SUPPLY CHAIN SUSTAINABILITY ANALYSIS OF HERRING IN SWEDEN

Potential and Limitations of the Swedish Herring Industry

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Table of content

Table of content **1**
Tables and figures **2**
Abbreviations **2**
Abstract **3**
Introduction **4**
Aim and objectives 5
Literature review **6**
Herring fishery and its environmental impact 7
Environmental impact of herring processing 8
Maximized side-streams utilization 9
Summary 9
Methodology **12**
Design 13
Data collection 14
Results **16**
Sorting of the data 16
Combined results of the fishery and process & side-stream 18
Fishery and P&S comparison 20
Discussion **24**
Outstanding results 24
The potential of actions towards more environmental sustainability – Fishery 25
The potential of actions towards more environmental sustainability – P&S 25
How limitations to the actions fit into the context 27
Strengths & Challenges 28
Conclusion **29**
Acknowledgement **30**
References **31**
Appendix **38**

Tables and figures

Figure 1	Prisma model for the literature review	6
Figure 2	Method overview	13
Figure 3	Average rating of each category	18
Figure 4	Sum of each limitation	19
Figure 5	Average rating of the action by the individual limitation	20
Figure 6	Average rating of each category. Divided into fishery and process & side-stream	21
Figure 7	Frequency of each limitation. Divided into fishery and process & side-stream	22

Table 1	Overview of the most important findings in the literature review	10
Table 2	Definition of the categories	16
Table 3	List of the limitations and their explanation	17
Table 4	Abundance of each limitation in the different categories	19
Table 5	Abundance of limitations	23

Abbreviations

CO^2	Carbon dioxide
ESP	Environmental sustainability potential
kWh/t	Kilowatt-hours per ton
MSC	Marine Stewardship Council
NGO	Non-governmental organizations
P&S	Process and Side-Stream
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
SD	Standard deviation
TAC	Total allowable catch

Abstract

As global concerns about food security are increasing, questions regarding the sustainability of the seafood industry move into focus. This study focuses on the herring industry in Sweden due to the prominent position of herring in the European fisheries and its economic and environmental impacts. The objective of this research is to assess the environmental sustainability of the Swedish herring industry and propose recommendations based on input from relevant stakeholders. The methodology involves conducting interviews with industry professionals along Sweden's west coast to understand their views on sustainability in the herring industry and how these views differ from the literature.

Analysis of these interviews aims to disclose leading sustainability practices, evaluate their efficiency, and identify obstacles to their widespread adoption. Findings indicate that, although sustainable practices are commonly employed, major gaps persist in their implementation due to knowledge deficits, operational limitations, and financial constraints.

At the same time, an accumulation of individual obstacles to measures is not directly linked to their potential for greater environmental sustainability. This shows that different parts of the supply chain face different challenges. These require both individual measures and a movement towards interdisciplinary and cross-stakeholder efforts. The article proposes various actionable measures to enhance the sustainability of the herring industry, with potential benefits for both the economy and the environment. These recommendations aim to assist herring industry stakeholders and governmental bodies in formulating a more sustainable herring fishing and utilization strategy, which could serve as a blueprint for addressing similar challenges in other seafood industries and fishing nations.

Keywords: Herring industry, Environmental sustainability, Supply chain management, Sustainable fishery, Processing

Introduction

With a growing population of up to 10 billion by 2050, global food security is a challenge international organizations, non-governmental organizations (NGOs) and states are trying to overcome (Guo et al., 2016). While large parts of Africa have already been suffering from serious food insecurity (Global Report on Food Crisis, 2024), even Europe is steering towards a lack of self-sufficiency for goods such as proteins (Jerzak & Śmiglak-Krajewska, 2020; Smith et al., 2024). To counter those trends, numerous programs are getting launched every year. The European Union alone spent up to €8 billion between 2020 and 2024 (European Commission, 2022b). With the goal to improve the situation not only in Europe but globally (European Commission, 2022a). A key role is to strengthen the supply chain of food by gaining more independency from those supply chains that are vulnerable and pose a risk when they collapse, as well as by creating redundancies to counter supply shortages of single goods. One way to approach vulnerable supply chains is to shorten them. By producing food as close to the consumer as possible, the chance of interruptions along the way is limited (Zasada et al., 2019).
Besides creating food security, industrialized countries, that are not at risk of facing serious food shortages, turn to improving the environmental impact of the food supply chain (European Commission, 2022a; Smith et al., 2024). This implies the use of natural resources in a way that guarantees a long-lasting value to coming generations. The agriculture sector in Europe has to work with soils of which 60% are damaged by over-fertilization and erosion (Heinrich-Böll-Stiftung, 2024). Agriculture in general is more present in people's conscience and changes in this sector can be noticed quicker. The marine ecosystem, however, is under pressure as well with significant environmental and economic consequences (Dickey-Collas et al., 2010).

The marines environmental sustainability can be managed by controlling the inflow of fertilizers that lead to eutrophication of the oceans (Bachari Fouzia, 2019). Further damage to the marine environment is done by an unsustainable outtake of fish from the wild populations. While in the Mediterranean Sea it's estimated that 90% of the fish is overexploited, in the Northeast Atlantic 40% of the fish stocks are overfished (European Commission. Joint Research Centre., 2019; Sumaila & Tai, 2020).
Sweden only has a small share of the Europewide fishing volume with 1% (European Commission. Directorate General for Maritime Affairs and Fisheries. & EUMOFA., 2023). However, from 2001 to 2019 Sweden was a leading nation in fishing more than they were scientifically advised, by fishing 32% above the total allowable catch (TAC). Of those 31%, herring is the biggest share of overfishing (Carpenter, 2020; Eumota, 2019). Therefore, this calls for a more responsible handling with resources such as herring to prevent the population from collapsing (Hannesson, 2022).
The easiest way to reduce the impact on the herring stock would be to take less herring out. To do so it's worth taking a look at what the herring is used for. Europe-wide herring is the most caught fish by volume and second most used fish for non-food purpose (European Commission. Directorate General for Maritime Affairs and Fisheries. & EUMOFA., 2023; European Commission & EUMOFA, 2021). On a Swedish scale in 2022, a total 45 911 metric tons of herring were caught, of which only 40% went to human consumption, of those, depending on their purpose, only 40% end up as food on our plate (Ericson, 2023; Wu et al., 2022). As a result, only 16% of the herring are destined for food. With the goal in mind to increase the food security as well as decrease the environmental impact of the seafood sector, it seems irrational to catch this much herring and not use it for direct consumption.
Within the commercial herring business there are two approaches that address the increase of the sustainability of herring in Sweden. The fishery sector is the step in the supply chain that will continue to exist when herring should be consumed in the future. A means for improvement is to

optimize the resource efficiency in this step, so that the unavoidable step does as little harm to the environment as possible (Hornborg et al., 2022). The continuous steps of processing and changing the industry seem more complex. New improvements need to be developed and implemented (Cottrell et al., 2021; Ruiz-Salmón et al., 2020).

The herring industry is being continuously optimized. This is done through innovations, regulations, and research projects aimed at promoting the sustainable and responsible management of herring as a valuable resource, leading to a complex network of stakeholders. Government agencies, fishing associations, companies, and environmental organizations are all involved in the process of change. Trying to cooperate and coordinate between these stakeholders is difficult but crucial for the management and utilization of sustainable herring stocks (Lewin et al., 2023).
Since a "one solution fits all" doesn't exist, policies can be too general and don't fit the cause (Lagares & Ordaz, 2014). For the improvement of certain sectors, it's important to evaluate the challenges on the level where they should be taking place. The conviction and opinion of those who implement the ideas within the supply chain is decisive for the success of the innovations. Thus their opinion is of great value. Moreover, it is crucial for a successful and sustainable supply chain to coordinate challenges and efforts with the entire supply chain (Barbosa-Póvoa et al., 2018). A place to start this exchange with the herring industry is the Swedish west coast, as it is home to the most important fishing ports in Sweden (European Commission, 2023). While having the highest share of herring for human consumption in relation to the total herring landings, the herring industry's stakeholders such as fisheries and processors have a big leverage to improve the sustainability of the supply chain by optimizing their environmental impact (Ericson, 2023). By a direct exchange with the stakeholders at the Swedish west coast, the people who are the closest to the supply chain, they can be involved in the evaluation of the supply chain's environmental sustainability. Also, this way it can be investigated on what is hindering a further implementation of actions that promise a positive change.

Aim and objectives

The aim of the paper is to look at the West Swedish herring industries' potential for a change to more environmental sustainability. The focus is on fishery, processing, and side-streams, regarding their efficiency and resource consumption out of the perspective of experts from the industry. To do so the following objectives will be:

1) Identify critical areas for improving sustainability practices in the herring supply chain.
2) Formulate proposals for optimization based on feedback from stakeholders (as expressed by experts in the field).

Literature review

The literature review was done with the "Preferred Reporting Items for Systematic reviews and Meta-Analyses" (PRISMA) – Method (Page et al., 2021). It was used as a guideline to complete a systematic literature review on the exciting sources on the topic of environmental sustainability of the herring industry. The search was done with the database of Scopus, www.scopus.com, due to its large database and interdisciplinary content (Stahlschmidt & Stephen, 2020). The literature search was done in three independent rounds. The keyword search was as follow:

Herring fishery: *TITLE-ABS-KEY (herring AND fishing AND sustainable) AND NOT TITLE-ABS-KEY (pacific)*
Resulting in 74 findings

Herring processing: *TITLE-ABS-KEY (herring AND (industry OR process) AND sustainable) AND NOT TITLE-ABS-KEY (pacific)*
Resulting in 58 findings

Side-Streams and By-Products from herring: *ALL (herring AND waste AND process) + byproducts and side-streams*
Resulting in 23 findings

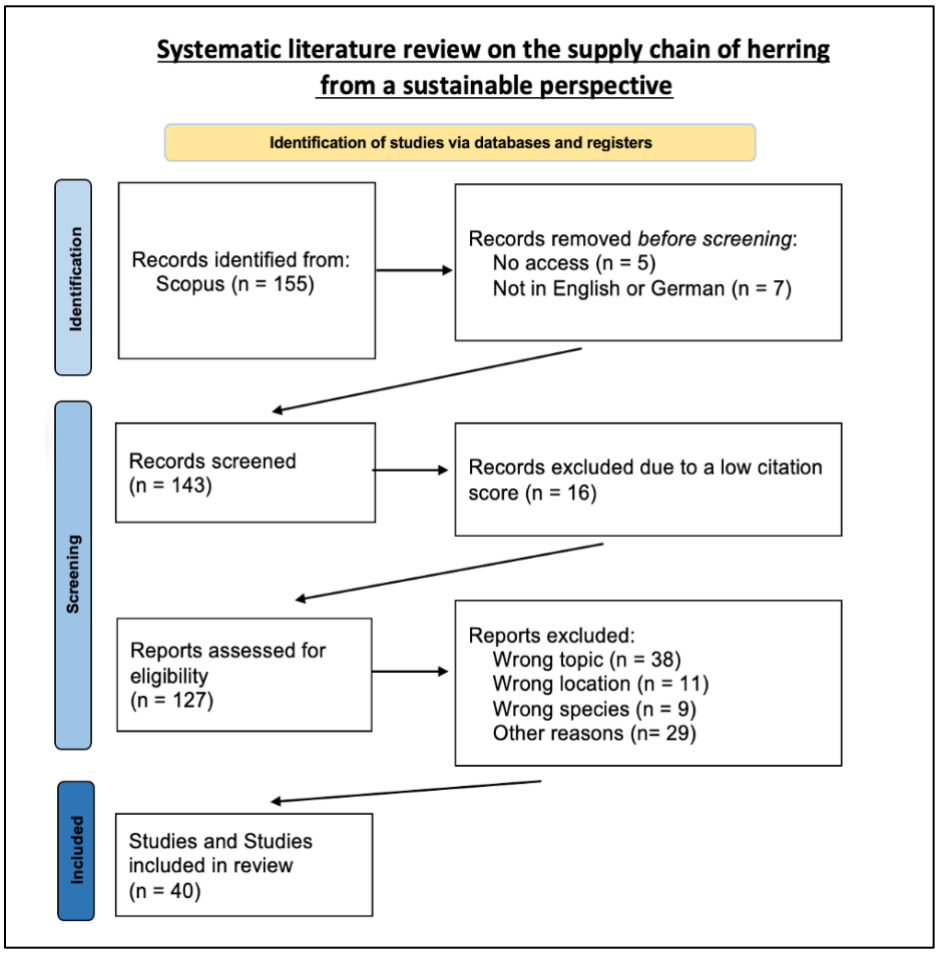

Figure 1: PRISMA-Model for the Literature review (Page et al., 2021). Showing the steps "Identification", "Screening" and "Included". For the figure the results across all three literature reviews were combined.

The specific exclusion of "pacific", in the keywords, was done to avoid literature about the pacific herring, that was too far away from the aim of this paper and guarantees comparability with the experts. For the entire literature review 155 reports and studies were identified. In the final literature review 40 references got included. Figure 1 shows how many sources got excluded in what stage and for what reason.

The literature shows that there is rising interest in a sustainable supply chain of herring. Across the selected sections of the supply chain there is literature found that supports a shift to a more sustainable herring industry. The review gives an overview on how the herring industry is dealing with their role to minimize their environmental impact. The focus of the research is on Sweden and the neighboring regions, with similar conditions. Partially there was literature, that was not directly referring to the Swedish herring industry, but there were similar challenges that were dealt with. Those papers where included as well and set in perspective to the objectives of this paper. With the following literature review relevant pieces of information were gained and could be set into context within the further research of this paper.

Herring fishery and its environmental impact

The supply chain starts with the fishing of herring. Here, CO^2 emissions and the effect on the biodiversity pose a possibility for adjustments. Since fuel consumption is responsible for 90% of the total emissions in fishery, scientists are researching in particular on how to decrease those emissions (Sandison et al., 2021). However, it should be noted that catching pelagic fish, such as herring, has some of the lowest emissions when compared to other species (Parker et al., 2018). Improvements can be expected through various upgrades, such as engines, sonar, and navigation. When the vessel size is considered, medium sized vessels (12-24 m) have the best fuel efficiency (Ziegler & Hornborg, 2014). To improve the fuel usage per catch further, the vessels should vary their target fish as well as fishing technique (Hornborg et al., 2022). At the same time, the Swedish government subsidizes fuel for fishing boats to an extent which is way above the European average (OECD, 2021). This is criticized as being counterproductive and setting the wrong signals to financially support fossil fuel, instead of spending it on sustainable changes. Especially since bigger boats are profiting from financial benefits the most and can only survive with the help of those subsidies, these bigger boats are mostly used for catching fish as feed and not for human consumption (Lewin et al., 2023).
Another major impact politics has on the fishery is the TAC which gets set by the European Council after a proposal from the European Commission (Council of the European Union, 2023). Even if the proposals of the Commission is based on scientific facts, the final TAC often shows a higher allowed amount than recommended (Eumota, 2019). This is caused by the often contradicting interests of sustainability and the European economy (Williams & Capps, 2022). Leading to sustainability standards that are too soft and not precise enough. Also, reliable data on herring stocks are missing, resulting in inaccurate proposals of the European Commission (Tenningen et al., 2021).
Sweden has exceeded their TAC by an average of 32% in the past. Especially with herring from the Swedish west coast, the importance of a sustainable herring sock gets highlighted in multiple sources (Carpenter, 2020). Since climate change and fishing put pressure on the stock, it can lead to an imbalance in the trophic cascade (Arlinghaus et al., 2023; Serpetti et al., 2017). Herring as a forage fish is of great importance to its predators and an imbalance can change the carbon, nutrient and oxygen cycle at the lower end of the food web (Clausen et al., 2018; Scotti et al., 2022). This underlines the herring's importance as a key species to an environmentally sustainable sea as well as an economically sustainable sea, as not only herring fisheries depend on it, but also the fisheries that catch the predator fish that feeds of the herring.

On a more indirect level, sustainability certificates can help to improve the way of how herring is fished. Labels, such as the Marine Stewardship Council (MSC), are claiming to have a positive impact on the industry and to give the costumers a feeling of trust (Asche et al., 2015). Even though MSC has an impact on the environment, it is often criticized for not addressing all sides of the industry. For instance, social aspects are only covered marginally (Arton et al., 2020; Carlson & Palmer, 2016). The focus seems to be on the economic benefits of promoting an environmentally friendly handling of the fish population.
One potential is to support local and small fisheries. Because of the TAC and pressure of larger fisheries, alternative incomes might be a solution. By creating new sources of income, the acceptance of quotas can be raised, since the income is not focusing on one source only and there are more financial securities for the fishermen. Alternative incomes can be in form of direct marketing of the herring products, leaving more profit to the fisheries and supporting the consumption of local products. To be more independent from the fishing market overall, the fishermen can expand their business towards tourism (Lewin et al., 2023). With the location at the seaside, owners of fisheries have an appreciated destination for visitors of the coast.

Environmental impact of herring processing

Processing is the next major step along the herring supply chain. One of the adjustable factors to control the environmental impact is the energy consumption. The numbers vary, stating the energy consumption of herring products is between 124 kWh/t (Thrane et al., 2009) and 1000kWh/t (Schmidt & Thrane, 2006), with the most recent number of 216 kWh/t (European Innovation Council and SMEs Executive Agency., 2023; Hornborg, 2023; Winther, U., Hognes, E. S., Jafarzadeh, S., & Ziegler, F., 2020). One approach to optimize the environmental impact is upgrading the machines to be more energy efficient. Powering the machines with renewable energy on site is one way to do so. This can be done by either installing solar power on the facility premises or wind power to generate energy locally (Qu et al., 2021; Ruiz-Salmón et al., 2020). Disposable biomass in form of herring by-products offers a potential for the industry to produce their own biogas of biofuel production on site as a thermal energy source (Cooney et al., 2023; P Baron et al., 2015).

Outside the factory, distances between facilities should be kept short. This saves fossil fuels for the transport of the product to the wholesaler and the by-products that need to go to other facilities for further utilization (Schmidt & Thrane, 2006; Thrane, 2004). As this requires long-term planning, however, this cannot be seen as an immediate solution. Instead, it will presumably need major investments in facilities.

During the further processing the traceability is a crucial point to inform consumers about how sustainable the product is. Because of a variety of different ingredients, depending on the final product, the origin is challenging to trace back. But in the case of seafood in general across the whole EU the labeling is handled with care (Tinacci et al., 2019). This can give a costumer security on the producers' information. Advanced attempts of having a closed information network are currently under research. A possibility can be to involve the system of blockchains, acting as an insurance for authenticity (Howson, 2020; Shamsuzzoha et al., 2023). With the help of this method the costumer can rely on the information the final product is providing. For side-stream products the willingness of consumers to try and eat those can be even increased, when the packaging provides information about food safety and health benefits (Murillo et al., 2023).

Maximized side-streams utilization

The Scandinavian countries are playing a pioneer role in “fish waste management” in regards of publications and international recognition (Sultan et al., 2023).
When the further use of the by-products is decided, it’s important to plan the whole processing chain accordingly. Strict hygiene measures are required for the use of the by-products as fish feed as well as for human consumption (Thrane et al., 2009). To ensure a safe product for the costumer, it’s necessary to maintain the cold chain for all needed steps. For further utilization it is beneficial to separate the waste into liquid and solid waste to simplify the process (Coelho et al., 2023). Looking at the filleting of herring, only 40% are intended for direct human consumption (Wu et al., 2022). This leaves opportunities for further usage of a share of the 60% remaining. Out of the herring by-products different side-streams can be created. Listed from highest to lowest value from a sustainability perspective, these are the following (Cooney et al., 2023; Venugopal, 2022):
1) human consumption (incl.: protein, lipids, minerals, vitamins)
2) fish feed
3) fertilizer
4) energy (for example: biogas)

For the extraction of individual components from solid by-products, the focus is currently on proteins (Wu et al., 2022). In this process, called ph-shift, other by-products such as lingonberry and apple pomace or seaweed can be added as well (Coelho et al., 2022). Depending on the composition of the herring by-product close to 90% of the proteins can be recovered (Undeland et al., 2002, 2005). The process is still being optimized to be as resource-efficient as possible (Surasani, 2018). One factor in doing so is to simplify the process steps needed, minimize investment costs and making it easier for small processors to implement them into their daily business (Hinchcliffe et al., 2019).

The liquid waste, like waste water and brine, can be used to grow other products, such as seaweed or marine yeast (Stedt et al., 2022; Warwas et al., 2023). By ultrafiltration the direct recovery of nutrients from the brine is possible as well (Undeland et al., 2002). The usage of process water and brine not only contributes to circularity. The growth of seaweed can get increased by the factor four and marine yeast grown in brine has an increases share of protein and essential fatty acids with 50% (Stedt et al., 2022; Warwas et al., 2023). Those new grown protein sources can replace animal proteins and relieve stress from the conventional and climate harmful meat sources.

Summary

The results of the literature review represent all steps in the supply chain of herring and they put those steps into a perspective of sustainability. When looking at the process and the topic of side-stream, it can be seen that they are strongly depending on each other. Due to the many similarities, the process and side-stream sections will be combined in this paper and abbreviated as P&S.

Two challenges come up when looking at the researched literature. Especially in the process step, which is not well documented in full, only a few sources give a good insight into how the herring is handled. This hinders an easy access to the topic and might affect the problem solving of future research. Further, most of the literature is only on an experimental stage. An increase of literature over the years regarding a more sustainable herring industry can be seen in academia. But some findings, such as the protein extraction (Undeland et al., 2002, 2005), are over 20 years old. On the other hand, more recent literature is still stating that a broad implementation is not doable yet (Hinchcliffe et al., 2019; Surasani, 2018). If there are more introductions of large-scale feasibility

studies, the literature is missing those. According to the literature, the interest is there, it just needs to be put into practice.
Table 1 provides an overview of all the major findings that are referring to the environmental sustainability of the herring supply chain, separated by the main sectors fishery, processing and side-stream as well as sup-topics within the sector. The numbers in the brackets behind the individual sub-topics indicate the amount of how often this sub-topic has been the focus in the literature.

Table 1: Overview of the most important findings in the literature review. The bracket behind the sub-topic indicates the frequency of the sub-topic mentioned.

Sector	Sub-Topics (n)	Key take away	References
Fishery	Technical (8)	• CO2 emissions can be approached by: engines, fishing gear/navigation, monitoring by authorities. • Monitoring and data collection of the fishing boats can provide valuable information for scientific purpose. • Appr. 0,4 kg of Co2eq. get emitted while fishing for pelagic fish. Herring fishing therefore has one of the lowest GHG emissions. • Trawlers of a medium size (12-24m) have the best fuel efficiency.	(Bastardie et al., 2022; Driscoll & Tyedmers, 2010; Hornborg et al., 2022; Lewin et al., 2023; Parker et al., 2018; Sandison et al., 2021; Tenningen et al., 2021; Ziegler & Hornborg, 2014)
	Climate (4)	• Global warming changes the rhythm of the herring's egg development → leading to a hatching time of a critical situation of food, as zoo plankton. • With sustainable fishing and a slow & steady increase of water temperature, the herring stocks can recover. • The literature states a lack of reliable models in a long-term lead to an insufficient understanding.	(Arlinghaus et al., 2023; Bartolino et al., 2014; Bossier et al., 2021; Serpetti et al., 2017)
	Food Web (5)	• Herring has a crucial role as a forage fish in the trophic cascade. • An abundance of the herring would affect species further up the food chain → a negative impact on those species can have an effect on the fishing of bigger fish. • Changes can spread downwards the trophic cascade and effect the carbon, nutrient, and oxygen cycle.	(Arlinghaus et al., 2023; Bossier et al., 2021; Clausen et al., 2018; Scotti et al., 2022; Serpetti et al., 2017)
	Quotas (4)	• The total allowable catches (TAC) get decided by the EU. Based on a Commission's proposal and a final decision of the council. • Even though the TAC proposal is based on science the actual TAC is often significantly higher. • The Council's decision on the TAC is based on the current prices and economic factors. • Additionally due to missing and incomplete data the quotas can be set incorrectly and give a false sense of sustainability.	(Council of the European Union, 2023; Eumota, 2019; Tenningen et al., 2021; Williams & Capps, 2022)

	Environmental Management (7)	• Sustainability and economic interests often stand in contradiction. • States giving out environmentally harmful subsidizes → Sweden subsidizes fuel for fishing boats which decreases incentives for resource efficiency. • Big boats that are mainly fishing for non-human consumption, are only profitable to tax breaks.	(Bartolino et al., 2014; Froese et al., 2015; Lewin et al., 2023; OECD, 2021; Scotti et al., 2022; Williams & Capps, 2022; Ziegler & Hornborg, 2014)
Process	Technique, Separation and Labelling (8)	• Reliable numbers for the energy consumption in the process of herring vary greatly. • Antioxidants are a key ingrediency in the processing of herring → they prevent the fish from oxidation of lipids and increase the health benefits • Due to mixing of different ingrediencies, depending on the final product, traceability of the single products can be compromised → can lead to contamination and misleading of consumer. • The fish industry has an overall successful information system → consumers can trust the labels' information on the product regarding ingrediency and origin.	(European Innovation Council and SMEs Executive Agency., 2023; Frosch et al., 2008; Hornborg, 2023; Kheiri et al., 2022; Schmidt & Thrane, 2006; Thrane et al., 2009; Tinacci et al., 2019; Winther, U., Hognes, E. S., Jafarzadeh, S., & Ziegler, F., 2020)
	Waste (5)	• Waste dominates the literature for the sustainable process of herring. • Waste is mostly referred to as side-streams and by-products, which indicates the awareness of a value to it. • The process chain must be adapted appropriately if the maximum value of the waste products is to be secured. • Waste predominantly ends up as fish feed, fertilizer or biomass for energy production and not for human consumption. Even if there is a potential. • Wastewater gained focus as a nutrient rich source to grow other products. For example: sea lettuce.	(Bendiksen et al., 2011; Coelho et al., 2023; H. J. Fisher et al., 2020; Stedt, Gustavsson, et al., 2022; Thrane et al., 2009)
Side-Stream	Circularity (9)	• During the production of herring fillets only 40% are intended for direct human consumption, while the rest has the potential for further utilization. • Herring by-products can be used for (value sorted from highest to lowest): human consumption, fish feed, fertilizer or energy. • The pH-shift technology is a key in the circularity of herring side-streams. With the goal of recovering nutrients. • By-products from the fruit industry or seaweed can improve the yield of extraction as well as the resource-saving way of food production.	(Coelho et al., 2022, 2023; Cooney et al., 2023; Sultan et al., 2023; Surasani, 2018; Undeland et al., 2002, 2005; Venugopal, 2022; Wu et al., 2022)

	Usage of Solid Waste (6)	• Literature focuses on extraction of proteins for human consumption. Lipids, vitamins (E, D, B12), calcium, selenium and iodine can be filtered out as well. • The process of extracting nutrients from herring side-streams is not economically viable yet. • A simplification of the process steps is needed to make it more attractive for the industry to implement those. • A higher value product for human consumption would prevent the side-stream from going to the fish feed industry. Therefore this is more resource-efficient and sustainable.	(Coelho et al., 2023; Hinchcliffe et al., 2019; Jonas Ericson, 2023; Venugopal, 2022; Wu et al., 2022)
	Usage of Wastewater (3)	• Brine from marinated herring can be used to cultivate seaweed and marine yeast. • Marine yeast cultivated in marine yeast has over 50% protein and can be used to substitute fish feed. • Seaweed grows faster in herring process water and had a 4 times higher protein content. • Further use of the wastewater and brine reduces the effort of disposing. • By recycling wastewater the industry can decrease the cost for fresh water as well as waste water charges.	(P Baron et al., 2015; Stedt, Gustavsson, et al., 2022; Undeland et al., 2002; Warwas et al., 2023)
	Pollution and Health (5)	• By recycling water on site the effect on the surrounding environment can be minimized. • The use of recycled water as well as further use of herring side-streams has to be approved by the Food Safety Authorities. • Keeping the cold chain intact gets more difficult since the process gets extended. • The new products from side-streams must meet health and nutrient criteria to add a real value to the food market. • Herring products from side-streams have already been approved by the European Food Safety Agency.	(Coelho et al., 2023; Cooney et al., 2023; P Baron et al., 2015; Undeland et al., 2002; Wu et al., 2022)

Methodology

To set the results from the literature review into perspective of the industry, interviews with experts for the data collection were conducted. The included experts can be seen as actors as well as stakeholders in the context of this study. On one side they are different actors within the system of making profit from their business with herring. While also being individual stakeholders, since the fisherman, processors including side-stream are operating from different angles in the herring business. Fisherman are depending on the removal of the herring, while the stakeholders on land are involved by processing the herring. Thereby having different impacts on the environmental sustainability.

During the search for experts, there was a relatively low positive response rate. However, there was a great willingness to participate by companies on the Swedish west coast. Therefore, the scope of the work was adapted to this region. Due to covering every step across the supply chain,

the experts were qualified to represent a large share of herring industry at the west coast with their opinions and expertise.
The experts' opinions are of great value because they are close to the topic in their everyday work life while dealing with the environmental sustainability as a part of their job. At the same time, those experts pose the link between fulfilling sustainability goals while being in the position to support a viable business. As part of the data collection, the experts were asked about their assessment of the potential of various measures, further called "actions", resulting from the literature. They were also asked to name obstacles that limit these actions from reaching their full potential.

Design

For the data collection a systematic research approach was used which was an adaptation of the broadly used descriptive analytics method (Johnston et al., 2014; Safari & Areeb, 2020). A qualitative methodology was chosen as the focus was on the qualification of experts who have the knowledge to answer questions on the more complex topic of environmental sustainability. While the group of participating experts represented a large share of the involved in the herring industry at the Swedish west coast, they also brought seniority and expertise along. Therefore they were in the position to give qualitative answers that can be seen as a qualified insight. Their qualifications get defined further down.
The data collection in form of interviews took place in the period from 20 March 2024 to 10 April 2024. Figure 2 shows the entire process of the data collection which in the following will be explained in detail. Every step is labelled and will be referred to.

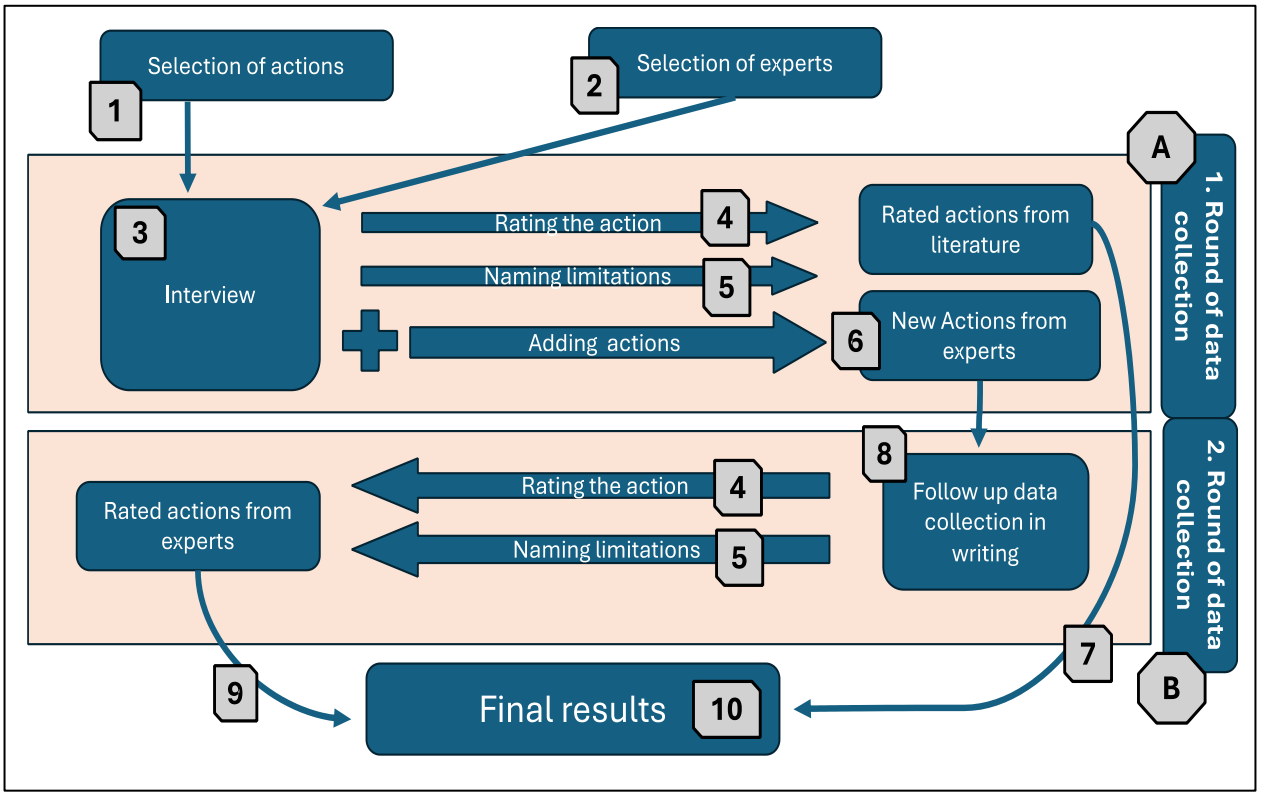

Figure 2: Method overview. Illustration of the data collection process with numbering of the individual steps.

The data collection was designed to be conducted in two rounds. The actions with a potential positive impact on the environmental sustainability on the supply chain of the herring industry were earlier extracted from the literature, as shown in figure 2 as step 1. Those actions presented to the experts were divided into two sectors: Fishery and P&S. The division was made to simplify the data collection by clarifying the two topics to the experts. A total of nine actions were picked for the herring fishing sector and twelve for the P&S. A list of all chosen actions, including their references as scientific background, can be seen in appendix 2.

The experts for giving their professional opinion on those actions were chosen from public assessable governmental registers and open-source search. Based on the following criteria the experts were chosen and considered as participants in the study. Those criteria were set individually based on the needs of this research (Step 2):

Experience:
The expert had to be in current or former (self-)employment in the herring industry. In addition, they had to have 10 + years expertise in the industry. Alternatively, their company had to have a history of at least 50 years in the industry on which the expert could draw on.

Position:
The expert had to hold a position of direct involvement with environmental sustainability. Alternatively, they had to be in a high managing position that allows them to be involved in decision making in relation to environmental sustainability.

Geographically:
Their (former) company had to have their operations at the Swedish west coast. In case the company had multiple sites, at least one had to be at the Swedish west coast.

A total of approximately 60 potential experts across Sweden were contacted directly via e-mail. Multiple potential experts in one company were contacted in some cases. This was done before the narrowing of the scope to the Swedish west coast was done. In case of no response to the e-mails, every remaining contact attempt was followed up with calling on their publicly available phone numbers. Companies in the surroundings of Gothenburg were visited in person to get in touch with representatives of the herring industry. The attempts to recruit experts for this study started in February 2024 and were completed at the beginning of April 2024.
Besides the direct contacting of experts, the snowball system was used. Every contact, which was made in the process of recruiting experts for this research, was asked, if they had further connections in the industry that meet the criteria and that had not been contacted yet. A total of seven experts, all from the Swedish west coast, agreed to contribute to the study. With change of scope towards the Swedish west coast the chosen experts displayed a good share of the herring industry of the Swedish west coast. The identity of the experts is not disclosed in order to ensure that they were able to speak freely and express opinions that may be unusual for the industry.

Data collection

The first half of the data collection, labeled with A in figure 2, was done in the format of an interview. The interview (Step 3) was either done in person or in the form of an online meeting.
Before the interview, it was emphasized that the expert was seen as a representative of the industry. Only their expertise and experience in environmental sustainability were valued. Their answers should not reflect their companies' interests. The experts knew from the beginning of the interview on that there will be a section about fishery and one about P&S. If they didn't have expertise on an entire section, this section was omitted.

A list of all actions (action list) was sent to them at least a day before the interview to give them time to prepare and pose questions if needed. During the interview the experts were presented actions one at a time, both verbally and by a visual presentation to avoid misunderstandings.
The expert was now asked to give a rating for each of the actions (Step 4). The rating was intended to reflect their opinion on the potential for this action to have a positive impact on environmental sustainability, further referred to as "Environmental Sustainability Potential" (ESP). The possible answers were on a numerical scale from 0 to 100. 0 stands for no added value for environmental sustainability and 100 stands for the absolute best that can happen in terms of environmental sustainability. Example question: "On a scale from 0 to 100 where would you put the action when considering its potential to have a positive impact on the environmental sustainability?"
The numeric scale was chosen to ensure that every expert had the same benchmark on where their ratings must be placed. This allowed to later compare and analyse the actions between each other and see which action has the highest potential in relation to the remaining (M. J. Fisher & Marshall, 2009). Multiple ratings of the same value were possible.

Besides the ESP rating, the experts were asked to state if they see any limitations, that hinder the given action to be fully implemented and realize its full potential (Step 5). "Could you name one or more limitations that hinder the action to be fully implemented and unfold their full potential". The experts were free in their answers. Without a maximum count of limitations or any prepared answer options. This made it guaranteed an impartial insight. Alternatively, to limitations, the expert had the possibility to say that the action is already fully implemented or if the expert didn't have enough experience on the specific action, the answer was filled by "No Comment".
At the end of each interview, the expert was asked if they had actions to add to the list. All the added actions, for fishery as well as P&S were added to the existing list and included in the interviews of the experts, that were conducted after them. This concludes the first round of data collection (Step A).

Round two was structured like the first (Step B). Due to little available time of the experts, this data collection was done via email and with multiple days' time for completion. The experts were sent all the actions that got added to the list after their interview (Step 8). The questions were the same as in the first round (Steps 4&5), which accordingly did not require a detailed introduction, only a reminder. The experts had been asked to fill in the ESP rating and the limitations to the actions before sending it back. After all the answers from the experts had been received, the answers from the first and second round of data collection were combined (Step 7&9) to provide the final results (Step 10). Appendix 3 displays the entire list of answers, both to the actions that were originally included and those that were added later.

Results

The data collection with the industries experts on the environmental sustainability in their field gave a variety of insights. A total of seven experts participated in the data collection, of which all seven completed the first and second round. Two experts had to skip the section about fishery, due to only a limited amount of expertise in this topic. The chosen descriptive analysis method based on the collected ESP-rating and correlation of limitations is suited for smaller sample sizes (Fisher & Marshall, 2009; Kim et al., 2017). Accordingly, a proper method to collect results with the available number of experts which enables the fulfilment of the aims.
After gathering all the data, the number of actions totals 32, which are all displayed in appendix 2 with an assigned codes for identification. The original nine actions in fishery were expanded by four actions by the experts, resulting in 13 actions for fishery. In P&S, the original twelve actions were extended by seven actions from experts, thus resulting in a total of 19 actions for the P&S sector.
By collecting the data from the ESP and the limitations for each action, 198 individual pieces of information are obtained, each containing the ESP and limitations data. The results from the experts will further be summarized and explained.

Sorting of the data

To simplify the analysis, the actions were categorized into subgroups for a better presentation of the results. The actions were divided into four categories. This was done after completing the data collection in order to create categories that can also capture the actions of the experts. The four categories are defined as follow in table 2:

Table 2: Definition of the categories.

Category	**Action gets defined by:**
Governmental (GOV)	Must be dealt with on a political level. Regulations and laws are involved on a national or international level.
Individual (IND)	Every company must handle it on their own. Decisions concerning this action can be made independently.
Organization (ORG)	Must be handled within the industry between the different stakeholders. Multiple parts of the supply chain are involved.
Knowledge (KNO)	Aiming towards more education and knowledge within the herring industry and public.

Across the entire action list, there were a total of three actions assigned to the Governmental (GOV) category, 18 actions to the Individual (IND) category, eight actions to the Organization (ORG) category and four actions to the Knowledge (KNO) category. Action “P&S 12” (see appendix 2) was the only action to be assigned to the ORG and KNO categories. Due to the proximity to consumers as well as the involvement in the entire supply chain to promote environmental sustainability.

Table 3: List of the limitations and their explanation. Showing nine limitations as well as the answers that actions are already fully implemented or no limitation could be named.

Limitation Group	**The limitation gets defined by / keywords mentioned**
Finance (*Fin*)	Could be overcome with a certain amount of money.
Politics (*Pol*)	Has its origin in the governmental level and is dependent on the legislative.
Operational (*Op*)	The limited ability of a company to implement actions, due to lack of personal, to high complexity and too specific for an individual company.
Demand (*Dem*)	Demand, acceptance, trust, ignorance.
Logistics (*Log*)	Barriers due to infrastructure, geographically given limits.
Legal (*Leg*)	Including permissions and public administration.
Knowledge (*Kno*)	Lack of suitable technology and innovation as well as a general knowledge about the given action.
Time (*Time*)	The action is already implemented but need more time to develop its potential.
Tradition (*Trad*)	Describes the barriers, which are rooting in a more conservative understanding of herring. Mostly in combination with older consumers
Fully implemented (*Impl*)	The action is already in use and applied. No further implementation is needed.
No comment (No com)	The expert couldn't give a limitation for this action.

The limitations mentioned by the experts were very diverse due to no predefined answer options. This allowed many different impressions to be gathered. Nevertheless, clear tendencies could be identified that allow different answers to be grouped into different limitation groups. To give an example, the answers: "high investment costs", "low return on investment", "alternatives are cheaper", were all assigned to the financial limitations group. Shown in table 3, the experts' answers were sorted in such a way that each group can be attributed to a central problem that restrains the potential of the action for more environmental sustainability.

The answers from the interviews gave valuable information and pose the counterpart to the literature. By rating the actions one by one it's possible to identify which actions have a greater potential in comparison to others to improve the environmental sustainability. By using the same scale for all experts, the gap in rating between the individual actions can represent the difference in potential for more environmental sustainability.
The limitations for themselves as well as their abundance in all the interviews gave the possibility to see what limitations are slowing down those actions. In the final step of the interview the experts added measures that they consider suitable for improving sustainability. Especially those which were not emphasized so much in the literature. With the second round of interviews, it was guaranteed that every expert had the chance to comment on the added actions.

Combined results of the fishery and process & side-stream

All interviews combined revealed an average rating of 68,02 ESP, out of the maximum 100, across all 32 actions. The average rating for the 21 actions given by the literature is 65,92 ESP. While the 11 later added actions named by the experts have an average ESP of 72,04, which comes to a 6,12 higher ESP rating for the later added action by the experts. All the answers including rating and limitations are combined in appendix 3.

Figure 3 shows the average ESP rating for every category as displayed in table 2. Actions from the knowledge category have the greatest potential to improve environmental sustainability. The remaining three categories are all in the upper 60s between an ESP of 65 and 70.

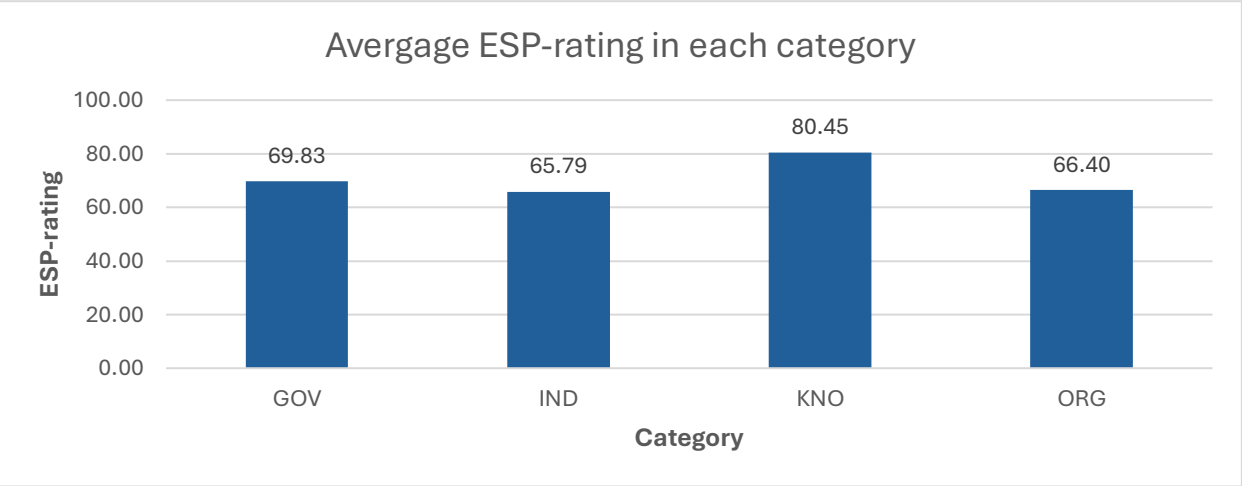

Figure 3: Average rating of each category across the entire data collection.

The experts identified different limitations, defined in table 3, in relation to each measure that hinders the transition to greater environmental sustainability in the herring industry. Figure 4 shows how often a limitation was mentioned.

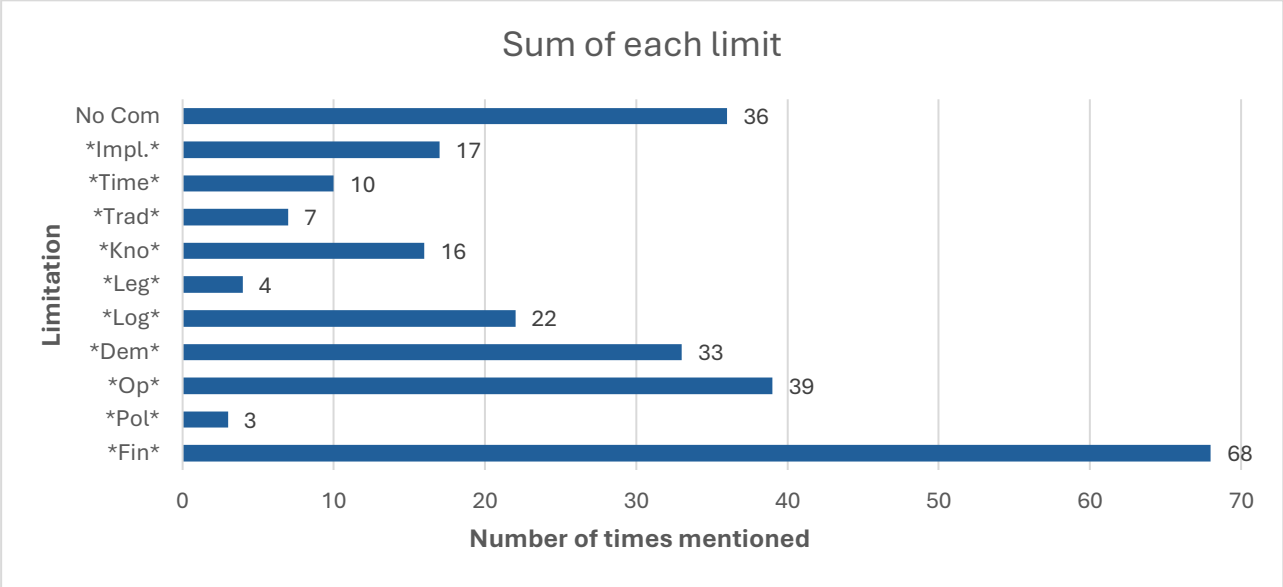

Figure 4: Sum of each limitation for the entire data collection.

Here, several entries were possible for one action. 32 times the experts couldn't give a limitation to single actions. Excluding the 17 times the actions were apparently fully implemented results in 1,22 limitations per action. The limitations stated the most actions were due to financial, operational and demand reasons. While political actions were mentioned three times and legal limitations four time, these limitations consequently form the lower end.
Due to the nature of some action certain limitations were named more often within certain categories. The abundance of the limitation in relation to the categories are displayed in table 4. The abundance is adapted to the missing two data sets in the fishing section. Governmental related actions where mostly limited due to financial reasons, with 71% of the actions being affected by financial limitations. The same applies to individual actions of which 41% get limited due to financial reasons. Limits to knowledge actions are more distributed but most frequently get limited to a lack of demand with 23%. Organizational actions have the most mentioned limitations in the operational group by 33%. This shows where the experts see the most barriers to the environmental sustainability in relation to different action categories.

*Table 4: Abundance of each limitation in the different categories. The highest value in each case (excluding *Impl* and No Com.) was highlighted.*

	Fin	*Pol*	*Op*	*Dem*	*Log*	*Leg*	*Kno*	*Trad*	*Time*	*Impl*	No Com
GOV	70,59%	17,65%	5,88%	11,76%	0,00%	0,00%	5,88%	5,88%	0,00%	0,00%	29,41%
IND	41,23%	0,00%	18,42%	17,54%	11,40%	3,51%	7,89%	4,39%	4,39%	6,14%	15,79%
KNO	11,54%	0,00%	15,38%	23,08%	0,00%	0,00%	15,38%	3,85%	11,54%	15,38%	23,08%
ORG	12,50%	0,00%	33,33%	12,50%	18,75%	0,00%	4,17%	0,00%	4,17%	16,67%	16,67%

The data from the experts for each individual action allows a direct correlation to the answers for the ESP and the associated limitations. Figure 5 shows how high the ESP is for measures that are

hindered by the corresponding limitations. The limitation of time has the highest rating of 93 ESP towards the actions, when those were further implemented. While time is the only implementation, that cannot be overcome by more effort. This is followed by high potentials that get slowed down by tradition with 86 ESP, limited knowledge with 84 ESP and political frameworks with an ESP of 83. Experts that named logistical and legal limitations attested those actions the lowest potential to have a positive impact, those actions with ratings of 60,5 ESP and 61 ESP.

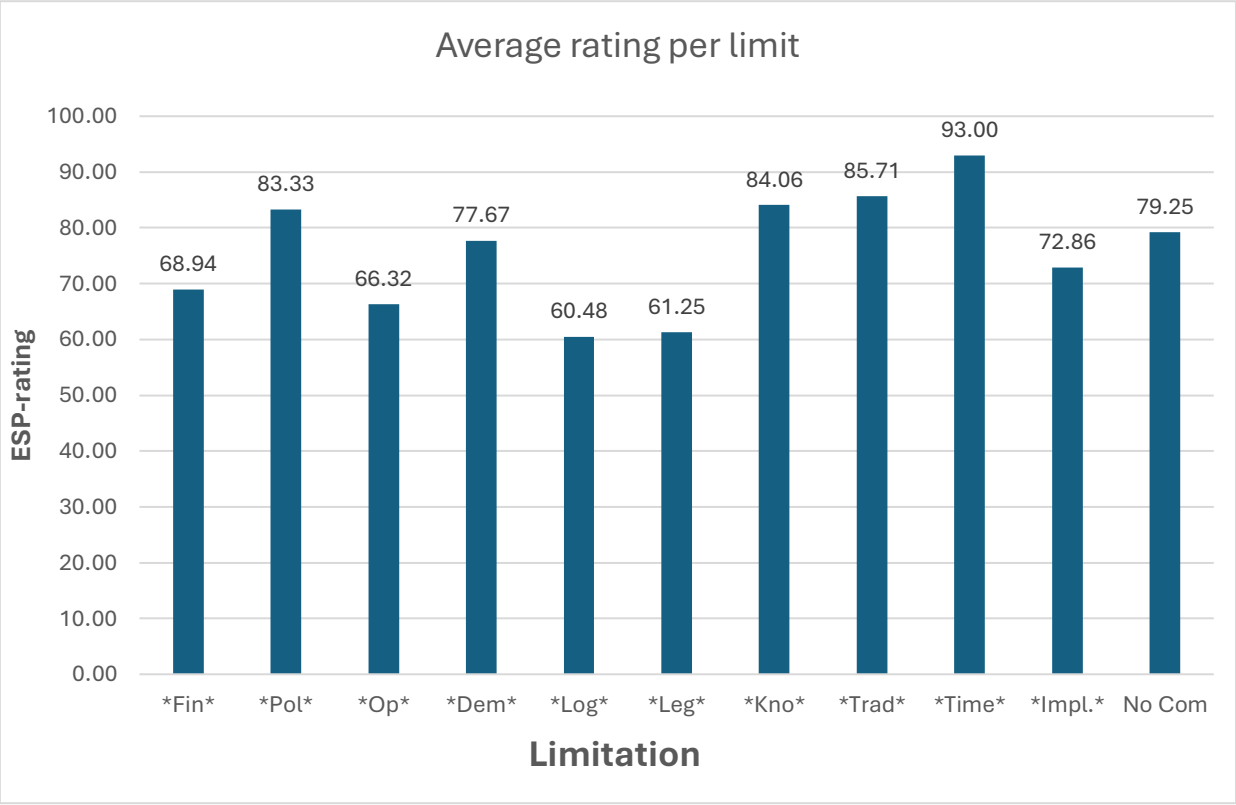

Figure 5: Average rating of the action by the individual limitation mentioned alongside with it.

Fishery and P&S comparison

As the literature has revealed, fishery is a sector that will have to adapt more strongly to the challenges of the future. P&S is already more in the position to develop new ways to environmental sustainability. Accordingly, the data for fisheries and P&S are set alongside each other, as displayed in the following figures.

For fishery, to the presented nine actions based on the literature, the experts added four more actions. Five out of the seven experts answered for the topic of fishery. Out of the 13 actions the distribution of the categories was as follow: Governmental: 2; Individual: 6; Knowledge: 1; Organization: 4.

In P&S additionally to the original twelve actions based on the literature, the experts added seven more actions. All seven experts answered the topic of P&S. Out of the 19 actions the distribution of the categories was as follow: Governmental: 1; Individual: 12; Knowledge: 3; Organization: 4.

Combining all ratings in the fishery sector resulted in an average ESP rating of 61,81. For P&S it was 72,48.

The highest rating for fishery was the action “Lower catch quotas for herring” with 92 ESP out of a 100. The action to decrease the financial support for fuel, however, had the lowest ESP rating with 37,50, followed by alternative incomes for fisherman through tourism and direct marketing with an ESP of 40 and 50.

P&S has the highest potential in the actions: Upscaling the processing of side-stream for humans with an ESP of 86,67, better knowledge in the public sector (schools and canteens) with 86,43 ESP and the providing of more product variations of side-streams to humans with 85 ESP. The lowest potential was seen in having biogas (50 ESP) and wind energy (53,57 ESP) on site. Appendix 3 shows those answers again, alongside all the remaining ratings for the entire action list. When looking at the ratings for each category in figure 6, actions in relation to knowledge and education stand out with both average ratings being around 80 ESP. This category has the greatest potential to improve the environmental sustainability, especially for the herring fishery. For all the remaining categories fishery has an overall lower ESP rating compared to the P&S. With difference of about 15 ESP in the categories GOV and IND. For organizational actions the gap decreases to an ESP difference of seven.

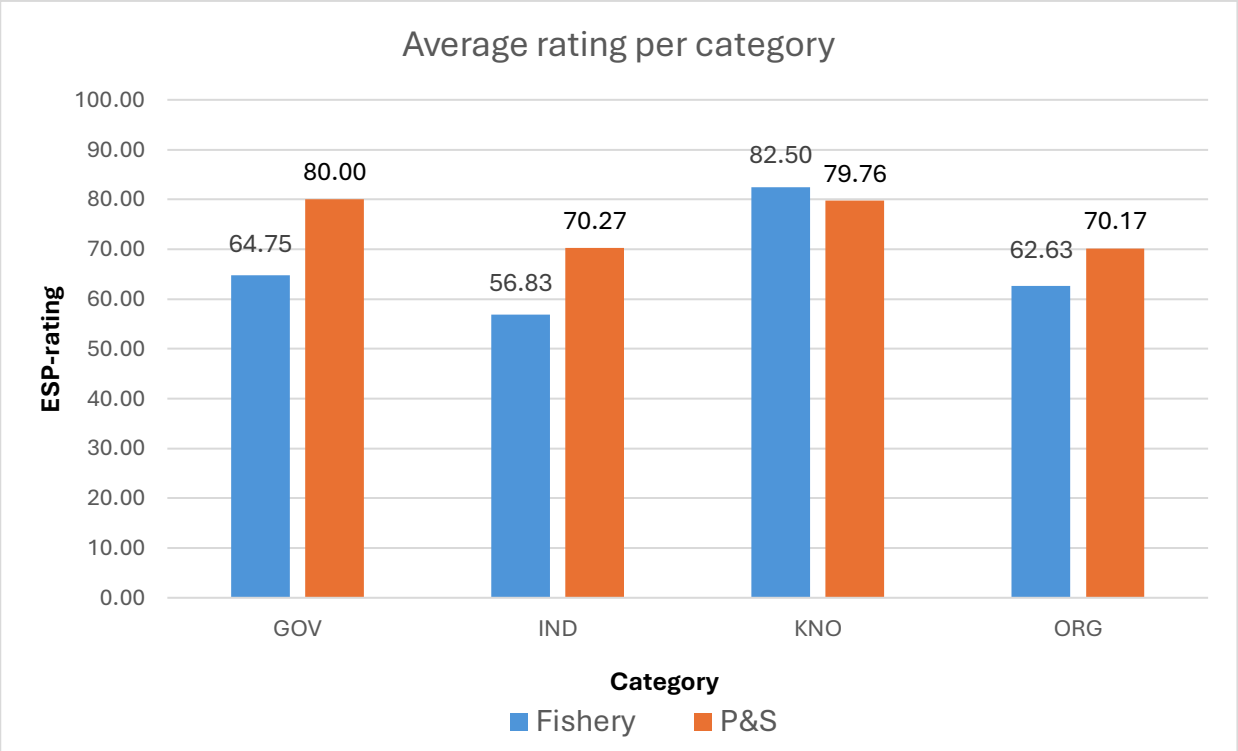

Figure 6: Average rating of each category. Divided into Fishery and Process & Side-Stream.

As the second half of the data collection in relation to the individual actions, the limitations to the implementation of fishery and P&S were collected and compared below. Fishery has an average number of 0,83 limitations for each action across the five interviews, excluding fully implemented actions and "no comments". P&S has 1,09 limitations for each action across the seven interviews, excluding fully implemented actions and "no comments".

For both sections, figure 7 shows the frequency with which the limitations were mentioned. Financial limitations were mentioned the most in both sectors. Despite the difference in numbers of actions and experts, finance was the most pressing limitation across all sections. While it was mentioned as a limitation in 38% of the answers in fishery, it was mentioned in 31% of all cases in P&S. Only the limits demand and knowledge show a significant difference of more than 5 percent points between the two sectors as well. Within both these limitations the actions in P&S had a higher frequency. The other limitations do not show any major differences between fishery and P&S. The two cases in which there was no mention are political limitations in P&S and legal limitations in the fishery sector.

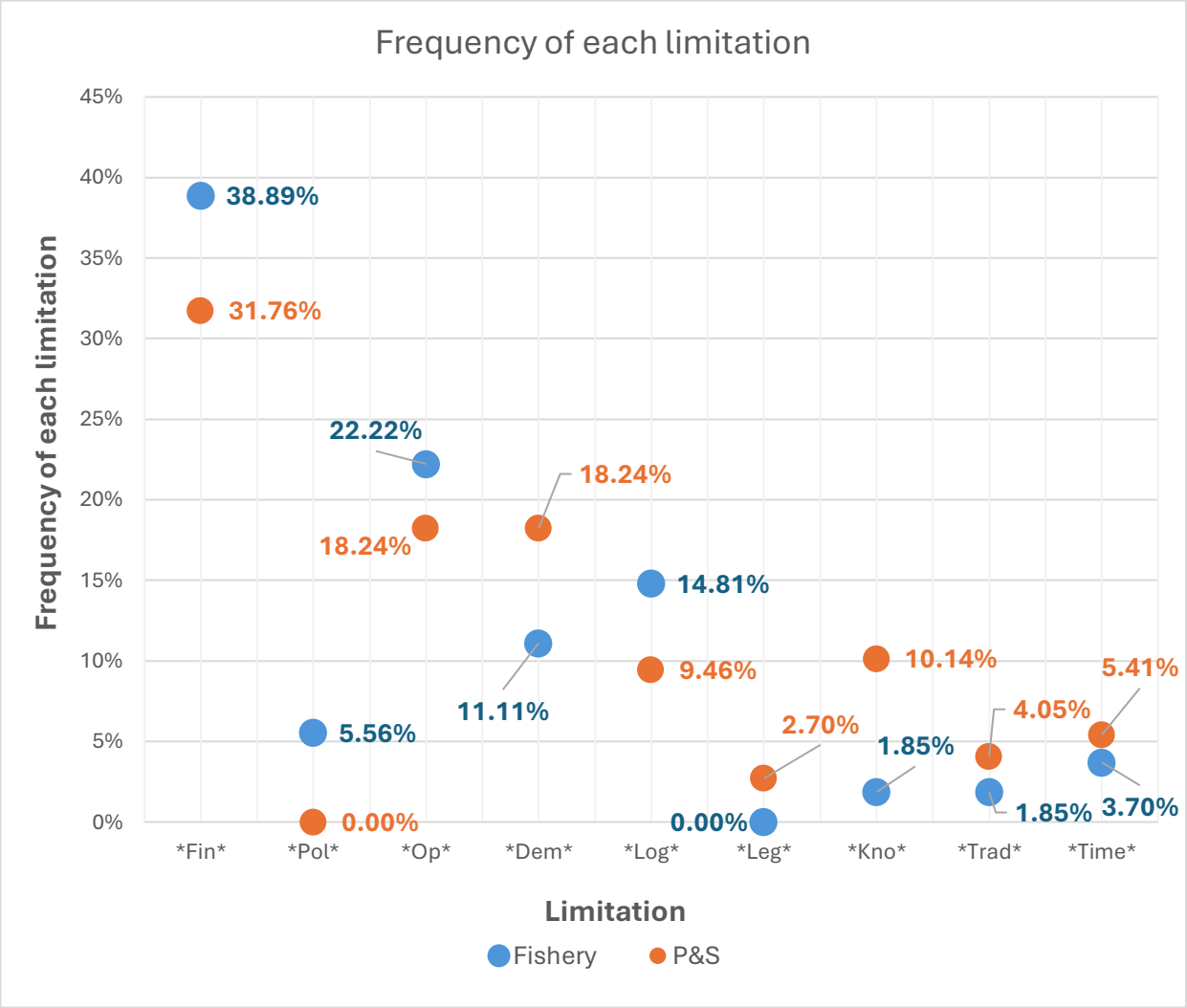

*Figure 7: Frequency of each limitation. Divided into Fishery and Process & Side-Stream. Excluding the limitations *Impl* and "No Com".*

When the limitations get further differentiated into the category, an even more detailed insight is possible. Table 5 presents how often a limitation compromised an action from a specific category within the fishing or P&S. Displaying financial reasons in the GOV and IND category, for fishery and P&S, they have the absolute largest weighting as a limit. Fishery and P&S do not differ in the abundance. In the knowledge category, there is a difference between the maximum value in the financial limits at fishery with 20%, but no noticeable impact on P&S. P&S within the knowledge category has the highest abundance for the limitation due to demand. Action, focusing on the organization have the most limitations due to operational barriers, for fishery and P&S. Whereas P&S has a higher percentage than the fishery sector.
In many of the cases, there is at least a slight difference in terms of what prevents the actions in this category and sector from having a major impact on environmental sustainability. By indicating the weighting of the individual values in the third column, it is made clear how great the influence on the overall result is. Although financial limitations dominate the governmental actions, this only accounts for 9% of the overall result.

Table 5: Abundance of limitations. Divided into categories as well as Fishery and Process & Side-Stream.

Category	Sector	Share of all actions	Limitation →	*Fin*	*Pol*	*Op*	*Dem*	*Log*	*Leg*	*Kno*	*Trad*	*Time*	*Impl.*	No Com
GOV	Fishery	6%		70,00%	30,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	30,00%
	P&S	3%		71,43%	0,00%	14,29%	28,57%	0,00%	0,00%	14,29%	14,29%	0,00%	0,00%	28,57%
IND	Fishery	18%		36,67%	0,00%	20,00%	6,67%	16,67%	0,00%	3,33%	3,33%	0,00%	10,00%	16,67%
	P&S	36%		42,86%	0,00%	17,86%	21,43%	9,52%	4,76%	9,52%	4,76%	5,95%	4,76%	15,48%
KNO	Fishery	3%		20,00%	0,00%	20,00%	0,00%	0,00%	0,00%	0,00%	0,00%	20,00%	0,00%	40,00%
	P&S	9%		9,52%	0,00%	14,29%	28,57%	0,00%	0,00%	19,05%	4,76%	9,52%	19,05%	19,00%
ORG	Fishery	12%		10,00%	0,00%	25,00%	20,00%	15,00%	0,00%	0,00%	0,00%	5,00%	25,00%	15,00%
	P&S	12%		14,29%	0,00%	39,29%	7,14%	21,43%	0,00%	7,14%	0,00%	3,57%	10,71%	17,86%

Discussion

By connecting the answers from the interviews with the literature the actions get set into a new perspective. The results get reviewed again in relation to the literature that was used in the beginning and the foundation of all original action list. It demonstrates how relevant the suggestions from various sources are and what areas are critical for improving sustainability practices in the herring supply chain. With a spotlight on the stakeholders of the herring industries at the Swedish west coast, proposals for optimization can be made individualized for this group. The goal is to identify which of the suggestions from the literature have the potential to be successful at the Swedish west coast and which do not seem to have the anticipated effect. The limitations give an insight on where the group of stakeholders at the west coast sees the challenges for the environmental sustainability. From the added actions given by the experts some of those already can be found in the literature, in different variations. Some actions, however, point out possibilities that haven't been highlighted in literature yet and still got rated to have a high potential. This indicates that the actors are currently working on solutions that are not as much represented in research. With the associated limitations, the critical areas can be identified, and suggestions made for industry and research.

Even though some experts stated that single actions have been already fully implemented from their point of view, this was not the case throughout an entire action. Always at least half of the experts saw limitations to the action that indicate that the action is not fully implemented across the industry. This allows the assumption, that none of the listed actions have yet reached their highest potential.

Outstanding results

The results from the interviews have shown which actions are considered to have an overall positive potential for environmental sustainability. Moreover, some actions have a much lower or higher potential than others. Four actions got a rating which was below 50: tourism (40 ESP) and direct marketing (50 ESP) as alternative incomes for fisheries next to a decrease of fuel subsidies (37,50 ESP) and biogas on the processing site (50 ESP). Those actions where seen as the least effective for the environmental sustainability of the herring industry. With a rating of 85 or higher the following actions have the highest potential and can be seen as critical areas that need further focus. Those were: Lower catch quotas for herring (92 ESP), upscaling the processing of side-streams for humans (86,67 ESP), better knowledge in the public sector (schools, canteens) (86,43 ESP) and providing more product variations of side-stream to human (85 ESP). Across all actions, those based on improving knowledge and education had the highest ESP with 80,45.

When considering the limitations as well as the ESP to the actions, certain limitations were named more frequently, while having a high ESP. Those limitations represent the critical areas that could have the most benefits when reduced. The limitations to actions with the highest potential were time (93 ESP), tradition (85,71 ESP), and lack of knowledge (84,06 ESP). At the other end the two limitations with the lowest potential for improvement were: logistical (60,48 ESP) and legal (61,25 ESP). Financial reasons were mentioned 68 times as a limitation to an action, which equals to 33,66% of all mentioned limitations. The actions they limit were rated with average of 68,94 ESP, which is close to the overall averaged potential of 68,02 ESP.

The potential of actions towards more environmental sustainability – Fishery

In the fisheries sector multiple actions were in line with the literature and strive for the goal of a more environmentally sustainable herring industry. The highest potential was seen in the reduction of the TAC of herring, which is consistent with the literature. This is also based on the pressure and recommendations of the European Council, that is suggesting a decrease in the allowed catch of herring to guarantee its future availability (Council of the European Union, 2023; Eumota, 2019). The named limitations towards this action only consisted of political and financial reasons, which supports William and Capps, who reveal that there is a conflict between economic and environmental interests. Both are getting discussed within the political framework, where those two apparent interests are weighted against each other, resulting in tensions (Williams & Capps, 2022).
The action subsequently added by the experts to improve the scientific effort in fisheries can also be found in the literature. Here it states that more monitoring of the fishing effort helps to improve the quality and reliability of data that is used for the decision on the TAC. With the fisheries position and involvement in the supply chain, contribution to this action by the fishery sector to an even further extend seems to be important (Tenningen et al., 2021).
The experts also suggested that smaller boats can have a positive impact on the environment, by decreasing the impact on large herring schools. Bigger boats can also have a positive impact, by being more fuel efficient and emitting less greenhouse gases per kg of herring, even though those two suggestions are contrary, which was pointed out by the experts as well. Both actions were rated with a relatively low ESP. This opinion is shared in the literature, where medium sized boats (12-24 m) are named as the best option to decrease the impact on the environment, especially due to their fuel efficiency, which was at an optimal at a medium sized boat, which even opposes the proposal from the experts (Ziegler & Hornborg, 2014).

Further measures are not necessarily in line with the literature. However, it should be noted that the literature is not directly related to the herring industry on the west coast. Therefore a different opinion shows less an incompatibility and more that the west coast has different challenges and experiences. The action to improve the fuel efficiency of the fishing boats (Sandison et al., 2021; Ziegler & Hornborg, 2014) was given a rating of 70 ESP, while the action to decrease the financial support of fuel (OECD, 2021; Ziegler & Hornborg, 2014) had the overall lowest rating with 37,50 ESP. This indicates a slight contradiction since both actions are aimed at lower fuel consumption. The assumption of promoting sustainability by alternative incomes, such as opening up for tourism and direct local marketing (Lewin et al., 2023), does not have a huge potential at the Swedish west coast. The potential is seen as low in average and is limited by multiple reasons.

The potential of actions towards more environmental sustainability – P&S

The P&S sector had an overall higher ESP rating than the fishery. Nevertheless, the renewable energy on site had a surprisingly low ESP, with solar power as the highest potential at 65,71 ESP. An explanation why renewables don't get seen as beneficial as the literature suggests (Cooney et al., 2023; P Baron et al., 2015; Qu et al., 2021; Ruiz-Salmón et al., 2021) could be that the current energy mix within the Swedish industry. A majority of the electricity and energy for the Swedish industry sector, which processes seafood, gets supplied by renewable sources (The Swedish Energy Agency, 2023). Therefore, a further upscaling of energy production on site might seem not as beneficial due to the already sustainable supply. The literature still states that renewable energy can be an improvement (Winther, U., Hognes, E. S., Jafarzadeh, S., & Ziegler, F., 2020). This however cannot be confirmed by the interviews with the experts. Further results regarding the energy consumption state that optimizing the energy efficiency of the machines has a higher potential (83,33 ESP) to improve the environmental sustainability within the herring process. This

statement fits within the scientific findings (Winther, U., Hognes, E. S., Jafarzadeh, S., & Ziegler, F., 2020).
Meanwhile an implementation of a circular economic process as for water faces equal competition as the previous mentioned actions P&S 3, P&S 4, and P&S 5. It has a below average rating of 61,43 ESP, which can be the consequence of a currently sustainable availability of freshwater in Sweden (RISE, n.d.). As a result, the need of recycling the wastewater during the process is simply non-existent. Besides the competitive opportunity costs of fresh water compared to recycling, it's stated that wastewater is one of the emissions during the process of herring. Subsequently the implementation of circularity would still lower the risk of pollutions and relieve pressure on sewage treatment plants (Coelho et al., 2023; Schmidt & Thrane, 2006).

An action that is generally regarded as positive is the coordination of sustainability goals within the supply chain, having a high rating for the fishery (73,33 ESP) as well as the P&S (84 ESP). According to sources that included the entire European seafood sector the stated potential is justified because a coordination across supply chain links has a great potential and challenges can be addressed together (Ruiz-Salmón et al., 2020). As for the action "forwarding comprehensive information to costumers", which was presented in the fishery and P&S sector, the rating is below average with 62,50 ESP in fishery and average with 70 ESP in P&S. The lower/average rating could be seen as a confirmation to the academic opinion since literature states it as just one tool for more information on environmental sustainability. Therefore, the indirectly beneficial might lower the potential (Howson, 2020; Shamsuzzoha et al., 2023). Whereas other research attests the information and labelling system in the EU to be in a good state and consumer-friendly (Tinacci et al., 2019), this would indicate a deficit at the Swedish west coast. Since the answer "fully implemented" was only given in three out of twelve possible times. Indicating a gap to the apparently good situation described in the study by Tinacci et al.

Answers for actions based on literature for further use of the solid and process water side-streams, as well as optimizing the machines to do so, had an average rating. This indicates that the herring industry sees it as one part of the solution.
The added actions by the experts can be found in most parts in the existing literature. The idea to decrease the volume of herring by-products for the energy and fertilizer production and increase the fish feed production is rated with 74 ESP. This gets supported by the papers that rank the further use of herring side-streams on their sustainability, depending on how it is used. Here, the fish feed is higher ranked than the energy or fertilizer production (Cooney et al., 2023; Venugopal, 2022). But the same literature states that herring side-streams should contribute to the human consumption as the best solution and therefore this action should be viewed critically. Despite the elevated ESP ratings, the use of herring by-products for fish feed should not be the benchmark and should not be at the cost of less herring towards the food industry. Nevertheless, there are parts of the herring that can't be used for the human consumption and fish feed, so fertilizers biogas can be an option.
The linked actions "Providing more product variations of side-stream to human" and "Upscale the processing of side-streams for humans" got rated with 85 ESP and 86,67 ESP. This shows an understanding of the industry on how to use the herrings side-stream in the most sustainable way (Cooney et al., 2023; Venugopal, 2022), getting further underlined by the high potential of 82,86 ESP for action the action "Research into by-products for human consumption". Showing that the importance of research for more product options from the herring side-streams to diversify the options for costumers is present in the industry (Coelho et al., 2023; Stedt, Steinhagen, et al., 2022; Undeland et al., 2002). Parallel to this, new product options from the whole herring are not as promising, nevertheless they still have potential (67,14 ESP). Possibly rooted in the long history of herring in Sweden this allows the assumption that the utilization of the whole herring is maxed

out (Skåra et al., 2015). Further reasons could be traced back to the uncertainty of consumers that the herring could have a negative effect due to harmful substances, like heavy metals or dioxide. Although this concern is unfounded for most of the population excluding young or pregnant women, who are vulnerable. Especially herring that is caught on the west coast contains uncritical amounts of heavy metals and dioxides (Swedish Food Agency, 2023; Tuomisto et al., 2020).
To spread awareness on food options of herring side-streams one expert mentioned the action to educate the public about the possibilities by offering products in canteens or schools. With a rating of 86,43 ESP, this is one of the highest rated actions. This is supported by literature that states education and outreach as one key to a more sustainable industry (Cooney et al., 2023). Related to this, the acceptance of herring can be further increased by creating dishes that are easy to eat and cooking suggestions (Pihlajamäki et al., 2019).

How limitations to the actions fit into the context

Limits are an important part of this paper due to their value to identify the critical areas among the actions that hinder the process of improvement on environmental sustainability. But due to an insufficient explanation of barriers to the described actions in the literature a comparison is difficult. Yet certain actions limit each other and need particular attention.
Individual actions are limited not only by a lack of financial resources, but also by operational circumstances. These include too high complexity, a lack of personal or cross-organizational barriers. At the same time actions such as coordinating sustainability goals with the whole supply chain have a high potential, when implemented. This means that the promotion of this action reduces the limitations for individual actions.
Overall, the financial limitations are mentioned most frequently. This could lead to the assumption that subsides in all sectors could have the biggest effect. But the experts' answers show that actions that are limited by financial reasons only have a potential to improve environmental sustainability that is just average, as it was shown in Figure 5. The literature doesn't give further details about the negative effect of a financial deficit on the implementation of certain actions. It can only be assumed that developments and positive effects get further delayed.
But the apparent lack of financial resources calls for a rethinking regarding the distribution of funds and investments to create and prioritize opportunities for actions with high potentials. While fossil fuels for boats are subsidized, other actions, with a greater potential to the environmental sustainability, like the funding for more side-stream products to humans, could benefit from those fundings (OECD, 2021).

While financial limitations slow down more average rated actions, time is the limitation that, according to the experts, prevents the most potential (93 ESP). This was observed in the literature review as well, for instance, in the successful development of technology to recover protein which has been researched for over 20 years and still hasn't been implemented on a large scale (Hinchcliffe et al., 2019; Surasani, 2018; Undeland et al., 2002, 2005). A more forward approach by the stakeholders to scale up the production of side-stream products was suggested, which could be a learning from the missed opportunities of the past.
Other limitations mentioned that are slowing down actions with a high potential are tradition (85,71 ESP) and knowledge (84,04 ESP). Tradition describes the attitude of customers, who may be slightly more conventional and not particularly exposed to new ideas. Education and information can play a role within breaking up traditional beliefs to a degree that new approaches get accepted. This does not mean that older and established values must be replaced. But it explains the proximity to the limit "knowledge" and shows up that alternatives can encourage consumers to try new options.

The restriction caused by a lack of education is already recognized as such in research. The approach in the literature is to educate the stakeholder in the industry on how sustainable side-stream products can be created and on how to make consumers familiar with those new products (Altintzoglou et al., 2021; Pihlajamäki et al., 2018; Siddiqui et al., 2023), including the transparency about food safety and the health benefits of those products (Murillo et al., 2023). In the long-term perspective these should increase the demand and reduce the limitations of missing demand.

Further actions aimed at supporting the shift to more herring side-stream products from the suppliers' side are actions such as "public and private funding to accelerate the implementation of 'side-streams for humans'". These measures usually lack the resources to speed up the change in practice. The reason for the financial limitations can be explained with the opportunity costs, that come along with the investments made. Currently the investments don't generate enough profit to pose an attractive opportunity. Which could be a chance to governments to promote their idea of sustainable food production by supporting those ideas financially.
An example to explain the general abundance of financial limitations can be found when going back to the energy and water prices. Energy costs in Sweden are currently at a point where an investment doesn't have the return of investment which is needed. Continuously raising energy and electricity prices could decrease financial limitations in those areas (The Swedish Energy Agency, 2023), as the investment into own energy would not differ that much from the purchased energy. The same applies to the financial limitation of recycling water. Swedish water prices are compared with the investment costs which is suggesting that the investment into a recycling infrastructure cannot compete with the Swedish water prices (Kärrman, n.d.). This can be applied to all major action, being financially limited. As long as not implementing those actions is cheaper for the operation, a company, that is depending on profit, will have difficulties to justify those kinds of expenses.

Strengths & Challenges

The study is the combined experience of the seven experts from the Swedish west coast, set into relation with a wide range of literature. The experts had comprehensive experience and expertise across the whole considered supply chain starting from the fishery down to the side-stream utilization. With many years of experience as well as career of changing responsibilities, this ensures a differentiated point of view on interdisciplinary challenges that were presented to them. The basic data collection was carried out based on an extensive literature review consisting of 40 sources.
Although the number of experts included seems relatively small, they reflect the landscape of the herring industry on the Swedish west coast and certainly have an influence on the shaping of the industry. As employees of companies that manage and influence a large share of the herring at the west coast those expert insights are of high value for this research. A few more experts might have also contributed to the research. Unfortunately, it was not possible to recruit them for this thesis, although intensive efforts were made to involve them.
During the data collection, even though the experts understood that they should answer from their perspective on behalf of the environmental sustainability, they were still working for companies with an economic interest. This could be one possible explanation that the actions, that had to be implemented from the companies themselves, had the lowest average ESP.

The scale from 0-100 made it possible to rate all the actions and compared by their ESP set in relation. Since every expert used the same scale across the data collection as a benchmark.
The comparison of the results from the data collection with the literature posed a challenge since certain sources only do focus on one action, while their standpoint on how they would rate the ESP

or how they compare with other actions was not always identifiable, same applies to the limitations. As a solution to this problem, the statements of the literature were interpreted and put into context to information provided by the experts.
For future research, it makes sense to extend the same target groups to the Swedish east coast to see to what extent it differs from and is similar to the west coast. Based on this, further suggestions could be made that would benefit the Herring industry on a national level. It also makes sense to expand the group of stakeholders to include, for example, the group of policymakers or consumers to understand their views.

Conclusion

This paper shows that the path of the shift to a more environmentally sustainable herring industry at the Swedish west coast has been set. This can be seen in the interviews and gets supported by the literature. To maximize the industries' potential, critical areas along the supply chain were identified. Actions in critical areas were characterized by the fact that they were considered to have high potential for greater environmental sustainability or were limited largely by restrictions.
The most promising actions are those that promote knowledge and education about the sustainable herring fishery and processing. Starting with the fishing industry, which can provide more data on the state of the herring population (Tenningen et al., 2021). Another identified goal is to make herring side-stream products more viable. Tools to achieve this include more transparency in product information and easy access to new herring dishes, for example through simple recipes (Howson, 2020; Murillo et al., 2023; Pihlajamäki et al., 2019; Shamsuzzoha et al., 2023). The identification of industry limitations has shown that the financing of actions is the most frequent obstacle to greater environmental sustainability. This was followed by limitations relating to operational feasibility and lack of demand.
To gain a contribution and added value for research and industry from the findings, the potentials and limitations of the actions were set in relation to each other. Showing that the quantity of financial hurdles does not necessarily affect those actions with the greatest potential. As a result, research should increasingly focus on the practicability of new methods to accelerate change in the industry (Hinchcliffe et al., 2019). It is advisable to address the limitations that arise for the industry at an early stage through closer cooperation with the stakeholders concerned, to minimize delays in implementation. For the industry and politics, a rethinking is needed. As the financing of actions in particular represents a barrier here, investments and subsidies should be made in a more targeted approach which reflects the commitment to environmental sustainability (Williams & Capps, 2022). While fossil fuels are subsidized in the fisheries sector, measures with a high potential for environmental sustainability, such as lower catch quotas, financing of a faster implementation of side-stream products for humans and more public awareness need significant investments. The various interests involved must be well communicated between all the stakeholders to ultimately be supported by the majority. The frameworks that are created should be set at EU level and get more customized on the regional level. This guarantees that the development of the herring supply chain towards more environmental sustainability happens within the framework of local capacities and brings economic as well as environmental growth (Ruiz-Salmón et al., 2020).
The core focus of this paper is on the environmental sustainability of the herring industry in western Sweden, but the results are largely applicable to other areas as well. However, attention must be paid to ensuring that the actions are tailored to the needs of the individual stakeholders.

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Appendix

Appendix 1

Popular science summary

How will the herring of the future become more sustainable?

Of the 100 kilograms of herring originally caught, only 16 kilograms will end up on the plate as fillets. At the same time, Sweden is the leading nation for overfishing North East Atlantic herring off its own west coast. How does this fit in with the goal of sustainable use of marine resources? And more specifically, how do we ensure that a larger proportion of the herring can be used for direct consumption? As part of this thesis, various actions from the literature were identified that have the potential to strengthen the environmental sustainability of the herring industry. The focus was on the supply chain from fishing to the utilization of the side-streams from herring that are generated during production. Through qualitative data collection with stakeholders in the herring industry on the Swedish west coast, it was possible to determine which actions have the greatest potential. The individual obstacles that restrict and slow down the implementation of individual actions were also identified. By working together with stakeholders from the industry, it was possible to identify critical areas that show relevance in the practical implementation. It has been shown that actions that promote knowledge and education in connection with the utilization of herring have the greatest potential to shape the industry in an environmentally sustainable way. At the same time, a lack of knowledge is a limitation that hinders the implementation of actions, especially in processing and side-stream. This applies to both industry professionals and consumers, who can be encouraged to increase the proportion of herring in their diet through more education and proximity to herring products from side-streams. Meanwhile, it is becoming apparent that financial hurdles account for most of the limitations. However, eliminating these limitations would not necessarily make it possible to realize the actions that have the greatest potential. It is much more a question of achieving the greatest possible impact on environmental sustainability through targeted funding and the conscious use of available resources. What exactly these actions with the greatest potential are from the point of view of the west coast experts is shown in the work. The same applies to the complexity of challenges along the supply chain, which can both restrict and promote each other. Confirmed in part by the underlying literature, but it also shows differentiations between literature and stakeholders in the herring industry. All in all, it can be said that environmental sustainability is a task that must be tackled by the entire supply chain. By the stakeholders surveyed, who manage the herring for commercial reasons, on the political level, which must create the framework, and the final consumers, who can steer the market through their demand. From both an economic and environmental point of view, all parties involved should be keen to utilize the herring in such a way that its stocks are still available in the future, to protects its role as a key species in the marine ecosystem. The course for this has been set, it is now a matter of utilizing the potential in such a way that a larger proportion of the herring catch contributes directly to our food supply.

Appendix 2

These two lists show all the actions the data collection is referring to, separated into fishery and process & side-stream. The first column contains the individual code for each action. The last column lists the references the action is based on. The actions marked in green are those which were later added by the experts.

Code	Actions for Fishery	Reference
F1	Alternative incomes for fishery: **Tourism**	(Lewin et al., 2023)
F2	Alternative incomes for fishery: **Direct local marketing**	(Lewin et al., 2023)
F3	Lower catch quotas for herring	(Williams & Capps, 2022)
F4	Decrease financial benefits for fuel of boats	(OECD, 2021)
F5	Modernize boats: better fuel efficiency	(Sandison et al., 2021)
F6	Modernize boats: better sonar	(Ziegler & Hornborg, 2014)
F7	Forwarding comprehensive information for costumers	(Shamsuzzoha et al., 2023 Howson, 2020)
F8	Being certified by MSC etc.	(Asche et al., 2015)
F9	Coordinating Sustainability Goals with the whole supply chain	(Ruiz-Salmón et al., 2020)
	↓ Actions mentioned by the experts ↓	
F10	Bigger boats for less emissions	
F11	Smaller boats	
F12	Direct unloading at bigger docks close to the factory	
F13	More scientific effort in fishery for more reliability	

Code	Actions for Processing and Side-Stream	Reference
P&S1	More energy efficient machines	(Schmidt & Thrane, 2006; European Innovation Council and SMEs Executive Agency., 2023; Hornborg, 2023; Winther, U., Hognes, E. S., Jafarzadeh, S., & Ziegler, F., 2020)
P&S2	Upgrade machines to minimize and separate waste	(Coelho et al., 2023)
P&S3	Having solar energy on site	(Ruiz-Salmón et al., 2021)
P&S4	Having wind power on site	(Qu et al., 2021)
P&S5	Having biogas as an energy source on site	(P Baron et al., 2015 Cooney et al., 2023)
P&S6	Implementing of circular economy in the process (**water**)	(Coelho et al., 2023; Schmidt & Thrane, 2006)
P&S7	Usage of resources in the wastewater	(Undeland et al., 2002 Stedt, Trigo, et al., 2022, Warwas et al., 2023)
P&S8	Usage of solid waste as a resource	(Wu et al., 2022)
P&S10	Short distance to the wholesaler and by-product facility	(Mikkel Thrane, 2004; Schmidt & Thrane, 2006)
P&S11	Research into by-products for human consumption	(Undeland et al., 2002 Stedt, Trigo, et al., 2022 Coelho et al., 2023)
P&S12	Forwarding comprehensive information for costumers	(Howson, 2020; Shamsuzzoha et al., 2023)
P&S13	Coordinating sustainability goals with the whole supply chain	(Ruiz-Salmón et al., 2020)
	↓ Actions mentioned by the experts ↓	
P&S9	Upscale the processing of side-streams for humans	
P&S14	Providing more product variations of side-stream to human	
P&S15	Better knowledge in the public sector (schools, canteens)	
P&S16	Processors should lead the way to more side-streams for humans	
P&S17	Public + Private funding to speed up the implementation of “side-streams to humans”	
P&S18	New products from the WHOLE herring	
P&S19	Promote the idea to use side-streams more for fish feed. Instead of fertilizer and energy)	

Appendix 3

The two tables show all the answers given by the experts separated into fishery and process & side-stream. The limitations are already categorized. Fishery has five out of the seven experts' answers included. The last column shows the standard deviation. Added actions by experts are marked green.

	Fishery	*Int.1*		*Int.2*		*Int.4*		*Int.5*		*Int.6*				
		Rating	*Limit*	*Rating*	*Limit*	*Rating*	*Limit*	*Rating*	*Limit*	*Rating*	*Limit*	*Cat.*	*Avg.*	*SD*
F1	Alternative incomes for fishery: **Tourism**	50	Fin,Op	60	Op	20	Fin		Impl.	30	Fin	IND	40,00	18,26
F2	Alternative incomes for fishery: **Direct local marketing**	80	Op	50	Op	0	Log	50	Dem	70	Dem	IND	50,00	30,82
F3	Lower Catch quotas for herring	90	Fin	70	Fin	100	No Com	100	Fin, Pol	100	Pol, Fin	GOV	92,00	13,04
F4	Decrease financial benefits for fuel of boats	10	Fin	40	Fin		No Com	50	No Com	50	Pol, Fin	GOV	37,50	18,93
F5	Modernize boats: better fuel efficiency	70	Fin	70	Fin		No Com	80	Impl.	60	Fin	IND	70,00	8,16
F6	Modernize boats: better sonar	70	Fin		Impl.	30	Kno	100	No Com	/	No Com	IND	66,67	35,12
F7	Forwarding comprehensive information for costumers		Impl.	80	No Com	50	Fin	80	Op	40	Op	ORG	62,50	20,62
F8	Being Certified by MSC etc.	10	Impl.		Dem	10	Dem	80	Dem	80	Fin	ORG	45,00	40,41
F9	Coordinating Sustainability Goals with the whole supply chain	50	Op		Impl.		Impl.	100	Log	70	Op	ORG	73,33	25,17
F10	Bigger boats for less emissions	50	Op,Log	60	Fin,Op,Log	0	Log	100	Trad	70	Log	IND	56,00	36,47
F11	Smaller Boats	50	Fin		No Com	50	Fin		No Com	75	Fin	IND	58,33	14,43
F12	Direct unloading at bigger docks close to the factory	80	No Com	80	Op, Log	0	No Com	100	Impl., Time	30	Dem, Log	ORG	58,00	41,47
F13	More scientific effort in fishery for more reliability	100	No Com	60	No Com		Fin	100	Time	70	Op	KNO	82,50	20,62

	Process & Side-Stream	Int.1 Rating	Int.1 Limit	Int.2 Rating	Int.2 Limit	Int.3 Rating	Int.3 Limit	Int.4 Rating	Int.4 Limit	Int.5 Rating	Int.5 Limit	Int.6 Rating	Int.6 Limit	Int.7 Rating	Int.7 Limit	Cat.	Avg.	SD
P&S1	More energy efficient machines	100	Fin	90	Fin	50	Fin	100	Op, Fin	Impl.		60	Fin	100	Time, Kno	IND	83,33	22,51
P&S2	Upgrade machines to minimize and separate waste	80	Fin	80	Fin	70	Fin	100	Dem	20	no com	75	Fin	70	No com	IND	70,71	24,57
P&S3	Having solar energy on site	90	Fin, Time	80	Impl.	70	Fin & Op	50	Log	20	Fin	50	Fin	100	Log	IND	65,71	27,60
P&S4	Having wind power on site	85	Fin & Leg	70	Fin, Leg	40	Fin & Leg	20	Log	50	Fin/Leg	60	Fin	50	Fin	IND	53,57	20,96
P&S5	Having biogas as an energy source on site	/	No Com	30	Op	/	Log, Op	0	Log	100	Fin/ Log	70	Impl.	50	No com	IND	50,00	38,08
P&S6	Implementing of circular economy in the process (**water**)	50	Fin	50	Fin	70	Fin	30	Fin	100	Log	60	Fin, Time	70	Fin, Kno	IND	61,43	21,93
P&S7	Usage of resources in the wastewater	70	Fin, Op	80	Time	60	Dem	50	Kno	100	Op, Log	65	Fin, Op	70	Fin	IND	70,71	15,92
P&S8	Usage of solid waste as a resource	50	Op		Impl.	100	Dem, Trad	100	Kno	100	Trad, Time	70	Fin, Op	30	Dem	IND	75,00	30,17
P&S9	Upscale the processing of side-streams for humans	60	Fin	80	Dem/Op	100	Dem, Trad	100	Kno	100	Kno	80	Fin, Op, Dem		No com	IND	86,67	16,33
P&S1	Short distance to the wholesaler and by-product facility	80	Op, Log	50	Log	/	No Com	30	Log, Op	100	Op, Log	50	Log	100	Fin	ORG	68,33	29,27
P&S1	Research into by-products for human consumption	90	Impl.	80	Impl.	100	Trad, Time	100	Kno, Dem	100	Fin	60	Dem	50	Dem	KNO	82,86	20,59
P&S1	Forwarding comprehensive information for costumers		Impl.	80	Op	Impl.		80	Dem	80	Op	40	Op		No com	ORG, KNO	70,00	20,00
P&S1	Coordinating Sustainability Goals with the whole supply chain	50	Op		No Com	Impl.		100	Fin	100	Log	70	Op	100	Op	ORG	84,00	23,02
P&S1	Providing more product variations of side-stream to human	75	No Com	90	Dem, Fin	80	Dem, Fin, Kno	100	Kno, Dem	100	Op, Fin, Dem	70	Op, Dem	80	Dem	IND	85,00	11,90
P&S1	Better knowledge in the public sector (schools, canteens)	100	No Com	50	No Com	80	Kno, Dem	100	Fin, Kno	100	Dem	75	No Com	100	Time, Kno	KNO	86,43	19,30
P&S1	Processors should lead the way to more sidestreams for humans	80	No Com	60	No Com	/	Fin	100	Time, Kno, Fin, Dem	50	Op	35	Kno	25	Op	ORG	58,33	28,05
P&S1	Public + Private funding to speed up the implementation of “side streams to humans”	100	No Com	60	No Com	90	Fin, Op	100	Dem, Fin	100	Fin, Kno	60	Fin	50	Trad, Fin, Dem	GOV	80,00	22,36
P&S1	New products from the WHOLE herring	70	No Com	80	No Com	10	Dem	100	Dem	100	Dem	60	Dem	50	Dem	IND	67,14	31,47
P&S1	Promote the idea to use side streams more for fish feed. Instead of fertilizer and energy)	100	No Com	80	No Com	90	No Com	50	Fin, Op		No Com	/	No Com	50	Trad, Op	IND	74,00	23,02