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FRESHNESS ASSESSMENT OF HERRING STORED IN ICE USING DIFFERENT METHODS

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ABSTRACT

Atlantic herring (*Clupea harengus*) was stored in ice for up to 2 weeks. Changes during storage were observed by different sensory methods: the Quality Index Method (QIM), Torry scheme, and Quantitative Descriptive Analysis (QDA); texture measurements: puncture tests and Texture Profile Analysis (TPA) tests on texture analyser TA.XT2i; and electronic nose measurements using FreshSense instrument. Shelf life of herring in ice could be predicted by QIM with ± 2.5 days using 5 herring per lot. High correlation between Torry scores and storage time was found. The QDA attributes greatly changed after 8 days of storage, which was the maximum storage time for human consumption. No correlation between instrumental texture parameters and storage time or between sensory and instrumental texture parameters was found. Electronic nose measurements could be used to detect the onset of spoilage.

Key words: herring; sensory evaluation; freshness; shelf life

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1. INTRODUCTION

Freshness of fish and fish products is an important part of product quality and is of great concern in the fish sector and fish inspection service (Martinsdottir 2002, Martinsdottir *et al.* 2000). Sensory evaluation is the most important method of freshness measurements nowadays. There has been a trend to standardise sensory evaluation to make it an objective measurement to assess freshness (Olafsdottir *et al.* 1998). The Quality Index Method (QIM) is a promising method to measure the freshness of whole fish stored in ice, and is both rapid and reliable (Martinsdottir *et al*. 2001). To evaluate sensory attributes of cooked fish, it is common to evaluate cooked fillets by Torry schemes, which provide scores correlating to storage time (Martinsdottir *et al*. 2001, Huss 1995). In research, Quantitative Descriptive Analysis (QDA) is used for cooked fillets to establish a detailed description and quantify product sensory aspects (Stone and Sidel 1985).

Besides sensory methods, various techniques have been studied to monitor fish freshness. Changes in texture of fish during storage have been measured by texture analysers for several fish such as farmed salmon, cod and haddock, and correlation with sensory texture attributes and storage time were found (Sveinsdottir *et al.* 2002, Tryggvadottir *et al.* 2001, Tryggvadottir and Olafsdottir 2000).

Recently, gas sensors or "electronic noses" have been employed for the rapid detection of volatile compounds formed by the degradation of food composition as indicators of freshness or quality (Olafsdottir *et al.* 1998).

In Vietnam, it is common to assess the freshness of fish by sensory, chemical and microbiological analysis. Different sensory methods are used (e.g. methods based on EU scheme, structured scaling, etc.), but QIM is still not familiar in practice. The application of instrumental methods using texture analysers or electronic noses is also rare. Better understanding of the application of the Quality Index Method and other methods of sensory assessment, and in assessing freshness by instrumental methods would offer a new prospect for fisheries production quality management in Vietnam.

Herring is an important commercial fish (Stroud 2001). Total world catch of herring in 2000 was 2.83 million tons (FAO-Fishstat Plus 2002). Herring is also a common fish species in Vietnam (Fishbase 2002; Vietnam-Camaupage 2003). This fat fish species is used for producing many delicacy products such as salted, kippers, marinated, canned in oil etc. (Stroud 2001), however a large proportion of the herring catch is used for production of meal and oil for animal feed (Underland 1998). Due to climatic condition, there was a decline in world marine capture production (FAO 2003a). Fish production does not meet the increasing demand due to human population increases and increased incomes (Pauly 2002, FAO 2003a). There has been a trend to increase the proportion of herring for human consumption: from 57-64% in 1991-1993, to 74-75% in 1994-1996, and 82-86% in recent years of the total catch in the Northeast Atlantic (Herring network 2003). Based on these facts, herring is used as a subject of this study.

The aim of conducting this project was to become familiar with the freshness assessment methodology involved in using QIM, Torry Scheme, QDA; texture analyser and electronic nose, and to find out the correlation between the methods and how they can be used to estimate the shelf life of herring stored in ice.

2. LITERATURE REVIEW

2.1 Herring

Atlantic herring (*Clupea harengus*) caught off Britain, Norway and Iceland is 23-36 cm long, sometimes more; and weighs approximately 100-400 g. The weight for a given length can vary considerably from season to season and from year to year (Stroud 2001).

2.1.1 Handling and transporting herring

Handling at sea

Herring is a highly perishable fish, therefore rapid cooling and careful handling are very important to keep it fresh for human consumption. The fish is normally not gutted at sea. It is often chilled or frozen whole soon after capture.
The traditional method of chilling herring on board is in ice. The fish is stowed in boxes with layers of ice above, below, and some among the fish. The ratio of ice to fish should be about 1:3 in summer. If the catch is of large quantity, herring is sometimes stowed in bulk in the fish-room with or without ice. Sometimes the fish is not iced adequately, and some of the fish might be damaged in deep bulk stowage (Stroud 2001).
An alternative method of chilling is stowage in fixed tanks with refrigerated seawater (RSW) or portable tanks containing ice and seawater (CSW). Herring stored in tanks keeps as well or better than in ice for the first 3-4 days, but then it starts to spoil more quickly (Stroud 2001, Kelman 2001).
Storage time depends on the fat content of the fish and the amount of food in the gut. Herring with high fat content will keep for a shorter time than with low fat content (Stroud 2001). Shelf life in ice for fat (summer herring) and low fat (winter herring) fish is 2-6 and 7-12 days, respectively (Huss 1995).

Handling on shore

For long lorry journeys, the fish should be well iced. The ratio of ice to fish should be about 1:3 for long trips in warm weather, especially if the lorry is not insulated. A mixture of ice and salt is sometimes used to lower the temperature of the fish and thus reduce spoilage during long journeys. This treatment is called “klondyking”, and also used for transhipments consigned by sea on carrier vessels to land (Stroud 2001).

2.1.2 Chemical composition

The chemical composition of herring varies considerably with the season and the breeding cycle. The fat content of herring may be less than 1% (right after spawning), or more than 20% (before spawning season).

Table 1 shows the water, fat and protein content of herring.

Table 1: Chemical composition of herring (Burt and Hardy 1992, Stroud 2001).

	Water %	**Fat %**	**Protein %**
Whole herring	60-81	1-24	17-21
Herring flesh	57-79	0.8-24.9	14-17

There is correlation between the water content and fat or protein content of herring (Figure 1 and Figure 2). Therefore, it is possible to estimate fat and protein content of the fish based on its water content (Stroud 2001, Kent *et al.* 1992).

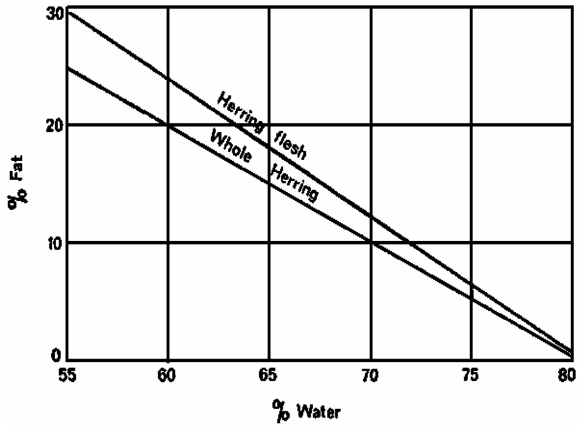

Figure 1: Fat content of herring (Stroud 2001).

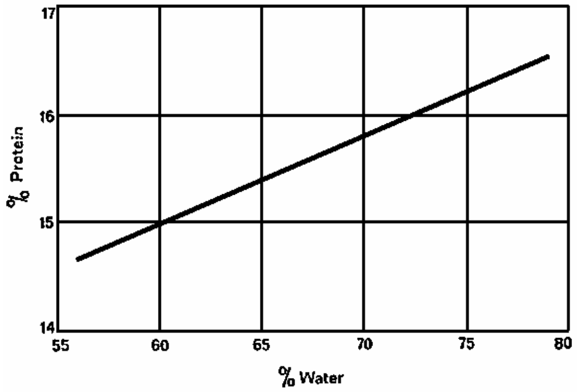

Figure 2: Protein content of herring (Stroud 2001).

In herring, the fat is mainly in the flesh. Raw flesh of a moderately fat herring, containing 11% fat, has an energy value of about 7.4 kJ/g (Stroud 2001). Herring lipid is rich in n-3 fatty acids such as eicosapentaenoic acid (EPA, C20:5) and docosahexaenoic acid (DHA, C22:6) which have positive effect against cardiovascular disease, cancer, etc. (Underland 1998, Burt and Hardy 1992). Herring is also rich in minerals (e.g. iron, calcium and iodine) and vitamins (
Table 2).

Table 2: Vitamins in herring flesh mg/kg (Stroud 2001).

A	D	B vitamins						
		Thiamine	Riboflavin	Niacin	B_6	B_{12}	Pantothenic acid	Biotin
6-120	7-25	0.1-1.3	0.9-3.3	20-63	3.5-4.2	0.08-0.14	9.3-9.7	0.09-0.16

2.2 Sensory evaluation

"Sensory evaluation is defined as the scientific discipline used to evoke, measure, analyse and interpret reactions to characteristics of food as perceived through the senses of sight, smell, taste, touch and hearing" (Huss 1995, p.130).

Sensory evaluation performed in a proper way is a rapid and accurate tool providing unique information about food. It offers immediate measurement of perceived attributes and provides useful information for a better understanding of consumer responses (Martinsdottir *et al.* 2001).

The analytical objective test used in quality control can be discriminative or descriptive tests. Discriminative tests are used to determine if a difference exists between samples such as triangle test, ranking test, while descriptive tests are used to determine the nature and intensity of the differences such as Quantitative Descriptive Analysis (QDA). Assessment in quality control must be objective (Huss 1995).

Subjective tests are based on a measure of preference or acceptance. They can be applied in the fields such as market research and product development where the reaction of the consumer is needed (Huss 1995).

It is necessary to establish a sensory panel or trained inspectors to perform sensory analysis on the daily production in the fish sector. To get reliable results, assessors must be trained and have clear and descriptive guidelines and standards (Martinsdottir *et al.* 2001).

2.2.1 Quality Index Method (QIM)

The QIM method was originally developed by the Tasmanian Food Research Unit in Australia (Bremner 1985), and has been developed further by European fisheries research institutes. QIM is based on well-defined characteristic changes of raw fish occurring in outer appearance of eyes, skin and gills; in odour and texture. QIM uses the system of scores from 0 to 2, or 0 to 3 demerit (index) points depending on the weight of each attribute. Descriptions of each score for each parameter are given in the QIM scheme. The scores for all the characteristics are summarised to give sensory score called Quality Index. QIM gives scores close to zero for very fresh fish while increasingly larger totals result as the fish deteriorates (Huss 1995, Martinsdottir *et al.* 2001). QIM Schemes have been developed for various species of fish including Atlantic herring (*Clupea harengus*) (Jonsdottir 1992; Martinsdottir et al. 2001). One of the unique advantages of QIM is that the Quality Index increases linearly with storage time in ice, so the information may be used in production management (Martinsdottir *et al.* 2001). QIM can be used to estimate storage time in ice, remaining shelf life and Torry-scores of cooked fillets. Shelf life of fish is the period which it can be stored until becoming unfit for human consumption. Spoilage due to microbiological activity is the main limitation of the shelf life. Fish (especially, fat species) may also spoil because of lipid oxidation that leads to rancidity. Estimated storage time in ice is the number of days that the fish has been stored in ice. The remaining shelf life (= shelf life - estimated storage time) is affected by various factors such as the handling of the fish, rapid cooling after catch and uninterrupted cold storage, different fishing gear, bleeding and gutting methods, the season and catching ground, etc. Therefore the estimation should be used with caution (Martinsdottir 2002).

In the EU-project Development and Implementation of a Computerised Sensory System (QIM) for Fish Freshness, a linear relationship between the Quality Index (QI) and storage time in ice has been found for studied species. There is a high correlation between QI and storage time, e.g. $R^2 = 0.986$ for haddock; 0.965 for cod. As for herring, it is lower ($R^2 = 0.740$). A linear relationship was also found between QI of raw material and Torry score of cooked fillets (haddock and cod from two seasons) (Martinsdottir *et al.* 2001, Martinsdottir 2002). *Sveinsdottir et al.* (2002) reported that by assessing three salmon per lot, storage time may be predicted with ±2.0 days at 95% significant level, but examining greater number of salmon per lot might increase the precision. Larsen *et al.* (1992) reported that when using an average of the assessors' scores it is possible to predict the remaining storage life of the fish within ± one day.

2.2.2 Torry Scheme

The Torry scale, which is used to evaluate the freshness of cooked fillets, is a descriptive 10-point scale developed at the Torry Research Station. This scale has been developed for lean, medium fat and fat fish species. Scores are given from 10 (very fresh in taste and odour) to 3 (spoiled). It is considered unnecessary to have descriptions below 3, as the fish is then no longer fit for human consumption (Martinsdottir *et al.* 2001). At the Icelandic Fisheries Laboratories (IFL) the average score of 5.5 has been used for most of fish species as the limit for consumption. Then the members of the sensory panel detect evident spoilage characteristics, such as sour taste and hints of "off" flavour (Martinsdottir *et al.* 2001). As for herring, at the score of 7 there are some hints of off-flavour (Appendix 1), so that 7 may be used as the limit score for human consumption.

Results of assessment of cooked redfish have shown that there is a linear relationship between Torry score and storage time in ice for both flavour and odour with the correlation of 0.97 and 0.95, respectively (Mausse *et al.* 2000).

2.2.3 Quantitative Descriptive Analysis (QDA)

QDA is a technique used to define the sensory attributes of food such as texture, odour and flavour. It provides a detailed description of all attributes both qualitative and quantitative. A trained panel is handed a broad selection of reference samples and use the samples to create terminology that describes all detectable aspects of the product under guidance of a panel leader (Huss 1995, Stone and Sidel 1998). The words used to describe the perception are labels without implying any causality (Stone and Sidel 1998). The concepts are listed and used to evaluate the product using an unstructured scale for each concept to quantify the attributes. Panel members are trained to use the scale before performing the sensory analysis (Stone and Sidel 1998). The panel leader is responsible for selecting the product that will be evaluated in each session, facilitate the discussion and assist where there is conflict or disagreement about a particular wording. Choosing people that know the product too well should be avoided (such as producers) as they may provide what is believed to be the expected response, rather than what was perceived (Stone and Sidel 1998).

Sveinsdottir *et al.* (2002) reported that in Quantitative Descriptive Analysis the words used to describe the odour and flavour of the fish can be grouped into "positive sensory parameters" and "negative sensory parameters", depending on whether they described fresh fish or fish at the end of the storage period.

2.3 Texture measurements

Texture is an extremely important property of fish muscle for both raw and cooked material as it is a part of quality. Fish may become tough because of frozen storage or soft and mushy due to autolytic degradation (Huss 1995). There are two types of texture measurement tests: measurement by instrument or sensory evaluation by a panel (Bourne 1982).
Various instruments have been developed to measure texture parameters of food, which can carry out reliable objective tests. They may be destructive or non-destructive tests. In food industry texture is often measured by the Stable Micro Systems texture analysers, model TA.XT2i which perform tests in both tension and compression for cycling, flexure, constant strain and stress relaxation (Stable Micro System Ltd. 2002).

Texture profile analysis (TPA)

TPA is a test performed by compressing a bite-size piece of food twice in a reciprocating motion that imitates the action of the jaw, and extracts from the resulting force-time curve a number of textural parameters that correlate well with sensory evaluation of those parameters. The height of the force peak on the first compression cycle (first bite) is defined as hardness. The ratio of the force areas under the first and second compressions is defined as cohesiveness. The distance that the food recovers its height during the time elapsing between the end of the first bite and the start of the second bite is defined as springiness or elasticity (Bourne 1982).

Puncture Testing

The puncture test measures the force required to push a punch or probe into a food. The test is performed by a force-measuring instrument. Penetration of the probe into the food causes irreversible crushing or flowing of the food. The depth of the penetration is usually held constant. Puncture tests were originally developed by Lipowitz in 1861 to measure the firmness of jellies. Later other methods were developed to measure firmness and hardness of food, e.g. a work of Cobb in Australia in 1896. He measured the hardness of wheat grains by measuring the force required to cut a grain of wheat in half (Bourne 1982).

It was found that the instrumental hardness of salmon decreased with storage time in ice. The texture evaluated in QIM (stiffness) was correlated to instrumental texture parameters. Salmon with firm texture according to instrumental texture measurements was assessed firm in QIM (Sveinsdottir *et al.* 2002). Puncture test on deskinned haddock fillets has shown that the firmness value obviously decreased between day one and four of ice storage, and after that this value changed very little. Hardness of haddock fillets also decreased from day one to four but increased again later on during the storage (Tryggvadottir *et al.* 2000). Study on cod has also showed that the overall trend is a decreasing firmness during the first four days, which levels off during extended storage (Tryggvadottir *et al.* 2001).

2.4 Electronic nose

Gas sensor array technology together with multivariate data processing methods is a promising and potential technique for rapid non-destructive analysis of food quality. It may be applicable in quality control of raw material, food processing or products. An “Electronic Nose” is an array of chemical gas sensors with a broad and partly overlapping selectivity for measurement of volatile compounds within the sample combined with computerised multivariate statistical data processing tools (Haugen 2001). Icelandic Fisheries Laboratories and Element Sensor Systems have developed the electronic nose called FreshSense. It is based on a closed, static sampling system and electrochemical gas sensors that are sensitive to the main classes of volatile compounds, namely, alcohol, carbonyls, sulphur compounds and amines, which accumulate because of microbial activity and lipid oxidation during storage of fish (Olafsdottir *et al.* 1998, 2000).

In a study on freshness of iced redfish, it was found that the response of CO-sensor was highly correlated to results of the QIM method for both air storage and storage under modified atmosphere (Olafsdottir *et al.* 2002). The combination of all sensors (CO-, SO_2-, NH_3, and H_2S- sensors) could explain the growth of *Pseudomonas* spp. and H_2S-producers. The SO_2- and H_2S- sensors appeared to give information about H_2S-producers such as *Shewanella putrefaciens* which is a late spoiler in iced stored fish (Olafsdottir *et al.* 2002).

The results of electronic nose measurements of haddock from different seasons showed the same overall trend, the response of all the sensors (CO-, SO_2-, NH_3-, and H_2S sensors) increased during storage (Tryggvadottir and Olafsdottir 2000). The electronic nose measurements can discriminate between samples of haddock heads with different storage time (6, 8, 11, and 15 days). The electronic data for haddock can not be used to discriminate between the first days of storage (1-6 days). However, the measurements can be used to detect the onset of spoilage and can discriminate between days when fish has spoilage signs (8, 11, 13-15 days) similar to results of the heads (Tryggvadottir and Olafsdottir 2000). Studies on cod fillets and cod heads also showed the same overall trend, the CO sensor gave the highest response and the response increased during storage (Tryggvadottir *et al.* 2001).

3. MATERIALS AND METHODS

3.1 Materials

A total of 164 Atlantic herring (*Clupea harengus*) from Vestmannaeyjar (batches 1, 2, and 3) and Neskaupstadur (batches 4 and 5)[1] was used in this experiment. The fish

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[1] There were 5 fish batches used in training and evaluation periods and they were numbered successively according to the catching time. The idea of getting different batches was to have the samples of at least two different storage time at each sensory evaluation session. Batches 1 and 2 were used for training only.

had been stored for about 3-5 days in ice (from catch) in polystyrene boxes or barrels on arrival at the laboratories. Fish was rechecked and put alternately with layers of flake ice. Holes were made in the bottom of the boxes for the draining of melting ice. The boxes were covered with lids and stored in a chill room at temperature 0-2 ^{o}C. Temperature inside the boxes was monitored by electronic thermometer Optic StowAway Temp WTA32 –37+75 241028 (US PAT 5373346) that sent the signal to the computer every 30 minutes. The ice in boxes was checked and added if necessary every three days. Herring was stored up to 2 weeks, and samples were taken every 2-4 days for sensory analysis, texture and electronic nose measurements. Day 0 is the catching day.

3.2 Methods

Figure 3 shows the sampling plan of the study.

Fish from Vestmannaeyjar was from the South Coast of Iceland and stored in RSW. Fish from Neskaupstadur was caught in Vopnafjardargrunnur square 613 and stored in CSW.

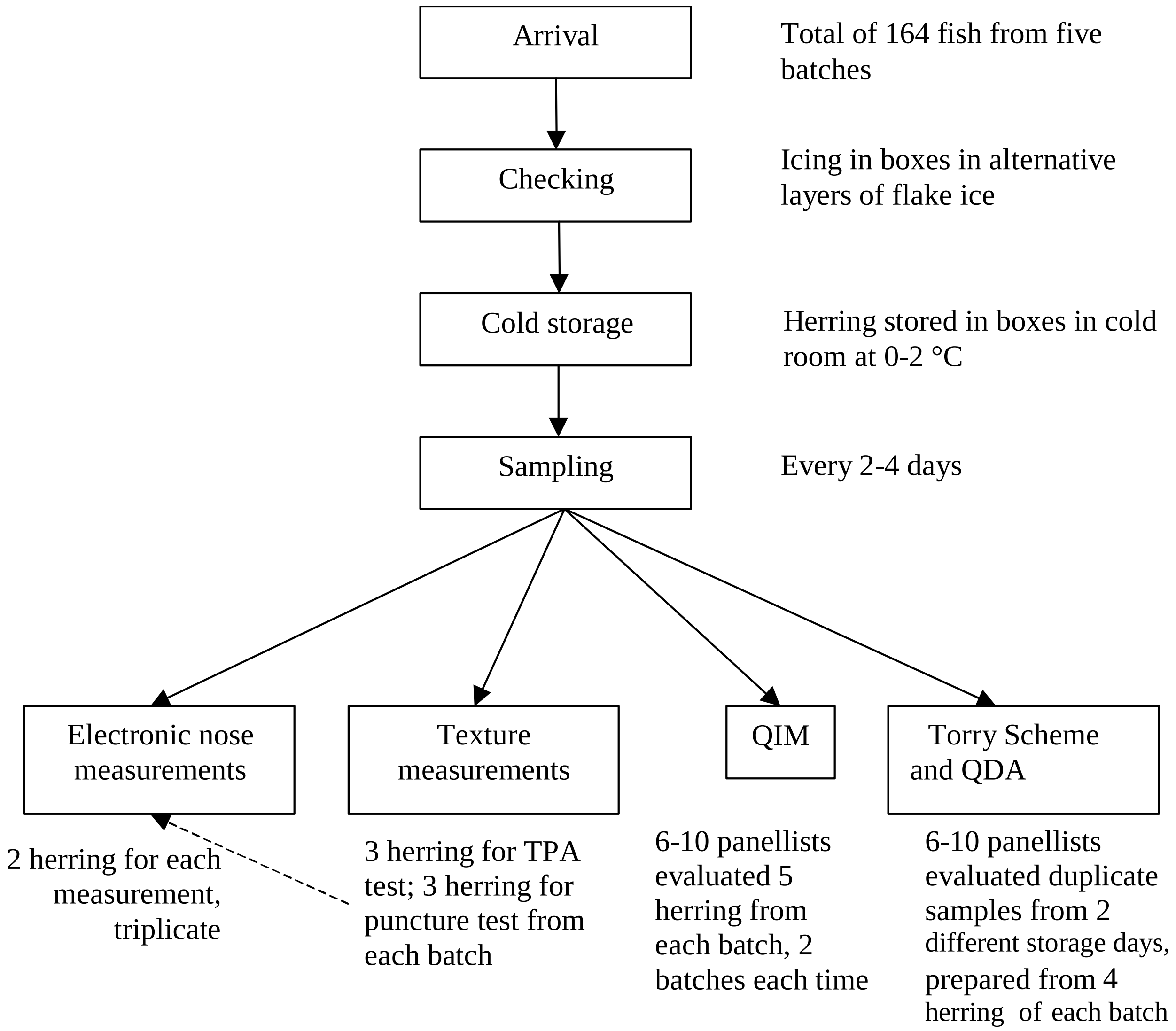

Figure 3: Sampling plan of the study.

3.2.1 Sensory analysis

Prior to the experiment, a panel of 13 judges was trained during one session using QIM scheme for herring (Appendix 3), Torry scheme for herring (Appendix 1), and QDA method (introduced by Stone and Sidel 1985) (Appendix 2). The judges were all employees at the Icelandic Fisheries Laboratories (IFL), had years of experience, and were trained according to ISO 1993. They were used to performing the methods described (QIM, Torry, QDA), using them frequently evaluating fish including herring. The training was to freshen up their skill in freshness evaluation of herring. Six to ten panellists participated in the sensory analysis each time. All sample observations were conducted accordingly to international standard (ISO 1988). The observations were carried out always in the same room (for QIM) or booths (for Torry and QDA), with as little interruption or distraction as possible, at room temperature, under white fluorescent light.

Quality Index Method (QIM)

A total of 48 herring were analysed with QIM during the training and evaluation period.

In the training session, 10 whole fish from 2 different batches (5 fish from each batch) were used. The judges observed herring (the storage time in ice was given) and the scheme was explained to them at the same time.

For the QIM evaluation (5 sessions over 5 sampling days) 5 fish from each batch were used each time, except for day 12 of batch 4 there were 3 herring used. The samples were collected from the iceboxes and placed on a clean table 30 minutes before assessment. Each herring was coded with a random 3 digit number.

Sensory evaluation of cooked herring

Sensory evaluation of cooked fillets was carried out parallel to the QIM evaluation using Torry scheme and QDA. A total of 44 herring was used in training and evaluation sessions (4 fish from each storage day). Fillets were trimmed from belly part and tail part (3-4 cm long), cut to pieces of about 2-2.5 cm long and 2-3 cm wide. Pieces were placed in aluminium boxes and cooked in the electric oven Convostar (Convotherm-German, the oven was preheated) by steam at 95-100 °C for 7 minutes. Each panellist got duplicate samples from 2 different storage days. The samples were coded with random 3 digit numbers.

3.2.2 Texture measurements

Triplicate measurements were applied for six fish from each batch using the Stable Micro Systems texture analyser model TA.XT2i and Texture Expert programme. Six fish were collected from each batch from cold room, placed to polystyrene box with ice. Fish was removed from ice right before measurements. Each fish was measured at 3 different points along the lateral line, the first point was placed about 2-3 cm from the gillcover, and distance between two contiguous points was 2-3 cm (Figure 4). The results were calculated and the averages of the 3 measurements were given as a result for each fish. The tests were the Texture Profile Analysis (TPA) (3 fish) and firmness test (puncture test in compression) (other 3 fish) using Ebonite cylinder probe 10 mm in diameter (P/10) with the following parameters:

- Pre test speed 2.0 mm/s; speed in the sample 0.8 mm/s; past test speed 10.00 mm/s;
- Distance 5.0 mm; force 0.98 N; time 5 seconds.

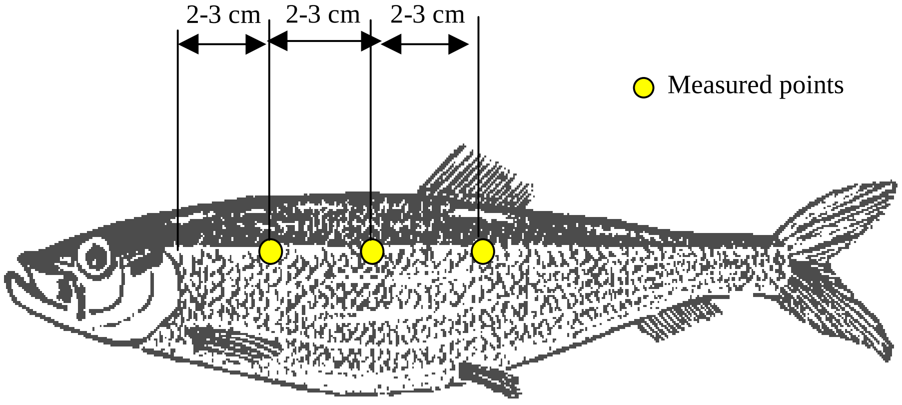

Figure 4: Locations for instrumental texture measurements on herring.

3.2.3 Electronic nose measurements

Triplicate measurements were performed using the FreshSense developed by the IFL and Bodvaki Element Sensor Systems. The small sampling container of 2.3 L was used. The sensors gave responses on CO, SO_2, NH_3, and H_2S compounds. Two fish of about 650-900 g were used for each measurement (the fish were from the texture measurements). Fish was kept on the table for about 30 minutes to warm up to $8 \pm 3^{o}C$ (temperature in the gills) right before measurement. Measurements were taken every 10 seconds for 5 minutes. The reported value is the average of last three measurements of the 5-minute measurement cycle (Tryggvadottir and Olafsdottir 2000, Tryggvadottir *et al.* 2001)

3.2.4 Data analysis

Microsoft Excel 97 was used to calculate means and standard deviations for all multiple measurements and to generate graphs. Texture Expert programme was used to calculate the hardness and firmness of the samples. Data from cooked fish evaluation was treated and collected in FIZZ© (Version 2.0, 1994-2000, Biosystems). Data from different days of cooked fish assessment was analysed by statistical programme NCSS 2000 (PASS Trial 2000) to see if there was any significant difference between the samples, or between judges. Pearson correlation coefficients were used to see if there was any correlation between instrumental texture parameters and storage time, or between sensory and instrumental texture attributes. Multivariate analysis was performed by Unscrambler® 7.5 software package (CAMO A/S). Principle component analysis (PCA) was performed to study the main variance in the data set. Partial least square regression (PLS-R) was conducted to evaluate the possibility to predict storage time with sensory methods and instrumental techniques.

4. RESULTS AND DISCUSSION

4.1 Sensory analysis

4.1.1 Quality Index Method

The Quality Index (QI) was calculated for each storage day of sampling and formed a linear relationship with storage time (Figure 5). Figure 5 also shows the correlation between Torry score and time.

The linear relationship between QI and days in ice was: y = 0.8383x + 4.1009 (x - Days in ice; y - QI). The correlation (R^2 = 0.7596) was higher than the one studied by Martinsdottir *et al.* (2001) (R^2 = 0.740). The slope and intersection are quite different from that recorded (Martinsdottir *et al.* 2001). This may be caused by the difference in the studied materials (catching seasons, catching grounds, fish handling, etc.).

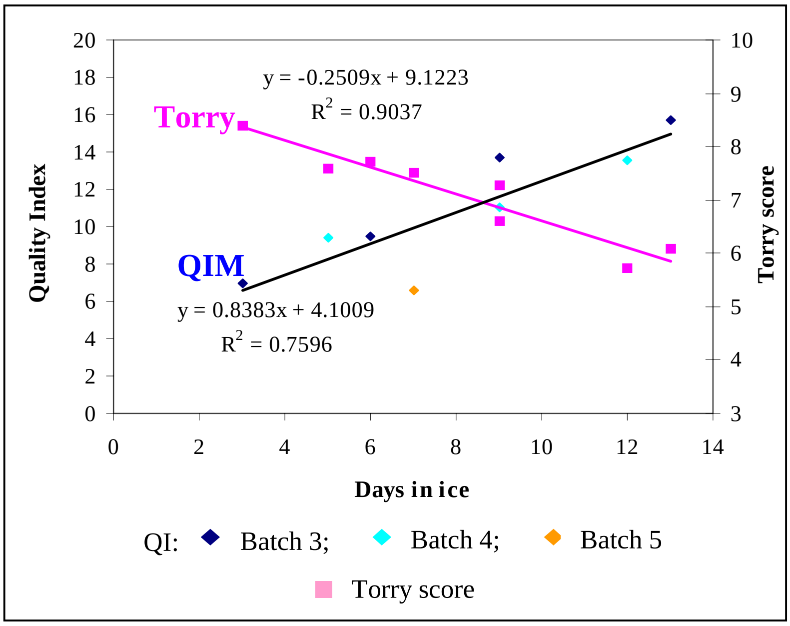

Figure 5: Quality Index and Torry score of herring.

The scores of most attributes increased with the storage time (Figure 6). The low values of most attributes at day 7 may be explained by the difference between the studied batches (in catching areas, chilling on board and handling before arrival at the laboratories). The scores of the attribute “Blood on gillcover” did not increase with storage time as most attributes. This phenomenon can also be observed in Figure 7 where other attributes clustered together with storage time to the right side of PC1 (principle component 1) while “Blood on gillcover” was on the opposite of this PC. It might be because the QIM scheme just gives the scores based on the area of blood on the gillcover, which does not change during storage time. The results could change if the given scores were based on the colour of the blood.

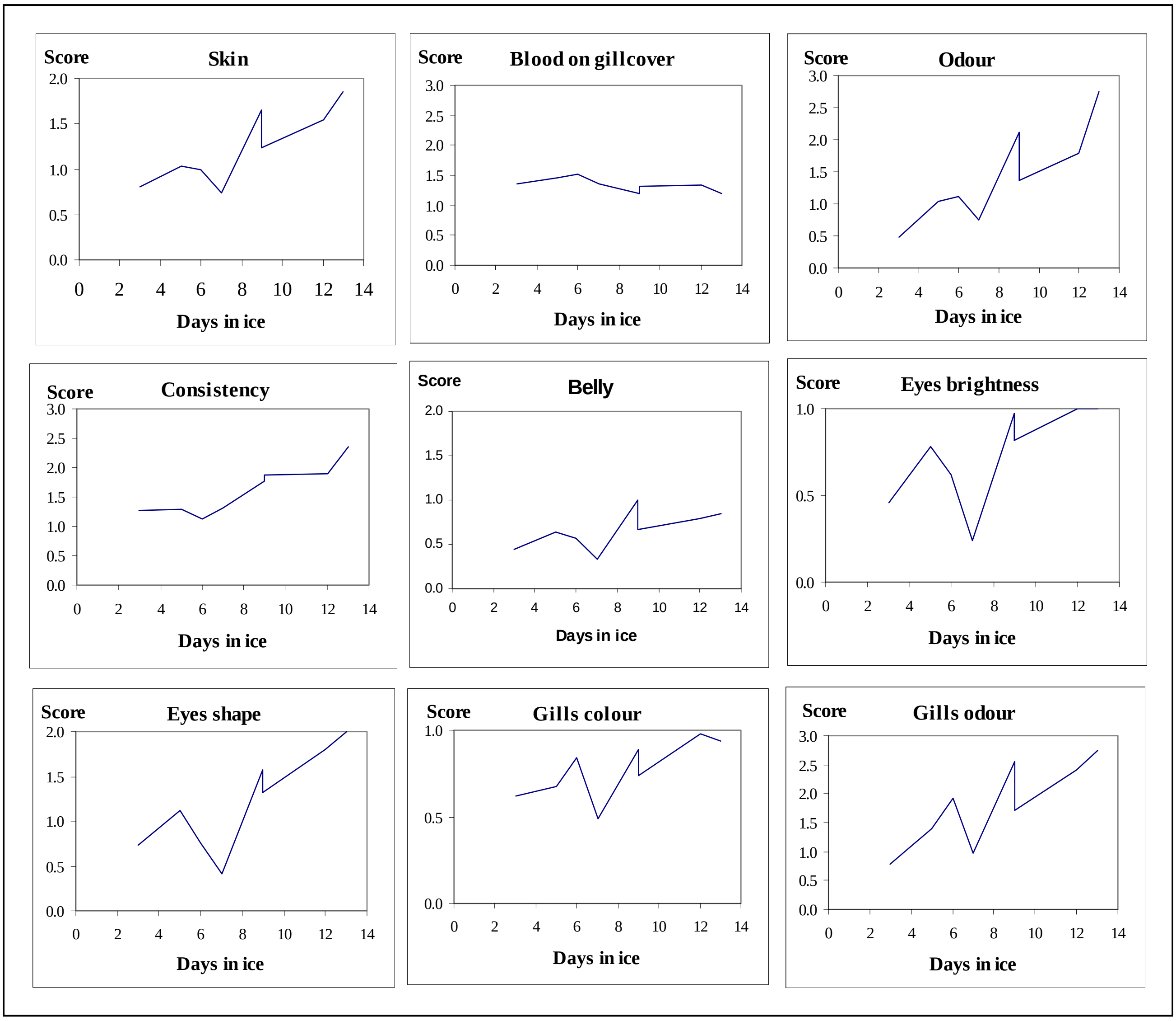

Figure 6: Average scores of each quality attributes assessed with QIM scheme for herring against days in ice.

The scores of the attribute “Belly” (Figure 6) were not close to the maximum value given in the QIM scheme by the end of the storage time. It is possible that the belly had not “burst” (reached maximum score) by the time the whole fish became unfit for human consumption. Therefore it might be better if the maximum score of this attribute is replaced by a higher level of belly softening through storage time.
It was difficult to distinguish the difference between days of storage (after day 8) for the attribute “Gills colour” (Figure 6). Compared to other fish species, the gill colour of herring might change differently by storage time (see also pictures in QIM manual by Martinsdottir *et al.* 2001). It might cause the mentioned difficulty. There was some suggestion from the judges that it would be better if the scheme had higher maximum score (wider range of scores) for this attribute.
This may explain why the QI did not reach its maximum score (20) even when the fish was spoilt.

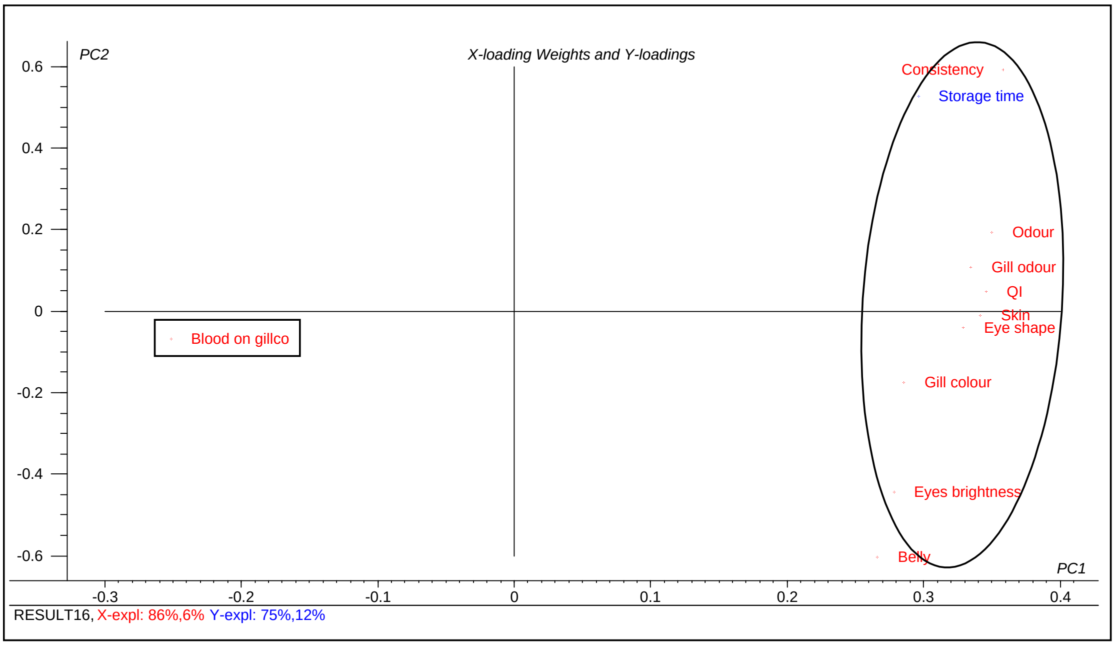

Figure 7: PLS1 loading plot of QIM data from herring stored in ice using full cross validation. Average QI for each storage day based on assessment of five herring.

There was a variation in the QI given by different judges (Figure 8). The variation between panellists appeared to be higher than in a study by Sveinsdottir *et al.* (2002), assessing salmon by QIM scheme using experienced panellists with 2 sessions of 1-hour training. Therefore, the results may be improved by further training.

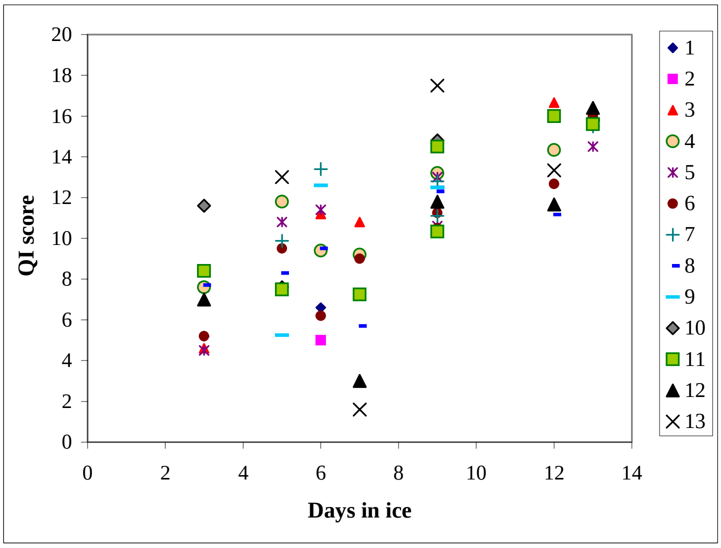

Figure 8: Average QI of herring with storage time in ice, as given by each panellist (1 through 13).

The results were analysed with partial least square regression (PLS) to examine how the QI predicted the storage time in ice of herring (Figure 9). The standard error of performance (SEP) may be used to evaluate the precision of predictability. As QI was the sum of 9 attributes evaluated in the QIM scheme, a normal distribution can be assumed (O'Mahony 1986), therefore 2*SEP could be regarded as a 95% confidence interval (Esbensen et al. 1998). So it can be assumed that the QI (if 5 herring were assessed) could be used to predict storage time with ± 2.5 days. Based on the value of SEP, it is advisable to use 5 herring or more from each batch in the assessment, as using fewer herring might reduce the precision of evaluation and predictability.

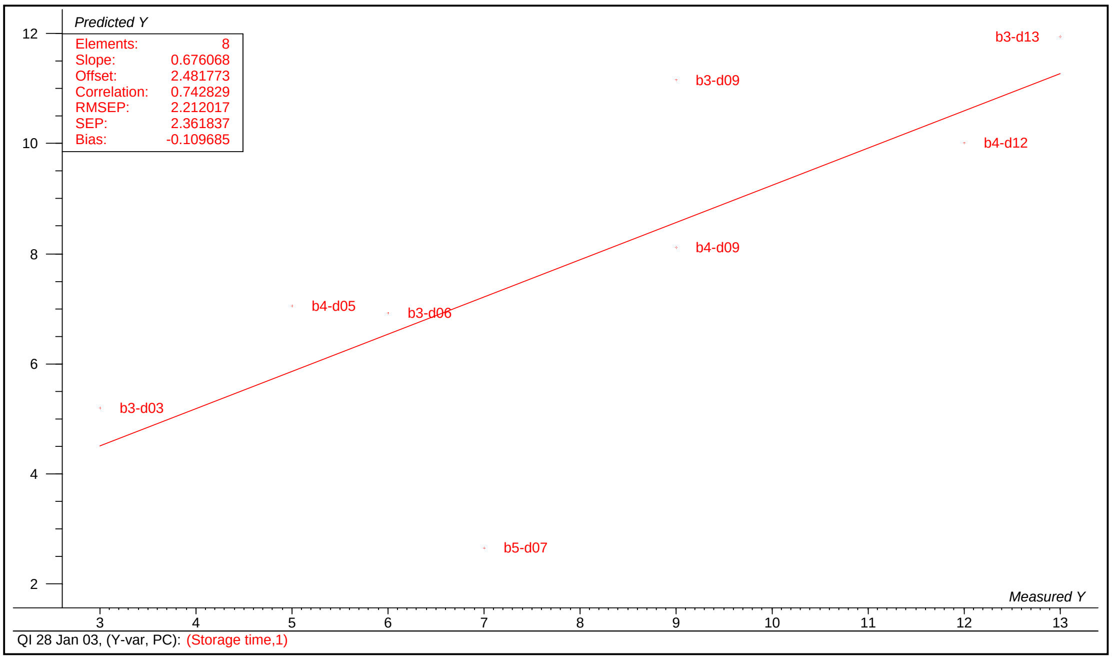

Figure 9. PLS1 modelling of QIM data from herring stored in ice using full cross validation: predicted against mesured Y values. Average QI for each storage day based on assessment of 5 herring used to predict storage time.
Note: "b" stands for batch number; and "d" for days in ice.

4.1.2 Evaluation of cooked fish

There was a high linear correlation between Torry score and storage time, $R^2 = 0.9037$ (Figure 5). At day 9 of storage the scores were around 7 which indicated slightly rancid and sour odour and flavour.

The positive QDA attributes of cooked fillets such as characteristic flavour, firmness, juiciness, and tenderness decreased by storage time, more rapidly after day 8 (Figure 10). Negative attributes such as off-flavour and rancid flavour increased with time, more clearly after day 8 of storage.

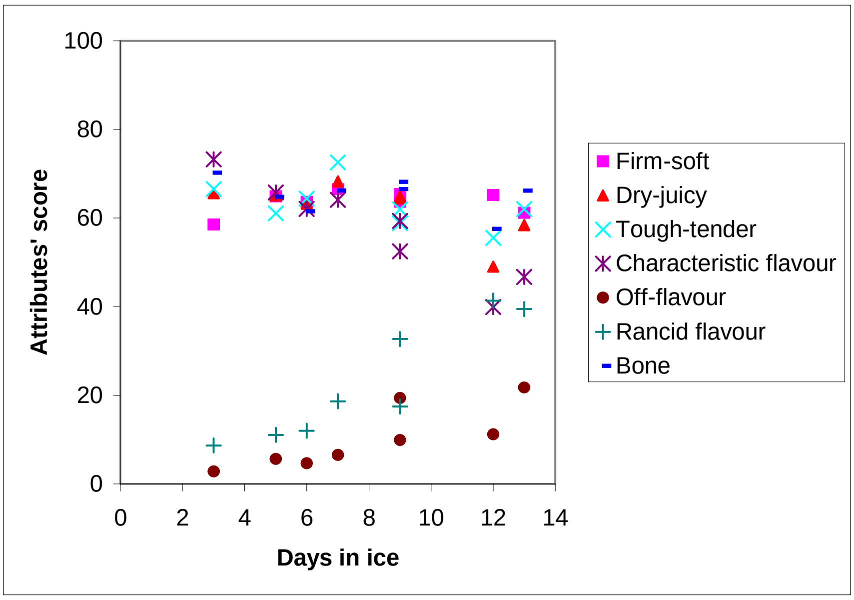

Figure 10: Sensory evaluation of cooked herring (QDA) against days in ice.

The data from QDA supported the results of the Torry scheme that the herring is not fit for human consumption after 8 days of ice storage (Torry score < 7). It is in agreement with the information given in Martinsdottir *et al.* (2001) that the shelf life of herring stored in ice is 8 days.

Characteristic flavour is a clear indicator of fresh herring while rancid flavour is for old fish (Figure 11, Table 3). Off-flavour did not change much until the fish became unfit (Figure 10). No difference between compared days was found (Table 3). It might be because most of off-flavour during storage time was rancid, or the rancid flavour might be so strong that it biased other off-flavour. It is well known that the rancid flavour is caused by secondary products of lipid oxidation (such as aldehydes, ketones, and alcohols) even at very low concentration of them (Underland 1998). The off-flavours are mainly caused by bacterial metabolism. For marine temperate water fish they can be bitter, offensive fishy, rotten, and/or H_2S off-flavours (Gram and Huss 1996) which accumulate at later stages of storage. However, the description of off-flavour should have been discussed in more detail and defined by the panel before the study.

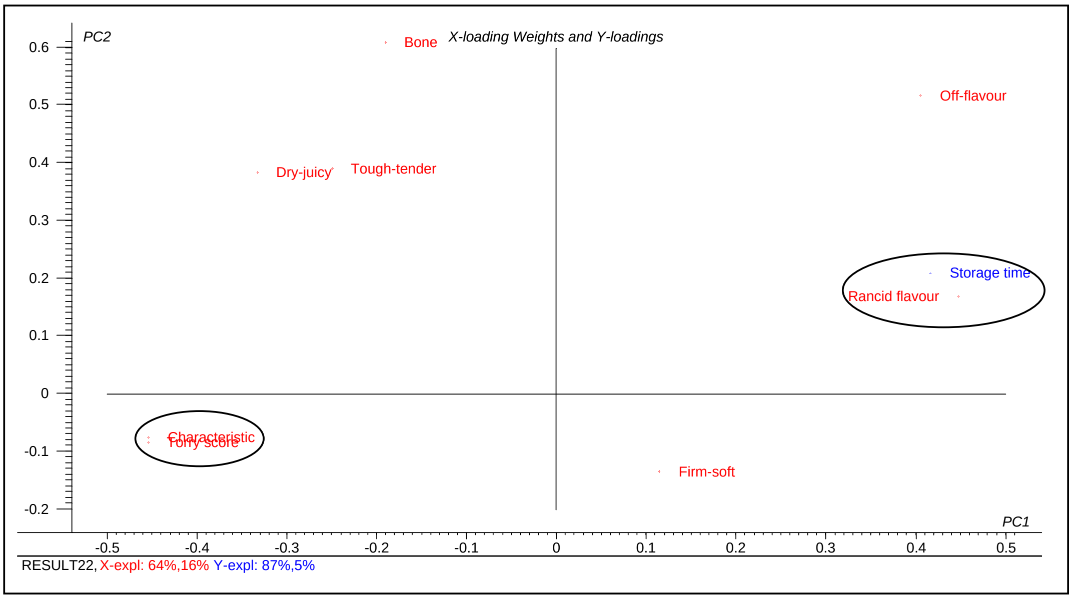

Figure 11: PLS1 loading plot of cooked herring attributes (Torry and QDA) and storage time in ice using full cross validation.
Note: “Characteristic” stands for characteristic flavour.

Table 3: Statistical analysis of Torry and QDA scores of cooked herring using 2-factor design with interaction ANOVA, Duncan’s tests for multiple comparison showing the storage day when difference is significant. “y” indicates a significant difference between judges.

Batch number - Days in ice	**Torry score**	**Texture**			**Flavour**			**Bone**
		Firm-soft	**Dry-juicy**	**Tough-tender**	**Characteristic**	**Off-flavour**	**Rancid flavour**	
b3-d03	**b4-d12*, y***	**b4-12*,y***	**y***		**b4-d12*,y***	**y***	**b4-d12*,y***	**y***
b4-d05	b3-09**,y***	**y***	**y***	**y***	b3-d09*,y*	**y***	b3-d09**, y***	**y*****
	b4-d12*, y*	**y***	**y***	**y***	**b4-d12*, y***	**y***	**b4-d12*, y***	**y***
b5-d07	**b4-d12***, y***	**y*****	**b4-12* y***	**y***	**b4-d12**, y****	**y*****	**b4-d12**, y*****	**y*****
b3-d09	b4-d05**, y***	**y***	**y***	**y***	b4-d05*, y*	**y***	b4-d05**, y***	**y*****
	y*	**y***	**y***	**y***	**b4-d12*,y***	**y***	**y***	**y***
b4-d09	b3-d13*, y**	y*		y*		y**	b3-d13*,y***	
b4-d12	b3-d03*, y*	**b3-03*, y***	y*		b3-d03*, y*	**y***	b3-d03*, y*	**y***
	b4-d05*, y*	**y***	**y***	**y***	**b4-d05*, y***	**y***	**b4-d05*, y***	**y***
	b5-d07*, y***	**y*****	**b5-07*, y***	**y***	**b5-d07**, y****	**y*****	**b5-d07**, y*****	**y*****
	y*	**y***	**y***	**y***	**b3-d09*, y***	**y***	**y***	**y***
b3-d13	b4-d09*, y**	y*		y*		y**	b4-d09*, y***	

Note: * significant at 5%; ** significant at 1%; and *** significant at 0.1%. “b” stands for batch number, and “d” for days in ice. The comparison was conducted only between evaluation days with the same panellists.

Changes in perception of bone were not very clear (Figure 10). No significant difference between storage days was found (Table 3). It seems that the bone got softer with storage time (Figure 11), but this needs to be studied further.

Texture attributes such as firmness, juiciness and tenderness in general were not significantly different between days in ice, except for day 3 (batch 3) and day 12 (batch 4) in firmness; day 7 (batch 5) and day 12 (batch 4) in juiciness (Table 3). It might be because the texture attributes of cooked herring changed less than other attributes according to the panel.

Table 3 shows a significant difference between judges for each cooked fillet attribute. This is a well-known phenomenon in sensory evaluation. The main types of differences among judges may be caused by confusion about attributes, individual differences in the use of the scale, or individual differences in precision (Næs *et al.* 1994). More training might be desirable to improve performance.

The results of cooked fish assessment (Torry and QDA) were analysed with PLS to examine how the storage time in ice could be predicted (Figure 12). As the Torry score and 7 QDA attributes were evaluated, a normal distribution can be assumed (O'Mahony 1986), and 2*SEP could be regarded as a 95% confidence interval (Esbensen *et al.* 1988). Based on these facts, the data from sensory evaluation of cooked herring could be used to predict storage time with ± 2.0 days using duplicate samples.

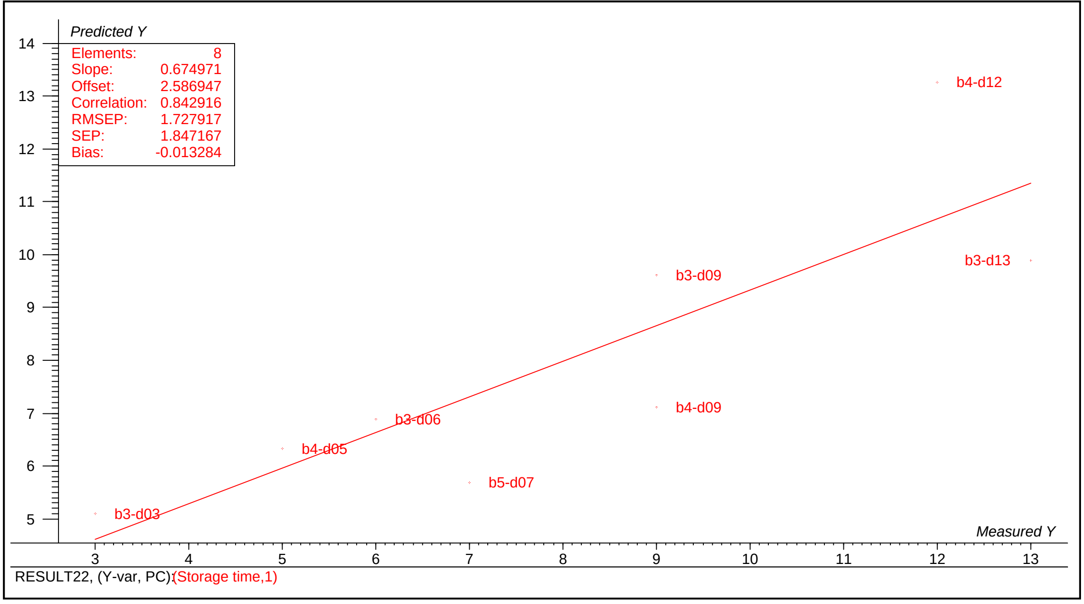

Figure 12: PLS1 modelling of cooked herring attributes (Torry and QDA) and storage time: predicted against mesured Y values.

Note: "b" stands for batch number; and "d" for days in ice after catch.

4.2 Instrumental texture measurements

Hardness and cohesiveness were obtained from the texture profile analysis as the maximum force value and the ratio between the areas, respectively. Firmness was the maximum force value in the puncture test measurements. There was a high variation in the data due to differences between individual fish (Figure 13). Tryggvadottir and Olafsdottir (2000) also reported a great individual variation in destructive TPA test measurements of deskinned haddock fillets.

Batch number 5 appeared to be harder, firmer than batches 3 and 4 (Figure 13), indicating better raw material in batch 5. This is in good agreement with the results from other methods of evaluation in this study, where batch 5 was evaluated or measured of higher degree of freshness. It might be caused by the difference in handling of materials before arrival at the laboratories.

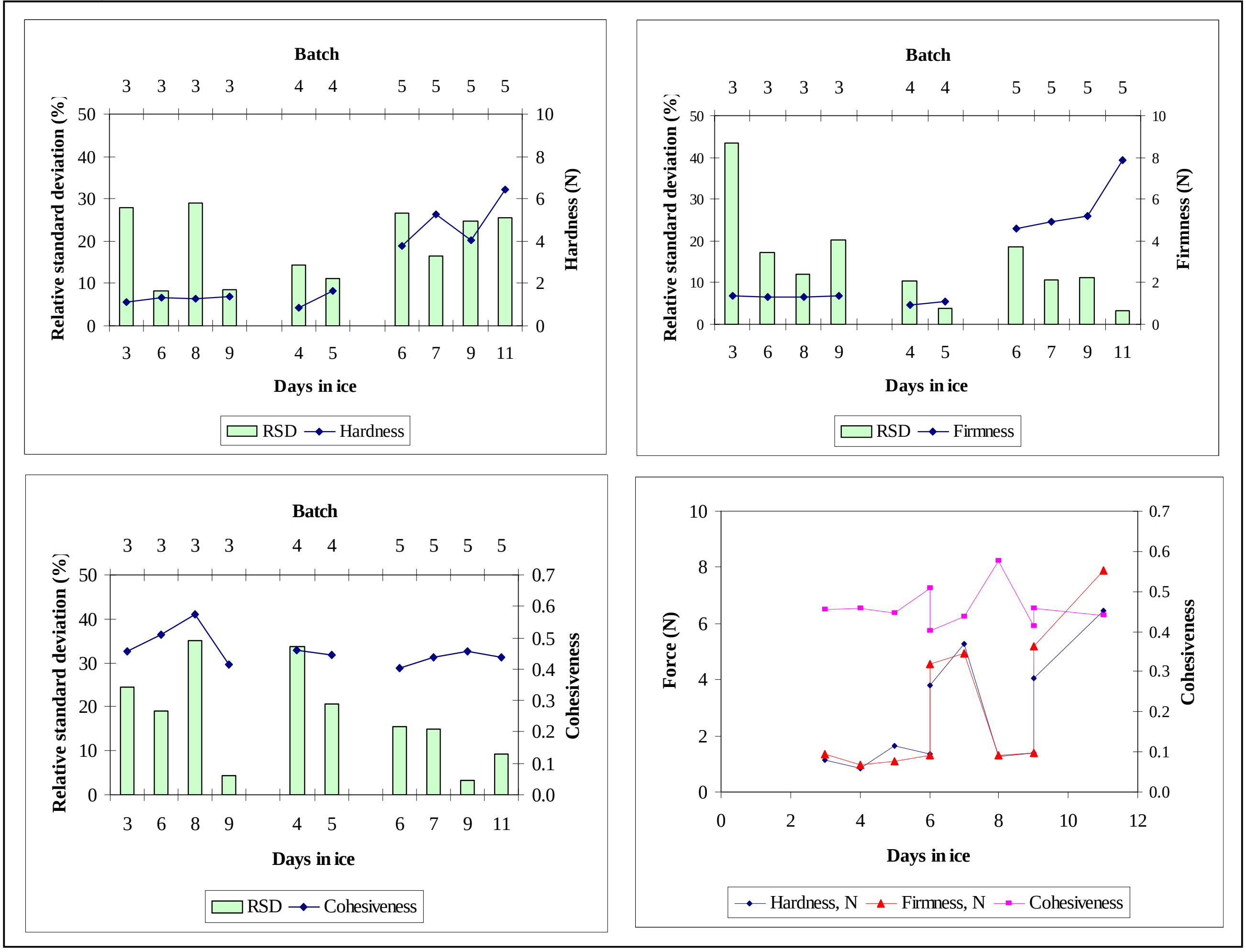

Figure 13: TPA (hardness and cohesiveness) and puncture (firmness) measurements of herring during ice storage.

Note: Each texture value is an average of measurement results from three fish of the same batch. RSD is the relative standard variation between the three fish.

The correlation between instrumental texture parameters and storage time (days in ice) was analysed (Table 4). Computed values were compared to the values for a two-tailed test in table G.16 of O'Mahony (1986) to analyse if a significant correlation between parameters and days in ice existed. Table 4 shows the critical values for degree of freedom 2 and 8, which relate to 4 samples of batch 3 (or batch 5) and 10 samples of all three assessed batches. In Table 4, data from batch 4 was omitted.

Table 4: Correlation between instrumental texture parameters and days in ice

Texture parameters	Computed values of correlation r[a]			Level of significance (p)	Table values of correlation coefficient (for two-tailed test)	
	Batch 3	Batch 5	Batches 3, 4[a] and 5		Df = 2	Df = 8
Hardness	0.8241	0.6959	0.6215	0.05	0.9500	0.6319
Cohesiveness	0.0908	0.6327	-0.0080	0.01	0.9900	0.7646
Firmness	-0.0859[b]	0.8604[b]	0.6511*[b]	0.001	0.9990	0.8721

Note: * - significant at 5%; Df - Degree of freedom.

No significant correlation between instrumental texture parameters and storage time was found except for the firmness of batches 3, 4, and 5. However, it should be noticed that the correlation of firmness and time of batch 3 and 5 were insignificant and controversial, which is negative correlation for batch 3 and positive for batch 5 (Table 4, (b)). It means the significance of positive correlation between the firmness of all three batches and time should be rechecked by more measurements.

4.3 Electronic nose measurements

There was a difference between batches (Figure 14, Figure 15, and Figure 16) when measured with the electronic nose. Batch 3 gave higher responses for all sensors than the other two batches that might indicate some abuse in storing and handling of the material. It should be noticed that herring from batch 3 was caught and delivered from a different place than batches 4 and 5. In a study on cod fillets by Di Natale *et al.* (2001), there was a variation in response of the sensors for different batches due to difference in handling, which caused different spoilage rate. However, Figure 14 and Figure 15 show the overall trend that electronic nose responses for CO, SO_2, NH_3, and H_2S volatile compounds increased during storage time. There was a drop in responses of day 9 (batch 3) for all sensors, that was caused by some disconnection of the container lid when operating the FreshSense. Therefore, data of day 9 (batch 3) was kept out of PCA and PLS analysis.

The measurements were more precise at high values of responses (Figure 14). That means the electronic nose is more precise when used to measured/detect above certain level of volatile compounds (Appendix 5). That phenomenon is quite understandable because the concentration of volatile compounds in fresh fish was under the detection limit of the instrument used.

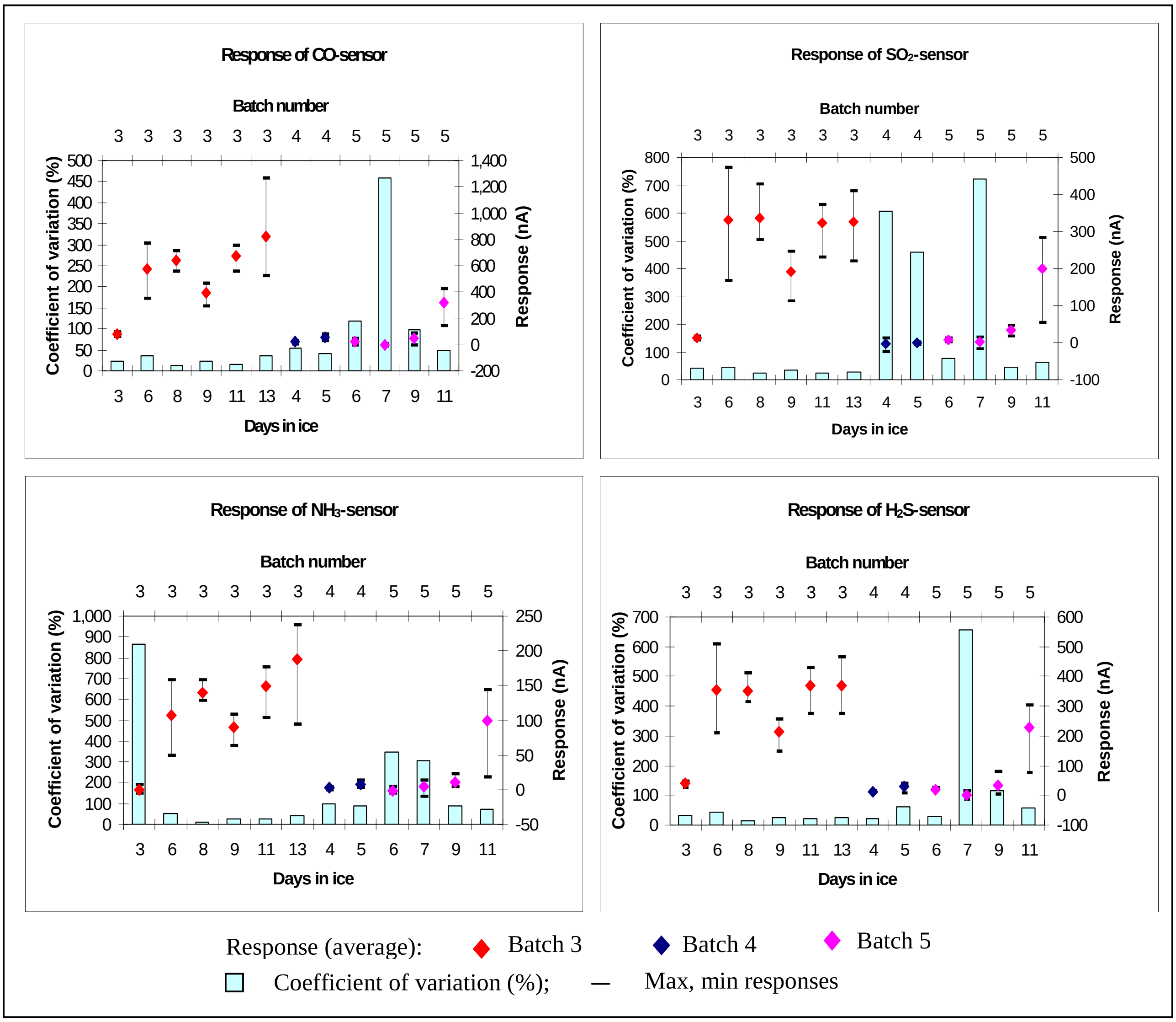

Figure 14: Electronic nose measurements of herring stored in ice.

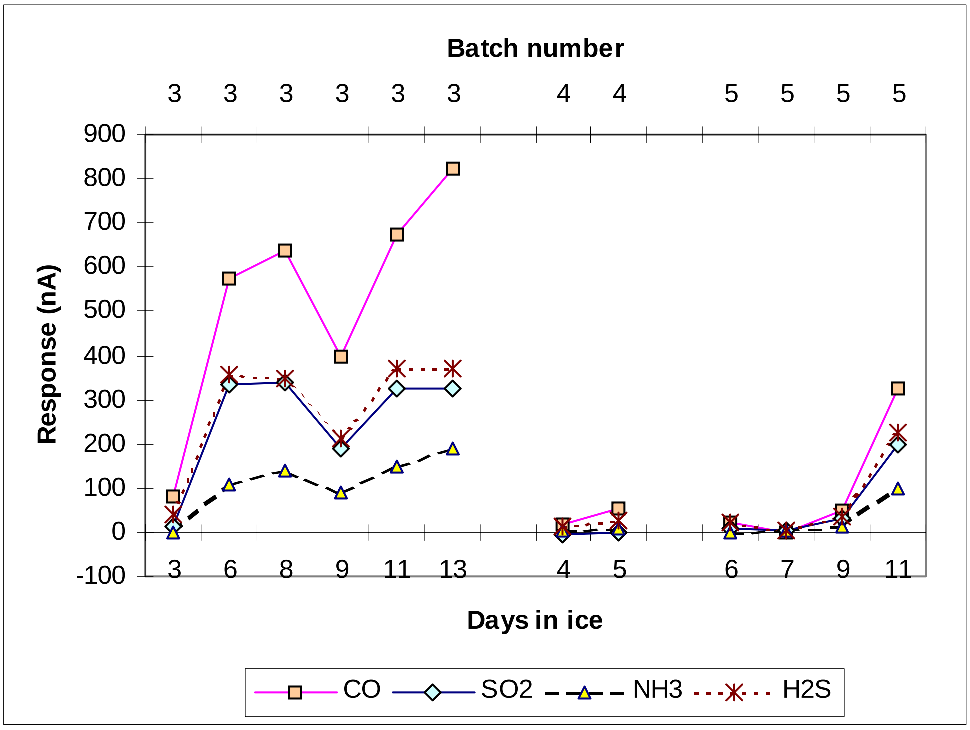

Figure 15: Electronic nose measurements of herring stored in ice. Each value is an average of three measurements.

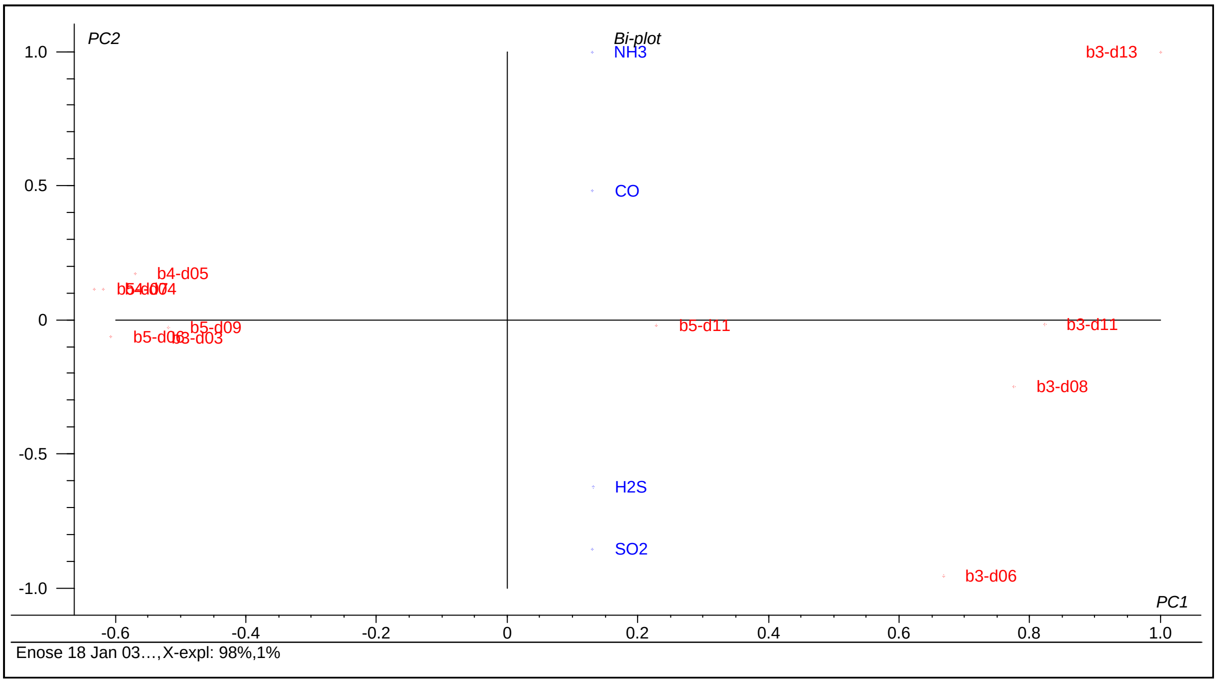

Figure 16: PCA bi-plot of electronic nose measurements during storage time.
Note: "b" stands for batch number and "d" for days in ice.

The PCA bi-plot (Figure 16) shows that the data of fresh fish was located on the left side of PC1 (describing 98% of the variation between samples) while the non-fresh fish was located on the right side of this PC. All data of fresh fish grouped together that might indicate that electronic nose measurements could not discriminate fresh samples by storage days. However, the instrument was very sensitive to slight/small changes at later stages of storage that resulted in broad distribution of data on the PCA plot. It is in agreement with studies on capelin and redfish that the sensors are sensitive during later stages of storage (Olafsdottir *et al.* 2000, 2002). Based on these facts, an electronic nose can be used to detect the onset of spoilage or some abuse in storage or handling.

Electronic nose can also be used to predict storage time with the precision of < ± 2.0 days by triplicate measurements (Figure 17).

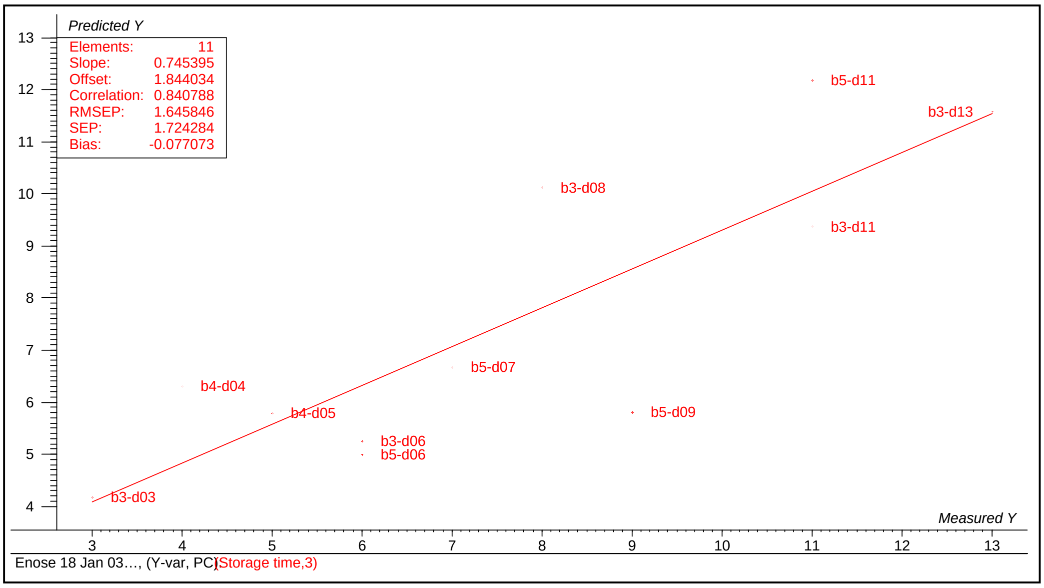

Figure 17: PLS1 modelling of electronic measurement data from herring stored in ice using full cross validation. X-axis and Y-axis are the measured and predicted storage time, respectively.

Note: “b” stands for batch number and “d” for days in ice.

4.4 Comparison of methods

A linear relationship was found between QI of raw herring and Torry score of cooked fillets: $y = -0.242x + 9.7303$; $R^2 = 0.7776$ (x - QI; y - Torry score). High correlation between QIM and Torry is desirable because then QIM could replace sensory evaluation of cooked fish, as QIM is performed earlier in the production chain and is more rapid (Martinsdottir *et al.* 2001).

Figure 18 shows that the precision of shelf life prediction might be slightly improved if we assess both whole fish (by QIM) and cooked fillets (by Torry scheme and QDA) rather than using just one of the methods (see also Figure 9 and Figure 12). However, it would not be practical to use all the methods at the same time, as it will be costly and time-consuming. It is desirable to use QIM for the whole fish as it can be performed earlier and more rapidly in the production chain.

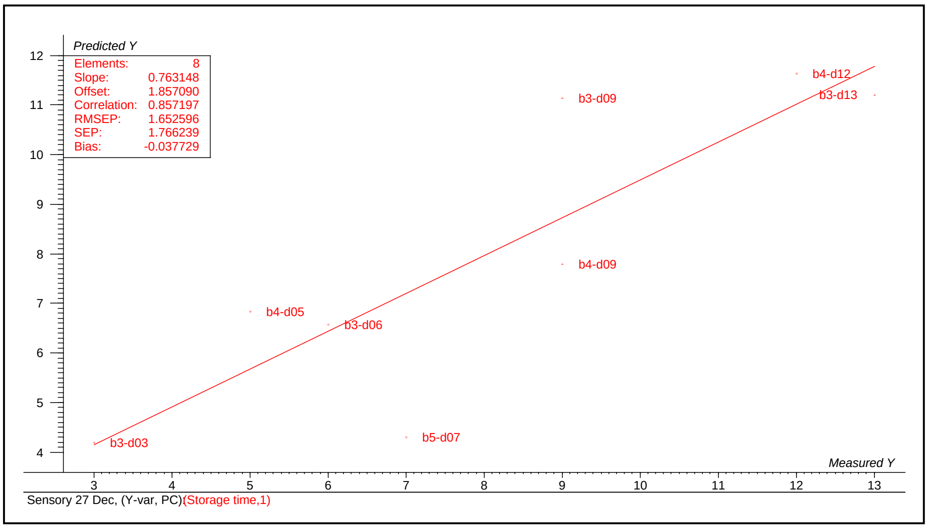

Figure 18: PLS1 modelling of all sensory attributes (QIM-QI, Torry score, and QDA) against days in ice. X-axis and Y-axis are the measured and predicted storage time, respectively.

The correlation between instrumentally measured texture parameters and those of sensory evaluation was analysed (Table 5). Computed values were compared to the values for a two-tailed test in table G.16 of O'Mahony (1986) to analyse if a significant correlation between parameters existed. For degree of freedom 3, which relates to 5 same sample days for both sensory evaluation and instrumental texture measurements, Table G.16 gives the following values: 0.8783 (p = 5%), 0.9587 (p = 1%) and 0.9912 (p = 0.1%) (O'Mahony 1986).

Table 5: Correlation (r) between sensory and instrumental texture parameters of herring stored in ice.

Texture parameters	**QIM**	**Firm-soft**	**Dry-juicy**	**Tough-tender**
Hardness	0.8701	0.6377	0.2604	0.0900
Cohesiveness	-0.4351	-0.3965	-0.8733	-0.4752
Firmness	0.7430	0.5903	0.4499	0.3578

Note: If there was any significant correlation, the r values would be marked with * (significant at 5%), ** (significant at 1%), or *** (significant at 0.1%).

Correlation between consistency of whole raw fish evaluated by QIM; or firmness, juiciness and tenderness of cooked fillets evaluated by QDA and the instrumental texture parameters was not found (Table 5). It should be considered that the texture measurements in the texture analyser were performed on whole fish with bone and skin on, as done in texture evaluation by QIM. It is not surprising that correlation between instrumental texture parameters and storage time was not found here either. The correlation between sensory and instrumental texture parameters might exist but could not be observed in this study. Negative correlation between juiciness and cohesiveness was very close to being significant, which might indicate that cohesiveness expresses/simulates dryness/juiciness of the (cooked) samples. It might be clarified with more measurements.

The PCA bi-plot (Figure 19) shows that the data of fresh fish was located on the left side of PC1 (describing 65% of the variation between samples). With storage time, the data moved to the right side of this PC. It is obvious that the same batch gave the same pattern of results even in different methods of freshness assessments (see also Figure 9, Figure 12, Figure 17, and Figure 18). The results show that batch 5 was of better quality than batches 3 and 4 and batch 3 was the worst, indicating differences in origin, storing and handling conditions of the batches.

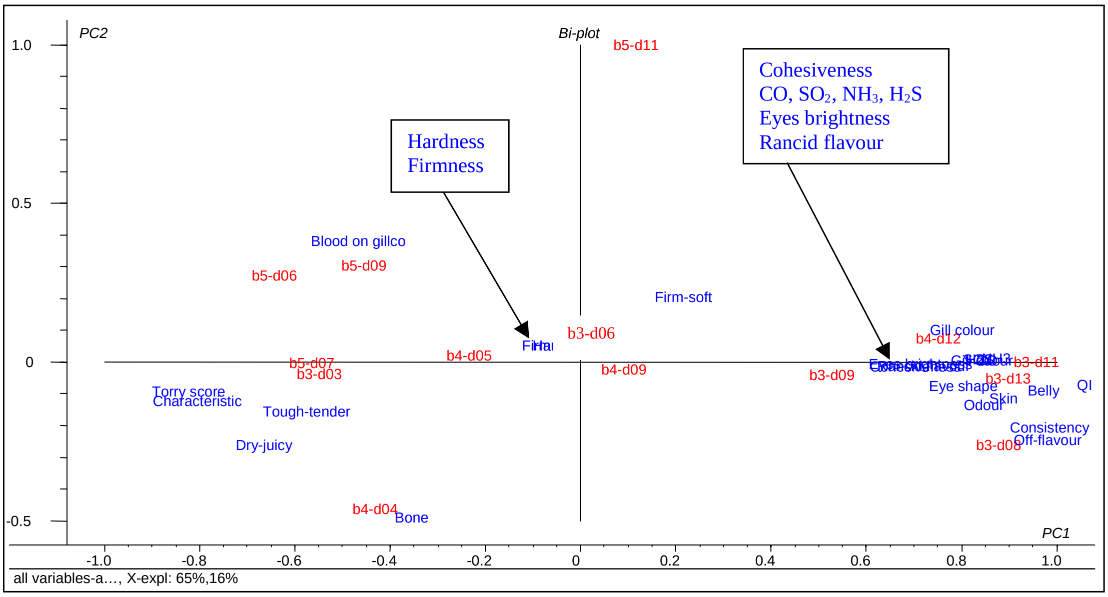

Figure 19: PCA bi-plot of sensory evaluation, instrumental texture measurements, and electronic nose measurements during storage time, using full cross validation.
Note: “b” stands for batch number and “d” for days in ice.

Hardness and firmness of fish measured on a texture analyser is on the left side of PC1 (Figure 19), which might indicate that the fish got softer during storage. It is in agreement with sensory evaluation results. It was reported that instrumental hardness of salmon decreased with storage time, which indicates softening of salmon flesh (Sveinsdottir *et al.* 2002). Cohesiveness is on the right side of PC1, which might indicate that the fish became stickier during storage.

Among the methods used in this study, sensory evaluation of cooked fillets (using Torry and QDA) gives the best results of freshness with detailed descriptions of attributes and high shelf life predictability. However, the method is more complicated than QIM in training, performance, data collection, and statistical analysis. In addition, it is time-consuming.

QIM is a promising method. It would give better results of freshness and shelf life estimation if some of the attributes are revised. This method is easy to used, fast and the most practical as it can be performed early in the production chain for the whole raw fish.

Significant correlation was not found between sensory and instrumental texture parameters. However, negative correlation between juiciness and cohesiveness was very close to be significant, which might indicate that cohesiveness simulates dryness/juiciness of the (cooked) samples. It might be clarified with more measurements. However, it is not clear that instrumental texture measurements are suitable for freshness evaluation, as the results depends a lot on individual of fish and other factors (such as biological state of fish before capture, handling condition, the choice of tests, etc. - Olafsdottir *et al.* 1998).

Electronic nose shows to be a strong tool in prediction of spoilage onset or some abuse in storing or/and handling conditions as it is very sensitive to small changes in volatile compounds above certain concentration. However, it can not be used to evaluate the freshness at early stages of storage, as it is not sensitive in distinguishing the freshness degree at the first days in ice.

5. CONCLUSION

QIM may be used to predict the shelf life of herring stored in ice with the precision of ± 2.5 days (at the 95% level of significance) by assessing five herring from each batch per storage day. A minimum of five herring should be included in the assessment of each batch; using fewer herring might reduce the precision of evaluation and predictability. Precision of predictability might be improved by revising some of the attribute scores in the QIM scheme for herring such as “Blood on gillcover”, “Belly”, and “Gills colour”.

Torry scores were highly correlated to storage time in ice. It indicated the end of storage time around day 8 when slightly rancid and sour odour and flavour were observed on the next day.

QDA attributes greatly changed after day 8 of storage. Characteristic flavour decreased, but rancid flavour increased clearly after 8 days of storage. This also indicates that the shelf life of herring is 8 days in ice.

Sensory evaluation of cooked fillets by Torry scheme and QDA can be used to predict the shelf life of iced herring with the precision of ± 2.0 days with duplicate samples. The predictability might be more precise when combined methods (QIM, Torry scheme, and QDA) are used. However, it is not practical, as it is costly and time-consuming.

QI was linearly correlated to Torry score. High correlation between QIM and Torry is desirable in order to replace evaluation of cooked fillets by whole raw fish with QIM, as QIM is the most practical method, which can be performed earlier and more rapidly in the production chain.

According to instrumental texture measurements, the fish seemed to become softer and stickier during storage. However, no significant correlation between instrumental texture parameters and storage time or between sensory and instrumental texture parameters was found. More measurements are needed in this field.

Electronic nose measurements may be used to detect the onset of spoilage at later stages of storage; or to detect some temperature abuse or changes in storing or/and handling conditions. The electronic nose used was not sensitive in distinguishing the freshness degree of herring at early stages of ice storage. However, the technique may be used to predict the storage time in ice of herring with ± 2.0 days by triplicate measurements.

Differences between batches of fish in origin, storing, and handling conditions must be taken into consideration when predicting shelf life.

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Appendix 1. Torry Freshness Score Sheet

Freshness evaluation of cooked herring

(Give one score for odour and flavour)

Freshness score

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

10 9 8 7 6 5 4 3

10	Fresh oil, sweet, meaty, creamy, metallic, faint odour
9	Fresh oil, sweet, meaty, creamy, musty, characteristic for the species
8	Oily, sweet, meaty, creamy, burnt, neutral
7	Oily, sweet, meaty, creamy, slightly rancid, slightly sour
6	Oily, sweet, old meat, creamy, rancid, sour
5	Rancid, sweaty, musty, sour
4	Rancid, sweaty, cheese, sour fruits, trace of bitter
3	Rancid, cheese, sour, bitter, spoiled fruits

(introduced by Shewan *et al.* (1953) and modified by IFL)

Appendix 2. QDA parameters

Texture

Firm-soft

Firm Soft

Dry-juicy

Dry Juicy

Tough-tender

Tough Tender

Flavour

Characteristic for the species

None Much

Off-odour

None Much

Rancid odour

None Much

Bones

Soft-inconspicuous Hard-accentuate

Comments:

Appendix 3. Quality Index Method (QIM) Scheme for Herring

Quality parameter		Description	Score
Appearance	Skin	Very shiny	0
		Shiny	1
		Matt	2
	Blood on gillcover	None	0
		Very little (10-30%)	1
		Some (30-50%)	2
		Much (50-100%)	3
	Consistency	Hard	0
		Firm	1
		Yielding	2
		Soft	3
	Belly	Firm	0
		Soft	1
		Burst	2
	Odour	Fresh sea odour	0
		Neutral	1
		Slightly secondary odour	2
		Strong secondary odour	3
Eyes	Brightness	Bright	0
		Somewhat lustreless	1
	Shape	Convex	0
		Flat	1
		Sunken	2
Gills	Colour	Characteristic red	0
		Somewhat pale, non-glossy, opaque	1
	Odour	Fresh, seaweedy, metallic	0
		Neutral	1
		Some secondary odour	2
		Strong secondary odour	3
Quality Index			0-20

(Martinsdottir *et al.* 2001)

Preferably more than one inspector should carry out the assessment. Evaluate all three to ten fish using the QIM scheme as provided. All attributes are to be assessed in the same order for each fish.

The whole fish is inspected for the appearance of the skin and fins. The skin of herring iced in tanks or boxes is usually more shiny than the skin of herring chilled in seawater (it loses the scales at an earlier stage). Therefore it is necessary to know the storing condition in the fishing boat.

The odour of the skin is assess by smelling the spine. If the fish has been laying more than 15 minutes on the table, it should be turned over and smelled on the other side. The smell of herring chilled in seawater becomes sweet and musty when it spoils, but the spoilage smell of herring iced in tanks or boxes is also slightly rancid.

The bloodstains on the opercula are usually bigger and more obvious on herring that has been iced in tanks or boxes than on herring chilled in seawater.

The tecture is assessed by pressing a finger (firmly, but not too hard) on the spine muscle and observing if/how fast the flesh recovers. Only fish in rigor is given a score of 0. Pre-rigor fish is soft/very soft and therefore given a high score, but if it is known that it is a pre-rigor fish, the texture should be 0.
Consistency of the belly is assessed by pinching it between fingers or by stroking it with the fingertips.
(Martinsdottir *et al.* 2001)

Appendix 4. Estimated remaining shelf life of herring

Quality Index=2.3*days in ice + 0.97
(R^2=0.740)

Quality Index	Storage time in ice (days)	Remaining shelf life (days)
1	0	8
2	0	8
3	0	8
4	1	7
5	1	7
6	2	6
7	2	6
8	3	5
9	3	5
10	3	5
11	4	4
12	4	4
13	5	3
14	5	3
15	6	2
16	6	2
17	6	2
18	7	1
19	7	1
20	8	0

(Martinsdottir *et al.* 2001)

Appendix 5. Reproducibility of CO sensor responses to different concentrations of aqueous ethanol solutions

	Concentration (ppm)	CO response (nA)			Average	Stdev	RSD (%)
(08 Nov. 2002) y = 6.4918x - 40.681 R^2 = 0.9938	0	-61.03	-10.18	-13.56	-28.26	28.43	-100.62
	10	47.47	13.56	27.13	29.39	17.07	58.08
	50	261.09	250.92	237.36	249.79	11.91	4.77
	100	647.65	640.87	586.61	625.04	33.46	5.35

Appendix 6. Raw data

Samples	Batch number	Storage time	Texture instr.			E-nose measurements				QIM										Torry score	QDA						
			Hardness	Cohesiveness	Firmness	CO	SO_2	NH_3	H_2S	Skin	Blood on gillcover	Odour	Consistency	Belly	Eyes brightness	Eyes shape	Gill colour	Gill odour	QI		Firm-soft	Dry-juicy	Tough-tender	Characteristic flavour	Off-flavour	Rancid flavour	Bone
b3-d03-1	3	3	0.79	0.40	0.81	98.34	9.05	-4.52	24.87	0.60	0.90	0.20	1.10	0.40	0.40	0.60	0.70	0.65	5.55	8.25	62.50	60.75	73.13	72.13	2.50	11.25	68.38
b3-d03-2	3	3	1.15	0.38	1.29	77.99	18.09	6.78	49.73	0.80	1.70	0.70	1.20	0.40	0.30	0.20	0.50	0.75	6.55	8.56	54.50	70.50	60.00	74.38	3,13	6,13	72,00
b3-d03-3	3	3	1.42	0.58	1.99	61.04	9.04	-4.52	47.47	1.00	1.50	0.40	1.40	0.60	0.50	1.30	0.70	0.85	8.25								
b3-d03-4	3	3								0.70	0.90	0.40	1.05	0.30	0.50	0.90	0.80	0.95	6.50								
b3-d03-5	3	3								0.90	1.75	0.70	1.60	0.50	0.60	0.70	0.40	0.70	7.85								
b3-d06-1	3	6	1.34	0.62	1.30	776.50	474.72	158.24	510.89	0.89	1.44	1.22	1.00	0.33	0.67	0.89	0.56	1.61	8.61	7.22	60.44	61.22	60.33	60.44	5,44	15,11	61,11
b3-d06-2	3	6	1.25	0.47	1.08	349.25	167.28	49.73	210.23	1.00	1.67	1.11	1.22	0.56	0.56	0.67	0.89	2.00	9.67	7.72	66.78	65.22	68.44	63.67	3,89	8,89	61,89
b3-d06-3	3	6	1.47	0.44	1.53	603.56	354.90	115.29	345.87	1.00	1.56	1.17	1.11	0.56	0.56	0.78	0.78	2.33	9.83								
b3-d06-4	3	6								1.11	1.56	0.94	1.11	0.67	0.67	0.78	1.00	1.89	9.72								
b3-d06-5	3	6								1.00	1.39	1.11	1.22	0.72	0.67	0.67	1.00	1.78	9.56								
b3-d08-1	3	8	0.91	0.45	1.15	562.88	278.05	131.11	316.48																		
b3-d08-2	3	8	1.66	0.81	1.46	712.07	429.50	158.24	413.68																		
b3-d08-3	3	8	1.26	0.47	1.29	640.87	302.91	128.85	318.74																		
b3-d08-4	3	8																									
b3-d08-5	3	8																									
b4-d04-1	4	4	0.78	0.64	0.84	16.96	13.57	4.52	15.82																		
b4-d04-2	4	4	0.79	0.39	1.03	10.17	-22.61	2.26	11.30																		
b4-d04-3	4	4	1.00	0.35	0.99	30.52	0.00	0.00	11.31																		
b4-d04-4	4	4																									
b4-d04-5	4	4																									
b3-d09-1	3	9	1.37	0.40	1.14	464.54	214.75	99.46	255.44	1.56	1.44	2.22	1.78	0.94	1.00	1.44	0.89	2.67	13.94	6.50	64.30	65.50	58.30	52.80	18,00	33,90	69,40
b3-d09-2	3	9	1.51	0.44	1.32	298.39	113.03	63.29	149.20	1.56	1.11	2.33	1.89	1.00	1.00	1.78	0.78	2.50	13.94	6.70	68.50	63.10	65.80	54.90	16,90	29,50	65,10

Samples	Batch number	Storage time	Texture instr.			E-nose measurements				QIM										Torry score	QDA						
			Hardness	Cohesiveness	Firmness	CO	SO_2	NH_3	H_2S	Skin	Blood on gillcover	Odour	Consistency	Belly	Eyes brightness	Eyes shape	Gill colour	Gill odour	QI		Firm-soft	Dry-juicy	Tough-tender	Characteristic flavour	Off-flavour	Rancid flavour	Bone
b3-d09-3	3	9	1.27	0.40	1.69	430.64	246.40	108.51	237.36	1.75	0.94	2.38	1.75	1.00	0.88	1.75	1.00	3.00	14.44								
b3-d09-4	3	9								1.56	1.11	1.50	1.44	0.89	1.00	1.33	0.78	2.11	11.72								
b3-d09-5	3	9								1.83	1.33	2.17	2.00	1.17	1.00	1.58	1.00	2.50	14.58								
b4-d05-1	4	5	1.60	0.54	1.05	50.86	2.26	13.56	36.17	0.78	1.22	0.78	1.22	0.72	0.89	1.00	0.61	1.28	8.50	7.55	67.70	65.70	67.80	63.10	7,00	10,80	63,10
b4-d05-2	4	5	1.86	0.36	1.11	77.99	0.00	2.26	40.69	1.25	1.63	1.06	1.25	0.56	0.75	1.38	0.63	1.13	9.63	7.65	62.10	64.50	54.30	68.50	4,30	11,30	66,50
b4-d05-3	4	5	1.50	0.43	1.14	33.91	-4.52	4.52	9.04	1.11	1.11	1.11	1.33	0.56	0.83	1.22	1.00	1.67	9.94								
b4-d05-4	4	5								1.14	1.86	1.57	1.43	0.71	0.64	1.00	0.57	1.57	10.50								
b4-d05-5	4	5								0.89	1.44	0.67	1.22	0.67	0.78	1.00	0.56	1.33	8.56								
b3-d11-1	3	11				559.49	230.58	103.98	273.53																		
b3-d11-2	3	11				701.90	372.99	165.02	406.91																		
b3-d11-3	3	11				759.54	366.21	176.32	429.51																		
b3-d11-4	3	11																									
b3-d11-5	3	11																									
b3-d13-1	3	13				522.19	221.54	94.94	275.79	2.00	1.00	2.58	2.00	0.83	1.00	2.00	1.00	3.00	15.42	6.08	58.00	56.67	61.67	45.50	19,00	39,17	64,17
b3-d13-2	3	13				847.71	343.60	237.36	361.69	1.83	0.83	2.67	2.17	1.00	1.00	2.00	1.00	2.67	15.17	6.08	64.33	60.17	62.33	48.00	24,50	39,83	68,17
b3-d13-3	3	13				1102.02	411.42	230.58	467.94	1.80	1.20	3.00	2.40	1.00	1.00	2.00	1.00	2.60	16.00								
b3-d13-4	3	13								1.80	1.40	2.80	2.60	0.60	1.00	2.00	0.70	3.00	15.90								
b3-d13-5	3	13								1.83	1.50	2.67	2.58	0.83	1.00	2.00	1.00	2.50	15.92								
b4-d09-1	4	9								1.00	1.80	1.20	1.80	0.60	0.50	0.60	0.60	1.50	9.60	7.08	69.17	64.67	59.50	58.17	6,17	20,50	66,33
b4-d09-2	4	9								1.17	1.00	1.33	1.67	0.50	1.00	1.17	0.67	2.00	10.50	7.50	58.17	65.17	58.17	60.50	13,67	14,50	70,00
b4-d09-3	4	9								1.83	1.00	2.33	2.50	1.00	1.00	2.00	0.83	2.50	15.00								
b4-d09-4	4	9								1.20	1.00	1.00	1.80	0.80	0.80	1.60	1.00	1.20	10.40								
b4-d09-5	4	9								1.00	1.80	1.00	1.60	0.40	0.80	1.20	0.60	1.40	9.80								
b5-d06-1	5	6	2.62	0.33	4.99	-3.39	13.56	-4.52	15.82																		

			Texture instr.			E-nose measurements				QIM											QDA						
Samples	Batch number	Storage time	Hardness	Cohesiveness	Firmness	CO	SO_2	NH_3	H_2S	Skin	Blood on gillcover	Odour	Consistency	Belly	Eyes brightness	Eyes shape	Gill colour	Gill odour	QI	Torry score	Firm-soft	Dry-juicy	Tough-tender	Characteristic flavour	Off-flavour	Rancid flavour	Bone
b5-d06-2	5	6	4.28	0.42	3.60	20.35	2.26	4.52	27.13																		
b5-d06-3	5	6	4.44	0.45	5.14	47.47	6.78	-4.52	18.08																		
b5-d06-4	5	6																									
b5-d06-5	5	6																									
b4-d12-1	4	12								1.71	1.00	2.14	2.29	0.86	1.00	2.00	1.14	2.79	14.93	5.89	67.00	49.11	54.00	41.33	11,00	41,22	57,33
b4-d12-2	4	12								1.57	1.57	1.71	1.71	0.86	1.00	1.57	0.79	2.29	13.07	5.56	63.33	49.00	57.11	38.56	11,33	41,56	57,78
b4-d12-3	4	12								1.33	1.42	1.50	1.67	0.67	1.00	1.83	1.00	2.17	12.58								
b4-d12-4	4	12																									
b4-d12-5	4	12																									
b5-d07-1	5	7				-13.57	6.78	6.78	15.83	0.67	1.25	0.67	1.17	0.33	0.33	0.50	0.58	0.83	6.33	7.72	66.33	68.33	73.11	67.33	5,89	14,44	65,78
b5-d07-2	5	7				0.00	15.83	-9.05	4.52	0.57	1.43	0.71	1.14	0.29	0.21	0.64	0.14	1.00	6.14	7.28	66.67	68.22	72.11	60.89	7,22	22,89	66,67
b5-d07-3	5	7				6.78	-15.83	13.57	-13.57	0.86	1.57	0.86	1.43	0.36	0.43	0.43	0.50	1.00	7.43								
b5-d07-4	5	7								0.86	1.57	0.79	1.57	0.43	0.21	0.50	0.71	1.14	7.79								
b5-d07-5	5	7								0.71	1.00	0.71	1.29	0.29	0.00	0.00	0.50	0.93	5.43								
b5-d09-1	5	9	4.46	0.46	4.57	-3.39	18.09	6.78	4.52																		
b5-d09-2	5	9	4.75	0.44	5.74	57.64	33.91	22.61	18.09																		
b5-d09-3	5	9	2.89	0.47	5.25	91.55	47.47	4.52	79.12																		
b5-d09-4	5	9																									
b5-d09-5	5	9																									
b5-d11-1	5	11	8.35	0.39	4.27	142.42	54.25	18.08	76.86																		
b5-d11-2	5	11	5.69	0.47	6.25	403.51	262.23	135.63	302.91																		
b5-d11-3	5	11	5.32	0.45	13.14	423.86	284.83	144.67	300.65																		