Maximising the quality and storage life of fresh seafood products

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Introduction

This briefing note is aimed at businesses that catch, process, buy, sell or trade fresh seafood products; it seeks to improve the understanding of those factors that cause the natural deterioration of seafood products due to spoilage, and to ensure that businesses are able to mitigate and remediate those changes as far as possible to ensure that the maximum storage lives for their products are achieved.

Seafood is highly perishable, this means that unless there has been an intervention which changes the physical nature of the product, such as freezing, cooking, drying, smoking or canning, fresh seafood products will continually deteriorate in quality over time. Visual and physical changes effect the consumer's perception of the product to the eventual point where it would be considered unappealing or even inedible.

Aspects of freshness and quality related to the natural deterioration of the product due to spoilage are:

- Aroma – development of objectionable 'off odours' in raw and cooked product
- Flavour – development of unpleasant 'off flavours' in cooked product
- Colour/appearance – loss of desirable visual characteristics, discolouration, drying of surfaces etc.
- Texture/gaping – breakdown of connective tissue to cause visual gaping and ragged appearance of muscle blocks.

This paper does not intend to discuss aspects of quality that are not related to natural spoilage. Non-spoilage aspects of quality include:

- Filleting specifications/standards
- Specification for the tolerance of bones
- Specification for the presence and numbers of nematode parasites
- Tolerances for blood spotting and bruising of the flesh
- Specified levels of glaze or other means of added water

Traditional means of preservation

In his 1899 work 'The preservation of Fishery products for Food', Charles H Stevenson wrote:

> *'It is now a generally accepted opinion that all putrefaction is caused by the development of living organisms known generally as bacteria or putrefactive germs, this theory being announced first in 1837 by the German physiologist, Theodore Schwaun. "Putrefaction," says Cohn, "begins as soon as bacteria, even in the smallest numbers, are introduced, and progresses in direct proportion to their multiplication."… After life is extinct, heat, moisture, and air are all more or less necessary to the development of bacteria, and it is principally by removing one or all of these factors that preservation is accomplished.'*

After more than a hundred years since these words were written, the fundamental principles of preservation remain the same, and technologies which aim to extend the safe shelf-life of fishery products still largely rely on the control of temperature, moisture and oxygen.

In pre-industrial times, preservation technologies mainly focussed on the reduction of water in the product through drying, curing and smoking processes. Before the advent of refrigeration and freezing technologies, fish products were dried by exposure to the natural sun and wind in such treatments as 'stockfisk' (on wooden frames) or 'klipfisk' (on rocks or cliffs). The steeping of fish fillets in salt is another traditional means of reducing the water content of a fresh fish fillet and the long shelf lives attained by salting cod to produce 'bacalao' enabled cod to became one of the world's first truly internationally traded commodities.

Smoking fish over smouldering wood chippings enables shelf life extension by drying the product whilst at the same time exposing its surface to phenol and other phenolic compounds which are found in wood smoke. These compounds act as antioxidants, which slow the rancidification of animal fats, and as antimicrobials, which act to slow bacterial growth. Light cold smoking of white fleshed fish in modern processes does not have a significant preservative effect as the process has evolved to focus on the development of flavour profiles rather than to achieve increased storage life.

Another early and traditional form of achieving shelf life extension was pickling. Such products as soused or roll-mop herrings are preserved by soaking the raw product in vinegar or a similar acidic liquid such as cider or wine; this results in a reduction of the product's pH and the creation of a mildly acidic environment in which bacteria cannot survive.

All of these traditional methods of preservation result in a fundamental change to the nature, appearance and eating qualities of the original raw material and it was not until the invention of industrial refrigeration and ice-making technologies in the mid nineteenth century that the trade in so-called 'fresh' fish products was able to flourish.

What is fresh fish?

There is no legal definition of the word 'fresh' in the context of fishery products and indeed, the term is widely understood to have two separate and different meanings. Firstly, 'fresh' can be seen simply as a differentiation between fish that has never been frozen and that which is or has been frozen – the term 'wet fish' has the same meaning in this context. Secondly, and perhaps more commonly in the wider food industry, the word 'fresh' is considered to be an indication of newness and optimal quality as opposed to old or decayed product.

These two definitions give rise to one of the most common disputes in the seafood trade – the freshness comparison between never-frozen and frozen fish. It is entirely possible that a fish that has been held in frozen cold storage for many months may exhibit better flavours, odours and textures than a so-called 'fresh' fish that has been held in sub-optimal storage conditions for just a few days. In this scenario, frozen fish can be perceived to be fresher than fresh fish. It is important therefore to be clear about how the term is being used and to be mindful of the important point that freshness is not simply a measure of the age of the product, but also of its physical characteristics.

Given that the freezing process is an efficient means of almost halting bacterial activity, in this paper, we will be concentrating on the freshness and quality aspects of never-frozen 'fresh' fish. It is worth considering that these discussions apply to the fresh fish that is used to create frozen products and that whilst freezing may arrest bacterial deterioration, it cannot reverse the process and any spoilage and putrefaction that has already occurred before the freezing process takes place will still be evident upon defrosting or consumption if cooked from the frozen state.

Different types of fresh fish supply chains

In distinguishing between fresh fish and other product formats such as frozen, dried, smoked or canned, we should also recognise that there are a number of routes to market for fresh fish, and that these all have different implications on shelf life and product quality dependent upon the capability of maintaining low product temperatures and adequate protection against deterioration. Fresh fish sold at a harbour side fish monger or restaurant may have different shelf life and quality aspirations to similar product sold in a major multiple high street retailer. Even within the retailer supply chain, pre-packaged product and bulk packed product sold loose on the in-store fish counter may have different temperature and storage regimes which could affect the overall shelf life and product quality at point of sale.

It is important to recognise that the total available shelf life and the optimal freshness and quality of the product as sold, may vary in accordance with a number of factors, and that each supply chain should be viewed individually. Decisions about the total shelf life of any product in any supply chain will depend upon the market's prioritisation of the balance between the maximum possible quality and the maximum possible shelf life.

An introduction to bacteria and enzymes

Bacteria

Bacteria are tiny, single celled microbes, they are neither plants nor animals, they belong to a group entirely by themselves. Bacteria are found everywhere in nature and are an essential part of life. They are so small that even the largest is visible only with the aid of a powerful microscope. Bacteria are responsible for the breakdown of amino acids in the tissue of dead fish into substances such as putrescine and cadaverine. This process is known as 'putrefaction' and leads to the distinctive and undesirable smells and flavours that we associate with off or rotten fish.

Bacteria occur naturally in the marine environment and on the skin and in the slime of living fish, where they do no harm. They are also found in large numbers in the viscera (guts) of fish, and whilst these bacteria do not affect the flesh of the living fish, very soon after the fish has died, they begin to attack the protein structures and progressively break them down into the products of putrefaction until ultimately, it becomes unfit for human consumption.

Some bacteria are harmful to human beings; these are known as 'pathogenic' and can cause illness if ingested in sufficient quantities. Pathogenic bacteria are a particular problem for products that are intended to be consumed without any heat treatment by cooking which could kill them. As an example, Listeria species are widely found in the marine environment, and if these bacteria survive the processing of ready to eat seafood products, they can cause Listeriosis, a severe and potentially lethal form of food poisoning.

In its purest and untreated form, fish is a highly perishable food product with a short shelf life when compared to other animal proteins. Fish has a relatively neutral pH value and is high in both water content and protein, so it is an ideal growth-medium for both spoilage and pathogenic bacteria. To maximise the safe shelf life and the eating quality of fresh fish, we must therefore seek to control those factors which have the most influence over the growth of bacteria, these principally being hygiene and temperature management. The reduction of oxygen through vacuum packing or packing in a modified atmosphere may also be used in some parts of the distribution chain to inhibit bacterial growth and potentially to maximise product shelf life.

No matter how carefully the fish are gutted, washed and stored, some of the bacteria will inevitably remain on the skin and in the bellies. These will continue to multiply from the time that the fish are first caught until they are cooked and eaten. Quick freezing followed by cold storage can halt bacterial activity, but during the chilled storage of wet fish this activity continues, albeit at a reduced rate. The numbers of bacteria can be kept down by making sure that the fish is kept as close to 0^{o}C as possible at all times, and ensuring that every surface it touches and every person who touches it is scrupulously clean.

Although it appears to enjoy a reputation to the contrary, with some exceptions, seafood is rarely associated with food poisoning outbreaks. This is because:

- Seafood is typically rendered inedible through spoilage before bacteria reach levels where they would be injurious to health. The strong smells of spoiled fish act as an effective deterrent to consumption
- Most seafood is not infected by, or carries pathogenic food poisoning bacteria
- The cold temperatures (such as melting ice) in which seafood is typically stored, means that most food poisoning bacteria grow poorly
- Seafood is traditionally eaten cooked, so any bacteria present are destroyed by heat treatment during cooking

It is important to note that these are general rules and observations and that in some very specific circumstances there may be non-spoilage related factors, such as the presence of toxins or allergens that cannot be detected by smell or taste, that would affect the safety of the product.

Enzymes

Food spoilage can also come about through the action of enzymes. Enzymes are chemicals which are present in all food. Whilst the fish is alive, enzymes fulfil an important role in helping them digest their food, however, once the fish has died, enzymes speed up chemical changes that result in loss of flavour and changes to colour and texture. This process is known as autolysis, which means self-digestion - in some species such as squid and herring, the enzymatic changes precede and therefore predominate the spoilage of product, in others, autolysis contributes to varying degrees to the overall quality loss in addition to the microbial processes.

In the same way that enzymes are responsible for the cut surfaces of an apple or potato turning brown, they are the reason why seafood products change colour over time. The activity of enzymes in food also makes it easier for the micro-organisms responsible for food spoilage to enter the food. As enzymes are mainly composed of protein, they are sensitive to heat and this is why vegetables are often exposed to boiling water to fix their colour in a ‘blanching’ process. For fresh fish where blanching is not possible, we must rely on refrigeration and freezing processes to slow down enzyme activity, but they can remain very slightly active, even at the low temperatures found in cold stores and freezers.

Gaping

When fish are filleted, the cut surface is normally smooth and glossy. Sometimes, however, the flakes (or myotomes) separate from one another so that slits or holes appear in the fillet and, in severe cases, it may even drop to pieces when it is skinned; fillets like this are said to 'gape'. Each myotome is separated from the next by a thin membrane called the myocommata, which can usually be seen as a bluish shiny surface where the flakes have parted. The flesh is joined to this membrane by little threads of connective tissue which run through the flakes and merge with the membrane at the join; when the threads break, the fillet gapes.

The connective tissue of newly caught fish is very sensitive to small rises in temperature; it is weakened after only 4 hours at 17°C, the temperature of a mild day. At 20°C it weakens more quickly, and fish kept at 25°C before freezing will almost always gape severely. When a newly killed fish is warmed by lying on a warm deck for half an hour, it quickly stiffens in rigor, and the strong muscle contraction breaks the weakened connective tissue, so that at temperatures of 20°C or more, severe gaping will almost certainly occur.

When the fish are warm, any handling such as gutting, washing or moving them about almost invariably results in severe gaping. However, when warm fish are cooled again in ice or cold sea water, the connective tissue recovers most of its strength. Provided the warm fish did not go into rigor, rapid chilling will enable the fish to be handled in the usual way without increasing the risk of gaping. If the temperature reaches 30°C, as it quickly can on a warm deck, then subsequent cooling will not help much; the connective tissue will have been damaged too badly.

Good handling practice will help to reduce the incidence of gaping. Fish should be chilled as soon as they are caught, and kept cold at all times thereafter. Any fish that have warmed should be cooled in cold sea water or in ice before being further handled.

- Do not force bent fish straight again while they are still stiff (in rigor).
- Treat fish that are feeding after spawning with particular care; some gaping is almost inevitable.
- Fish caught at or just before spawning time are least likely to gape.

Vacuum Packing and Modified Atmosphere Packing

Bacteria are living organisms and many types require the presence of oxygen for their respiration, these are known as 'aerobic bacteria'. Vacuum Packing (VP) and Modified Atmosphere Packing (MAP) both offer the potential of inhibiting the growth of spoilage bacteria through the removal of, or significant reduction in available oxygen levels inside the package. VP has the added benefit of achieving a small reduction in pH on the surface of the product because when Carbon dioxide gas (CO_2) is introduced into an air-tight, sealed pack, it is absorbed by the moisture on the fish to produce a weak form of Carbonic acid.

It is most important to understand the limitations of shelf life extension that can be achieved through VP and MAP. Some types of pathogenic bacteria such as *Clostridium botulinum* for instance, do not require the presence of oxygen to survive – these are known as ‘anaerobic’ bacteria and if present, they are able to thrive without competition from aerobic colonies.

Clostridium botulinum is able to grow and form toxin in VP and MAP packages, even at chilled temperatures – this powerful toxin causes the serious illness botulism and it is therefore important that a comprehensive Hazard Analysis and Critical Control Point exercise (HACCP) is conducted to ensure that the appropriate safe shelf life has been identified for VP and MAP packed products.

For this reason, the Advisory Committee on the Microbial Safety of Food (ACMSF) and the Food Standards Agency (FSA) have produced guidance on the safety and shelf life of modified atmosphere packed chilled foods with respect to non-proteolytic Clostridium botulinum. These guides outline the specific controlling factors that have been identified when establishing the shelf life of VP and MAP products:

- Heat treatment of 90^{o}C for 10 minutes or equivalent lethality.
- Acidity in the food of pH5 throughout the food.
- Salt Content to be a minimum of 3.5% in the aqueous phase throughout the food and throughout all components of complex foods.
- Water Activity of 0.97 or less throughout the food and throughout all components of complex foods.
- A combination of heat and preservative factors which can be shown consistently to prevent growth and toxin production by non-proteolytic C. botulinum.

Unless these measures are demonstrably in place, the shelf life of chilled VP and MAP foods should not exceed 10 days from when the product was first VP or MAP packed.

Assessing the spoilage of fish products

Immediately after capture, seafood is considered to be absolutely ‘fresh’ and the tissue is microbiologically sterile even though the skin, the gills and the viscera are not. In the first couple of days after death, the changes that occur in seafood are mainly due to chemical processes such as those that create the effects of rigor mortis. However, after a few days, bacteria begin to penetrate the flesh where they degrade the tissue components and produce the distinctive off odours and flavours of stale fish.

The specific types of bacteria can differ between different types of fish and fish from different origins, but it is generally possible to equate degrees of spoilage with the number of bacterial organisms identified by laboratory microbiological analysis. Microbiological analysis can therefore be used as a means to predict fish age and the remaining shelf life of the product, but because bacterial growth is highly influenced by temperature, these predictions must take into account known time/temperature conditions prior to assessment and during the remaining shelf life of the product.

Many seafood retailers and brands specify acceptable starting point bacterial counts for a range of spoilage and pathogenic micro-organisms, these specifications may differ in accordance with factors such as species and packaging format but the intention is to ensure that bacterial levels do not exceed safe levels at any point during the product’s stated shelf life under advised storage conditions. Because this aspect of shelf life has food safety implications, the law requires that the storage conditions are clearly displayed in the same field of vision as the expiry 'Use By' date.

Non-sensory testing

In addition to microbiology, there has been a longstanding quest to identify other empirical means of quantifying the freshness and determining the shelf life of fish products. These non-sensory methods principally rely on the measurement of the various chemical compounds that are created as by-products of the spoilage process. Some retailers, brands and enforcement agencies seek to use these non-sensory methods in their routine quality control and surveillance activities.

Total volatile bases (TVB)

Perhaps the most widely used chemical method to determine the quality of seafood is the measurement of total volatile bases (TVB). Ammonia and trimethylamine (TMA) are examples of *bases*; another base, dimethylamine (DMA), can also be formed during spoilage of fish, together with traces of others. These bases are known chemically as *amines.* The combined total amount of ammonia, dimethylamine and trimethylamine is called the total volatile base (TVB) content of the fish and is a commonly used as an estimate of spoilage.

Alternative terms used are *total volatile base nitrogen* (TVBN) and *total volatile nitrogen* (TVN), since the results of the analysis are always given in terms of the nitrogen content of the bases. Corresponding French and German names, sometimes met with, are *Azote Basique Volatil total* (ABVT) and *Flüchtiger Basenstickstoff.* TVB can be measured easily and quickly using relatively simple apparatus and, for this reason, a TVB value is often used as a rejection limit in regulations and commercial specifications.

A range of methods are used to measure TVB. In all of them the fish, or an extract of the fish, is made alkaline, the bases are distilled off and collected, then measured by titration. Some of the substances used to make the fish, or the extract, alkaline can convert other substances present in the fish to ammonia during the distillation, so that the apparent amount of TVB increases as distillation proceeds. Several other factors can affect the result so that the measured TVB depends quite significantly on the details of the method used. It is possible, by two different methods, to get results on the same sample that differ by a factor of 2. For this reason TVB, though widely used, is not a particularly good index of spoilage; when a limiting value of TVB is included in a specification or standard for any particular species, it is important that the method of measurement to be used is described in detail.

Hypoxanthine

A substance called adenosine triphosphate (ATP), is important in the utilisation of energy in most living things. When fish die, the ATP is broken down over a period of days by enzymes present in the flesh, through a succession of different substances. The final stage of this process is the formation of a compound called hypoxanthine, which gradually increases in quantity over time and can therefore be used as a measure of the duration of icing. The rate of accumulation of hypoxanthine is not the same in all species and this must be remembered when interpreting the results. The amount of hypoxanthine present is measured either by an enzymic method that converts hypoxanthine into uric acid, or by separating the hypoxanthine from any remaining ATP and the intermediate compounds by a technique called high pressure liquid chromatography (HPLC). In both cases the last stage is to measure how much of a particular wavelength of UV light is absorbed by the solution of uric acid or hypoxanthine itself; the instrument used is a spectrophotometer.

K value

The K value is a calculation developed by researchers in Japan in the 1950s to measure the extent of the enzymatic breakdown of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) and inosine monophosphate (IMP). The further breakdown of ADP and IMP then results in the accumulation of inosine and hypoxanthine which are indicators of spoilage. It is the ratio of inosine and hypoxanthine to the initial ATP present at death that is used to calculate the K factor. The lower the K value, the fresher the fish.

Trimethylamine (TMA)

Most marine fish contain a substance called trimethylamine oxide (TMAO). Certain bacteria that occur naturally on the skin and in the guts of fish and in sea water can break down TMAO to trimethylamine. The amount of TMA produced is a measure of the activity of spoilage bacteria in the flesh and so is an indicator of the degree of spoilage. TMA can be measured by a chemical method that produces a coloured solution; the amount of the coloured product is measured using a spectrophotometer. Alternatively, TMA can be separated from similar compounds, and its amount measured, by gas chromatography (GC).

Ammonia

Bacteria can generate small amounts of ammonia in spoiling fish, mainly from free amino acids; the amount of ammonia can give an indication, though not a particularly accurate one, of the extent of spoilage. Much larger amounts of ammonia are produced during spoilage of the elasmobranch fishes, skate and dogfish for example, because they have large amounts of urea in their flesh. Shellfish, also, may develop more ammonia than most marine fish and at an earlier stage. There are several chemical and enzymic methods for measuring ammonia.

Histamine

Certain families of fish, notably the mackerel family, contain histidine, an amino acid, in larger amounts than other families. During spoilage of these fish, especially if the temperature rises to above 10°C, histidine may be converted to histamine. Histamine is a substance that is produced by the body as part of the allergic response to foreign substances, as in hay-fever. For example, when spoiled mackerel is eaten, any histamine present is usually inactivated in the stomach and rendered harmless (except in rare cases where certain medicines are being taken). There is evidence, however, that some other, unidentified substance is produced in the spoiling fish along with histamine and this substance causes marked gastrointestinal disturbance. Measurement of the amount of histamine in fish is used as a guide to the potential of the sample for causing this form of food poisoning, the so-called *scombroid poisoning.*

To measure histamine a protein-free extract is first prepared; the histamine is separated from interfering substances by extraction first into an organic solvent followed by back extraction into an aqueous solution. The histamine is treated with a substance that gives a fluorescent product and the amount of this product is measured using an instrument called a fluorimeter. Histamine can also be measured by HPLC, along with certain other amines including putrescine and cadaverine; the term "biogenic amines" is often used to describe these substances.

Physical methods

The electrical properties of fish skin and muscle change systematically after death and can be used as the basis of an instrument; a few models are commercially available, including the Torrymeter. The change in electrical properties is not caused directly by bacterial action or other spoilage mechanism, but the instrumental readings on iced fish can be correlated with the stage of spoilage, as measured by sensory methods or by one of the non-sensory methods already described. The instruments can be used only on whole fish or fillets with skin. Frozen fish, when thawed, give no response to the meter and this can be used as a basis for checking whether fish have been previously frozen.

Sensory testing

Despite the development of numerous microbiological and chemical tests in recent years to identify the spoilage indicators of fish flesh, the human senses remain one of the most sensitive and important tools for any seafood business to determine the quality and shelf life of their products. Sensory assessment relies on assessing the appearance, odour and texture of the seafood in its raw or cooked states to derive an overall score.

Several sensory assessment methods have been used in the UK over the past 30 years. These include the Torry Sensory Assessment scheme, the European E-A-B scheme and the Quality Index Method. Although there are variations in how these schemes work, they all rely on the identification of physical characteristics to determine a score or rating to give an indication of the freshness of the product. In Torry and QIM the score is used to estimate the 'days on ice' of the seafood and (QIM only) to estimate the remaining shelf-life.

All the schemes have been developed using seafood that has been produced according to good manufacturing practice (i.e. held in melting ice since capture). This makes it possible to identify seafood that shows atypical characteristics or which appears to have spoiled more quickly than expected, and this can be linked to poor storage and handling practices such as temperature abuse, inadequate icing etc.

Whilst sensory testing has some disadvantages over non-sensory testing, for instance because it relies on operator training and risks inconsistency between individuals depending on their sensitivity and ability to identify the odour and flavour characteristics of spoilage, it does have a number of distinct advantages:

- It directly mirrors the consumer's human experience of the product.
- It is a 'real time' test.
- It does not require expensive laboratory equipment.

For more detailed information about sensory scoring systems, see the Seafish report at the following link: http://www.seafish.org/media/Publications/sensory_assessment_scoresheets_14_5_10.pdf

Some useful video guides to sensory testing are available at the following YouTube links:

- https://www.youtube.com/watch?v=9No0yWcQ78w
- https://www.youtube.com/watch?v=fGRfdZwCytA
- https://www.youtube.com/watch?v=C7fYNFItMOA

The Torry System

The Torry system was devised by the then Torry Research Station in Aberdeen. In the 1940s and 50s, when the UK had a large distant water trawler fleet, it was decided that a means of determining the freshness of the catch at point of landing was needed – in those days, the trawlers relied on steeping the catch in ice to keep it as fresh as possible, but with a typical fishing trip lasting around three weeks or more, it was inevitable that the first of the catch would be considerably older and of lower quality than the last day's trawling. The then White Fish Authority, a precursor to today's Seafish was charged with devising scoring scales for whole fresh fish and cooked fillets based on sensory indicators of spoilage related to the number of days that it had been held in ice – this became known as the Torry scale.

The Torry scale presumes a perfect freshness score of ten at point of capture, with points deducted to reflect the sensory deterioration of the product over time.

Different fish species deteriorate at different rates; Torry schemes were developed to cover most of the main commercially important species and it is important to ensure that the correct scheme is being used for the species being assessed. Some species of fish now available in the market place do not have Torry schemes.

In simple terms, the fish at point of catch is a Torry score of ten. Subsequent to this, white fish will lose approximately two Torry points for every five to six days held on ice. In theory, provided that the fish is held at exactly the temperature of melting ice ($0^{o}C$), then after 5 days, a piece of fish will have a Torry score of 8 and after 11 days, this score will have reduced to 6. A Torry score of 6 is significant in that this is the point at which the fish exhibits largely neutral flavours and odours, without the pungent off markers of bitterness and sourness that will develop if it is allowed to remain in storage. It is therefore, the lowest Torry score that would not exhibit any off or stale flavours and odours to the consumer.

Example of Torry scores for fresh fish held in melting ice.

Days on ice	Sensory score
0	10
2	9
5	8
8	7
11	6
14	5
17	4
20	3

The European E-A-B Scheme

The only seafood quality grading system that has legal status in Europe today, is the method used and recommended for quality assessment of raw fish in the industry and the inspection service, as defined by the Council Regulation (EC) No 2406/96 of November 26, 1996. All fish sold at EU auction markets are required to be graded against the E-A-B scheme by the selling agent or the Fisheries Inspector. In this scheme, three grades of freshness are established: E, A and B, corresponding to various stages of spoilage. E (Extra) is the highest possible quality, while fish scoring below B is considered to be unfit for human consumption. The EU-scheme is commonly accepted at auction levels however its use has been disputed by the industry as it gives rather limited information about the condition of the fish.

Quality Index Method (QIM)

As with the Torry system, QIM is based on sensory quality attributes for whole fish using a number of weighted quality parameters. Also in common with the Torry system, QIM is a demerit scoring system, but instead of using a scale of 10 to 0, QIM is scored from 0 to 3. The scores for all the characteristics are added to give an overall sensory score, the so-called quality index (QI). A QI of zero is given for very fresh fish and the QI score increases as the fish deteriorates.

During the development of QIM, one of the objectives was to develop a linear correlation between the sensory quality (expressed as the QI) and the storage time in ice, thereby making it possible to predict remaining shelf life in ice. Results from the well-controlled storage experiments carried out by fish research institutes in Iceland (IFL), the Netherlands (RIVO) and Denmark (DIFRES) are used to predict the remaining storage time. The end of storage time is defined when a trained sensory panel detects spoilage flavour in cooked samples of the fish to the point where it is considered unfit for human consumption. A linear relationship between the Quality Index and storage time in ice has been found and the best fit of the regression lines calculated for each species and shown in tabular form. The regression lines are used to predict storage time in ice after evaluation of the Quality Index. The remaining shelf life is found by subtracting predicted storage time from estimated total shelf life.

Example of QIM remaining shelf life (in ice) calculation for cod

QIM Scores - Cod		
Quality Index	Storage time in ice (days)	Remaining shelf life (days
1	1	14
2	2	13
3	3	12
4	3	12
5	4	11
6	5	10
7	6	9
8	7	8
9	8	7
10	8	7
11	9	6
12	10	5
13	11	4
14	12	3
15	13	2
16	13	2
17	14	1
18	16	0

What do the numbers mean?

It is not possible to lay down exact rules for deciding what values of any of the freshness indices should be regarded as indicating any particular stage of spoilage or acceptability. There are differences between species, the kinds of bacteria causing spoilage may vary, the methods of analysis, as noted for TVB, can affect the values and the mode of handling may influence the results. Ideally, the relationship between the freshness as measured by sensory assessment and the various freshness indices described should be derived for the species of interest, using well defined methods, and for the particular handling procedure concerned. This is not always done: it is common for a particular level of, say, TMA or TVB to be taken as indicative of an unacceptable degree of spoilage in a range of species and without reference to the handling procedure or the measurement technique.

Purely as a guide to the relative magnitude of certain indices in iced cod, values of hypoxanthine, TMA and TVB, measured by methods used at Torry Research Station, and readings on the Torrymeter (one of the instruments mentioned that measure the electrical properties) are compared in the table below with the time on ice and a sensory score.

Days on ice	Sensory score	Hypoxanthine	TMA	TVBB	Torry-meter
2	9	2	less than 1	19	14
5	8	5	less than 1	20	13
8	7	9	2	22	11
11	6	14	5	27	10
14	5	21	11	37	8
17	4	30	24	56	6
20	3	43	45	85	4

Practical measures to ensure optimal shelf life for fresh fish products

Different fish species have different shelf lives depending on their oil levels, catch area, season, intrinsic condition and how they have been stored and handled since capture. Those aspects within the control of the processing sector largely pertain therefore to the management of temperature and hygiene during product storage and handling processes.

Chilled temperature control

Shelf life is defined as the amount of time that the product remains both safe to eat and palatable to the consumer. Shelf life (or storage life) is dependent on time and temperature and there is a linear relationship between the rate of decay and the temperature of the product. At low temperatures, i.e. close to the temperature of melting ice (0^oC) bacterial levels increase slowly. Conversely, at higher temperatures, bacteria grow more rapidly, accelerating the spoilage rate. This means that 1 day held at 0^oC does not equal 1 day held at 5^oC and therefore, temperature improvements achieved in upstream supply chains cannot be directly passed on as shelf life enhancements downstream on a like for like basis. Referring to the table over page, we can see that the shelf life of product can be more than doubled by reducing storage temperature from 5^oC to 0^oC.

Shelf life (days) of product stored in ice at 0^oC	Shelf life at chill temperatures (days)		
	5^oC	10^oC	15^oC
6	2.7	1.5	1
10	4.4	2.5	1.6
14	6.2	3.5	2.2
18	8	4.5	2.9

In practical terms, it can be demanding to maintain product temperatures consistently close to 0^oC. Refrigeration technologies can cool the air in the holding room (or 'chiller') but they are not an efficient means of maintaining uniformly low product core temperatures. A greater consistency of temperature control can be achieved by steeping product in good, food quality ice, or immersing it into an iced water slurry or binary ice mixture. The addition of salt to ice water slurry and binary ice mixtures allows for the freezing point of the water to be reduced below 0^oC and subsequently for the production of colder ice. Product stored in fluid ice mixtures can be maintained between 0^oC and -1^oC although care must be taken not to reduce product temperatures below this level as ice crystal formation will begin in white fleshed fish species at around -1.5^oC and the product will begin to freeze.

Good attention to the temperature control of stored seafood products is the best way to ensure that the shelf life of the product is optimised. Given that the ability to control product temperature is potentially greater within a manufacturing environment than it is in downstream distribution and retail environments, the most efficient use of optimised shelf life is that taken as 'work-in-progress' storage, and the share of total shelf life allocated for distribution to customers or to consumers as in-pack code life must take into account the temperature profile in the downstream supply chain.

The size of an item and its surface area to volume ratio are both important factors when considering the ability to mechanically cool items and to keep them cold. Smaller products will lose heat and gain heat faster than larger ones; thin items will lose heat and gain heat faster than bulky ones. A thin and flat item such as a plaice fillet has a higher surface area to mass ratio than a bulkier product such as a chunky cod loin. It follows then, that it takes less energy to cool a small, flat item to its core than it does to cool a large, bulky one, but once the target core temperature has been reached, the bulky item will hold its temperature for longer than the thin one.

In practical terms, this means that smaller items such as fillets or prawns can be cooled quite quickly by refrigeration or immersion in flaked ice, but they will need to be constantly held in a temperature controlled environment that is managed to maintain the target temperature. The discipline of steeping product in ice or transferring it directly from the production line to chilled storage conditions in-between processing steps is of paramount importance in maintaining the maximum quality and freshness of the product. Good Manufacturing Practice is a major factor in maximising product quality as mechanical processes, manual handling, immersion in process water and exposure to factory floor operating temperatures can produce rapid rises in product temperature which in turn accelerates the spoilage processes.

Sub-zero chilling (super-chilling)

In recent years, there has been research into the means to further exploit the linear relationship between spoilage rates and temperature through the use of technologies that aim to hold product just below zero degrees Celsius, but without the product becoming solid through the change of water to ice crystals within the cell structures. There is a narrow temperature range at which this is possible, typically between zero and -1.5°C for many white fleshed species, with -0.9°C the target temperature. As well as shelf life extension and quality optimisation, another apparent advantage of sub-zero chilling is the redundancy of the need to use ice in transport, thereby enabling more product to be shipped instead of paying to transport ice.

Claims of total shelf life extension between four and seven days have been made by commercial businesses specialising in the sale of sub-zero chilling technologies, but extensions of this order would only be possible if the sub-zero temperature regime could be maintained for the entire lifecycle of the product. Once removed from the sub-zero chilled regime, normal rates of spoilage will ensue dependent on the new temperature conditions.

Hygiene

Because fish are naturally laden with bacteria and enzymes, spoilage is an inevitable consequence once the animal has died. Whilst some preservation technologies such as freezing and cooking may be able to effectively halt these deterioration processes, for fresh fish, we must rely almost entirely on temperature control and good hygiene and handling practices to assure optimal quality and maximised shelf life. Good temperature control is a means of reducing the growth rates of the intrinsic microflora on the fish, good hygiene and handling practices are means of preventing or limiting the addition bacterial loading of the product through contamination with bacteria present in the storage, distribution and processing environments.

Particular attention should be paid to any areas to which the fish has direct contact. These include:

- Boxes and kits – all fish containers must be kept clean; they should be stored under cover in clean and dry conditions prior to use and cleaned after use.
- The manufacturing environment - any fish contact surfaces such as conveyors, tools and other equipment should be kept clean, with working debris removed on a regular basis and full chemical clean-downs carried out after or before use.
- Food handlers and their Personal Protective Equipment (PPE) – food handlers should always wash their hands before handling food and wear gloves and overalls which must be kept clean and changed on a regular basis.
- Packaging materials – these should be stored in a clean and dry condition in sealed outer containers until use.
- Ice and water – this should be made from potable (drinking quality) water and stored in clean containers until use.

Microbiological testing

When discussing the freshness and quality of seafood, aspects of food safety must also be considered, especially in the determination of safe shelf-life.

From 1st January, 2006, a new package of food hygiene rules (Regulation 2073/2005) replaced a number of

existing pieces of legislation. Guidance on Regulation 2073/2005 from the Food Standards Agency can be found at the following link:
https://www.food.gov.uk/sites/default/files/multimedia/pdfs/ecregguidmicrobiolcriteria.pdf

The Regulation applies to all food business operators involved in the processing, manufacturing, handling and distribution of food, including retailers and caterers. Most primary producers are at present not directly affected, as specific microbiological criteria have not been set for primary products, other than sprouted seeds and live bivalve molluscs, echinoderms, tunicates and gastropods.

Food business operators must ensure that foodstuffs comply with the relevant microbiological criteria and to comply with the regulation fully, they must also take the required action if a product is found to fail any of the criteria.

Two types of microbiological criteria were introduced:

- Food safety criteria

These criteria should be used to assess the safety of a product or batch of foodstuffs. These apply throughout the shelf-life and if they are not met, the food business operator will not be able to place the food on the market or will need to remove it from the market, and in some cases, a product recall may be required. The food safety management procedures should also be reviewed to ensure the products are likely to comply in the future.

The routine microbiological testing of manufactured products may form part of this assessment, but it is the responsibility of food business operators to consider in what circumstances it is appropriate to use microbiological testing to demonstrate compliance with the criteria. Except for carcasses, minced meat, meat preparations and mechanically separated meat, where harmonised minimum sampling frequencies are specified, the Regulation does not require food business operators to carry out routine microbiological testing or to wait for the results of any testing carried out before the food is placed on the market. The criteria should be used to ensure that the food safety management procedures are functioning correctly, for example, where food safety management procedures based on Hazard Analysis and Critical Control Point (HACCP) principles and good hygiene practice are in place. The routine monitoring of physical parameters (such as time/temperature profiles, pH, level of preservative and water activity) may provide adequate assurance that the criteria are being met. Evidence that the business is following guidance from the Food Standards Agency, Local Authorities or industry guides to good practice can also help demonstrate compliance.

- Process hygiene criteria

These criteria help show that the production processes are working properly. These apply throughout every stage of manufacturing and handling. If a process criterion is exceeded this should lead to a review of current procedures to improve product hygiene.

Because bacteria are microscopic, it is not always possible to tell whether or not a surface or process is microbiologically clean. Even tools, equipment and surfaces which appear to be clean on the basis of a visual inspection may harbour residual levels of bacteria which could be transferred to any product that comes into contact with it. It is advisable for food manufacturing operations to take the advice of a hygiene specialist to ensure that the correct cleaning chemicals are being used (and at the right concentrations and application methods) to ensure effective cleaning. It is also useful to carry out regular microbiological swab testing of the environment and equipment post-hygiene or pre-production to ensure that cleaning processes have been effective in removing bacteria.

Advice on cleaning services and microbiological product and swab testing can be found at the numerous hygiene specialist businesses and laboratories that offer their services to the industry.

Establishing the shelf life of fresh fish products

Many different factors will affect the quality and safety of food, and as such, there is no simple answer to how long a shelf-life should be. There are good practice guides available for food business operators to follow which will help them to accurately estimate, set and validate the shelf-life of foods, such as the Campden BRI Guideline Number 46 – Evaluation of Product Shelf Life for Chilled Foods (2004). Businesses that are unsure about setting and validating the shelf life of their products should consult such a guide or take expert advice.

In estimating and setting shelf-life, the primary objective should be to ensure food safety. If the shelf-life is too long or food business operators assume that food is going to be produced, distributed and stored under unrealistic conditions, then there is an increased risk of food safety issues arising, potentially resulting in people becoming ill.

With this in mind, shelf-life should always be an integral part of a food business operator's procedures, based on HACCP and good hygiene practice and should always take into account, reasonably foreseeable conditions of distribution, storage and use of the food including consumer practices in the home. The method used to determine the shelf life should therefore take into account:

- The age and quality of the raw materials used at the point of manufacture of the goods.
- The expected temperature and storage conditions of the product whilst in distribution, up to and including those within the consumer's home.

The samples used should be taken from standard production so as to represent typical product as manufactured. These representative samples should be held in storage temperature conditions which replicate those during the entire shelf life; taking into account that temperatures during haulage, storage, at point of retail sale and in domestic refrigeration may be different. Product should be tested at an accredited microbiology lab on the day of manufacture and subsequently, each following day until the microbiological counts reach the maximum advised levels.

Product should be tested for a range of bacteria which may be used to indicate product age/spoilage and cross-contamination through typical storage and handling processes. Given the wide variety of fresh fish product types and the multiplicity of supply chains, food businesses should take advice from professional microbiological laboratory service providers or a trained microbiologist on which organisms to test for and what would represent a safe maximum limit for each of these.

Duplicate samples should be tested each day using a sensory assessment method to ensure that the quality and freshness of the product is maintained at an acceptable level for the consumer even at the end of shelf life.

Summary

The fundamental means of managing the quality and freshness of fresh fish and seafood products have not changed for many generations. The most important aspects have been and will probably always be, the management of time and temperature. We may have improved our technical capability to manage temperature through refrigeration and ice making technologies, and temperature control throughout the whole supply chain from catch to point of sale can be maintained more effectively – but our expectations of shelf life in the retail environment and in the home, have also changed, and we expect longer shelf lives than ever before.

The trade-off between maximised freshness and maximised shelf life is inevitable, and each business will need to determine their priorities to meet customer expectations of their product. Optimising storage and handling conditions is essential in either case to ensure that product reaches the market in its best possible condition, irrespective of the shelf life aspiration or the length of the supply chain.

Without technical intervention through such means as the use of additives and processing aids, fish will always deteriorate in a linear relationship with the temperature that it is held at. For a manufacturer to maximise the shelf life that is offered to the downstream user, there are three variables that can be controlled:

a) Post-harvest age (days on ice) of the fish at point of processing;
b) Time and temperature profiles during processing, packing and distribution;
c) Hygiene and good manufacturing practice.

Unless exceptional abuse has occurred, the best quality fish will be that with the shortest shelf life from point of capture. Temperature control cannot restore lost quality, but it can maximise storage life by slowing down the natural microbiological and enzymic changes that take place in any animal post-mortem; this means that temperature control and hygienic practices are the most important aspects of ensuring that shelf life and freshness are maximised.

References & further reading

- FAO - Post mortem changes in fish; http://www.fao.org/docrep/v7180e/v7180e06.htm
- FAO – Non -sensory assessment of fish quality; http://www.fao.org/wairdocs/tan/x5990e/x5990e01.htm
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- FAO – The handling of wet fish during distribution; http://www.fao.org/wairdocs/tan/x5884e/x5884e01.htm
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- COMMISSION REGULATION (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs
- COUNCIL REGULATION(EC) No 2406/96 of 26 November 1996 laying down common marketing standards for certain fishery products
- Food Standards Agency - Guidance on Regulation 2073/2005 https://www.food.gov.uk/sites/default/files/multimedia/pdfs/ecregguidmicrobiolcriteria.pdf
- International Commission on Microbiological Specifications for Foods - Microorganisms in Food, Use of Data for Assessing Process Control and Product Acceptance (Springer, 2011)
- CCFRA Guideline Number 46 – Evaluation of Product Shelf Life for Chilled Foods (2004, Campden BRI)
- The Preservation of Fishery Products for Food, Charles H Stevenson, 1899
- Information on training courses in seafood quality:
  - http://seafoodacademy.org/Topics/1Topic%20Quality%20Assesment.htm
  - http://seafoodacademy.org/SeafoodQualityAssessment.html

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