Traceability and Quality Monitoring throughout the Fish Value Chain

D2.1 User requirement specification (v1.0)

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PB	Project Board
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EXECUTIVE SUMMARY

The objective of WP2 "Tracking hazards and potential measures" is to track potential hazards across the Bluebio value chain affecting food quality and safety along three crucial value chains in Europe, and more precisely: 1) the Atlantic salmon value chain, 2) the Atlantic whitefish value chain, and 3) the Mediterranean seabream/seabass value chain. In addition to tracking potential hazards, WP2 is targeting to map the critical parameters affecting the quality and also the safety by employing a non-destructive sensor (VideometerLight), a multispectral imaging instrument; meaning the use of non-destructive measures to be included in the iFish Management System (iFMS) for hazard control and prevention and alerting mechanism to be developed in the project.

The present report presents data from Task 2.1, focusing on the current situation, stakeholders' needs for non-destructive quality and safety sensors, and intelligent managing systems. All data used was collected through semi-structured interviews with Icelandic, Norwegian, and Greek stakeholders covering the Atlantic Whitefish, Atlantic salmon, and Gilthead seabream/European seabass value chains, respectively, as well as searching the literature and the partners' knowledge and experience. More specifically, this report defines the value chains of interest, summarises the current practice for quality and safety measurements, and unwanted incidents and hazards occurring along the defined value chains. Moreover, this report presents identified user requirements for non-destructive sensors, intelligent management systems, a tentative sampling protocol, and analytical data acquisition as input to Deliverable 2.3.

Both the salmon and the whitefish industry highlighted parameters such as blood spots, brushes, gaping, texture, and residual bones to be of high interest for improved traceability. Moreover, parasites are highly important for whitefish, whereas microbial pathogens such as *L. monocytogenes*, and spoilage microbiota are relevant for the Atlantic salmon industry (salmon is often eaten raw or minimally processed). Concerning seabass and seabream, microbial hazards are defined as most important. However, the presence of parasites (Seabass) and environmental and aquaculture drug hazards (for farmed fish) are also significant.

Identified hazards and quality parameters of interest will be further studied in well-designed pilot studies (described in Deliverable 2.3) to investigate and evaluate the potential of the VideometerLite system to identify and quantify these parameters. All measures will be evaluated by traditional methodology to evaluate the novel methodology and to make predictions for systematic use in the iFMS system to be developed.

1 INTRODUCTION

Herein we present the first version of the deliverable for Task 2.1., dedicated to the user requirement specifications for destructive and non-destructive methods for quality and safety measures as well as tracing hazards. This first version presents the outcomes from mapping stakeholders' needs and expectations to a roadmap of needs for the three user cases considered, i.e., Atlantic salmon, Gilthead seabream/European seabass, and Atlantic whitefish, respectively. The report defines the value chains of interest, summarises the current practice for quality and safety measurements, and unwanted incidents and hazards occurring along the defined value chains. Moreover, Deliverable 2.1 presents identified user requirements for non-destructive and destructive methodology, intelligent management systems, a tentative sampling protocol, and analytical data acquisition as input to Task 2.2.

The three user cases will be harmonised under a standard pilot design since, apart from the raw first material (type of fish) and the specific identified hazards in each case, the rest of the value chain remains more or less identic. The pilot variables that needed to be defined correspond to the hazard of interest, time, and place of data acquisition, where time and place refer to the different value chain sites (i.e., production, transportation, food processing, and storage). The definition of those variables is critical to sufficiently and efficiently data completeness coverage of the whole value chain.

In this first version of the user requirement specifications, we have identified the current status and needs for non-destructive and destructive methods for tracing quality and quality deviation and potential hazards along the selected value chains. A report at the end of the first pilot phase will outline the identified variables for monitoring the products along the food chain and the corresponding ones in terms of technological variables in the context of the pilots. It will provide the overall pilot definition and design that will be applied throughout the project for all the three use cases/types of fish considered.

2 NON-DESTRUCTIVE AND DESTRUCTIVE METHODS FOR TRACING QUALITY DEVIATION AND POTENTIAL HAZARDS

Although the importance of the traditional methods for measuring quality and safety (Fig. 1) is unquestionable (Hassoun & Karoui, 2017; Oehlenschläger, 2014), they do not have the potential to be implemented for rapid practical use when many samples need to be analysed on/at-line in the food industry. Spectroscopy in the ultraviolet (UV), visible (VIS), and infrared (IR) regions of the electromagnetic spectrum are becoming more attractive as an analytical technique for measuring hazards and quality parameters in food, where this makeshift has been driven by decreasing instrument prices, improved equipment, more available data power, and better chemometric tools. Moreover, an essential advantage of using spectroscopic methods is rapid data acquisition, the possibility of simultaneous determination of several quality parameters, and the ability to replace expensive and time-consuming reference techniques (Hassoun & Karoui, 2017). In recent years, several qualitative and quantitative applications of spectroscopic methodologies have been developed in the fish sector (Hassoun & Karoui, 2017; Hassoun, Sahar, Lakhal, & Aït-Kaddour, 2019; Melado-Herreros et al., 2022). These applications include: (i) evaluation of fish freshness; (ii) relevant authenticity issues of fish that concern species, geographical origin, and production method (wild/farmed, fresh/frozen–thawed); (iii) detection of microbial behaviour and spoilage; and (iv) prediction of some physicochemical and textural parameters.

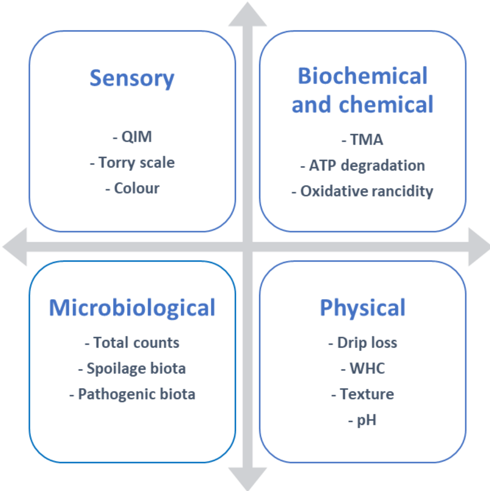

Figure 1. Traditional methods for quality and safety measurements of seafood.

The Videometer Spectral Imaging Technology is one such **non-destructive** technology that allows detecting hazards and safety issues as well as a product's chemical and physical structure, performing analyses that keep the product intact. Videometer spectral imaging instruments measures more than 12 million spectra on a food sample within a few seconds. Every pixel in the image is a spectrum covering UV, visual colour, and NIR ranges, including a fluorescence option, and of areas down to 30×30 µm. The analytical power of the technology offers a unique potential for fast characterisation of food integrity in terms of colour, surface chemistry, texture, shape, and size without touching the sample and with little or no sample preparation. Videometer has an unprecedented experience and track record for putting spectral imaging to work in everything from R&D laboratories to in-line production systems (some examples are shown in Fig. 2). Videometer has developed advanced spectral imaging systems for 24/7 in-line sorting that have been in production since 2002 (https://videometer.com/).

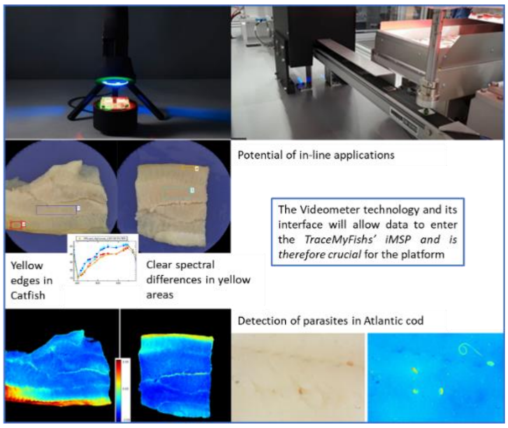

Figure 2. Videometer spectral imaging systems, and examples on seafood applications.

As a tool in *TraceMyFish*, Videometer AS will provide a modified version of the VideometerLite system (VideometerLite - Videometer) that will be used to collect data as input for the project iFMS. VideometerLite is a portable and wireless spectral imaging device designed for easy, straightforward, and accurate image analysis. With its state-of-the-art technology, the instrument allows for the determination of, e.g., colour, texture, and chemical composition on surfaces up to 110 mm in diameter per image. Using strobed LED systems, VideometerLite efficiently combines the measurements of seven wavelengths into a single spectral image, where each pixel corresponds to a different reflectance spectrum. The device can include visual and NIR wavelengths for a precise, accurate, and thorough quality inspection of foods. The commercial version of VideometerLite will be customised with specific wavelengths and algorithms covering the user requirement specifications identified in Task 2.1 of the project.

3 DATA COLLECTION AND PARTICIPATING ENTERPRISES

All data used was collected through semi-structured interviews with Icelandic, Norwegian, and Greek stakeholders covering the Atlantic Whitefish, Atlantic salmon, and Gilthead seabream/European seabass value chains, respectively, as well as searching the literature and the partners' knowhow and experience.

Stakeholder data was collected by using a semi-structured interview guide containing three main topics. In addition to the fixed questions, the initial answers were followed up by relevant additional questions aiming to gain more information. The fixed questions used were as follows:

1. Value chain Hazards
   - Which are the most significant hazards in your company's value chain?
   - How does your company deal with those hazards?
2. Reasons for complaints
   - What are the most common reasons for complaints?
     - Quality, eventually which parameters?
     - Safety, eventually, which concerns?
3. Today's systems for traceability?
   - Please describe your company's routines regarding quality and hazard control
   - Which technology and management systems do your company use for tracing
   - Do your company have any on/at-line sensor?
   - What kind of information is connected to your bach/lot ID systems?
   - Which hazards are most challenging in your value chain (including quality and safety issues)?
   - Looking at your systems, where do you see a potential for improvements?
     - Where are the most significant bottlenecks in your current systems?

Input from the Atlantic Whitefish value chain was gathered by visiting two large Icelandic enterprises (Brim and Lysi). During our visit, a semi-structured interview of key personnel in their organisation was conducted.

A short description of the two Icelandic enterprises is as follows:

- **Brim** is the leading fish company in Iceland and one of the world's largest demersal and pelagic seafood producers. They offer an integrated operation of fishing (three own trawlers counting 95% of the raw material used), processing, and marketing that promotes more efficient production and ensures an unrestricted way for the buyer to catch. It is easy to trace the path of the products from delivery back to the sea. The key to the company's success lies in the excellent staff at sea and on land who strive to deliver quality products to buyers and consumers.

  Brim has actively developed a sustainable fisheries sector and will continue to do so with complete determination. The company's vision is for Brim to actively shape the future of a sustainable fisheries sector based on innovation, technological development, and sustainability. We want to show in action how understanding and respect for society, our colleagues, and the environment go hand in hand with a healthy and lucrative business.

- **Lysi** is the world's biggest cod oil producer with an annual turnover of NOK 800 mill (85 mill US$ in 2020). The domestic marked counts for 4% whereas 96% of the products are exported to 70 countries. One of the most growing markets is South America, including Mexico. The total annual capacity is 13000 tons of fish oil. In total, they have 190 employees, of which 19 have their daily work in the control and quality department.

Input from the Atlantic Salmon value chain was gathered by online meetings with two large Norwegian enterprises (Lerøy Seafood Group and SalMar). The task leader and the personnel at NTNU know both companies well through other projects. Due to that, online meetings were found most convenient for the companies' key personnel and for us. However, the meeting agenda was similar to that present for the Icelandic participants.

A short description of the two Norwegian enterprises is as follows:

- **Lerøy Seafood Group** is a world-leading seafood corporation with a history reaching back to 1899. The Group's core business is the production of salmon and Trout, catches of whitefish, processing, product development, marketing, sale, and distribution of seafood. Every single day, all year round, our 5,500 employees deliver seafood corresponding to five million meals. They have an extensive range of sustainable, healthy products served on tables in more than 80 countries.

  Lerøy is involved in every stage of the production of salmon and Trout, the catch and processing of whitefish and shellfish. In other words, they are involved in catches and fish farming, packaging and processing of fish at their plants, and the distribution of thousands of different seafood products to shops, restaurants, canteens, and hotels - in more than 80 countries worldwide.

  One crucial element in Lerøy Seafood Group's strategy is to be a fully integrated supplier of the company's essential products, and the business is operated via a number of subsidiaries in Norway and abroad.

  The Farming segment comprises the Group's production of salmon, Trout, and cleaner fish up to the time of harvest. The Group has three fully integrated value chains for the production of salmon and Trout, located in North Norway, Central Norway, and West Norway.

  Lerøy has a global reach within the VAP, Sales & Distribution segment. The company works with sales, market and product development, distribution, and simple processing of the Group's raw materials, but also a large volume of raw materials from partners and a network of suppliers. Lerøy Seafood Group has wholesalers, factories, and fish-cuts in several different markets worldwide. The VAP, Sales & Distribution segment is involved in the processing of mainly salmon and Trout, as well as other species. Our facilities are located on the island of Osterøy outside of Bergen, in Smøgen in Sweden, in Finland, the Netherlands, Spain, France, Portugal, Italy, and Turkey. The segment's products are increasingly sold to the global market.

- **SalMar** is one of the World's largest and most efficient producers of farmed salmon and has farming activity along the coast of Norway from Møre and Romsdal in the south to Troms and Finnmark in the north. SalMar was founded in February 1991 following the acquisition of a license to produce farmed salmon and a whitefish harvesting/processing plant from a company that had gone into liquidation. These events took place during one of the most turbulent periods in the history of the Norwegian aquaculture industry, which subsequently also led to the collapse of the fish farmers' own sales organisation (Fiskeoppdretternes Salgslag AL). The vast majority of Norwegian salmon had been exported as fresh or frozen round gutted fish until then. This was the start of a significant restructuring of the Norwegian aquaculture sector, which gradually led to a substantial increase in its level of industrialisation.

  Since its inception in 1991, SalMar has developed into a vertically integrated aquaculture enterprise whose production stretches from roe/broodfish to the sale of finished products. SalMar has gone from a single company with one license to produce farmed salmon in Norway to an international company with farming activities in Norway, Iceland, and the UK, and sales offices in Asia. Today, SalMar is the World's second-largest producer of Atlantic salmon. During the same period, the number of employees has risen from 11 to around 1900. In short, SalMar has made spectacular progress since its inception and is looking forward to an equally exciting period of development in the years to come.

  Since SalMar was established in 1991, harvesting and processing have been vital elements in the SalMar Group's strategy. Over the years, both the market and the production technology used by the industry and SalMar have developed significantly. After several years of meticulous planning, SalMar decided in 2009 to invest in what is today one of the World's most innovative and cost-effective facilities for the landing, harvesting, and processing of salmon. The new facility, called InnovaMar, is situated right next to the old plant in Frøya. Through a higher rate of automation and new combinations of technical solutions, InnovaMar will enable SalMar to strengthen its competitiveness, increase its capacity and flexibility, and improve the quality of its products. InnovaMar is an essential element in realising the company's strategy, which focuses heavily on industrial development and value creation.

Around NOK 550 million has been invested in buildings and machinery at the InnovaMar facility, covering 17,500 m2 of floor space. The harvesting plant went into operation in September 2010, though a fire in a storeroom in mid-October that year put it out of action until 6 December 2010. Towards the end of the year, the harvesting plant was operational again, while the processing plant started up gradually in the first and second quarters of 2011. Due to the harvesting profile of SalMar's own farmed salmon output, neither the harvesting nor the processing plants were working to total capacity in 2011. More than 80,000 tonnes of salmon were harvested at InnovaMar in 2011.

The facility comprises two departments (harvesting and processing). Considerable resources have been devoted to challenging traditional solutions. Critical elements in the development work were fish welfare, working environment, food safety, internal logistics, and efficiency. This has led to the adoption of innovative technologies in production, which increase the quality of the final product, reduce costs and improve the employees' working environment. The facility has a capacity of around 150,000 tonnes of salmon, while each of our four up-to-date holding pens can accommodate some 350 tonnes of live fish.

In addition to fish welfare, the working environment, efficiency, and food safety, InnovaMar has other essential features in its design. These include energy consumption, the handling and use of offcuts, and a reduced transport requirement through increased sales of filleted rather than whole fish. These are aspects of InnovaMar that SalMar is extremely happy to have developed to a level exceeding today's industry standards. The flexibility that the facility affords also makes it particularly well able to cope with any future changes in production that may arise as a result of the needs and requirements of both customers and regulatory authorities.

Input from the Gilthead seabream/European seabass value chain was gathered with online meetings between Avramar, Agritrack and NTNU as well as input from AUA. Avramar is one of the largest companies providing Mediterranean fish to the marked, whereas Agritrack provide traceability systems to the food industry. The task leader, and personnel from Agritrack, AUA and from the quality department of Avramar participated in the different meetings. The meeting agenda was equal to that present for the Icelandic and the Norwegian participants.

A short description of the enterprises is as follows:

- **Avramar** is a leading producer and supplier of Mediterranean fish to the market. The company is located in Greece and Spain and established by merging three fish farming and one feed producing companies. Now that the passion and expertise are combined together as one, Avramar can soar evolving needs and aspirations of their loyal customers, they consistently strive to deliver the right solutions and the smartest innovations, meeting and exceeding their expectations with the highest quality products. Avramar is leading a transformation in Mediterranean aquaculture, bringing the industry closer together as one cohesive and dedicated community. New challenges are opportunities that offer great rewards. Avramar believe that the path to success is to leverage the knowledge, skills, and ideas of people from diverse backgrounds. They work in partnership with their colleagues, suppliers, and customers to constantly improve their products and supply chains.
- **Agritrack** is an enterprise that helps participants collect and streamline food information. Enable smarter and faster data collection from the field and operations using IoT, achieve transparent and safe dissemination of food’s journey using a permissioned & permanent ledger and leverage real time food quality decisions using Machine Learning and Imaging Technologies. The end goals are simple: reduce costs, risk and waste while increasing the efficiency and the security of our food’s value chain. Agritrack covers the entire value chain including farmers, food processing and distribution, and retail and consumers. Related to food processing and distribution they aim to digitize all the touch points from field to production and assess quality quickly and reliably. Food journey reports updated by physical events in the supply chain and accessible only by permissioned parties. It is time to re-invent how product information is collected and shared!

4 DEFINITIONS AND FINDINGS

Herein, we define value chains, before reporting the current practice, and potential unwanted incidents and hazards along the three chosen value chains: i) the Atlantic salmon value chain, ii) the Atlantic whitefish value chain, and iii) the Gilthead seabream/European seabass value chain. After that, user requirement specifications are summarised and a tentative Pilot plan for each case is present. The identified variables will be employed and used towards the final pilot plan (Task 2.2, Deliverable 2.2) and the continuous non-destructive monitoring of the products as they are assumed in the project.

Furthermore, all hazards and unwanted incidents (changes in temperature while transportation or storage) capable of causing adverse effects in the final or intermediate products across the food chain are identified. Hazard characterisation, where the qualitative and/or quantitative evaluation of the nature of the adverse effects of contaminants (e.g., pathogenic bacteria, parasites, chemical contaminants, etc.) present in the products as mentioned above (raw, processed, in storage) along the value chain, are undertaken.

4.1 THE ATLANTIC SALMON VALUE CHAIN

4.1.1 Value-chain definition

The salmon value chain is defined as the product flow from farming to the end customer (Fig. 3). Out of total production in Norway, some 80% is exported as whole HOG (head on gutted), mostly fresh but also frozen. The fresh, chilled HOG salmon is typically transported in Styrofoam boxes (EPS) by trucks from Norway to secondary processors and wholesale/retail markets in Europe (80%), and to Asia (13%), and other markets where fresh products are transported mainly by airfreight. The most common secondary processing for salmon is smoking. About 47% of the EU market supply is of fillets, 12% whole, 28% of smoked salmon, and 13% of other VAPs.

Figure 3. The Atlantic salmon value chain

Among other value-added products (VAP) (13%), convenient ready-to-eat and ready-to-heat products dominate. Such products are either portioned and packaged in vacuum pouches, vacuum skin, or in a modified atmosphere (often in heat-resistant trays ready for home cooking). Salmon products originate from pre-, and post-rigor filleted salmon. The boundaries in the present project were fixed to the value chain from farming through harvesting and processing, ending as convenient consumer-friendly VAP at retailers/consumers.

4.1.2 Current practice for quality and safety measurements

The product quality is maintained through gentle transfers between operations and production lines. The efficiency is enhanced through a high automation rate, e.g., in connection with portion packing and palleting. Furthermore, together with its equipment suppliers, the industry works extensively to improve the machinery's hygienic design. This has facilitated optimal cleaning and washing procedures, which secure safe food production.

The salmon industry put great efforts into controlling product quality and food safety. Since salmon often are eaten raw or mildly processed, the foodborne pathogen *Listeria monocytogenes* is one of the salmon industry's most severe food safety concerns. Although the prevalence of *L. monocytogenes* in raw salmon products is low, it is regularly detected in salmon slaughterhouses and poses a potential risk. Furthermore, detecting *L.*

monocytogenes in pre-packaged products can lead to costly withdrawals of whole batches. Although many resources are used to control food safety, most of the complaints are due to fish health, e.g., winter-ulcer (caused by *Moritella viscosa*), and physiochemical parameters such as soft texture, colour deviations, melanin, and blood.

It is common for Atlantic salmon producers to have a large quality department controlling both the processing environment and the fish going through slaughtering and processing. From each batch usually, 20 fish is selected for quality control following the producers' standard protocol (30 if there are indices of diseases or poor quality). Some consumers also have stricter requirements than the market standard (e.g., a zero-tolerance against *L. monocytogenes*, and specific requirements related to color).

All orders sent from the producer are followed by a certificate of analysis giving the product information set by the customer. A typical certificate informs about the fish health, vaccine program, temperature data, and results from the quality control of the given batch.

4.1.3 Unwanted incidents and hazards

The product quality is maintained through gentle transfers between operations and production lines. Efficiency is enhanced through a higher automation rate, e.g., in connection with portion packing and palleting. Furthermore, together with its equipment suppliers, the industry has worked extensively to improve the machinery 's hygienic design. This has facilitated optimal cleaning and washing procedures, securing safe food production.

Unwanted incidents are often caused by diseases (e.g., pancreas disease), infections (e.g., *Moritella viscosa*), temperature abuse due to a broken cold chain, and poor bleeding. Unwanted incidents in the value chain are often followed by increased complaints due to poor quality. Although, the salmon industry is using a lot of resources to control the microbiota, including *L. monocytogenes* in the processing environment, and on the fish, most complaints are caused by poor fish health, blood and melanin spots, winter-ulcer (caused by *Moritella viscosa*), and soft texture and gaping.

All orders are followed by a certificate of analysis giving the product information set by the specific consumer. A typical certificate informs about the fish health, vaccine program, temperature, and results from the quality control of the given batch (often including food safety parameters and parameters such as colour, texture, gaping, melanin, etc.). Some customers have a zero tolerance regarding *L. monocytogenes*. Due to this, some batches must be re-routed if *L. monocytogenes* has been detected either in the processing environment that specific day, or on the fish from the specific batch. Such fish is then sent to customers not producing sashimi quality or other RTE products. However, it is important to point out that there is a zero-tolerance to export salmon where listeria counts are higher than the regulations set by the governments (normally 100 CFU/g at end of product shelf-life).

4.1.4 User requirements for non-destructive and destructive methods for tracing hazards

Today the salmon industry uses different systems for traceability. BarentsWatch is a Norwegian system following, e.g., fish health in aquaculture (https://www.barentswatch.no/fiskehelse/settings). However, the Norwegian industry does not provide data on fish health to customers, except for vaccine statistics and regular veterinary controls. BioMap provided by Aquatic (https://aquatiq.com/en/case/biomap-leroy-seafood-group/) is a system several stakeholders use to control quality and safety assurance data. Through this system, they receive data input from external and internal laboratories at the one-touch button. BioMap is often used to generate a Certificate of Analysis following each order and to follow analytical trends as a function of time, allowing actions against potential hazards threatening the quality and safety of the products. Moreover, a third system is used to handle temperature data from the cold chain. Other companies have their own systems, build to fit the companies needs. However, some of these systems are old-fashion and does not have the possibilities to transfer data easily from one system to another. To trace the value chain from broodstock to harvest, a system provided by AKVAgroup is often used. This system is called Fishtalk Control (https://www.akvagroup.com/digital/fishtalk-control-).

The industry does not have an extended use of sensors in their processing units. They have sensors following temperature, and some of their newest processing plants are equipped with x-ray systems detecting residual bones in fillets and portions. However, today, data obtained from these sensors are only for internal use connected to the lot number and barcode on the package. They do not have any imaging or hyperspectral sensor connected to their processing units. However, **they were interested in sensor systems with a potential detection of melanin and blood spots, as well as soft texture, especially if the system was connected to the lot number and even better to the specific package.**

The industries' overall view on traceability is that **they want systems for internal use**. They are not interested in systems increasing the value-chain transparency that allows consumers more insight. They want to control the available information profiting themselves and the industry's reputation (our words). The stakeholders do not see how such specific systems increasing the traceability and value chain insight could improve their total income in a short or long term.

4.1.5 Tentative sampling protocol and analytical data acquisition

The tentative sampling protocols for salmon quality control include small and medium scale experiments simulating unwanted incidents and hazards along the value chain

- **Stress/handling**: Stress and rough handling of fish affects textural and colorimetric properties. In this experiment we will simulate long term rough handling by stressing the fish daily for one month to measure how these treatments affect fish pigmentation, coloration, and texture. We aim to use the VideometerLite system and confirm measures with traditional wet-chemistry methodologies. The experimental setup is a part of a project funded by the Research Council of Norway (project nr 174260) that can provide experimental fish to our project. The experiment will be conducted in June 2022.
- **Soft texture**: Soft texture is affected by a range of parameters including stress, rough handling and rapid growth. To study the effect of growth we aim to set up an experiment comparing textural properties related to growth. We aim to use fish from NTNU's research farm by sampling fish in November 2022 (after an extensive growth period) and in March/April 2023 when the growth is less significant. We will use the VideometerLite system and confirm measures with traditional wet-chemistry methodologies.
- **Broken cold chain**: To chill the fish properly and to keep the cold chain unbroken is essential to remain quality from farm to fork. We aim to set up 2-3 small scale experiments simulating different incidents related to a broken cold chain (e.g., slow chilling, melting of ice/re-icing, short term heating, etc.). We will use the VideometerLite system and confirm measures with traditional wet-chemistry and microbiological methodologies. The experiments will be conducted in Q1/Q2 2023. It might also be an option to include measures from another ongoing project (FHF - Norwegian Seafood Research Fund, project nr FHF 901 778) following the cold chain (trucks) from the processing plants in Norway to the European marked.

To follow up hazards identified in the initial part of the project (WP2 – Task 2.1) we will include parameters such as melanin and blood spots, soft texture, temperature control, and predicative and experimental microbiology. For the experiments we will use the VideometerLight equipment for data acquisition as well as traditional chemical, physiochemical, and microbiological (APC, listeria, Pseudomonas) laboratory methodologies that fits the specific experimental setup.

4.2 THE ATLANTIC WHITEFISH VALUE CHAIN

4.2.1 Value-chain definition

The Atlantic whitefish value chain is defined as the product flow from catch, mainly by trawlers or longliners, through processing to the end customer, as well as connected side-streams (Fig. 4). The time from catch until the fish enters the processing plant take 2-5 days, depending on the distance from the fishing ground and weather conditions. A modern demersal fish processing plant focuses on producing fillets and fillet pieces from Atlantic whitefish (e.g., cod, redfish, and saithe). The fish is sized, decapitated, filleted, skinned, and trimmed before being cut into pieces according to the buyer 's criteria. The products are both exported fresh and frozen all year round. Fresh products are shipped the same day by air or in refrigerated containers by ship to foreign markets, while frozen products are exported in freezer containers or by pallet vessels. The fish enters the processing plant with a core temperature of approximately -1.5 °C (chilled by onboard RSW tanks) and it takes less than 40 minutes from when the fish enters the processing line until the fish is ready for export. In addition to the fresh/frozen value chains a significant part of the total Atlantic whitefish ends as salted product, such as, e.g., lightly salted, or fully salted fish (e.g., bacalao). Producers of both fresh and salted products have shown interest in the TraceMyFish project, and the technological developments included in the project. Mapping of value chains from both fresh and salted Atlantic cod products will therefore be included in the project. Furthermore, producers of fish oil have also shown interest in applying the developed tools, and trials from the fish oil side stream value chains will therefore also be included.

Icelandic marine products were exported to 95 countries in 2020, around 80% of the total were sold to Europe which is the most important market for Icelandic seafood. Frozen products account for 44.1% of the export value of marine exports. The single most valuable fish species for Icelandic seafood exports is cod which accounted for 49% of the export value of marine products in 2020 (https://www.responsiblefisheries.is/seafood-industry/export-statistics).

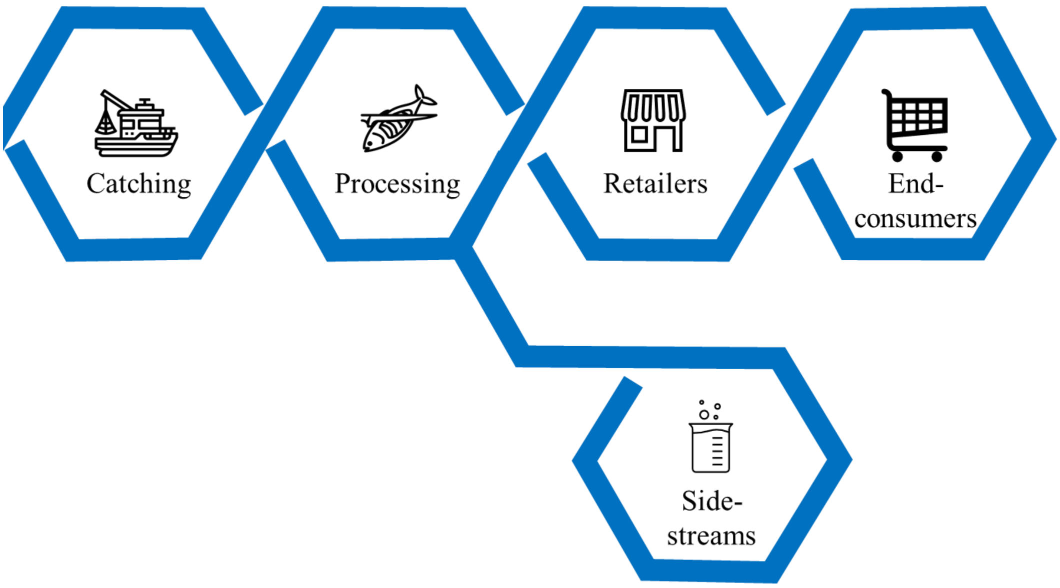

Figure 4. The Atlantic whitefish value chain

4.2.2 Current practice for quality and safety measurements

Fresh and frozen cod fillets

Fish entering the processing facilities are labelled based on the catch (location and time, along with generic catching information (catching gear, temperature etc.)) and the processing condition (when and how). A quality report for each lot is made based on in-house quality control system, and all data are stored in an in-house database for traceability. According to the cod processing industry, the general fish quality has improved significantly in later years due to improved chilling systems at the trawlers and during processing.

Fillet gaping, the occurrence of blood spots, bruising, parasites, and residual bones or other foreign objects are the most challenging quality issues of cod fillets products. The current practice is to detect residual bones by x-ray scanning and then remove the bones manually, which is a labour-intensive process, with a risk that bones pass the manual error correction and the quality check. A random sampling plan is the basis for the in-house quality control. The key analysis is occurrence of parasites and blood spots, colour, smell, microbial counts (measured at least every month for each product), fish size and temperature.

The interviews identify a need for more automated, in-line machine vision systems to spot blood, parasites, and other mentioned quality parameters.

Sidestream products

The Atlantic cod value chain includes the formation and utilization of several side streams. The aim is to utilize the raw materials 100%, and the lively innovation and entrepreneur environment existing in the marine sector in Iceland is supporting this development goal. Traditional utilisation includes the production of cod liver and oil (www.lysi.is and www.akraborg.is) and drying of cod heads and backbones (www.haustak.is) mainly for export to Western Africa. In the last decade several interesting entrepreneur companies have risen, adding high tech product development and utilisation of other cod side steams, such as the utilisation of the skin for gelatine and bioactive compounds (www.codland.is), or for wound healing (www.kerecis.com), and enzyme production from the gut and skin (www.zymetech.co.za), to mention a few.

Cod liver oil is an important sidestream product in the whitefish value chain, and processing plants of cod liver oil receive raw materials from various companies across Iceland. Products of cod liver oils are mainly for human consumption as nutritional supplements but are also used as feed ingredients. Due to the large scale of this production, the focus on side stream utilization is put on these side streams.

Temperature control between catch and processing is essential to prevent oxidation and maintain high-quality raw materials. Increased awareness of raw material treatment has resulted in using a sub-chilling (-1°C) regime until processing.

4.2.3 Unwanted incidents and hazards

Fresh and frozen cod fillets

The mentioned quality issues (section 4.2.2) often cause unwanted incidents, e.g. fillet gaping, blood spots, parasites, and residual bone. Gaping and blood spots only affect consumers' perceived quality; however, residual bones represent a food safety hazard. Parasites also represent a food safety issue, but the risk is significantly reduced by heat treatment or freezing of fillets before consumption.

Sidestream products

Chemical contaminants are a food safety hazard of significance, and considerable attention is given to measuring the arsenic content of fish oils. The toxicity of arsenic compounds depends on the chemical form, and the major arsenic compound in fish is the non-toxic form. Thus, attention must be directed to inorganic arsenic, a highly toxic compound. The Codex Alimentarius Commission of the Food and Agriculture Organization/World Health Organization has defined the maximum level of inorganic arsenic in fish oil to be 0.1 mg/kg. Another food safety concern in producing cod liver oil is the content of vitamins in the final product. Vitamines are added as antioxidants to prevent oxidations of the oils, but the concentration must be below the toxic level stated by the food and health authorities. Recent developments also add the concerns of microplastic contamination in marine products. This issue should thus be investigated in the value chains as well.

However, the main quality issues of cod liver oils are related to colour deviation and oxidation, and consumer complaints are often related to these quality parameters. Oxidation affects the colour and results in off-odour and/or off-taste due to product rancidity. Unwanted incidents in the value chain can be caused by temperature abuse in handling raw materials and products, slow logistics of raw materials resulting in reduced quality and product exposure to light and/or oxygen.

So as to ensure the applicability of the sensor along the value chain and also the effective design of the cloud services that will be provided to the end user of the TMF platform/solution.

4.2.4 User requirements for non-destructive and destructive methods for tracing hazards

One of the main benefits of the Icelandic white fish value chains is that the raw material acquisition, and main processing are often owned by the same company, making tracking and tracing of the main products easier. Production equipment are most commonly produced by large scale producers, such as Marel or Baader, and often include associated data management and traceability software solutions, for automatic monitoring of basic parameters, such as generic catching data, and temperature and weight changes during production. Most production facilities have small quality assurance laboratories, where chosen physical and chemical quality parameters are tested on samples from each batch. For this testing, traditional physicochemical analytical methods are usually applied. These methods are often, sample destructive, expensive, time consuming, and may include the use of dangerous solvents or other chemicals. Although process automation is high during processing in the larger companies, producers call for more automation for quality assessment and monitoring.

BRIM is one of the largest whitefish producers in the world. Stakeholder meetings with them in April 2022, showed that they are highly interested in testing the VideometerLite and VideometerLab solutions in their processing lines. An overview of their current production facilities in Reykjavík, Iceland can be seen in the summary and videos in the link. https://marel.com/en/news/the-future-of-whitefish-processing-has-arrived-at-brim.

Current quality assurance includes computer vision solutions, x-ray for bone and contaminant detection and removal, water cutting for portioning, automatic scales, etc. The Innova software, from Marel is used for process monitoring and traceability.

Adverse effects of contaminants (e.g., pathogenic bacteria, parasites, chemical contaminants, etc.) will be tested alongside the VideometerLite and VideometerLab solutions.

4.2.5 Tentative sampling protocol and analytical data acquisition

The experiment and sampling protocols that will be applied in the TraceMyFish project within the whitefish value chain are as follows:

Fresh and frozen fillets
The main activities within the whitefish value chain will focus on the main production of fresh and frozen fillets at Brim in Reykjavík. Samples will be taken regularly throughout the production to assess the quality changes occurring during processing and to identify where adding the Videometer technologies will give the most representative quality assessment and where it gives most value to the production. Traditional physicochemical and microbiological assessments will be run alongside spectroscopical assessments, to allow the building and validation of potential spectroscopical or image analysis-based quality prediction models. Microbial counts, processing yield, chemical composition, near infrared (NIR) and time domain nuclear magnetic resonance (NMR) spectroscopy, colour, pH, texture, and water holding capacity assessments will be analysed as references. These trials will take place in September 2022 and February 2023, to allow inclusion of seasonal variations of the raw materials.

Salted fish
Discussions with Vísir hf., which is a major producer of light and heavily salted cod products, showed that the company is interested in applying the Videometer technologies in their value chains. Value chains of chosen salted products (lightly or heavily salted products) will be analysed in detail. Salting leads to more extremes in chemical composition and physicochemical characteristics than the fresh and frozen fillet production does. Including the salted fish value chains are thus important since they increase the potential future applications of the Videometer technologies.

Detailed experimental setups will be discussed with the company in September 2022.

Fish oil and/or canned cod liver
Lýsi hf and its sister company Akraborg hf, produce cod liver oil and canned cod liver, respectively. The main quality assurance parameters in these value chains include colour deviations and oxidation parameters. By

including the processing of these sidestreams all major quality aspects of the Atlantic cod value chains can be assessed. Reference measurements for these trials include proximate composition, fatty acid composition, oxidation product assessments (peroxide values, anisidine and/or TBARS), vitamin composition.

4.3 THE GILTHEAD SEABREAM/EUROPEAN SEABASS VALUE CHAIN

4.3.1 Value-chain definition

The gilthead Seabream and European Seabass value chains are defined along the "voyage" of the product from farming to the end customer (please refer to Figure 5). Avramar has a market "core", which is Greece, Italy and Spain and at the next level has also some existing markets where they foresee to expand more (i.e. France and Germany, going beyond the Mediterranean). At the next level of international markets there is North America where there is a particular interest for Avramar's products since U.S. has embraced the Mediterranean diet quite diligently, beyond the Italian and Greek communities. Thus, Mediterranean diet is a very interesting platform that's highly appealing, exhibiting great potential in the U.S. and Canada.

Eighty five percent of aquacultural production of gilthead seabream (Sparus aurata; hereafter seabream) in Europe and other countries mostly takes place in floating cages (Basrco, Lovatelli, & Garcia, 2011)[1]. Production in 2013 was estimated to be 179,924 tonnes [2], while the main European producers are Greece (42%), Turkey (23%)and Spain (9%). Just over 93% of the seabream produced along the Spanish Mediterranean and Atlantic coasts comes from offshore cages, which are exposed to storms and strong hydrodynamic conditions.

The initial part of the value chain in aquaculture in general, but also in seabass and seabream production specifically, includes the total activities related to farming. At first, a significant branch of this step is the suppliers. This group includes -among others- feed manufacturers, equipment and pharmaceutical suppliers as well as energy supply. Additionally, seed production is considered as an important procedure, including hatcheries and nurseries, followed by the fish farming up to their harvest. The processing after harvest could be divided in primary and secondary processing. Procedures such as cleaning, grading, gutting, and packaging are included in the primary processing, while filleting, smoking, retail packaging and preparation of ready meals are regarded as secondary processing's activities/treatments. The retail of the products consists of the distribution of them, including transport, warehousing and export/import operations as well as multiple retailers involvement, fishmongers and food service, whilst the last - but equally important - part is the end-consumers.

Figure 5. The Gilthead Seabream/European Seabass value chain.

4.3.2 Current practice for quality and safety measurements

The EU requires all food business operators, feed producers and primary producers of animals to have in place traceability systems (Regulation (EC) No. 178/2002). Relevant EU regulations also include regulations No. 178/2002, 852/2004, 853/2004, 854/2004, 882/2004 and 183/2005. Additionally, guidelines included in the ''Codex Alimentarius" play a significant role in quality management systems. The 'Codex Alimentarius' (FAO & WHO 2018; managed by the Codex Alimentarius Commision CAC since 1963 and continuously evolving) forms a global rule book for food quality and safety, compiling international food standards, guidelines and codes of practice (e.g., threshold levels for food additives, contaminants, veterinary drug residues, labelling, inspection and certification etc.). Nevertheless, Codex texts are recommendations only, meaning that member countries need to take legal action to incorporate those into their legislation or regulations.

The current quality control system is based on (i) product specifications, (ii) process specifications and (iii) inspection methods. Product specifications are related to the description of the product and of the quality factors it should possess. Also sets tolerance limits for individual quality parameters, including size, odour, appearance, texture, and defects. Moreover, the process specifications are related to time (operation, freezing time etc.), temperature (freezing, drying, cooking, storage etc.), contamination (external materials), damage or deterioration (e.g., physical damage, freeze burn, permitted additives), hygiene/sanitation (e.g., cleaning and sanitation procedures), equipment, packing, yield/efficiency (e.g., weight changes during processing etc.).

Finally, in the current quality assessment system, methods to inspect and test the products quality are defined, applying to both raw materials and the final product. Parameters which are investigated by sensory, microbiological, or instrumental methods are:

- Freshness (how much the fish/fish product has spoiled when held in wet state, product freshness before canning or freezing etc.),
- species (identification methods applied to frozen, canned, cooked and wet fish), condition, texture (e.g., plumpness, thinness, toughness, oiliness etc.),
- blemishes (intrinsic defects of raw materials, handling defects, or detection of parasites e.g., worms),
- off odours, flavours (badly stored frozen fish; mainly cold storage odour and flavour or rancidity),
- bacterial count (presence/quantity of harmful strains: e.g., Staphylococcus aureus, Salmonella and Coliforms; and overall organism load/count indicative of contamination or spoilage),
- additives, colouring materials (e.g., polyphosphates to prevent drip loss, antioxidants to control rancidity, and flavourings; governed by legislation),
- composition (chemical and nutritional composition),
- salt content,
- colour, gloss,
- shape, size

The current food safety management system, although largely based on good design of processes, products and procedures, end or finished product testing (analysed for certain hazards), it is considered to be the control measure of the production process. Microbiological or chemical analyses (e.g., for chemical hazards) have certain disadvantages, such as, they are (i) time-consuming providing retrospective results (ii) costly, (iii) require high-tech molecular tools and thus highly trained personnel; and (iv) usually destructive to test products, limiting thus their potential to be used on-, in- or at-line. A novel, more effective Food Safety Management System could be based on analytical approaches that have been forwarded for non-destructive rapid methods, which provide means for quantitatively monitoring characteristics of food safety and quality.

4.3.3 Unwanted incidents and hazards

During farming, harvesting, handling, primary processing and distribution, various microorganisms from the environment or workers might enter pre- or post-harvest handling/process and contaminate fish. These microorganisms might be serious microbial spoilers of fish or seafood-borne pathogens. For gutted and filleted fish, contamination with such bacteria is more possible than the whole fish due to the use of tools and equipment in handling and processing. Microorganisms may cause a pathogenetic impact responsible for the deteriorating quality of fish flesh. The most common pathogens in fish are *Salmonella typhi*, *E. coli*, *Pseudomonas florescens*, *Aeromonas hydrophilla*, *Proteus vulgaris*, *Staphylococus aureus*, *Shigella* spp. To ensure sensorial and microbiological quality in cultured fish it is necessary to control environmental factors, take measures to prevent the contamination of seawater, and hygiene practices. If the fish are stressed and alive, the lactic acid level will be increased, therefore the pH value will decrease dramatically; in case of prolonged stress, all glycogen will be consumed, leading to a high level of pH. Meantime psychrophile and psychotropic aerobic, gram-negative bacteria, usually living on the fish begin to multiply and cause the characteristic odors affecting sensorial quality. *Pseudomonas* spp. are usually the dominant microbial group that may cause spoilage in aerobically packed, cultured gilthead seabream and sea bass. Lactic acid bacteria, *Brochothrix thermosphacta* and H_2S-producing bacteria have been reported as the dominant spoilage bacteria in MAP gilthead seabream, using high CO_2 concentrations.

Apart from the microbial hazards, there several other species- or process- related hazards, including the presence or natural toxins, histamine hazard, parasite hazard, environmental and chemical hazards as well as aquaculture drug hazards. Concerning seabass and seabream specifically, among the aforementioned hazards, the presence of parasites (Seabass) and environmental and aquaculture drug hazards -for farmed fish- are the most significant ones.

4.3.4 User requirements for non-destructive and destructive methods for tracing hazards

As being the fastest growing food-producing sector in the world, Aquaculture continues to develop, expand and intensify, working towards “maximizing economic growth whilst minimising production costs, optimising resource use, minimising environmental impact and ensuring the quality of the aquaculture product”. The development of the aquaculture sector is strongly influenced by markets, trade and consumption preferences, with a clear demand to produce safe, high-quality products. Sustainable growth and responsible production in aquaculture thus require the involvement of producers in decision-making and regulation processes, to strengthen their self-regulatory power whilst ensuring the production of high-quality and safe-to-consume aquaculture products. Towards this direction, a modification in the current quality systems is required by replacing traditional practices for tracing hazards with rapid, real-time and at the same time efficient technologies.

Traceability systems are subject to independent audits and certification processes. Although retailers claim that they require a functioning traceability system, for product recall and for sustainability reasons. As it is stated, the system should allow product tracing from start to finish (hatchery to plate). Although this is often advertised as being the case, some concerns around its traceability systems are raised. As mentioned in aforementioned sections, the seabass/seabream industry does not have an extended use of sensors in their processing units, apart from some specific cases using sensors for temperature, oxygen and salinity measurements.

4.3.5 Tentative sampling protocol and analytical data acquisition

At first, relevant legislations and regulations for seafood quality are stated and considered as minimum reference source during all TMF actions. Additionally, the parameters and conditions in the various production stages that are crucial for the seabass and seabream quality will be defined in detail. Finally, technology requirements will be identified and inform the design for the technology development in sensor techniques and analytics for food quality and safety assessments, and validation of the effect on the fish and seafood quality.
The quality as well as the safety of fish will be determined and assessed against analytical approaches which are based mainly on multispectral imaging but also on other sensor technologies. All these methodologies are considered to be rapid and non-invasive. Except for the spoilage potential, the use of the VideometerLite sensor to identify other quality attributes such as the presence of toxins or parasites, will be investigated.

Indicative sampling protocol and analytical data acquisition

Seabass
Assessment I: Microbiological quality of farmed seabass assessed using conventional microbiological methods and multispectral imaging analysis using VideometerLite.

TASK: Assessing the quality of fresh finfish throughout storage at different temperature conditions (0 to 12 °C).

MATERIAL: Industry will provide 5-7 kg per batch of fresh finfish. A minimum of 30 fish will be analysed, with individual weights of no less than 200 g, to perform microbiological and MSI analyses. Moreover, fish of the same species will be obtained from different selling points and will be used for the validation of the results.

METHODS: AUA will perform microbiological analyses, including total aerobes (TVC) and specific microbial groups such as Enterobacteriaceae (e.g., *E. coli*), *Pseudomonas* spp., lactic acid bacteria, yeasts, moulds and sulphur producing bacteria throughout the storage at different temperature conditions. Moreover, multi-spectral imaging analysis (MSI) will be evaluated as means of estimating the microbiological spoilage of these fish species.

EXPECTED OUTPUT: Estimation of the microbiological quality of specific fish species. Additionally, the acquired spectral data as well as the measurements (counts) of microbial consortium will be used for the development of models related to either fish quality classification or prediction of their shelf life.

5 CONCLUSION

By this report we highlights the current status and needs for non-destructive and destructive methods for tracing quality and quality deviation and potential hazards along the selected value chains. Both the salmon and the whitefish industry highlighted parameters such as blood spots, brushes, gaping, texture, and residual bones to be of high interest for improved traceability. Moreover, parasites are highly important for whitefish, whereas microbial pathogens such as *L. monocytogenes*, and spoilage microbiota are relevant for the Atlantic salmon industry (salmon is often eaten raw or minimally processed). Concerning seabass and seabream, microbial hazards are defined as most important. However, the presence of parasites (Seabass) and environmental and aquaculture drug hazards (for farmed fish) are also significant.

Identified hazards and quality parameters of interest will be further studied in well-designed pilot studies (described in Deliverable 2.3) to investigate and evaluate the potential of the VideometerLite system to identify and quantify these parameters. All measures will be evaluated by traditional methodology to evaluate the novel methodology and to make predictions for systematic use in the iFMS system to be developed.

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