Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Natural Sciences
Department of Biotechnology and Food Science

Henriette Nygaard Skjørbæk

# Improved utilization of side-streams from pelagic fish industry by value chain mapping

Master's thesis in Matvitenskap, teknologi og bærekraft
Supervisor: Eva Falch
Co-supervisor: Jenna Coprotova
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# Preface

This thesis is written at the Department of Food and Biotechnology at NTNU autumn 2023 and spring 2024. The assignment marks the end of the two-year Master's programme in Food Science, Technology and Sustainability.

The thesis has been a journey of challenges, insight and learning, which has created a new understanding about issues in the food industry.

The ambition was to contribute to a more sustainable industry for pelagic fish and create an understanding of what processes the fish goes through than it ends up as fillet or recycled into a new product. In addition, the ambition was to discuss and investigate how much of the fish ends up directly as human consumption.
There was a desire to look at the practical and economic parameters that are important for industry. In this context, a positive contribution to sustainability has been an important motivator for the task.  Another wish with the task was to develop a concept that can help companies understand how the fish end up.

I would like to say a big thank you to my main supervisor Eva Falch and co-supervisor Jenna Coprotova, for helping to find answers when it was difficult for me to get in touch. In addition, a big thank you for the good guidance I have received through the project, to think in other ways and innovatively.

In addition, I wish that the players in the pelagic industry who have taken the time to be interviewed and known around the company so that I could carry out my analyses. In addition, a big thank you for sharing their broad knowledge on the subject.

Trondheim, 14. May 2024

## Summary

This master's project is a theoretical project that maps the value chain for selected pelagic fish such as herring and mackerel. With the help of the mapping, it can be assessed, evaluated and promoted the circular economy and reduce waste in industry.

The purpose of the assignment is to map and analyze the value chain of pelagic fish, in order to understand what processes the fish and its by-products must go through before it leaves the farm. In this way, the project will investigate the processing and utilization rate in Norwegian farms. The research question for the project is defined as follows: "Improved utilization of side-streams from pelagic fish industry by value chain mapping".

To solve the problem, the assignment will include a development method Design thinking, which will include literature search, interviews and observation as the first part. Interviews will be conducted on various players in the industry. In addition, observations will create a broader understanding of primary and secondary production. In this way, the understanding that forms the basis for the mapping is achieved. The mapping is carried out by designing a Material Flow Analysis, which analyzes all the processes the fish pass through. In addition, material flow analysis can show how the fish's by-products also run through the process.

In connection with the flow analysis, a quality flow will be developed, which aims to visualize where the fish's side streams occur and which quality parameters must be met in order for everything to be utilized.

Since interviews and literature searches made it clear that the majority of the fish is exported to Japan, an MFA model has been made of the processing of fish in Japan. In this way, it could be investigated whether it is worthwhile for Norwegian companies to export fish, and whether it has an impact on the overall utilization of the fish's by-products. Finally, a SWOT analysis is carried out that makes it possible to examine positive and negative parameters associated with the implementation of the quality flow.

The results show that changes have already been made in the industry, where waste of side streams is minimal, as it is used for fish oil and proteins that end up as feed for e.g. Salmon. However, the results also show that the fish exported to Japan are processed into new products, if any, if any, by-products. This means that there is a lot of waste in the Japanese pelagic industry. The result also highlighted that the processing rate in Norway is very low, however, the utilization rate is 100%. This means that all fish processed in Norway is utilized, however, very little is processed. Of all the products processed in Norway, only primary products end up as human consumption. Thus, there is great potential if more of the fish is to be for human consumption. This could provide both financial and environmental savings.

Quality flow analysis has promoted an understanding of where the fish end up, and it has also created an in-depth understanding of where to intervene if more fish are to end up as human consumption. This includes using a different method of preservation than ensiling, as well as exporting smaller fish. The quality flow analysis has therefore helped to create more knowledge for companies about the production of the fish.

# Sammendrag

Dette masterprojekt er et teoretiske projekt der kortlægger værdikæden for udvalgte pelagiske fisk som sild og makrel. Ved hjælp af kortlægningen kan det vurderes, evaluere og fremme den cirkulære økonomi og reducere spild i industrien.

Formålet med opgaven er at kortlægge og analysere værdikæden af pelagiske fisk, for at forstå hvilke processer fisken og dens sideprodukter skal igennem inden den forlader bedriften. Derved vil projektet undersøge bearbejdnings- og udnyttelsesgraden i norske bedrifter. Problemstillingen for projektet er defineret således "Improved utilization of side-streams from pelagic fish industry by value chain mapping".
For løsning af problemstillingen vil opgaven indeholde en udviklingsmetoden Design thinking, der vil inkludere litteratursøgning, interviews og observation som den første del. Interview vil blive fortaget på forskellige aktør i industrien. Desuden vil observationer skabe en breder forståelse af den primære og sekundære produktion. Derved opnås den forståelse der ligger grundlaget for kortlægningen. Kortlægningen udføres ved udformning af et Materiale flow analyse, som analyserer alle processer fisken kommer igennem. Desuden kan materiale flow analyse vise hvordan fiskens biprodukter også løber gennem processen.
I forbindelse med flowanalysen, vil der blive udviklet et kvalitetsflow, som har til formål at visualisere hvor fiskens sidestrømme opstå, og hvilke kvalitetsparametre der skal opfyldes for at alt kan udnyttes.

Da interview og litteratursøgning gjorde det klart at den største del af fisken eksporteres til Japan, er det blevet lavet en MFA-model over processering af fisk i Japan. Derved kunne det undersøges om det kan svare sig for norske virksomheder at eksport fisk, og om det har en betydning for den samlede udnyttelses af fisken sideprodukter. Afslutningsvis fortages der en SWOT-analyse der gør det mulig undersøge positive og negative parameter der er forbundet med implementering af kvalitetsflowet.

Resultaterne viser at der allerede er fortaget ændringer i industrien, hvor spild af sidestrømme er minimalt, da det bruges til fiskeolie og proteiner, der ender som foder til bla. Laks. Dog viser resultaterne også at de fisk der eksporteres til Japan at intet hvis meget lidt biprodukt bliver videreprocesseret til nye produkter. Derved er der meget spild i den japanske pelagiske industri. Resultatet fremhævede også at bearbejdningsgrad i Norge er meget lav, dog er udnyttelsesgraden 100 %. Det betyder at alt fisk der bearbejdes i Norge udnyttes, dog er det meget lidt der processeres. Af alt der behandles i Norge er det bare primære produkter der ender som humant konsum. Derved er der stor potentiale, hvis mere af fisken skal være menneskeligt konsum. Dette vil kunne give både økonomiske og miljømæssige besparelser.

Kvalitetsflow analyse har fremmet forståelse af hvor fisken ender henne, desuden har det skabt en dybdegående forståelse af  hvor der skal gribes ind hvis mere fisk skal ende som humant konsum. Dette er bl.a. at bruge en anden konseveringsmetode end ensilering, samt at eksportere mindre fisk. Kvalitets flow analysen har derfor været med til at skabe mere viden for virksomheder omkirng produktionen af fisken.

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# Abbreviations and definitions

**Abbreviation**
**EPA:** Eicosapentatenenoic acid
**DHA:** docosahexaenoic acid
**MFA:** Materiale flow analysis
**FHF:** Nutrition for fisheries and mariculture (Fiskeri- og havbrugsnærings forskningsfinacering)
**UN:** United Nations

**Definitions**
**Material:** What comes in and out of a system. The material is what is processed in processes in the system. (Brunner & Rechberger, 2004)

**Process:** Steps that the material must go through. In this project, a process can be «catch». (Brunner & Rechberger, 2004)

**System/System Boundary:** It is the description of the MFA, i.e. the part of a production to be examined. It is used to create an overview and make the MFA easier to understand (Brunner & Rechberger, 2004).

**Flow:** This is the route the material goes through once it is inside the system. (Brunner & Rechberger, 2004)

**Silage:** Fish materials that have undergone enzymatic degradation in which acid is added to inactivate the enzymes. (Stephenson & Smedbol, 2003)

**Rest raw material:** It is defined as not the primary main product using a raw material. Primary raw materials are fish and shellfish, which are farmed and caught from Norwegian quotas in Norwegian waters and/or landed in Norway (Myhre, et al., 2022).

**Side streams:** Includes products from the fish that can be further processed into new products that are used for human consumption, while by-products are products from the fish that are not suitable for human consumption (Välimaa, et al., 2020)

**Fishmeal:** Extracted from the fish side streams, or round fish that have been sorted out. The fishmeal is proteins from the side streams. (Sáenz, 2021)

**Fish oil:** Extracted from the fish side streams with found and in the flesh of the fish. The fish oil has health benefits that make it attractive to consume. (Mirian Pateiro, et al., 2021)

**Reactive oxygen compounds (ROS):** Are oxygen radicals that react with lipids, proteins, and vitamins. ROS can destroy essential amino acids and fatty acids, thereby losing nutrients their nutritional, chemical and physical properties in the fish. (Domínguez, et al., 2021) ROS often attacks substances that are more unstable such as omega-3 fatty acids, which in particular allows fish fatty acids to become oxidated. How much oxidized depends on the amount of free fatty acids. (Domínguez, et al., 2021)

**Food loss:** Food loss refers to all food that is eliminated throughout the supply chain before it reaches retail. This product does not have another productive purpose. (Eufic, 2021)

**Circular economy:** To promote sustainability, it would be ideal to create a circular economy. This includes production focused on a system that minimizes waste and side streams by converting it into new products. A model of consumption and production is created, in which changes are made in the life cycle of the product. This is done primarily to create a better eco-friendly design. (Ghosh, 2020)**.**

# 1. Introduction

Sustainability as a concept includes the reduction or elimination of losses and also, in addition to this upliftting of the use of fish side streams from low value applications such as fish meal to high- value application. As well as the reduction of climate impact in industries. It includes the least possible strain on the planet and the resources as the main focus (Buallay, 2021).

Sustainable development is covered by three factors: environmental, social and economic. All three of these must be connected to create a sustainability development. It is just as important to examine the social conditions as the impact on the environment, in order to create sustainability (arena, u.d.).

With this background, reports are published every year from the United Nations to see how the world is developing. The reports show that the world is behind the desired goals. This is despite the fact that the world wants a more sustainable society. The food industry is one of the biggest baddies when it comes to impact on the climate. As much as 30% of the total climate footprint comes from food that is discarded or does not achieve its optimal use. This includes, among other things. Side streams or offal that end up as waste. In connection with their reports, the UN has developed 17 Sustainable Development Goals to create a more sustainable society. One of these goals is Goal 12 Responsible Consumption and Production (UN, 2023).

Today, far more resources are used than the earth and humans can grow and shape themselves. This means that new directions must be looked at, such as circular economy

This goal includes creating a more circular economy, thereby promoting the sustainability of new forms of production (UN, 2023). The goal is to create more for less, which can benefit the food industry.


*Figure 1.1- the relevant SDG for this project. This excludes Objective 12, which is responsible consumption and production, which is considered a crucial part of this project.*

The pelagic fishing industry has a number of sidestreams associated with production, because it is one of the biggest users  of resources (fødevare, 2019). However, in recent years, work has been done to use these offcuts to form new products. This creates more value and economy for the enterprise (Ziegler, et al., 2013). Figure 1.2 outlines the distribution of these side streams from the fish. With the use of side streams, a secondary production is formed, next to the primary production. By using this process, the pelagic fishing industry is well on its way towards the sustainability goal 12.

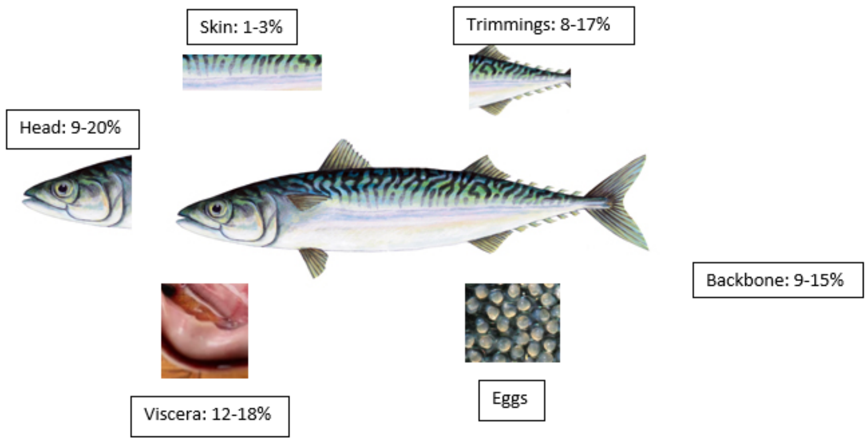


*Figure 1.2 - illustrate the proportion of different side streams of the fish. The largest proportion comes from heads and backbone.*

Although work is being done to further process side streams, there are still challenges in utilising these. The side streams contain the essential omega 3 fatty acids EPA and DHA, which have health-promoting properties. This could be used as good dietary supplements for humans, however, it is limited how much actually ends up as human consumption (Balange, et al., 2023). The report from (Myhre, et al., 2022), which is the basis for this project, prescribes that only 13% of the sidestreams end up as human consumption. This is also illustrated in Figure 1.2. Thus, as much of the fish primarily ends up as expensive feed 67%, and as much as 20% is used as biogas, and thus for humans does not directly benefit from a product that is caught for human consumption. However, further processing of side streams has an indirect connection to us humans.

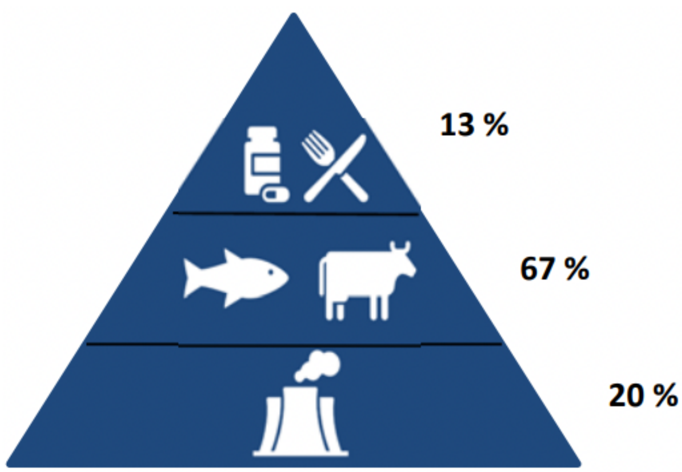


*Figure 1.3 - The proportion of side streams for the pelagic industry that ends up as biogas, feed, or human consumption. The majority ends up as feed for fish or other animals, while only 13% end up directly as food for humans. (Myhre, et al., 2022)*

To meet these challenges, a comprehensive mapping of the pelagic industrial value chain is needed. This project will investigate how side stream can be better utilized for human consumption through upcycling, but also how processing can be improved so that more fish is utilized. Therefore, this master's thesis will focus on mapping and analyzing the pelagic fishing industry's value chain, to identify potential co-products and the possibility of upcycling.

The main objective of the project is to create a basis for upcycling of processing side streams (proteins and lipids) from selected pelagic value chains by mapping material and quality streams.

In addition, the following sub-goals have been set for the project to be successful.

- Identify side streams with potential for upcycling.
- Collect data and conduct a material flow analysis.
- Develop a new concept called quality flow analysis for the pelagic value chain.
- Use data to suggest upcycling potential side streams.

Through in-depth interviews, observations, literature searches and analyses, this assignment will contribute to raising awareness of the importance of a holistic approach to resource management in the pelagic fishing industry. In addition, the project will work to identify and develop innovative solutions, such as the use of quality flow to the development of residual materials for human consumption.

The project will use the concept of side streams, which in this project includes all material removed from the fish, which must be included in further processing for new products.

# 2. Theory

## 2.1 Pelagic fish

Pelagic fish live in the open sea in shoals, far from both the coast and the seabed. This project focuses on the two pelagic fish species herring and mackerel (Kaylor & Learson, 1990).

The fish contains three types of muscle tissue, which are of great importance for the nutritional content of the fish. The three muscles are striated, skeletal and smooth muscle. The striated muscle is the muscle used for fillet pieces during processing and is of crucial importance when it comes to the movement of the fish. The skeletal muscle consists of a dark and a light part. The dark muscle makes up to 48% of the body weight of pelagics. This is what parts of the fish's fat deposits are. The muscle is important and relevant for the pelagic fish, because the dark muscle is used in fish that move a lot. The white muscle is of minor importance to the pelagic (Huss, 1995).

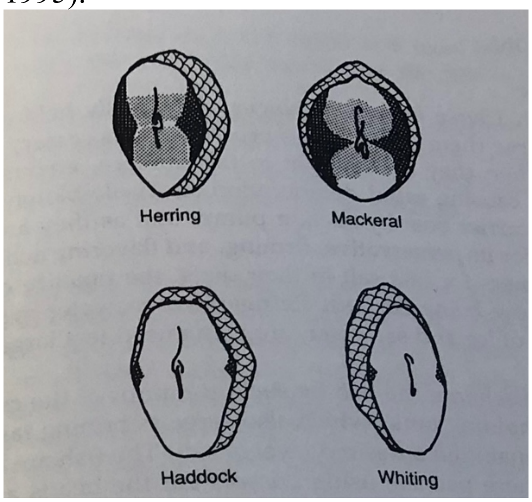


*Figure 2.1 - cross-section of the muscles of active fish at the top compared to cross-section of the muscles of less active fish at the bottom; (Kaylor & Learson, 1990).*

### 2.1.2 Mackerel

*Figure 2.2- The Atlantic mackerel (Scomber scombrus) is caratized by the bluish-greenish color it has across its back.*

The Atlantic mackerel (Scomber Scombrus) is a pelagic fish species. It is widely distributing throughout the North Atlantic Ocean. Mackerel is a significant species, with some benefit, because it has a highly valued for its meat quality and omega- 3- fatty acid content. To obtain fish with the best quality, they should be caught around late summer and autumn. During this period, the mackerel fat percentage will be 18-30%. Of this, the amount of essential fatty acids such as EPA and DHA will also be large. However, the high fat percentage makes the mackerel gentler, which means that it is more easily affected by a hard-sided treatment. Handling is therefore very important to maintain the favorable quality (Carl, 2019). The mackerel has more black muscle as it is pelagic and thus always in motion. This is also why it contains their high amount of fat in summer/autumn, as it needs a lot of energy all the time. It also means that the mackerel eats and larger during this period as it prepares for winter and spawning. (Carl, 2019)

A mackerel caught in winter or early spring will have a significantly lower fat percentage, and this will be reflected in the quality. The deterioration in quality is because when the fish spawn, it requires a lot of energy. Thereby, the built-up fat deposits will be used. Access to food during the winter period is also reduced, therefore only the stores provide the mackerel with energy (Falch, et al., 2006).

In the past, fish was primarily caught to turn it into fillet. However, new studies have shown that fish side streams contain high amounts of EPA and DHA. In addition to fatty acids, mackerel and its side streams contain proteins and various vitamins, such as D, B12, but also the minerals selenium and iodine. (Even Fjære, 2020). Table 2.1 shows the proportion of different mackerel side stream caught in October.

*Table 2.1 – Average content of mackerel side streams in October.* (Falch, et al., 2006)

| | Head | Guts | Trimmings | Backbound |
|---|---|---|---|---|
| **Average** | 14,3 % | 7,0% | 13,9% | 6,8% |

Since there has been a tendency for many years to overfish, among other things. To preserve mackerel, quotas were introduced for mackerel fishing. This quota regulation is important to keep the mackerel stock up so that it does not become extinct. (Quotes, 2005)

### 2.1.3 Herring

*Figure 2.3- NVG- herring (Clupea harengus) (Sildelaget, u.d.)*

The NVG herring of the species Chupea harengus) is also a pelagic fish. During its best fishing season (June - September) it will have a fat percentage between 18-22%. The herring fat, like mackerel, contains the essential fatty acids EPA and DHA. Thus, the utilization of herring's side streams could also have health properties that are good for us humans. In the past, herring was caught primarily so that fillet and cuts could be made from it. Today, the side streams are being worked and researched. (Sildelaget, u.d.)

There are two relevant herring species in Norway, where it is NVG herring that is used in this project, because it is this herring that is exported the most.

Herring spawns like mackerel in winter or early spring, and therefore the quality of the herring will be less good. In addition, the fat percentage will also be low during this period, making it disadvantageous to eat. In September, when the herring has built up the fat deposits again, the quality will be the best possible. The herring is not nearly as oblique as the mackerel, which makes it easier to cope with hard-sided treatment. However, herring continues to be sorted out when they arrive at the farm. The high fat percentage found in the herring is due to the mackerel, the herring is in motion all the time and therefore needs a lot of energy. This also means that the herring has a large dark muscle. (Ariño, et al., 2013)

Herring, side streams, and fish meat are, in addition to fat, a good source of vitamins D and B12, as well as minerals such as iodine and selenium. It therefore makes it more attractive to utilize everything from the herring, due to the health value and sustainability of using everything from the fish (Wu, et al., 2022). The distribution of fat in herring side streams is shown in Table 2.2.

Tabel 2.2 – Proportion of fat in the different side streams (Falch, et al., 2006)

| | Head | Guts | Trimmings | Backbound |
|---|---|---|---|---|
| **Average** | 12,7 | 17,0 | 17,3 | 51,0 |

There have also been problems with overfishing with herring fish, which has meant that quotas have now been set. This ensures that NVG herring is also found around Norway in the future and can continue to be a source of income. (Quotes, 2005)

## 2.2 Fish side streams

Both proteins and lipids constitute vital macronutrients found in all living organisms, including fish and humans. This means that all organisms play a significant role for each other. Lipids, also known as fats, act primarily as a source of energy during periods of limited access to food. The fats consist of a lot of triglycerides, which are bound to three fatty acids. It is these fatty acids that help to create a health value. A fatty acid consists of a long chain of carbon atoms, most of which are connected by a simple bond. Simple of these carbon atoms can be bonded together with double bonds. The more double bonds there are in a fatty acid, the more unsaturated, unstable, and sensitive it is to changes in the environment. Some of these unsaturated fatty acids are essential and can therefore only be consumed through diet. Fish contains these essential fatty acids, which makes fish a good eater (Kristensen & Mønster, 2017).
The essential fatty acids can be omega-3 fatty acids like EPA and DHA. It has been studied that the essential fatty acids are found in all parts of the fish, which also underlines the importance of utilizing all parts of the fish. However, it is important to examine the fatty acid composition of the fish fat, as it can vary depending on what the fish has consumed of food, as well as the time of year. This means that from side streams fatty acid is extracted, which is used for fish oil. These fish oils will be rich in EPA and DHA (Gunnars, 2023).

Proteins, also found in fish, help repair and build worn tissue in the body. Proteins are made up of amino acids, and some of these can be essential amino acids. This, as with fatty acids, only makes it possible to get into the body through the diet, as the body does not produce these itself.

Collagen is a protein found in fish, and it is essential for bones and connective tissue in the body. In fish, collagen makes up about a quarter of the total protein content. Collagen has a high-water binding capacity, which makes it ideal to use for the texture, thickening in food products. In addition, it also has the properties of emulsification, stabilizer that also makes it attractive to extract fish side streams (Jafari, et al., 2020).

The primary product, fish proteins used to today be in the dried state as fish meal. The fishmeal mainly ends up as feed for farmed fish. Today, there are two ways to temperature treat the material. The two types are Low Temperature Flour and High Temperature Flour, where the primary difference is of the temperature used. Flours that have been high-temperate may have a lower nutritional value, as well as a reduction in protein digestibility. In addition, the high temperature can damage other nutrients like vitamins. With low-temperature flour, there is a risk of pathogen bacteria since the temperature does not get high enough to kill them. Therefore, there are many considerations associated with fishmeal. (commission, 2003)

Since side streams have a limited shelf life, methods must be carried out that help the problem. One method that can be used is ensiling, where the fish retain until further processing. The method works by preserving side streams by lowering the pH to 4.5 or less using acids such as formic acid or hydrochloric acid. Formic acid is an organic acid that effectively penetrates the cell wall, accelerating the autolytic process. The process of acid addition is necessary to inactivate the spoilage enzymes. Silage production is a method of temporary storage of fish side streams, where it is preferred by there is minimal bone, due to the high calcium content, so can neutralize the acid. (Carswell et al., 1992).
In addition, the fish's legs should also be separated before ensiling, because this can make it difficult to pump the mass out of the tank in which ensiling takes place. Ensiling is an effective method, however, it comes at a cost, while techniques have not been developed to fully utilize the bone fraction (Stephenson & Smedbol, 2003).

## 2.3 Quality Parameter

**Catching**

Herring and mackerel will often be caught using purse seines and pelagic trawls. Purse seines are a large circular net that floats on the surface of the water. When the pelagic fish swim into the net, they are directed to the center, where the fish gather (Kjerstad, et al., 2005).
Pelagic trawling is another frequently used method, which takes place as a large floating net, with weight at the bottom. This weight keeps the net down in the water. When the net floats through the water, the fish are caught before they are transported on the vessel (Kjerstad, et al., 2005).
The catch is the first step that can significantly affect the quality of the fish. The fish can become stressed during the catch, which is a major cause of quality deterioration of the final product. To minimize the stress level of the fish, it must be treated with care and caught with the right method. This is in line with the quality manual, which underscores the importance of handling the fish gently to maintain optimal quality (Grimsmo, et al., 2011).
During the catch and handling, different types of injuries can occur, some of which cause the fish to be discarded. Figures 2.5 and 2.6 illustrate some of the injuries highlighted in the quality manual as injuries that occur when the fish has been subjected to hard-gripped treatment (Grimsmo, et al., 2011).

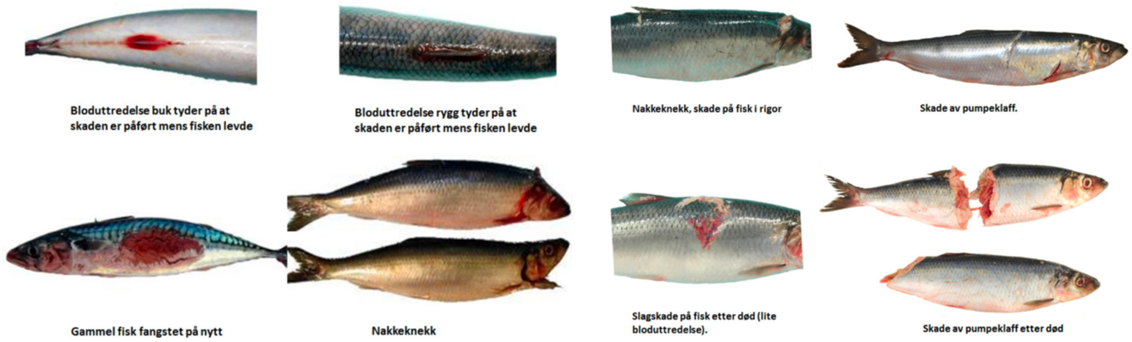


*Figure 2.4 - typical damage associated with handling the catch. The top pictures show fish with blood draws. Thus, the injuries are inflicted on the fish while the fish is alive.  At the bottom right, the fish has got a neck crack. While at the bottom left is an old fish that has been caught again. (Grimsmo, et al., 2011)*

**Oxidation**

Oxidation is a reaction in which free radicals are formed and a chain reaction that breaks down the fatty acids and can result in a rancid taste of the fish. Under favorable conditions, such as a bright and warm environment, this reaction can take place faster, because there will be more free fatty acid. The free radicals lack a proton to reduce charge. The missing proton steals the free radical from a free fatty acid, meaning the fatty acid is now negatively charged. (Grimsmo, et al., 2011).

**Enzyme activity and rigor mortis**

The enzyme activity refers to the rate at which endogenous and bacterial enzymes break down proteins into peptides and amino acids. This activity significantly affects the properties and quality of the fish, including taste, smell, and texture. The more active these enzymes are, the faster they break down the proteins and fat. (Huss, 1995)

The meat of fish is rich in proteolytic enzymes, which are essential for the quality of the fish. When the fish die, the breakdown of the fish muscle begins, which means that the muscle darkens. It is due to the breakdown of myofibril proteins and extracellular matrix of enzymatic activity. In this process, the myofibrils are broken down into smaller filaments, then into smaller peptides and finally into free amino acids. An increase of four amino acids in storage indicates enzymatic breakdown of proteins. The main proteases in the muscles are calanes, cathesins and collagenase. (Huss, 1995)

The first time after death, calaureates are the most active proteolytic enzymes, and they begin the degradation of the myofibril proteins. After rigor, it is cathessins that are important proteolytic enzyme. To get fish of the best possible quality, it must be understood when rigor mortis should be accessed. (Carlos A´ lvarez, et al., 2019)

Rigor mortis is a condition the fish strikes when it dies. If rigor mortis is not understood correctly, it will harm the quality of the fish. Just when the fish dies, that body is soft for a few hours before going into rigor mortis. When rigor occurs can be varied according to the fish treatment after death. While the fish is in rigor mortis, the fish is hard, and after that it becomes limp again. A fish treated after rigor will have a quality impairment, such as sensory changes. (Huss, 1995)

In industry, a long pre-rigor is beneficial, because it makes it possible to treat the fish. By treating the fish in pre rigor, it will be finished processed before rigor, which makes the fish appear fresh. Due to the tension of the fish, it is easy to treat in the machines without harming the fish. The problem of treating the fish in pre. The rigor is that it can clump, but with the right equipment this can be reduced (Stroud, 2001).

A fish in rigor should be avoided and should not be treated. This results in miscuts and a smaller yield. In addition, a fish in rigor will have an arc shape. This arc shape must be straightened before the fish can be treated. Therefore, this must be avoided. A fish treated according to rigor will have a significant deterioration in quality. Among other things the water retention capacity will be poor, and thereby much will be lost during storage. Fish treated after rigor will have a risk of splitting, which affects the price (Boge, 2022).

**Cooling in the pelagic fishing industry**

Proper cooling is essential for the fishing industry to maintain high quality fish. Improper cooling can have a negative effect on the quality of fish and lead to quality deterioration. (Grimsmo, et al., 2011)

When the fish comes on board the vessel, it must be cooled down, as it is important that the core temperature of the fish must be brought below 0 degrees. This temperature must be maintained evenly throughout the cooling process. This step is especially critical for fish such as mackerel, which are high in fat. If the fish is not refrigerated, the environment will be able to start an oxidation process in the fish. A fish that is oxidized will either be sold at a cheaper price or end up as a discarded product (Towers, 2011)

In addition, it is common in the fishing industry to use the Refrigerated Sea Water (RSW) method, which is used to preserve and cool fish freshly caught at sea. Therefore, this system is primarily used on board the vessels. The system works by pumping seawater on board and used to cool and store the fish. Since the seawater has a natural cooling property, it will keep the fish at a low temperature, thereby being able to maintain the freshness of the fish. When the water has done its job, the water will be sent back to the sea (Dellacasa, 2003).

In combination with refrigeration, cold stores are also used so that the fish quality can be maintained for as long as possible. However, it has been shown that fish in cold storage can continue to oxidize, underlining the importance of efficient and correct handling throughout the processing process (Grimsmo, et al., 2011).

**Sensory characteristics**

The sensory characteristics of the fish are of great importance when it comes to judging quality. This can be the color of the fish, which changes depending on whether the fish is alive or dead. The fish must retain its natural color in order to be assessed as good quality. The same is the case with the fish brilliance. A fresh fish will have a shiny overflow with no visible dry areas or spots. In addition to appearance, the odors also release a meaning of quality. If the fish has a mild, sea-like smell, it indicates that the fish is fresh. In contrast, a fish with an ammonia odor will indicate an incipient deterioration (Andhikawati & Akbarsyah, 2021).

The texture of the fish is also of great importance, because a fish with firm flesh tells you that the fish is good, but if it crumbles, it is bad. These are the sensory properties that are considered to be relevant for this project.

## 2.4Theory behind the methods

**Design thinking**

Design thinking is a method of creative problem solving where the user's needs are in focus. Based on the user's needs, innovative solutions are created. Meotden is used in product development and problem solving. Design thinking consists of the following phases (Franziska Dolak, 2013):

- Empatize: create an understanding of the user's needs and perspective. This is done through observations and interviews.
- Define: Define the problem based on the insights from the first stage.
- Ideate: Create a lot of ideas and through creative thinking and other methods of brain flow.
- Prototype: Make small models to test and evaluate the ideas.
- Test: test the prototypes with the user and use feedback from there to develop even better prototypes.

### 2.5.1 Qualitative methods

The term encompasses a variety of survey methods such as semi-structured interviews, observations, and focus group interviews. It is the possibility of obtaining a knowledge that does not include numbers, however, the qualitative method will help to achieve a strong internal validity (Tenny, et al., 2022).

**Litteratur search**

With a literature search, the search process must be approached in a structured way and the search must be organised in advance. Thus, keywords, choice of database, and the use of different search methods must be thoroughly considered before starting. In this way, there is a greater chance of avoiding uncertainties in the literature. Everything that goes on in the literature search must be thoroughly documented so that the searches are reproducible (Grewal, et al., 2016).

**Semi-structured interview**

The semi-structured interview uses the interview guide as a focal point. This includes questions that are desired to be answered during the interview. With the semi-structured interview, the order of the questions may vary, while it is also possible to ask in-depth questions. This makes it possible for the interviewer to steer the interview in the desired direction (Tenny, et al., 2022). 8 respondents would provide a good basis for this qualitative method if a good selection method is used (Mæhle, 2023).

**Observation**

With a literature search, the search process must be approached in a structured way and the search must be organised in advance. Thus, keywords, choice of database, and the use of different search methods must be thoroughly considered before starting. In this way, there is a greater chance of avoiding uncertainties in the literature. Everything that goes on in the literature search must be thoroughly documented so that the searches are reproducible (Thomas, 2019).

### 2.5.2 Quantitative methods

The term of a quantitative method is that it is carried out through interview or observation, and the purpose is to collect quantitative data, based on a series of questions. When using a quantitative method, an external validity and generalizability are often given. (Bhandari, 2023)

**Material flow analysis**

MFA is a method used to study material flows in a value chains. The method quantifies the ways in which materials are used, recycled, or lost. In this way, it can also be used to study the circular economy, or how much loss there is in a production. (Brunner & Rechberger, 2004)
By studying the material base, it is possible to gain insight into what is coming in or out (like side streams) of the system. The MFA can vary from one system to several systems of flows and volumes. (Brunner & Rechberger, 2004)

It is possible to choose between static and dynamic modeling. The static model shows how the system is at a given time when the analysis is carried out. It can also show a change over time, but by comparing with models from other time periods. In this modelling method, inputs and outputs can be calculated based on each other. Outdoor flows are possible to calculate from other flows in the system, as well as flows that enter the system. In the dynamic model, the time aspect is included in addition to the different flows. Each process in a system is set up as an equation that results in variation from the influence of other processes. (Montangero, 2008)
The method does not have to stand alone but can also be used as an aid for other purposes.

The MFA has some key elements that could be relevant to build the analysis from. This may be: (Montangero, 2008):

1. Data collection: By examining material consumption, material production, distribution, and waste management, it will help build the MFA.
2. System Delineation: Which part of a production should be defined in the MFA. What processes are important for the system. It can be the extraction of raw materials, consumption, and waste treatment.
3. Identify systems: By examining systems, areas can be identified where there is scope for improvement, reduction of waste or more efficient use of resources.
4. Develop improvement strategies: Based on the analysis, strategies and recommendations can be put in place that can optimize material use, reduce waste, and minimize the overall environmental impact.

The MFA is an important tool for understanding and improving the sustainability of a system. By building the MFA in the best possible way, it is possible to understand production.

This example is taken from the report from (Cencic & Rechberger, 2008). The result of an MFA model is shown in a Sankey diagram, where the width of the arrows is proportional with the pill's value of the mass flow. The models in this project are without noted uncertainties, as it was not possible to establish. All data that is part of the MFA models has been made anonymous by combining acoustic data and fictitious data.

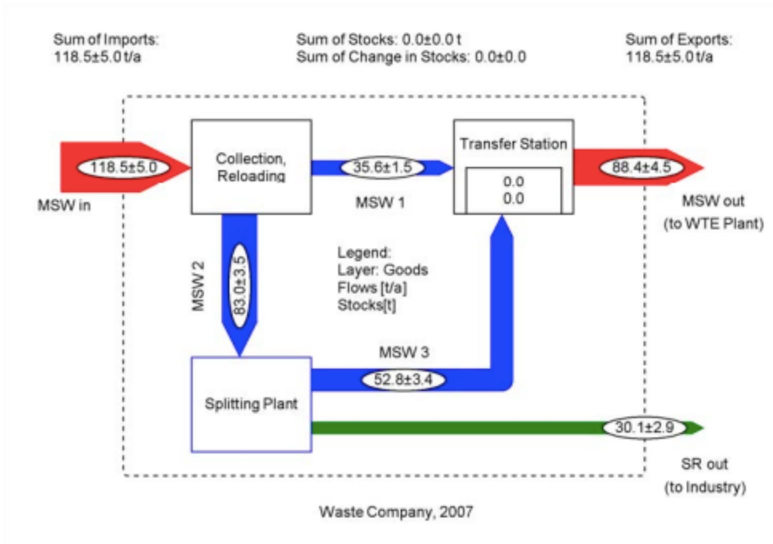


*Figure 2.5 - example of what a Sankey chart in STAN might look like. The system boundary is the striped quadrangular that surrounds the system. The small boxes symbolize processes, and all the pills are flows.*

**Quality flow**

A quality flow analysis is not an established method yet but is a novel method on the development stages suggested by my supervisor Eva Falch based on a need. It intends to provide more knowledge than the existing methods used in the field of resource utilization by adding the quality status of the side streams to the material flow analysis. It should be a useful tool to study how and where side streams are generated and sorted throughout the value chains (mainly the first parts such as primary production and processing).

Thus, the process steps where most side streams are generated and sorting out are identified and assessed to create improvement potential. This includes all impacts on the fish such as fishing method, storage method, etc. The purpose of a quality flow is to create an overview of the quality changes of the side streams and fish, as well as when fish are sorted out through the process and thus identify areas where improvements can be implemented so that more of the fish end up as human consumption. The steps in the quality flow will include important quality parameters and levels and will be a future tool for decision-making regarding different applications such as products intended for food applications.

**SWOT Analysis**

The SWOT analysis is a simple tool for forming an overview of a strategic position. The title of the method comes from the terms: Strenghts, Weaknesses, Opportunities and Threats. In this way, the analysis emphasizes internal and external factors that are linked to positive and negative factors that influence the strategy (Gürel & Tat, 2017)

# 3 Method

The methods chapter shows the research methods used to achieve the purpose. It was a time-consuming process to search for literature, as well as evaluating each source, and collecting data from the literature. Literature search was partly carried out during the first six months of the assignment, to gain the necessary knowledge to start the interview. The literature search forms the basis for the previous theory part (and as a basis for the interviewguide, Material flow analysis and quality flow). Description of the research method used in the assignment is important to give the reader an understanding of how the results were found. Figure 3.1 illustrate the process that has taken place through the method.

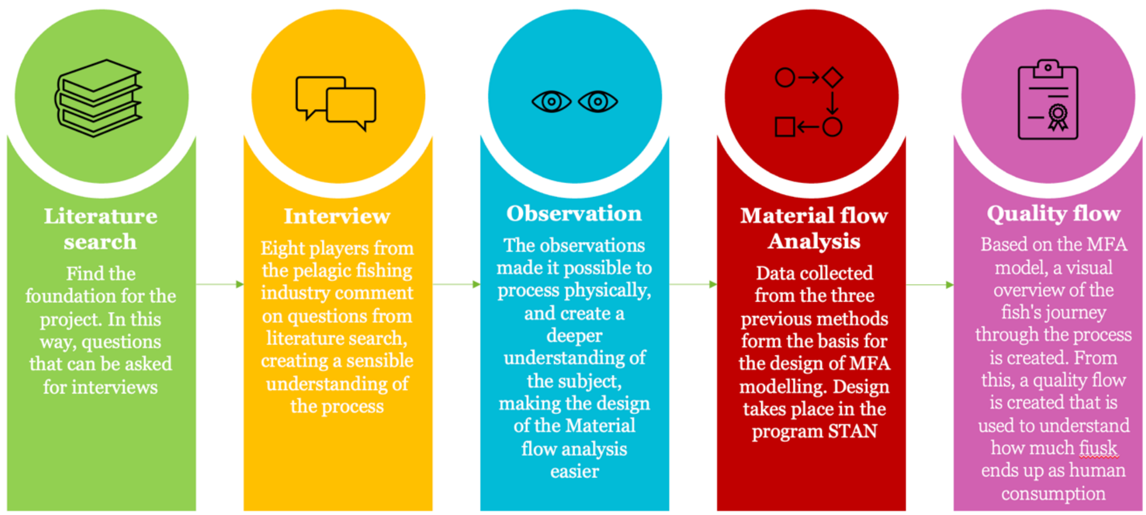


*Figure 3.1 - Illustrate the methods, starting broadly with literature search, after which the methods are more specific with interviews and observations. The last methods material flow analysis and quality flow are very specific, to solve the problem statement.*

## 3.2 Collection of data for flow analysis (and industry insight)

This master project is based on interviews with various stakeholders related to the pelagic industry, observations, and literature search. The interviews were semi-structured, which also made it possible to ask unprepared questions. In addition, e-mail correspondence aligns with follow-up questions that arose during the project.

The literature search was used to create the initial understanding of material management within the pelagic fishing industry.

A complete list of respondents can be found in appendix A respectively.

The system definition was tested along the way with the interviews were carried out, as it provided the information about barriers that exist today to have a better material flow. Therefore, literature searches and interviews are the basis for understanding the Pelagic fishing industry, and from this the establishment of the system definition.

To understand the quality and its importance in the fishing industry, the quality manual was used as a guideline for why fish are sorted out and not used for human consumption. This laid the foundation for the development of the quality flow, which helps to understand how the fish and its side streams end up.

### 3.2 Design thinking

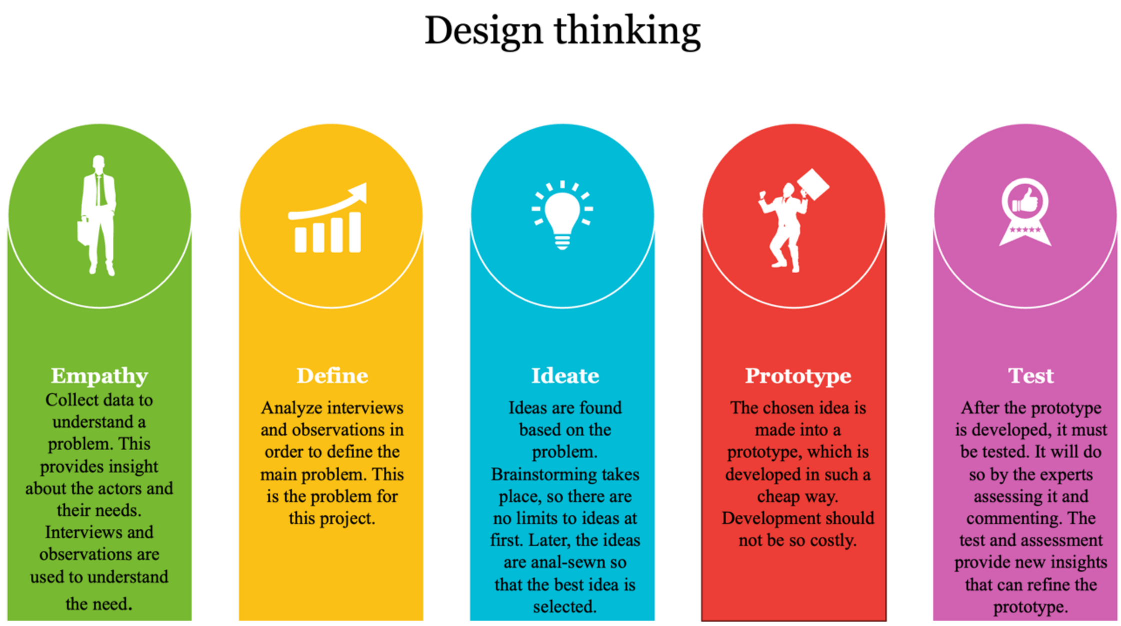


*Figure 3.2 – shows all steps a design thinking method.*

**Step 1**: Empire involves interview different players from the pelagic fishing industry to investigate where shrinkage occurs and why. In addition, to understand how the process works, to develop the quality flow. Here, 8 interviews were conducted, which gave the in-depth understanding of the topic that made it easier to develop a concept.

**Step 2**: After background, the problem must be defined which is the problem statement in this project. Based on the problem statement which is a mapping of the value chain for pelagics, to find an upcycling potential for the side streams.

**Step 3**:
Some of the ideas that emerged during the idea generation phase:
- Flowchart with data showing where all material disappears through each process. For human consumption, feed or anything else.
- A drawing showing how much goes to human consumption and where does a proportion go to animal feed.

**Step 4**: One or more prototypes have been developed, which are a combination of to understand how a quality flow will work and look. The deselected prototypes are not part of this project. The prototype is developed in power points, which are the skills that were available for the project.

**Step 5**: Selected respondents were sent the quality flow and thereby they help assess whether the flow is good or bad. The respondents used for this are respondents 1, 3 and 4, because they have different backgrounds, and thus the best possible quality flow can be formed. An unapproved prototype was changed until the respondents thought it was the best possible. With feedback and comment from the respondents, the quality flow used in this project is the best possible.

### 3.3 Literature search

By clarifying the search, the most relevant results are obtained. This was done by employing strategies that include key keywords and the application of Boolean operations. Operations such as "AND" and "OR" were used to further specify the search. "AND" is used so that all keywords were included in the results, while "OR" meant that at least one of the keywords was present in the results. The use of Boolean operations in the searches is shown in Table 3.2.

At the beginning of the project, the search engine Google was used to understand the topic and thereby identify the direction of the project. Once the direction was clear, the focus shifted to Oria, Scope and Google Scholar, where further searches were made. The search in the search engines was adapted as needed, using different sorting options. This ensures varied results. The three search engines were used to make it easier to find results relevant to the project. Later in the project, physical books were used to supplement the literature further. This was done with the expertise of the library at NTNU.

*Table 3.1 shows the overview of keywords and selected search engine, as well as the number of results.*

| Index | Keywords | Search engines | Result |
|---|---|---|---|
| **1** | Pelagic fish / mackerel AND herring | Oria | 83 |
| **2** | Pelagic fish / mackerel AND herring | Scopus | 17 |
| **3** | Pelagic fish / mackerel AND herring | Google Scholar | 105 |
| **4** | Processing of mackerel in Japan AND Norway | Oria | 103 |
| **5** | Processing of mackerel in Japan AND Norway | Scopus | 42 |
| **6** | Processing of mackerel in Japan AND Norway | Google Scholar | 100 |

These searches resulted in many results, various sorting rounds were carried out as illustrated in Figure 3.3. Sorting out resulted in 20 relevant articles left that could be used for this project.

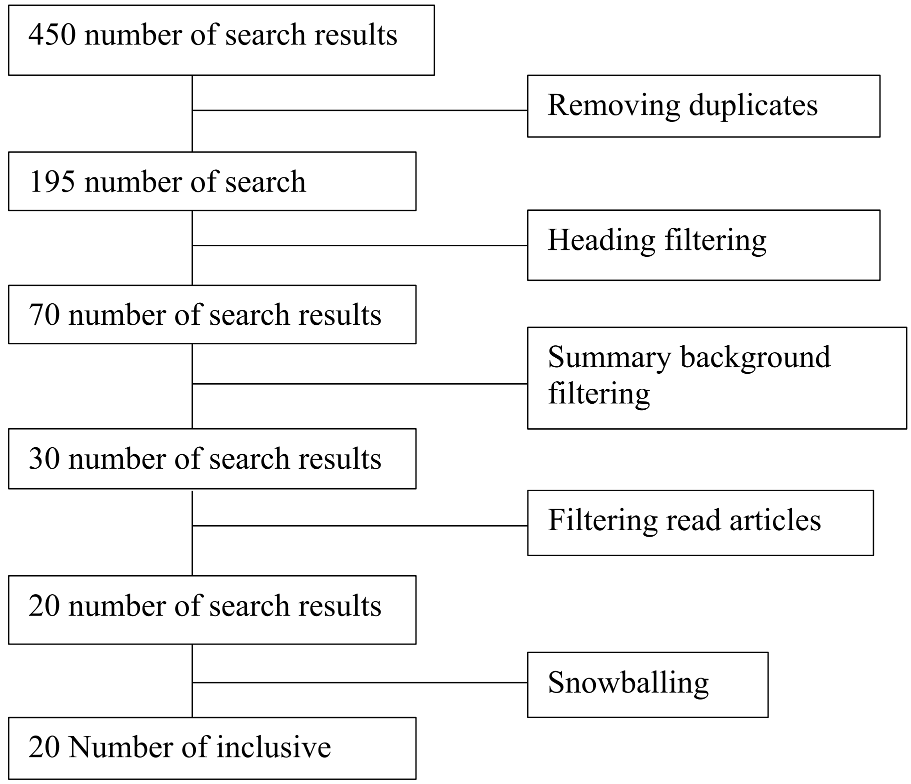


*Figure 3.3 – Illustrate the process that has been carried out to find useful and relevant literature. It resulted in 20 sources.*

**Source evaluation**

The source criticism in this master thesis was carried out using the TONE principle. The principle carries out an assessment of the parameters: credibility, objectivity, accuracy, and suitability for all selected sources. By evaluating these parameters, a better basis is formed for the information source to be fit and reliable.

All sources were assessed with the TONE principle before being used in the project. With TONE, it became possible to ensure that only proper and reliable sources. In this master assignment, all sources used are selected based on TONE. With TONE, it was possible to select the best possible sources for use in the task. This strengthens the validity and reliability of the results obtained.

## 3.4 Semi-structured interviews of industry actors

Eight interviews were conducted with various players in the pelagic fishing industry, that were strategically chosen. The players are from different parts of the industry, to create a broader knowledge of all parts of the industry. All interview objects are anonymous and will be described as respondents 1-8 as a reference in the project.

The interviews were conducted with audio recording and note letter, through teams, phone calls, or in person. Recordings were accepted by the respondents before the interview started, making it easier to remember everything that was said. The audio recordings were deleted after transcription; therefore, they are not available in this report. The transcription can be found together with notes in appendices.

For the structure of the interviews to proceed in the same way, an interview guide was prepared which forms the basis for the structure and structure of the interviews. The interview guide can be found in table 3.4. The interview guide makes it possible to conduct semi-structuring interviewing, which is the primary interview method used in this dissertation. For each interview object, in addition to the interview guide, individual questions have been prepared that fit each of the interview objects.

*Table 3.2- The interview guide that forms the basis of the interviews. It is structured by five themes. 1) general sustainability, 2) Value chains and products, 3) Biproduct and waste, 4) Quality control and challenges 5) Export Each theme contains different questions from a general level to a more specific level.*

| **Theme 1** | **General sustainability** |
|---|---|
| **What do you lie in the concept of sustainability?** | |
| **How do you work with it?** | |
| **Have you changed your approach to become more sustainable in recent years?** | |
| **Do you think that residual raw material is sustainable, why, and why not?**<br>**1. Do you think that residual raw material is carrying power, why and why not?**<br>2. **Do you think something can be done before it becomes sustainable?** | |

| **Theme 2** | **Value chains and products** |
|---|---|
| **Can you describe which products and value chains you work with?** | |
| **If you know, what fishing methods are used and why?**<br>- **Vary it throughout the season?** | |
| **What do you do during catch/reception to prevent an injured or stressed fish?** | |
| **Do you know what proportion of fish is discarded throughout production?**<br>- **Where does a proportion of these go respectively to further processing of oil, protein**, **or feed?** | |

| **Theme 3** | **Side streams and waste** |
| --- | --- |
| - **What have you done so that as much by-product as possible is further processed instead of it becoming waste?** | |
| **How do you think these challenges can be improved?**<br>1. **Have you done anything already?** | |
| **Who is responsible for ensuring that the resources are used in the best possible way?** | |
| **Is there someone in your organization who is responsible for this?** | |

| **Theme 4** | **Quality control and challenges** |
| --- | --- |
| **Do you know how the resources are used?**<br>1. **And do you know if they are being utilizing adequately?** | |
| **What quality parameters do you check for?**<br>- **And what are the typical injuries?** | |
| **Are these injuries seen in the same way in herring and mackerel, respectively?** | |
| **How specific are these checks?**<br>- **Qualitative or quantitative measurements?** | |
| **Greater quality deterioration is probably seen in the high season due to the fat content and enzyme activity. Are you doing anything specific to prevent this?** | |
| **What do you do with fish that are not of the correct quality?** | |
| **If you are to be able to use side streams for human consumption, what should the quality be?** | |

| **Theme 5** | **Export** |
|---|---|
| **Who do you sell your products to geographically?**<br>- **And what proportion of herring and mackerel exports?** | |
| **What are the pros and cons of exporting to those countries?** | |
| **Outside the high season, how can you deliver the desired quantity?** | |
| **Do you know how the by-product is used in export countries?** | |

Six of the 8 interviews were conducted through Teams, since the interview objects are from different parts of Norway, this was the easiest way to conduct interviews. One interview was conducted by phone, due to technical issues with Teams. The last interview took place physically because an observation also had to be made.
After each interview, follow-up questions were sent out, as well as a thank you for the time and help.

Interviews with 4 Japanese seafood actors in Japan (the international seafood market Tyosu, April 2024 has been conducted. As it was not possible for the student to conduct the interview themselves, it was carried out by the supervisor.

**Target group**
The target group in this assignment are various actors from the pelagic industry. They have experience in fishing, production, or research in the industry. Because the stakeholders are from different parts of the industry, it provided an opportunity to discuss different perspectives in connection with the mapping of the herring and mackerel value chain. The inspiration for the choice of respondents came from the main and co-supervisor. In addition, each respondent was eventually asked who they think should contact to gain even more insight. The current candidates were contacted, and this resulted in 8 respondents.

*Table 3.3- Interview respondents and which part of the industry they belong to.*

| | |
|---|---|
| **Respondent 1** | Primary Industry |
| **Respondent 2** | Primary Industry |
| **Respondent 3** | Research |
| **Respondent 4** | Primary and secondary industry |
| **Respondent 5** | Secondary industry |
| **Respondent 6** | Research |
| **Respondent 7** | Research |
| **Respondent 8** | Vessel |

The Japanese respondents were not that deeply into the topics that we had chosen for the interview.

**Processing data from interviews**
All the data from the interviews has been systematically approximated. This approximation is illustrated in figure 3.3.

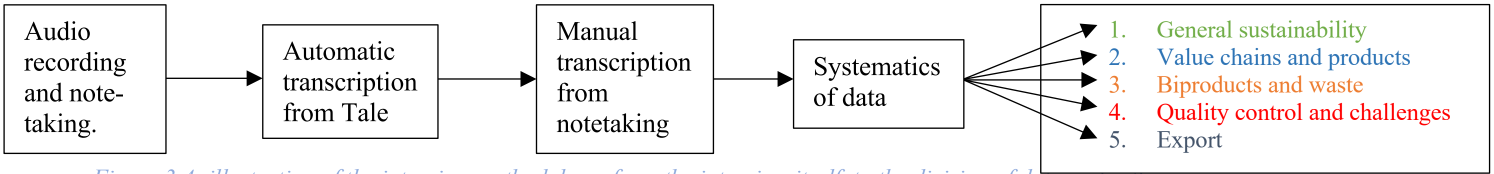


*Figure 3.4: illustration of the interview methodology, from the interview itself, to the division of data under themes.*

The automatic transcription is done through "Tale" application, where audio recording from Team can be transferred directly to the application. "Tale" can be transcribed a combination of Danish and Norwegian conversations into English, which made the program advantageous for the project. The data had to be divided into the categories illustrated in Figure X. This will have to be done manually. Transcribed was done after each interview, which allowed everything from the interviews to be remembered well, which made the data accurate. The transcription was done to prepare the data collection that can be used for further analysis. If transcription was not done, it would not be possible to design the MFA and the quality flow.

## 3.4 Observations studies of the Hydrolysis experiment

For this experiment, 1 kg of chopped frozen mackerel biproduct was used, excluding the stomach. The fish mass had to be thawed before use. This took place in a 30-minute water bath, where the internal temperature rises so that it comes as close to 50 degrees. It is better that the core temperature does not hit 50 degrees than that the water bath is more than 30 minutes, because the heat increases the risk of oxidation. The enzyme Alcalase is added, and thereby the enzyme activity can proceed. After 30 min enzyme activity, the enzyme was inactivated. This was done by heating the mass for 10 minutes in a microwave. After the microwave, the bones were sorted out, after which the remaining part was cooled in an ice bath. In the ice bath, you can see the beginning of the separation. To be able to see more clearly the phase separation, the product is centrifuged, after which it is very clear that the lipids lie at the top, while the proteins have fallen to the bottom. The separation phases are done manually.

Several different carriers were used- which may mean that a small part will be lost. These are such small quantities that they are not thought to have a major impact on the result. However, this could have a greater impact if the hydrolysis were on a large scale. Probably, the method will also be made differently. It is therefore something that should be considered when this is discussed.

The extracted protein is dark when compared to proteins from salmon, where it is white/light. It is not known why, but perhaps it is the particles. Photos of this have disappeared, but it is not believed to have a bearing on this project.

## 3.5 Observations studies of the industry observation

The fish is pumped from the vessel into the bleeding tank. Then the fish is sorted by size of rails, with the smallest fish falling through first and the largest fish last. Each size of the fish has its own processing band, to maintain control over the fish and to monitor the quantity of fish exiting at the end. To ensure proper filtering of the fish on the conveyor belt, they must be placed headfirst. This is accomplished using a flipping mechanism where fish facing the wrong direction are rotated so that the head leads. It is crucial that this process is carried out gently to prevent any deterioration in fish quality.

Within the processing machine, the entire fish undergoes processing. The head, tail, skin, and viscera are automatically sorters out, while fillets or cuts are conveyed on the belt. Quality control is again conducted manually at this stage. Consequently, any fillets that do not meet the requirements are sorted out. The item that passes through the quality control are placed into barrels for marinating and then transferred to storage with lids. These barrels are stored until they are ready for delivery. The entire production process operates within an open system, so it is possible to control the quality of the fish.

## 3.6 Material flow analysis

By investigate flows in the pelagic industry, transparency can be created. This provides the opportunity to analyze the pitfalls that exist in the material streams.
From the observation, an understanding was created that made it possible to set up the process steps. These process steps include the concrete steps as described in Table 3.6. Then the flows were set up. They did this based on the insights that had been created from the interviews. With the flows set up and the process, the amount of flows had to be calculated, which could be done in STAN. Input used as starting data is taken from (Myhre, et al., 2022). The result from the MFA models is a combination of data from literature, interviews, and observations.

First, the process steps necessary for the entire production will be formed. Then the process steps are connected to an arrow (flow), from which it is possible to see which way the flow runs. When flows and process steps are in place, calculations will be made in STAN, which provide a visual overview of all flows and their volumes.

To create a visual understanding, Sankey arrows have been used, which vary in size according to how large the flow is. This makes it easier for people from outside to see and understand which processes affect the volume of the flow. All the arrows there are black, while the input and output arrows are striped. (Cencic & Rechberger, 2008)
Two separate MFA models were developed, one for mackerel and one for herring. This is due to the diversity of data. Although the processing steps are similar whether it is herring or mackerel that is studied, a model representing the Japanese approach was also developed to allow a comparison of the processes.

*Table 3.4 – processes P and flow F shown in the MFA model, as well as a description of each.*

| No | Process | Description |
|---|---|---|
| **P1** | Catch | In this process, the fish is caught with any method of capture |
| **P2** | Quality control | Through quality control, fish that do not meet requirements for processing are discarded and used for further processing. |
| **P3** | Sorting | The fish is sorted by largest |
| **P4** | Filleting | Treatment of the fish so that only fillet and bites remain. The fish side streams are used for further processing. |
| **P5** | Quality control | Checking the quality of the fish before it is passed on. |
| **P6** | Packing | The fish is packed properly to maintain the best possible quality and shelf life. |
| **P7** | Storage and distribution | The fish is transported either for sale or further processing, and stored in storage until it is needed. |
| **P8** | Further processing | Discarded fish or by-product is used to form fish oil and meal, or and stored as ensiling. |

| No | Flow | Description |
|---|---|---|
| **F1** | Whole fish | The fish has not been processed yet. And that's why it's still whole |
| **F2** | Whole Fish | The fish has not been processed yet, and therefore it is still whole |
| **F3** | Fish without entrails and heads | The fish has been through the first processing step, where the guts and heads are sorted out. |
| **F4** | Fillets | After the process, only fillets remain in the process |
| **F5** | Fillets | Approved fillets are passed on, while unapproved fillets are sorted out and must be further processed |
| **F6** | Fillets | The file is passed on in the process. |
| **F7** | Fillets | Fillets that are approved are packaged so that they are ready for distribution |

The program STAN is programmed to calculate the result itself from entered data. Among other things, it calculates the mass balance itself. This equation is:

$$\sum input = \sum Output$$

Since there is no stock in this model, it should not be included in the mass balance sheet. If there was stock, it had to be included in the model. This is the only equation relevant to this project. This equation will contain unknown, measured, and accurate variables. This should allow STAN to be able to calculate a missing or unknown value. However, it is important that as much as possible is known because it will give a more accurate result. With that said, there could also be errors in the data provided. Therefore, it will always be best to inscribe uncertainties to the provided data. However, uncertainties are not used in this project since it was not possible to calculate. However, this also means that there may be bias associated with MFA models.

### 3.6 Quality flow

Udfra MFA-modellen fremstilles der en dybere forståelse af hvad der går ud af de forskellige processer. Det første der beskrives er hvilke processen der opstår skadet fisk og side streams, og derfra bliver skabes der en forståelse af de kvalitetsparameter der er relevante. Dette er bliver opstillet i en tabel, der skaber en visuel forståelse af kvaliteten. Kvalitetsflowet viser procestrin, og på hvilke procestrin sidestrømme og skadet fisk opstår.

**SWOT-Analysis**

After developing the concept, a SWOT analysis was carried out. This analysis is helps to understanding the advantages and disadvantages of a quality flow. The method allows identifying and analyze the positive factors (strengths and opportunities) as well as then negative factors (weaknesses and threats).

Based on this methodology, the quality flow has been developed. Its description and explanation are based on (Grimsmo, et al., 2011).

# 4 Result

This section describes the current situation of material flows in the pelagic fishing industry, where a quantification of the MFA model using material streams. In addition, a basis for quality flow will be formed, which will create an overview of where the side streams end up.

## 4.1 Material flow analysis

### 4.1.1 Process flow

The flowchart in figure 4.1 shows the overall process of the observational study from which the MFA model was developed. All fish processed at the Norwegian companies are caught at sea and received on land.  It was observed that the fish were sorted into 4-5 size after receipt.
After sorting, the fish is filleted or wrapped round for export. The fish is whole when cut into fillet. Side streams from filleting are sorted from secondary production, whereas fillet is transported on conveyor belts for further processing.
The observation showed that the processed fish fillets are packed in barrels with brine and then put in storage. The round fish are frozen in boxes and stored until further notice, to export.

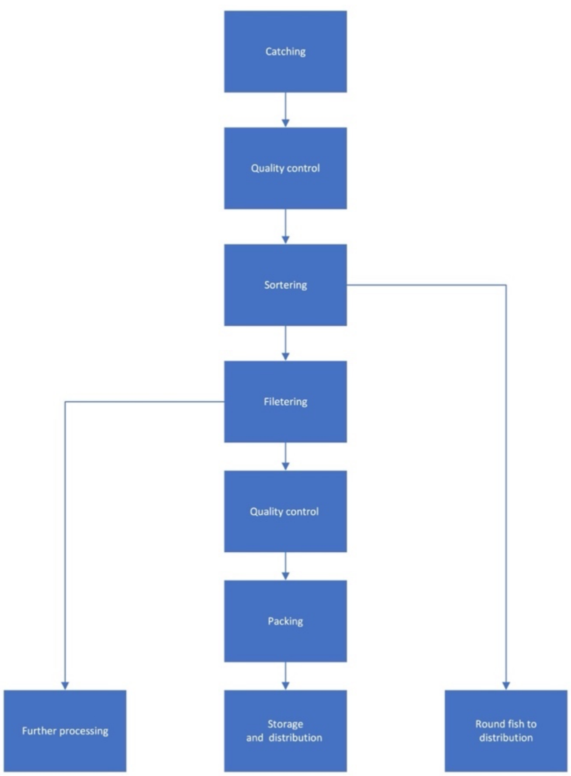


*Figure 4.1 - Overall process of the fish when caught. Based on this diagram, the system boundary is determined. The system is covered from catch to distribution for both herring and mackerel. Flowcharts include further processing and distribution of round fish.*

## 1.2 Mackerel

The illustration shows the mackerel's journey through production from the time it is caught until it ends up as a final product. Each box is a process step where the mackerel is processed, while each arrow illustrates the route the fish can take. Each number shows the amount of fish in each flow. All numbers have the unit of tons. The process is a general process that is a linking of literature, interviews and observations.

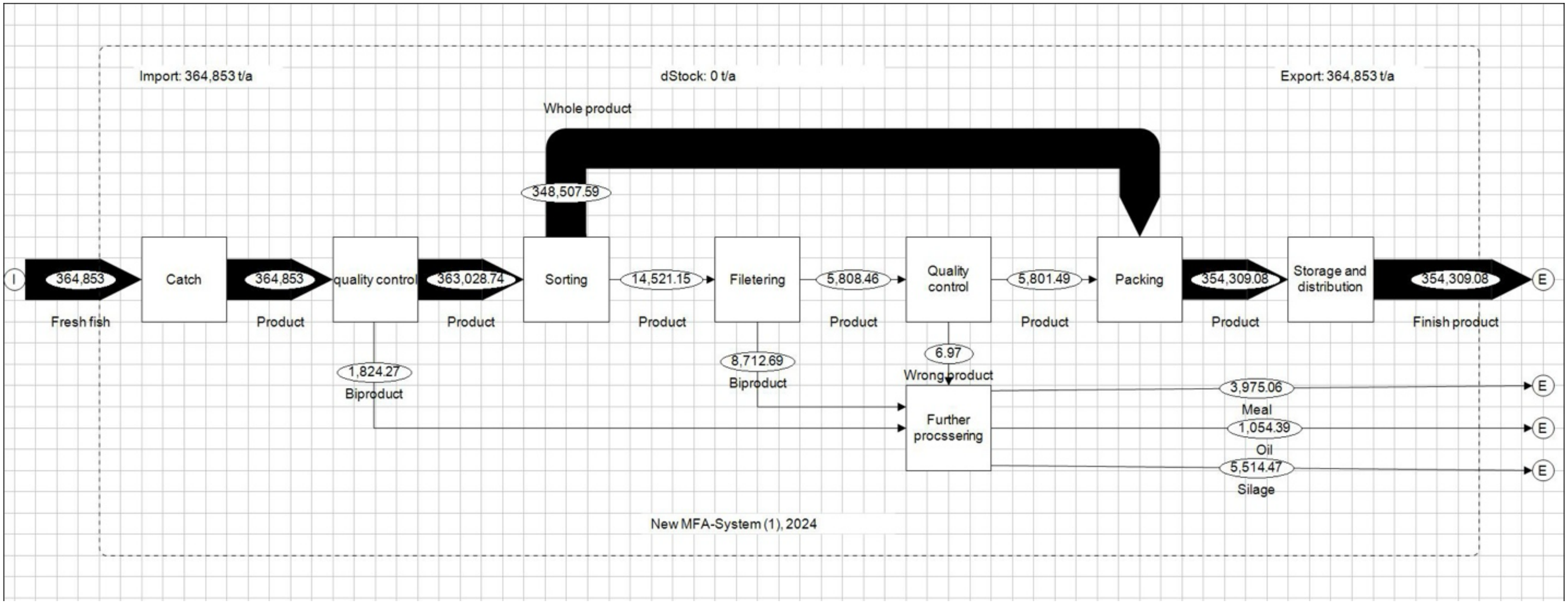


*Figure 4.2 - illustration of the supply chain of Mackerel from catch to consumption using the STAN program. The figures presented are based on data from report "Analyse av marint restråstoff 2021", which, however, was calculated based on actual percentages. Detailed calculations can be found in appendix F, where manually, prepared data ensure and understanding of the data presented in STAN.*

The result from the model (figure 4.2) shows an extensive supply chain ranging from capture to consumption. The system boundary is set to include all processes in Norway, as each step is crucial to shaping the final product. According to data from SINTEF's report (Magnus Myhre og Roger Richardsen, 2022) 364,853 tons of mackerel are caught daily.

During the quality control, a small proportion of mackerel, primarily fish with damage, is sorted out, which according to the respondents has been reduced due to a more careful treatment of the fish in the industry. Respondent 4 also believes that this proportion is less than the 0.5% spent in this task.

After sorting, the fish are divided into two groups: those to be exported and those to be further processed. Only 4% (14,521.15 t) of the total catch is processed in Norway, while up to 96% (348,507.59 t) of the fish is exported as round fish, primarily to Japan.
Of the 4% processed in Norway, by-product accounts for 60%. A significant part of the by-product, according to the literature and respondents 4 and 6, is ensiled to prevent spoilage of the part that is not immediately used. About 53% is ensiled, while 10% and 37.7% are initially processed into oil or flour.

During the second quality control, only 0.01% of the cut fillets were sorted out. Respondent 4 states that this control is primarily designed to ensure that the fillets look appealing in terms of appearance and to minimize the risk of product complaints. Since filleting is an automatic process, there is minimal error at this step. The exact amount that is rejected is not known, but is estimated to be very small, reflecting the minimal occurrence of errors in this process.

In this model, the "whole product" is reintroduced into the system and is considered part of the "finish product" as it is sold on to customers. Ideally, it would be a product out of the system and have its own packing and conveying step. Nevertheless, it is presented as in Figure 4.2, since the round fish are also packaged and stored before distribution.

*Table 4.1 – The mass balance of the MFA model for mackerel*

| **Input** | **Output** | **Difference** |
|---|---|---|
| **(100%) 380.750 ton** | (100%) 380.750 ton | 0 ton |

The mass balance of this MFA model for mackerel is in balance, whereby everything that is captured ends up as value-adding materials. Thereby, there is no food loss connected to the fish. This is not a surprise, as it has long been known that everything that is processed in Norway is exploited (Myhre, et al., 2022).
Everything is used even if it does not directly go to human consumption. In this way, it can be assessed that the quality of the processing and treatment of the fish is good, as well as the costs associated with the companies are well covered.
The SINTEF report (Myhre, et al., 2022) explain that the processing rate in Norway is very low. The report estimates that it is the large proportion of fish exported out of the country that can explain the low processing rate. Respondents agree, however, respondents 1 and 4 have not thought about the fact that it gives a low processing rate, because the utilization rate in Norway is 100%. Respondent 2 has not thought about this problem since respondent 2 just deliver round fish. All respondents comment that it is always about demand. If the demand to process more fish is not sufficient, this will not be done.

## 4.3 Material flow analysis for herring

The illustration shows the herring´s journey through production from the time it is caught until it ends up as a final product. Each box is a process step where the herring is processed, while each arrow illustrates the route the fish can take. Each number shows the amount of fish in each flow. All numbers have the unit of tons. The process is a general process that is a linking of literature, interviews and observations.

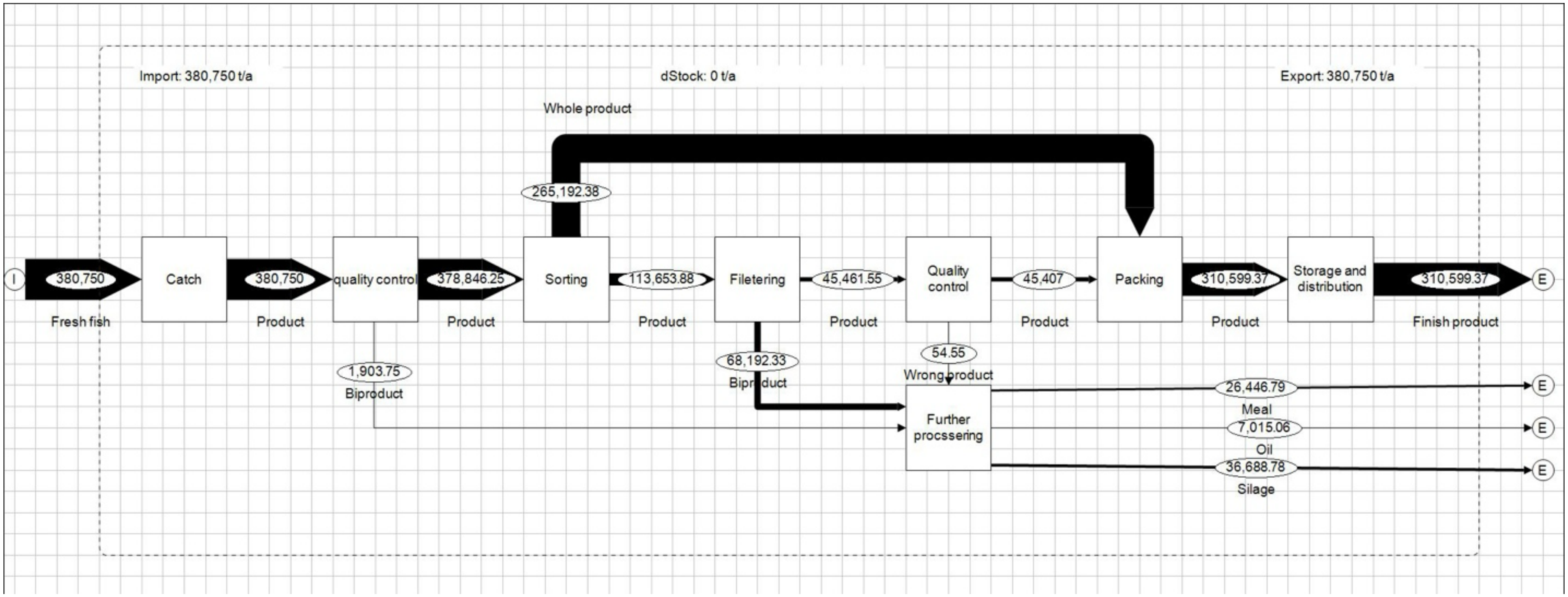


*Figure 4.3 - illustration of the supply chain of herring from catch to consumption using the STAN program. The figures presented are based on data from report "analyse marint restråstoff 2021", which, however, was calculated based on actual percentages. Detailed calculations can be found in appendix F, where manually, prepared data ensure and understanding of the data presented in STAN.*

According to the SINTEF report (Myhre, et al., 2022), more herring is caught than mackerel. The respondents agree with this claim. In this MFA, 380750 tons of herring are caught per day and, as with mackerel, the bulk is exported, which is up to 70% (266,192.38 tons). As a result, only 30% of the herring caught is processed in Norway. According to respondents 1, 2 and 4, there will be less rest raw material available from herring, for the primary reason that herring has less enzyme activity than mackerel and is therefore more resistant to damage. In the MFA model, however, it is estimated that 0.5% of herring is rejected at the first quality control. Respondent 4 believes that this proportion is probably high, but still thinks the value can be used as an indicator.

As with mackerel, approximately 53% of side streams are ensiled. Respondent 4 believes this is correct because the bulk of the by-product is ensiled so that the shelf life can be extended. However, this means that it is not possible to use for human consumption.
"Whole product" is also being reintroduced into the process, primarily to illustrate that it is also being packaged and stored.
The model shows that everything that enters the system also comes out again. There is thus a basis for mass balance in the system when examining the fish as a material.

*Table 4.2 – The mass balance of the MFA model for herring*

| Input | Output | Difference |
|---|---|---|
| **(100%) 380.750 ton** | (100%) 380.750 ton | 0 ton |

For herring, the mass balance is also 0, and thus all the material of the fish is used. Whether it is not for human consumption, then for feed or biogas, but the essence is that all material is value-creating. This also shows that companies have a sustainable approach that will make them attractive also in the future.

The high export rate of herring and mackerel is considered a significant export product for Norway and makes pelagic fish an important commodity on the international market. The analysis underlines the importance of local processing of fish resources to create economic value and sustainability. Respondent 1 expresses a desire to be able to produce fillets for export to ensure better control over the sustainability of production. Respondents 2 and 4 understand the desire to see the export of round fish as an essential source of income that they see no reason to change. However, respondents understand the problem when it comes to maintaining and improving sustainable initiatives in the industry. The Japanese respondent fears that processed fish will have a higher price, making it less attractive to buy Norwegian fish. In section 4.1.6 an in-depth description and analysis of processing in Japan is made.

### 4.1.4 Processes

It is relevant to understand the processes from the MFA model, whereby the next part is a description of the process from the interviews, and the literature. Moreover, it includes the thoughts and commentary the interviewees had when talking about each process step.

**Catch**
Fangsten er en afgørende processen når det kommer til produktion af pelagiske fisk. Derved kræves der en hensigtmæssig og skånsom metode, for at undgår skader på fisken, som forskellige fangstmærker. Disse mærker kan betyde at fisken frasorteres senere.

Ressponterne havde forskellige meninger forbundet til fangstmetoden. Respondent 4 nævnte at brugen af trawl eller ringnot afhang af  fangstbetingelserne. Dette bekræftede repsondent 8 er rigtig, og at alle fartøjer idag har implementeret begge typer net. Fiskene ankommer til virksomhederne inden en time efter fangst. Denne tid er ifølge responerne afgørende for at kunne minimere stress af fisken, og der af  sikre ideel kvalitet ved ankomst.
Måden den pelagiske fisk kommer fra fartøjet til virksomheden er ifølge litteratur (Møen, et al., 2017), gennem en pumpe. Den hastighed fisken pumpes med er ifølge respondent 1,4 og 8 vigtig for bibeholdelse af fiskens kvalitet. Er pumpen defekt er det fartøjernes ansvar at vedligeholde den. Idag er pumpen dog ikke et stort problem da der er fortaget en del ændringer den sidste tid (Møen, et al., 2017).

**Quality control during catching**
After pumping, the fish undergo initial quality control. All respondents agree that this point is crucial, as fish that do not meet the strict quality requirements are sorted out. The sorting is done by internal control, where all fish are checked for damage and freshness. According to respondents 1, 3 and 4, non-compliant fish are sent to secondary production, whereas according to respondent 2 they are simply sold at a reduced price. Approved fish, on the other hand, will be used for primary production of fillets or round fish. According to the quality manual, minor damage will continue to cause the fish to be used in primary production, if it meets the requirements for use for human consumption.
According to respondents 1 and 2, the small proportion of fish sorted out in quality control is since vessels have become better at treating the fish well. However, respondent 1 notes that there will always be a variation because more mackerel than herring is generally sorted out due to mackerel vulnerability. Respondent 4 points out that enzyme activity is higher for mackerel, resulting in vulnerability as more fat and protein oxidation during the process.
In addition to the visual control of damage, the freshness and temperature of the fish is also checked, because respondent 4 has previously observed fish that had gone into rigor mortis. Fish in rigor mortis are not desirable, and although they are rarely observed, the pliability of the fish becomes the test. Respondent 4 says that a fish with good pliability is not in rigor mortis.

When asked if there are challenges associated with quality control, respondents 1 and 2 have not observed any challenges. According to respondent 4, the challenge is not in quality control. It is more later in the process, when respondent 4 means it is because fish have a very high enzyme activity. The high enzyme activity makes the fish very careful not to destroy the gastrointestinal system. Destruction could lead to contamination of fillets and side streams, rendering them unfit for human consumption.

Another parameter examined in quality control is the catch of bycatch. It is a focal point for the respondents; however, the respondentts know the exact amount of bycatch. Respondents 4 and 8 comment that it is something that happens frequently because the fish live freely in the sea and can interact with other species.

In the inside observation study, an entire box of sorted fish left in the production environment was observed. This was interesting as there is a risk of contamination and oxidation of the by-product. In addition, this by-product will have a smaller possibility of sale for human consumption due to strict requirements. This observation was discussed with respondents 1, 4 and 7, where everyone believed that it had a minimal effect.

These controls also involve inspectors from certain exporting countries. These are especially important when it comes to exporting fish. In literature by (Abrahamsen & Håkansson, 2014). The respondents agree with this, as they have some external controllers connected to their companies. However, these controls go hand in hand with internal controls.

**Sorting**

Once the fish has passed the quality control, it must be sorted by size, because the size can vary between 4-5 sizes. During the industrial observation, sorting was carried out using two roller degrees, where the distance between these increases the further the fish it falls through. Small fish will therefore come through early, and large fish sent. From this, the fish lands on a processing boat that is tuned to this size.

Sorting takes place regardless of whether the fish are to be exported or cut, to ensure that the quality of the fish does not deteriorate further during sorting, it must be done at a responsible speed. At too high a speed, the fish will be handled too quickly, and this can result in injuries. In addition, it is important that the fall from the rolling degrees is not too long or hard, as this can also cause injuries to the fish.

The respondents also explain that sorting is important in relation to packing, as it is easier to pack a certain amount if the weight and size of the fish are known. Therefore, it is also relevant to sort round fish by size. The respondents explain that the rolling degrees streamline production and reduce manual work. SINTEF report (Toldnes, et al., 2016) shows, however, that the rolling degrees can sometimes treat the fish harshly. This, however, the respondents assess is minimal, in the damage that occurs. Respondent 2 explains that manual sorting also shows damage to the fish, which is therefore believed that it is more important to go with the automatic method.

Fish that after sorting need a more detailed treatment will go through a maceration phase to maintain the quality of the fish. This process varies by literature or holding. According to (Grimsmo, et al., 2011) this process must take place most the fish is alive to ensure that the blood continues to be transported around the fish. However, this step is only relevant for fish that need to be treated and therefore not round fish, says respondent 2.

**Cleansing and filleting**

Once the fish has been sorted, it lands on a conveyor belt leading to the filleting machine. For the fish to hit the filleting machine, it is crucial that the fish turns correctly with its head first. During the observation, it was noticed that the fish are shaken gently to ensure that they are turning right before moving on to filleting. Fish turning with their tails are shaken in the opposite direction using a pump. This pump must be gentle and run at the right speed, to preserve the fish quality.

In connection with the filleting machine, the fish is also cleaned of viscera and other side streams. This should be done as carefully as possible, due to the fish's gastrointestinal system, to avoid contamination of the fish's meat. Although this is an automatic process, according to respondent 4, it remains to check that this works correctly and at the right speed. The 60% of the fish cut is passed on to secondary production. For respondent 1, the by-product is sold to other companies, while for respondent 4, they process the by-product into fish oil and flour themselves.

Once the fish has been filleted, the fish is in the most vulnerable condition, as it no longer has the skin and its immune system as a protective barrier, which increases the risk of oxidation, and a shorter shelf life. Respondent 1 estimated that cold water is used on the conveyor belt before and after filleting, to slow oxidation and other degradation of components. The cut fish pieces are washed to remove any bacteria from the gastrointestinal system or other viscera. Respondents 2 and 3 agree and say that they take all necessary precautions to ensure that the fish goes through the process with as little loss of quality as possible.

Once the fish have been filleted, they are transported to further for a manual quality control. The side streams, on the other hand, are transported for further processing on a different belt, where they are either treated immediately or stored as ensiling.
Fish to be exported round will not go through this process, but rather arrive at the packing and storage stage, while the whole fish remains intact.

**Quality control in the processing**
As mentioned earlier, the fish cuts undergo manual quality control to ensure that they meet the requirements for sale. According to the respondents, this control assesses quality with the human eye. Respondent 4 comment that this process is manual because the volumes are so small that it would not be profitable to implement an automated system at this time. However, this may be a solution in the future.

In this control, the meat is put on the fish and wobbly. If it has a whitish color or visible gapping, it indicates that the fish quality is not optimal. Respondents 1, 4 and 7 say that there is minimal rejection during this rejection phase, however, respondents occasionally see these fillets with the whitish flesh.

**Transportation and storage**
After processing, the fish will be directly packed and stored. For respondent 4, this is done by placing the fish cuts in brine. For the other respondents, their fish is packed in boxes, or through vacuum packing. After that, the fish comes into stock. This is done at a temperature of about -5 degrees to prevent rigor mortis and oxidation of fats and proteins. The freezing of the fish, which occurs when it comes into storage, is crucial to minimize drip loss and gapping when the fish is thawed. A large drip loss happens when the fish is not frozen properly (Sørensen & Zeuthen, 2015), at the right speed. The longer the fish is in storage, the greater the risk of a lesser taste in the fish, however, it prevents decomposition. How long the fish is stored in the warehouse will vary, however, respondents believe that it is typically up to a week. With that said, round fish could be stocked up to a year. Before exporting. The temperature in the warehouse is controlled automatically, where according to respondent 2 there is a sensor that reacts to any temperature increases in the warehouse. Respondent 1 also comments that it is crucial that the warehouse, as

well as the transport, takes place in the dark. Since darkness is also a parameter that reduces the degradation of the fish.
Although a lot of pre-rules have been made, respondent 4 mentioned that they have had some problems with a deterioration of the mackerel when it was stored in the warehouse. However, they blame the high enzyme activity as the primary cause of the problem. When asked, respondent 4 has not found a solution for this problem. The other respondents have not been experienced quality deterioration.

No quality control has been implemented after packing and the warehouse, however, respondents 2 and 4 say that there have been no complaints, indicating that the temperature is correct throughout the period. This is even if the companies lose control of the product when it leaves the farm. The whole process from reception to storage takes about 5 min, means all the respondents.

**Further processing**
The rejected material and side streams will come through the secondary production, where it will be converted into fish oil or meal. This process is essential to reduce food loss in the pelagic fishing industry. Respondent 4 comment that all material will not be used immediately, and to prevent degradation, the remaining part will be ensiled. The ensiled material will later be extracted into oil and flour. However, ensiled material can never be used for human consumption. However, this method is something respondent 4 uses as a backup, unfortunately that the backup is necessary. When asked, respondents 3 and 4 say that the demand for fish oil and flour for human consumption is very small, which means that the respondents do not see much problem in using ensiling. If demand increases, it could be that they should investigate another solution. The respondents believe that there will be more focus on this in the future.
To extract oil and flour, different methods can be used, with this project focusing on hydrolysis.

The fish exported as round fish do not go through further processing, however, respondents 1 and 2 point out that there are strict requirements for these fish. This is, among other things, that there is a good quality of the fish. With a focus on sustainability, the respondents also have more focus on processing the fish themselves, as they want to know exactly what happens to the fish and its side streams. In section 4.1.6, there will be a deeper analysis of the Japanese treatment of the fish.

**Hydrolysis**

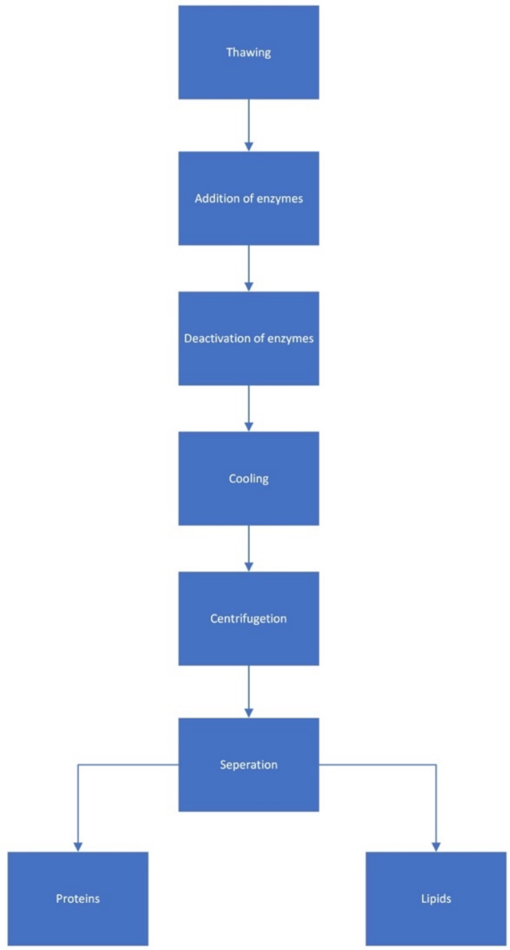


*Figure 4.4 - process diagram of hydrolysis, with all the steps connected to perform hydrolysis on a small scale.*

This section examines how hydrolysis is carried out on a small scale and how it could be scaled up to a larger production volume. Notes from the observation are described in Appendix D. Thawing frozen fish mass and subsequent enzyme treatment is essential to form a separation in which there is careful control of temperature to achieve the desired result. Thawing should not take too long because it will result in an incipient oxidation. In addition, after adding the enzyme, it is necessary to heat the mass again, to inactivate the enzymes after they have done theirs.

The observation of the process showed that centrifugation was used to improve separation and thereby increase the yield of oil and proteins. Finally, phases were separated manually. Automating this process through membrane filtration would be an effective method of scaling up.

The small-scale experiment showed that 10% oil and 37.7% flour were extracted. This data is used to estimate the yield of a larger production. In the MFA models for herring and mackerel, 10% oil and 37.7% protein powder are extracted, respectively. These percentages are calculated from the hydrolysis experiment. On a larger scale, this is likely to be different. The result shows that a significant part of the by-product can be used efficiently to produce oil and protein. This process is best carried out under optimal temperature and environmental conditions for the maximum yield and quality of extracted products to be achieved. However, there will be practices that need to be changed before it can work in a large production.

### Material flow analysis for Japan

It is interesting to see how the mackerel or herring from Norway is treated and processed in Japan, as 96% and 70% respectively are exported. Respondent 1 expressed a wish to be able to process the fish before exporting. For this to succeed, Norway faces some challenges in meeting the specific requirements set by Japan. This may include differences in production costs and labour. According to the Japanese respondent and (Abrahamsen & Håkansson, 2014), the pelagic fish is processed in China or Thailand respectively because it is cheaper.

The report from (Abrahamsen & Håkansson, 2014) prescribes that there is a lot of manual work in China, which can lead to a greater risk of errors, as well as a lower production rate, which could significantly affect quality. The report examines other reasons for processing in China instead of Norway, to which the conclusion is that Norwegian companies do not have sufficient production to meet the high demand. This may explain why the Japanese prefer the round fish and independently do the processing.

The illustration shows the mackere´s journey through In Japanese production from the time it is caught until it ends up as a final product. Each box is a process step where the herring is processed, while each arrow illustrates the route the fish can take. Each number shows the amount of fish in each flow. All numbers have the unit of tons. The process is a general process that is a linking of literature.

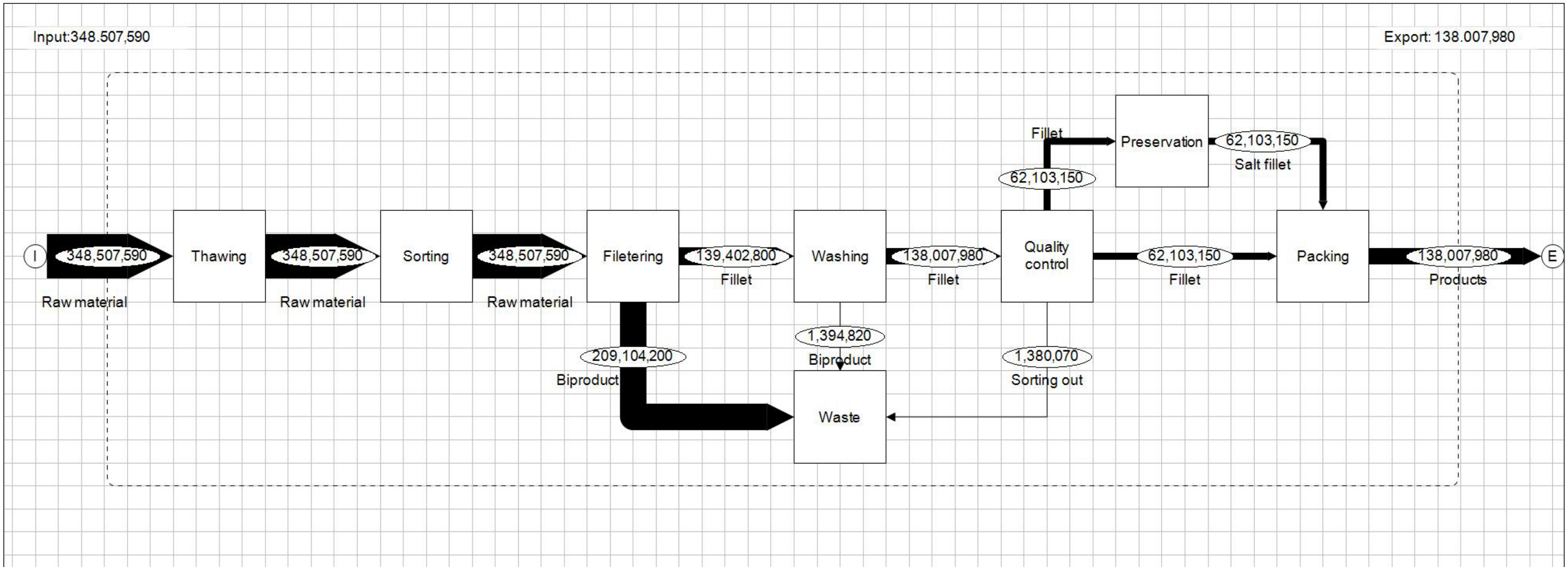


*Figure 4.5 - MFA model of the production part of mackerel in Japan, where more than 60% of the fish ends up as waste. The process is very similar to production in Norway; however, more manual work is associated with this process.*

The MFA model shows 60% of the total amount is sorted out as a by-product. This 60% disappears from the system as food loss. The remaining 40% is processed and ends up in some product used for human consumption. The calculation with the mass balance table 4.3 shows that there is no balance in the system. Despite this, the entire part that is part of balance is used for human consumption. Thus, there is a very large proportion of that end up as something non-value-creating, which indicates that there is very little sustainability associated with this achievement. The mass balance is if nothing else is sorted out in the process, and therefore the difference will be greater.

*Table 4.3 - The mass balance of the MFA-model for mackerel in Japan*

| Input | Output | difference |
|---|---|---|
| **(100%) 348.507,59 ton** | (40%) 139.403,04 ton | (60%) 209.104,55 ton |

**Process in Japan**

The fish is frozen and stored in Norway before shipment. This is the most effective way of preserving the quality of the fish and ensuring that it arrives in good condition. The Japanese respondent says this is important as there is a temperature difference. In addition, the report from (Abrahamsen & Håkansson, 2014) estimates that there is also a difference in freezing technologies, which makes it advantageous that storage takes place in Norway. The Japanese respondent explains that one reason why so many imports are the more expensive production prices, which also explains why it is countries like China and Thailand that process. The Japanese respondent explains that in addition to ships, there have been tests in using aircraft, for a shortening of the transport time, as well as possible improvement of the fish.

The process of thawing, sorting, cutting, and storing mackerel and herring is essential to maintain their quality and ensure that they reach the consumer in the best possible condition. The manual cutting process, as described in the video (Mackerel processing in Japan by Yoshukogyo , 2017), involves the removal of internal organs and bones. Washing the fillets is essential to remove unwanted components, therefore it is done right after filtering.

Once the mackerel or herring has finished processing, they will be sent back to Japan where they are sold to restaurants and consumers. According to the Japanese respondent, the sorted viscera and bones cost a lot of money to send for further processing, which means that the side streams primarily end up as food loss. The Japanese respondent comments that it is desirable to be more sustainable, which is why some cities have introduced that it is free to deliver the side streams for further processing. In these cities, according to the Japanese respondent, it is seen that more oil and flour is extracted. Another explanation for not being mined is that the Japanese companies do not have the technology to extract side streams from mackerel, and the technologies that exist need to be improved, and therefore there is still a lot of waste today. The Japanese respondent also comments that there is not enough knowledge about this type of technology.

### 4.4 Quality flow

This concept will analyze the places where side streams and discarded material will occur, as well as which quality parameters should be focused on. A developed quality flow has been created for the overall process, as the mackerel and herring processing process is the same.

In the future, a quality flow will be realistic in relation to available resources and technologies. In addition, it must be possible within the existing production conditions and financial constraints. In order for the quality flow to function optimally, it should be flexible enough to account for changes or variations in the production process and market needs. It must be dynamic and adaptable to any changing requirements or new discoveries in quality and safety.
Finally, it should promote continuous improvement and learning within the company. It will facilitate feedback, evaluation, and adjustments to achieve an increasingly higher quality standard for the product.

This figure illustrates the primary production, and where in that production side flows and damage occurs. The yellow circles describe the places in the process where injured fish occur or are discovered. These are fish that cannot be used for primary production. The red circles are places in the process where no side streams occur, but the green circle describes places in the process where side streams from the fish such as guts and nests occur. From knowing their resurrection place, it is possible to assess the quality parameters that are most relevant for more side stream and injured fish to be further treated The figure is based on data from interviews, observations and literature.

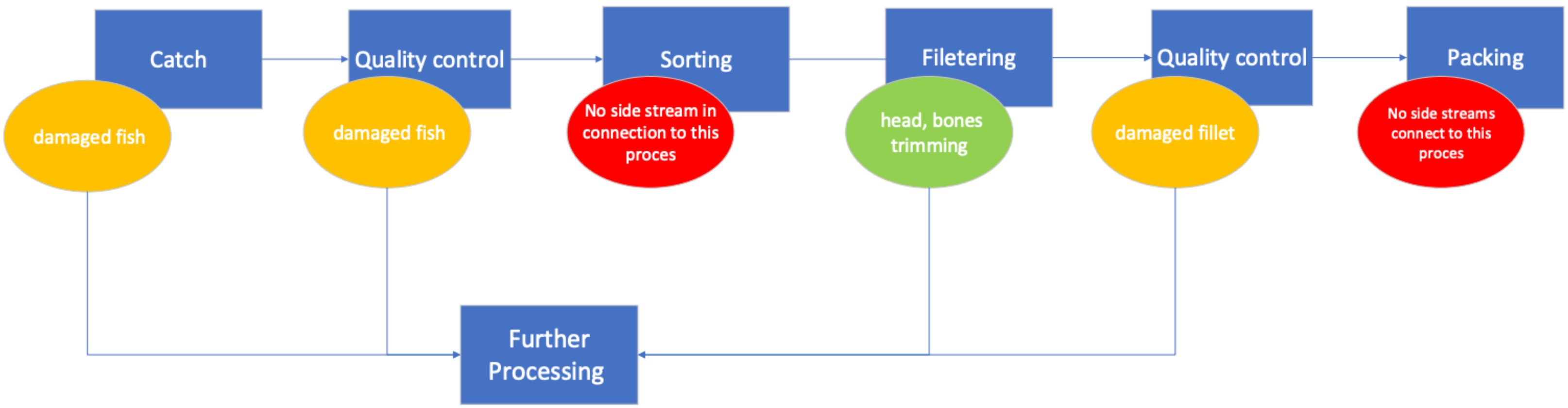


*Figure 4.6.- quality flow for pelagic fish is an illustration of where side streams and injured fish occur and are discovered in the process.*

*Table 4.4 Quality assessment of side streams and injured fish from the quality flow*

| Quality Parameter for damaged fish | Evaluation |
|---|---|
| **Sensory characteristics** | It is important that the sensory properties are as good as possible. Does the fish smell, the appearance looks strange, or is the texture poor.<br>These are parameters that are very important if the fish is to be exploited. A good sensory quality is important to ensure that the fish can be used for human consumption. |
| **Biological aspects** | Oxidation can negatively affect quality. Therefore, this is a parameter that is important to monitor to ensure that the fishing meets quality. In addition, it is important to do everything possible to side the currents and the injured fish. An oxidized fish, because it is stored under the wrong conditions, will result in the fish not being further processed and just ending up as biogas.<br>An injured fish may have an elevated concentration of fatty acids due to the breakdown that occurs in the triaglyceride. This can affect the quality so much that fish oil must not be used for humand consumption. |
| **Discharge quality and properties** | When the fish is injured, it can lead to changes in nutrients, pH and other relevant parameters. In the worst case, these changes may result in a restriction on use.  If a fish is severely injured, its discharge properties will, according to respondent 5, affect the fish's approval for various types of use. |

| Quality parameters | |
|---|---|
| **Sensory characteristics** | The characteristic smell that the fish produces during decomposition may make side currents unacceptable. This is therefore important to assess the taste and smell of the fish so that the product actually goes to oil and flour. |
| **Fat content** | Since the fat content will vary in the pelagic fish, it must be carefully considered which uses there are with side streams. Whether it's for fish oil or feed. |
| **Oxidation** | Since the fish contains the amount and type of fat it does, the risk of oxidation will be present. A quality parameter such as measuring fatty acid composition and the degree of oxidation will be a tool for assessing side streams and the products that are formed from them. |

As Table 4.4 shows, it is estimated that the sensory properties are of great importance for the quality of the fish. This is both when it comes to side currents or injured fish. In terms of appearance, freshness is assessed. Respondent 5 explained that a fresh fish has a shiny skin, a natural colour and a clarity of eyes. It is equally important that the injured fish also have these properties, especially if the fish is to end up for human consumption.
Even if the fish is damaged, the fish should still have a good and acceptable smell. These sensory parameters are also important: the fish should be used for fish oil or flour. Respondent 5 explains that the high standards for fish used for oil are due to the fact that they want to make oil of the best quality, and therefore it is important that fish used from here are of the best possible quality.

In the table, it is also assessed that biological factors such as oxidation are an important quality parameter. When oxidation with the free radicals starts, hashing is formed. This parameter can be used in conjunction with the sensory characteristics, because rancidity negatively affects the sensory characteristics of the fish. This makes the fish less acceptable to use as food. All respondents more that this is the hardest process to avoid. However, the industrial observation shows that sorted fish are not treated as optimally as fish for primary production. The observation showed injured fish, placed in a box that was just standing in the production room. Despite the cooling environment, there will be a risk of oxidation taking place here. With this, there will also be a risk of degradation from microorganisms. When the microorganisms break down the fish's tissue, it will lead to a deterioration in quality. From here, the box with injured fish could have started its decomposition. It is therefore somewhat discouraging when respondents 4 and 5 explain that injured fish and side streams are stored in the best possible way, so that fish oil and fishmeal are of the best quality. Interestingly, good handling is not so important when the oil is made. Respondent 5 states that the oil will be of good quality as long as it is stored properly or does not have the same high quality standards as before the production of the oil.

For injured fish, it has been assessed that the discharge of the fish has a lot to say. This should be understood as the characteristics of the fish are reduced according to respondent 5. It is assumed that the fish has a certain nutrient profile, and if this is not the case, it may mean that the injured fish is not used for what is desirable.
This quality flow and its quality assessment, when fully developed, will contain more and more relevant quality parameters. The quality parameters chosen in this project are considered most relevant to the task.

**SWOT analysis for the quality flow**

The SWOT analysis shows the strengths, weaknesses, opportunities, and threats of implementing a quality flow in a business. This is parameter every business must be able to assess to know if the quality flow improves or worsens the situation in the company.
The parameters set up in this SWOT analysis are a combination of comments from the interviews, but also own assessment, of parameters that are believed to be important for the implementation of the quality flow.


*Figure 4.7- The SWOT analysis. Divided into factors that can affect the implementation of quality flows for companies in the pelagic fishing industry. At the top left, the strength factors are described. At the bottom left the options. The top to the right, weaknesses are described, while threats associated with the quality flow are described at the bottom right. SWOT analysis made in the program canva.*

**The analysis of internal factors:**
One strength is increased product development, because implementing quality flow will be able to improve the quality of pelagic fish. In addition, the flow will be able to provide an insight to understand the problem. With the insight, more co-product can be used for human consumption. With the quality flow, it will also be possible to send the fish at a higher price, because there is the quality of the fish is the best possible. This is partly because more good quality fish will come through production and be used for the primary product. In addition, the quality flow will be able to provide better traceability. This will be a strength, as it will make it easier to find out where a possible problem has arisen. In addition, strengthened traceability could also improve quality and food safety. In the same way, it can help to strengthen confidence in the consumer. One more strength is efficiency, as the quality flow can help optimize processes leading to increased efficiency throughout the supply chain, including capture, processing, and distribution. The deeper understanding created by quality flow will also make it easier to implement measures that benefit the company effectively. A final strength can be the competitive advantage, because by implementing an efficient quality flow, companies can differentiate themselves in the market,

thus gaining a competitive advantage over competitors. A quality flow can also provide a long-term experience in the pelagic fishing industry, which can have a solid foundation and expertise to implement a quality flow successfully because there is a deep understanding of the industry's needs and challenges. Such as that there is a need for more by-product to be used as human consumption, but more importantly it is to make money, which currently includes exporting pelagic fish to Asia.

There are also some weaknesses in the introduction of the quality flow. A weakness can be the cost because there may be a need for maintenance of a quality flow. This can be costly, especially for smaller businesses that don't have the necessary resources. There may also be resistance to change, which includes employees and stakeholders being reluctant to new changes in production. This can make implementing the quality flow difficult. This may be, among other things, that it is more important to make good money than that all by-product and other sorted material is recycled. Also, one of the weaknesses is legislation. According to Mattilsynet, if it is by-product, it cannot be used for human consumption. It should only be side streams/rest raw material.

A quality flow can be complex because there are different fishing methods and market needs that can make it challenging to implement a consistent quality flow. In addition, this complexity must also make it costly for a company, because the business will most likely have to invest in the design of an MFA model before the quality flow can be developed. MFA will provide an easier approach to the quality flow.

An additional weakness is related to the complexity, due to fragmentation in the industry. This is due to many small and medium-sized businesses that can make it difficult to reach agreement and collaborate on implementation across the entire supply chain. This refers to vessels being owned by an external company, which is also the case for some further processing operations. Therefore, the quality flow will most likely be different depending on who is working with the implementation.

**Analysis of the external factors:**

The external factors are factors outside the company that matter. Some options may be market differentiation because the quality flow can position companies that are leaders in quality and sustainability. This means that opportunities can be opened for new markets and consumer segments. In addition, the quality flow can motivate innovation in fisheries technology, sustainable fishing methods and processing. One more option may lead to increased demand due to the consumer's increasing awareness of food safety, quality, and sustainability. With the quality flow, the overview can be created that can increase demand, because more transparency is created in the industry. Quality flow may open opportunities for new certifications and standards, as well as being able to maintain the existing certifications. With the possibility of new standards, companies can enter new markets. The quality flow can help with new research and development, for new technologies and processes that will improve the quality, traceability, and sustainability of the pelagic fish. The concept can additionally encourage vertical integration, allowing companies to control multiple stages of the supply chain, providing greater control of the quality and efficiency of processes. A final option may be to develop new partnerships and collaborations that allow knowledge from different actors to be shared.

The additional factors that have a major impact on whether the quality flow is implemented are threats. One factor here may be competition, because competition in the pelagic industry can be intense, whereby companies that do not maintain high quality may lose market share to competitors, and to large customers such as Japan. Other external threats can be unpredictable factors such as climate change, seasonality, overfishing and regulatory changes. This is all something that could ultimately mean that even less by-product or cut is used for human consumption. These factors can affect the availability and quality of pelagic fish. In connection with this factor, raw material shortages can also be a threat, as it can affect availability and increase costs. The lack of pelagic fish can lead to trade barriers, such as trade restrictions or tariffs, that will affect the export of pelagic fish. It may also be changes in consumer preferences and demand that will challenge the company's ability to maintain a competitive quality flow. Another threat can be image and reputation because a quality flow that shows quality problems can damage the company, and the industry's reputation. This leads to distrust on the part of the consumer. It is therefore important to maintain a new and relevant quality flow. If it is not updated, it will be the parent who will cause the consumer to build up distrust.

### 4.5 Barriers to more processing for human consumption

Respondent 4 extracts oil and flour, and although they use all side streams, a very small proportion is used for human consumption, and the primary explanation is a lack of demand. Another factor is the inactivation of enzymes, which occurs when using Mauric acid. The use of Mauric acid means that the product may not be used for human consumption. But by omitting the acid and inactivating the enzymes in another way, it will have some significance. The low temperature used in processing also inhibits activity, however, the process will still run.
If oil and flour are to be used for human consumption, it is important to comply with legislation in this area. The quality flow red arrows show side streams that are used for feed because it is processed in a way that does not make approved for food. Based on the MFA models, a large proportion is still used for ensiling. This is another explanation for why it doesn't work as it should.

Another barrier may be too small tanks, resulting in ensiling. A tank that is too small means that it is not possible to process the amount that is. Thereby, it prevents the growth of human consumption. In addition, more than half of the catch is exported as round fish to, among other things, the United States. Japan. This does not mean that the next steps are known which also explains why the non-machining percentage is not greater.

**Customer requirements**

The Japanese customers have strict requirements for their mackerel, which means that they have an inspector attached to each company, to ensure that the purchased fish is of the best possible standard. Some fish will therefore be discarded if the requirements are not complied with. It can be seen in both the MFA models and the flow of quality that most of the fish caught are exported. It is therefore the primary customer, which makes it even more important that the fish meet these requirements. The report from (Abrahamsen & Håkansson, 2014) describes the parameters examined by the Japanese controls. These are in line with the quality parameters used by the respondents to assess whether the fish is of good or poor quality.

Although the fish have a good quality through the first control, it must be maintained throughout the rest of the process so that the fish that come to Japan are of the best possible quality. This is especially very important when 96% of the caught mackerel is exported.

It can therefore be seen that there is potential for improvement that much more creates value for us humans, however, the very basic attitude must be changed among companies. When asked, some companies saw the potential in implementing a quality flow. However, there are quite a few parameters to consider.

# 5 Discussion

The broad literature search on the topic together with the insights from interviews of professionals and observations made a good basis for the material flow- and quality flow analysis. These are discussed below.

## 5.1 Literature search

The literature search itself proved to be a challenging process, especially because of the fluctuating literature available on the subject. This was surprising to note that on certain parameters there had been no significant improvements over the last 20 years. This raised the question of why there was not more development and research in certain areas of the pelagic fishing industry. In addition, it was sometimes a challenge to find newer literature, in order to create more credibility of the older sources. However, this was confirmed by the interviews. This coincidence between literature and interviews helped to strengthen the credibility of the project's results.

## 5.2 Insight from interview with professionals

The interviews have played a key role in this project and there have been some uncertainties associated with it. This is also seen in the project, where these uncertainties are explained. The bigger challenge was getting the appropriate respondents to participate in interviews. This has meant that not as many interviews were conducted as first expected. That said, respondents have contributed valuable knowledge and confirmation of literature, which has formed a solid basis for the project. While more respondents would have been desirable to achieve a wider range of perspectives, consensus among respondents has helped to strengthen the credibility of the results. The positive thing about the 8 respondents in this project was that they came from different parts of the industry, which has given the project additional perspective, as well as strengthened credibility. In addition, the Japanese angle got a new and interesting angle to work on, because the most important thing for them is the economy associated with it.

Another uncertainty to consider is the risk of bias in interview data.  All respondents explain their personal experiences and interpret the topics in their own way. In this thesis, interview subjects from different stakeholder groups were included, and therefore there are different approaches to the same topic. A wider range of stakeholders should reduce the risk of bias. 8 respondents are low, especially when it is desirable to minimize bias. However, it has not been possible to find more respondents due to the limited time and resources.

Respondents were selected based on interest and knowledge about pelagic fish exploitation. This means that the selected people have strong opinions on the topic than interested people in general. The 8 respondents are from different parts of the pelagic fishing industry, which helped create an in-depth understanding of each process step. This includes people from the primary product, people who work with the secondary production. Finally, respondents from research institutes were also interviewed.

The interview with the Japanese respondent, unfortunately, turned out not to be as effective as hoped. This meant that the thoroughness and level of detail of the Japanese section did not turn out as desired. However, the interview had sub-components that were needed just to understand the Japanese thinking about different situations. It would also have been more beneficial if the researcher had had the opportunity to conduct the interview himself, but since this was unfortunately possible, the next best thing was to get help with this. Interviewed part of the project, and therefore important that it was carried out.

Interviews as a method represent a new approach for the researcher to collect data, which has meant that the first interviews may not have been conducted in the most optimal way. However, this was offset through the later interviews. Despite the thorough research of the interviewees, it turned out that a simple one was not as relevant as desired. This meant that the time spent preparing and conducting the interview could have been spent more efficiently on more preparation of the other interviews.

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The automatic transcription with the program Tale performed well and gave fairly accurate data from interviews.  This works best with Speech and the manual transcription, while the interviews conducted were still new in memory, to be able to rewrite the simple incomprehensible sentences. The automatic and manual transcripts were compared to reduce any uncertainties that might arise due to language barriers. Both the automatic but especially the manual transcription was a long and time-consuming process, especially due to the time spent sorting through data.

## 5.3 Evaluation of Material flow Analysis

Material flow analysis has proven to be a valuable method for analysing material flows in the pelagic fishery and thus provides an overview of the potential for improvement and opportunities for more sustainable development. The MFA model has provided a systematic approach that provided a holistic understanding of resource utilization, and similarly made it possible to identify inefficient processes and areas with potential for improvement. In addition, it helps to show processes with sustainable improvement potential, which in this project is the reuse of resources. The MFA models in this project have also proven to be beneficial in several ways. The models made it possible to visualize the current handling of herring and mackerel, which made it possible to assess the system's compliance with the quality requirements. In addition, the MFA models served as a framework tool for storing data on material flows, which could optimize material utilization by identifying these material flows in the process for pelagic fish. It was no surprise that everything that comes into a system also comes out at the Norwegian industries, this includes everything both the fish used in the primary or secondary production. The MFA model for the Japanese fisheries shows that there is a lot of potential for upcycling based on the identified side streams.

For MFA to work optimally, extensive and reliable data was needed, which was difficult to collect. This would come from credible sources, and probably be the companies' own data. In order for this project to have a well-developed model, there has been a need to use data from literature, together with data from interviews. To improve accuracy, respondents have seen and sent feedback for building. This was done to ensure that the respondent agrees on the design and process. Feedback meant that the MFA model must be considered to be the correct model. In addition to feedback, the respondents have contributed valuable knowledge and confirmation of literature, which has formed a solid foundation for the project. Without this knowledge, it would never have been possible to properly complete the project and design of the MFA models and the Quality Flow.

**Processing in Norway**
Exports are a major source of income, and it can be difficult to opt out of these exports to increase the degree of local processing. The desire for increased local processing must be balanced against the economic benefits associated with exports. This means that at this stage it will be difficult to improve the degree of local processing. Although there is a desire among some of the respondents to increase this processing, companies face strict requirements and standards from exporting countries that make it difficult to change the procedure. Although this is something that hampers sustainability, the degree of processing happening in Norway is far on this front. All fish and fish side streams are all utilized, which means that the amount of food loss is minimal. However, the challenge when it comes to side streams used for human consumption, as this it is minimal how much is used. The demand for human consumption is different. Whereby some experts state that there is no demand for this. While other players who are targeting the humane market for fish oil have empty stocks early because the global demand is high. Therefore, for players it can be ideal to look abroad.

The interviews with the respondents underline the lack of demand for fish oil and proteins from side streams, reflecting the small space this has in the market. If there is no market for these products, companies will be reluctant to invest in this. Therefore, there is some way to go before it becomes possible to use the largest part for human consumption. For investment to take place, it is necessary to explore market opportunities to promote side streams for human consumption. A method of storing the large proportion of side streams removed from the fish is necessary. The large proportion makes it impossible to process everything at once. However, the problem is that the side stream will quickly decay, which makes this process complicated. If products rot it will end up as food loss, so this is not an option. Companies use ensiling as a method of preservation to store it for later. The acid used to lower pH is acid that must not be used for products to be used for human consumption. Thereby, a potential new source of supplements is not an option. This means that if more is to become human consumption, there is a need to investigate other methods of preservation, or an acid must be used, or innovative treatment technologies. This could be freezing the product until it is to be used, as with the side streams used for the hydrolysis experiment. The freezing inactivates the same enzymes as the acid, and thus an extended shelf life can be created.

Ringnot and trawl methods used in fishing have not been shown to have significant differences in quality today. The fish are not significantly affected, thus indicating that one method is better than the other. However, trawl will be tougher on the fish. There is a broad knowledge from the crew, and therefore it is assessed that there is no potential for improvement in the area. Then it should be that even smaller fish could be sorted out. The pump, which has been known to be critical, has been improved significantly that it is minimal how much it affects the fish.

A lot of emphasis is placed on catch creators according to Kvalitetshåndboken, but since it is also an older book, it may mean that the pelagic fishing industry has come a long way to reduce the physical damage to the fish. The book also puts a bit of emphasis on the biological damage, which the project has known is the one the companies struggle with the most. In particular, the biological damage such as oxidation and degradation has proven to be a challenge. This will mean that a finished product is produced for human consumption, instead ends up for further processing. Companies are working hard to solve this problem, so this is a place where there is a potential for more to end up as food.
By following the quality manual and understanding the SINTEF reports «pelagic boost», this will be able to increase the level of human consumption in Norway.

**Processing in Japanese Industry**
This Master has shown that it is a long time before Japan utilizes their side streams. This understands why Norwegian companies want to process more Norwegian fish in Norway before exporting it to Japan.

One of the main Japanese professionals also describes that in terms of sustainability, they are far behind, for example, in terms of sustainability. Norway, because there has not been much support for it. It is desirable to spend and utilize more, but the price for it is too expensive, compared to what they get out of it. As the Japanese respondent himself points out, the Japanese yen is depreciating while the euro is rising. This makes it less attractive to buy Norwegian fish. In addition to prices, there are also many parameters that need to be changed and improved before production can become as efficient as in Norway. In addition, it is well understood why respondent 1 would like to carve fillet in Norway, because there is too much loss associated with a Japanese production.
Production could probably become more efficient if more process steps were automated.

It is a limited proportion of the by-product extracted that is used for human consumption. Therefore, it could be interesting to investigate whether there is a market, and then implement a quality flow, so that each company for a necessary insight into the distribution of fish. As there are many players involved in the Japanese pelagic industry, the quality flow will be able to provide the overview needed. They could, among other things: Use it in combination with a material flow analysis.
Through these two analyses, Japanese industry will be able to gain an understanding of the quantitative and qualitative aspects of the supply chain, thereby creating a broader understanding of resource consumption, environmental impact, quality control and sustainability. When implemented, these methods can ensure long-term viability. Using material flow analysis as a method, Japanese companies will quantitatively see materials coming through the system. In addition, MFA will be able to help identify sources of fishery resources and fish that come through production.
With the quality flow, it can help fish maintain their quality throughout the supply chain. It may be to find the right speed for thawing and freezing, so that the fish maintains its good quality and freshness right up to the consumer.

To have as correct a result as possible, it would ideally have been best to use completely accurate and accurate data. However, this was an impossible process, as the Japanese respondent did not have the knowledge imaginable. Moreover, it was written for various Japanese achievements, but none of them answered, which was rather not expected. However, this made it difficult to find data and the precise process for designing the MFA. After assessing and discussing a lot, it was decided that the Japanese companies should be part of the project, because so much Norwegian fish ends up in Japan. In addition, based on the MFA model established, there is a typical indication that the Japanese have some way to go before they use their by-product for new products. Both literature and the Japanese respondent agree with this claim, therefore the result is considered credible.

**Further processing as hydrolysis**

Although hydrolysis is not a direct part of further processing of pelagic fish, the method does play a crucial role in this specialty. The method is essential as it helps to separate proteins and fat from each other and provides the possibility of extracting the product. The hydrolysis provided the necessary insight to understand what the fish's by-product goes through to become fats and proteins.

However, the risk that the results from the method are not correct is present, as the hydrolysis is only observed on a small scale. This is because observation of the separation process on a large scale was not an option. In this small-scale experiment, many different measuring cups were used. This means that a small part is lost with each cup. If the process proceeded exactly like this on a large scale, the loss will probably be more significant, however, it is also very likely that the process will proceed differently.

Based on the observations during hydrolysis, no processes have been identified that could improve quality because the treatment of the mass was considered in advance, which is reflected in the guidelines regarding temperature and time. This is one of the reasons why in the thawing phase great emphasis was placed on the mass not being heated more than 30 minutes, as exceeding it could result in oxidation and thus deterioration of quality.

The study of hydrolysis shows that it is an essential part of the process of extracting proteins and fats from the side streams of pelagic fish. Although there is some risk of material loss, this risk can be minimized by careful handling and compliance with criteria. It is important to pay attention to these factors to ensure a reliable and accurate analysis of the side streams.

### 5.4 Quality flow analysis

A fully developed quality flow should be able to analyze the production processes thoroughly to be able to understand how side streams and injured fish occur, and what quality parameters are needed before the material is transformed into the final product. Being able to understand quality standards and identify quality critical points is the key aspect for optimizing the quality flow. An evaluation of methods related to the quality flow is ideal for being able to use the quality flow in the future. The development of the quality flow and quality parameter is crucial for side streams and injured fish to be handled correctly, which will ultimately increase product utilization for human consumption.

The quality flow, when fully developed, will have a crucial role in the production process, for a better understanding of side streams. The complete quality flow should be able to help with compliance with quality standards, potentially reducing costs. The quality flow in this project is only a prototype, thus more grainy work is needed before the quality flow can really contribute in companies.
Feedback on this quality flow is, among other things. to incorporate a more detailed insight of side streams and injured fish while their listeners quality parameter.

Based on data, there are many parts of the process that have the potential for more upcycling of side streams. Firstly, less pelagic can be exported. Secondly, the industrial observation has shown that the handling and storage of injured fish is not sufficiently successful. This means that less injured fish is available. Since less is available, there will be less to be able to make oil and fluoride.

**Improving results**
The quality flow and material flow analysis are still unknown methods, whereby it required a lot of preparation, which took a little longer than expected before the methods were feasible. STAN was the program used for designing the MFA models because it was scarcely available. That said, there might be better programs available, but it worked fine for this project. Since neither respondents nor supervisors knew about this program, it was not possible to get tips and tricks for modeling and to know if there were better programs.
It was a long process to determine the design of the quality flow, because there were no examples of anything like this. This will probably be easier in future work, as there are now examples of quality flows.
In the future, it could be beneficial to look at other parts of the pelagic fishing industry, such as water and energy consumption or other parameters that can promote sustainability in the industry.A fully developed quality flow should be able to analyze the production processes

**Evaluation of quality**
The quality of the fish is crucial for both producers and consumers. Through interviews and literature searches, it was established that the quality of Norwegian mackerel and herring is a key factor for the pelagic fishery. In (Myhre, et al., 2022)`s repport The quality guidelines were considered to be in line with respondents' comments, even though they were several years old. The rapport (Myhre, et al., 2022) is not going in depth, with all process steps, but other reports, including reports from SINTEF, have contributed to a better understanding of how to achieve optimal quality.
The strict controls carried out in the companies help to ensure the highest quality for consumers. These checks include visual inspection, odor testing, and measuring temperature and resistance. Optimal quality not only ensures a better product experience for consumers, but can also lead to increased use of fish for human consumption and the use of more side streams for food purposes in the future.
It is therefore clear that quality plays an important role in the whole process and that it maintains the high quality. Therefore, it is important for businesses to continue to implement strict quality controls and follow guidelines like the quality manual to ensure the best possible product quality and consumer satisfaction.

## 5.5 Barrier to preparing workforce.

As mentioned earlier, the biggest challenges in relation to increasing the processing rate are the income associated with exports, demand on the Norwegian markets, and finally the quality when the fish is received. The main income for pelagic industry is exports. By eliminating or reducing exports, many companies will struggle for survival. Moreover, the demand for treated fish is not high enough to justify an increased processing rate. Although the processing rate is low, the utilization rate is 100%, which also justifies for the respondents that so much mackerel and herring are exported. In addition to this, strict requirements have been set by exporting countries, which will further make it difficult for companies to process the fish in Norway. To make this possible, investments must be made in new technologies. This is interesting why all the fish processed in Asia is manual. So why is it so difficult to get Norwegian companies to work? This explained the respondents had something to do with the increased price the Norwegian companies had to pay for carrying out the work. For this to change, there is a need to integrate all actors and invest together in research and development across the sector if machining rates are to be increased in the future and existing barriers overcome.

The quality of the fish is the best possible, which also makes it difficult to improve the degree of processing in this area. All the measures have been taken that could end in a culling out. Although the quality is good, external factors such as the environment will play an important role, because the environment will be able to influence the availability of mackerel and herring, but also the quality. The changes with the climate may also affect regulations and quota allocation, which may have consequences for production capacity and the economy.

If the demand for Norwegian mackerel and herring is not high in Norway, it will be difficult to promote the degree of processing, as the extra processed fish will end up as food loss. This is because more people do not buy the fish just because more is produced. If companies want to increase the rate of processing in this direction, they must do a great deal of work to increase the demand for this type of fish.

## 5.6 Limitations of the study

The main limitation of the study was its time frame. It is a master's thesis; the total time is approximately 1 1/2 semesters. This limitation meant that the scope and depth of the project had to be specified. Of this, pelagic fish were chosen as the focus of the project. This limited time also meant that there were limits to data collection, with e.g. limitations on always observations, but also on the design of the quality flow. Despite the early start of the project, it was time-consuming to find stakeholders who wanted to participate. This took valuable time away from the project. Most data were found through reports and combined with data from the interviews since it was difficult for the industry part to supply all data.

The respondents who ran did not have the desire or opportunity to release data relevant to the MFA models. It was therefore necessary to find data from reports and combine it with real data before the MFA model could be designed. A realistic model would have had uncertainties associated with data, however, the demanding work, just to have little data, is because there are no uncertainties in MFA models. Uncertainties explain that there is variation in the amount of catch because it is never caught the same every day. However, MFA models show how much is captured, exported, processed, which is the whole purpose of the project.

Other limitations are the quality of the data collected, which can be influenced by various factors, such as lack of accuracy of the reports. In addition, there have been methodological challenges that could have affected the validity and reliability of the result. However, the report from which the data is used was published in 2021, which means that there are no major changes until 2023/24, and therefore it was assessed that the data was valid enough to use.

# 6 Conclusion

Improved exploitation of side streams from pelagic fisheries will be achieved in the future through value chain mapping, where careful mapping and understanding of the entire value chain is essential to identify potential optimisation opportunities. The review of the value chain has shown that all co-products and resources are utilized 100% in Norway. These products are fish oil, fish meal and feed made from fish that do not meet the standards of direct human consumption. Fish and their side streams fit for human consumption are still used as feed for other fish because there is no demand for their use as human consumption.

The mapping showed steps where the fish are collected, processed and recycled to create added value. Hence how small a proportion is used for human consumption. By being able to identify and utilize side streams, it can help minimize food losses and increase revenue opportunities in the industry. For this to succeed, close cooperation across the value chain is needed, as is already seen today. The exporting countries, which are part of the value chain, still have a lot of work to do before they are at the same level of sustainability as Norwegian agriculture.

The mapping is a valuable tool for the value chain to identify and exploit potential opportunities for better exploitation of side streams from pelagic fisheries. By creating a more sustainable and value-adding approach to resource management, industry can not only reduce food losses, but also create new revenue opportunities and contribute to a more sustainable future.

In order to increase the use of mackerel and herring side streams for human consumption, there is a need to see more global vision, but also a need for new acquisitions in companies. Before it can end up as human consumption, there is a need to meet quality standards, so the products must be consumed. This includes working with a preservative method other than ensiling, or another acid approved for food. In addition, there is an increased need to raise awareness of these side streams for the consumer. This can be done by telling more about the health benefits, but also the sustainability of the products.

The quality flow will certainly help to shed light on problems, especially with the exploitation of side streams. And how the fish is actually distributed throughout the industry. With this concept, there is an opportunity to give companies a new understanding of the subject, as well as an eye-opener. In the future, the quality flow will contribute to more lateral flow having an increased potential for upcycling.

In order for all this to succeed, we need cooperation between all the players in industry, but also training for the companies. This could increase the utilisation of mackerel and herring side streams for a food purpose, thereby further reducing food losses in the pelagic fishing industry.

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# Appendix

## Appendix A – Litterature search

The table shows the considerations associated with the start of the literature search.

| What am I looking for? | Search tools | What can I find? |
|---|---|---|
| - **Definitions**<br>- **Short explanation of rest raw materials**<br>- | - Encyclopedias (Google scholar, Oria, Scopus) | - Definitions and concepts<br>- Explanation of words<br>- Translations |
| - **News articles**<br>- **Trade journals and Magazines** | - Sjømatbedriften<br>- Norsk sildelag<br>- Norsk sjømatråd<br>- Sjømat Norge | - Catch and export statistics.<br>- Quotas |
| - **Scientific material from universities** | - "Kvalitetshåndboken"<br>- NTNU<br>- FHF | - Workingspaper<br>- Reports<br>- Theses |
| - **Literature to the reports, theory**, **and method** | - The library<br>- Scientific databases | - Learning books and articles<br>- Scientific treatises<br>- Scientific articles |

For a deeper understanding of how to perform a literature search, NTNU Library was contacted so they could provide guidance. The library had the necessary expertise to be able to carry out the method correctly.

The implementation of the TONE principle as a critical method.

| Evaluation | Description |
|---|---|
| **Believable (Troværdighed)** | Here we look at these parameters:<br><br>- Who is the author?<br>- Who is responsible for the article?<br>- Where is source published?<br>- What sources and references are listed? |
| **Objective (objektivt)** | Objective analyses examine, among other things, whether the source is open-minded. To evaluate this, the following can be used: - How is the information presented?<br><br>- What intention does the author have?<br>- Is there agreement with other sources or research?<br>- Are there several sides to the matter and are they all elucidated?<br>- Is it informed in an accurate way? |
| **Accurate (nøjagtighed)** | Here it is examined, be precise and thorough the source is. It can be assessed based on the following:<br><br>- When is the source from?<br>- Is the information up to date?<br>- Can information be confirmed by at least two other sources?<br>- Is there noise in the language, structure, or data? |
| **Suitable (egnet)** | This looks at whether the source is useful or useful for the project. Therefore, the following can be assessed:<br><br>- Who is the source's target audience?<br>- Is the source relevant to the problem?<br>- Is data and information relevant? |

## Appendix B – Interview respondents

| Interview subject | Association | Interview type | Date |
| --- | --- | --- | --- |
| **Respondent 1** | Primary production | Semi-structured / via teams | 12.01.2024 |
| **Respondent 2** | Round fish | Semi-structured / via teams | 23.01.2024 |
| **Respondent 3** | Research | Semi-structured/ Telephone | 01.02.24 |
| **Respondent 4** | Holding of primary and secondary production | Focus Group Interview | 08.02.24 |
| **Respondent 5** | Secondary production | Semi-structured/ | 14.03.2024 |
| **Respondent 6** | Research | Semi-structured/ Telephone | 07.04.2024 |
| **Respondent 7** | Research | Semi-structured / Teams | 23.04. 2024 |
| **Respondent 8** | Vessel holding | Semi-structured / Teams | 01.05.2024 |

Appendix C – Display analysis

| | Theme 1: General sustainability |
|---|---|
| **Respondent 1** | Hmm I don't really know. It is then primarily to use the residual raw material to develop new products. We already do this by passing it on for processing. So, I think we're doing what is being done now. |
| **Respondent 2** | Well, we either sell our poor-quality fish at a cheaper price or we send it on for further processing. It is important for us to earn a little from the fish we catch. After all, we will not do that by throwing them out. We therefore do not really have any waste associated with the fish itself.<br>Perhaps there is some waste associated with exporting countries. However, it's not something I've sat myself into.<br><br>But besides that, we want to use less plastic when packing the fish, but if we remove it, it can promote the spoilage process. |
| **Respondent 3** | The sustainable measures we take include using as much as possible from the fish, and that the packaging is as sustainable as possible. Fish production as it is now in the most sustainable way possible right now. Therefore, there is no waste, side products of the fish are used on an equal footing as the primary part of the fish.<br>Of course, there are processes and methods that can be prepared in the long term. But with the knowledge we have now, we have done everything possible. |
| **Respondent 4** | By using as much as possible of the fish, waste and waste are minimized. Therefore, we also develop fish oil and flour ourselves from side streams from primary production.<br>Since we use the side streams to extract oil and flour for the feed industry, we create circular economy, which provides a lot of sustainability. Our packaging is as sustainable as possible, but it can always get better. It is therefore something that is being worked on. |
| **Respondent 5** | As much as possible is being done. Everything from the fish is used, either for human consumption or feed to fish. Side streams produce fish oil and flour, which give a waste product a new lease of life. |

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| **Respondent 6** | You see, there is minimal waste in the pelagic fishing industry, which helps to create a sustainable production, as well as a circular economy. Other sustainable initiatives can be changing packaging. After all, sustainability does contribute to the reduction of waste. |
| **Respondent 7** | Hmm sustainability is reusing a product again, instead of discarding it. This is the case, for example, with side streams from the fishing industry. |
| **Respondent 8** | In relation to us, it is that the quotas have been introduced so that in the future it is possible to catch fish in the sea. After all, this is a sustainable way of maintaining ecosystems. Otherwise, I know that a lot of sustainable initiatives are made in the companies, to have less waste associated with production. |

## Theme 2: Value chain and products

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| **Respondent 1** | Our vessels arrive at us approximately. An hour after the fish is caught. To ensure that the fish are as little stressed as possible. We catch our fish with straw because we believe that this method stresses the fish as little as possible.<br>In addition, the pump on the vessel has improved so much that minimal damage to the fish occurs. |
| **Respondent 2** | It takes an hour from when the fish is caught until we receive them at the factory. It is important so that the fish is as fresh as possible. We use straw, as it is the gentlest method of not stressing the fish. |
| **Respondent 3** | It varies how long it takes. The fish are in tank before they come ashore, and then they are pumped ashore. I'm not quite sure what to use in relation to pelagic fish. But I'm thinking it's ring not. Besides, I know there is something called pelagic straw, which is probably used for hake. |
| **Respondent 4** | We catch with trawl and ringnot, where trawl is the method that is most the fish. When which one is used, we do not know. It is the vessel that determines it based on conditions and other things.<br>I would say that if the boats are going to open harbours and the fish are stressed, you often see that you have to use trolling.<br>The first catch on this boat was a trawl of 350 meters.<br>Yes, so it's a safety drop there, for the fish, because it's huge. Then you get poorer quality. |

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| | We do not know much about the vessels, but most of the vessels have both trawls and purse seines. However, some boats only have ring seines, with which boat type has what I do not know.<br><br>Whether they use trawls or purse seines is something that is assessed on the boat, as they use what is best suited to how the fish are in the water and how they behave.<br>Purse seines can catch fish down to 100 meters. |
| R**espondent 5** | We work with the fish's side streams to give it a second life. This is done will extract fats and proteins from the side streams |
| **Respondent 6** | The fish are caught from external companies, which sell them to the processing companies. From there, they are in control of the fish. After this, the fish is treated in different ways, depending on how the fish is to be used.<br>All by-product and sorted fish are used for new products and therefore there is minimal waste associated with the process. |
| **Respondent 7** | Well, the fish are caught by an external catching company, and then companies buy them from there. Trawls and ringnol are the most common means of fishing used today. |
| **Respondent 8** | After all, we catch the fish and out and sell them on for processing. We are therefore the first step in such a value chain. |

## Theme 3: Sidestreams and waste

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| **Respondent 1** | We have a limited amount of waste, as everything on the fish is used in one way or another. However, I know that there is some waste in relation to water and blood. However, this is not something we have control over. I just know that the whole fish is used either for human consumption or feed for salmon, among other things. |
| **Respondent 2** | No, we don't really have any waste. A bad or damaged fish is either sold at a cheaper price or used for further processing. We try to discard as little as possible, which is why it is important to sell the fish at a cheaper price. I don't know much about side products however our product is round fish, but I think then that our customers do what they can to reduce waste. |
| **Respondent 3** | In the industry, you want to use everything from the fish, to minimize waste. It is, of course, blue. By using by-products in |

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| | side streams. I therefore assume that everything is used in some way. |
| **Respondent 4** | Between 0.5 and 1% are discarded upon receipt. This is not included. By-catch, as it has no control. The day I was there it was even down to 0.2-0.3%. It is therefore something that varies greatly and is therefore not a fixed value.<br>All defects and side streams are used for human consumption, and therefore it is important to say that these fish comply with the rules of human consumption. If they do not comply, they are used to feed for salmon or other animals and fish. |
| **Respondent 5** | The waste in the pelagic industry is limited because everything is used in one way or another. I don't really know how they use it in exporting countries, but I think there are rules for it.<br><br>With us, quality is important, but as soon as the oil is produced, it is much more hand-held, as long as it is handled correctly, but there are not the same quality requirements as when we receive the side streams. |
| **Respondent 6** | In the industry, we are far ahead when it comes to resource use and recyclability. Therefore, all fish are used as primary or secondary products when processed in Norway. I am not familiar with the processes used in exporting countries. But I don't think they're as far ahead as we are. |
| **Respondent 7** | I don't know much about that. Our fish are sold to the companies, and it is therefore they who process the fish. However, I am sure that as little waste as possible is being worked on. |
| **Respondent 8** | There is not so much waste associated with us, as the fish is sold to companies. So, I don't know. |

## Theme 4: Quality control

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| **Respondent 1** | Cooling is the most important parameter. This is what we control, because if the temperature is not low enough, the fish will prematurely reach rigor mortis. The water should be around 0 degrees preferably -3 degrees. We use water taken from the open sea, and not at the harbor, to minimize contamination.<br><br>And then we also check the fish when they come ashore, to ensure a high level of food safety. The fish that do not pass the |

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| | control are used for further processing, therefore we discard nothing from the fish.<br><br>We do not process side stream ourselves, but deliver them, so I assume that they meet the quality requirements. |
| **Respondent 2** | We only use cooling. Although, of course, we have quality control when the fish arrives. But after this check, it is just cooling that protects the fish.<br><br>A fish which does not meet the requirements at the time of inspection is sold as far as possible at a lower price. If not, they are used for feed for, among other things. salmon. |
| **Respondent 3** | Well cooling is the best method. Of course, the fish can go rancid under light, but when processing is so short I don't see a problem. The storage temperature is also short enough.<br>You want to hit about -3 degrees, because rigor mortis occurs, as we want.<br><br>Poor quality fish are sold at a cheaper price or for further processing. |
| **Respondent 4** | There is manual quality control. Upon receipt, there is control and after the pieces are produced. There is one person who controls the fillets and one person who controls the pieces.<br><br>We felt the fish where we could feel that the fish was still moving, which means that the fish has not come in rigor mortis. In addition, the smell in the production was fresh, which also indicates that the fish is of the best possible quality.<br><br>In terms of quality, one of the biggest challenges is when the mackerel is in stock due to its high enzyme activity. This means that the mackerel decomposes much faster than the herring.<br><br>In seasons when the fish play the most, enzyme activity is also high. Therefore, during this period, fish are more vulnerable. This is especially relevant for the mackerel, as it is very affected by this.<br><br>There is an internal control system where, among other things, there is a system of internal control. Counterattack control is a critical point. There is a visual check when the fish enters. Here |

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| | the fish is temperature checked, as well as freshness. Based on that, an assessment is made.<br><br>The biggest challenge in relation to human consumption is that fishing takes place in areas where there is a lot of food available, and then the fish have a high enzyme activity in the stomach and intestines, and then<br>it is like, when it is dead, it dies on its own.<br>So the stomach and intestinal region gets thinned and destroyed,<br>and then we end up with a product that we may have to cancel for food consumption.<br><br>In the control after the finished line, it is assessed whether a fish looks nice, or something else that affects sales.<br><br>We sort CAR; however, we have some challenges in relation to hygiene, which is important in order to send fish on for human consumption. We worked based on legislative "by-product category 3" this category may not be used for human consumption, but as ingredients for foot.<br>So, we call it a silage.<br>Yes, a silage.<br>It is a separate process, it does not go to our own oil production, but it goes to someone else,<br>and we can do it from time to time, so it is called by-product category 3. |
| **Respondent 5** | Quality is very important to us. If the sensory properties of the fish are not favourable, it will probably end up as biogas. The products we receive must be of such a quality that it is acceptable for human consumption. |
| **Respondent 6** | The appearance and freshness of the fish are checked even before they arrive at us. The fish must be of just the right quality before it can be used. However, most fish are today because they have become better at treating the fish gently. |
| **Respondent 7** | We do not have quality control as such, but we have over the last many years improved a lot, so that the fish for damage associated with the catch. Among other things, the pumps have become more efficient, so less fish are damaged. |
| **Respondent 8** | There is no quality control on the vessel, but a lot of optimization and gentle treatment has meant that the fish is not damaged in the same way. |

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| | Therefore, the fish are kept cool throughout the process on the boat to do as much as possible to ensure that the quality of the fish is top-notch. |
| | **Theme 5: Export** |
| **Respondent 1** | We produced fish fillet sold throughout Norway. This includes both herring and mackerel. By contrast, 80% of round mackerel is exported to Japan or.  Thus, the fish are first processed in China before arriving in Japan. This does not know whether side streams and damaged fish are further processed or become waste. There is a great desire for the fish to be treated by the respondent before export. unfortunately, there are strict requirements from Japan which do not make this possible. |
| **Respondent 2** | Most of the mackerel caught is exported to Japan, where it is processed. The export is by vessel in which there is a warehouse temperature of -3 degrees, which means that the quality of the fish does not deteriorate during transport. When the fish leaves the farm, it is no longer our responsibility. We therefore expect that the quality is ideal on the vessel, especially since we have never received any complaints about the fish.<br><br>I don't know what the Japanese do with the fish, but I think there are strict requirements for both treatment and further processing, otherwise they probably eat the side streams in some way.<br><br>Sometimes we have delivered fish to Africa but in those situations the fish will be at a lower price because the quality of the fish will be affected by the hot temperature. |
| **Respondent 3** | I do not know much about this. However, I know that Norwegian mackerel is of good quality, and therefore a lot is sold to Japan.<br>I'd rather not do anything about processing, but I reckon that the Japanese have many strict requirements, and therefore I think they use as much as possible. |
| **Respondent 4** | We export to Southern Europe and Asia, including Japan, where the fish is used for Bukka Pinball.<br>For the quality to be ideal, the Japanese have their own inspectors here when fishing. They want to see how the fish comes in to approve the quality. They note all the specific smells. |

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| | If not, enough fish are caught, fish from the warehouse are implemented. This is due to the challenge that the fish are seasonal, because they have their own walking patterns throughout the year. In addition, we must distribute fish according to a quota and fish in our territorial waters. And if there is a high demand for it, then deliveries to the market should be frozen. |
| **Respondent 5** | We export so much that our stock is often sold out because we simply do not receive enough in relation to the demand abroad. |
| **Respondent 6** | After all, Norway is famous for their mackerel, and especially Japan. |
| **Respondent 7** | There are many countries that buy fish from Norway. Mackerel fish is mainly exported to Asia and mainly Japan. While herring more is being exported to countries like Germany and Poland. A proportion is frozenly shipped to Asia. |
| **Respondent 8** | Well, Asia is a big customer for the pelagic fishing industry in Norway. Otherwise, the fish will be exported to other European countries. This is mainly because there is not a large enough demand for the large number of fish caught. Since we must have an income, the fish must be sold somewhere. |

## Appendix D – Interview Japan

**How do you work with sustainability?**

This company does not work directly with sustainability, but we do have an MSC- license contributes to more sustainability in Japan. Today, it is more common with an MSC-license and most companies do.

The marked used to only be closed on Sundays, but now its closed on Sundays and Wednesdays. This is because of less employment and younger people not that interested in working at the market anymore. This has cut suppliance and production of seafood in Japan, which has affected the sustainability.

**Is the company working with rest raw materials?**

Yes, most of the rest raw material is handled by the company. They also handle many types of milts.

Often, importers in other countries buys the materials and decides what comes into the marked. Many Japanese importers work in Norway.

Japan wants to export to other countries, but bigger volume is required first. Before, other countries paid high price for Japanese seafood, but not as much now because of other countries exporting same wares and are able to provide bigger amounts.

**Who are the biggest costumers?**

Mainly restaurants in Japan. Mostly sushi and Japanese restaurants. Some French and Italian restaurants too.

Normal people rarely buy it themselves directly from Toyosu. Many retailers and supermarkets buy from Toyosu and then normal people buy from them.

**Mackerel trading and handling**

Mackerel is normally sold fileted without head. In autumn season, a new type of mackerel is used, or it is imported via airplane

Yen is lower than Euro, deflation.
Production price in Japan is lower, which makes importing from other countries difficult. But Japan has a history of importing many species earlier.

Japan is not main buyer anymore of more specific species such as octopus and shellfish (abalone, urchin)

**How does the mackerel come to Japan?**

Often directly imported to Japan, but only fileted. If other processing is required, then it is often done in Thailand. 85% of mackerel comes from Japan. Norwegian mackerel is mostly fileted in Norway. Frozen mackerel comes by boat.

**Who buys mackerel in Japan?**

Mostly restaurants and consumers but will also go to more processing

**How do you think about utilizing rest raw material?**

In Toyosu, most of the rest raw materials is discarded because it is hard to differentiate between species and sort it that way. It is also a very busy marked, and therefore no time.

But in some other direct markets, it may be possible.

Japan is trying to develop technology to improve utilization, but very difficult so a lot of waste today.

Norway -> Limited species, high amounts of fish fished Japan -> Many species, smaller amounts of fish fished

Japan also has many species varying on the seasons. Also, location for catching may differ for species. Tuna is for example caught in the north during winter/autumn, but in the south during spring/summer.

It is hard for Japan to keep track for the species count.

**Are you interested in more lipids in fish?**

Currently content of lipids is very good in fish, like salmon. They (Japanese) like the fat amount in salmon.

Good quality is good lipid content in salmon, but too much is also not good.

Younger people like fattier fish, but older people like lean fish.

Eastern people in Japan also like more lean meat, but in Tokyo, fatty fish is popular.

Taiwan and China like fattier fish than Japan.

Fatty meat is expensive and easy to taste good quality. Lean fish is harder to taste for good quality.

**Thoughts on rest raw materials?**

Total collected may be about 40% and is bought to the auction every day.

Rest raw material costs money to be thrown away. But in Toyosu, it can be brought to "waste"-part for free. Then it is not waste, but processing

They have a plane to produce pet food from rest raw materials and byproducts.

## Appendix E – Calculations and data connected to the Material flow analysis.

All data are fictitious but calculated based on percentages told by the interviewees. This is to ensure that all data is anonymous.

### Herring

70% of the caught herring goes to fillet. From the report “Analyse Marint restråstoff 2021” 32700 tons of herring are used for oil or flour. The answer to:

$$\frac{32.700\ t}{70\%} * 100\% = 46.714\ t$$

This is the amount in tons needed for fillet, where 21,800 tons become fillet. Based on interviews, about 40 are turned into fillets. Of the remaining percent, only 28% is available residual raw material:

There is 70% herring sold and exported as round fish, which is calculated to tons.

$$\frac{46.714\ t}{70\%} * 100\% = \frac{46.714t}{0,7} = 66.734\ t$$

$$77.857\ t - 54500\ t = 23.357\ t$$

This means that 23 357 tons of herring are exported every year. This means that the entire degree of machining is not known. Processing for all known fish is:

### Mackerel

350,000 tons are exported per kilogram. Year mackerel: this corresponds to 96% of everything caught.

By then, x is used for fillet:

$$\frac{350000}{0.96} = 364.583\ t$$

$$\frac{364.583\ t}{100\ \%} * 4\ \% = 14.583\ t$$

There are 14,583 tons used for fillet, while of the available by-product there is 28%.

$$\frac{14.583\ t}{100\%} * 28\% = 4.083,24\ t$$

NTNU

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