# DATA COLLECTION AND USE IN THE ICELANDIC FISHING INDUSTRY

June 2010

**Ari Ólafsson**

Master of Science in Decision Engineering

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# Data Collection And Use In The Icelandic Fishing Industry

by

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at Reykjavík University in partial fulfillment of
the requirements for the degree of
**Master of Science** in **Decision Engineering**

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## Abstract

Apart from geothermal and hydro-electric energy, Iceland boasts only one significant natural resource: the fish in the ocean. The country's economy depends heavily on revenues generated by seafood exports and will continue to so for the foreseeable future. With customers increasingly demanding freshness and traceability, it is important as ever to experiment with innovative solutions. Most Icelandic fisheries already collect vasts amount of data, e.g. through electronic log-books. By converting this data into useable information, both long- and short-term decision making could be greatly eased. Furthermore, such information could present regulatory authorities with a powerful weapon to combat a built-in problem of the ITQ system, namely, at-sea discarding of fish.

# Gagnasöfnun og -notkun í íslenskum sjávarútvegi

Ari Ólafsson

Júní 2010

## Útdráttur

Að undanskilinni þeirri orku sem fæst úr jarðvarma og vatnsföllum, býr Ísland aðeins að einni raunverulegri náttúruauðlind; fiskimiðunum. Frá landnámi hefur þjóðin nýtt þau bæði til fæðuöflunar og sköpunar útflutningsverðmæta. Hlutfallslegt mikilvægi sjávarútvegsins í útflutningi er enn hátt, og eftir hremmingar síðustu ára er ljóst að svo verður um ókomin ár. Því er mikilvægt sem aldrei fyrr að viðhalda, og auka, arðsemi iðnaðarins. Til að mæta kröfum neytenda um ferskleika hráefnis og rekjanleika verður að gera ákvarðanatöku skilvirkari. Sjávarútvegsfyrirtæki safna nú þegar miklu magni gagna, t.d. gegnum afladagbækur, sem bjóða upp á mikla möguleika í þessum efnum. Með því að beita á þau aðferðum aðgerðagreiningar og tölfræði mætti auðvelda alla ákvarðanatöku til muna. Í gagnaathugun gæti einnig leynst öflugt vopn gegn óhjákvæmilegum fylgifiski kvótakerfisins, brottkasti.

*To Hugo, with whom I had so many wonderful years*

# Acknowledgements

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# Chapter 1

# Introduction

For a good reason, Iceland has long been synonymous with the fishing industry. Ever since the country gained independence in 1944, seafood products have been at the backbone of its economy, representing a majority of the industrial export value until relatively recently. They still account for a major percentage, 39.1% in 2009 [13], even though the economy has in the last decade diversified into various other sectors, notably investment banking and power-intensive industries. With the collapse of the Icelandic banking system in late 2008 there is little doubt that the small island nation will rely heavily as ever on fishing in the coming years.

Maintaining, and increasing, the profitability of the industry is therefore important as ever. Due to constraints imposed by quota regulations however, that is not simply a matter of catching more fish. On the contrary, total allowable catch (TAC) has decreased historically and seems likely to continue to do so [22]. With the supply of raw material constrained, revenues are mainly determined by the raw material yield and product prices obtained. Over the years Icelandic fisheries have focused on these variables, managing to largely maintain the total value of fish caught despite decreasing catch volumes [14].

Technological advances in the past years have made it increasingly simple to collect and store detailed data on the quality of fish caught at different times in different areas. Most Icelandic fisheries already maintain large databases to meet legal requirements and quality standards. Electronic log-books have for instance gradually been made mandatory, with every vessel in Icelandic waters required to maintain one from June 16, 2010 [23]. The data collected remains largely unused, but it has a great deal of potential for easing decision making.

# Chapter 2

# Background

## 2.1 Recent Developments

The market for seafood products has undergone dramatic changes in the past years. Consolidation of retailers has created international companies selling a large part of their products under their own label. The size of these conglomerates enables them to put pressure on producers with regard to prices. This development, coupled with increasing competition from not only other seafood producers but also producers of e.g. chicken, suggests that economics of scale will play a big part when competing for the attention of consumer with decreasing buying power. With food products expected to become more expensive in the future however, e.g. due to competition for raw materials with the energy sector, sharp decreases in prices are unlikely [28].

Another significant change has to do with increased customer awareness of things such as health and sustainability. While fish has long been acknowledged to have a positive effect on health [10], the subject of sustainability has only recently begun affecting consumer behaviour. Specialist stores have sprouted in recent years. These cater mainly to higher earning consumers, offering style and differentiation at an extra cost. Products are commonly sold with statements or guarantees of sustainability or origin, so traceability has become a major issue. Although the current economic climate will no doubt lead consumers toward focusing mainly on prices, it is fairly safe to assume that environmental concerns will be a priority in coming years.

While attempting to keep up with customer demands, Icelandic fisheries are also subjected to an increasingly constrained supply of raw material. The total amount of fish caught in Icelandic waters is constrained by regulation, i.e. quotas. These quotas are determined by the government under recommendation by the MRI (Marine Research Institute). As evident from Figure 2.1, the TAC has almost consistently decreased since the inception of the ITQ (Individual Transferable Quotas) system in 1984. Keeping in mind a recent report on the Icelandic fish stocks by the MRI, that trend seems unlikely to change drastically [22]. Aquaculture might hold the solution to this problem and it has gained considerable ground in Iceland, especially in the last decade [9].

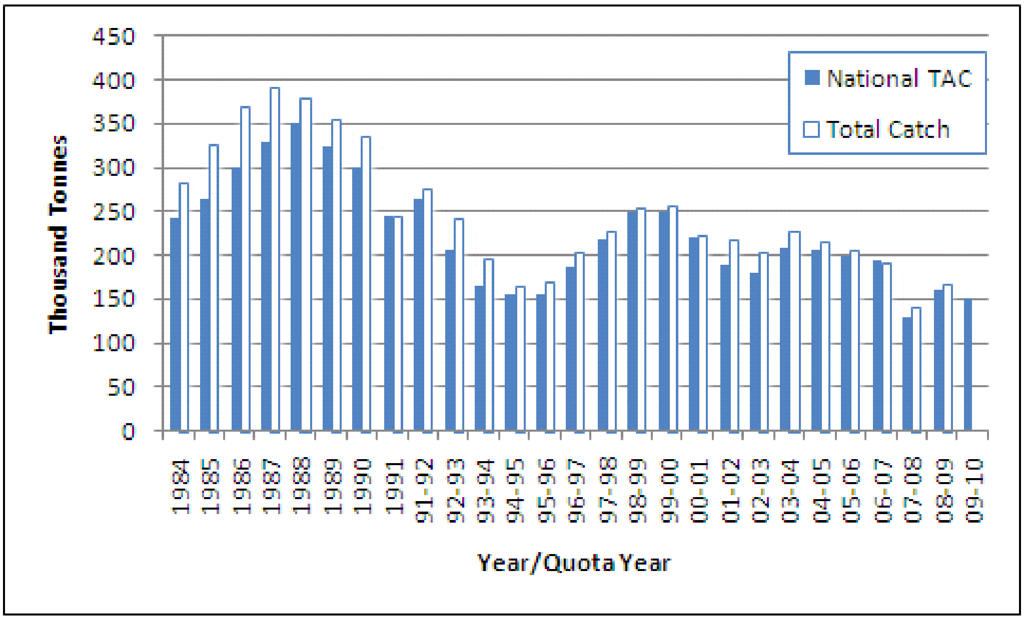


Figure 2.1: Catch volume and quotas for cod in Icelandic waters from 1984-2010 [22]. The TAC has almost constantly declined during that time, reaching an all time low in 2007-2008. The differences observed between landings and TAC are mostly due to catches caught under the effort regime not being taken into account [7]. Fishing effort control was gradually removed, beginning in the quota year 2004-2005, resulting in TAC exceeding landings in 2007-2008 for the first time.

## 2.2 The Problems Facing Icelandic Fisheries

In terms of the seafood value chain, the developments discussed above have placed pressure on the processing link of the chain. The flow of goods has largely reversed from pushing to pulling, meaning customers now mostly set the standard by requesting products with certain characteristics. Customer focus has been towards fresh products in the last decades, with traceability and sustainability also becoming increasingly important [18].

These demands have pushed the seafood industry towards closer cooperation between links in the value chain, because the activities included in the chain are heavily interdependent [11]. Decisions made in fishing, processing and labour allocation may therefore play a part in determining the final quality, and price, of a product. That means that in order to supply fresh fish markets with quality products; trawler scheduling, handling of raw material, process scheduling, product mix and logistics must be coordinated. Otherwise there is a danger of factors such as improper handling early on affecting the quality of the end product, and thereby the final price obtained. Improper cooling or icing will, for example, result in higher temperature of the flesh, stimulating bacteria growth. These bacteria in turn shorten shelf life, which is immensely important to retailers.

The age of the raw material is also important, making a well organized time plan from catch to processing necessary. Producers having more time to process a given quantity of raw material can be expected to produce more valuable products than producers struggling under time pressure, so sufficient time for processing and beforehand knowledge of the raw material to organize the processing is very important.

The cost of catching and processing is also something to consider. Ideally, producers prefer fish that both satisfies quality demands and can be caught relatively close to the processing plant. The latter is immensely important because long trips to and from catching grounds will not only increase oil costs but also make it more difficult to supply consumers with fresh products. To give an indicator of how long distances can affect the bottom line, it was estimated in 2004 that an average trawler uses 25% of its total oil consumption on sailing (i.e. not on catching) [2]. Since oil costs currently account for more than 45% of total operational costs of trawlers [24], this is not an insignificant amount. There is no doubt that oil prices are a major influencing factor on the profitability of the fisheries.

Another common problem faced by processing managers is staff scheduling in the processing plant. The most manually intensive process in the captured fish chain is the trimming and final de-boning of the fish fillet. To estimate the number of employees needed, the production manager needs to know not only the expected performance of the workers, but also how labour intensive the trimming is expected to be. By maintaining a performance history for each employee it is possible to get a good idea of the production capacity at each time, but estimating the labour intensity of the trimming is considerably more complex. The work involved in manual trimming depends mainly on the size of the fish, but also its species, size and texture. Generally, the fish species is known in advance, but detailed data about the other properties are not directly available in advance. What is known is that many other factors, like fishing area, time of year, temperature, gear type and treatment on board, influence the size, shape and texture [18]. Important decisions must therefore be made based on a large, complex and interrelated set of data, some known and some estimated. Getting the number of employees right is obviously quite important. Too many, and trimmers stand idle. Too few, and a bottleneck forms in front of the trimming line which in turn causes a significant increase in throughput time, and a corresponding decrease in quality of the finished product.

## 2.3 Quantitative Methods Used in Icelandic Fisheries

Considering the relative importance of the fishing industry to the Icelandic economy, it is not surprising that a great deal of research has focused on it. Various quantitative techniques have been employed, notably operations research. Simulation and optimization models have been built and experimented with, although no such model has been widely accepted or used. This is largely due to a lack of comprehensive and reliable database. Following is a short review of research focusing on the Icelandic fishing industry.

The first OR project concerning the Icelandic fishing industry was carried out in 1966 when a computer program simulating the fishing and landing of herring was built. The project was collaborated on by an Icelandic and Danish team [25]. The next major project was carried out by Sigvaldason et al. in 1969, who compared the economics of different sizes and types of trawlers [29].

In 1981, Jensson introduced a simulation model for analyzing fleet operation. His focus was, among other things, on analyzing the effect of fleet operations on total catch and utilization of different factories and boats [15]. A later project by Jensson, concerning the day-to-day production planning of a fishery, is also of interest [16].

In the late 1990's, Ólafsson et al. were commissioned by the Ministry of Fisheries to build a simulation model. It utilized existing databases and served as a support tool in fisheries management [12]. Another simulation model was constructed by Millar and Gunn in 1990. It assessed the impact of catch rate variability on the cost-performance of a coordinated fishing fleet. Their conclusion was that such models could serve as useful decision making tools in the industry [21].

In 1994, Wallace et al. introduced a model of a national fishing fleet operated by a number of independent companies. The model, developed by Icelandic and Norwegian scientists, simulated the fishing stocks, quota system and decision making of individual companies [30].

Combining a simulation model with a linear optimisation model, Randhawa and Bjarnason in 1992 attempted to analyze trawler operations and determine labour requirements, inventory and production levels to maximize net revenues. They concluded that such integrated models showed great promise as decision support tools [26]. In 2006, Hasan and Raffensberger offered an even more detailed model which coordinated trawler scheduling, fishing, processing and labor allocation of a fishery [11].

Finally, it is well worth mentioning the 2007 dissertation by Margeirsson [18]. Analysing comprehensive data on cod catching and processing collected between 2002 and 2006, he built an optimisation model to ease decision making. A 2006 MSc thesis by Guðmundsson built on the work of Margeirsson and presented another optimisation model [8]. That model aimed to help decision makers schedule fishing and allocate the catch, and it serves as the basis for the model considered in this paper.

# Chapter 3

# Methods

As mentioned earlier, the Icelandic fishing industry relies on various technological solutions in both locating and processing fish. In addition to maintaining electronic logbooks, most companies also use state-of-the-art processing and accounting software. Vast amounts of electronic data on the catch and its properties are collected, presenting decision makers with various interesting possibilites. The challenge lies in converting the raw data into information, and putting that information to use.

This paper attempts to show that quantitative methods can be of use in all aspects of decision making in the fishing industry, both short- and long-term. Long-term decision making is used to refer to planing the operations of the company as whole over an extended period of time, e.g. a year. Short-term decision making on the other hand implies greater immediacy, for instance adapting the long-term plan with a week's notice to account for something unexpected. Also, an interesting idea that could be of use to regulatory authorities is presented. It involves using statistical methods to compare the size range reported by individual vessels with what has been observed in the past. This could help combat at-sea discarding, a built in problem of the ITQ system.

# Chapter 4

# Experiments

## 4.1 Long-Term Decision Making

At the beginning of each quota year, a vessel (or a fishery operating several vessels) is allocated a certain quota. Over the course of the next twelve months the decision makers aim to maximise the net profit of the operation as a whole, subject to certain constraints. To this purpose, various optimisation models have been built and experimented with, some of which were mentioned earlier. However, no model has yet achieved widespread use or been acknowledged as a success [8].

The model presented below is based on a model built by Guðmundsson and presented in his 2006 MSc thesis [8]. It is part of the FisHmark software currently being collaborated on by a number of Icelandic companies. It solves a multi-commodity network flow problem that describes the entire operation of a fishery. Multi-commodity refers to the fact that goods flow through the network between different source and sink nodes. The known solutions to a problem of this sort are all based on linear programming [6].

### 4.1.1 Modeling Preliminaries

As mentioned before, the qualities, or attributes, of the goods change depending on their route through the network [27]. The seven different indices used to keep track of these changes are listed and defined in Table 4.1.

The model returns values of thirteen decision variables, listed in Table 4.2. They can be described as belonging to one of three tiers. The first tier covers the actual catching and processing of the fish, determining the production quantity of each product, employee

Table 4.1: Indices used by optimisation model.

| Index | Definition |
|---|---|
| $v$ | Fishing area |
| $s$ | Vessel |
| $h$ | Harbor |
| $r$ | Producer (plant, market, etc.) |
| $a$ | Product |
| $t$ | Time period (months/quarters) |
| $f$ | Species |

hours at the processing plant, and days spent in each fishing area. The second tier variables all relate to the use of quota - how much is transferred or rented to and from each species, and how much quota is left unused. The third tier consists of variables that determine how much fish is caught in each area and how and where it is produced.

Table 4.2: Decision variables used by optimisation model.

| Decision Variable | Definition |
|---|---|
| $U_{at}$ | Quantity of product $a$ produced |
| $WH_{rt}$ | Working hours at processing plant $r$ |
| $OH_{rt}$ | Overtime hours at processing plant $r$ |
| $Days_{vsth}$ | Days spent by vessel $s$ in area $v$ |
| $TO_f$ | Quota transferred from species $f$ |
| $TI_f$ | Quota transferred to species $f$ |
| $RO_f$ | Quota rented from species $f$ |
| $RI_f$ | Quota rented to species $f$ |
| $Qused_f$ | Used quota in species $f$ |
| $Qunused_f$ | Unused quota in species $f$ |
| $C_{vshtf}$ | Species $f$ caught in area $v$ by vessel $s$ |
| $Cass_{vshrtf}$ | Species $f$ caught in area $v$ by vessel $s$ and assigned to producer $r$ |
| $Cprod_{vshrtf}$ | Species $f$ caught in area $v$ by vessel $s$, assigned to producer $r$ and product $a$ |

To yield accurate and useful results, the model requires a large amount of data. Gathering the data is relatively straightforward and mostly a matter of extracting numbers from different databases. Product prices and employee wages for instance are readily available through accounting software, while expected catch quantities and yields can be estimated using historical data. Table 4.3 lists all the scalars needed and gives explanations of what they stand for.

Table 4.3: Data and constants used by optimisation model.

| Data | Definition |
|---|---|
| $EXP_{svhtf}$ | Expected quantity of species $f$ caught by vessel $s$ in area $v$ |
| $Cprice_{rtf}$ | Price of species $f$ to producer $r$ |
| $Vvar_{stvh}$ | Variable operating cost of vessel $s$ |
| $Acost_{rt}$ | Cost of assigning catch to producer $r$ |
| $Y_{vrfat}$ | Yield for species $f$ caught in area $v$, produced by $r$ and resulting in product $a$ |
| $CEQ_f$ | Cod equivalence factor for species $f$ |
| $TRcost_{hrt}$ | Cost of transporting from harbor $h$ to producer $r$ |
| $EFF_{ra}$ | Efficiency of processing plant $r$ |
| $Vfix_{st}$ | Fixed cost of vessel $s$ |
| $Vprop_{st}$ | Proportional cost of vessel $s$ |
| $Dmax_{st}$ | Maximum days at sea for vessel $s$ |
| $Dmin_{st}$ | Minimum days at sea for vessel $s$ |
| $Amax_{tv}$ | Maximum days in fishing area $v$ |
| $Amin_{tv}$ | Minimum days in fishing area $v$ |
| $PPfix_{rt}$ | Fixed cost of processing plant $r$ |
| $PPdays_{rt}$ | Available working days at processing plant $r$ |
| $PPwh_{rt}$ | Available working hours at processing plant $r$ |
| $PPoh_{rt}$ | Available overtime hours at processing plant $r$ |
| $PPhw_{rt}$ | Hourly labor cost at processing plant $r$ |
| $PPow_{rt}$ | Overtime labor cost at processing plant $r$ |
| $EMP_{rt}$ | Number of employees at processing plant $r$ |
| $PPown_{rt}$ | Binary variable that equals 1 if plant $r$ is ours but 0 otherwise |
| $Q_f$ | Quota in species $f$ |
| $RImax_f$ | Maximum allowed rent increase in species $f$ |
| $ROmax_f$ | Maximum allowed rent decrease in species $f$ |
| $Rprice_f$ | Rent price for species $f$ |
| $Qexp_f$ | Tax for exporting unprocessed fish of species $f$ |
| $Qdisc_f$ | Quota discount for fish of inferior size |
| $QTmax_f$ | Maximum allowable increase of quota in species $f$ |
| $Lprop_h$ | Proportional cost of landing at harbor $h$ |
| $Lfix_h$ | Fixed cost of landing at harbor $h$ |
| $Price_{at}$ | Price of product $a$ |
| $Contracted_{at}$ | Quantity of product $a$ needed to fulfill sales contracts |
| $Rcost$ | Cost of renting quota |
| $MCR$ | Minimum allowable caught ratio |
| $MQD$ | Maximum quota decrease through renting |

### 4.1.2 Objective Function

As previously mentioned, the model aims to maximise the net profits of the vessels and processing plants as a whole. This requires considering the costs incurred and revenues generated by both factors. First considering the vessels, Equation 4.1 adds up the entire income of the entire fleet. It consists of the sales price of the fish caught, along with what is earned through renting out quota.

$$\begin{aligned} Vessel\ Revenues &= \sum_f \sum_r \sum_t \sum_v \sum_h \sum_s Cprice_{rtf} Cass_{vshrtf} \\ &+ \sum_f RO_f Rprice_f \end{aligned} \tag{4.1}$$

Similarly, the total costs are calculated by adding up a number of terms as shown in Equation 4.2. It covers the fixed, variable and proportional operating costs, as well as the costs incurred through landing and distributing the fish. Also included is the money spent on renting quota to and from the vessel.

$$\begin{aligned} Vessel\ Costs &= \sum_s \sum_t Vfix_{st} \\ &+ \sum_v \sum_s \sum_t \sum_h Vvar_{stvh} \cdot Days_{vsth} \\ &+ \sum_f \sum_r \sum_t \sum_v \sum_h \sum_s Cprice_{rtf} \cdot Cass_{vshrtf} Vprop_{st} \\ &+ \sum_v \sum_h \sum_r \sum_t \sum_f \sum_s Cass_{vhrtfs} \cdot Lfix_h \\ &+ \sum_v \sum_h \sum_r \sum_t \sum_f \sum_s Lprop_h \cdot Cass_{vhrtfs} \cdot Lfix_h \cdot Cprice_{rtf} \\ &+ \sum_v \sum_h \sum_r \sum_t \sum_f \sum_s Acost_{rt} \cdot Cass_{vshrtf} \\ &+ \sum_f RI_f \cdot Rprice_f + Rcost \cdot \sum_f RO_f \cdot Rprice_f \end{aligned} \tag{4.2}$$

The net profits of the vessels can then be calculated by subtracting Equation 4.2 from Equation 4.1.

The processing plants must also be considered. As shown in Equation 4.3, their profits consist simply of what is generated through product sales.

$$Plant\ Revenues = \sum_a \sum_t U_{at} \cdot Price_{at} \tag{4.3}$$

Processing plant costs are calculated using Equation 4.4. It consists of the total wages paid to employees, including overtime, along with raw material, transportation and fixed operating costs.

$$
\begin{aligned}
Plant\ Costs \;=\;& \sum_r \sum_t PPown_{rt} \cdot WH_{rt} \cdot PPhw_{rt} \cdot EMP_{rt} \\
+\;& \sum_r \sum_t OH_{rt} \cdot PPow_{rt} \cdot EMP_{rt} \\
+\;& \sum_f \sum_r \sum_t \sum_v \sum_h \sum_s Cprice_{rtf} \cdot Cass_{vshrtf} \\
+\;& \sum_h \sum_r \sum_t \sum_v \sum_s \sum_f TRcost_{hrt} \cdot Cass_{vshrtf} \\
+\;& \sum_r \sum_t PPfix_{rt} \qquad (4.4)
\end{aligned}
$$

The net profits of the plant can then be calculated by subtracting Equation 4.4 from Equation 4.3.

Using the above equations, the objective function can be described in a concise way. It simply maximises the net profits of the operations of a whole by adding together the results for both the vessels and processing plants being considered.

$$\max\ [Vessel\ Revenues - Vessel\ Costs] + [Plant\ Revenues - Plant\ Costs] \quad (4.5)$$

### 4.1.3 Constraints

The constraints of an optimisation model serve as boundaries to the solution space, determining the feasibility of solutions. In this case, the constraints ensure that all rules and requirements of the ITQ system are met, while also preventing the model from returning unpractical solutions.

The first constraint ensures that the total quota assigned to, or acquired by, the company equals the quota used by, or transferred from, the company.

$$RO_f + TO_f + Qused_f + Qunused_f \;=\; Q_f + RI_f + TI_f \qquad \forall f \quad (4.6)$$

The second constraint states that the total quota used, i.e. the fish caught, is equal to what is distributed to markets or processing plants.

$$Qused_f \;=\; \sum_v \sum_s \sum_t \sum_h \sum_r Cass_{vshrtf} \qquad \forall f \quad (4.7)$$

The ITQ system specifies a maximum allowable increase and decrease in quota in each species through renting, 4.8-4.9. Similarly, there is a limit on how much quota can be transferred between species, 4.10-4.12.

$$
\begin{aligned}
RI_f &\leq RImax_f & \forall f \quad (4.8)\\
RO_f &\leq ROmax_f & \forall f \quad (4.9)\\
\sum_f CEQ_f \cdot TI_f &= \sum_f CEQ_f \cdot TO_f & \forall f \quad (4.10)\\
\sum_f CEQ_f \cdot TI_f &\leq MQD \cdot \sum_f CEQ_f \cdot Q_f & \forall f \quad (4.11)\\
\sum_f TI_f &\leq QTmax_f \cdot \sum_f CEQ_f \cdot Q_f & \forall f \quad (4.12)
\end{aligned}
$$

It is also necessary to makes sure that the total catch is equal to what is assigned to producers, and in turn that what is assigned equals what is produced.

$$
\begin{aligned}
C_{vshtf} &= \sum_r Cass_{vshrtf} & \forall f \quad (4.13)\\
Cass_{vshrtf} &= \sum_a Cprod_{vshrtf} & \forall f \quad (4.14)
\end{aligned}
$$

The total quantity of each product produced in a certain period can never be greater than the product of the quantity and projected yield of the raw material supplied.

$$
U_{at} \leq \sum_s \sum_v \sum_h \sum_f \sum_r Y_{vrfat} \cdot Cprod_{vshrtf} \qquad \forall a, t \quad (4.15)
$$

The next three constraints relate to the fishing process itself. They give a maximum for the quantity of fish caught, and give a minimum and maximum lenght of fishing trips.

$$
\begin{aligned}
C_{vshtf} &\leq Days_{vsth} \cdot EXP_{svhtf} & \forall v, s, t, h, f \quad (4.16)\\
\sum_v \sum_h Days_{vsth} &\leq Dmax_{st} & \forall s, t \quad (4.17)\\
\sum_v \sum_h Days_{vsth} &\geq Dmin_{st} & \forall s, t \quad (4.18)
\end{aligned}
$$

There is also a maximum and minimum of days spent in each fishing area.

$$\sum_s \sum_h Days_{vsth} \leq Amax_{tv} \qquad \forall v, t \quad (4.19)$$

$$\sum_s \sum_h Days_{vsth} \geq Amin_{tv} \qquad \forall v, t \quad (4.20)$$

Four constraints cover the processing plant. The first one ensures that the production quantity is sufficient to cover all sales contracts. The second one limits the production capacity, as determined by the number of employees and available hours. The last two limit the number of working hours that can be scheduled.

$$U_{at} \geq Contracted_{at} \qquad \forall a, t \quad (4.21)$$

$$WH_{rt} \cdot EMP_{rt} + OH_{rt} \cdot EMP_{rt} \geq \sum_a \sum_s \sum_f \sum_v \sum_h \frac{Y_{vrfat} \cdot Cprod_{vshrtf}}{EFF_{ra}} \forall r, t \quad (4.22)$$

$$WH_{rt} \leq PPdays_{rt} \cdot PPwh_{rt} \qquad \forall r, t \quad (4.23)$$

$$OH_{rt} \leq PPdays_{rt} \cdot PPoh_{rt} \qquad \forall r, t \quad (4.24)$$

The last constraint guarantees that the minimum catch ratio (i.e. the ratio of quota that must be used) is adhered to.

$$\sum_v \sum_s \sum_h \sum_t \sum_f CEQ_f \cdot C_{vsht\,f} \geq \sum_f MCR \cdot CEQ_f \cdot Q_f \quad (4.25)$$

### 4.1.4 Discussion

The above model yields a rough blueprint of how a fishery should organise itself over an extended period of time, typically a quota year. However, it is important to realise that due to the inherit uncertainty of the industry, for instance with regard to the state of fish stocks, such a plan can never be completely accurate and must therefore be constantly questioned. It makes sense to stay roughly within the parameters suggested by the model, while also using data analysis and the experience of captains to make alternations. This way of also thinking short-term lets us take unforeseen events into account and is discussed below.

### 4.1.5 Short-Term Decision Making

Currently, the predominant method of determining catch location mostly involves the captain of each vessel relying on his past experience and gut instinct [8]. The aim is typically to maximise the catch, catch value or total earnings of each vessel [29]. Due to lack of information, however, captains cannot generally consider the latter two and therefore focus mainly on catch volume. Since the weight of the catch does not necessarily go hand in hand with the quality of it, this method will rarely result in optimal use of the quota. For instance, a captain may focus on an area that has proved fruitful in the past, without considering the cost of travelling or the average quality of the fish caught there. Furthermore, it is impossible for the captain to consider all other factors, such as the production capacity and need of the processing plant. Although this method has obvious short-comings, its often remarkable success suggests that it has some merit. As discussed above, a combination of it and the results of an optimisation model are an interesting option. A more scientific approach to the short-term decision making, while still considering the opinions of experienced people, would complement the optimisation model nicely.

### 4.1.6 Data Overview

We consider data supplied by a prominent Icelandic fishing company. It operates a number of freezing and fresh fish trawlers, and employs a few hundred people. Our focus is on a single fresh fish trawler that catches cod, during the period from May to October in 2008. The trawler is serviced exclusively by one processing plant, and mostly uses one landing harbor. The data was harvested from two seperate databases. Firstly, the electronic log-book that records the location and time of each haul. And secondly, the quality control software used at the processing plant. It records the weight of the raw material at different points during processing, keeping track of the raw material yield obtained. Figure 4.1 is a map of Iceland. The fishing areas visited by the vessell are depicted as numbered circles.

Table 4.4 summarises the data gathered. A total of fourteen fishing trips occur during the time period in question, each lasting around seven days. The landing date refers to the date of unloading at the landing harbour and the order of fishing areas corresponds to what is shown in Figure 4.1. Three yields are shown for each trip. Since the exact numbers are confidential, they are shown relative to the averages obtained in each processing leg. This means that any yields represented by numbers higher than one are above average. Conversely, numbers below one signify below average yields. The most important number

| Fishing Trip | Landing Date | Fishing Area | Intermediate Yields | | |
|---|---|---|---|---|---|
| | | | Heading | Filleting | Trimming |
| 1 | 2008-05-09 | 4 | 1.00474 | 0.99749 | 1.02673 |
| 2 | 2008-05-19 | 1 | 0.99526 | 0.98938 | 1.05221 |
| 3 | 2008-05-26 | 1 | 0.99536 | 0.98894 | 1.03332 |
| 4 | 2008-06-09 | 1 | 0.99643 | 0.96790 | 0.96256 |
| 5 | 2008-06-18 | 1 | 0.99613 | 0.94328 | 0.98427 |
| 6 | 2008-06-25 | 1 | 0.99357 | 1.02379 | 1.05408 |
| 7 | 2008-08-11 | 2 | 0.99874 | 1.02406 | 0.98883 |
| 8 | 2008-08-19 | 1 | 0.99999 | 1.07078 | 1.04816 |
| 9 | 2008-08-28 | 2 | 1.01330 | 1.00041 | 0.94364 |
| 10 | 2008-09-09 | 5 | 0.99876 | 1.02227 | 1.02381 |
| 11 | 2008-09-16 | 2 | 1.00019 | 0.99594 | 0.98976 |
| 12 | 2008-09-23 | 3 | 0.99777 | 0.97049 | 0.97782 |
| 13 | 2008-09-30 | 3 | 1.00676 | 0.98984 | 0.95243 |
| 14 | 2008-10-07 | 3 | 1.00298 | 1.01543 | 0.96238 |

Table 4.4: Details on cod caught by a fresh fish trawler, over a period of roughly six months. Fourteen individual fishing trips occur, each lasting around seven days. Landing dates refer to the date of unloading at the harbour and the order of fishing areas corresponds to what is shown in Figure 4.1. All yields are presented relative to the average obtained during each processing leg.

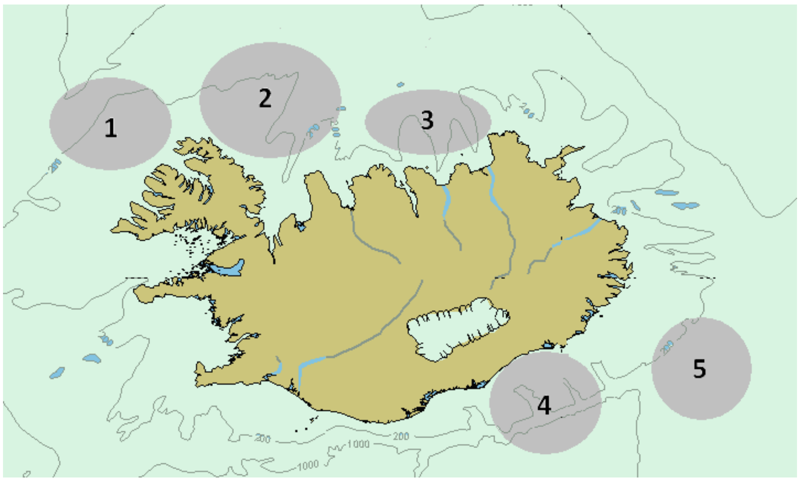


Figure 4.1: A map of Iceland, depicting the five different fishing areas considered. Areas 1-3, located of the north coast, are considerably closer to the landing harbour than areas 4-5, lying to the east of the country.

to decision makers is obviously the trimming yield, shown in the last column. It depends on a number of factors, including the diet and age of the fish caught [3], and has been shown to greatly affect the profitability of fisheries [20, 19]. However, the other numbers are also interesting to examine, specifically, the correlation they have with the trimming yield.

Although the yields above deviate from the average by what might be considered a small range, the magnitude of the fishing industry means that small differences can translate to huge financial losses or gains.

### 4.1.7 Data Analysis

Using data from Table 4.4, fishing trips can be compared. Figure 4.2 shows such a comparison, between trips 2, 5 and 8. The three trips are all to the same fishing area, number one, but occur in different months. They result in roughly the same heading yield, but differences are observed with the other yields. Trips 2 and 8 converge to roughly the same trimming yield, but a significantly lower yield is observed with trip 5.

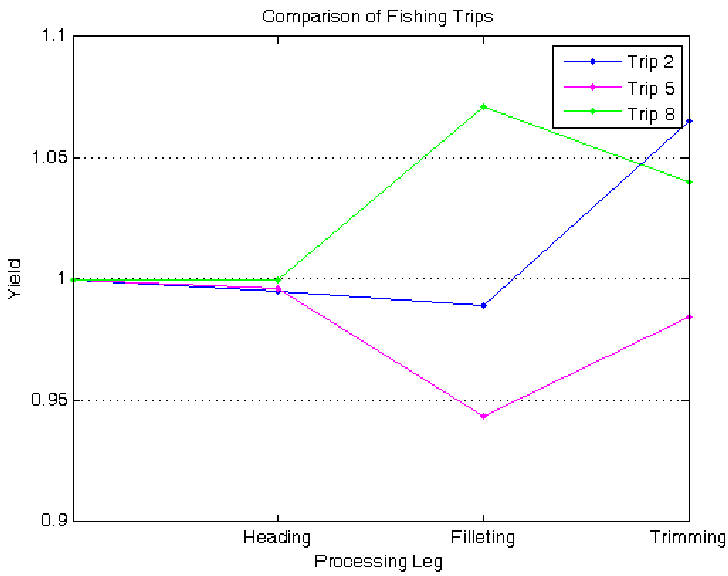


Figure 4.2: Fishing trips 2,5 and 8 compared. All trips were to area number one and occured in May, June and August respectively. The heading yield is similar for all trips, but the trimming yield for trip 5 is considerably lower than for the other two.

Similarly, we can compare the last three fishing trips, number 12-14. This comparison is shown in Figure 4.3. The trips are all to area number three and occur in successive weeks at the end of September and beginning of October. Not surprisingly, the results for all trips are quite similar. The yields are roughly the same, although a very slight downward trend is observed with the final yield.

Figure 4.4 compares trips 7, 9 and 11 in the same way. Those trips are all to area 2 and occur over a period of roughly one month in August and September. The results are in line with what was observed with fishing area number three, i.e. all fishing trips result in roughly the same final yield.

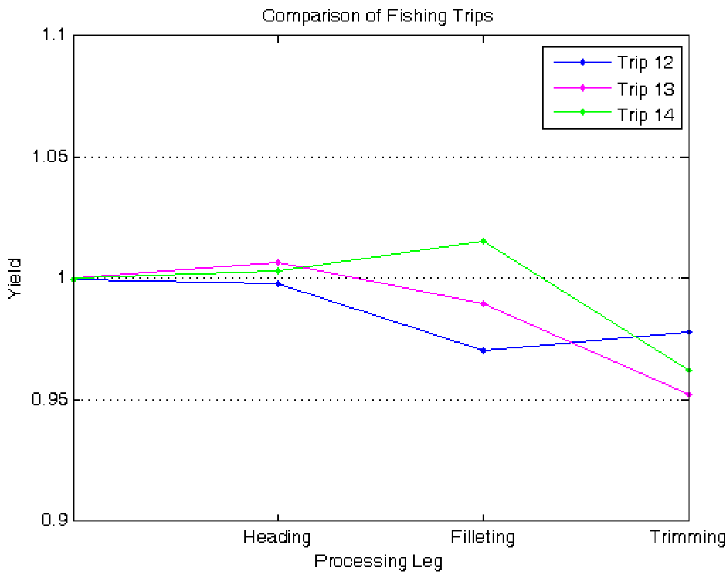


Figure 4.3: Comparison of fishing trips 12, 13 and 14. All trips are to fishing area three, and take place in consecutive weeks in September and October. Not surprisingly, the results of the three trips are very similar.

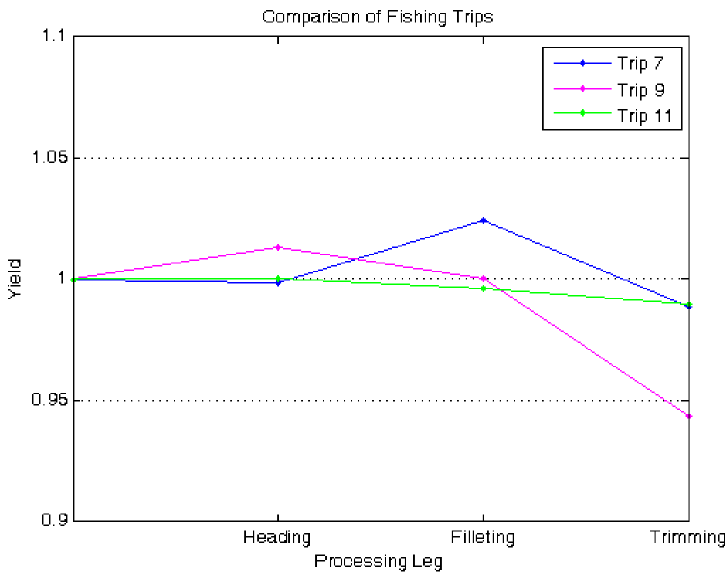


Figure 4.4: Fishing trips 7, 9 and 11 compared. All trips are to area two, and they occur over a period of roughly 30 days in August and September. The results are very similar for all trips.

The fishing areas can also be compared with regard to trimming yield. This information is listed in Table 4.5, giving the number of trips to each area and the relative yield obtained there. Since the number of total fishing trips is relatively low, these numbers are probably not very accurate.

| Fishing Area | Number of Trips | Fishing Trips | Relative Yield |
|---|---|---|---|
| 1 | 6 | 6,7,8,9,10,12 | 1.022434 |
| 2 | 3 | 11,14,16 | 0.974076 |
| 3 | 3 | 17,18,19 | 0.964209 |
| 4 | 1 | 5 | 1.026730 |
| 5 | 1 | 15 | 1.023811 |

Table 4.5: Average final yields for each fishing area, calculated using the information from Table 1. The number of fishing trips to each area varies significantly, which is not ideal.

Examining the numbers, no area deviates severely from the average. Areas 2-3 all show below average numbers, but the other perform better. Given the location of the landing harbour, it would be interesting to examine the trade-off between spending money and time and travelling, and catching fish of a superior quality. Figure 4.5 plots the data from table 4.5.

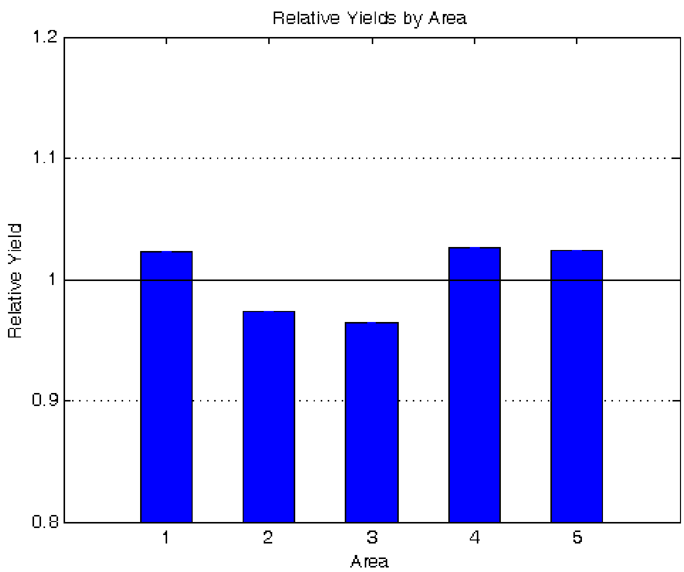


Figure 4.5: Relative yields obtained in the fishing areas considered. Areas 2-3 perform below average, while the rest are all above average.

In the same way that fishing areas are compared, it is logical to compare the trimming yield achieved each month. Table 4.6 summarises the averages during the six month period in question. Note that the month of July is omitted, as the company does not operate during that month and no data is therefore available for it. Since the trips typically last seven days each, there are around three trips for each month. October is the exception with only one. The table lists this number of trips, along with the fishing areas visited in chronological order.

| Month | Number of Trips | Fishing Areas | Relative Yield |
|---|---|---|---|
| May | 3 | 4,1,1 | 1.03742 |
| June | 3 | 1,1,1 | 1.00030 |
| August | 3 | 2,1,2 | 0.99354 |
| September | 4 | 5,2,3,3 | 0.98595 |
| October | 1 | 3 | 0.96238 |

Table 4.6: Relative trimming yields each month during the six month period. July is omitted as the company does not operate during that month. For whatever reason, the yield drops consistently as time passes.

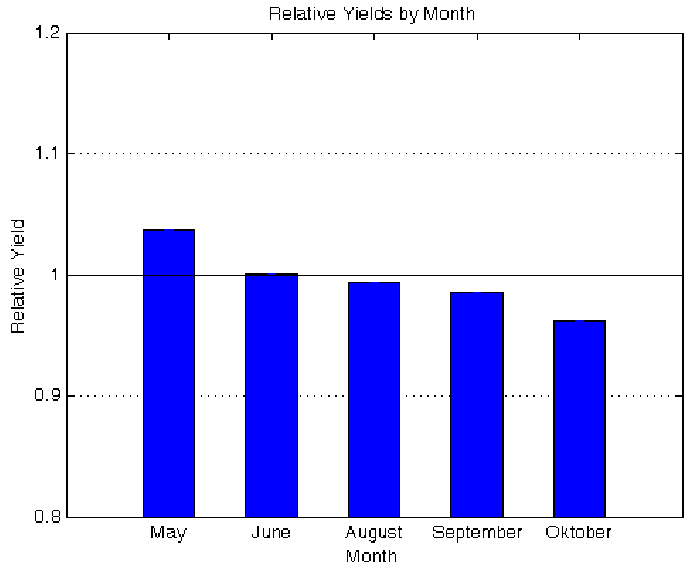


Figure 4.6: Average trimming yields for each month during the period in question. A downward trend is observed

The relative trimming average drops consistently during the time period in question. It is difficult to speculate as to what reasons are behind this downward trend, but the two factors that likely play the biggest role are the time of year and location of the catching grounds [18].

### 4.1.8 Discussion

As stated before, the analysis above is based on far too little data to be of any practical use. However, the charts and calculations go to show that given sufficient data it is easy to get a sense of what kind of fish can be expected in a certain area at a certain time. It is also important to remember that the actual harvesting of the data was by no means a laborious process. Should one wish to collect more data to obtain a clearer picture, little else would be required other than full access to databases.

### 4.1.9 Combating at-Sea Discarding of Fish

The introduction by the Icelandic Government of an Individual Transferable Quota (ITQ) system of fisheries management in the mid 1980's was followed by a ban of at-sea discarding of fish [1]. This practice, known as high-grading, involves the throwing of non-optimal fish back into the ocean in order to maximize the total value of the catch. The fish discarded will most likely not survive, and since it is typically small and sexually immature, the potential spawning stock biomass decreases. This risks the fish stock being unable to replenish itself and collapsing, crippling the fish industry [5, 4]. Discarding remains a major problem for world fisheries, with a 2005 report by the FAO (Food & Agricultural Organization of the UN) estimating the global discard rate at 8% of total catch volume [17].

Nations have adopted a variety of methods to deal with discarding. Bans are generally regarded as the most effective of these methods, although they have proved difficult to enforce. The Directorate of Fisheries is responsible for implementing laws and regulations regarding fisheries management in Iceland. This includes monitoring the catching process with regard to discarding. It relies mainly on on-board observers but has also experimented with technological solutions, such as video surveillance technologies (CCTV systems). Since any fisherman suspected of discarding will not discard in the presence of an observer however, proving criminal activity is often difficult. An obvious solution would be to assign an observer to every single fishing vessel, but this would not be cost feasible.

In need of an effective tool to combat discarding, regulatory authorities may need to look no further than statistics. First of, the Directorate of Fisheries already receives electronic data from every significant vessel fishing in Icelandic waters. This data includes information on the location of vessels at each time and total weight of the catch, but perhaps most importantly, the size distribution of the fish caught. By comparing the size distribution reported by different vessels fishing in a certain area, it is possible to detect those likely guilty of discarding if they deviate significantly from the norm. This comparison could be made using a simple t-test, the null hypothesis being that the distribution in question is similar to the average distribution. Should the hypothesis be rejected for a certain vessel, the next step would be to assign an on-board observer to it during their next trip. The observer would simply need to guarantee that no discarding takes place during that particular fishing trip. If the size distribution remains similar to what was reported before, the vessel would be vindicated. If, however, the distribution is more in keeping with the norm, or average, a strong case can be made that the vessel is indeed guilty of discarding.

# Chapter 5

# Conclusions

The fishing industry faces major challenges in the future. An increasingly constrained supply of raw material, coupled with ever increasing customer demands of price and quality, mean that every effort must be made to streamline and optimise the entire seafood value chain. Although the complexities of the industry make this a veritable challenge, it is clear that the databases maintained by most modern fisheries represent a great deal of untapped potential. Converting this data into information and putting that information to use, through optimisation models and statistical methods, could greatly benefit decision makers in the industry with regard to both long- and short-term planning. Regulatory authorities may also benefit from further utilising the raw data they have collected over the years, notably by putting it to use in the difficult battle against at-sea discarding.

A problem that might arise in trying to put the aforementioned databases to use has to do with the way they are organised. While working on this project, the author often found himself having difficulty understanding exactly what the numbers he was looking at stood for. In order to make the data accessible to not only the most computer-savvy, it is important to make sure that it is stored in the simplest way possible. Otherwise, there is a real danger that it will never be put to use.

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