Advances in the development and use of fish processing equipment. Use of value chain data

Sveinn Margeirsson and Sigríður Sigurðardóttir
Matis ohf
Reykjavik, Iceland

SUMMARY
Advances in the development and use of fish processing equipment, with respect to the whole value chain, are discussed. The situation in Iceland is described briefly, especially in terms of how seafood production has increasingly taken a value chain perspective into account. Focus is put on how different modules have been linked together, allowing for constant monitoring of yield and economic performance of the catch and processing operations. The different data collection equipment, such as electronic logbooks, processing information systems and marketing information systems are discussed and as is how the data from each link are used for management within the link. Application of traceability is also discussed and how such an application can integrate data from different links in the value chain. When such integration is achieved, more information can be produced from the data. Such information include, for instance, processing related variables like nematodes in the fish and fillet yield and their connection to fishing grounds, as well as environmentally related variables such as oil usage. Future aspects of value chain management, including decision support, more efficient fisheries management and increased data collection to increase the fineness of the traceability granularity are also discussed.

INTRODUCTION
The value chain concept has been increasingly used in the Icelandic food industry in the last years and the management of seafood companies has changed accordingly. Today, managers in the seafood industry consider catching, processing and marketing simultaneously when making decisions. The fact that the same party often owns Icelandic fishing vessels, fish processing companies and marketing companies has also impacted on the value chain approach; the aim is to maximize the profit of the total chain – from catch to consumer – instead of only looking at an isolated link in the value chain.

Increased use of automatic data capturing methods, such as electronic logbooks and weighing machines onboard the vessels, has also enabled better inventory management based on the age and size of the raw material, and other factors considered useful for planning the processing. Use of RFID labelled fish tubs is also increasing, making inventory control and traceability more automated and accurate and therefore enabling different processing of raw material with different properties.

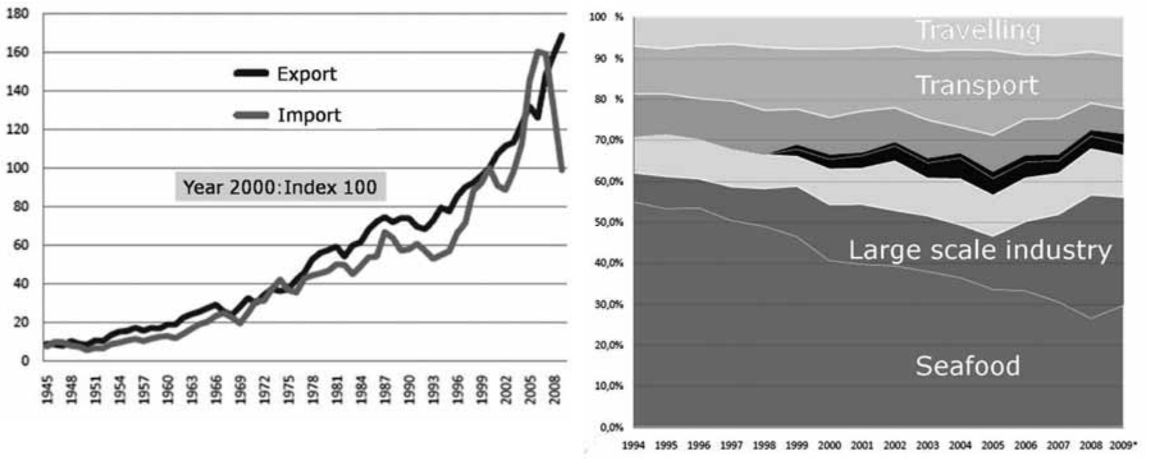
IMPORTANCE OF SEAFOOD PRODUCTION FOR THE ICELANDIC ECONOMY
Despite growth in other industry sectors, the seafood industry is the single most important industry for Iceland. It was estimated in 2004 that fisheries and seafood production, together with ancillary industries, accounted for at least 30 percent

of domestic production (Árnason I, 2004). In 2007, this was still the case (Jóhannesson S, Agnarsson S, 2007).

The worldwide economic downturn has impacted negatively on Iceland. This is partly because Icelanders spent too much during 2004 to 2007, as apparent from Figure 1(a), but also because, apparently, the Icelandic banking industry has been badly mis-managed over the last decade. There are other reasons, of course. However, one of the consequences of the economic crash in Iceland in 2008 has been the increased importance of fisheries and seafood production for the country's economy. Seafood production is again considered the most important industry in Iceland, not only in terms of the export value (Figure 1(b)), but also in terms of growth opportunities. Companies like Marel (www.marel.com), Trackwell (www.trackwell.com) and Hampidjan (www.hampidjan.is) are all examples of innovative companies servicing Icelandic fisheries and seafood production and also exporting their products and services, contributing importantly to the Icelandic economy.

The export value of seafood in Iceland in 2009 was approximately 200 billion ISK (US$1.5 billion). This is approximately 30 percent of the country's total export value (Statistics Iceland, 2010). The transportation sector is heavily reliant upon seafood production and accounts for approximately 10 percent of the export value of Iceland. Thus, altogether, seafood is responsible for at least one third of the export value of Iceland.

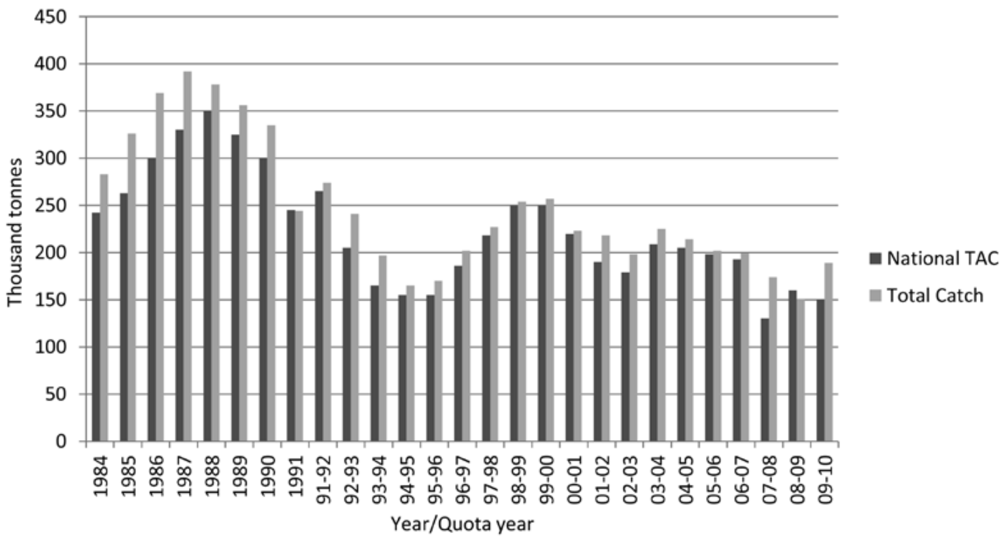
FIGURE 1
Export and import index from 1945–2009 and
Proportional distribution of export value between industries in Iceland



Notes: Left figure - Icelandic export and import index from 1945–2009. Note the increase in imported goods from 2004–2007, much higher than the increase in value of exported goods. In 2009, the value of imported goods fell sharply, while the value of exported goods increased fast. Right figure - The proportional distribution of export value between industries in Iceland. Note the increase of the importance of seafood production from 2008 to 2009. The transport industry in Iceland relies heavily on the seafood production and therefore, seafood production account for even higher proportion of export value than appears at first.
Source: Statistics Iceland and the Federation of Icelandic Industries, 2010.

The most important species for value creation in Icelandic seafood production is cod. The Icelandic economic zone is in the north Atlantic Ocean, and there, as in many other waters, catch volumes have declined in the last decades. After attaining annual catch volumes of 300–400 thousand tonnes during the late 1980s, a sharp decline in catch volumes followed. In the decade after the onset of the Icelandic quota system in 1984 and again from 2000–2006, quite large differences between total allowable catch (TAC) and the actual total catch can be noticed (Figure 2).

FIGURE 2
Catch volume and quotas for cod in Icelandic waters from 1984–2010



Source: Sigurdsson, 2006.

Even though the cod stocks did recover to some extent, after the actual implementation of the fisheries management system that had been established in 1984, the high catch volumes of the 1980s are distant memories. Such a decrease in catch volumes called for new methods to maintain profitability of the fish industry. Therefore, in the 1990s, focus was put on improving the handling and processing of cod and the development of new and more valuable products. The first decade of the 21st century has led to the development of a more comprehensive management of the cod value chain as a whole.

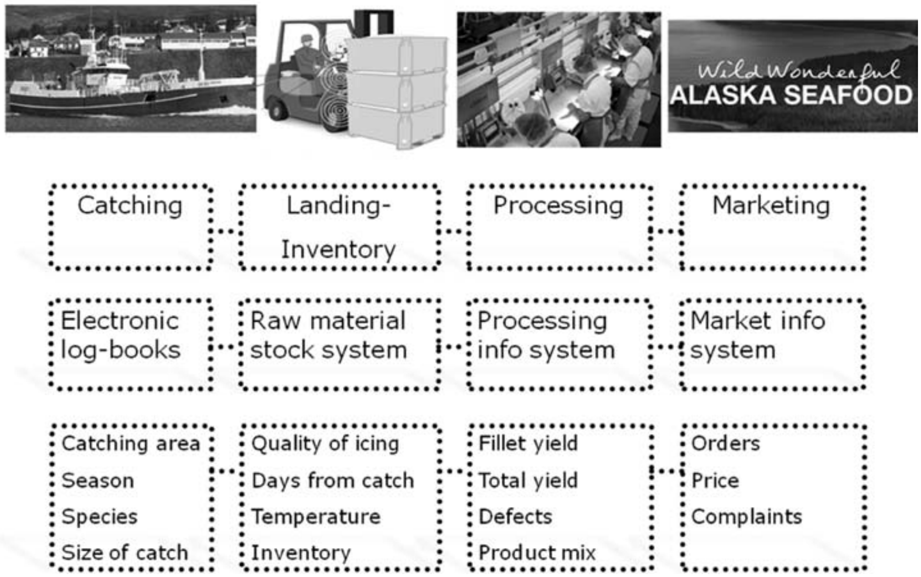
VALUE CHAIN PERSPECTIVE

The concept of the value chain (Figure 3) has been increasingly used in the Icelandic seafood industry in recent years and the management of seafood companies has changed accordingly.

Today, many managers in the seafood industry consider catching, processing and marketing simultaneously when making decisions. Many of the seafood companies have integrated value chain operations, so in fact the whole value chain is owned and operated by the same party. This has led to a more holistic approach to management by not only focusing on maximising the profit from one link in the value chain but looking at the value chain as a whole. It is now possible to estimate the properties of any catch, based on historical data, and to evaluate sailing times and the value of the catch because it has been shown that the properties of the catch and the corresponding value are both spatially and temporally dependent (Margeirsson, B. *et al.*, 2010; Margeirsson, S. *et al.,* 2007; Margeirsson, S. *et al.,* 2006).

Increased use of automatic data capturing methods, such as electronic logbooks and weighing machines onboard the vessels, has also enabled better inventory management based on the age and size of the raw material and other factors considered useful for planning the processing. The use of RFID labelled fish tubs, for instance, makes inventory control and traceability more automatic and precise and facilitates the use of different processing options for raw material with different properties.

FIGURE 3
The value chain of seafood



Note: The first layer (top) shows the operations within the value chain. The second layer shows the medium for data collection within each link and the third layer shows examples of data which are collected.

The amount of data recorded in the Icelandic cod industry has increased greatly in the last decade, in parallel with the decreased costs of acquiring data through automation and computer systems. Some companies have started to utilise the data for management purposes. Data can also be used to respond to consumers' demands for more information about their food products, such as origin, catching method and impact on the environment. This flow of data is based on traceability being in place in the value chain.

Traceability leads to transparency within the chain and is a key factor when linking data. Vertical integration and partnership relationships have increased the motivation within the food industry, as well as in other industries, to share information from one link to another in the value chain. Increased sharing of information and data has and will continue to improve decision making concerning catch and processing of cod in Iceland. Information on fillet yields, gaping and parasites and further analysis of that information has helped in managing the fleet of each company. The size of the catch is no longer only taken into account when choosing catching grounds, but also the properties of the catch for processing, time from catching ground to processing, oil cost and other economic related factors.

When information, such as grading and location data, are available for the catch, modern communication technology allows transmission of data to the processing companies, facilitating the organisation of the processing lines long before the catch is landed. The processing companies are then able to estimate how much and what kind of products they will be able to supply to retailers. This makes marketing more focused and more efficient.

THE ROLE OF TRACEABILITY

Traceability is a term that is often discussed in relation to seafood production and food production in general. Different definitions for traceability in the food sector exist, such as:

- The ability to trace the history, application or location of that which is under consideration. (ISO, 2000).

- The ability to trace and follow a food, feed, food producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution (Regulation EC No 178/2002 (EC, 2002)).
- The ability to follow the movement of a food through specified stage(s) of production, processing, and distribution" (Codex Alimentarius, (CAC, 2008)).
- The creation and maintenance of records needed to determine the immediate previous sources and the immediate subsequent recipients of food (U.S. Bioterrorism Act 2002 (PL107-188, 2002)).

No matter which definition is used, traceability can be used to trace products up and down the value chain. Most commonly, the value chain is seen as starting with raw material and ending with the consumer. The flow of goods defines the stream – downstream is in the direction to the consumer, upstream is in the direction to the raw material. Tracing products upstream (or backward) is often called tracing, whereas tracing products downstream (or forward) is called tracking. Tracing enables "source finding". It enables for instance health authorities to find the source of a particular problem (Bechini *et al.*, 2005; Deasy, 2002; Dupuy *et al.*, 2005; Frederiksen *et al.*, 2002; GS1, 2009; Olsson and Skjöldebrand, 2008; Schwägele, 2005). From the processing manager‘s point of view, it enables tracing the catching ground of a particular product and thereby linking the attributes of the product to the catching area. Such attributes might include water content, water holding capacity and other physical properties of fish muscle. They might also include analysis of the contribution margin of the product, thereby enabling the processing manager to choose catching areas based on expected contribution margins.

The captain, on the other hand, may be interested in tracking his catch. What happened to the catch? Was it properly utilised? Did all the quality arrangements onboard affect the price of the catch? Tracking is also used in a product recall. If, for instance, mercury contamination is found in a seafood product entering the EU market, it is necessary to trace its origin back to the source and when the source of the contamination is found, track all products that may have been contaminated in the same way.

Generally there are two categories of traceability. Internal traceability is the ability to trace the product information internally in a company and external traceability (or chain traceability) is the ability to trace the product information through the links in a value chain. It is important to note that traceability is not the product information itself. Traceability is the ability to trace and is, as such, only a tool that makes it possible to trace this information through the chain. This was emphasized by Olsen and Karlsen (2005).

A traceability system should, in the same way, not be understood as a system that holds all the data, but rather a system that enables an actor in the value chain to trace back or track forward. The systems that hold the data are referred to as information systems. Experience has shown that in complex food value chains, such systems must be electronic if they are to be effective. However, theoretically a traceability system might be based on pens and paper.

There may be numerous benefits of applying traceability. Traceability allows health authorities to trace and track contaminated foodstuff and reduces the risk and cost of food borne disease outbreaks (Hobbs, 2003). For the food industry, including seafood producers, the benefits occur at the market end and back to distribution and processing.

Some of the benefits of applying traceability are as follows:

1. Lower recall cost is probably the most widely accepted benefit. If contamination is found in seafood products and the producer cannot show that the problem is isolated to a small portion of his production, a full product recall may be the

result. For many producers, such recalls may mean an end to their business and therefore it is of utmost importance to isolate the problem and thereby reduce the cost of a recall. A rule of thumb is that the smaller the production lot, the smaller the recall cost. It is, however, important to estimate the risk of a recall, as having small lots may increase cost; for instance, by slowing down processing. It is therefore important, from an economic point of view, to take the whole value chain into account and weigh risks and costs when deciding on the methods used for traceability.

2. Related to this, benefits from the reduction of lawsuits may accrue. If a producer can show that problems with their products are not related to their operations but rather the operations of another processor, a transporting company, a retailer or even the consumer, then lawsuits may be avoided. This may save the producer from penalties and a possible loss of trade owing to a damaged reputation and a weakened brand (Can-Trace, 2007; Frederiksen *et al.,* 2002; Poghosyan *et al.,* 2004).
3. Market benefits may occur simply because, by being able to trace products, companies become compliant with EU and US regulations. There may also be some consumer requirements regarding traceability, especially at the high-value end of the market (Golan *et al.,* 2004).
4. Improved natural resource management is possible through analysis of the resource utilisation. In fisheries this may be an analysis of how well the natural resource (fish stocks) are utilised - if the catch is coming from a sustainable stock, if the utilisation of the catch is for human consumption, how much of the catch is utilised and how much is discarded, either before or after processing (as waste or byproducts).
5. Improved environmental management, for instance through Life Cycle Assessment (LCA) and calculation of carbon footprints. The use of LCA and carbon footprints may offer a viable way of expanding the discussion on the sustainability of seafood production and providing a more holistic view on the matter of sustainable seafood than that offered by the adoption of popular ecolabels, such as the Marine Stewardship Council (MSC).
6. There are numerous process improvements possible if traceability is applied. From the authors' point of view, this area has by far the most potential for economic benefits, excluding benefits from limiting food poisoning events. A more thorough discussion on the opportunities related to some of the benefits may be found later in the chapter, but the benefits may include:
   a) Improved supply chain management
   b) Improved company management
   c) Increased production efficiency
   d) Improved planning of processing
   e) Improved inventory management
   f) Lower cost of distribution
   g) More focused raw material acquisition
   h) Improved quality management
   i) More focused product development

USING INFORMATION SYSTEMS IN THE VALUE CHAIN

Different information systems are responsible for managing data in the different links of the value chain. Figure 3 (middle layer) shows how the information systems relate to individual links and what kind of data may be expected in each link. The following section discusses this in brief.

Information systems in catching

In Europe, reporting the catch of individual vessels has been required for some time. This reporting has been done by filling out so called logbooks. Electronic logbooks are widely used in Icelandic fisheries and are being adopted in more fisheries, such as in Norway and the Faroe Islands. Today, hundreds of vessels report their catch through electronic logbooks, or e-logbooks as they often are called. The e-logbooks are basically an electronic edition of the paper based logbooks that have been used for decades in those countries and more widely. The captain of the vessel enters the catch, by haul or days, depending on the fisheries. Catch reports are created with information on the size of the catch, relative size of each species, catch location, date, weather conditions and other factors, depending on the fisheries. The reports are received by the Directorate of Fisheries and the Marine Research Institute. The Marine Research Institute uses the reports for scientific purposes, for instance regarding calculations of fish stock sizes. The Directorate of Fisheries compares the data from the reports to landing data for fisheries management purposes.

The use of electronic logbooks has frequently been enhanced by new regulations. A good example is the law on fisheries management in Iceland, which now requires electronic logbooks if vessels are above a certain limit. Today, suppliers of seafood into the European Union must show that their supply is not coming from illegal, unreported, unregulated (IUU) fisheries. This will most probably further enhance the use of electronic logbooks. The electronic logbooks will create enormous volume of data concerning the catch. It is therefore important for all parties of the value chain to realize how they can benefit from the use of electronic logbooks.

The owners of the vessels also receive copies of the catch data. The owners of the vessels are often also the owners of processing factories and they use the data for management of their operations. Some examples of different kinds of analyses that help decision makers include:

1. Catch rates in different catching areas and seasons.
2. Species distribution (proportion of different species) in different catching areas and seasons.
3. Size distribution of the catch in different catching areas and seasons.
4. Comparison between different vessels, if companies use more than one vessel for catching.
5. Bait utilization, i.e. how different bait results in different catches, even mapped down to different catching areas and seasons.
6. Comparison of catching areas in terms of expected profit making, taking into account both revenues (sales) and costs (oil cost, for instance).
7. Analysis of vessel movements during fishing trips and catch, possibly taking into account environmental conditions such as salinity, currents and weather conditions.

Raw material stock systems

Raw material stock systems or information systems at landing include data such as quality of icing, temperature measurements and inventory levels. The information systems are normally not as advanced as those used in e-logbooks and may be a mixture of a database based software solution, spreadsheets and paper. Radio frequency identification (RFID) tags have been used as identifiers of storage units (most often for fish tubs) and even for data storage. However, the use of RFID tags in seafood production is not common yet because of the harsh conditions (cold and humid environment) that makes reading of RFID tags more difficult. The same applies for bar codes, which have also been used as identifiers. In Iceland, the most common method for identification is labelling the fish tubs with either the haul number or date. In some instances the label may even be the trip number.

Information from this link of the value chain can be used widely. Quality management of icing is one example. Many processing plants in Iceland pay a quality premium, because icing of the catch is vital for the quality and freshness and this premium quality opens up the possibilities that the processing plant has for further processing. Another example is scheduling of the processing workforce. By knowing the inventory level and details of the catch (size and age distribution, for instance) and adding data from the e-logbooks (incoming supply), the processing managers can organise the processing for the following days, determine if there is enough raw material to fulfil orders (and also determine if additional supplies are needed from the fish market) and, based on the market price of different products and the workforce available, schedule which products are to be produced and how – with the ultimate goal of profit optimization.

Information systems in processing

There are different processing information systems available. In Iceland, the most common systems are Wisefish from Maritech, Innova from Marel and SAP systems. All of these systems vary greatly, but have in common the feature to manage data from processing and sometimes from marketing. The utilisation of the data can take many forms. Marketing needs to know the product inventory. Processing managers may require different information from the systems. Contribution margin calculations are based on information from the systems, as well as monitoring of yield at different stages of processing. Defect monitoring is also important, as well as monitoring of quality. Connecting quality inspections to the single employees helps with staff education, but may also serve as part of a salary system, with higher salaries for higher quality work.

Information systems in marketing

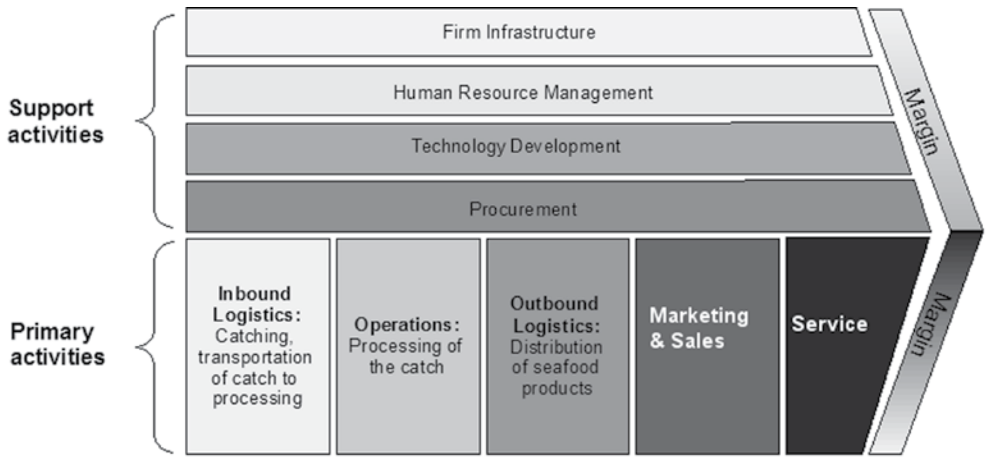
Information systems in marketing are often well connected to the processing information systems or at least to the product inventory. However, when it comes to displaying marketing information from the other parts of the value chain, no such system is available in the seafood industry. Thus data experts need to use raw data and manipulate and analyse this data to provide information of value to managers. With that in mind, at least an informal link exists between the marketing and processing parts of the value chain.

It is useful to look at the value chain using Porter's generic value chain model (Porter, 1985) to better understand the different activities throughout the chain (Figure 4). The primary value chain activities are:

- Inbound logistics: Receiving and warehousing of materials and their distribution to manufacturing.
- Operations: The processes of transforming inputs into finished products and services.
- Outbound logistics: The warehousing and distribution of finished goods.
- Marketing and sales: The identification of customer needs and the generation of sales.
- Service: The support of customers after the products and services are sold to them.

People are getting more and more conscious of the food they consume and discussion about genetic modification of foods has increased the demand for traceability, because consumers want to be able to obtain information about the food throughout the value chain. As a result, traceability can be used as a marketing tool, while recognising the limitations mentioned previously with regard to full chain data analysis when it comes to displaying marketing information from the other parts of the value chain.

FIGURE 4
Visualisation of Porter's Generic Value Chain



LINKING THE INFORMATION SYSTEMS

It is of extreme importance to link all the data collected in the value chain in order to make full use of the data. To illustrate the importance of this, one may look at the current typical method of determining catch location. This mostly involves the captains of vessels relying on their past experience and gut instinct with the aim of maximizing the catch, catch value and total earnings of each vessel. However the captain lacks hard information to consider the latter two factors, so the focus will mainly be on catch volumes. This method has proved remarkably successful but has some obvious shortcomings. The overall value of the catch, taking into account the value creation in processing is, for instance, not taken into account. A combination of the tacit knowledge of vessel captains and processing managers and a more scientific method would be a good option for decision making at sea. An optimization model based on work of Margeirsson *et al.* (2007) has been proposed (Olafsson *et al.*, 2010) for both long-term and short-term decision making for a fishery operating several vessels. A prototype of the software, called Fishmark, has been developed to support decisions in the seafood industry in Iceland and has been taken up by a number of Icelandic companies. The aim is to solve a multi-commodity network flow problem that describes the entire operation of a fishery. However, the shortcomings lie in the linking of data from different links of the value chain. An important part of such decision support systems is the statistical model, based on previous data, that gives indications on what kind of fish can be expected in a certain area at a certain time and helps in deciding the location for catching. This could surely be a very helpful tool but in the current situation, reliable and sufficient data are missing for the model to be of practical use.

The results of Olafsson *et al.* (2010) are, however, quite interesting. They showed that by linking data from electronic logbooks, onboard vessels and data from the information systems in processing, significant information can be created with a variety of possible uses. One application, for instance, might be the statistical analysis of size distributions of catches in order to highlight possible high-grading or at-sea discarding.

Another approach to linking information systems is being explored by an EC funded project called EcoFishman. The overall aim of the project is to develop and contribute to the implementation of a new integrated fisheries management system in Europe, based on results based management. The proposed method is to develop a geographical tool that will integrate relational databases containing the latest traceability tools with web based and geographical information system (GIS) technology. The geographical visualization tool / decision support system will provide a unique interface to view the interaction and interdependency of relevant data of different types.

The databases to be integrated are both proprietary, such as those described in previous chapters, and those that consist of data from three case studies where responsive fisheries management system (RFMS) will be designed and simulated. The different data sets to be collected include biological, social, legal and economic indicators. Because many of those indicators have a geographical component, the GIS technology is very applicable. The collected datasets will have an important role when it comes to predicting and simulating the effects of the RFMS.

Relevant sources of data include the numerous technological tools that are available for assisting in managing fisheries, such as logbooks, satellites, data systems for markets and processing, camera systems onboard vessels (CCTV), technological tools to mitigate bycatch and more.

DECISION SUPPORT: FLEET AND PROCESSING MANAGEMENT

In the case of the seafood industry, the total allowable catch is constrained by regulations. Therefore the revenues are determined by the price of the product and the production yield from the supply of raw material. With this in mind, one can see the importance of utilizing fish optimally as well as making sure that the properties and volumes of catches meet the demands from consumers.

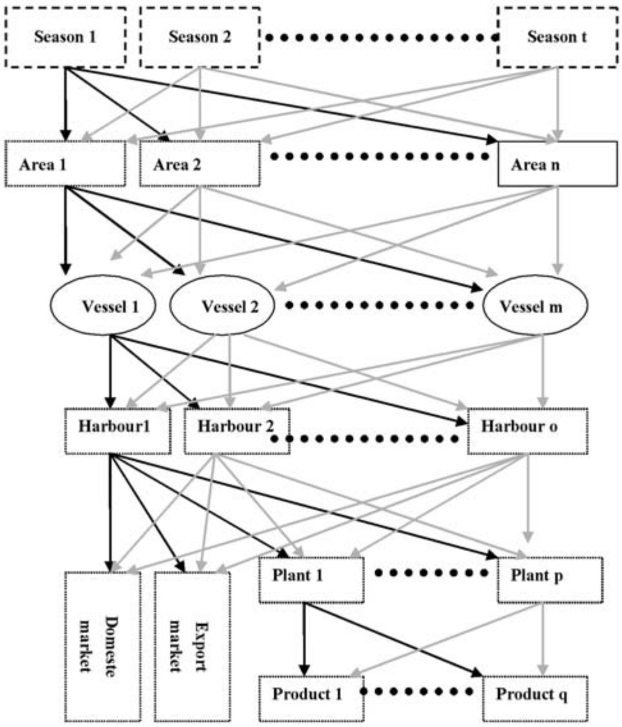
Activities included in the seafood value chain are dependent on each other. Decisions on fishing, processing, labour allocations, quota allocation and marketing may play an important role in the final quality of the final product and thus the revenue obtained. Decision support systems (DSSs) can play an important role in the industry. They have been defined as interactive and adaptable computer-based information systems and are especially developed for supporting managerial decision-making activities.

As an example of a DSS tool for the value chain, a linear optimization model, has been proposed (Margeirsson *et al.,* 2010) to solve the problem of choosing the right parameters for material acquisition. The model is a combination of an assignment problem and a production problem, where the objective is to assign vessels to fishing grounds and to determine the allocation of the expected catch. When constructing the model, the authors realized that good communication between the manager of the catch and the managers of processing and marketing is required to optimize the profits of the value chain as a whole. Four different data categories are taken into account:

1. Catching ground data: Catch volume, species composition, sailing distances, etc.
2. Catch properties in terms of processing properties: Age of the catch, size distribution, etc.
3. Operations expenses: Fishing, transport and processing.
4. Market data: Demand, price of fish from the vessels and price of fish products.

The proposed model may be described as a multi-commodity flow model, where fish is the flowing object. The flow is shown on Figure 5. Properties of the fish change as it moves through the network and the model needs to keep track of the properties of the fish and its associated costs and revenues.

FIGURE 5
A network for one season that shows a flow of caught fish through the company's value chain

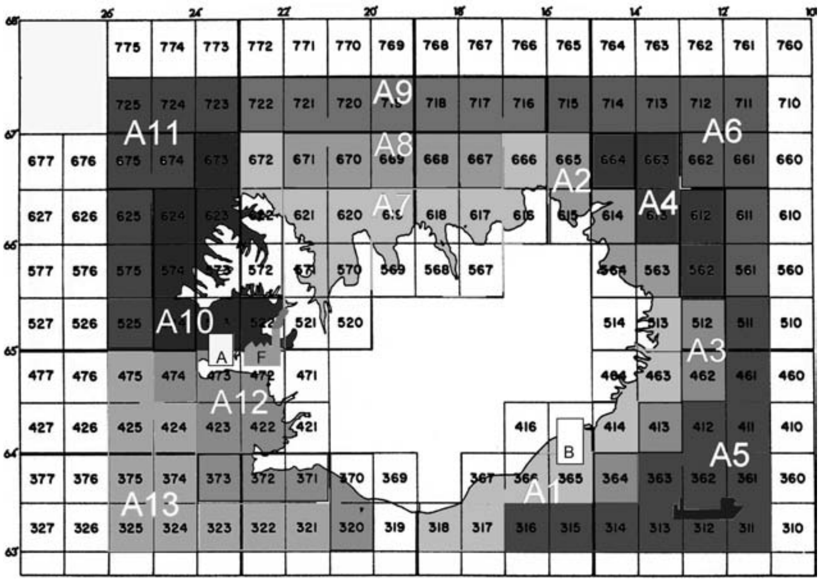


Icelandic fish processors are highly developed technically so that much of the information needed to make the correct decisions is already collected and available. Many of the processing plants have undergone radical changes in recent years, with installation of new processing equipment, such as Marel's concept of 'flowlines'. An important part of flowlines is a continuous weighing of fish parts at different unit operations of processing. The weight of the head, fillets, different products and byproducts can all be monitored. This allows processing managers to follow the yield through processing and, if traceability is applied, to map the yield to different catching conditions such as catching areas, seasons, towing times and other parameters. A few hypothetical, but still realistic, scenarios were constructed for a small company in Iceland. In one of the four scenarios, it was assumed that the company operated one trawler and one land-based fish processing plant and that the trawler could choose between two different harbours (A and B), as shown on Figure 6. Harbour A was located on the west coast of Iceland, close to the processing plant whereas harbour B was located on the east coast. The model assumed that fish landed in harbour B would be transported by land to the fish processing plant. The Icelandic waters were divided into 13 different areas and the year into four seasons.

The results show, for instance, that the most profitable catching areas would be A11 and A12 (see Figure 6). Another scenario revealed that if the processing took place in the south eastern part of Iceland (Harbour B location), the profits of the company would be higher than in the first scenario. From this it can be concluded that with traceability, fisheries can retrieve information on, for example, size distribution of the fish or fillet yield from different catching grounds. This confirms the value of traceability.

FIGURE 6

Partition of Icelandic waters into 13 different areas (A1-A13)



Note: The figure also shows the locations of two harbours A and B and the fish processing plant F. Harbours A and B are the harbours where the trawler of the company in the scenario can land. Fish processing plant F is owned by the company.

Moreover, the results show that creation of decision support systems in the form of linear programming models is viable. They require reliable and continuous data flow within the seafood value chain and that the data are accessible for analysis and modelling. Traceability must be applied to link the different actors in the value chain. When it comes to such linking, the high level of integration in Icelandic seafood value chains helps to ensure the data flow.

Decision support such as proposed here may be used to answer different "what-if" questions. Such questions may be about quota price, choice of catching areas and seasons for catching, location of processing plants and the possibility of responding to different market conditions. Historical data are important for the precision of the model, but new data on product price, as well as market forecasts may be of use.

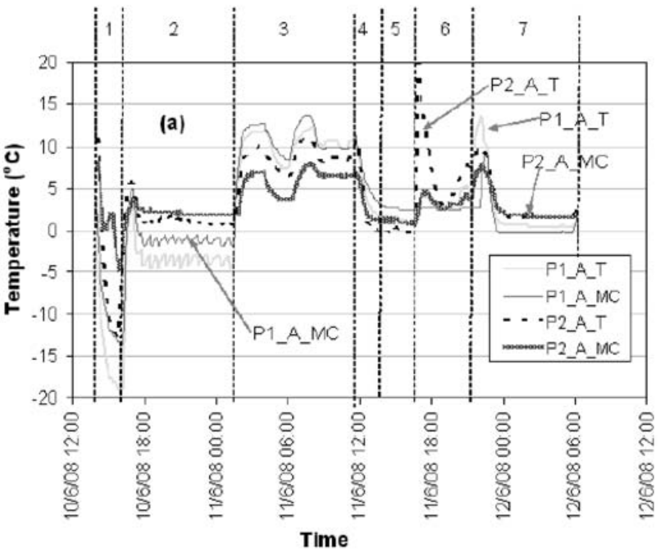
DECISION SUPPORT: COOLING CHAIN

It is of extreme importance that the cooling of the transported fish is well monitored, because the temperature of the fish throughout the value chain affects the quality of the product and, therefore, the revenue achieved. Freezing has for a long time been the most important preservation method in the seafood industry, especially in remote areas such as Iceland that require a longer periods to transport their products to the market. In the past decade or so, the importance of freezing has decreased while chilling has become more and more important. Icelandic consumers and consumers in Western Europe are the most important market for Icelandic seafood. In more recent times, these consumers have lost interest in frozen food, or put more accurately, they want their food in a fresh state if they can have access to it in that state. The economic crisis may have impacted on this to some extent, but this is the general trend. Many of the higher quality producers in Iceland and Norway have welcomed this because it has resulted in partial protection against double-frozen seafood that is processed in Asia and other low wage areas. This move to fresh fish has, however, demanded more efficient cooling because microbiological and enzymatic spoilage is much faster in chilled seafood compared with frozen seafood. In the first five years of the

21st century, this was solved mostly by transporting the fresh products to the market via airfreight, but environmental pressure as well as increasing fuel prices has necessitated the development of chilling techniques that allow sea freight to be used to meet the demands for chilled products. One such successful technique is superchilling. In superchilling, products are chilled below 0 °C, partially freezing the water contained in the products but doing it in such a way that the physical changes that occur when traditional freezing is used do not occur. Experiments have shown that the storage life may be prolonged by 4 to 6 days for both cod and arctic charr, which is approximately the time it takes to sail from Iceland to Western Europe. An important further benefit from superchilling, which takes place after filleting but before trimming and further processing, is an increased yield from the raw material, because the chilling treatment improves mechanical processing of the fillets. Superchilling combined with modified atmosphere packaging can result in further increases in shelf-life, to 14 to 20 days for cod fillets (Sivertsvik *et al.*, 2002).

However, it is not sufficient only to use superchilling during processing. Accurate control of the product temperature throughout the chill chain is essential in order to minimize cost and maximize product quality and thereby product value. This is unfortunately not always the case. Figure 7 shows an extreme example of what may be expected in terms of temperature fluctuations in air freight from Iceland to the United Kingdom.

FIGURE 7
Temperature fluctuations in an air freight transport of fresh fillets from Icelandic processor to further processing in United Kingdom



Source: Mai *et al.*, 2010.

The product temperature is affected by packaging and the ambient temperature. The fact that different transportation modes have various interfaces can cause problems in the chill chain, for example during loading, unloading, delivery operations and temporary storage. All of these stages can introduce delays and are normally not well monitored in terms of ambient temperature, at least not as well as the transportation links themselves. When ambient temperature rises, heat is transferred from the environment through the insulating packaging and starts affecting the product quality through stimulation of spoilage processes. The type of packaging used decides how serious this thermal load becomes, but factors such as air velocity and humidity also affect the transfer of heat from the environment through packaging. The effect of including frozen cooling packs inside fresh fish boxes has been studied (Margeirsson *et al.,* 2009; Margeirsson *et al.,* 2010). Their findings revealed that using cooling packs in fish boxes is an effective way to protect fresh fish fillets against temperature abuse. The same study showed that the insulating performance of expanded polystyrene boxes is significantly better than of corrugated plastic boxes, independent of usage of cooling mats, but the difference is even larger if cooling mats are used (Margeirsson *et al.,* 2010). Thus the management of the chilling chain can become more effective and efficient by taking into account all data from the value chain.

To retrieve the necessary information to monitor the temperature of the product, time-temperature indicators can be used. These are small devices or labels that can be attached to the food or the food package and are in close contact with the food. They show an easily measurable, time-temperature dependent change which must be irreversible and easily correlated to the food deterioration process and remaining shelf-life (Taoukis and Labuza, 1989). Because actual temperature measurements at all stages of the value chain of fresh fish may not be feasible, the use of time-temperature indicators has been suggested to enable estimation of the shelf-life of fresh seafood products (Kreyenschmidt *et al.,* 2010; Riva *et al.,* 2001; Taoukis and Labuza, 1989; Tsironi *et al.,* 2008).

ENVIRONMENTAL DECISION SUPPORT

The emphasis on the environment in the marketing of seafood products has increased greatly during the last decade. This has come about for at least two reasons. Firstly, pressure from non governmental organisations, consumer organisations and retailers has demanded it and, secondly, if seafood companies want to remain in business in the long term, they need to ensure a sustainable utilisation of fish stocks, otherwise they will have no raw material. Long term interests for an industry must be kept in mind at all times. For Icelanders, the crash in the herring stocks in the late 1960s, with the resulting economic crisis, was a tough lesson.

Life cycle assessment (LCA) evaluates the impacts that a product has on the environment over the entire period of its life cycle. One of the shortcomings of the method is, however, that it does not fully take into account the different origins of raw materials and the routes they take in the value chain. It is however widely used and may be among the most advanced tools available for environmental impact assessment.

In recent research, Guttormsdóttir (2009) studied two different value chains in Iceland; the catching of cod by long liners and by bottom trawlers. The environmental impacts of both catching methods were evaluated by applying LCA. Information from the processing phase was gathered and the product was followed from the processing plant to Sevilla in Spain were it was sold and consumed. The study revealed that fish caught by bottom trawling has a larger environmental impact than long line caught cod, within all categories assessed such as climate change, respiratory organics/inorganics, ecotoxicity, acidification and fossil fuel. The most environmentally unfriendly phase within both methods is the fishery phase, the reason being the heavy fossil fuel consumption. To elaborate, 1.1 litre of fuel was consumed by the trawler to obtain 1 kg of processed cod compared with 0.36 litres by the long liner to obtain the same amount of cod. Substantial environmental impact also arises from the processing phase, especially within the trawled cod product – this is mainly because of the refrigerants used in the processing plant. For long lined cod the second greatest environmental impact is the transportation with most of the environmental impact coming from the trucks that transport the product in Iceland and in the target country. Carbon footprints were also calculated. The trawled cod resulted in 5.14 kg CO2 equivalence while the long lined cod was calculated to be 1.58 kg CO2 equivalence. Much further research is needed to assess the environmental impact of a wider range of seafood products in different value chains so that catching, processing and transportation can become more environmentally friendly.

FURTHER WORK

The future of fisheries is based on the ability to maintain, or increase, production. However, this must be done in such a way that fish stocks are not overutilised, and that diversity and the well-being of the environment and society are maintained. One key to attain this is by ensuring traceability in the value chain and enhancing the use of it for managerial decision making. This is one of many important areas for future research and development in the seafood industry.

First of all, it is clear that the databases already maintained by many modern fisheries represent a great deal of untapped potential. Converting this data into useful information, through optimization models, statistical methods or any type of DSS could prove extremely useful for the decision makers. Moreover, regulatory authorities may also benefit from further utilization of the raw data collected over the years, including use of industry data. Still more data is needed as an input for DSSs and preferably this data should be collected automatically throughout the value chain.

Another issue that should be addressed in the near future is the sustainability of the seafood value chain. The value chain concept should be more tightly integrated in the day-to-day operations and information should be made available that will help companies to support the long term sustainability of their operations.

One may well foresee an extended version of LCA (call it LCA+) that uses traceability to allow even better analyses than are possible with current LCA methodology. This enhanced methodology will better incorporate ethical and socio-economic aspects. Moreover, LCA+ will allow its application to different food production chains to elicit differences with respect to sustainability attributes. It will enable Food Business Operators (FBOs) and other stakeholders to identify sustainability hot spots within production, processing, packaging and transportation, as well as allow for comparisons across various chains.

With the current use of DSS, most focus is put on financial outcome and optimisation of processes. However there is a need for a tool such as LCA+, or a system supporting decisions regarding environmental aspects of the value chain, which also takes economic factors into account. For an ideal DSS system to become useful the following data and parameters must be incorporated:

- Real-time traceability data;
- LCA+ results from analysis with the new parameters and data provision time-temperature indicators;
- Identified sustainability indicators;
- Expected consumer behaviour, if available. Consumer values of interest to FBOs relate thereby to increased demand or wider price margins for products meeting obvious consumer needs. They will support sustainable management with respect to their business operations.

By these means, managers within the respective chains will be able to use the DSS to aid decision making that can affect sustainability. Increased sustainability can then be achieved when informed decisions can be taken by the FBOs themselves and informed assessment can be performed by other stakeholders e.g. governmental agencies, certification agencies and NGOs.

Because the overall sustainability level of products consists of the sum of the sustainability of the operations throughout the production chain, an integrated approach is required. It is therefore necessary to increase the effort to utilise and disseminate information from all production processes in production chains – from catching the fish, through the value chain to the consumers buying the food in retail outlets or in a restaurant. A method such as LCA+ would be extremely useful for attaining these goals of transparency, traceability and improved decision making.

REFERENCES

Anonymous. 2007. *Nytjastofnar sjávar 2006/2007, aflahorfur fiskveiðiárið 2007/2008 (State of marine fish stocks in Icelandic waters 2006/2007, prospects for the quota year 2007/2008).* Hafrannsoknastofnunin Fjolrit 129. 180 pp. (in Icelandic, English summary)

Árnason, I.J.P. 2004. Impact of the cost of the time resource on efficiency of economic processes. *European Journal of Operational Research*, 172: 616–630.

Bechini, A., Cimino, M.G.C.A., Lazzerini, B., Marcelloni, F. & Tomasi, A. 2005. *A general framework for food traceability*. Paper presented at the Proceedings of the 2005 Symposium on Applications and the Internet Workshops (SAINT-W'05).

Codex Alimentarius Commission. 2008. *Procedural Manual, 18th Edition*. Joint FAO/WHO Food Standards Programme. Rome, WHO and FAO. 188 pp.

Can-Trace. 2007. *Cost of traceability in Canada: developing a measurement model*. AAFC No. 10327E. Ottawa, Agriculture and Agri-Food Canada.

Deasy, D.J. 2002. Food safety and assurance: the role of information technology. *International Journal of Dairy Technology*, 55(1): 1–4.

Dupuy, C., Botta-Genoulaz, V. & Guinet, A. 2005. Batch dispersion model to optimise traceability in food industry. *Journal of Food Engineering*, 70(3): 333–339.

EC. 2002. Regulation (EC) No 178/2002 of the European Parliament and of the Council. *Official Journal of the European Communities*.

Frederiksen, M., Østerberg, C., Silberg, S., Larsen, E. & Bremner, A. 2002. Info-Fisk. Development and validation of an internet based traceability system in a Danish domestic fresh fish chain. *Journal of Aquatic Food Product Technology*, 11(2): 13–34.

Golan, E., Krissoff, B., Kuchler, F., Calvin, L., Nelson, K. & Price, G. 2004. *Traceability in the US food supply: economic theory and industry studies*. Document Number 830. Washington, DC, Economic Research Service, USDA.

GS1. 2009. *GS1 Standards Document GS1 Global Traceability Standard*. Vol. 1.1.0. 77 pp.

Guttormsdóttir, A.B. 2009. *Life cycle assessment on Icelandic cod product based on two different fishing methods*. Reykjavík, University of Iceland, School of Engineering and Natural Sciences. (MSc thesis)

Hobbs, J.E. 2003. Traceability in Meat Supply Chains. Current Agr., Food, and Resource, (4), 36–49.

ISO 9000:2000. 2000. *Quality management system - fundamentals and vocabulary*. International Organization for Standardization.

Jóhannesson, S. & Agnarsson S. 2007. *The fishing industry's share in the national economy.* Document number C07:05. Reykjavík, Institute of Economic Studies, University of Iceland.

Kreyenschmidt, J., Christiansen, H., Hübner, A., Raab, V. & Petersen, B. 2010. A novel photochromic time-temperature indicator to support cold chain management. *International Journal of Food Science and Technology*, 45(2): 208–215.

Mai, N., Margeirsson, B., Margeirsson, S., Bogason, S., Sigurgisladottir, S. & Arason, S. 2011. Temperature mapping of fresh fish supply chains – air and sea transport. *Journal of Food Process Engineering*, 34: [online] no. doi: 10.1111/j.1745-4530.2010.00611.x

Margeirsson, B., Arason, S. & Palsson, H. 2009. *Thermal performance of corrugated plastic boxes and expanded polystyrene boxes*. Report no. 01-09. Matiso.

Margeirsson, S., Jónsson, G.R., Arason, S. & Thorkelsson, G. 2007. Processing forecast of cod - Influencing factors on yield, gaping, bruises and nematodes in cod (*Gadus morhua*) fillets. *Journal of Food Engineering*, 80: 503–508.

Margeirsson, S., Nielsen, A.A., Jonsson, G.R. & Arason, S. 2006. Effect of catch location, season and quality defects on value of Icelandic cod (*Gadus morhua*) products. *In* J.B. Luten, C. Jacobsen, K. Bekaert, A. Sæbø & J. Oehlenschläger, eds. *Seafood research from fish to dish – quality, safety and processing of wild and farmed fish*, pp. 265–274.Netherlands, Wageningen Academic Publishers.

Margeirsson, B., Gospavic, R., Palsson, H., Arason, S. & Popov, V. 2010. Experimental and numerical modelling comparison of thermal performance of expanded polystyrene and corrugated plastic packaging for fresh fish. *International Journal of Refrigeration*, 34(2): 573–585.

Olsen, P. & Karlsen, K.M. 2005. *Material flow and information flow at Insalus, a mineral water company*. Report no. 17/2005. Tromso, Norway, Fiskeriforskningo.

Olsson, A. & Skjöldebrand, C. 2008. Risk management and quality assurance through the food supply chain –- case studies in the Swedish food industry. *Open Food Science Journal*, 2(1): 49.

PL107-188. 2002. *Public Health Security and Bioterrorism Preparedness and Response Act of 2002* [online]. frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=107_cong_public_lawsanddocid=f:publ188.107.pdf

Poghosyan, A., Gonzalez-Diaz, F. & Bolotova, Y. 2004. Traceability and assurance protocols in the global food system. *International Food and Agribusiness Management Review*, 7(3): 118–126.

Porter, M.E. 1985. *Competitive advantage*. New York, USA, Free Press.

Riva, M., Piergiovanni, L. & Schiraldi, A. 2001. Performances of time-temperature indicators in the study of temperature exposure of packaged fresh foods. *Packaging Technology and Science*, 14(1): 1–9.

Schwägele, F. 2005. Traceability from a European perspective. *Meat Science*, 71(1): 164–17.

Sigurdsson, T. 2006. *State of marine fish stocks in Icelandic waters 2005/2006. Prospects for the quota year 2006/2007*. Document Number 129. Reykjavik, Marine Research Institute.

Sivertsvik, M., Jeksrud, W. & Rosnes, J. 2002. A review of modified atmosphere packaging of fish and fishery products - significance of microbial growth, activities and safety. *International Journal of Food Science and Technology*, 37: 107–127.

Taoukis, P.S. & Labuza, T.P. 1989. Applicability of time-temperature indicators as shelf-life monitors of food products. *Journal of Food Science*, 54(4): 783–788.

Tsironi, T., Gogou, E., Velliou, E. & Taoukis, P.S. 2008. Application and validation of the TTI based chill chain management system SMAS (Safety Monitoring and Assurance System) on shelf-life optimization of vacuum packed chilled tuna. *International Journal of Food Microbiology*, 128(1): 108–115.