Increased sustainability in Aquaculture

- with focus on feed and sidestreams

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Ágrip á íslensku:	Norðurlöndin eru stórir aðilar í fiskeldi m.a. á laxi (*Salmo salar*). Mörg krefjandi umhverfismál tengjast þessari framleiðslu og þau eru að finna í hverju skrefi ferlisins. Megináherslan í þessari skýrslu hefur verið lögð á ný fóðurhráefni og bætta nýtingu hliðarafurða. Bæði þessi mál snúa að miklu magni og það skiptir miklu máli fyrir atvinnulífið sem og sjálfbærni og umhverfisáhrif þessarar mikilvægu starfsgreina að þau séu tekin á betri og skilvirkari hátt en núverandi aðferðir. Framtíðarmatvælaöryggi fyrir matvæli fyrir jarðarbúa okkar, á sjálfbæran hátt til lengri tíma litið, krefst byltingar í því hvernig við framleiðum matinn okkar. Brýn þörf er á að hámarka sjálfbæra fóðurframleiðslu.		
Lykilorð á íslensku:	Fiskeldi, sjálfbærni, nýprótein, hliðarafurðir, fóður		
Summary in English:	The Nordic countries are big players in salmon aquaculture (*Salmo salar*). Many challenging environmental issues are related to this production, and they are to be found in every step of the process. The main focus in this report has been put on novel and alternative feed ingredients and sidestreams utilisation. Both those issues involve vast volumes and it´s of high importance for the economy as well as the sustainability and environmental impact of this important profession that they are tackled in better and more efficient manner than current approaches. Future food security for our global population that does not compromise the long-term sustainability of our ecosystems requires a revolution in the way we produce our food and there is an urgent need for nutritionally optimise a sustainably produced feed ingredient for inclusion in aquafeeds.		
English keywords:	Aquaculture, sustainability, alternative proteins, sidestreams, feed		

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1 Introduction

The production of salmonids in aquaculture, especially salmon (*Salmo salar*), holds a significant role in the Nordic countries, yet it poses various environmental, economic, and social challenges. Addressing these challenges necessitates a steadfast commitment to sustainability at every step of salmon production. In relation to this AG-Fisk funded project and the subsequent workshop, here are some key identified facts and challenges:

- Economic importance: Salmon farming is a crucial sector for the Nordic countries, particularly Norway, which is one of the world's largest producers. It provides employment opportunities and contributes significantly to the GDP of these nations.
- Environmental Impacts: Salmon farming can have significant environmental impacts, including:
  - Escapes: Farmed salmon escaping into the wild can interbreed with wild salmon, potentially harming wild populations' genetic integrity.
  - Disease and Parasites: Concentrated fish populations in aquaculture facilities can lead to the spread of diseases and parasites, which can affect wild fish populations. The use of pharmaceutical to combat disease and parasites in aquaculture can also have negative impacts on ecosystems.
  - Feed: The production of feed for salmon farming, often relying on imported soybean meal, can lead to ecosystem degradation and greenhouse gas emissions.
  - Waste: Excess feed, feces, and other waste from salmon farms can lead to nutrient pollution, harming water quality and marine ecosystems.
- Sidestreams: Sidestreams in salmon production refer to the by-products or waste generated during the process. These include:
  - Fish Waste: Parts of the fish not used for human consumption, such as heads, tails, and trimmings.
  - Wastewater: Effluents from salmon farms containing uneaten feed, feces, and chemicals.

Utilizing sidestreams effectively is a challenge but also an opportunity for the industry to reduce waste and improve sustainability. Methods such as recycling waste for use in agriculture or converting it into value-added products like fish oil or protein supplements are being explored.

- Alternative Proteins: The salmon farming industry is increasingly exploring alternative protein sources for fish feed to reduce reliance on Imported agriculture Ingredients and wild-caught fish for feed production. Some alternatives being researched and implemented include:
  - Insect Meal: Insects like black soldier fly larvae are being investigated as a potential protein source for fish feed.
  - Single-cell Proteins: Microorganisms like algae and yeast can be cultivated to produce protein-rich biomass for use in feed.

Implementing alternative protein sources can help reduce the environmental footprint of salmon farming.

Establishing a robust and collaborative network among Nordic countries, where science, politics, and industry converge towards a common goal of achieving sustainable salmon production, is of paramount importance.

The overarching objectives of the AG-Fisk project, titled "Increased sustainability in aquaculture with focus on fish-feed and sidestreams," was to foster collaboration through a conference and subsequent workshop followed up by report writing. These initiatives aim to facilitate the exchange of views and experiences on the feed production and utilization of sidestreams and alternative proteins. Additionally, they seek to identify challenges, assess the state of knowledge, and address logistical and legal gaps in aquaculture feed and sidestreams.

The report is divided in several parts: A short discussion regarding the workshop held while more detailed information is to be found as an Appendix and online. Then a part discussing feed for aquaculture followed by a section that handles use for sidestreams from aquaculture. In the final part, conclusions and future remarks are presented.

2 The Workshop

A workshop was held in Reykjavík the 11th of October 2023. The workshop agenda included people both from industry and academia and was divided into three sessions: Session 1 - Towards sustainable feed Ingredients, Session 2 - Diverse products from sidestreams and finally a workshop with round table discussions (for Agenda see page 4).

Figure 1. Oddur Már Gunnarsson Matís CEO starts the workshop by giving opening words.

Main points from the round table discussions can be found in Appendix page 28 and the results were also used in the report writing. Throughout these intensive sessions, participants engaged in lively conversations, shared experiences, and exchanging valuable insights. The structured format allowed for a comprehensive exploration of key topics. Online slides and video uptake from the conference can be found: [Aukin sjálfbærni í fiskeldi með áherslu á fóður og hliðarstrauma - Matís (matis.is)](matis.is).

Agenda

AG FISK 2023
CONFERENCE PROGRAMME

INCREASED SUSTAINABILITY IN AQUACULTURE WITH FOCUS ON FEED AND SIDE STREAMS

WEDNESDAY THE 11TH OF OCTOBER 2023

08:30 – 9:00 OPENING CEREMONY

Opening words
Oddur Már Gunnarsson, CEO, Matís

Welcome address
From the Ministry of Food, Fisheries and Agriculture
Jón Þrándur Stefánsson

Nordic Co-operation

09:00 – 10:30 SESSION 1 - TOWARDS SUSTAINABLE FEED INGREDIENTS

Chairpersons: David Stutter, Matís

KEYNOTE ADDRESS

Environmental impact of aquaculture
Friederike Ziegler, RISE, (Se)

TALKS

Economics and policy regarding alternative proteins as fish feed
Sveinn Agnarsson, Sjókovin & HÍ, (Fo/Is)

Blue-Bio, Alternative proteins for fish feed
Rasa Slizyte, SINTEF (No)

New Raw Materials for Salmon Feed: Realistic Expectations
Paul Morris, Mowi Feed (No)

Single cell pekilo protein for aquafeed
Heikki Keskitalo, EniferBio (Fi)

Oleaginous yeast doing lipid in sustainable use of agriculture and forestry byproducts
Jana Pickova, SLU (Se)

10:35 – 11:10 Coffee break

11:10 – 13:00 SESSION 2 - DIVERSE PRODUCTS FROM SIDESTREAMS

Chairperson: Margrét Geirsdóttir, Matís

KEYNOTE ADDRESS

Pavle Estrajher, Arctic Protein (Is)
Challenges for 100% use of sidestreams

Nordic Co-operation

TALKS

Exploration of the environmental mitigation potential by farming blue mussels in connection to fish farms. Case study in a Faroese fjord
Gunnvør á Norði, Fiskaaling (Fo)

Salmon blood – a diamond in the rough
Runar Gjerp Solstad, Nofima (No)

Bioretur – Fish Sludge & Circular Economy
Hermund Ramsøy, Bioretur (No)

High value biochemicals
Sumesh Sukumara, Biosustain (Dk)

Unbroken - A success story – what have we learned?
Sandra Liliana Magnúsdóttir, Unbroken (Is)

13:00 – 14:00 Lunch break

14:00 – 16:00 SESSION 3 – WORKSHOP

ROUND TABLE DISCUSSIONS

CLOSE-UP

17:00 – 18:30 RECEPTION – LAX-INN

RECEPTION AT LAX-INN

Mýrargata 26, 101 Reykjavík

The workshop featured a distinguished lineup of speakers, each addressing crucial aspects of sustainability in aquaculture towards sustainable feed ingredients with insights from the. More detail information on the workshop presentations is in Appendix and online.

3 Feed for aquaculture – status and future aspects

The key research questions for this section are presented below. The questions are then each divided into chapters that discuss and attempt to answer each topic with Information and Insights from the workshop combined with literature state-of-the-art.

1. What is the current use and research of alternative proteins in feed?

2. Is there a current market for alternative proteins in feed?

3. How can we strengthen collaboration between research and industry in the Nordic countries with the overall aim of reaching sustainable utilization of marine resources and production of high-quality products, and thus strengthening the Nordic marine bioeconomy.

3.1 Current use and research of alternative proteins in feed

In pursuit of more sustainable feed ingredients, the growing demand for proteins globally prompts the exploration of alternative and economically viable sources. Europe's reliance on imported proteins raises concerns about food security and regional competitiveness. Initiatives such as the utilization of insect meal, single-cell protein, fermented products, and microalgae in salmon feed in Norway showcase the beginning of a transformative process. Microalgae, certain microbes, and insect species present promising sources of alternative proteins produced through innovative bioconversion processes, utilizing by-products or waste streams. These alternative proteins can potentially be produced with a lower environmental footprint, addressing concerns related to greenhouse gas emissions, water usage, land utilization, and fuel consumption. The scientific community, stakeholders, and policymakers acknowledge the potential of these sources to contribute to global food and feed security sustainably.

Historically, the two most important ingredients in fish feed have been fish meal and fish oil (Figure 2 and Figure 3). The use of these two marine raw materials in feed production has been reduced in favour of ingredients such as **soy, sunflower, wheat, corn, beans, peas, poultry by-products** (in Chile and Canada) and rapeseed oil. This substitution is mainly due to heavy constraints on the availability and high prices of fish meal and fish oil, but now more recently also due to environmental concerns.

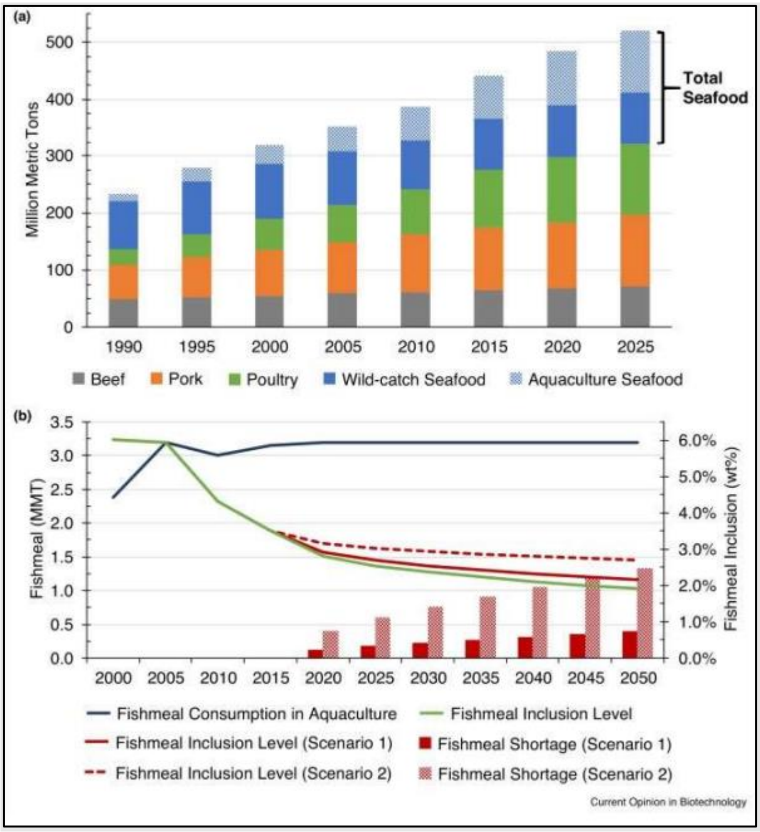

Figure 2. a) total animal protein production (million metric tons) from 1990 to 2025, b) Fishmeal consumption for aquaculture applications through 2015 and projected consumption through 2050 (Jones et al.*, 2020).*

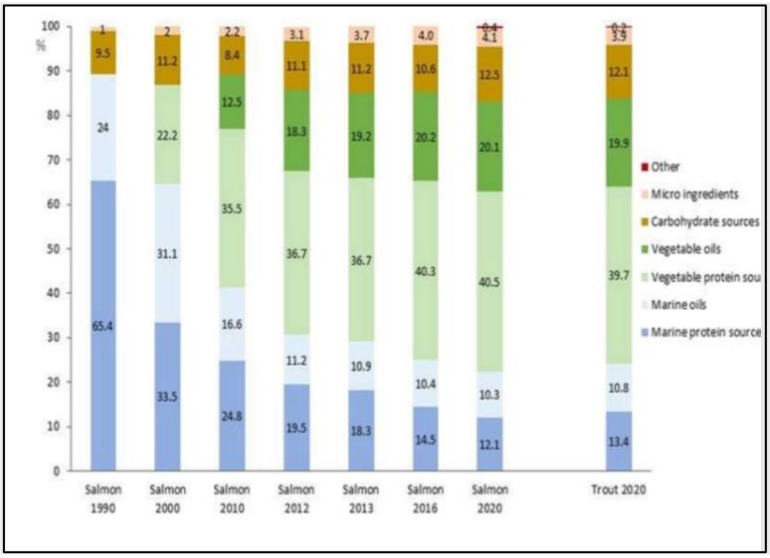

Figure 3. Sources of feed ingredients (% of feed) in Norwegian salmon and trout feed in 2020 and comparison through last decades (adapted by Sigurgeirsson, 2023 from Aas et al.*, 2022 a & b).*

Salmonid feed raw material has changed a lot in the last two decades, with marine protein sources and fish oil inclusion decreasing from over 90% to currently around 23% in Norway (Skavang *et al.*, 2024). At present, there are salmon feeds on the market with even higher inclusion levels of plant raw materials.

A main strategy for the salmon industry is to grow fast a healthy fish at the lowest possible cost. Feed is the most important input factor in salmon production, and the shift from marine ingredients to plant ingredients is economically beneficial as it has allowed the industry to grow (Figure). This shift is also important for nature, as it reduces the pressure on marine ecosystems and promotes more sustainable aquaculture practices. It is, however, important to be aware that high inclusion levels of certain plant ingredients in salmon diets may have adverse effects on fish health and welfare, biological performance, and fillet quality due to imbalanced nutrient composition and anti-nutritional factors.

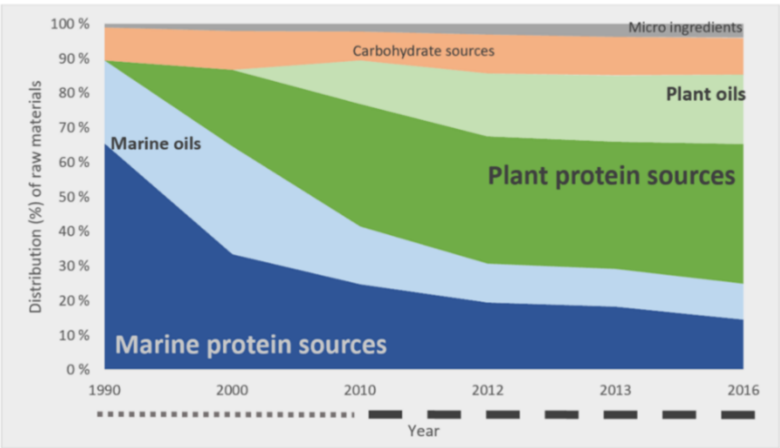

Figure 4. Nutritional factors for fish feed Adapted from Aas et al.*, 2019.*

Major reductions in carbon footprint could potentially come from exploring and developing feed ingredients that close the nutrient loop in the salmon industry (that increase overall resource efficiency) and developing ingredients from resources that are not utilised today. For example, products derived from insects, fermentation, CO_2 capture, and forestry are currently being explored.

Atlantic salmon have specific nutrient requirements for amino acids, fatty acids, vitamins, minerals, and other lipid- and water-soluble components. These essential nutrients can in principle be provided by the range of different raw materials listed above. Fish meal and other raw materials of animal origin have a more complete amino acid profile and generally have a higher protein concentration compared to proteins of vegetable origin. As long as a fish receives the amino acid it needs it will grow and be healthy and the composition of its muscle protein is the same irrespective of feed protein source. Consequently, feeding salmon with non-marine protein sources results in a net production of marine fish protein.

Future need for salmonid feed is enormous. In Norway alone, the plan is to produce five million tonnes of salmon in 2050, for just over one million tonnes today. For every tonne produced there is a need of 1.1 tonnes of fish-feed. The challenge will be to find six million tonnes of feed for salmon in the next decades, just in Norway.

This feed needs to fulfil sudden criteria: first, it must be sustainable, so the ingredients are not taken from intensive resource itself. Like from fully utilized fishing grounds over exploitive farming sides. Energy used for feed production must be renewable and the feed have high yield and nutritional content and availability. The quantity needed is enormous so the production scale must be high. And at last, but not the least, the fish must grow in healthy and sustainable environment that takes care of their basic needs and welfare.

Starting with the amount needed today and the availability for the growth next twenty years. The total production of the global protein meal (millions of tonnes) 2021 was around 350 million tonnes (Figure). Protein from fishmeal isa great source of nutrients for salmon, but it is expensive with limited supply and has no potentials in growing supply in the future. Animal feed production was around 1,266 million ton in 2022, with 54-million-ton production for aquaculture as aquafeed. The projection for 2028 is around 65 million tons for aquaculture (AquaFeed, 2024). Around 70% of fishmeal is used as feed for the aquaculture industry today.

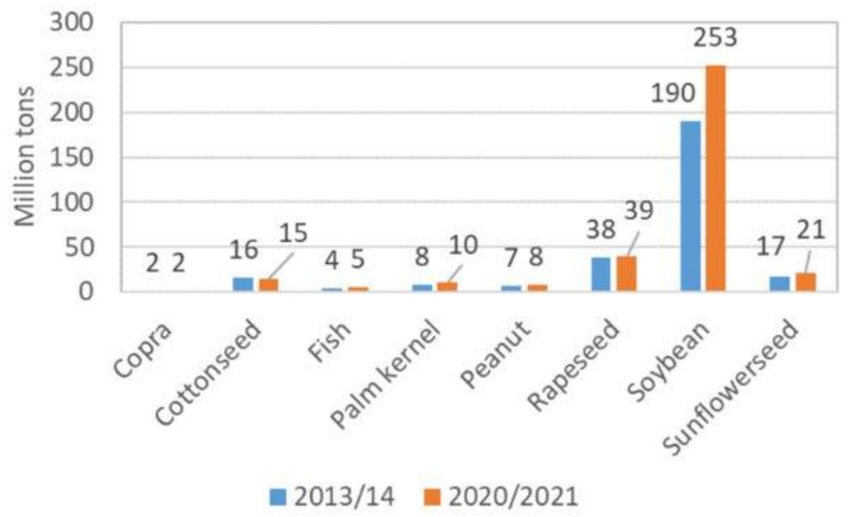

Figure 5. Total production of global protein meal (millions of tonnes) (USDA, 2024).

The challenges are availability and cost of fish feed raw material sector, with increased competition with other sectors. There is a high demand in this area with limited supply in local and global market. With more concern of environmental effects, social acceptability will be high in the future, as well as demand for quality. Growing aquaculture production is likely to dominate the seafood market in the future, influencing supply, pricing, and availability of seafood. However, the same precondition for the novel raw material sources will determine the raw material supply.

In the Nordic countries, the use of alternative proteins in aquaculture feed is gaining momentum as the industry seeks to improve sustainability and reduce reliance on traditional feed ingredients like fishmeal and soybean meal. Alternative proteins include insect meal, single-cell proteins (SCPs) derived from bacteria and yeast, plant-based proteins and micro and macroalgae. Although actual metrics are very difficult to assess at this point in time, it is evident that the use of alternative proteins in aquaculture feed in the Nordic countries is rapidly expanding. Companies are actively integrating, at least for research purposes, alternative proteins into their feed formulations to enhance sustainability and reduce environmental impacts. These efforts are supported by scientific research demonstrating the efficacy and benefits of these alternative proteins in maintaining fish health and growth. As general Nordic examples, BioMar, a major feed producer in Denmark, has integrated various alternative proteins into their aquaculture feeds, including insect meal, microalgae, and SCPs. They report that their sustainable feed formulations can reduce the environmental impact of aquaculture by up to 30%. Skretting, a global feed company with significant operations in Norway, has developed feeds incorporating alternative proteins like insect meal and microalgae. Mowi, one of the largest salmon farming companies globally, headquartered in Norway, has been a pioneer in using alternative proteins. They have partnered with companies like Calysta to include SCPs in their fish feeds. Mowi aims to significantly reduce their reliance on fishmeal and fish oil by 2025.

On the following pages, a more detailed description of each alternative protein source can be found**:**

Insect Protein: In the Nordic countries, the use of insect-based proteins in aquaculture feed is gaining traction as a sustainable alternative to traditional fishmeal and soybean meal. This approach leverages the high protein content and favourable amino acid profiles of insects such as black soldier fly (*Hermetia illucens*) larvae and mealworms (*Tenebrio molitor*), which are particularly well-suited for fish diets due to their natural presence in the diets of many fish species. Several scientific studies have highlighted the potential and current applications of insect meal in aquaculture. For example, the larvae of *Tenebrio molitor* have been shown to be a promising alternative protein source for various fish species, including rainbow trout (*Oncorhynchus mykiss*). These insects can convert low-quality organic waste into high-quality protein, making them an eco-friendly option for sustainable aquaculture feed production (Hameed *et al*., 2022; Freccia *et al*., 2020).
In Denmark, research has demonstrated the successful inclusion of insect meal in fish diets without compromising growth performance or health. Studies have shown that the nutritional quality of insect meal, particularly its protein and lipid content, can meet the dietary needs of many aquaculture species. Additionally, insects like black soldier fly larvae can be reared on organic waste, which not only provides a high-quality feed ingredient but also addresses waste management issues (Freccia *et al*., 2020).
In Sweden, researchers are exploring the large-scale production of insects for aquafeed, focusing on optimizing breeding conditions and feed formulations to ensure the economic viability and sustainability of insect-based feeds. The use of insects such as black soldier fly larvae is being investigated for their ability to replace significant portions of fishmeal in the diets of commercially important fish species like salmon (Hameed *et al*., 2022).
Furthermore, regulatory changes in the European Union since 2017 have facilitated the use of insect meal in aquafeeds, which has spurred increased interest and investment in this sector. As a result, several commercial initiatives and pilot projects in Nordic countries are now focusing on scaling up insect production for use in aquaculture feed (Freccia *et al*., 2019).
While the production of insect protein is still limited, significant investments are being made to scale up production and reduce costs. Companies like Entoprotech are investing heavily in insect cultivation to enhance the feasibility of black soldier fly larvae as a competitive alternative to fishmeal (Eurofish Magazine, 2022). Protix, a leading insect-based protein producer, is collaborating with Skretting, one of the largest aquafeed producers in Norway.
Overall, the incorporation of insect meal in aquaculture feeds in the Nordic countries is progressing, driven by the need for sustainable and cost-effective alternatives to traditional feed ingredients.

Continued research and development, along with supportive regulatory frameworks, are essential for realizing the full potential of insects in this context.

The use of both microalgae and macroalgae in aquaculture feed is being increasingly explored as a sustainable and nutritious alternative to traditional feed ingredients. This shift is motivated by the high nutritional value and environmental benefits associated with algae.

Microalgae, such as Chlorella and Spirulina, are highly valued for their rich protein content, essential fatty acids, vitamins, and pigments like astaxanthin, which are beneficial for the health and growth of farmed fish. Several studies have demonstrated the efficacy of microalgae as a feed ingredient in the Nordic aquaculture sector. Research has shown that incorporating microalgae into fish diets can enhance growth performance, immune response, and overall health. For instance, a study highlighted that microalgae can effectively replace fishmeal in diets for species like salmon and trout, improving the nutritional profile and reducing reliance on marine resources (Vijayaram *et al*., 2024; Han *et al*., 2019). Microalgae cultivation has the added benefit of contributing to environmental sustainability in aquaculture practices. They can be grown on non-arable land and require fewer resources compared to traditional crops. Moreover, microalgae can be used for bioremediation of aquaculture wastewater, absorbing excess nutrients, and thereby improving water quality (Han *at el*., 2019).
In Norway, extensive research is being conducted on the large-scale cultivation of microalgae for aquafeed. Projects are focusing on optimizing growth conditions and integrating microalgae into commercial fish farming operations to enhance sustainability and reduce environmental impact.

Macroalgae, such as seaweed (Laminaria, Ulva, and Porphyra), are also being utilized in aquaculture feed due to their high nutrient content and beneficial bioactive compounds. They are rich in polysaccharides, minerals, and bioactive compounds like antioxidants, which contribute to the health and growth of aquatic species. They provide an excellent source of dietary fiber and essential micronutrients (Vijayaram *et al*., 2024). Macroalgae cultivation requires minimal inputs and can be integrated into existing aquaculture systems. For example, in Denmark and Sweden, integrated multi-trophic aquaculture (IMTA) systems are being developed, where macroalgae are grown alongside fish and shellfish to create a balanced and sustainable ecosystem. This approach not only improves nutrient cycling but also reduces waste and enhances overall productivity. Research in the Nordic countries is actively exploring the full potential of algae in aquaculture. For instance, studies are investigating the optimal inclusion rates of micro and macroalgae in fish diets, the impact on fish health and growth, and the economic feasibility of large-scale algae production. Collaborative projects involving universities, research institutes, and industry players aim to develop innovative solutions for integrating algae into sustainable aquaculture practices.

Single-Cell Proteins (SCPs) refer to protein-rich biomass derived from microorganisms such as bacteria, yeast, fungi, and microalgae. These proteins are being explored as sustainable alternatives to traditional aquaculture feed ingredients due to their high nutritional value and potentially environmentally friendly production processes. Single cell proteins can be for example bacteria based or yeast based. Bacterial proteins offer a high protein content with a well-balanced amino acid profile, making them suitable for inclusion in aquaculture feeds. They also contain beneficial lipids, vitamins, and minerals. The production of bacterial proteins typically involves the use of low-value substrates, such as agricultural or industrial by-products, which enhances the sustainability of the process. Yeast proteins, such as those derived from *Saccharomyces cerevisiae*, are rich in essential amino acids, B-vitamins, and bioactive compounds that support fish health and immunity. Yeast cell walls contain β-glucans and mannan oligosaccharides, which can enhance the immune response and improve gut health in fish (Ritala *et al*., 2017; Øverland & Skrede, 2017; Jones *et al*., 2020).

As example, two Nordic companies are developing SCPs. EniferBio, a Finnish company, is developing SCPs from fungi using waste streams from the agricultural and food industries. Their product, Pekilo® protein, is derived from the fermentation of a specific fungal strain that grows on sidestreams from the forest industry. EniferBio's SCPs are being tested in aquaculture feeds, showing promising results in terms of fish growth and health. The company's focus on sustainability aligns with the broader goals of reducing the environmental footprint of aquaculture (EniferBio, n.d.). Solar Foods, another Finnish company, produces Solein, a novel protein ingredient created through the fermentation of hydrogen-oxidizing bacteria. This innovative process uses electricity, water, and air to produce protein with minimal environmental impact. Solein is being explored as an ingredient in aquaculture feeds. Its high protein content and sustainable production method make it an attractive alternative to traditional feed ingredients. Initial studies indicate that Solein can support fish growth and health effectively (Solar Foods, n.d.).

Grass Proteins: Companies like Aller Aqua are testing the use of grass protein concentrate in trout feed. This approach leverages locally available biomass, promoting regional sustainability and reducing dependency on imported ingredients (Eurofish Magazine, 2022).

Animal By-Products such as poultry by-product meal, blood meal, and feather meal are rich in protein and essential nutrients, making them suitable alternatives to fishmeal in aquaculture feeds. Using these by-products contributes to environmental sustainability by reducing waste and lessening the demand for wild-caught fish for fishmeal. Research has shown that these ingredients can support good growth performance and feed efficiency in various fish species. Studies have demonstrated the successful inclusion of poultry by-product meal in salmon diets, showing no adverse effects on growth or health (Macusi *et al*., 2023).

Plant-Based Proteins such as soy protein concentrates are widely used in aquaculture feeds due to their high protein content and relatively balanced amino acid profile. Advances in processing technologies have improved its digestibility and reduced anti-nutritional factors. Pea protein and other legumes are being explored as viable alternatives to soy. These plant proteins offer good nutritional profiles and can be sustainably produced, reducing the environmental footprint of aquaculture feeds (Eurofish Magazine, 2022).

3.2 Current market for alternative proteins in feed

The market for alternative proteins in aquaculture feed in the Nordic countries is experiencing growth, driven by a strong focus on sustainability and reducing the environmental impact of aquaculture. Although still in the early stages, the market is expanding at a significant rate, with an estimated compound annual growth rate (CAGR) of 7-10% for alternative proteins in aquaculture feed globally. The Nordic region is potentially experiencing similar growth. Several factors contribute to this growth, including increasing consumer demand for sustainably farmed seafood, regulatory pressures to reduce environmental impacts, and technological advancements in protein production. Major feed producers such as BioMar, Skretting, and Cargill are actively developing and incorporating alternative proteins into their products. In addition, innovative companies like EniferBio and Solar Foods are making significant contributions to this market.

Insect meal, particularly from black soldier fly larvae, is one of the prominent alternative protein sources being used. Companies like Protix are integrating insect meal into fish feeds, demonstrating good performance in terms of fish growth and health. Microalgae are also being utilized for their high protein content and beneficial omega-3 fatty acids. Companies such as Veramaris and Aliga Microalgae are producing microalgae-based ingredients. These ingredients are being integrated into aquaculture feeds, with incorporation levels of up to 15% shown to maintain fish health and growth (Chauton *et al*., 2015). Macroalgae or seaweeds are also being used for their rich nutrient profile and health benefits. Norwegian companies like Seaweed Solutions and Ocean Rainforest in the Faroe Islands are producing seaweed that can be incorporated into fish feeds. Inclusion rates of macroalgae can range from 5% to 10% in fish diets, depending on the species and specific nutritional needs (Valente *et al*., 2015).

The regulatory environment in the Nordic countries supports the adoption of alternative proteins, with regulations promoting sustainable aquaculture. Policies aimed at reducing reliance on marine resources and promoting circular economy principles are particularly influential. Industry initiatives and collaborations, such as those facilitated by the Nordic Council of Ministers, are helping to advance the market for alternative proteins. These initiatives focus on research, development, and scaling up production of sustainable feed ingredients.

Companies like BioMar and Skretting are leading the way in integrating alternative proteins into their feed formulations. BioMar reports that their sustainable feed formulations can reduce the environmental impact of aquaculture by up to 30%. Skretting has developed feeds incorporating insect meal and microalgae, focusing on reducing dependency on marine resources. Mowi, one of the largest salmon farming companies globally, headquartered in Norway, has partnered with companies like Calysta to include SCPs in their fish feeds, aiming to significantly reduce their reliance on fishmeal and fish oil by 2025.

The global alternative protein market size was estimated at USD 15.29 billion in 2023 and is expected to reach USD 16.52 billion in 2024. The global alternative protein market is expected to grow at a compounded growth rate of 8.2% from 2024 to 2030 to reach USD 26.52 billion by 2030. With growing awareness of the sustainability benefits associated with alternative proteins, there is a robust opportunity for them to be positioned as a vital component of a sustainable lifestyle for both humans and animals (Grand View Research n.d.).

3.3 Strengthening the collaboration between research and industry in the Nordic countries.

The following is mostly from conversations, insights, and knowledge-sharing from the Workshop*:*
Collaboration between research projects is crucial for advancing the aquaculture sector in the Nordic countries. Establishing a platform to connect researchers and organize research and development (R&D) efforts more effectively is essential. A more strategic approach to research, rather than an opportunistic one, will enhance the utilization of feed raw materials and promote sustainable practices in aquaculture. Government incentives are necessary to support novel protein producers, such as those producing single-cell proteins. Currently, these producers do not receive subsidies similar to traditional land farming operations, making them less competitive due to the high capital expenditures required for setting up new operations. To address this disparity, governments could provide financial incentives, such as subsidies or grants, to encourage the development of novel protein factories.

Information on the storage stability, safety, and quality of developed ingredients and products is vital for the Nordic countries. The high costs associated with implementing new materials into the food and feed cycle pose a significant challenge. Upscaling production is expensive, and the capacity thresholds for feed companies are very high. To facilitate the adoption of novel raw materials, it may be necessary to subsidize these materials or accept that their products will be more expensive initially. Alternatively, taxing traditional raw materials like soy could artificially increase their price, promoting the use of novel raw materials. The price of these materials should be reasonable and reflective of their nutritional potential.

Political measures, such as implementing sustainability standards that require feed manufacturers to use novel or sustainable raw materials, can also drive the adoption of alternative proteins. These standards could include metrics like CO2 equivalents and life-cycle assessment scores. However, the regulation of novel products needs to be balanced; while caution is necessary, the registration process should be expedited to prevent raw material producers from exiting the European market. Regulations should differentiate between simple protein compounds and health claims to avoid misleading marketing practices.

The use of marine protein sources, such as mesopelagic species, polychaetes, and krill, requires careful consideration. Sustainable utilization of these resources depends on a thorough understanding of their ecology and life cycles. Exploring the agricultural potential of the oceans, including the production of species like blue mussels and algae, is essential, though some options have been overestimated. Additionally, the use of land animal proteins, such as poultry and feather meal, should be further explored, despite current underuse in the European salmon industry.

Salmon feed research and development is a dynamic area, especially in understanding the feed requirements of salmon growing in extreme environmental conditions, such as low temperatures. Technical solutions to minimize fish movements in sea cages during winter could improve fish conditions. Sharing findings from ongoing research among leading aquaculture players is crucial for progress. The ingredients in fish feed significantly affect the gut health and function of the fish. Feed should not cause biological stress and must consider how ingredients affect the gut microbiota and overall health of the fish. Understanding the impact of novel fish feed ingredients on the quality of the final product is essential, as a healthy and functional intestine is key to converting feed into fish flesh efficiently.

Developing sufficient and appropriate raw materials for fish feed will be challenging in the near future. The raw materials must be available in sufficient volume, at the right price, sustainable, and environmentally friendly, without compromising the health and welfare of the fish. Reflecting the natural diet of fish, where possible, is important. Gaps exist regarding the usability of novel raw materials. Information on digestibility, maximum potential inclusion levels, interactions with other raw materials, and performance in large-scale experiments is needed. There is often an overestimation of the value of novel raw materials, such as insect meals, where the protein content is overestimated due to the presence of chitosan. Fish nutrition studies should focus on individual chemical and physical compounds of raw materials to better understand their digestibility and impact on fish health.

Improving formulations requires a better understanding of antinutrients and other factors that render raw materials digestible or palatable for fish. Combining several single-cell organisms could be beneficial, as lipid production requires no nitrogen. Selecting the most developed alternative ingredients where knowledge gaps exist, including nutritional, digestibility, and feed formulation aspects, is essential for the future of fish farming.

In conclusion, strengthening collaboration between research and industry in the Nordic countries is vital for advancing sustainable aquaculture. Addressing challenges related to the implementation of novel raw materials, regulatory frameworks, and the development of suitable feed ingredients will be key to the success of this endeavour. AG-Fisk can be seen to have a central role in knowledge- and experience sharing.

4 Sidestreams from aquaculture

To ensure the sustainability and to adopt an ecosystem approach to salmon aquaculture in the Nordic countries, specific objectives were outlined, such as increasing the value from aquaculture sidestreams products and leveraging currently underutilized resources. Realizing these objectives requires concerted efforts, including research exploration, and emphasizes the importance of cooperation within the profession. Strengthening collaboration between research and industry in Nordic countries is crucial for achieving sustainable utilization of marine resources and producing high-quality products, thereby fortifying the Nordic marine bioeconomy. Similarly, enhancing competitiveness and innovativeness in the Nordic marine sector by improving process technologies and handling of aquaculture sidestreams is imperative.

The key questions posed at the Workshop for the sidestreams production were:

1. What is the current use of sidestreams from aquaculture?
2. What possibilities and opportunities are for value increase from aquaculture sidestreams?
   - Are there some specific ideas in relation to increasing the value of **low value** products from high bulk sidestreams?
3. How can we strengthen the competitiveness and innovativeness of the Nordic marine sector by improving process technologies and handling of the aquaculture sidestreams?
4. Would better utilization of aquaculture sidestreams have a societal, economic, and/or environmental impact?

Salmon production generates considerable amount of sidestreams. For example, the production of salmon fillet with skin, around 40% are sidestreams whereof 12% is blood and viscera, 11% the head, 10% the spine, 4% belly flaps and 3% other cut-offs (Þórðarson & Arason 2022). Those by-products can be used into different products as functional food products, cosmetics, food supplements and pharmaceuticals as well as for feed and pet-food. In the last decade, many start-ups and companies have established value chains of medium to high-end products from Salmon farming sidestreams. Those include Nordic companies like Biomega, Havsbrun, Scanbio, and Hordafor which are generating products such as fish silage, fish meal and oil for feed, pet food and for human consumption. Recently food supplement from hydrolysed salmon proteins, Unbroken®, was launched and has had great success among athletes. There is though still work to be done in this field in relation to lowering cost, improve products and find new markets.

The volumes generated during production and processing within aquaculture are high and contain large amounts of water and do quickly get damaged. With increasing aquaculture including land-based production, the importance of finding ways to utilize aquaculture sidestreams are growing as for example:

- During slaughtering sidestreams like viscera and other particles in the processing water are generated and currently unused.
- Sludge from land farming

- Biological debris from fish farming cage nets (feed, sludge, algae etc.)
- Lumpfish used for salmon louse elimination.
- Blood / process water

A collaborative approach is instrumental in order to achieving the following outcomes:

- Exploring possibilities and opportunities for value increase from aquaculture sidestreams, an underutilized resource.
- Converting waste streams into valuable next-generation ingredients for aquaculture feed.
- Exploring upcoming and potential sustainable, local alternative protein sources for inclusion in Nordic aquaculture feed.
- Optimizing collection, extraction, and separation methods of ingredients for further high-quality product development for both human and animal consumption.
- Investigating pet-food special aspects, including nutritional quality.
- Providing an overview of best practices in handling sidestreams within aquaculture to enhance their overall quality.

4.1 Current use of sidestreams from aquaculture

Aquaculture is becoming an important pillar in Nordic economy, especially in Norway, Faroe Islands, and Iceland. Development is fast in the industry, with many challenges and opportunities.
Sidestreams from salmon production, generated in large quantities, are as it is today not always of high enough quality to be used in the production of valuable products. The volumes generated during production and processing are high and contain large amounts of water and do quickly get damaged. With increasing aquaculture including land-based production, the importance of finding ways to utilize aquaculture sidestreams are increasing, including:

- K1 - Sludge from land farmed fish.
- K2 - Materials from fish that for various reasons die in the cages. These materials are not allowed to be used for human consumption, nor can they be used to feed animals that will be used for human consumption. The main markets for K2 materials are therefor as feed for animals that are not raised for food production, such as fur-animals (minks) and pets.
- K3 - Sidestreams from slaughtering and processing such as viscera, heads, frames, and cut-offs (Figure). These materials can be used for human consumption, though with some restrictions.

Sidestreams production needs economies of scale to be profitable. Therefore, logistic from farming sides and slaughterhouses is important, distributing the raw material to the factory side from many locations. The transformance from sidestreams to valuable raw material is important to make this economically viable. Also, to concentrate on the quality of sidestreams and exclude the “waste mentality”, to make value creation possible.

In Iceland around 50 thousand tonnes of salmonid were produced in 2022. According to plans this amount could go up to 120 thousand tonnes in 2030 (Agnarsson *et al.*, 2021). Most of this fish is exported chilled headed and gutted (HOG), but this product gives around 11% of sidestreams products. Value adding processing by filleting will give and extra 28% sidestreams with skin on, and around 33% by skin less fillets.

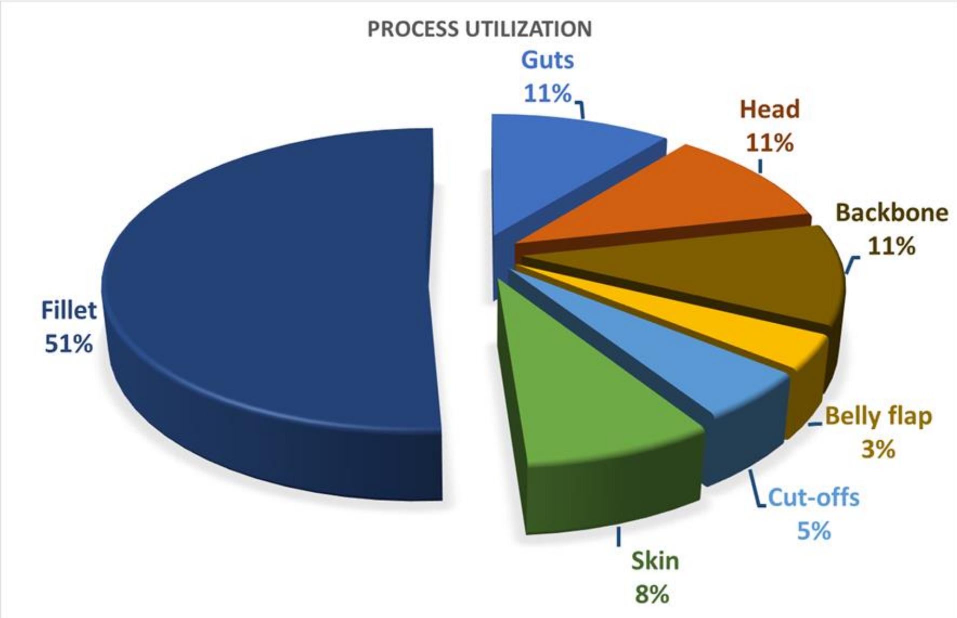

Figure 6. Process utilization of salmon (Þórðarson & Arason, 2022).

HOG contributes many sidestreams in Iceland today. In 2021 around 4,800 tonnes of K2 and around 4,400 tonnes of K3. Secondary processing contributed around 1,400 tonnes of sidestreams (bones, heads, cuts e.tc). It is important to find a sustainable and valuable of processing these raw materials.
Today these sidestreams are processed into silage and shipped to Norway for further processing. The silage from K2 can be used for feed production for farmed animals, but K3 can only be used for feed production for pets or furs, not for human consumption or for animal for human consumption.
Both K2 and K3 are processed in silage by using enzymes or formic acid, breaking the proteins down from solid state in liquid state, and by lower pH below the survival of microorganisms. Therefore, silage can be stored for long time without getting spoiled. Quality problems are common in K2 processing with the mindset of “waste management”. Supply is irregular, often in connection with some accidents in the farming or natural disaster’s (parasites, algal bloom or whether). It is a low value product and necessary to minimize cost and manhour in collecting, processing and transportation.

4.2 Possibility and opportunities for value increase for sidestreams

With the growth of land-based aquaculture, particularly the expansion of hatcheries and large-scale land-based salmon farming, there is an increasing need to find innovative solutions for managing and utilizing sidestreams from aquaculture production. These sidestreams, such as sludge, contain valuable components like zinc, phosphorus, and nitrogen, which, if effectively harnessed, can contribute significantly to creating added value and reducing environmental impact. Sludge from aquaculture systems, rich in nutrients like zinc and phosphorus, presents an opportunity for resource recovery and waste minimization. Currently, much of this sludge is discarded into landfills, in compliance with EU regulations on biodegradable waste. However, innovative approaches can transform this waste into valuable products. For instance, phosphorus is a critical nutrient for plant growth and can be recovered and reused in agricultural fertilizers. Similarly, zinc, an essential micronutrient, can be extracted and repurposed. Research has shown that sludge can be a valuable feedstock for fermentation processes, producing high-value chemicals and materials. Unlike biogas production, which is relatively low-value, fermentation can yield products like organic acids, enzymes, and biopolymers that have higher market value and can provide greater revenue streams. For example, phosphorus from fish sludge can be converted into struvite, a slow-release fertilizer, through crystallization processes (Kabbe *et al*., 2015). This approach not only recovers valuable nutrients but also helps in managing waste more sustainably.

A significant challenge in utilizing aquaculture sludge is the presence of contaminants like cadmium. Removing cadmium is essential to ensure that recovered materials are safe for further use, especially in agriculture or food production. Technologies that can selectively capture cadmium and other heavy metals from sludge are crucial. Nordic expertise in environmental engineering and waste treatment can be instrumental in developing such technologies. Advanced filtration, ion exchange, and adsorption techniques could be employed to isolate and remove cadmium effectively.

Improving fish feed efficiency can also reduce the quantity of waste generated. Current advancements suggest that it takes approximately 1.1 kg of feed to produce 1 kg of fish, resulting in less faecal waste and firmer faeces. By adding specific enzymes to fish feed, the bioavailability of phosphorus can be increased, leading to better nutrient absorption by the fish and less excretion. This not only improves fish growth but also minimizes the nutrient load in sludge, making it easier to manage and utilize.

To fully harness the potential of aquaculture sidestreams, there is a need for advanced technologies that can extract valuable components from sludge and other secondary raw materials. These materials, which are not suitable for direct human consumption, can be transformed into high-value products through fermentation and other biotechnological processes. For instance, converting sludge into bio-based chemicals or biodegradable plastics can open new revenue streams while reducing environmental impact.

One promising approach is to use sludge as a substrate for microbial fermentation, producing high-value compounds like polyhydroxyalkanoate (PHAs), which are biodegradable plastics. This process not only valorises waste but also contributes to a circular bioeconomy. Additionally, integrating these processes with existing aquaculture operations can create closed-loop systems where waste is minimized, and resources are continually recycled.

To realize the full potential of these technologies, increased investment in research and education is essential. Collaborative efforts between industry and academia can drive innovation and develop scalable solutions for waste management in aquaculture. Training programs and research initiatives focusing on nutrient recovery, waste valorisation, and sustainable aquaculture practices can help build the necessary expertise and infrastructure.

4.3 Specific idea in relation to increasing value of sidestreams.

Optimisation of collection, extraction, and separation methods of the ingredients with the aim of using them for further high-quality product development and utilization for both human and animal consumption is important. To provide an overview of best practises in the handling of sidestreams generated within aquaculture to increase their overall value. To do so, detailed mapping and further research of the aquaculture sidestreams, both quantity as well as composition is necessary. It is important to understand the upcoming and most developed alternative/novel ingredients, which knowledge gaps exist (including nutritional, digestibility, feed formulation etc) and how they can be fast tracked to market. Market research and current use of product from sidestreams from aquaculture is necessary. It is a groundwork for optimizing treatment during the collection and storage of different sidestreams categories. To improve knowledge on extraction and purification methods to obtain higher quality ingredients from different aquaculture sidestreams. Storage stability of raw material and logistics need to be mapped.

In table 1 are prices and value of different processing levels form raw silage into more sophisticated products. By taking the oil out and the water to make silage extract can increase the value considerable. To evaluate the silage products by increasing the processing level can be difficult to understand market prices and marketing opportunities and insert to the table.

Table 1: Price and value of fish-meal base, processed from raw-silage from 10 thousand tonnes production (Þórðarson & Arason, 2022).

	Price and value based on fishmeal processing		Value assessment
	($/kg)	(millions US$/year)	(millions US$/year)
Raw Silage	0.99	8.9	8.9
Oil	4	5.0	5.0
Separate silage and oil	0.61	10.4	5.4
Silage concentrates and oil	1.21	10.4	5.4
Powder and oil	2.42	10.4	5.4

By valid process control it is easy to produce specialized proteins with certain characteristics. It is also possible to add enzymes or blend of enzymes (tailor made enzymes) to get more specialized characteristics of protein blended production.

- By using vacuum evaporator to remove water from the silage, a lot of energy is saved, compare of using ordinary dryer used in fish-meal factories. Around twice to five times of the energy is saved for removing the water. After removing around 60% of the water content (silage extract) the protein content will be like a fishmeal per unit volume. The density of fishmeal is around 0.5 – 0.55, but around 1.10 – 1.2 for silage extract. The processing route has that advantage to process non-standard materials into homogeneous product, which can be adapted customers need, and process according to customers and consumers preferences.
- For the K3 raw material a constant process through the year is possible, but K2 is more unstable. This process offers use of high-tech with minimum use of manpower. It is also possible to use the process without adding acid but using specialized enzymes into the K3 raw material, suitable for human consumption (Þórðarson & Arason, 2022).

By extracting the raw silage by evacuation under vacuum by using temp of 30-50 °C is extremely gentle with the proteins and protects it from damage by burning. In tradition fish-meal factory the product is dried be using around 100 °C.
Extracted silage could be used for feed production, by cutting energy intensive and expensive process, as well as saving carbon footprint in products and make it more environmentally friendly.
This process could be valuable for the aquaculture industry for sidestreams from K2 and K3, but today is only costing process. *To take these ideas forward it will be necessary for the research community to work closely with the aquaculture industry, as well as the authorities setting the regulation for the process.*

- Extraction process is under vacuum and evaporation within 30-50 °C, protecting the proteins from damaging.
- In the future it would be possible to use this extraction strait to feed production and by cut the drying process, which is expensive (both investment and production cost) and environmental unfriendly. This gives the possibility of reducing carbon footprint of product (Þórðarson & Arason, 2022).

The next steps would be developed ideas in cooperation with the industry and the research community. The participates of authorities is crucial for success to fulfil the needs of all stakeholders.

It is also important to separate sidestreams due to regulations if allowed to use it as ingredients in production for human consumption, farmed animals, pets/furs animals or banned for feed production. Sludge will not be used for feed production but could be raw material for fertilizer and will only be collected from land-based aquaculture. The groundwork is important, starting with separate it considering nutrients and value of end production. Increase investments in fermentation both equipment and knowledge. This importance is not only to increase value of the production but also for the circular economy and therefore it is beneficial as a part of sustainability.

Utilization of whole fish that are killed in pens or in transport is well suited for silage processing. According to European regulations, these sidestreams from K2 may only be used in for fertilizer production or feed intended for pets or furs animals. Silage is made by mincing the raw material and use acid to lower the pH below survival of spoiling bacteria's and stimulate or accelerate the decomposition and liquefaction of solid substances in fish organs, but enzymes are present in the fish substance itself. Formic acid is mostly used to process silage, it is relatively safe to handle, cheap, organic, and widespread in agriculture for other uses, like hay. In addition, it is some guarantee that the acidity does not become too low, which causes damage to important amino acids (tryptophan) and increases the risk of further corrosion of processing equipment and storage containers. Furthermore, formic acid is not a toxic or negative factor in digestate if the correct amount is used, but this is determined by the final processing and product. Acidity hast to be enough to hinder bacteria or mould activity and to ensure breakdown of proteins.

Temperature is not a vital factor, but low temp (5 °C) needs longer time than with higher temp. Water content is most often around 60 – 80% and can easily be stored in tanks and been pumped. Samples taken from K3 raw material, viscera, from Arnarlax slaughterhouse in Bildudalur, had 67% water content. The amount of polyunsaturated fatty acids is similar in the carcass, head, and backbone or 29.7% to 31.1%. The same can be said for monounsaturated fatty acids in the same ingredients, which was about 52%, excluding heads, which was about 50.7%. The amount of saturated fatty acids was found to be around 17% in all groups (Þórðarson & Arason, 2022).

From a nutritional point of view, salmon contains a high percentage of valuable polyunsaturated fatty acids such as EPA and DHA, together with proteins, which is reflected in the by-products. There is a particularly high fat content in the rump and head. The spine contains calcium, phosphorus, and other minerals. Salmon blood accounts for up to 4% of the fish's weight and is rich in phospholipids, polyunsaturated fatty acids, haemoglobin, minerals, etc. The amino acid composition of proteins in salmon for fishmeal production is well suited for animal feed, and not least for human consumption if one looks at the requirements for the ingredient of amino acids.

Proteins in Atlantic salmon have a higher water resistance than egg white protein and soy protein concentrate, which would be suitable for meat products and show more suitable physical properties (Kristinsson & Rasco, 2000). The ability to bind fat is also better than for egg albumin and soy protein, which indicates good binding properties in various products.

4.4 Strengthening the competitiveness and innovativeness of the Nordic marine sector

Enhancing the competitiveness and innovativeness of the Nordic marine sector requires a multifaceted approach focused on improving process technologies and effectively managing aquaculture sidestreams. The Nordic region has the potential to lead the way in sustainable marine practices by turning waste streams into valuable resources. This approach not only addresses environmental concerns but also opens new avenues for economic growth and technological innovation.

A critical step in this direction is the optimization of process technologies within aquaculture operations. Advanced filtration, bioprocessing, and nutrient recovery systems can transform waste products such as sludge into valuable by-products. By investing in technologies that extract and purify these nutrients, the aquaculture sector can reduce waste disposal costs and create new revenue streams. Moreover, the development of efficient systems to capture and reuse water within aquaculture facilities can significantly reduce water consumption and enhance environmental sustainability.

Innovation in feed technology is another crucial area. By improving feed formulations to enhance nutrient absorption and reduce waste, the sector can achieve better growth rates and health outcomes for farmed fish. Incorporating enzymes that improve phosphorus digestibility, for instance, can lead to less nutrient excretion and firmer faeces, making sludge easier to manage. This not only benefits the environment by reducing nutrient run-off into surrounding waters but also enhances the economic efficiency of aquaculture operations.

Handling sidestreams more effectively can also drive innovation. Fermentation processes, for example, offer a promising avenue for converting aquaculture sludge into high value bioproducts. By using sludge as a substrate for microbial fermentation, it is possible to produce bioplastics, organic acids, and other valuable chemicals. These products often have higher market value than traditional biogas, providing greater economic incentives for aquaculture operators to invest in these technologies. Nordic expertise in biotechnology and fermentation can be leveraged to develop scalable solutions that transform waste into wealth, fostering a more sustainable and competitive marine sector.

Government support and regulatory frameworks play a vital role in this transformation. Providing financial incentives, such as subsidies or tax breaks for companies investing in waste valorisation technologies, can accelerate the adoption of innovative practices. Additionally, revising regulations to streamline the approval process for novel waste management technologies can encourage more rapid implementation. Policies that promote the use of sustainable raw materials and set high environmental standards can drive the industry towards more sustainable practices, ensuring long-term competitiveness in the global market.

Collaborative efforts between industry, academia, and government are essential for driving research and development in this field. Establishing research consortiums and innovation hubs focused on sustainable aquaculture can facilitate the exchange of knowledge and best practices (for example through AG-Fisk). These collaborations can lead to the development of cutting-edge technologies and processes that enhance the efficiency and sustainability of the marine sector. By fostering a culture of innovation and continuous improvement, the Nordic region can maintain its leadership in sustainable aquaculture practices.

4.5 Would better utilization of aquaculture sidestreams have social, economic, and/or environmental impacts?

The societal, economic, and environmental impacts of better utilization of aquaculture sidestreams are potentially profound, particularly when considering the potential to transform low-value, high-bulk products into valuable resources. Effectively managing and reprocessing these sidestreams can address environmental challenges, create new economic opportunities, and foster social benefits through sustainable practices.

A key societal impact of better sidestreams utilization is the potential to shift perceptions and create a more sustainable and resource-efficient aquaculture industry. The current terminology, which often refers to sidestreams as waste, carries a negative connotation that undermines the potential value of these materials. By redefining sidestreams as secondary raw materials, the industry can highlight their inherent value and encourage more innovative uses. This shift in perception can lead to broader acceptance and support for recycling and upcycling practices, ultimately promoting sustainability within communities. Additionally, exploring diverse applications for sidestreams beyond feed production — such as in cosmetics, textiles, and pharmaceuticals — can drive innovation and create new markets. For instance, fish skin, traditionally seen as a waste product, can be repurposed into collagen for medical or cosmetic applications, offering high-value alternatives that benefit society by providing new products and reducing waste.

Economically, better utilization of aquaculture sidestreams can lead to significant cost savings and revenue generation. Improved process technologies that extract valuable nutrients and components from sidestreams can turn what was once a disposal cost into a profitable venture. For example, processing fish sludge to recover phosphorus can produce high-quality fertilizers, addressing the growing demand for sustainable agricultural inputs. This not only reduces the cost burden of waste disposal but also creates new income streams for aquaculture operators. The development of centralized processing facilities can also enhance economic efficiency. By collecting and processing sidestreams such as blood, sludge, and offal at strategically located facilities, economies of scale can be achieved, lowering the overall cost of production, and increasing the feasibility of high-value product development. This approach is particularly relevant for countries like Iceland, where the dispersed nature of salmon farming necessitates innovative logistical solutions to make sidestreams utilization economically viable. Furthermore, the promotion of sustainable and local alternative proteins through process and cost analysis can identify the most economical and sustainable methods for sidestreams utilization. Reports and studies supporting these developments can provide the necessary data to guide investment and innovation in the sector, ensuring that new ventures are both economically sound and environmentally sustainable.

Environmentally, the effective management of aquaculture sidestreams can mitigate significant ecological concerns. Proper treatment and utilization of sludge, for example, can prevent nutrient runoff into aquatic ecosystems, which is a major cause of water pollution. By converting sludge into valuable products such as fertilizers or bioplastics, the environmental footprint of aquaculture operations can be substantially reduced. However, it is crucial to address the potential risks associated with sidestreams, such as the presence of heavy metals and pathogens in fish sludge. Technologies that can safely extract and neutralize these contaminants are essential to ensure that the resulting products are safe for use. For instance, developing methods to remove cadmium and other heavy metals from sludge can enhance the safety and marketability of derived products like biochar or fertilizers. Furthermore, the production of biogas from fish sludge should be carefully managed to ensure it contributes to a circular economy. While biogas production offers a renewable energy source, it must be integrated with other processes to maximize nutrient recovery and minimize environmental risks associated with excess bio residues.

5 Conclusions & future aspects

5.1 Feed

Innovative projects in the Nordic countries are advancing the use of alternative proteins. Despite challenges in scaling production and high initial costs, the market for alternative proteins is expanding, driven by sustainability demands and regulatory support. Collaborative efforts between research and industry are crucial for progress. Strategic research, government incentives, and supportive regulations are needed to facilitate the adoption of novel raw materials. Addressing the usability, digestibility, and economic viability of these ingredients will be key to the sustainable growth of the aquaculture sector.

5.2 Sidestreams

Reframing sidestreams as valuable resources can drive sustainability, cost savings, and revenue generation. Effective management prevents environmental issues like nutrient runoff and promotes new market opportunities in cosmetics, textiles, and pharmaceuticals.

Next steps in better use of sidestreams from aquaculture would be to invest in research and collaboration between industry and academia, develop technologies for nutrient recovery and waste valorisation and also to implement regulatory support and financial incentives for sustainable practices. Overall, better utilization of aquaculture sidestreams can significantly impact the environment, economy, and society, fostering a more sustainable and competitive marine sector in the Nordic region.

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8 Appendix

Slides and video uptake from the workshop can be found here:
https://matis.is/frettir/aukin-sjalfbaerni-i-fiskeldi-med-aherslu-a-fodur-og-hlidarstrauma/

8.1 Workshop in Reykjavik 11th of October

The workshop, cantered around the pivotal theme of "Increased Sustainability in Aquaculture with Focus on Feed and Sidestreams," commenced with an enlightening opening session. Mr. Oddur Már Gunnarsson, CEO of Matís, set the tone for the conference with his insightful remarks, providing a glimpse into the crucial role of sustainability in the aquaculture industry. Following his opening words, Jón Þrándur Stefánsson, representing the Ministry of Food, Fisheries, and Agriculture, delivered a warm and engaging welcome address. This marked the initiation of a forum where industry leaders, experts, and stakeholders converged to explore innovative strategies and solutions aimed at enhancing sustainability practices within aquaculture.

The workshop featured a strong lineup of speakers, each addressing crucial aspects of sustainability in aquaculture towards sustainable feed ingredients with insights from the following speakers:

8.1.1 Environmental Impact of Aquaculture by Friederike Ziegler, RISE (Se)

Friederike Ziegler of RISE (Research Institutes of Sweden) shed light on the environmental impact of aquaculture, providing valuable insights into sustainable practices and their implications for the industry.

8.1.2 Economics and Policy Regarding Alternative Proteins as Fish Feed, Sveinn Agnarsson, Sjókovin & HÍ (Fo/Is)

Sveinn Agnarsson delved into the intricate relationship between economics, policy, and the use of alternative proteins as fish feed. His talk, drawing on expertise from Sjókovin and Háskóli Íslands (University of Iceland), presented a comprehensive overview of the challenges and opportunities in this evolving landscape.

8.1.3 Blue-Bio, Alternative Proteins for Fish Feed, Rasa Slizyte, SINTEF (No)

Rasa Slizyte from SINTEF (Norway) explored the Blue-Bio project, uncovering innovative approaches to utilizing alternative proteins for fish feed. Her presentation provided a glimpse into cutting-edge research, paving the way for sustainable practices in aquaculture.

8.1.4 New Raw Materials for Salmon Feed: Realistic Expectations, Paul Morris, Mowi Feed (No)

Paul Morris, representing Mowi Feed in Norway, discussed the realistic expectations surrounding new raw materials for salmon feed. His insights, grounded in practical experience, offered a pragmatic perspective on the challenges and opportunities in sourcing sustainable feed ingredients.

8.1.5 Single Cell Pekilo Protein for Make Higher Quality Feed, Heikki Keskitalo, EniferBio (Fi)

Heikki Keskitalo of EniferBio in Finland introduced the concept of single-cell Pekilo protein for aquafeed. Exploring the potential of this innovative protein source, his presentation delved into the advancements that could revolutionize the aquafeed industry.

8.1.6 Oleaginous Yeast Doing Lipid in Sustainable Use of Agriculture and Forestry Byproducts, Jana Pickova, SLU (Se)

Jana Pickova, from the Swedish University of Agricultural Sciences (SLU), shared insights into the sustainable use of agriculture and forestry byproducts. Her focus on oleaginous yeast and lipid production showcased the potential for circular economy practices in aquaculture.

The diverse range of topics, before the lunch time, covered by these experts reflects the multifaceted nature of sustainability in aquaculture, sparking meaningful discussions and paving the way for future advancements in the field. And after the brake the workshop continued to delve into the challenges and promising solutions surrounding diverse products from sidestreams in aquaculture with insights from the following speakers:

8.1.7 Exploration of the Environmental Mitigation Potential by Farming Blue Mussels in Connection to Fish Farms: Case Study in a Faroese Fjord, Gunnvør á Norði, Fiskaaling (Fo)

Gunnvør á Norði from Fiskaaling (Faroe Islands) provided a case study on the environmental mitigation potential of farming blue mussels in connection to fish farms. Her exploration highlighted the symbiotic relationship between different aquaculture practices and their positive impact on the environment.

8.1.8 Salmon Blood – A Diamond in the Rough, Runar Gjerp Solstad, Nofima (No)

Runar Gjerp Solstad, representing Nofima in Norway, delved into the untapped potential of salmon blood. His presentation, "Salmon Blood – A Diamond in the Rough," explored the valuable components within this often-overlooked byproduct and its potential applications in enhancing sustainability.

8.1.9 Bioretur – Fish Sludge & Circular Economy, Hermund Ramsøy, Bioretur (No)

Hermund Ramsøy of Bioretur in Norway delved into the concept of Bioretur, focusing on fish sludge and its role in the circular economy. His insights illuminated the possibilities of turning waste into a valuable resource, contributing to a more sustainable aquaculture industry.

8.1.10 High-Value Biochemicals, Sumesh Sukumara, Biosustain (Dk)

Sumesh Sukumara, representing Biosustain in Denmark, shared expertise on high-value biochemicals. His talk provided a glimpse into the potential of extracting valuable compounds from aquaculture processes, contributing to the development of a more sustainable industry.

8.1.11 Unbroken - A Success Story – What Have We Learned?, Sandra Liliana Magnúsdóttir, Unbroken (Is)

Sandra Liliana Magnúsdóttir, representing Unbroken in Iceland, shared the success story of "Unbroken." Her presentation reflected on the lessons learned from this venture, offering valuable insights into the practical implementation of sustainable practices in aquaculture.

The collective expertise of these speakers contributed to a comprehensive exploration of sustainable practices in aquaculture, covering a spectrum of challenges, innovations, and success stories. Following a coffee break, the workshop transitioned into an engaging round table session, tailored to foster in-depth discussions. Attendees were divided into four groups, and each group had 25 minutes to collaboratively address diverse questions centred around the conference theme.

8.2 Round table discussions

8.2.1 Round Table 1.

Current se of Sidestreams from Aquaculture attends shared insights into the current utilization of sidestreams within their companies and countries, exchanging perspectives on existing practices.

Possibilities and Opportunities for Value Increase: Attendees in this group explored innovative approaches to increase the value of aquaculture sidestreams, with a particular focus on extracting value from low-value products in high-bulk sidestreams.

Strengthening Competitiveness and Innovativeness: Discussions revolved around strategies to enhance the competitiveness and innovativeness of the Nordic marine sector by improving process technologies and the handling of aquaculture sidestreams.

Societal, Economic, and Environmental Impact: This group delved into the broader implications of better utilizing aquaculture sidestreams, considering potential impacts on society, the economy, and the environment.

Strengths in Nordic Aquaculture: The strengths identified within Nordic aquaculture related to sidestreams and sustainable feed were collaboratively discussed in round table 1. These strengths included strategic advantages, capabilities, valuable assets and individuals, industry experience, financial stability, compelling value propositions, and a commitment to competitive pricing, high value, and quality.

8.2.2 Round table 2.

Upcoming and most developed Ingredients from Sidestreams: Participants discussed emerging and well-established ingredients derived from sidestreams, exploring the potential of these ingredients in sustainable feed formulations.

Knowledge gaps for sidestreams Utilization: The group identified knowledge gaps related to logistics, storage, existing laws, and rules pertaining to sidestreams utilization, aiming to address these gaps for more effective and sustainable practices.

Current market for sidestreams: Discussions cantered around the existing market for sidestreams, examining what is currently available, and where these products are in demand.

Fast-Tracking new ingredients to market: The group explored strategies to expedite the introduction of new ingredients from sidestreams to the market, considering factors such as innovation, collaboration, and regulatory pathways.

Improving knowledge on extraction and purification methods: Participants discussed ways to enhance knowledge on extraction and purification methods to obtain higher quality ingredients from various aquaculture sidestreams, aiming for improved efficiency and sustainability.
Weaknesses: In relation to sidestreams and sustainable feed, weaknesses identified by the group included disadvantages, gaps in capabilities, cash flow challenges, supplier issues, areas for improvement, causes of lost sales, and experiences that could be enhanced.

8.2.3 Round table 3

Upcoming and potential sustainable alternative protein sources: Participants explored potential sustainable and local alternative protein sources for inclusion in Nordic aquaculture feed, considering options such as grass protein and insect proteins.
Knowledge gaps for new feed ingredients: The group identified knowledge gaps related to nutritional aspects, digestibility, and feed formulation for new feed ingredients, seeking to address these gaps for informed decision-making.
Fast-Tracking new feed ingredients to market: Discussions focused on strategies to accelerate the introduction of new feed ingredients to the market, considering innovation, collaboration, and regulatory pathways.
Threats: Potential threats in Nordic aquaculture related to sidestreams and sustainable feed, as identified by the group, encompassed economic movements, obstacles faced, competitor actions, political impacts, environmental effects, loss of key staff, and market demand fluctuations.

8.2.4 Round table 4

Current use of alternative proteins in feed: Participants discussed the current utilization of alternative proteins in feed, examining existing practices within the industry.
Current market for alternative proteins in feed: The group explored the current market for alternative proteins in feed, identifying specific products and market locations where these proteins are in demand.
Strengthening collaboration between research and industry: Discussions focused on strategies to enhance collaboration between research and industry in Nordic countries, aiming to achieve sustainable utilization of marine resources, production of high-quality products, and strengthening the Nordic marine bioeconomy.
Opportunities: Opportunities in Nordic aquaculture related to sidestreams and sustainable feed, as identified by the group, included areas for improvement, exploration of new segments, aligning with industry trends, developing new products, fostering innovations, and establishing key partnerships.