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GAIN

Green Aquaculture Intensification

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GLOSSARY OF ACRONYMS

Acronym	Definition
CTRL	Control (diet)
FCR	Feed conversion rate
FPH	Fish protein hydrolysate
MIX	Mixed (diet combining emerging ingredients with small to moderate amounts of PAPs)
RAS	Recirculating Aquaculture systems
PAP	(diet rich in) **p**rocessed **a**nimal **p**roteins
NoPAP	(diet containing) no **p**rocessed **a**nimal **p**roteins
LCA	Life cycle assessment
EISI	Eco-intensification sustainability Index
LW	Live weight

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1. Press release

Costs and benefits of innovative eco-sustainable aquaculture practices

The latest GAIN project developments on the impacts of eco-intensification innovations, found that novel feeds with commercially available emerging ingredients, could lead to farm profitability losses in most cases. This was especially true for diets combining different emerging ingredients, and in diets with smaller amounts of processed animal proteins (PAP) in addition to these new ingredients.
The most pronounced losses were found for seabream production. This was partly due to the decreased feed conversion rates when using novel feeds. The already high feed costs per kg of fish produced, when compared with trout and salmon, was also a factor in profitability losses. PAP feeds, however, were more promising from an economic point of view, especially for Atlantic salmon production.

These results illustrate the demand for more affordable alternative ingredients, such as the upcoming GAIN-developed by-products. Consumer willingness-to-pay for more sustainable grown fish might also play a significant role in order for producers to stay profitable or to reach break-even.

Room for improvement was also identified for the valorisation of fish and shellfish by-products, especially for species with lower production volume and market-share of processed products, such as carp. The costs and benefits of the next generation of novel GAIN feeds, focused in adding value to by-products and side streams will be addressed in the upcoming work within the project.

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2. Executive summary

GAIN strives to facilitate the paradigm shift of eco-intensification in European aquaculture by developing and validating innovative production tools and knowledge at end-user level.
Innovation-related changes in production practices and investment may affect costs, but have also the potential to open up new marketing opportunities. Related knowledge is thereby essential for long-term sustainable success or growth of the European aquaculture sector.

Task 4.1 of the GAIN project is identifying costs and benefits of the eco-intensifying innovations developed within WP1 and WP2 as well as the side streams and by-products for the aquaculture and downstream industry such as the processing industry. For this purpose, the typical farm approach was applied and could be demonstrated as appropriate microeconomic tool to estimate impacts and opportunities on farm-level.

The cost-benefit analysis of the first block of novel feeds has shown that farms with a profit margin between 15-20% might not be profitable in the future for MIX -mixed diet combining emerging ingredients with small to moderate amounts of processed animal proteins (PAP)- and diet containing no processed animal proteins (NoPAP) - feeds, whereas PAP feeds are more promising, especially for salmon. This is particularly clear for seabream, partly due to already high control feed costs per kg fish produced and decreased feed conversion rate (FCR) under two of the three novel feeds. A final assessment of the suitability of novel feeds requires additional results on fish condition, as well as the results from the second feed block.

An overview of raw material flows relevant for fish and shellfish by-products and their market prices was conducted to understand added value potentials for these resources. The amount of occurring fish by-products within Europe was estimated to account for one third of the total available amount of live fish (10.16 million t in Europe). Fish by-products were found to be mostly marketed by larger companies and for the most common fish species. However, room for improvement was identified, especially for species such as carp and in general by adding further value to by-products. Upcoming results on cost-benefit analyses of novel feeds and other GAIN innovations will be included within D4.4

3. Introduction

The aquaculture sector in the EU is stagnating in growth in contrast to the increasing sector size at world level (FAO, 2018). In addition, the low number of licenses issued in recent years is a sign that the sector is struggling to expand (Lagares et al. 2018, FAO 2018). Hindering factors include pressure from imports and social pressure due to actual and perceived environmental impacts. In order to improve the competitiveness and social sustainability of

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European aquaculture it is necessary to create added value through quality and promotional activities (Lagares et al. 2018).

GAIN develops and validates innovative production tools and knowledge at end-user level to facilitate the paradigm shift of eco-intensification in European aquaculture. Improved feed design towards environmental sustainability and the use of Big Data for precision aquaculture are applied to aquaculture production. In addition, innovative approaches to re-use and valorise by-products and side-streams are considered for the secondary sector of production.

Changes in production practices and investment, such as feed composition or precision aquaculture, may impact several productivity parameters; these include bioeconomic productivity indicators such as growth, survival, and FCR, as well as capital investment, labour input or energy demand, all of which affect costs. Conversely, eco-efficient production and valorisation of by-products may open up new value chains and marketing opportunities.

Within Task 4.1, we are conducting cost-benefit analyses for eco-intensification innovations developed within the project in WP1 and WP2 and those of side streams and by-products for the aquaculture and downstream industry such as processing industry. The work conducted within Task 4.1 was divided into the following different steps:

i) Baseline data collection for typical farm models (see section 2.1) and downstream sector(s) of relevant species and production regions within the scope of GAIN to obtain an economic image of the target industries. The data collection was conducted in close cooperation with key stakeholders.

ii) Identification and related data collection of changes in production costs and revenues associated with innovative production tools implemented within GAIN.

iii) Cost-benefit analysis based on economic baseline and identified changes in costs and (potential) market returns, which will feed into the sustainability assessment of eco-intensification of Task 4.3.

iv) Up-scale from farm/single industry level to estimate the impact of the examined innovations for the whole sector, where applicable and complementary to Task 4.2.

We present the methodological approach of the cost-benefit analysis at farm scale and across the whole sector within GAIN. In addition, results related to eco-efficient feed and an overview of raw material flows relevant for fish and shellfish by-products and their market prices are included.

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4. Methodology

4.1 Typical farm approach

For the economic assessment of eco-efficient production of Europe's most important aquaculture fish species, the typical farm approach (TFA) will be applied as a baseline for farm-level predictions. TFA is an engineering approach: typical farm models are empirically grounded, 'virtual' datasets (Isermeyer 2012, Walther 2014). They combine focus groups, expert interviews, and farm observations to define representative farm datasets for selected production regions. The core element of these qualitative sampling methods is thereby represented by expert focus groups. These are organised with key stakeholders from the research and business sectors. The resulting farm-level economic datasets comprise a maximum of 548 variables, are validated discursively for their coherence, and allow a high detail of microeconomic analysis (see Lasner et al. 2017 for more details).

At present, the typical farm approach is implemented by several international agricultural institutions (ICFN 2019), including the *agri benchmark* network headed by the Thuenen-Federal Research Institute for Rural Areas, Forestry and Fisheries in Braunschweig (Germany) (for Standard Operational Procedure see Deblitz and Zimmer 2005). The TFA originated in the agricultural sector and was first applied to aquaculture production systems by the *agri benchmark* network in 2014. Within this pilot study, typical rainbow trout farms in Germany, Denmark and Turkey were defined and compared (Lasner et al. 2017). On this basis, the method was advanced and implemented for carp production in Germany and Poland (Lasner et al. 2019) within the EU Horizon 2020 Project **S**trategic **U**se of **C**ompetitiveness towards **C**onsolidating the **E**conomic Sustainability of the European **S**eafood sector (SUCCESS).

These existing datasets were updated for 2016 in the EU Horizon 2020 **C**limate change and **E**uropean aquatic **RES**ources (CERES) project, and complemented by new 2016 datasets including additional species and production countries. Within GAIN, we used existing and updated datasets to estimate the costs and benefits of eco-efficient aquaculture production in Europe. Further, we will define a new typical smolt farm dataset.

The applicability of typical farms to innovative production adaptations, was previously shown within a study on economic benefits of cork-enriched feed that provide sufficient buoyancy to raise eliminated material to the surface (Unger and Brinker, 2013; Behrens et al. 2019). The results led to the conclusion that the use of cork-enriched feed is only profitable for large farms, using cost-intensive filtration techniques. This study illustrates the range of economic impacts that innovative feed or other adaptations within production systems might have on different aquaculture farms.

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4.1.1 Typical farm approach for different production systems within GAIN

4.1.2 Typical grow-out systems

Typical farms are set up to cover all relevant enterprises (e.g. hatchery, nursery, grow-out, processing and marketing) that are part of a typical aquaculture operation unit relevant for the selected target species and production region. Within GAIN, we concentrated on the grow-out period in terms of novel feed formulations and data information systems according to the experimental focus that takes place within grow-out production systems. Therefore, we analysed typical grow-out systems for Atlantic salmon, rainbow trout and sea bass / seabream connected with these implementations. Typical farm datasets defined within the earlier projects SUCCESS and CERES are already available for these species (reference year 2016) and were applied to GAIN research questions.

GAIN partners (UNIVE, UoS, CSIC, SPAROS, GIFAS, ZUT, AWI, LLE) were trained on the TFA during a workshop in February 26th-27th, 2019 in Bremerhaven, or via a later virtual meeting (LEBCH). GAIN partners therefore received in-depth and hands-on training on the method in order to define costs and returns of typical aquaculture production systems in a standardized way. For turbot, despite active efforts from SPAROS and TI (invitation letters to relevant stakeholders, adaptation of data collection) it has become evident that defining a typical turbot farm is difficult due to the limited number of companies involved and confidentiality issues within this high-value niche sector. Alternatively, we aim to derive some general economic conclusions for turbot production based on the GAIN outcomes of novel feed and by-product experiments for this species.

For Polish carp production, the project investigates the shortening of the production cycle from 33 to 19 months by combining traditional pond production with a recirculating aquaponics system during the winter months (conducted by GAIN partner ZUT). This system, currently representing a pilot site, will be analysed for economic feasibility and compared to larger, more typical, farms with the normal production cycle length. The evaluation of this novel system thus offers the opportunity to include a cost-benefit analysis for an aquaponics system using nutrient-rich wastewater from carp production to grow watercress (*Nasturtium officinale*), supporting the circular economy focus of GAIN.

4.1.3 Typical smolt farm

The valorisation of aquaculture side streams such as nutrient-rich waste water, sludge and mortalities (see D2.1 & D2.2) will be economically analysed for land-based recirculating smolt farm systems as part of the evaluation of the GAIN technologies for sludge and mortalities.

For this purpose, the typical farm data categories were adapted to the characteristics of smolt systems. These will be defined together with relevant stakeholders in the county of Nordland, where 30% of Norway's smolt are currently produced (Meriac, 2019). It is further

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estimated that 70% of the smolts stocked in their grow-out operations were raised in recirculating systems (RAS), underscoring the suitability of defining a RAS smolt production system for Nordland to represent a typical operation for the sector.

For the valorisation of nutrient side streams, the implementation of an aquaponic system for algae is planned to be examined in combination with the typical land-based smolt farm. For this purpose *Ulva spp.* was identified as suitable species by the GAIN partner SHP. An economic feasibility analysis with different aquaponics scenarios is foreseen to analyse a) increasing productivity of the typical smolt farm and b) marketing of algae products.

4.2 Fish by-products

Valorisation of by-products is an important part of GAIN. These may constitute as much as 70% of fish and shellfish after industrial processing of seafood (Olsen et al. 2014). For example, viscera, heads (Fig. 1A), cut-offs (Fig. 1B), bone or skins are generated throughout the processing stage with subsequent flow into different categories of further utilisation. Fish production, primary and secondary processing and downstream industries such as feed or food often build the by-product value chain. High-value products to be used as dietary supplements, processing aids or pharmaceutical products, take a much smaller market share (Olsen et al. 2014).
Transformation of by-products into commercial products demands a market interest and a realistic possibility of sale at an economic margin within a reasonable time period. Quality of the raw material and the related knowledge as well as available volumes will determine manufacturing and marketing possibilities (Olsen et al. 2014, Arason 2003).

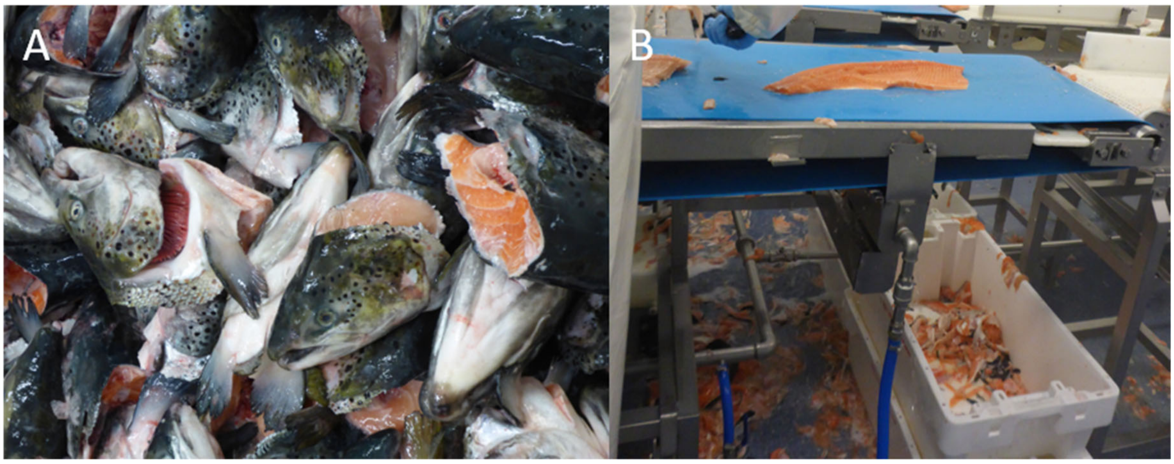

Figure 1 A/B*: Atlantic salmon heads (A) and cut-offs (B) that occur during processing activities (Pictures: C.Kreiss).*

Economic data collection within GAIN aims at relevant industry representatives within the EU in order to evaluate current costs and returns, as well as cost-benefits of added value to aquaculture by-products. In this way, GAIN takes into account both the processing and by-product sector and the upstream industry providing the raw materials.

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4.2.1 Processing industry

The UK, Spain, France, and Poland are important fish processing countries within the Europe, all employing high numbers (17,500-20,000 per country) in the sector and purchasing large volumes (1.7-3.5 billion t) of fish and other raw material for production (STECF, 2019). The sector is dominated by small and medium enterprises (SMEs) in numbers, although large companies still accumulate the main part of the activity.
There is also a trend for SMEs in some countries to integrate fish processing in aquaculture or fisheries, wholesale, trade or other food processing (STECF, 2019). Processing was also observed to be increasingly incorporated in larger Polish carp farms in order to increase added value to the final product, with a slow trend towards further processed products (pers. comm. Remigiusz Panicz, Piotr Eljasik (ZUT)).

In order to develop an overview of the utilisation of fish by-products within the seafood production and processing industry, a survey was conducted (9.-11.2.2020) at Fish International, the professional trade fair for the fish industry in Germany. Here, around 300 exhibitors from 29 nations in the areas of fish production and processing, fresh fish and gourmet products, as well as research and development, were present. The survey concentrated on fish processing and few aquaculture producers to obtain more information about type and volumes of fish secondary products, their collection, further use and recipients as well as costs/returns for disposal or marketing (see annex 1 for full questionnaire).

In addition, further data collection is in progress by GAIN partners, e.g. in Poland. About one third of Polish carp is sold as fresh semi-prepared product, only a small proportion frozen and the large majority as live fish (Polish carp producer organization, 2019). At present, carp by-products often seem not to be marketed by small processors and are incinerated.

However, they might also be utilized in mink farming or for other individual purposes. ZUT is working on developing a cost-effective on-farm method to produce silage from mortalities and carp by-products within GAIN. In the context of yet under-utilised carp by-products, potential opportunities and costs/benefits of these resources are especially interesting for the carp processing industry in Poland and will be further examined in GAIN.

4.2.2 By-product industry

Target industries for fish protein hydrolysates (FPH), collagen, and gelatines are e.g. animal feed producers, human food producers, and nutraceutical producers, whereas pharma and clinical producers might also be interested in collagen/gelatines and microbial culture media producers in peptones. These are distributed over different EU countries, with important companies in France (e.g. Nutrifish, Sopropeche, Copalis), Spain (e.g. Juncà, Valora Marine Ingredients), Ireland (e.g. Bio-marine Ingredients Ireland), Netherlands (e.g. Rousselot; Jelline), Germany (e.g. Bioceval), and other countries (Dibaq (Czech Republic), PetSelect (Spain), Biomar (Denmark & global), Skretting (Norway & global), Sparos (Portugal).

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In order to capture the costs and benefits for the industries producing fish protein hydrolysates (FPH), collagen/gelatines or peptones, the typical farm approach was adapted accordingly to a 'typical by-product industry' approach for these types of companies. Variable and fixed cost categories, but especially those for plant and equipment (see Table 1) were modified based on information from GAIN partners (CSIC, ANFACO, D.2.3) and literature (e.g. Petrova et al. 2018, Ali et al. 2017, Fallah et al. 2014).

***Table 1**: Adaptation of data collection for 'Plant and equipment' to by-product industry relevant categories.*

Plant and equipment	**A** Utilisation period in years Economic lifetime	**B** Replacement value
I Homogenation		
e. g. Mincer..		
II Solubilization		
e. g. pumps		
e.g. tanks		
e.g. bioreactor		
e.g. agitation blade		
III Separation		
e.g. centrifuge		
IV Filtration		
e.g. Plate/Frame filtration, membrane filters…		
Concentration		
e. g. Concentrator, evaporator		
IV Drying		
e.g. spray or freeze dryer…		
V Freezing/Cooling		
e.g. Freezer		
...		
IX Packaging		
e. g. …		
XI Minor equipment		
e. g. tool…		
XII Office and computing		
e. g. printer, PC…		
XVI Other, namely:		

However, it has become clear, that a transfer of production conditions of e.g. FPH by GAIN partners to industry scale is not achievable due to differences in equipment and methodology. We will therefore interview representatives of the by-product industry to estimate a potential added value of eco-efficient by-products that could be passed down to the aquaculture sector.

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4.3 Cost-benefit analyses of innovative production practices

Changes in production practices and investment, as well as the valorisation of aquaculture side streams, may have an impact upon several productivity parameters with subsequent effects on profitability. Within the economic analysis, we will calculate different scenarios on basis of our typical farms.

Within WP1, eco-efficient feed formulations for trout, turbot, salmon and seabream were developed and are currently estimated for their market price (SPAROS) (see Table 2 for feed block 1 prices). For each species, 4- 6 different feed formulations including: a) diets rich in **p**rocessed **a**nimal **p**roteins (diet PAP); b) diets combining emerging ingredients and allowing the reduction of both fishmeal and PAPs inclusion (diet NoPAP) and c) diets combining emerging ingredients and allowing the reduction of fishmeal, with small to moderate amounts of PAPs (diet MIX), were or will be tested against control diets (CTRL) that mimic a current standard commercial diet for each species (see D.1.4). These novel feeds are designed to improve circularity/sustainability, performance/yield, and will be evaluated for effects on feed conversion ratio (FCR), health aspects, growth rate, product quality and mortality (Fig. 2.1). All these aspects have or will be examined within GAIN and successful dietary formulations will be assessed in business case feasibility.

***Figure 2.1**: Impact of Eco-efficient feed formulations on aquaculture production parameters with subsequent effect on profitability.*

Novel feeds with a higher sustainability index are categorized as successful if they achieve similar (i.e. not statistically different) or better results than control feed with regard to the tested parameters mentioned above. For these formulations, cost-benefit and profitability break-even point analyses will be conducted under consideration of estimated market prices for novel feeds. The results from the feed trials cover only part of grow-out production cycle and will be interpolated for the whole cycle. Due to the (mostly) higher estimated prices of eco-efficient feed formulations compared to control feeds, marketing and consumer acceptance will be crucial as well. GAIN partners AWI and UoS are conducting consumer surveys focusing on fish consumption and consumer acceptance of specific novel feed ingredients. Based on their outcome and that of the economic analysis, conclusions on consumer feedback will be made. Further, potential price variation for the most critical ingredients of control feed compositions (e.g. fishmeal, fish oil) will be taken into account to estimate and compare potential future price developments of the different feed formulas.

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Another set of innovations in the primary sector investigated within GAIN WP 1 is the implementation of different sensors and Big Data for real-time feedback to farmers. This will enable aquaculture producers to make quasi-real-time adjustments to stocking density, harvesting, oxygen or feed management. Economic cost-benefit analyses are planned for selected cases (e.g. optimization of Atlantic salmon harvesting in Norway, optimization of oxygen management in salmon cages in Canada and in raceway rainbow trout farms in Italy). Therefore, scenarios will be applied to typical farm datasets/economic data in order to conduct profitability analysis on different time scales.

Within WP 2, innovative technologies for recovering nitrogen and phosphorus from sludge and wastewater are being tested on RAS smolt farms. The reduction in the environmental load will allow compliance with more stringent requirements on land-based aquafarm emissions, which are likely to be introduced in the legislation and, therefore, could be crucial for granting new farming licenses (see GAIN D.2.1). As a consequence, investment in equipment, installation, space, and training will occur in addition to maintenance, repair, labour, and energy costs. These will be considered together with potential marketing of valorisation strategies and included within the typical smolt farm profitability analysis (Fig. 2.2). Macroalgae aquaponics will be evaluated as an alternative to technical capture of dissolved matter from RAS aquaculture wastewater with different scenarios planned (see 3.1.2). Besides marketing of sludge or macroalgae, the economic analysis serves as a preparatory study to increase production or fulfil production requirements according to regulatory measures.

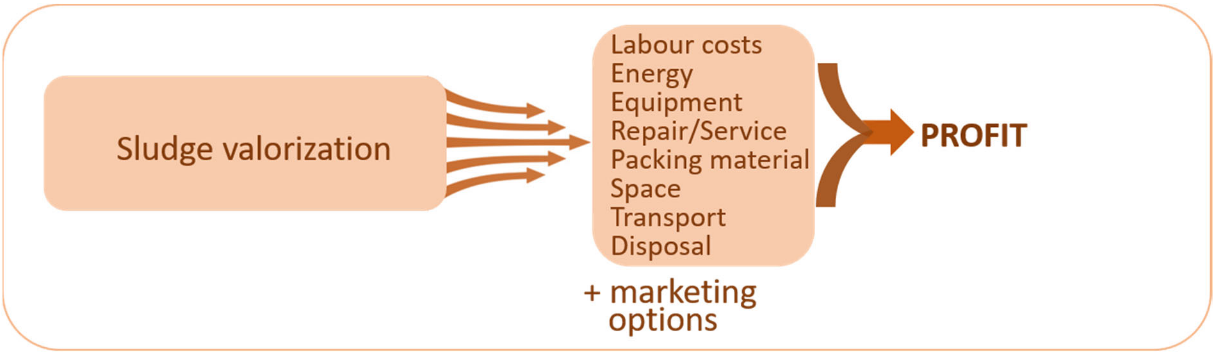

***Figure 2.2**: Impact of sludge and wastewater valorisation on aquaculture production parameters with subsequent effect on profitability and production.*

Mortalities or discarded fish need to be processed and are ideally converted into new resources to obtain eco-intensification of the aquaculture industry. For this purpose a dryer applying superheated steam from GAIN partner Waister was implemented to replace the current ensilage method (see D2.2). Besides a substantial reduction of the amount of water and thereby volume and weight of the final product, less consumables are required compared to the conventional ensilage procedure. On the other hand, investment in the dryer machine and related equipment, associated service and energy costs must be taken

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into account (Fig. 2.3). On this basis, cost-benefit analyses will be conducted for relevant typical farms considering also different disposal and marketing options of the final product.

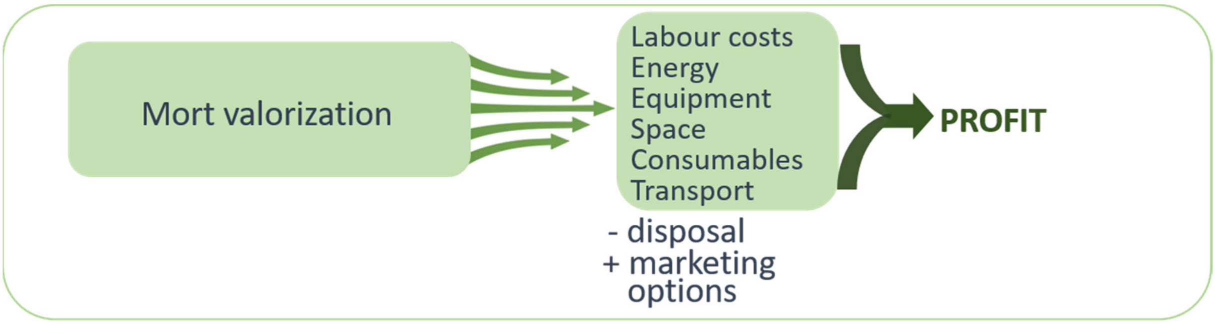
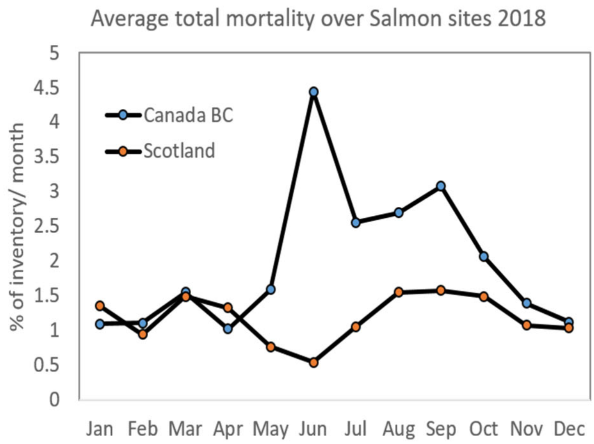


Figure 2.3: Impact of innovative mortality disposal on aquaculture production parameters with subsequent effect on profitability.

4.4 Upscaling of cost-benefit results to the whole sectors

In order to transfer cost-benefits from individual farms to the respective sector, data were collected to estimate consequences e.g. for a specific species at country level or at the EU level, where appropriate. For example, overall mortality rates for the salmon sector (Fig. 3), allow conclusions on the availability of resources for innovative disposal of dead fish and related marketing options. For Norway, Scotland and British Columbia, Canada the mortality rate for the year 2018 ranged from 13-21%.



% Mortality Atlantic salmon grow-out	
Norway 2018	ca. 16%
Scotland 2018	ca. 13%
Canada (BC) 2018	ca. 21 %

***Figure 3**: Average total mortality over all salmon sites in British Columbia (Canada) and Scotland in percentage per month (left) and over all salmon sites for Norway, Scotland, Canada in percentage per year (2018) (right). Sources: https://open.canada.ca; http://scottishsalmon.co.uk, https://www.barentswatch.no. High mortality in June for Canada is partly related to algae bloom impacts on two sites with 30-70% mortality.*

Other applications where sector data are useful to draw overall conclusions are those for the by-product sector. Here, the overall fish availability within Europe and the generation of by-products in different categories are of interest in order to estimate available resources that

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might be marketed with an added value. In 2018, the supply of whole finfish directed for human consumption of fishery and aquaculture products (domestic production plus import) accounted for 11,665,955 t live weight. 1,503,573 t whole finfish was exported to non-European countries and consequently 10,162,383 t remained in Europe (Eurostat, see Fig. 4). In Europe, fish in frozen and prepared forms represent more than two-thirds of the production of fish used for human consumption (FAO, 2018) and up to 50-70% of the fish may end up as by-products. Considering that two-thirds of finfish remaining in Europe is processed, of which half result in primary products, the available amount of secondary products from fish is about 3,390,000 t, corresponding a third of the total remaining finfish volume (finfish catches and aquaculture production plus imports minus exports) in Europe.

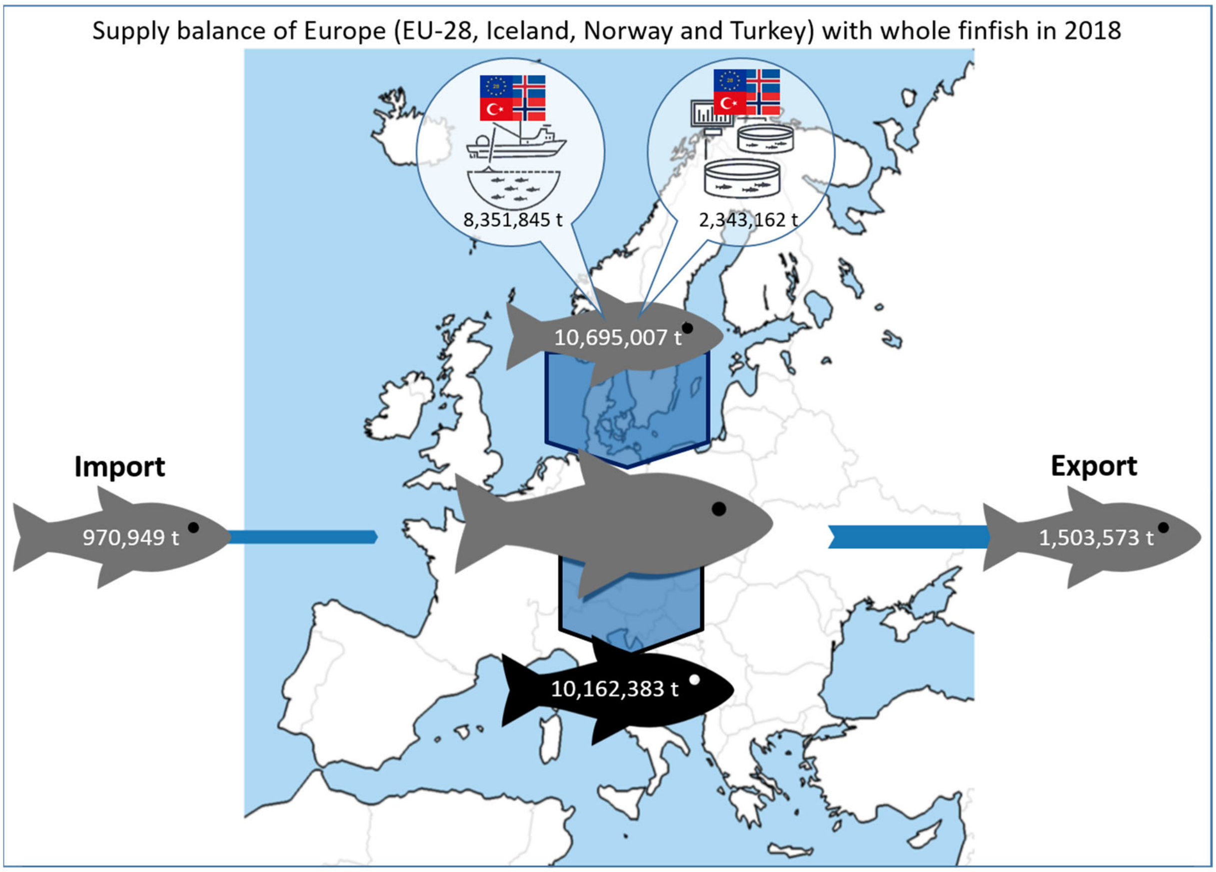

Figure 4: *Apparent use of whole finfish in Europe (former EU28 + Norway, Iceland, Turkey) in 2018. Considering the production of finfish (catches and aquaculture production) as well as imports and exports of whole finfish. Supply balance is built on the basis of the following equation, calculated in live weight equivalent based on EUMOFA conversion factors: (Catches + Aquaculture Production + Imports) – Exports = Apparent Use. Data Source: own calculation based on Eurostat data (fish_ca_main, fish_aq2a, comext).*

From this overall volume of secondary products from fish, a large variety of edible and non-edible goods of different quality and purpose are obtained. Annex 2 gives a detailed overview of the top five importers and exporters in volume (tonnes) and value (€/kg) per product category. For non-edible goods, Denmark is by far the country importing and

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exporting highest volumes, followed by Germany and the UK. The most traded good category overall by volume is thus ‘Flours, meals and pellets of fish, crustaceans or molluscs’ (import: 569,607 t, export: 423,812 t) and that of highest average price is ’Fish-liver oils and their fractions‘ (Annex 2). For edible products, the picture is more diverse. France, followed by Denmark, the Netherlands, and Spain import the highest volumes, whereas Poland is by far the most important exporter, followed by the UK, some distance from Germany and France.

Volumes of imported edible goods are comparably low and ’Frozen fish livers, roes and milt‘ have the largest share (11,515 t), whereas ’Frozen fish fins, heads, tails, maws and other edible fish offal‘ constitute by far the largest export volume (247,277 t), mostly to non-EU countries. The high ranking of Denmark with respect to trade of non-edible by-product goods is linked to its fishmeal and fish oil industry. The importance of the UK, France, and Poland as fish-processing countries is partly reflected in their export volumes of edible by-products**.**

5. Results

5.1 Farm-level results

The typical farm approach is appropriate for a detailed classification of individual farm cost categories. Below are two examples showing the most important cost drivers for a typical salmon farm in the region of Nordland in Norway and for a typical seabass farm in the Canary Islands (Fig. 5 and 6). The most important costs are feed (around 60 %) for both cage farms, followed by stocking. For the Norwegian salmon farm there are also quite high lease and water charge costs, veterinarian and diesel costs (for the powering of boats). In contrast, for the seabass farm in the Canaries production is more labour-intensive and has higher depreciation costs. However, the latter often benefit from economies of scale, which come into effect for the salmon farm (3680 tons) compared to the seabass farm (1200 tons).

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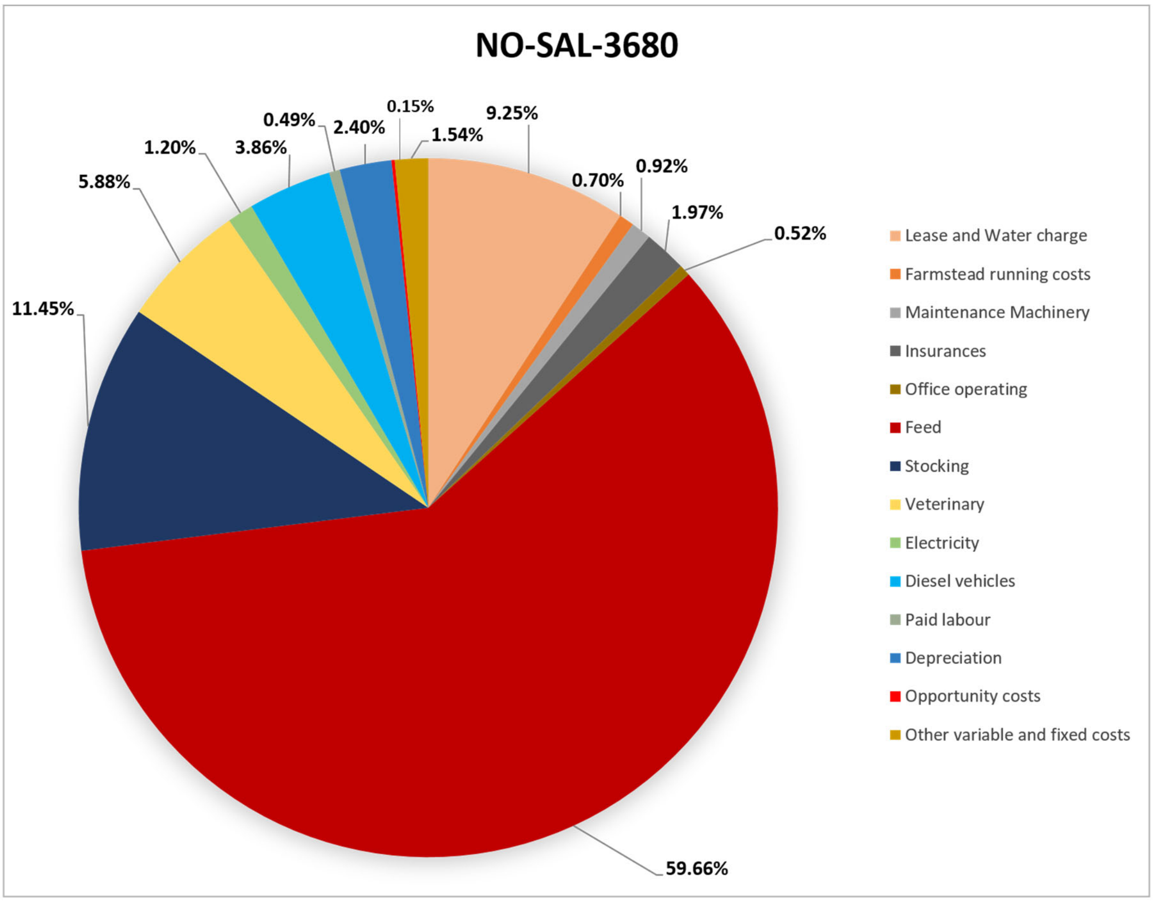

Figure 5*: Percentage long-term cost distribution for a typical salmon farm in Nordland, Norway, producing 3680 tons (reference year 2016).*

The two datasets show the high share of feed costs, where small changes in unit costs or feed demand have a major effect, which will be very relevant for the results on novel feeds in GAIN. Further, optimized feed management related to the information management system might lead to significant effects on profitability. Veterinary costs, which also take a relatively high share in overall costs in both cases, could be positively effected through closer monitoring that includes e.g. visual lice detection for salmon. Optimized management of oxygen addition will probably be more significant for freshwater production systems, or for marine cage systems located in shallow coastal sites in periods of insufficient water exchange.

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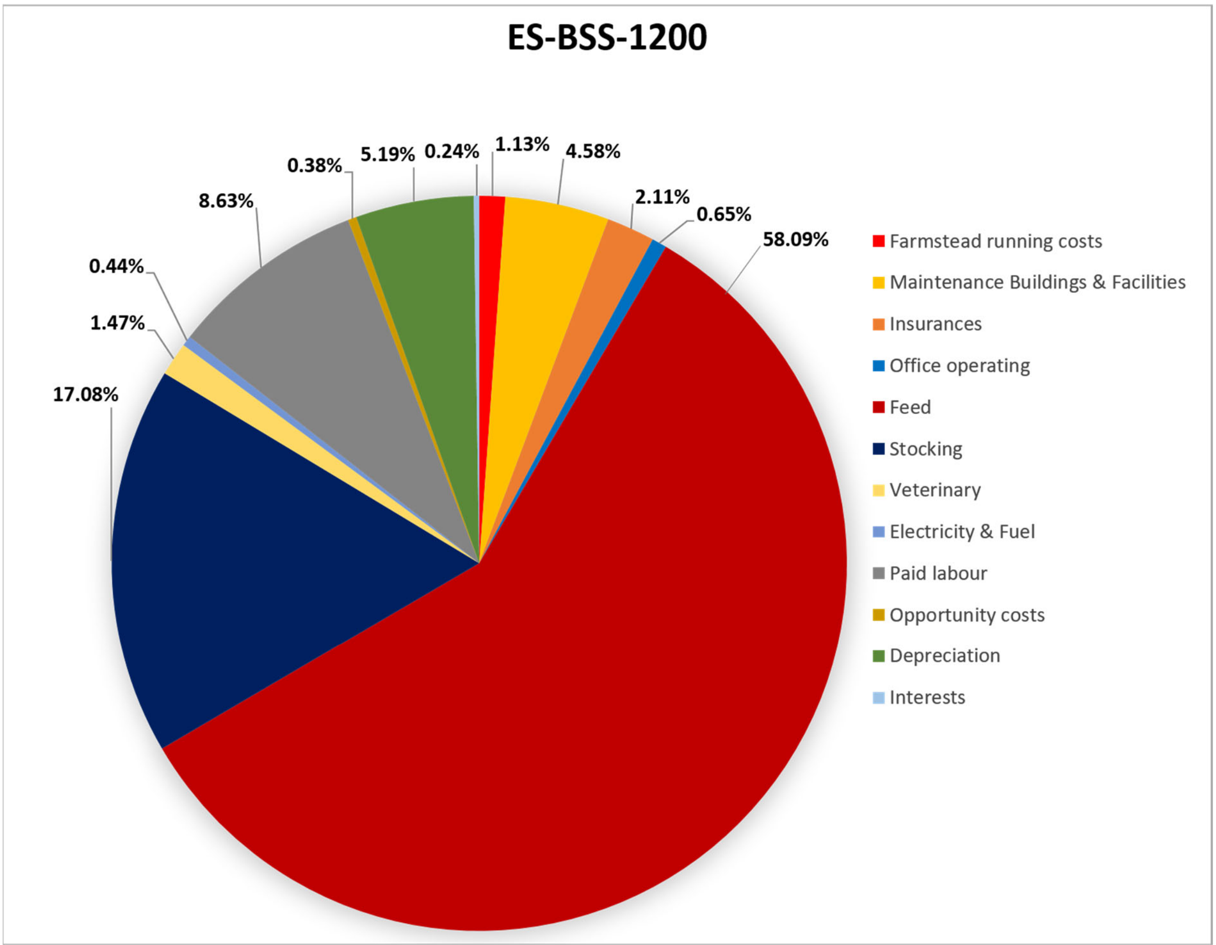

***Figure 6**: Percentage long-term cost distribution for a typical seabream farm in the Canary Islands producing 1200 tons.*

The results and novel feed prices (Table 2) of the first feed trial block for seabream, salmon and trout (Conceição et al. 2019) were transferred to selected typical farms of these species, obtained in the CERES project. The feed trial results on potential percentage change in mortality, growth and FCR (FEM: trout, SPAROS: seabream, GIFAS: salmon) as well as price estimations for the novel feed mixtures, were then taken into account. The latter were estimated by SPAROS to reflect real costs of feed processing and sourced ingredients, and are depicted in Table 2.

***Table 2**: Estimated fish feed prices (%) for novel feeds of the first experimental block, with the control feed representing 100%. NoPAP= (diet containing) no **p**rocessed **a**nimal **p**roteins, PAP= (diet rich in) **p**rocessed **a**nimal **p**roteins, MIX= diet combining emerging ingredients with small to moderate amounts of PAPs.*

	Control	NO-PAP	PAP	MIX
Trout	100	150	106	135
Seabream	100	157	117	158
Salmon	100	127	-	93

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Turbot	100	108	85	115

It must be considered that the first feed trial block aims at evaluating emerging ingredients that are already commercially available, thus paving the way for the second experimental block. The latter was designed to be more realistic with regard to formulation costs, while taking ingredient LCA's (Life cycle assessments) and EISI (Eco-intensification sustainability index) performance into account (Conceição et al. 2019). The results below should therefore be taken as a good example for the upcoming cost-benefit analyses of the second experimental feed trial.

The seabream feed trial results and estimated market prices of the respective novel feeds applied to a typical Turkish seabream farm led to substantial changes in profitability compared to the usage of control feed. Figure 7 shows the stacked costs and returns of such a farm, divided into feed costs and other cash costs representing short-term costs, depreciation as mid-term costs and opportunity costs as long-term costs.

The distance between the returns symbol and the top of the stacked costs represents the long-term profit/loss made by the farm. Under all three novel feed scenarios, the farm would not be longer profitable, if the control feed type was replaced by MIX, PAP, or NoPAP feed. The severe profit loss under the usage of MIX feed can be partly explained by a concomitant significant increase in FCR. This was also true when applying PAP feed, however due to the lower costs of this mixture (Table 2), the effect on profitability was much lower. For the NoPAP feed, no effects on FCR could be found in the feed trials.

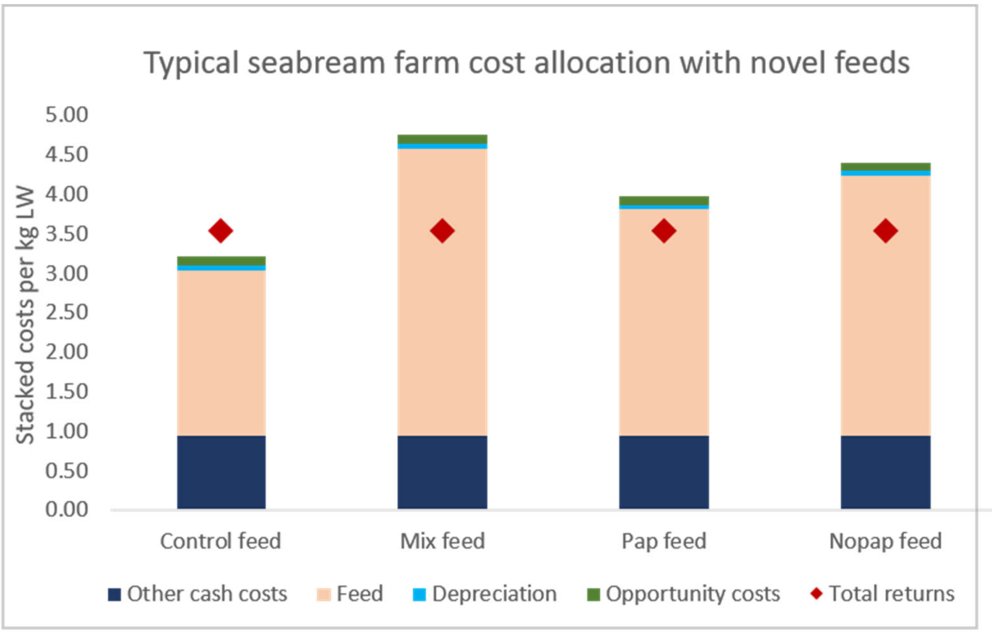

Figure 7: *Stacked costs and returns (farmgate) per kg LW (live weight) from a typical seabream farm in Turkey (1000 t y-1 production volume) model. The distance between the red returns point and the top of the stacked costs represents the long-term profit/loss made by the farm under control, PAP, MIX and NoPAP feed. Typical farm data was collected by the*

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University of Mersin within the CERES project.

As shown in Figure 8a, profit for a typical Turkish seabream farm was three times lower under the NoPAP-feed scenario, which would have to be balanced by an almost 45% higher fish price per kg (Fig. 8b) in order to reach the original profit. For salmon and trout, where no feed trial FCR impacts could be detected, the effects on profitability were less severe. Thereby, 'DE-TRR1', a German best practice trout farm as well as 'NO-SAL', a typical Norwegian salmon farm, showed lower profits for most cases, but stayed profitable under all novel feed scenarios. For the Norwegian salmon farm there was even a slight increase in profitability under the PAP-feed scenario, due to slightly cheaper pricing compared to the control feed (Table 2). From all novel feeds, the PAP-feeds had the most favourable price development and respective effect on farm profitability. 'DE-TRR2', a typical traditional German trout farm of smaller scale, and 'TR-TRR' a typical Turkish cage trout farm, were both no longer profitable under the NoPAP-feed scenario as well as under the mix scenario for the Turkish farm.

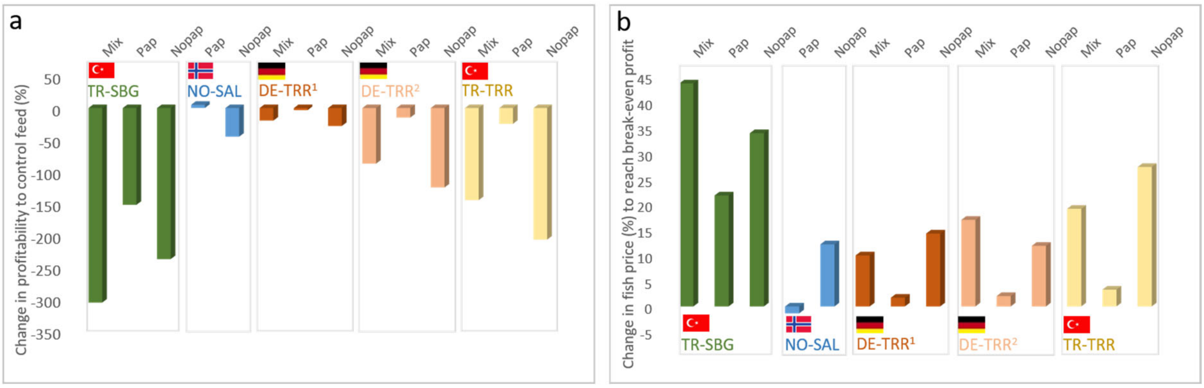

***Figure 8a &b**: Profitability change under PAP, MIX and NoPAP feed compared to control feed (%) for a typical Turkish seabream farm (TR-SBG), a typical salmon farm in the Northern part of the country (NO-SAL), a German best-practice trout farm (DE-TRR1), a typical traditional German trout farm (DE-TRR2) and a typical Turkish cage trout farm (TR-TRR) (a) and the required change in fish price to reach break-even profit for the same farms (b. Typical farm data was collected by TI, GIFAS and the University of Mersin.*

Differences in farm vulnerability to feed price changes can be partly explained by the control feed costs per kg of fish produced, as well as by the profit margin of the farm. Control feed costs per kg LW were highest for the Turkish seabream production, followed by Norwegian salmon and the small German trout farm, with the other two trout farms having clearly lower costs of about half of the Turkish seabream farm. Both Turkish farms and the smaller German trout farm had comparably lower profit margins (PM) under control conditions (approx. 15-20%) than the larger scale and professionalized Norwegian salmon and German trout farms (PM: 27-54%). The profit margin thereby defines the economic buffer of a farm e.g. for investments or to balance altered cash costs.

However, it is unlikely that aquaculture producers will accept substantial profit losses when replacing their current type of feed by a more sustainable product. With exception of the

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PAP feed for Norwegian salmon, the consumer willingness-to-pay for more sustainable grown fish will therefore play an important role in order to stay profitable or to reach break-even. For the final assessment of the suitability of novel feeds from the first experimental block, additional results on fish condition are required and in progress. The full economic analysis on novel feeds within GAIN will be finalised after completion of all feed experiments including the second feed trial block involving GAIN feed ingredients.

5.2 By-product results

During interviews at the Fish International exhibition an overview on the generation of type and volumes of fish secondary products, their collection, further use and recipients was obtained by approaching more than 20 different representatives of processors and aquaculture producers. Eight questionnaires were obtained, including mostly processors for salmon and cod, but also other demersal, flat (e.g. plaice) or pelagic fish (e.g. herring), as well as aquaculture producers of common and niche species. By-products were stated to be collected separately by species, product, certification status or for all reasons and the disposal of by-products was rather an exception.

All by-products illustrated in Figure 9 (heads, bellies, skin, frames, trimmings) were reported to be sold to feed producers and with the exception of skins all other by-product categories were also sold to the food industry for human consumption. Thereby, the Asian market was mentioned a few times. This is in line with the high volume of ‘Frozen fish fins, heads, tails, maws and other edible fish offal’ exported to non-EU countries as shown in Annex 2.

Besides marketing to the food industry, heads were additionally mentioned by one processor to be sold to the fertilizer sector as well as to fishmeal and fish oil producers. The latter industry was also stated to receive frames and trimmings. Skins were mostly stated to be sold to collagen industry and within our survey this was the only by-product indicated to be relevant for this particular sales channel. Production of mince as a common first step in processing of rest raw materials of fillet production such as cut-offs and frames (Arason et al. 2009) was confirmed by most companies. Either for re-usage within the own processing facility (e.g. for fish cakes) or to be frozen and sold as blocks. As mentioned above, very few companies stated that by-products are disposed and these were mostly young companies and/or producing niche aquaculture species that did not establish alternative trade channels yet. Empty shells from mussel production were stated to be taken back to the sea (Easterschelde, Netherlands), whereas clean shells from cooked mussels were stated to be used to balance acid soils in the local area (Galicia, Spain) or to enrich clay soil (Netherlands) as well as being used as seed collectors (Netherlands) and some being disposed.

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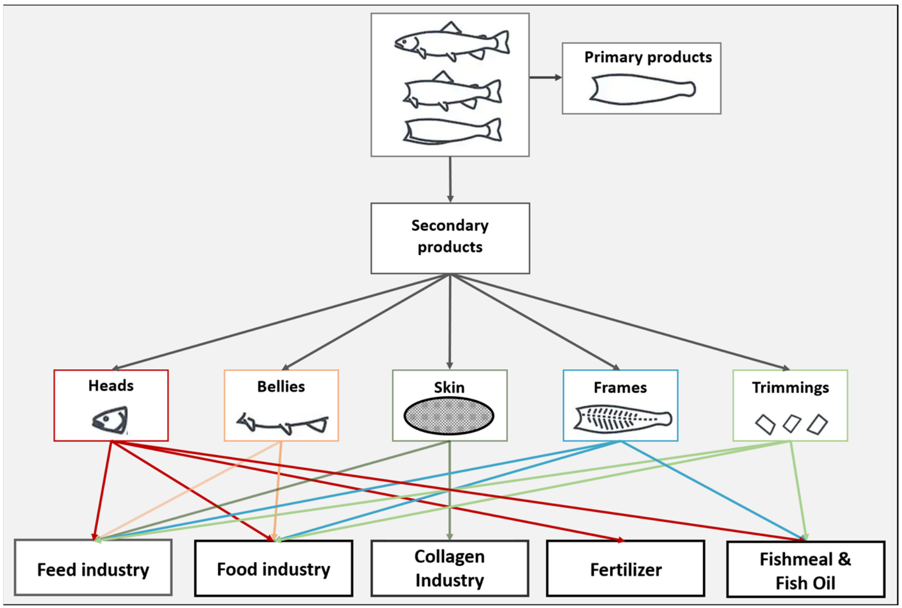

***Figure 9**: Summarized results of recipients for different fish secondary products derived from interviews during fish international fair in Bremen (February 2020).*

The large majority of fish by-products were stated to be marketed and three rough categories were identified based on answers from survey participants (Fig. 10). By-products sold unprocessed or to fishmeal/fish oil producers fetched a price of 0.1-0.12 €/kg. Salmon by-products (not rated as high-value goods) were sold for 0.5-1 €/kg. High value salmon or cod by-products e.g. for soup determined for the food industry/market achieved returns between 4 and 5 €/kg. The minimum return for processed secondary products (e.g. frozen and packed) was between 0.5 and 0.8 €/kg product.

If the category of high value salmon/cod by-products is compared to edible fishery and aquaculture products imported by European countries (Annex 2), we get a similar price range with an average of 4.5 €/kg (+/-3.3 €), whereas that of exported goods within this category is slightly higher with an average of 5.0 € (+/-6.2 €/kg), without the high price for fish liver oils exported by Germany.

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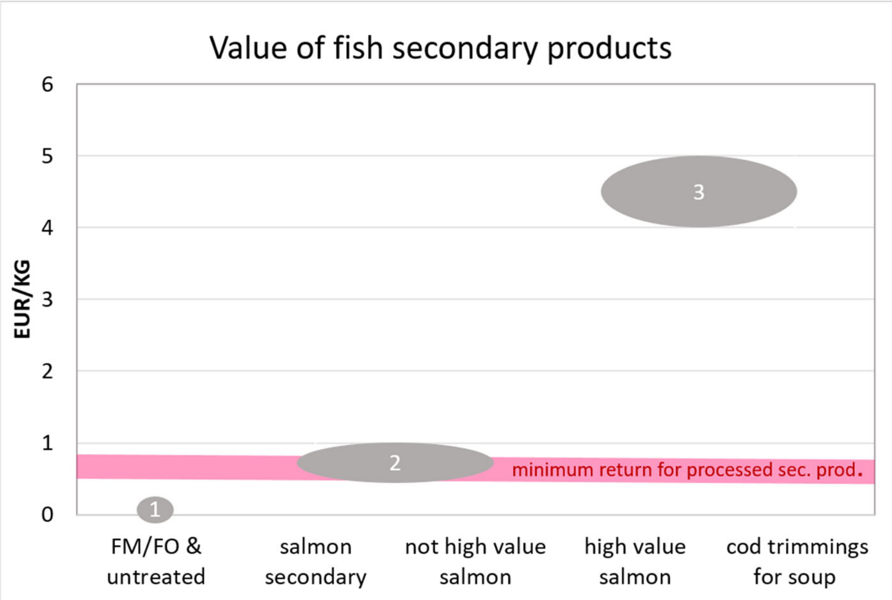

***Figure 10**: Summarized results of fish secondary product values derived from interviews during the fish international fair in Bremen (February 2020).*

Processors and (mainly) aquaculture companies lacking established marketing strategies for by-products, but also enterprises with established sale channels, were interested in more specialized customer industry and higher market prices for by-products. Products such as FPH, fish collagen, and peptone show high price ranges (quality-dependent) (Table 3), mostly above those of the high value by-products described in Figure 10. Dependent on the (passed down) profit margin of the by-product processing industry and the required quality and type of fish raw rest material, adding value to the latter could be profitable for different representatives of the value chain.

***Table 3**: Prices for value-added fish by-products deriving from information from GAIN partners (SPAROS) and online research (alibaba.com).*

Product	Price span (€/kg)
FPH	2.5-9
Fish collagen	11-100
Fish peptone	3-7

6. Concluding remarks and future work

The progress in GAIN Task 4.1 up to month 24 of the GAIN project includes the collection of part of the targeted data and a valuation of feasible and meaningful cost-benefit analyses to be conducted within the next year. The typical farm approach is an appropriate microeconomic tool to address the impact of altered costs on profitability. However, additional information and market assessments such as consumer willingness-to-pay for eco-efficiently produced fish and shellfish will be crucial for sector-relevant scenario calculations.

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Fish by-products seem to be mostly marketed, at least for larger companies of the fish sector and for the most common fish species. However, there is still room for improvement, especially for species such as carp and in general by adding further value to by-products. Within the coming year, typical farms will be updated and a typical smolt farm defined for Norway. Further economic data will be collected for the Polish carp sector. With the availability of feed trial results, sludge, wastewater and mort valorisation as well as big data, IMS and by-product results, the respective cost-benefit analyses will be conducted. With regard to COVID-19-related delays of these data inputs, a certain degree of flexibility depending on the data availability will be reserved. The final results will be included within D4.4, due by M36.

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ANNEX 1 – Questionnaire on secondary fish products

Questionnaire on secondary fish products

What is the specialisation of your company? (multiple answers possible)

- ☐ Filleting
- ☐ Freezing
- ☐ Smoking
- ☐ Specialities/Delicacies
- ☐ Canning
- ☐ Trader (no processing activities)
- ☐ Other: ____

Which type of raw goods are processed within your enterprise?

- ☐ Whole or gutted fish
- ☐ Partially processed (e.g. head-off, filets, boned, skinned)

Are any raw secondary products generated during further processing?

- ☐ Yes
- ☐ No

Volume of secondary fish products generated through processing in 2018?

_______________t in the year 2018

Which type and volumes (% of total secondary products) are occuring during processing?

- _____ % Heads
- _____ % Frames
- _____ % Trimmings
- _____ % Viscera
- _____ % Skins
- _____ % Sawdust
- _____ % Shells (shellfish)
- _____ % Crab shells
- _____ % Other: ____

How are these secondary products collected?

- ☐ Separated by species: ________________________________
- ☐ Separated by type of secondary product: ________________________
- ☐ Together

Who is the recipient of your secondary products?

- ☐ Fishmeal and -oil producer
- ☐ Waste disposal contractor
- ☐ Gelatine and collagen-peptide producer
- ☐ Feed-/ food industry
- ☐ Other:____

Which costs or returns are related to the marketing of your fish secondary products?

- ☐ Costs for disposal
- ☐ Sold as resource

__________________EUR/ton in 2018 ____________________ EUR/ton in 2018

Contact: Simone Brüning/Cornelia Kreiss, Thünen Institute of Sea Fisheries, Herwigstr. 31, Bremerhaven simone.bruening@thuenen.de/ cornelia.kreiss@thuenen.de, Phone: 0471

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ANNEX 2 – Imported/exported fish products Europe

Fishery and aquaculture products imported by European countries and exported to non-European countries considering whole fish (fish waste), fresh or frozen products. To calculate the import/export of Europe the data for the former EU28 (including UK) was used and amounts of Norway, Iceland and Turkey were deducted. CC= country code according to Iso alpha-2 coding representing the most important importing or exporting countries by volume. Data source: Eurostat (Comext).

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Non-edible goods	Import (Europe-Intra)					Import (Europe-Extra)				
	Volume [t]	Value [EUR]	CC	Volume [t]	Price EUR/kg	Volume [t]	Value [EUR]	CC	Volume [t]	Price EUR/kg
Flours, meals and pellets of fish, crustaceans or molluscs	300,591	374,296,459	GR	68,119	1.10	269,016	356,542,324	DE	79,503	1.21
			IT	45,726	1.34			DK	60,470	1.35
			UK	35,577	1.37			UK	57,566	1.41
			ES	21,311	1.33			ES	32,525	1.29
			FR	21,156	1.41			GR	16,258	1.31
Fish waste (incl.international landings of fish for industrial use)	215,143	64,597,614	DE	75,107	0.23	167,507	51,409,356	DK	74,445	0.21
			DK	44,358	0.23			IE	40,127	0.22
			ES	27,844	0.46			FI	17,119	0.28
			FR	22,305	0.39			FR	10,382	0.83
			PT	11,265	0.15			IT	8,237	0.84
Unedible products of fish or crustaceans, molluscs or other aquatic invertebrates	256,121	89,066,477	DK	235,016	0.24	65,970	53,611,036	DK	62,123	0.26
			ES	14,324	0.73			DE	1,322	3.81
			DE	2,019	1.19			UK	999	12
			PT	1,487	0.53					
Fish fats and oils and liquid fractions	104,095	174,774,331	IT	17,104	1.51	214,098	323,627,497	DK	104,086	1.37
			NL	13,940	1.58			FR	26,035	1.59
			ES	13,091	0.93			BE	25,775	1.21
			UK	12,113	1.5			GR	18,004	1.07
			GR	11,106	1.19			UK	13,315	1.66
Fish or mammal soubles, to supplement feeding stuffs produced in the agriculture sector	84,275	124,350,556	CY	12,981	1.08	16,179	15,459,552	ES	9,434	0.62
			PL	12,833	1.09			UK	2,610	1.08
			IE	10,801	2.44			DE	1,681	0.8
			CR	8,115	1.39			DK	1,145	1.29
			PT	6,458	1.28			SE	503	0.56
Fish-liver oils and their fractions	1,211	6,476,910	PT	433	3.87	1,469	6,711,817	UK	571	5.87
			IE	301	4.86			NL	439	2.67
			NL	219	2.41			ES	218	3.58
			IT	128	3.84			DK	153	3.09

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Non-edible goods	Export (Europe-Intra)					Export (Europe-Extra)				
	Volume of EU [t]	Value of EU [EUR]	CC	Volume [t]	Price [EUR/kg]	Volume of EU [t]	Value of EU [EUR]	CC	Volume [t]	Price [EUR/kg]
Flours, meals and pellets of fish, crustaceans or molluscs	286,886	390,075,934	DK	96,224	1.40	136,926	188,892,452	DK	109,934	1.39
			DE	77,371	1.34			FR	7,398	1.51
			ES	29,043	1.18			ES	6,753	1.01
			UK	20,229	1.55			UK	4,276	1.57
			IE	19,974	1.41			DE	4,139	1.58
Fish waste (incl.international landings of fish for industrial use)	183,861	67,000,900	PL	67,780	0.31	6,724	6,327,925	DE	1,904	0.42
			SE	27,550	0.25			DK	1,491	0.83
			FI	17,199	0.26			PL	1,337	0.80
			DE	11,129	0.23			SE	525	0.17
			ES	10,168	0.38			ES	503	1.20
Unedible products of fish or crustaceans, molluscs or other aquatic invertebrates	38,686	67,286,338	DE	27,319	1.33	4,456	21,783,510	DK	3,093	0.97
			DK	7,200	0.50					
Fish fats and oils and liquid fractions	143,348	203,010,693	BE	41,394	0.44	129,028	202,453,258	DK	110,985	1.37
			DK	31,309	1.40			BE	7,325	1.68
			FR	16,366	2.00			FR	5,492	2.19
			NL	13,869	2.78			NL	1,219	5.37
			DE	11,316	1.79					
Fish or mammal soubles, to supplement feeding stuffs produced in the agriculture sector	74,971	87,094,791	ES	18,666	0.56	80,490	115,731,106	UK	43,970	1.51
			IT	17,729	1.19			IT	12,766	1.29
			FR	17,310	1.27			ES	4,965	1.24
			UK	8,602	1.43			FR	4,836	1.91
			AT	5,511	0.78			DK	3,998	0.89
Fish-liver oils and their fractions	1,015	10,928,011	NL	418	6.00	797	2,515,233	FR	377	2.46
			UK	406	18.04			PL	331	0.98
			DK	105	3.36					

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Edible goods	Import (Europe-Intra)					Import (Europe-Extra)				
	Volume of EU [t]	Value of EU [EUR]	CC	Volume [t]	Price [EUR/kg]	Volume of EU [t]	Value of EU [EUR]	CC	Volume [t]	Price [EUR/kg]
Frozen fish livers, roes and milt	3,909	16,101,297	RO	1,186	2.55	7,607	42,060,473	DK	1,863	2.59
			ES	722	4.69			NL	1,812	3.75
			DK	521	2.57			ES	1,048	6.13
			FR	345	4.78			FR	692	4.51
			NL	286	3.25			DE	468	10.30
Frozen fish fins, heads, tails, maws and other edible fish offal	5,014	18,104,894	EE	1,274	0.85	2,097	3,719,777	DK	669	1.84
			DE	1,088	5.74			SE	431	0.64
			FR	946	1.72			ES	212	3.04
			IT	395	10.69			NL	210	2.14
			LV	284	1.22			UK	144	1.08
Fish-liver oils and their fractions	4,706	14,937,216	FR	3,793	1.48	1,988	7,952,596	FR	1,091	1.76
			DK	573	12.73			PL	323	6.62
								DE	149	4.36
								DK	147	9.19
Flours, meals and pellets of fish, fit for human consumption	3,014	9,443,219	SE	1,709	1.36	612	5,254,941	SE	409	9.00
			LV	333	0.97			DK	122	7.06
			IT	295	6.05					
			FR	240	4.80					
			UK	123	4.02					
Fish fins and other edible fish offal, smoked dried salted or in brine	1,550	4,439,025	ES	467	4.51	1,733	7,186,855	NL	884	5.01
			BE	296	3.14			PT	437	2.94
			LT	254	0.31			ES	326	2.96
			LV	161	0.34					
			NL	135	2.90					
Fish livers and roes, dried, smoked, salted or in brine	1,474	15,156,044	IT	351	12.42	3,199	13,471,781	SE	1,634	2.59
			GR	235	3.97			DK	796	6.33
			ES	213	8.91			NL	390	3.60
			UK	195	4.82			UK	183	4.75
			LT	94	12.47					

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Edible goods	Export (Europe-Intra)					Export (Europe-Extra)				
	Volume of EU [t]	Value of EU [EUR]	CC	Volume [t]	Price [EUR/kg]	Volume of EU [t]	Value of EU [EUR]	CC	Volume [t]	Price [EUR/kg]
Frozen fish livers, roes and milt	3,758	23,848,684	NL	1,236	3.98	4,755	22,523,246	DK	1,481	9.28
			DK	1,108	8.38			PL	1,372	2.04
			UK	378	0.43			UK	943	1.42
			SE	276	3.71			DE	353	3.54
			ES	229	10.73			NL	316	4.64
Frozen fish fins, heads, tails, maws and other edible fish offal	5,609	12,599,824	SE	1,258	0.67	241,668	25,806,965	PL	78,047	0.09
			NL	833	1.49			UK	51,411	0.09
			DK	766	8.35			DE	24,362	0.19
			FR	546	1.58			FR	22,816	0.09
			LV	512	0.35			LT	17,060	0.09
Fish-liver oils and their fractions	1,249	30,525,065	FR	594	2.97	409	3,118,553	FR	148	2.94
			DK	379	29.76			UK	102	10.70
			DE	148	107.1			DE	93	5.42
Flours, meals and pellets of fish, fit for human consumption	4,393	11,983,210	LV	3,520	0.97	920	2,501,669	DE	643	1.88
			SE	398	9.02			IE	154	1.33
			DE	151	1.15			UK	65	6.77
			DK	131	8.01			FR	49	9.82
			FR	86	29.16					
Fish fins and other edible fish offal, smoked dried salted or in brine	2,811	8,285,908	NL	939	4.33	2,006	2,719,524	PT	927	1.30
			PL	1,045	1.73			UK	568	0.40
			BG	287	0.17			NL	204	3.50
			LT	245	2.43			ES	134	1.74
Fish livers and roes, dried, smoked, salted or in brine	1,438	13,209,233	PL	448	6.56	400	5,594,137	DK	248	6.80
			DK	287	12.01			ES	52	8.47
			NL	240	5.44					
			IE	197	2.59					

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