Handbook of Meat, Poultry and Seafood Quality
Edited by Leo M. L. Nollet

VII
Seafood Quality

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39
Fish and Sensory Analysis in the Fish Chain

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INTRODUCTION

Fish are different from all other food commodities regarding method of harvesting, fragility of the product during transport to processing sites, and further in the chain, temperature dependency and variety of species. This sensitivity makes it necessary to monitor the product quality in the whole chain, and sensory analysis is ideal for this monitoring. Sensory assessment of fish and fish products has therefore for years played a natural part in the fishery chain.

Fish are generally defined as aquatic vertebrates that use gills to obtain oxygen from water with fins consisting of a variable number of skeletal elements called fin rays (Thurman and Webber 1984).

Fish are the most numerous of the vertebrates, with at least 20,000 known species, and more than half of the species are found in the marine environment. Marine fish are most common in warm and temperate waters of the continental shelves with more than 8,000 species. In the cold polar waters, about 1,100 species are found. In the oceanic pelagic environment well away from the effect of land, there are approximately 225 species. Surprisingly, in the deeper mesopelagic zone of the pelagic environment (between 100 and 1,000 meters' [m] depth), the number of species increases. There are some 1,000 species of so-called mid-water fish (Thurman and Webber 1984).

Each species is identified by a scientific name that has two parts—the genus and the specific epithet (binominal nomenclature). As an example, the scientific (species) name of the common cod is *Gadus morhua*.

THE LIVING FISH

During growth the size of each muscle cell increases, but not the number of muscle cells. Also, the proportion of connective tissue increases with age.

Most fish become sexually mature when they reach a size characteristic of the species and this is not necessarily directly correlated with age. In general, this critical size is reached earlier in males than in females. As the growth rate decreases after the fish has reached maturity, it is therefore often an economic advantage to produce female fish in aquaculture.

Every year mature fish use energy to build up the gonads (the roe and milk). This gonadal development causes a depletion of the protein and lipid reserves of the fish since it takes place during a period of low or no food intake. The length of the spawning season varies greatly between species. Most species have a marked seasonal periodicity, while others have ripe ovaries for nearly the whole year. The depletion of the reserves of the fish during gonadal development can be extremely severe, especially if reproduction is combined with migration to the breeding grounds. Some species, e.g., Pacific salmon (*Oncorhynchus* spp.), eel (*Anguilla anguilla*), and others, manage to migrate only once, then they degenerate and die. This is partly because these species do not eat during migration; in the case of a salmon, it can lose up to 92% lipid, 72% protein, and 63% of the ash content during migration and reproduction (Love 1970). Other fish species are capable of reconstituting themselves completely after spawning for several years. The North Sea cod lives for about 8 years before spawning causes its death, and other species can live even longer (Cushing 1975).

The Skeleton of Fish

Fish (vertebraes) have a backbone composed of segments (vertebrae) and a cranium covering the brain. The backbone runs from the head to the tail. The vertebraes are extended dorsally to form neural spines, and in the trunk region they have lateral processes that bear ribs. The ribs are cartilaginous or bony structures in the connective tissue between the muscle segments (see also Chapter 42 regarding texture of fish, fish product, and shellfish). Usually, there are also a corresponding number of false ribs or “pin bones” extending more or less horizontally into the muscle tissue. These bones have to be removed if a bone-free filet is the goal.

Muscle Anatomy of Fish

Fish have muscle cells (Figure 39.1) running parallel and connected to sheaths of connective tissue (myocommata) anchored to the skeleton and the skin. The bundles of parallel muscle cells are called myotomes. The myocommata run in an oblique

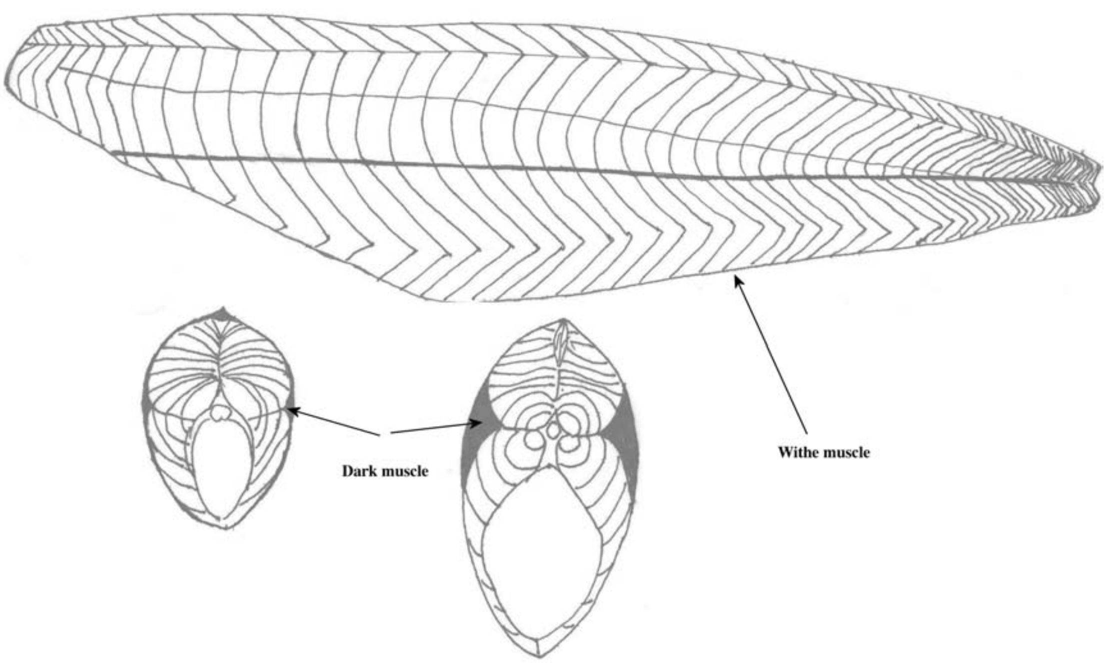

Figure 39.1. Muscle cells in fish.

pattern perpendicular to the long axis of the fish, from the skin to the spine. This anatomy is ideally suited for the flexing muscle movements necessary for swimming through the water. All muscle cells extend the full length between two myocommata, and run parallel with the longitudinal direction of the fish. The muscle mass on each side of the fish makes up the fillet, of which the upper part is termed the dorsal muscle and the lower part the ventral muscle.

DIFFERENCE BETWEEN FISH SPECIES

Difference in the fish muscle has consequence for the commercial value due to the effect on shelf life. In many species, most of the muscle is white or has a light color, but depending on the species, many fish will have a certain amount of dark tissue of a brown or reddish color. The dark muscle is located just under the skin along the body side (Figure 39.1). A typical pelagic fish as herring can contain nearly 50% of dark muscle required for prolonged aerobic muscle activity. The proportion of dark muscle varies with the activity of the fish. The more active the fish is, the larger the amount of dark muscle. There are many differences in the chemical composition of the two muscle types (e.g., higher levels of lipids and myoglobin in the dark muscle). From a technological point of view, the high lipid content of dark muscle is important and can give high intensities of desirable sensory notes, but a shorter shelf life due to lipid oxidation resulting in train-oil and rancid notes among others. Demersal species such as cod have a white flaky and tender muscle; textural changes such as toughness and chewiness are the most noticeable problem during storage. The white muscle is used for quick attacks or escapes, not for long destinations.

The reddish meat color found in salmon and sea trout does not originate from myoglobin but is a result of the red carotenoid, astaxanthin. The function of this pigment has not been clearly established, but it has been proposed that the carotenoid may play a role as an antioxidant. Further, the accumulation in the muscle may function as a depot for pigment needed at the time of spawning when the male develops a strong red color in the skin and the female transports carotenoids into the eggs. It is clearly seen that the muscle color of salmonids fades at the time of spawning. The fish cannot synthesize astaxanthin and is thus dependent on ingestion of the pigment through the feed. Some salmonids live in waters where the natural prey does not have high concentrations of carotenoid, e.g., in the Baltic Sea, thus resulting in a muscle color less red than salmonids from other waters.

DIFFERENCE BETWEEN INDIVIDUALS

There are not only differences between species, but also a considerable variation between individuals. These variations must be taken in to account when setting up experiments using sensory analysis to characterize fish and fish products. In farmed salmon for example, the lipid content can differ from 10 to 19% lipid in salmon from the same farm.

Also for herring there is a wide variation in lipid content within catches. A single catch can contain herring with lipid content ranging from 1 to 25%. This variation is due to heterogeneity caused by mixing between stocks (Nielsen and others 2005).

CHEMICAL COMPOSITION OF WILD CAUGHT FISH

The chemical composition of fish varies greatly from one species and one individual to another depending on age, sex, environment, and season.

The variation in the chemical composition of fish is closely related to feed intake, migratory swimming, and sexual changes in connection with spawning. Fish will have starvation periods for natural or physiological reasons (such as migration and spawning) or because of external factors such as shortage of food. Usually spawning, whether occurring after long migrations or not, calls for higher levels of energy. Fish having energy depots in the form of lipids will rely on this. Species performing long migrations before they reach specific spawning grounds or rivers may use protein in addition to lipids for energy, thus depleting both the lipid and protein reserves, resulting in a general reduction of the biological condition of the fish. Most species, in addition, do not usually ingest much food during migration and are therefore not able to supply energy through feeding.

During periods of heavy feeding, at first the protein content of the muscle tissue will increase to an extent depending upon how much it has been depleted. Then the lipid content will show a marked and rapid increase. After spawning the fish resumes feeding behavior and often migrates to find suitable sources of food. Plankton-eating species such as herring will then naturally experience another seasonal variation than that caused by spawning, since plankton production depends on the season and various physical parameters in the oceans.

The lipid fraction is the component showing the greatest variation. Often, the variation within a certain species will display a characteristic seasonal curve with a minimum around the time of spawning.

Although the protein fraction is rather constant in most species, variations have been observed such as protein reduction occurring in salmon during long spawning migrations (Ando and others 1985, Ando and Hatano 1986) and in Baltic cod during the spawning season (Borresen 1992).

A possible method for discriminating between lean and fatty fish species is to term fish that store lipids only in the liver as lean, and fish storing lipids in fat cells distributed in other body tissues as fatty fish. Typical lean species are the bottom-dwelling ground fish like codfish and flatfish species. Fatty species include the pelagics like herring, mackerel, and sprat. Some species store lipids in limited parts of their body tissues only, or in lower quantities than typical fatty species, and are consequently termed semifatty species (e.g., barracuda, mullet, and shark).

The lipid content of fillets from lean fish is low and stable whereas the lipid content in fillets from fatty species varies considerably.

Whether a fish is lean or fatty, the actual fat content is important for the technological characteristics postmortem. The changes taking place in fresh lean fish may be predicted from knowledge of biochemical reactions in the protein fraction, whereas in fatty species the changes in the lipid fractions have to be taken into account. The implication may be that the storage time is reduced due to lipid oxidation, or special precautions have to be taken to avoid this.

AQUACULTURE FISH

As demonstrated above, the chemical composition of the different fish species will show variations depending on season, migratory behavior, sexual maturation, feeding cycles, etc. These factors are observed in wild, free-living fish in the open sea and inland waters. Fish raised in aquaculture may also show variation in chemical composition, but in this case, several factors can be controlled, and the chemical composition may be predicted. To a certain extent the fish farmer is able to design the fish by selecting the farming conditions. It has been reported that factors such as feed composition, environment, fish size, and genetic traits all have an impact on the composition and quality (Reinitz and others 1979, Einen and Skrede 1998, Nortvedt and Tuene 1998).

In salmon aquaculture, astaxanthin is included in the feed, to compensate for the red color from crustaceans normally found in the natural feed of the wild fish. The red color of the flesh is one of the most important intrinsic quality criteria for salmon.

The world's production of fish from aquaculture has been steadily increasing in the last decades. One generation ago salmon was considered to be a primary luxury only consumed at special occasions or by the very wealthy. This has changed dramatically and now the price of salmon is below the price of cod. Chile and Norway have now a total production of more than 1 million tons of fish per year from aquaculture farms. The increasing growth has not been without drawbacks coming from parasites and virus. This in combination with a heavily fluctuating price on fish meal and oil due to climate phenomena such as El Nino has made the market for salmon very complex. An example of how aquaculture is meeting the new challenges is the Danish aquaculture sector.

The Danish aquaculture sector has been going through a major change in the last decade. The spotlight has been on the environment as the sector contributes to pollution. Recent consumer studies, however, have shown that aquaculture now is perceived according to the risk and benefit of eating the product. This is in contradiction to 10 years ago when the products were categorized at the same level as egg from battery hens or bacon from industrial pig farms.

This new status for the Danish aquaculture sector opens up new opportunities, both in credibility and new products. One of the future limitations of aquaculture is the access to a sustainable resource of fish or other sea living organism that can be used as part of the feed to aquaculture fish. Tests are already going on to use organisms from a lower tropic level than the traditional fish species used for fish meal and fish oil production. Another option is to use components that have a vegetable origin such as soy oil or rapeseed oil. This in combination with the use of more vegetable components such as vegetable proteins means that it is possible to produce a fish such as rainbow trout, which has been fed a diet consisting of a high degree of vegetable origin, and make a "green" rainbow trout. At the same time new legislation has opened up the possibility to produce organic fish in the Danish aquaculture sector.

SLAUGHTER AND PROCESSING OF FISH

In some fisheries, bleeding of the fish is very important as a uniform white fillet is desirable. Bleeding is more affected by time onboard prior to bleeding/gutting than by the actual bleeding/gutting procedure. The best bleeding is obtained if live fish are handled, but it is of major importance to cut the fish before it enters rigor mortis since it is the muscle contractions that force the blood out of the tissues. However, it should be pointed out that the effect of bleeding must be weighted against the advantages of having a fast and effective handling procedure resulting in rapid chilling of the catch. A practical solution could be handling small quantities of fish at the same time.

Discoloration of the fillet may also be a result of rough handling during catch and catch handling while the fish is still alive. Physical rough handling in the net (long trawling time, very large catches) or on the deck (fishermen stepping on the fish or throwing boxes, containers, and other items on top of the fish) may cause bruises, rupture of blood vessels, and blood oozing into the muscle tissue (haematoma).

Heavy pressure on dead fish, when the blood is clotted (e.g., overloading of fish boxes) does not cause discoloration, but the fish may suffer a serious weight loss.

Changes in Raw Fresh Fish

Rigor mortis starts immediately or shortly after death if the fish is starved and the glycogen reserves are depleted, or if the fish is stressed. The method used for stunning and killing the fish also influences the onset of rigor. Stunning and killing by hypothermia (the fish is killed in iced water) give the fastest onset of rigor, while a blow on the head gives a delay of up to 18 hours (Azam and others 1990, Proctor and others 1992).

The technological significance of rigor mortis is of major importance when the fish is filleted before or in rigor. In rigor the fish body will be completely stiff; the filleting yield will drop significantly, and rough handling can cause gaping in the fillets. If the fillets are removed from the bone prerigor, the muscle can contract freely and the fillets will shorten following the onset of rigor. Dark muscle may shrink up to 52% and white muscle up to 15% of the original length (Buttkus 1963). If the fish is cooked prerigor the texture will be very soft and pasty. In contrast, the texture is tough but not dry when the fish is cooked in rigor. Postrigor the flesh will become firm, succulent, and elastic.

SPOILAGE AND SHELF LIFE OF FISH

The spoilage rate and shelf life of fish are affected by many parameters and fish spoil at different rates. In general it can be stated that larger fish spoil more slowly than small fish, lean fish keep longer than fatty fish under aerobic storage, and bony fish are edible longer than cartilaginous fish (Table 39.1). Several factors probably contribute to these differences and whereas some are clear, many are still on the level of hypotheses.

Rough handling will result in a faster spoilage rate. This is due to the physical damage to the fish, resulting in easy access for enzymes and spoilage bacteria. The surface/volume ratio of larger fish is lower than that of smaller fish, and, as bacteria are found on the outside, this is probably the reason for the longer shelf life of the former. This is true within a species, but may not be universally.

The skin of the fatty pelagic fish is often very thin, and this may contribute to the faster spoilage rate. This allows enzymes and bacteria to penetrate more quickly. On the contrary, the thick skin of flatfish and the antibacterial compounds found in the slime of these fish may also contribute to the ability to keep flatfish. As described earlier, the slime of flatfish contains bacteriolytic enzymes, antibodies, and various other antibacterial substances (Hjelmland and others 1983, Murray and Fletcher 1976). Although large differences exist in

Table 39.1. Intrinsic factors affecting spoilage rate of fish species stored in ice.

	Relative spoilage rate	
Factors affecting spoilage rate	Fast	Slow
Size	Small fish	Larger fish
Post mortem pH	High pH	Low pH
Fat content	Fatty species	Lean species
Skin properties	Thin skin	Thick skin

the content of trimethylamine oxide (TMAO), this does not seem to affect the shelf life of aerobically stored fish but rather the chemical spoilage profile of the species.

OFF FLAVORS RELATED TO FISHING GROUND

Occasionally fish with off flavors are caught, and in certain localities this is a fairly common phenomenon. Several of these off flavors can be attributed to their feeding on different compounds or organisms. The planktonic mollusk, *Spiratella helicina*, gives rise to an off flavor described as "mineral oil" or "petrol." It is caused by dimethyl-β-propiothetin, which is converted to dimethylsulphide in the fish (Connell 1975). The larvae of *Mytilus* spp. cause a bitter taste in herring. A very well known off flavor is the muddy-earthy taint in many freshwater fish (Howgate 2004). The flavor is mainly caused by two compounds: geosmin and 2-methyl-iso-borneol, which also are part of the chemical profile of wine with cork flavor. Geosmin, the odor of which is detectable in concentrations of 0.01-0.1 μgram(μg)/liter (L), is produced by several bacterial taxa, notably the actinomycetes *Streptomyces* and *Actinomyces*.

An iodine-like flavor is found in some fish and shrimp species in the marine environment. This is caused by volatile bromophenolic compounds, and it has been suggested that the compounds are formed by marine algae, sponges, and Bryozoa and become distributed through the food chain (Anthoni and others 1990).

Oil taint may be found in fish flesh in areas of the world where offshore exploitation of oil is intensive or in areas where large oil spills occur. The fraction of the crude oil that is soluble in water is responsible for the off flavors. This is caused by the accumulation of various hydrocarbon compounds, where particularly the aromatic compounds are strong flavorants (Martinsen and others 1992).

THE SENSORY ANALYSIS IN THE FISH CHAIN

The fish chain is the flow that a fish follows from when it is caught or taken out of a fish cage in a fish farm to consumption. The numbers of links are determined by fish species and/or product type. The links can for instance be the fishing vessels, fish processors, transports, storage, and retail stores. (See Figure 39.2.) In each link the fish is exposed to different factors that all influence the sensory quality and the sensory characteristic of the product. These factors (extrinsic) can be environmental conditions like temperature but also different handling/processing steps like packing, cutting, or smoking. Besides the factors that fish are exposed to in the chain, the raw material also has a key influence on the product quality and characteristic. To ensure product quality, it is important to follow and control the quality in each chain link. Sensory assessment of fish and fish products are an ideal way of controlling the quality and should therefore be an integrated part of the working routine. Until now, sensory analysis has mostly been used in quality control and quality assurance in some part of the fish sector, and to a certain extent, in product development and optimization (Jonsdottir 1998). There has however until now been very little integration between the descriptive/discriminative analysis and marketing test. Sensory analysis in the fish chain has mostly been used to describe the intrinsic product qualities such as smell, taste, and texture, while consumer choice is based both on intrinsic and extrinsic qualities such as convenience and price.

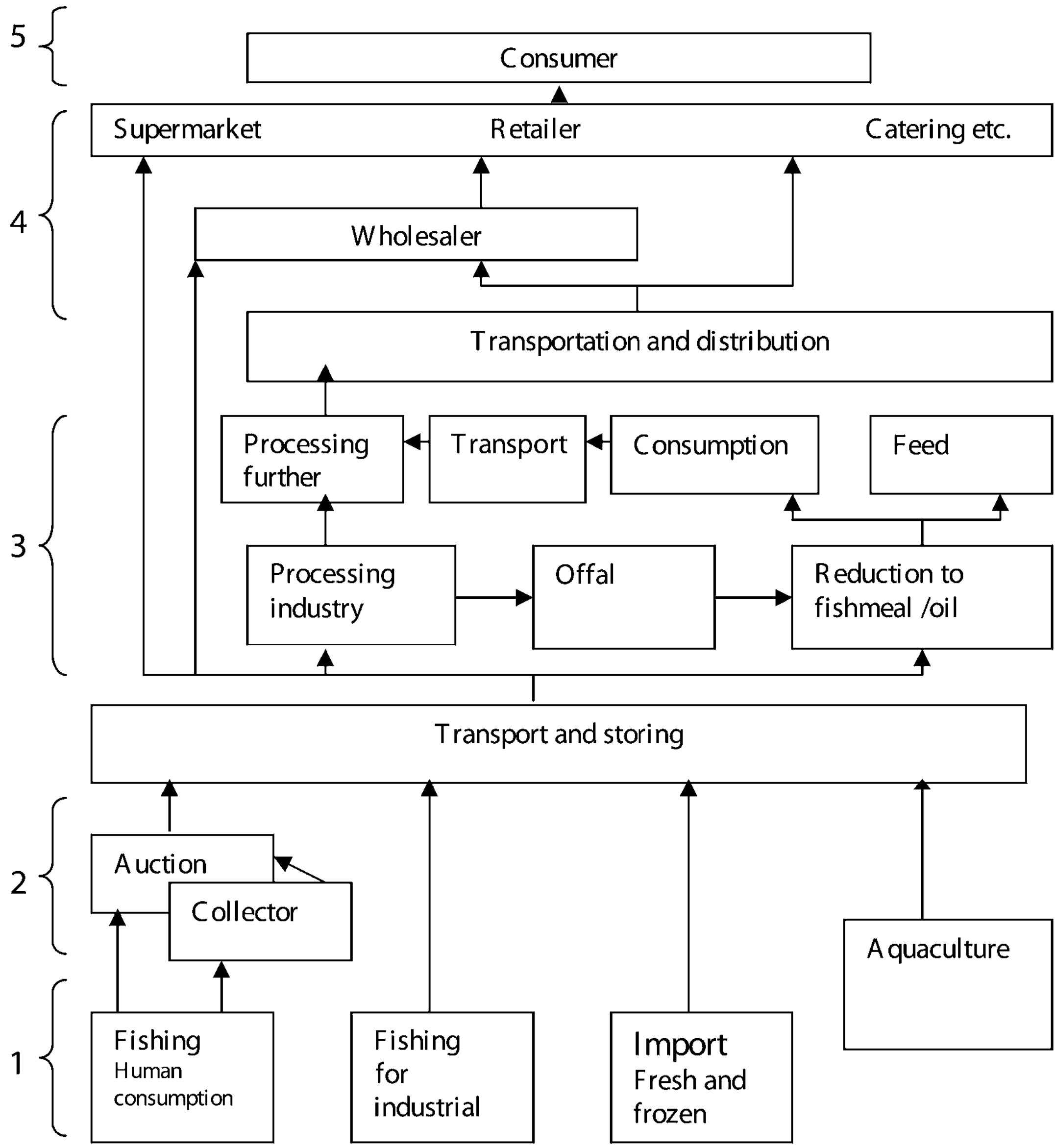

Figure 39.2. Overview of the fish chain from catch to consumer. 1) Primary producers, 2) First sale, 3) Processing, 4) Final sale, and 5) consumption.

Sensory analysis has primarily been used to control a batch of fish when it is received in a link. An example could be the entrance control in a processing plant with the purpose to evaluate quality in accordance with the price paid and to determine when and how the fish is going to be used in the production. This sensory analysis is different from the sensory analysis that is used by the processing plant quality staff to ensure that the final product is in accordance with the specification, for example, regarding fat content and texture. Both operations must be performed by highly professionally trained personnel, but in some instances the evaluations are more on an empiric basis, due to tradition.

A new area is now opening up for the use of sensory analysis in the fish chain. Starting January 1, 2005, the section of the "General Food Law" in the European Union (EU) Regulation 178/2002 dealing with traceability came into action. When introducing traceability in every link in the fish chain, it is necessary to have "tools" to control the validity of the information as part of traceability. Evaluation of the catching time in combination with registration of the actual time and temperature regime makes it possible to calculate the storage time and compare this result with specification of the batch.

Sensory Analysis of Fish

Several conditions are unique for sensory analysis of seafood. When selecting and training judges for sensory analysis, it is very important to be aware that some people cannot taste rancid flavor, iodine, or geosmin, and some have a very low response to cold-storage flavor and rancidity. Also some people are allergic or hypersensitive to different fish proteins, shellfish, or histamine.

Interpretors of the stimulus and response must be trained very carefully in order to receive objective responses. It is very easy, as an example, to give an objective answer to the question: Is the fish in rigor (completely stiff)?, but more training is needed if the assessor has to decide whether the fish is post- or prerigor.

Different Sensory Methods Used in the Fish Chain

Both objective and subjective sensory testing are used. The objective tests include discriminative (triangle test, forced choice) and descriptive (profiling, structured scaling) sensory tests. Both groups of tests are analytical measurements of the intrinsic quality of the product, whereas affective (subjective test) methods are used for consumer testing and measure the attitude and emotional response of the consumer toward the product. All of these methods are used in the fish chain (Figure 39.3). Each link in the chain has its own version of the tests as indicated by the numbers of the different methods (discriminative test 1, discriminative test 2, etc.) and coordination is needed.

When fish are landed in Europe today, the most commonly used method for quality assessment of raw fish in the inspection service is the EU scheme (Anonymous 1996). For cooked samples, the sensory methods that are used in some countries by fish industries and buyers of fish products are based on the Torry scale. The more objective and descriptive sensory methods such as sensory profiling and Quality Index Method (QIM) are described in the following chapters.

There are examples of subjective sensory tests in the chapter dealing with wild and farmed fish.

European Union Scheme

In the European Union (EU) scheme (Table 39.2), according to the Council Regulation (EC) No. 2406/96 November 26, 1996 (Anonymous 1996), there are three quality levels: E (Extra); A, B where E is the highest quality; and below B is the level where fish are discarded for human consumption. The EU scheme does not take into account the differences between species as it only uses general parameters and there are also problems with mixing subjective and objective sensory in the scheme. Several studies have shown that the QIM proved to be more reliable in assessing sensory changes of different fish species as compared to the EU grading scheme (Triqui and Bouchriti 2003).

Torry Scale

The Torry scale (Table 39.3) is a 10-point scale developed at the Torry Research Station (Howgate and others 1992). It is developed for cooked fish samples. Scores are given from 10 (very fresh in taste and odor) to 3 (spoiled). It is considered unnecessary to have descriptions below 3, as the fish is then not fit for human consumption. The average score of 5.5 may be used as the limit for consumption. The Torry scale has been developed for lean, medium fat, and fat fish species.

Translation of Sensory Results from One Part of the Chain to Another

Sensory analysis in the fish chain has principally been used to describe the intrinsic product qualities such as smell, taste, and texture, while consumer choice is based both on intrinsic and extrinsic qualities. Preference/acceptability tests have been widely used in both industry and research, but the tests do

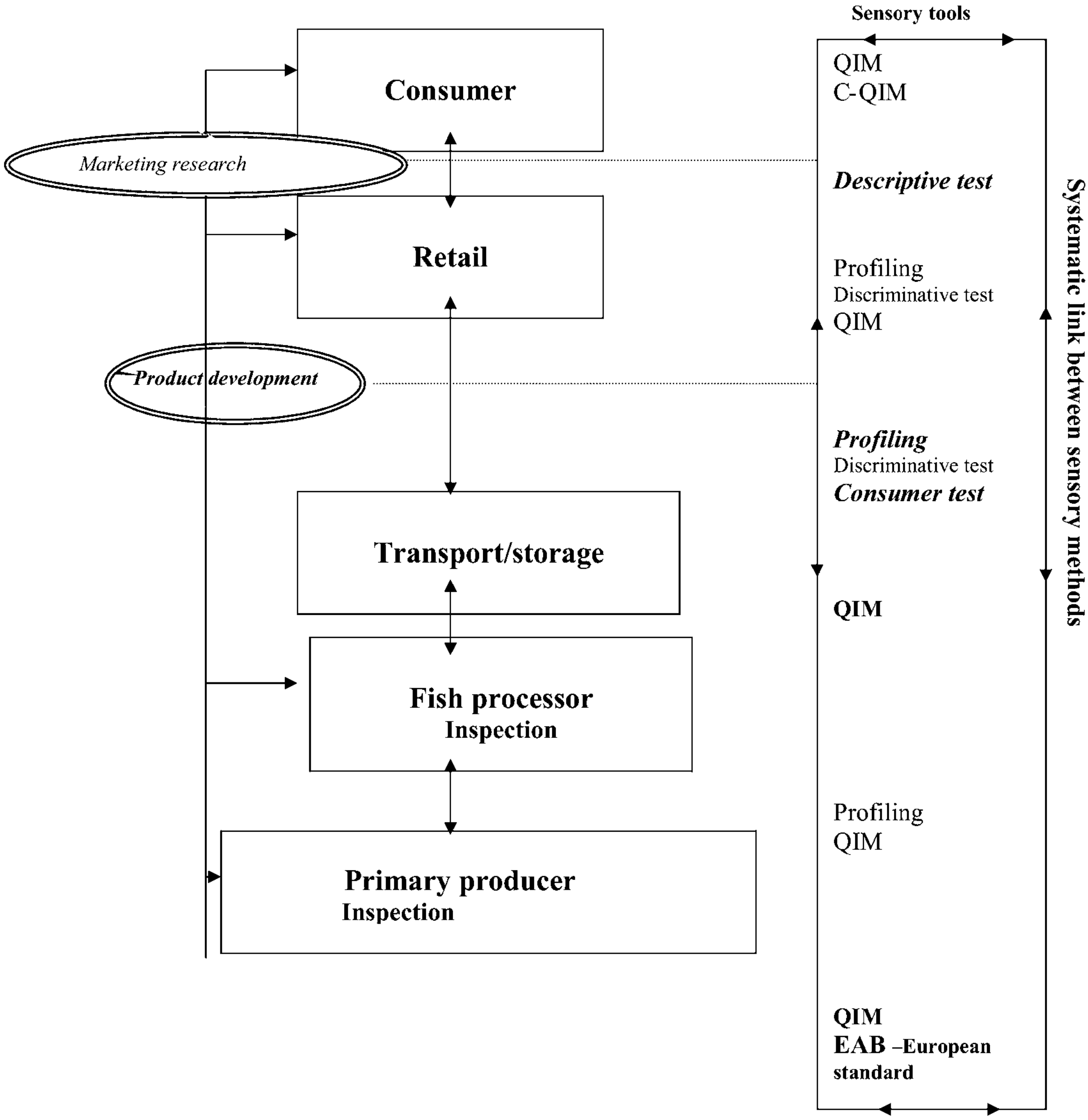

Figure 39.3. Sensory analysis in the chain from catch to consumer.

Table 39.2. White Fish: cod, saithe, haddock, whiting, plaice, redfish, ling, hake.

		E	A	B	Unfit (C)
Skin		Bright; shining; iridescent (not redfish) or opalescent; no bleaching	waxy; slight loss of bloom; very slight bleaching	dull; same bleaching	dull; gritty; marked bleaching and shrinkage
Outer slime		transparent; water white	milky	yellowish-gray; same clotting	yellow-brown; very clotted and thick
Eyes		convex; black pupil; translucent cornea	plane; slightly opaque pupil; slightly opalescent	slightly concave; grey pupil; opaque cornea	completely sunken; gray pupil; opaque discolored cornea
Gills		dark red or bright red; mucus translucent	red or pink; mucus slightly opaque	brown / grey and bleached; mucus opaque and thick	brown or bleached; mucus yellowish gray and clotted
Peritoneum (in gutted fish)		glossy; brilliant; difficult to tear from flesh	slightly dull; difficult to tear from flesh	gritty; fairly easy to tear from flesh	gritty; easily torn from flesh
Gill and internal odors	all except plaice	fresh; sea weedy; shell fishy	no odor; neutral odor; trace musty, mousy, milky, capryllic, garlic or peppery	definite musty, mousy, milky, capryllic, garlic or peppery; bready; malty; beery; lactic; slightly sour	acetic; butyric; fruity; turnipy; amines; sulphide; fecal
	plaice	fresh oil; metallic; fresh-cut grass; earthy; peppery	oily; sea weedy; aromatic; trace musty, mousy or citric	oily; definite musty, mousy or citric; bready; malty; beery; slightly rancid; painty	muddy; grassy; fruity; acetic; butyric; rancid; amines; sulphide; fecal

Table 39.3. Torry score sheet for freshness evaluation of cooked lean fish such as cod, haddock, and pollock.

Odor	Flavor	Score
Initially weak odor of sweet, boiled milk, starchy, followed by strengthening of these odors	Watery, metallic, starchy. Initially no sweetness but meaty flavors with slight sweetness may develop.	10
Shellfish, seaweed, boiled meat	Sweet, meaty characteristic	9
Loss of odor, neutral odor	Sweet and characteristic flavors but reduced in intensity	8
Wood shavings, wood sap, vanillin	Neutral	7
Condensed milk, boiled potato	Insipid	6
Milk jug odors, reminiscent of boiled clothes	Slight sourness, trace of off flavors	5
Lactic acid, sour milk, TMA	Slight bitterness, sour, off flavors, TMA	4
Lower fatty acids (e.g., acetic or butyric acids) decomposed grass, soapy, turnipy, tallowy	Strong bitterness, rubber, slight sulphide	3

not give good predictions of consumer behavior (Cardello and others 2000). There has, however, been very little integration between the descriptive/discriminative (objective methods) analysis and marketing tests (subjective methods). Further investigation in this area can perhaps make it easy to predict consumer behavior toward a product.

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