspersus fabricii*), the deep sea shrimp (*Pan-dalus bo-*

Table 13.14. Average chemical composition of crustaceans and mollusks

Crustaceans/ mollusks	Moisture[a]	Protein[a]	Fat[a]	Minerals[a]	Edible portion[b]
Shrimps	78	19	2	1.4	41
Lobsters	80	16	2	2.1	36
Crayfish	83	15	0.5	1.3	23
Oysters	83	9	1.2	2.0	10
Scallop	80	16	0.1	1.4	44
Mussel	83	10	1.3	1.7	18

[a] As % of edible portion.
[b] As % of the whole fish weight.

realis) and the larger species in tropical waters, such as blue Brasilian (*Penaeus* spp.) or the royal red shrimps (*Hymenopenaeus robustus*). Larger species are called prawn.
Shrimps are marketed soon after catch as: live, fresh with shell, with or without head, cooked in brine, or cooked without shell. They have very short shelf lives. Shrimps are also sold canned, deep frozen or as an extract or a salad ingredient. Canned shrimps are heated (pasteurized) at just 80–90 °C so as not to affect their flavor; hence, they are semi-preserves with a limited shelf life.

13.3.2 Crabs

Crabs live in shallow or deep water along the sea coast or in freshwater. Blue crab (*Call-inectes sapidus*) is the most common crab of the Atlantic coast of North America. Other important species are the common shore crab (also called green shore crab); the edible crab of Europe (*Cancer pagurus*), which lives in sandy, shallow water; the king crab of Alaska (*Pralithodes camchaticus*), also called Japanese crab; and the dungeness crab (*Cancer magister*) from the shallow waters from California to Alaska. These crabs differ in shape and size of their big claws, but all have no tail. The color and shape of the body varies, as does the ability to swim or to run sideways.
When crabs shed their shell and the new shell has not yet hardened, they are at their tastiest and are marketed as “extra choice soft” crabs. The forms sold are: live, fresh, frozen and canned. Crab paste, canned soup and crab cakes similar to deepfried fish cakes are delicatessen sea foods. In the trade, the term crab meat means white muscle meat, colored red only in leg muscles and chelae, and is distinguished from brown crab meat obtained from crab liver and gonads. The latter are usually processed into crab paste. All crab products are of limited shelf life.

13.3.3 Lobsters

The European lobster (*Homarus gammarus*) caught in the Atlantic is the largest in Europe. It reaches a length of 35–90 cm and a maximum weight of 10 kg. The major area of catch is Helgoland, the north and west sea coast of Europe, the Mediterranean and the Black Sea. The tastiest lobster meat is that from the breast shell. The American or northern lobster (*Homarus americanus*) is closely related to the European lobster. Lobsters are marketed live (remain alive up to 36 h after catch), whole boiled, or canned as cooked meat in its own juice or as soup (cream of lobster, lobster chowder). Lobster paste is also available. Cooking of lobster changes its color to red. The color change involves the release of astaxanthin from ovoverdin, a brown-green chromoprotein (cf. 3.8.4.1.2).
The Norway lobster (*Nephrops norvegicus*; also called Langoustine) also belongs to the lobster family. It is marketed fresh, frozen, semi-preserved, as in salad, or canned, as soup, paste or mildly-brined meat in its own juice.

13.3.4 Crayfish, Crawfish

Crayfish are freshwater crustaceans considered as a delicacy in Europe. The major crayfish of Europe belongs to Astacus spp. (Astacus astacus or *fluviatilis*). Its meat is the most tasteful in May–August when it sheds its shell and the new shell is still soft. The eastern part of North America has the freshwater crayfish of *Cambarus* spp. The Australian crayfish belongs to *Enastacus serratus*.

The cray(craw)fish die when they are dropped into boiling water. Their tail curls up – this is a sign that they were cooked fresh or alive. For the color change during cooking see above (cf. 13.3.3).

The seawater species of crayfish are called crawfish. They include *Palinurus, Panulirus* and *Jasus* spp. The most important crawfish are the European spiny lobster (*Palinurus vulgaris*), the Pacific North American counterpart (*Panulinus interruptus*) and others from Africa, Australia and Japan. The European spiny lobster is 30–40 cm long, up to 6 kg in weight, has rudimentary front legs shaped into sharp claws and has a knobby shell covering the body. It is often caught in the Mediterranean Sea, the west and south coasts of England, and along the coast of Ireland. The rock lobster (*Jasus lalandei*) and the Mediterranean crawfish (*Palinurus elephas*) are also available on European markets. The meat of these crawfish is rather coarse and fiberlike and is colored yellow to yellow-red.

The cray- and crawfishes are marketed fresh live, raw or cooked, and canned in differet forms: meat, butter (precooked meat mixed with butter), soup and soup powders, soup extracts (these are crawfish butter, spiced, salted and blended with flour) and crayfish bisque (French purée or thick soup of crayfish and lobsters).

13.4 Mollusks (*Mollusca*)

13.4.1 Mollusks (*Bivalvia*)

The bivalve mollusks include clams, oysters, mussels and scallops. The common oyster (also called flat native or European oyster) and the blue or common mussel are the most often processed molluscan shellfish.

Oysters (*Ostreidae*, e. g. the European oyster, *Ostrea edulis*) live in colonies along the sea coast or river banks, or are cultivated in ponds ("oyster farms") which are often connected with the sea. Oysters are usually sold unshelled. Only the adductor muscle is consumed; the pleated gills and the digestive system are discarded. In addition to the common oyster, the Portuguese oyster (*Gryphea angulata*) and the American blue point oyster, (*Crassostrea virginica*), used most commonly for canning, are of importance. The best meat is obtained from oysters harvested when they are 3–5 years old, with the top quality harvested between September and April (an old saying is: oysters should be eaten in months which have "r" in their names).

The blue or common mussel (*Mytilus edulis*) lives in shallow, sandy freshwater, while the sea mussel lives in ocean water or is cultivated in ponds or lakes. The shell, 7–15 cm long, is bluish black and the body meat is yellowish. The meat is rich in protein (16.8%) and also in vitamin A and the vitamin B-complex. The meat is eaten cooked, fried or marinated. The major mussel growing areas in Germany are the Kiel Bay and the East Friesian Islands.

In addition to common mussel, numerous other mussels are eaten, mostly canned in vegetable oil, e. g., Pacific Bay or Cape Cod scallops (*Pectinidae*) and cockles (*Cardidae*).

Due to rapid spoilage, mussels are marketed live or canned. They are eaten soon after being caught or after the can is opened, and are avoided in warm seasons. Moreover, they should originate from uncontaminated clear waters.

13.4.2 Snails

Snails are univalve mollusks, i. e. they have only a single, coiled shell. They are eaten preferentially in Italy, France and Germany, and are nearly exclusively the large Helix garden snail (*Helix pomatid*). Snails are sometimes collected wild in South or Central Germany and in France, but most are supplied by snail gardens and feeding lots where lettuce and cabbage leaves are the food source, or in damp shady cellars, where wheat bran and leafy vegetable leaves (e. g. cabbage) are used as a feed. The meat is considered a delicacy. Since the shelf life of the meat is very limited, snails are marketed live (with the shell plugged) or canned. Marine snails of various kinds are fried, steamed, baked or cooked in soups, and are also considered a delicacy.

13.4.3 Octopus, Sepia, Squid

Octopus, sepia and calmar (*Cephalopoda*) are softbodied mollusks with eight or ten arms, and without an outside shell.

The sepia or cuttlefish (*Sepia officinalis*), the squid or calmar (*Loligo loligo*) and the octopus or devilfish (*Octopus vulgaris*) are caught in the Mediterranean region, mostly in Italy, and other parts of the world (Atlantic and Pacific Oceans, e. g. the North American poulp, Japanese *Polypus* spp., etc.). They are consumed deep fried in oil, baked, cooked in wine, pickled in vinegar after being boiled, cooked in soups, in salads, stewed or canned.

13.5 Turtles

Turtles, tortoises or terrapin (for American freshwater turtles) are reptiles with a shell used as a "house". The logger head and green sea turtles are caught commercially for their meat. In Germany turtle is mostly eaten in soup or stew. The meat of the so-called soup turtle (*Chelonia mydas*) is faintly red to bright red, and is marketed canned. An imitation or mock turtle soup is prepared from edible parts of heads of calves and has no relation to turtles except for the name.

13.6 Frogdrums

The thigh portion (frogdrum) of a frog's hinged leg is sold as a delicacy. Frogs providing frogdrums are the common bullfrog (*Rana catesboniand*), the leopard frog (*Rana pipiens*) and others (*Rana arvalis, Rana tigrena, Rana esculenta*). The meat is soft in texture, white in color and tasty; however, it has a very limited shelf life as it readily deteriorates. Frogdrums are eaten cooked, roasted or stewed.

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