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GAIN

Green Aquaculture Intensification in Europe

Grant Agreement Number 773330

Deliverable D6.9
Report of the valorisation of secondary products in the aquaculture and biobased industries

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WP6

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Executive Summary

GAIN, Green Aquaculture INtensification in Europe, is a collaborative research and innovation collaborative project which is funded by the Horizon 2020 EU research programme supporting the ecological intensification of aquaculture in the European Union and European Economic Area. The ecological intensification of aquaculture should increase production volumes, profitability and the competitiveness of this sector, while ensuring sustainability, fish welfare and compliance with EU regulation on food safety and environment. These transdisciplinary and challenging objectives were achieved by integrating scientific and technical innovations with: an in-depth analysis of the value chains of the most important species produced in the EU/EAA, a review of current policies, in order to identify barriers to the ecological intensification of aquaculture, new approaches to the assessment of the sustainability of innovative feeds, husbandry practices and production processes. GAIN, in particular, focused on two pillars of the ecological intensification, which will open the way to the ecological transition of EU/EAA aquaculture, namely the implementation of Precision Fish and Shellfish Farming and the reuse of aquaculture by-products and side-streams, in the framework of the circular economy.

This deliverable summarizes the results of a comprehensive techno-economic analysis, aimed at assessing the potential exploitation of GAIN innovative circular processes, developed and tested in GAIN WP2. These processes concerned the cost-effective disposal and, whenever possible, reuse and valorization of:

- Aquafarming side-streams, namely: 1) **fish sludge** from RAS, Recirculating Aquaculture Systems, 2) **waste waters** from RAS; 3) **mortalities**.
- By products from fish and shellfish processing, namely heads, frames, trims, viscera.

They main results are summarized below.

Novel feeds, including as ingredients also Fish Protein Hydrolisates (FPH) extracted from by-products of farmed fish, were tested on Atlantic salmon, rainbow trout, seabass, seabream and turbot. The results of the feed trials showed that the growth performances, were, in general, comparable with those of commercial formulations, including higher pecentages of fish meal and fish oil derived from fishery. These innovative formulations, however, were in general more expensive and, at present, unsustainable from the economic point of view. Nevertheless, these feeds may become attractive for the industry in the near future, as, on the one hand, prices of fish meal and fish oil from fishery are likely to increase and, on the other, the demand for feeds with reduced or no such ingredients is increasing.

Fish sludge. Two processes for drying and sanitizing fish sludge were developed up to TRL 8 in GAIN. The first one combines a conventional filtering system and an energy efficient dryer, the second one is based on a standalone filtration/drying unit. In both cases, the final product is a sanitized powder, rich in organic matter, nitrogen and phosphrous, of high caloric content. The results of the economic analysis show that both systems are very promising options for sludge valorisation for a RAS smolt farm in Norway. Further arrangements, also with potential

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kickback opportunities when selling the final product to the biofertilisier industry, are conceivable. Considering the positive results of the environmental assessment of the two sludge valorisation methods (Christiano et al. 2021, D4.4), these methods might present valuable opportunities for enhancing RAS circularity.

Waste waters: open pond aquaponics. The results of the techno-economic analysis applied to a theoretical decoupled aquaponics system capturing dissolved nutrients from wastewater discharged by a smolt RAS in Nordland (Norway) showed that costs and returns of the theoretical aquaponics system seems to be a promising option. Besides potential additional returns and reducing wastewater nitrogen and phosphorus amounts, which might be required by future regulations, there could be the opportunity to increase production at the smolt farm site. In Norway, there is no precedence for increasing production by reducing the environmental loading, but it might be an option for a new facility and/or for smolt production outside Norway.

Waste waters: integrating carp pond farming and aquaponics. Including a RAS unit to replace carp wintering ponds is very promising and could ensure long-term profitability in the case of small-scale farms, such as the one investigated in the GAIN pilot case studies, which produces 26 tons/year. For this system, watercress is a self-sustainable co-product, with a share of 2.4 % of total returns. For future studies, it would be interesting to include marketing effort of aquaponic plant products within the cost-benefit analysis as well as a further exploration of culture opportunities of plant species other than watercress.

Mortalities. The innovative GAIN approach of processing mortalities and discarded fish utilizes the drying unit from Waister, sanitising fish biomass with a superheated steam drying technology. The results of the economic analysis indicate that this process has the potential to to turn dried mortalities into an interesting product, which could increase returns for the typical salmon grow-out farm taken as case study. They also suggest that conomic returns could be very promising for a (smolt) farm with labour-intensive ensilage process. The application of the process to other species would be straightforward.

Shellsfish by-products: shells as RAS biofilter filling media. GAIN tested he use of shells as filler for RAS biofilters. Even thugh this innovation achieved an intermediate TRL of 5, a preliminary economic analysis suggest that mussel shells could be a cost-effective alternative to plastic material. This is due to the assumption that mussel shells are free of costs except for their transport and that their disposal costs is assumed to be much lower compared to plastic material as well. At least in Spain, the mussel shell bio filter material could be used as soil fertilizer and only transport costs would occur here for their “disposal”. If this is also the case for Denmark is uncertain, but even here the disposal costs for natural material is assumed to be lower than for plastic material.

Fish by-products. In general, the processes tested in GAIN for extracting valuable secondary products from fish processing by-products turned out to be viable form the economic point of view. Of particular interest is the utilization of dry peptones and liquid peptones as growth media for LAC. The profitability of processing FPH is depending predominantly on the by-product type (trimmings/frames most promising for tested species and by-products). The valorization of fish by-products into gelatin did not proof to be profitable in the current input-

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output analysis, under the assumption adopted in the economic analysis carried out in GAIN. The supplementary analysis carried out for assessing the potential market of secondary products deriving from the processing of rainbow trout in Italy confirmed that farmers are interested in these innovations, but extraction processes require a minimum volume to become remunerative. Therefore, it is likely that only farmer OP /cooperatives with centralize processing plants, could undertake these circular valorization pathways.

Adding value to FPH as pet-food ingredients. The results of a comprehensive study indicates that the pet food sector is demanding high quality, sustainable ingredients and is shifting towards higher protein content feeds. A modified process for producing High Protein Partial Hydrolisates from seabass and seabream by-products is outlined. The results of an “a priori” financial analysis and a 5-year business plan estimating the necessary investments, the costs, the go-to-market strategy, as well as an estimated profit and loss, show that this process could become profitable for a rendering plant treating 5000 tonnes of product per year. High quality- partially hydrolysed and sustainable fish meal has wide applications in European pet-foods and will obtain for these purposes a price premium over a conventional meal, but to benefit from this the control of raw fish quality and of processing conditions must be very strict. Special types of fishmeal have proved beneficial in many applications, there is little doubt that, in future, a wider differentiation in the fishmeal products will be part of a sustainable aquaculture model.

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1. Introduction

GAIN, Green Aquaculture INtensification in Europe, is a collaborative research and innovation collaborative project which is funded by he Horizon 2020 EU research programme supporting the ecological intensification of aquaculture in the European Union and European Economic Area. The ecological intensification of aquaculture should increase production volumes, profitability and the competitiveness of this sector, while ensuring sustainability, fish welfare and compliance with EU regulation on food safety and environment. These transdisciplinary and challenging objectives were achieved by integrating scientific and technical innovations with: an in-depth analysis of the value chains of the most important species produced in the EU/EAA, a review of current policies, in order to identify barriers to the ecological intensification of aquaculture, new approaches to the assessment of the sustainability of innovative feeds, husbandry practices and production processes. GAIN, in particular, focused on two pillars of the ecological intensification, which will open the way to the ecological transition of EU/EAA aquaculture, namely the implementation of Precision Fish and Shellfish Farming and the reuse of aquaculture by-products and side-streams, in the framework of the circular economy.

Innovative circular processes were developed and tested in GAIN WP2 and assessed in WP4, taking into account the social, economic, and environmental sustainability pillars. In particular, the economic analyses were performed in Task 4.1, the environmental and social ones were carried out in Task 4.3. The potential impact of GAIN innovations on the value chains of the most relevant species cultured in the EU was investigated in Task 4.2. GAIN exploitation activities were carried out in WP6, Task 6.4: in accordance with the two main pillars of the project, this Task was divided into two sub-tasks, focused, respectively, on the exploitation of the tools developed for implementing precision aquaculture (6.4.1) and of the innovative circular processes (6.4.2).

This deliverable integrates the main outputs of Task 4.1, led by TI, and subtask 6.4.1, led by LLE and carried out in collaboration with UNIVE, in order to provide a comprehensive overview of the perspective exploitation of the GAIN output related to the enhancement of circularity in the aquaculture industry. The document includes an introduction, Chapter 1, and other 7 Chapters, which present the results of the economic analysis and potential valorisation of GAIN innovations concerning: fish feed (Chapter 2); reuse of fish farming side streams, i.e. wastewater and mortalities (Chapter 3); reuse of shells from the shellfish canning industry (Chapter 4); reuse of fish processing by-products, 5) a preliminary analysis of the potential exploitation of rainbow trout by-product, with focus on the Italian market (Chapter 6). Chapter 7 presents the results of a comprehensive study exploring the potential use of proteins extracted form seabass and seabass by products in the pet food industry. This study, besides proposing further technological innovations to be tested in future projects, provides quantitative elements which could be useful for designing a business plan. The main conclusions are summarized in Chapter 8.

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2. Novel feed

Within WP1, eco-efficient feed formulations for trout, turbot, salmon and seabream were developed to improve circularity and sustainability of feed as well as performance of production by using European sourced ingredients, GAIN ingredients from circular economy principles and partly emerging ingredients such as insect meal. Within feed trials conducted by GAIN partners, effects on feed conversion ratio (FCR), health aspects, growth rate and mortality were examined amongst other parameters. Information on feed formulations contain only the most important differences to currently used standard feed, for more detailed information on please refer to (Conceição et al., 2021).

The results presented in this section were obtained by carrying out a cost-benefit analysis based on the "typical farm" approach, described in detail in (Kreiss and Brüning, D4.1). Data concerning the results of feed trials (FEM: trout, CSIC: seabream, AWI: turbot; seabass, GIFAS: salmon) and novel feed prices (***Table 2.1***) of the second feed trial block for seabream, salmon and trout (Conceição et al., 2021) were used as input to selected typical or example farms of these species.. Thereby results, although covering only part of grow-out production cycle, were interpolated for the whole grow-out production cycle.

Table 2.1*: Estimated fish feed prices for novel feeds of the second experimental block expressed as % difference to a standard control feed (control feed representing 100%). NoPAP= (diet containing) no processed animal proteins, PAP= (diet rich in) processed animal proteins. + and – indicate expensive high quality ingredients or cost-effective ingredients, respectively. The addition of "30" and "60" indicates a formulation were 30% /60% of fishmeal is replaced by other ingredients.*

Diet	CTRL	NO PAP 30	PAP 30	NO PAP 60	PAP 60
Turbot	100	88	80	94	85
	CTRL	NO PAP	PAP	NO PAP+	PAP-
Seabass	100	149	130	166	112
Rainbow trout	100	123	112	149	93
Atlantic salmon	100	103	87	131	68
	CTRL	NO PAP SANA			
Seabream	100	139			

2.1 Salmon

The salmon feed trial results and estimated market prices of the respective novel feeds applied to a typical salmon farm in Nordland, Norway, led to substantial changes in profitability compared to the usage of control feed. **Figure 2.1a** 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 per kg gutted fish.

Feed costs differ for some feeds strongly between the type of feed (***Table 2.1***). And this leads to clear deviations of the typical farm's short-term profitability as shown in **Figure 2.1b**. Short-term profitability describes returns deducted by cash costs including feed costs.

Most novel feed types led to lower profits up to one third below control for the NoPAP feed including vegetable protein and fishmeal, besides emerging ingredients (**Figure 2.1b**). The

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improved NOPAP⁺ feed is the most expensive formulation, but due to no differences in fish performance compared to control feed (in contrary to the NOPAP feed, where FCR and weight GAIN were impaired compared to control), profits are slightly better than for NOPAP feed. PAP feed in general led to highest FCR and lowest weight GAIN within feed experiments, however the cheap version (PAP-), which costs almost one third less than the control feed, reveals the opportunity to increase profits by 9 %.

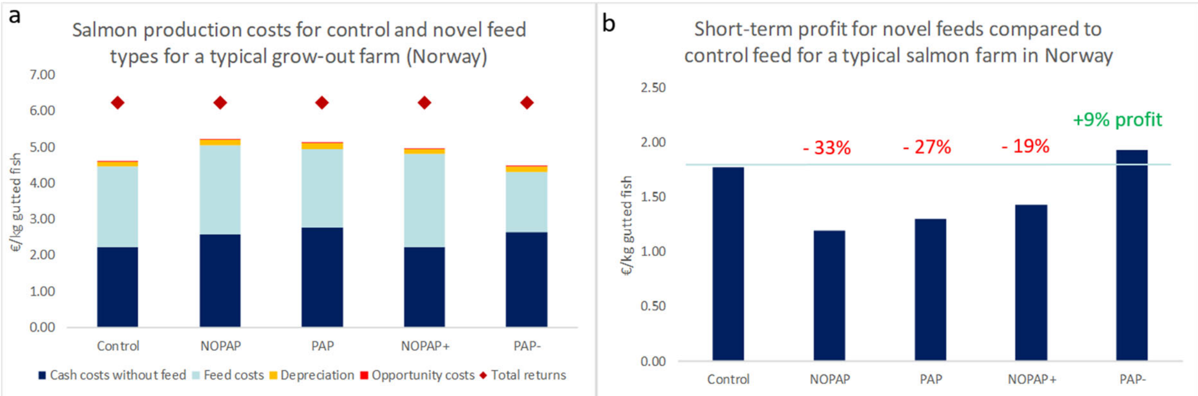

***Figure 2.1**: **a)** stacked costs and returns for the utilization of GAIN novel feed types compared to control feed for a typical grow-out salmon farm in Nordland, Norway (3200 t gutted fish/year, 2018 data GIFAS) and **b)** and deriving short term profitability indicating losses and additional profits for novel feed types compared to control feed.*

2.2 Turbot

The turbot feed trial results and estimated market prices of the respective novel feeds were applied to a modelled turbot example farm (land-based tanks) based on expert knowledge (TI) and literature (Person-Le Ruyet 2002, Bjørndal & Palmieri 2008; Bjørndal & Fernandez-Polanco, 2011)[1,2].

Figure 2.2a shows the stacked costs and returns of such a farm, whereas short-term profits indicating losses or additional profits for novel feed types compared to control feed are depicted in **Figure 2.2b**.

All novel turbot feeds represent cheaper alternatives to a typical control turbot feed (***Table 2.1***), whereas production performance differed significantly between these diets with subsequent impacts on short-term profit.

NOPAP30 feed, replacing 30% of fishmeal by other ingredients compared to control feed without adding land animal protein, has the potential to achieve a plus in profit (21%), as FCR, weight gain and mortality were not significantly altered compared to control. The utilization of the other feed types (PAP30 and PAP60 replacing respectively 30% and 60% of FM and including land animal protein); NOPAP60 replacing 60% of FM and containing no landanimal protein) lead to significant reductions in FCR and weight gain losses in profit, which cannot be balanced by lower prices in feed ingredients compared to control feed.

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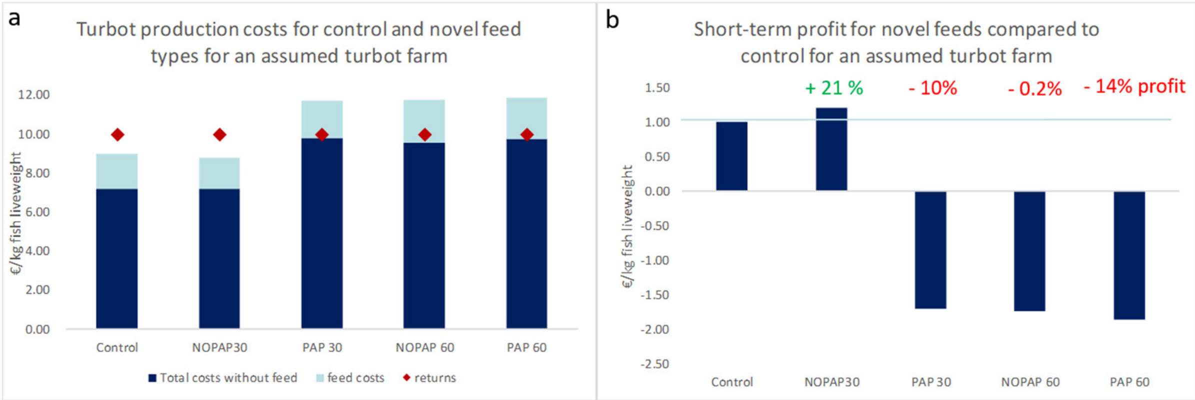

__Figure 2.2: a)__ stacked costs and returns for the utilization of GAIN novel feed types compared to control feed for an example grow-out turbot farm (250 t fish/year, 2018 data TI) and __b)__ and deriving short term profitability indicating losses and additional profits for novel feed types compared to control feed.

2.3 Seabream

A typical seabream farm located in Turkey and defined within the CERES project together with the University of Mersin was used as baseline to evaluate the costs/benefits of utilizing a novel feed formulation for seabream production. A typical netcage farm often combines seabream and seabass production, however in this section (**2.3)** we will only concentrate on seabream, whereas seabass is discussed in the following section (**2.4)**.

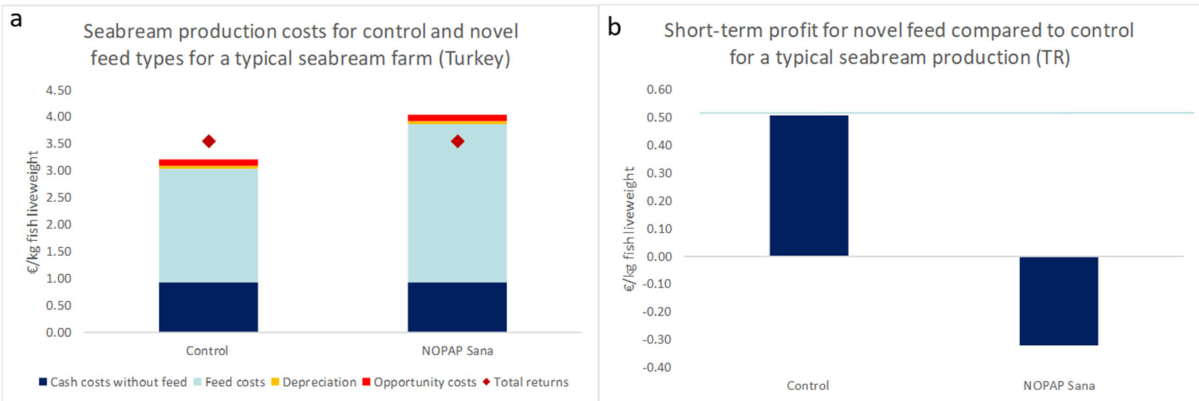

***Figure 2.3**: **a**) stacked costs and returns for the utilization of GAIN novel feed types compared to control feed for an example grow-out seabream & seabass farm in Turkey (1000 t fish/year, 2016 data) and **b**) and deriving short term profitability indicating losses and additional profits for novel feed types compared to control feed. Typical farm data was collected by the University of Mersin within the CERES project (Climate change and European Aquatic RESources, European Union's Horizon 2020 research and innovation programme under grant agreement No 678193).*

Stacked costs and returns of seabream production in Turkey are shown in **Figure 2.3a**, whereas short-term profits indicating losses/additional profits for the novel feed type NOPAP Sana compared to control feed are presented in **Figure 2.3b**.

NOPAP Sana is a formulation that replaces the usual fishmeal share within seabream feed by insect meal and bacterial fermentation biomass, supplemented with the health-promoter additive SANACORE®GM (Palenzuela et al., 2020). The latter component provides support for the intestinal flora equilibrium in order to prevent an increased susceptibility to enteric

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parasites that was associated with other low fishmeal diets (Piazzon et al., 2017). From a physiological perspective the NOPAP Sana is a promising diet, whereas the comparably high formulation costs (+39%, ***Table 2.1*, Figure 2.3a**) would result in a non-profitable production for the example presented here (**Figure 2.3b**).

2.4 Seabass

For sebass production four different novel diets (NOPAP, PAP, NOPAP+ and PAP-) were tested and the growth performance results as well as differences in feed formulation prices applied to a typical seabass netcage farm (1000 t) in Turkey (see also 1.1.3).

Figure 2.4a compares stacked costs and returns of the novel feeds compared to a typical control feed, whereas **Figure 2.4b** shows the overall impact on short-term profits relative to control feed.

NOPAP, PAP and PAP- diets are all free of fishmeal replaced by insect meal, fish by-products and yeast biomasse as well as land animal protein for the PAP formulations, whereas PAP- represents the highest share in land animal protein ingredients and was designed to represent a threshold with expected lower growth performance compared to PAP feed. NOPAP+ includes FM and was enriched with krill meal instead of fish by-products representing a very high quality formulation.

All diets were classified as viable alternatives to an industrial standard feed with regard to growth performance and no significant differences in FCR, weight gain or mortality could be detected in comparison to the control feed (see Conceição et al., 2021). Differences in costs and subsequent profits (**Figure 2.4a** and **Figure 2.4b**) therefore solely reflect differences in feed formulation prices (see ***Table 2.1***). Due to the more expensive novel feeds compared to the control diet, reduced profits were observed under all four novel feed types. With the use of NOPAP+ feed throughout grow-out production the farm would not be profitable any longer (on short-term scale), whereas expected losses would be less severe for the other novel diets (**Figure 2.4b**), with PAP feed being most promising from an economic point of view (-18% profit).

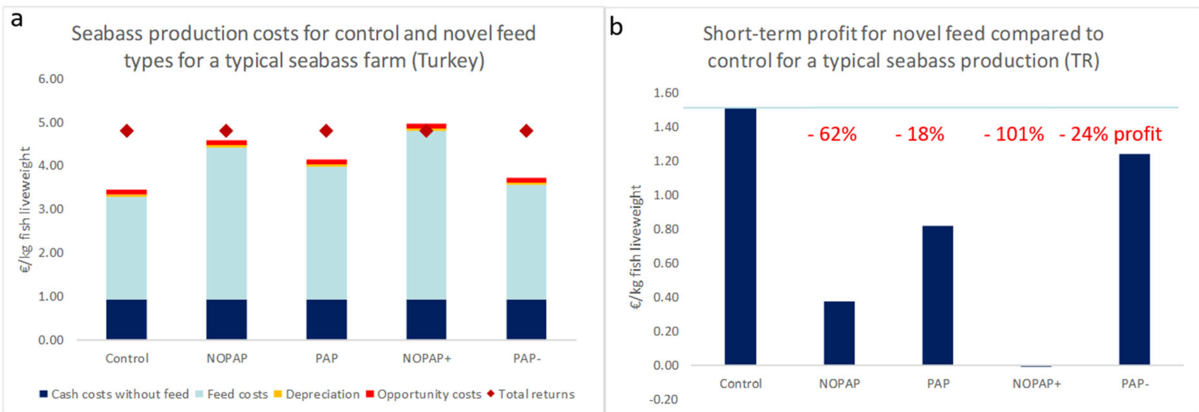

***Figure 2.4**: **a)** stacked costs and returns for the utilization of GAIN novel feed types compared to control feed for a typical grow-out seabass & seabream farm in Turkey (1000 t fish/year, 2016 data MEU) and **b)** and deriving short term profitability indicating losses and additional profits for novel feed types compared to control feed.*

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2.5 Trout

Applying the trout feed experiment results to a typical German trout farm producing in raceway and pond with a yearly volume of 50 tons reveals a slight increase in profit for PAP- feed, whereas profits under utilization of PAP feed is very similar to control feed (-2% profit) and both NOPAP feed types lead to losses of about 11-12%, although for these two feeds the growth performance was improved (**Figure 2.5a** and **Figure 2.5b**). In contrast, for PAP- feed the FCR was higher compared to control feed, but due to the comparably low price for this feed (***Table 2.1***) we can achieve slightly higher profits here.

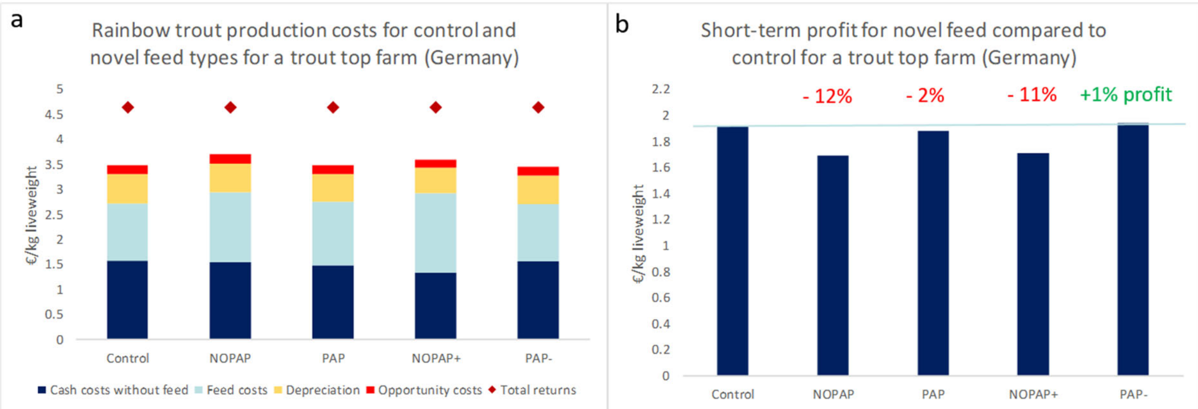

Figure 2.5: a) *stacked costs and returns for the utilization of GAIN novel feed types compared to control feed for a grow-out top partly RAS farm in Germany (150 t fish/year, 2019 data TI) and* ***b)*** *and deriving short term profitability indicating losses and additional profits for novel feed types compared to control feed.*

2.6 Overall discussion novel feeds

The results above confirm the importance of economic cost-benefit analyses in addition to feed trials, besides environmental sustainability assessment and the evaluation of social acceptance of novel feeds. In general, novel feeds that were promising from a growth performance perspective (NOPAP feeds), were in most cases economically unfavourable. The only exception here is NOPAP30 turbot feed, which offers the opportunity to increase profits (+21%) as this diet is cheaper compared to the standard diet, but did not significantly effect growth performance in contrast to all other diets tested for this species. Although growth performance results for PAP feeds were least promising within salmon, seabass and trout feed trials, formulation costs are comparably low (especially for PAP-) and for these species novel feeds including livestock by-products were economically most promising. For turbot the picture was different, the unfavourable growth performance exceeded by far potential benefits from cheaper formulation costs here.

In addition, differences in feed conversion and price per kg control feed for the presented species and typical farms should be taken into account as well. For the typical farms chosen here, similar costs per kg fish produced occur for seabream, seabass and salmon production, whereas turbot and especially trout require lower expenses per kg fish produced. The latter revealed also most promising results for growth performance, which explains to a large extend the comparably small impacts on profits across all novel feed types for trout.

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Especially for emerging feed ingredients, such as insect meal, future price developments are not easy to estimate. In general, commodity prices may vary for different reasons and especially those of globally traded commodities, which is often the case for feed ingredients. Price developments for marine substitutes are not expected to necessarily lead to lower feed prices in the future, especially if market prices are linked as previously assumed for fishmeal markets and soybean meal (Asche et al., 2013; Kreiss et al. 2020).

Consumer willingness-to-pay for fish produced according to more eco-efficient standards might therefore be crucial in order to balance potential profit losses. As pre-requisite, environmental sustainability assessments, the provision of their results in adequate form to the consumer as well as product-specific market knowledge, is very important. Preferences for sustainable lifestyle and products is known to differ between age, education and location of stakeholders/consumers (Krause et al. 2020 D3.7; Maesano et al. 2020).

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3. Valorization of aquaculture side streams

In this chapter we present the results of a cost-benefit analysis based on the "typical farm" approach, described in detail in (Kreiss and Brüning, D4.1),concerning the innovative processes for valorizing aquafarming side streams developed and tested in GAIN WP2, Task 2.1 namely:

1) fish sludge;
2) waste waters
3) mortalities

3.1 Valorisation fish sludge

Based on the results of particle removing from RAS wastewater (see Johansen et al. 2019, D2.1 and Bruckner et al., 2020, D2.5 and 2.5), a number of scenarios for the valorisation of dried and sanitized sludge were calculated and compared to conventional sludge treatment for a representative smolt RAS farm in Norway (producing 1300 t) (Nordland) (see also 2.3.1). The conventional method of treating sludge from wastewater at such a land-based smolt farm is a filter system including a drying process that increases the dry matter (DM) content of sludge to a level of about 20%. Within GAIN such a conventional filter system was 1) combined with a Waister 60 superheated dry steamer achieving a final sludge with DM content of 90-95%, and 2) replaced by the system "S3/S4" (LS Optics), that combines a filtration process with a vacuum supported infrared technology evaporating up to >90% of the water content (>90% dry matter). Besides differences in investment for the respective equipment and further costs for installation and maintenance of machinery, there are also differences in work effort, energy demand and additional control costs for lab analyses of the dried sludge, whereas disposal costs for wet sludge are avoided. For both processes: "conventional filter system + Waister 60" and "S3/S4" as standalone filtration/drying unit three different marketing scenarios were calculated and the results of the respective cost-benefit analyses compared to that of the conventional filter system, each for our representative 1300 t smolt farm.

Scenario 1 (Biofertiliser industry) refers to free-of-charge collection of dried fish sludge at the farm with transport costs paid by the bio-fertiliser company (30-34 €/ton) and no redistributed profit for the fish farm. Within scenario 2 dried sludge is delivered at the expense of the fish farm to a cement factory (12 €/ton) receiving returns of 27 €/ton for the product. Scenario 3 describes the delivery of the dried sludge product to a biogas plant at the expense of the fish farm (17 €/t) without receiving any returns.

As presented in **Figure 3.1** and **Figure 3.2**, short-term profits (returns- cash costs), but especially mid-/ and longterm profits (including depreciation) of a land-based RAS smolt farm can be increased when including a Waister drying unit in addition to the conventional waste water filter system or completely replacing the latter by a S3/S4 filter and drying unit. Short-term profit increases for both systems under all scenarios by about 3% (9-10 cents/kg smolt liveweight), whereas on mid- and long-term scale only a proportional increase of profit up to

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about 5 % for additional sludge drying with Waister 60, but not in absolute terms and up to 7% for the S3/S4 unit (12 cents/kg liveweight) can be achieved.

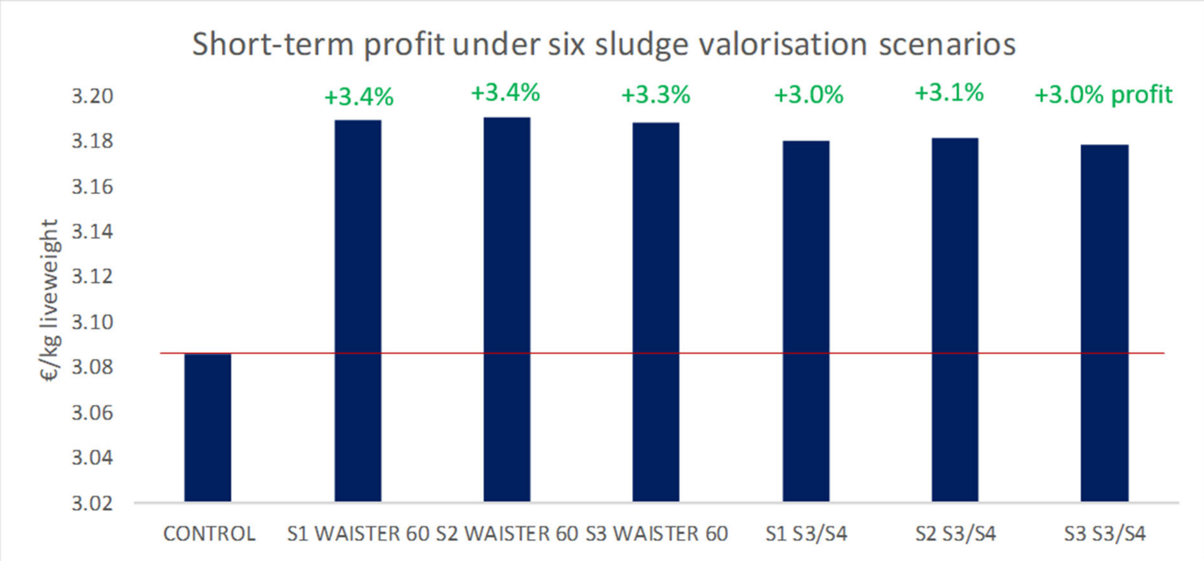

Figure 3.1: *Surplus returns for an example smolt farm in Norway (1300 t) per kg produced fish using a Waister 60 drying unit or a S3/S4 filter system and distributing the respective product (dried sludge) compared to conventional wet sludge being disposed (on mid-/long-term scale) for each of 3 scenarios: 1) collected free-of-charge for the fish farm by the biofertiliser industry without receiving returns 2) sold to cement industry including also transport costs paid by the fish farm, 3) transported to the bioplant industry at the expense of the fish farm without receiving returns.*

Although work effort (less for Waister 60, increased for S3/S4 system), electricity demand and fixed costs including maintenance of machinery, control costs for sludge quality and installation costs in the first year, differ compared to the conventional filter system, the avoidance of wet waste disposal costs (1.5 mio NOK/year) balances these mostly higher costs easily. This is even the case for scenario 3 were transport costs would have to be paid to deliver the dried sludge (102 t) to a bioplant industry without receiving returns.

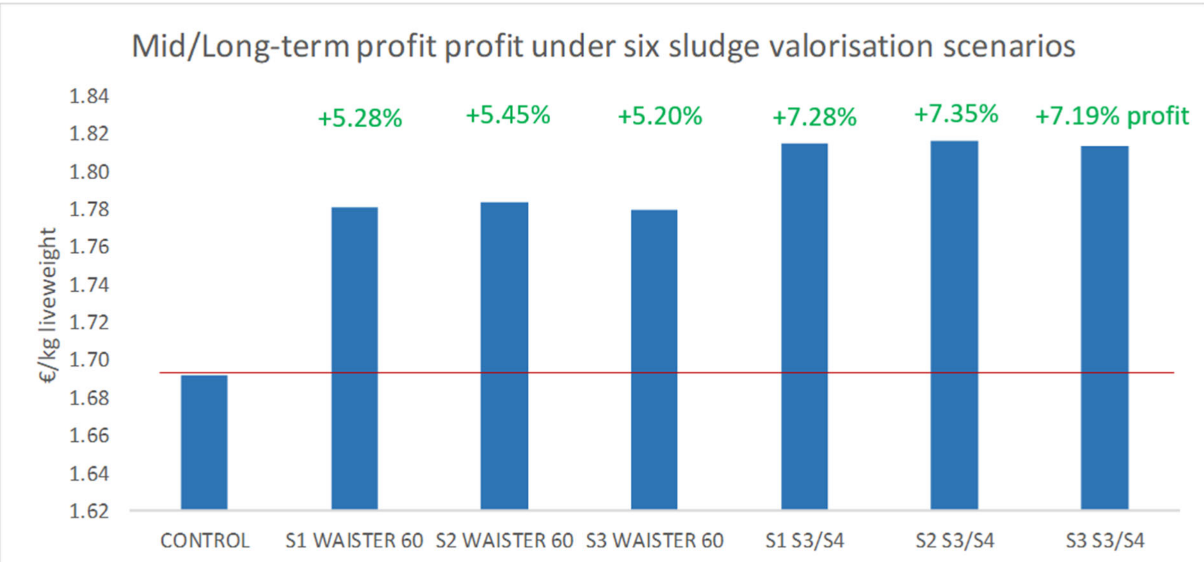

Figure 3.2*: Surplus returns for an example smolt farm in Norway (1300 t) per kg produced fish using a Waister 60 drying unit or a S3/S4 filter system and distributing the respective product (dried sludge) compared to*

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conventional wet sludge being disposed (on mid-/long-term scale) for each of the three scenarios: 1) collected free-of-charge for the fish farm by the biofertiliser industry without receiving returns 2) sold to cement industry including also transport costs paid by the fish farm, 3) transported to the bioplant industry at the expense of the fish farm without receiving returns.

On long-term scale, depreciation for the Waister 60 drying unit adds to the conventional filter system, but cash costs are further reduced compared to the short-term view as from the second year onwards no additional installation costs for the set-up of the Waister 60 are occuring. Total assets for equipment and buildings are significantly lower for the S3/S4 filter system compared to the conventional system in combination with Waister 60 (about 5.5 mio NOK), leading to higher profits on mid-and longterm scale (returns deducted by cash costs, depreciation (mid-term) and opportunity costs (long-term).

These results indicate, that both, the combination of the conventional filter system, as well as a replacement of the latter by the S3/S4 filter system, would be very promising options for sludge valorisation for a RAS smolt farm in Norway from an economic point of view. With commercial agreements being often arranged on individual basis, the scenarios described here should be understood as examples. Further arrangements, also with potential kickback opportunities when selling to the bio-fertiliser industry are conceivable. Referring to the positive results of the environmental assessment of the two sludge valorisation methods (Cristiano et al. 2021, D4.4), these methods might present valuable opportunities for RAS aquaculture operations in the future.

3.2 Valorisation of waste waters

This section includes the economic analysis of three processes, namely: 1) the extraction of dissolved inorganic nitrogen and phosphorus using open pond aquaponics, tested in Norway by SHP; 2) a low cost aquaponics system for shortening the carp grow-out cycles, tested in Poland by ZUT.

3.2.1 Valorisation of wastewater: Algae aquaponics

Based on the results of the pilot scale aquaponics experiments with Ulva lactuca (Bruckner et al., 2020, D2.5), a theoretical decoupled aquaponics system capturing dissolved nutrients from smolt RAS wastewater was defined for the region of Nordland in Norway (**Figure 3.3**). A production area of 9.9 ha was assumed to achieve a total yearly harvest volume of 1093.9 t fresh biomass of U. lactuca equivalent to 109.4 t of dry matter taking into account 15% biomass loss. The production period was set from February to October including 120 days of lower light condition (2.22 t biomass/d) and 153 days of good light condition (6.67 t biomass/d). This is equivalent to a total capturing capacity of 2.66-2.78 t of nitrogen (N) and 0.16-0.17 t of phosphorus (P) per year from the smolt RAS wastewater (see also Bruckner et al., 2020, D2.5). Five tons of wild U. lactuca was assumed as required initial stocking material. Re-stocking within the continuous production system is subsequently achieved through re-introducing part of the harvested U. lactuca biomass as shredded fresh material.

Based on the experience of SHP, it was assumed that 10% of the harvest is algae biomass with a high quality that can be marketed at 30,000-50,000 €/t, 50% is of medium quality (10,000-30,000 €/t), 20% is equal to feed quality (50-100 €/t) and the remaining 20% is of low quality (30-40 €/kg). Accordingly, a weighted average of 14,000 €/t (14,000 NOK) was assumed for

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the subsequent calculations. In addition, a price research on the B2B platform alibaba.com was conducted (see **Table 3.1**), confirming a wide span of market prices for Ulva products. However, it is very difficult to base an average price estimate on the available Alibaba offers, as not all qualities are offered here (to the same extend). Product quality and species' origin cannot be reliably assessed on the basis of the available information, but according to the price ranges found, mostly Ulva in feed quality is offered, most likely from wild collection. The highest quality level, aimed at the delicatessen market (e.g. seasoning), is only marketed rarely, whereas the lowest quality (e.g. for biogas industry) seems not to be marketed on this platform at all.

***Table 3.1**: Example offers and related price ranges for Ulva lactuca products from B2B platform alibaba.com with self-assigned quality category. Product categories were reproduced analogously. Keywords applied in product research: Ulva lactuca, sea lettuce, dried.*

Price range *Ulva lactuca* (dried) - examples; German Alibaba, 2021-06-10*

Category	Product description	Range per t ($)		Range per t (€)**	
Feed quality	Dried *Ulva Lactuca* Powder (Sea Lettuce)	$ 50.00	$ 100.00	41.50 €	83.00 €
Feed quality	*Ulva lactuca* dried green seaweed	$ 50.00	$ 90.00	41.50 €	74.70 €
High quality	Wholesale Japanese Sea lettuce *Ulva Lactuca* dried	$ 180,000.00	$ 250,000.00	149,400.00 €	207,500.00 €
High quality	Darkgreen Sea Lettuce *Ulva Lactuca* Extract high grade	$ 610,000.00	$ 720,000.00	506,300.00 €	597,600.00 €

* German alibaba, 10. Juni 2021
**1 $ = 0,83 €

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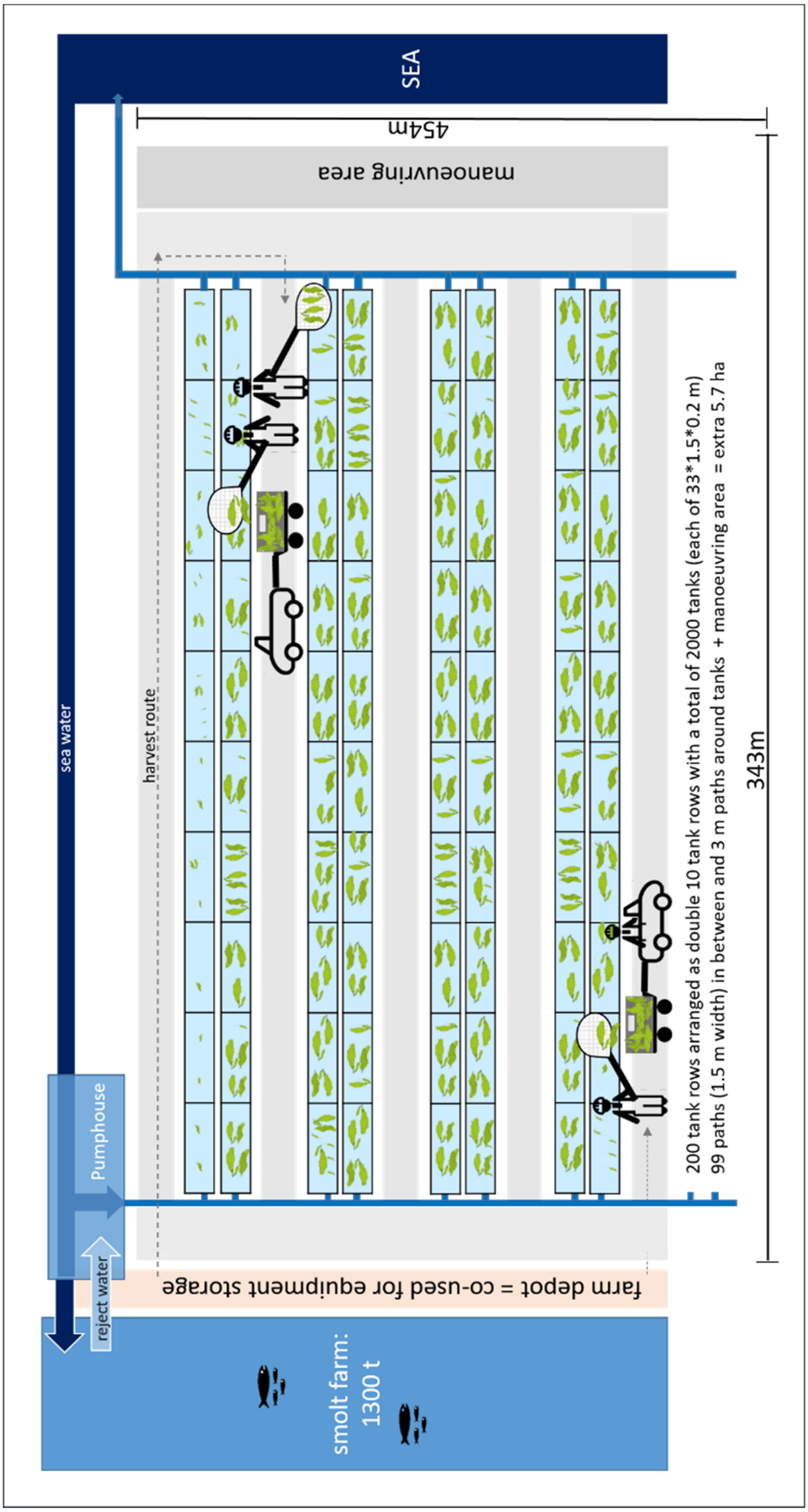

Figure 3.3: *Sketch of decoupled aquaponic system for Ulva lactuca grown in a mix of smolt waste water (30%) and seawater (70%) as downstream production system of a smolt RAS system (1300 t annual production) in Nordland, Norway. Total area is 15.6 ha, with 9.9 ha tanks, ordered in rows of 10 tanks each (33m length*1.5m width* 0.2 m depth) and 5.7 ha concrete paths/manoeuvring area. Water supply is provided through the facilities of the smolt farm (pumphouse), as well as part of the smolt farm production facilities is co-used (farm depot).*

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Besides the area of concrete basins for cultivation of U. lactuca, an additional area of 5.7 ha was assumed to provide access for maintenance and harvest of the algae as well as for vehicle manoeuvring. Harvesting was assumed to be conducted manually (hand nets) with the support of narrow track tractors and industrial trailers. All necessary equipment as well as related and additional fixed, variable and depreciation costs are specified in *Table 3.2*.

***Table 3.2**: Investment and costs for a theoretical U. lactuca decoupled aquaponics system ba sed in Nordland, Norway in NOK per year.*

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Investment/costs p.a. for 10ha *Ulva lactuca* decoupled aquaponic system; Nordland, Norway			
	Amount	**Lifetime (years)**	**Depreciation**
Production licence	30,000 NOK	30	1,000 NOK
Asphalt paths + manoeuvring area (56.894 m², 140 NOK/m²)	7,965,160 NOK	30	265,505 NOK
Concrete basins (99.000 m²)	15,000,000 NOK	30	500,000 NOK
Water supply system (pipes & valves)	1,700,000 NOK	10	170,000 NOK
Narrow track tractors for harvest, 5 vehicles à 35kW, 300.000 NOK	1,500,000 NOK	6	250,000 NOK
5 Industrial trailer for harvest, 5t, 35.000 NOI	175,000 NOK	20	8,750 NOK
Compost grinder, 20 kW	25,000 NOK	10	2,500 NOK
Total investment	**26,395,160 NOK**		
Total depreciation			**1,197,755 NOK**
Interests (1,49% of 1/2 investment)			**196,644 NOK**
Fixed costs			
Lease rate for total area (618 NOK/ha; 15,59 ha)			9,635 NOK
Rental fee common and washrooms, 5.000 NOK p.m., 9 mon			45,000 NOK
Fixed costs tractors (without interest and depreciation)			23,125 NOK
Fixed costs trailers (without interest and depreciation)			467 NOK
Insurance			7,000 NOK
Total fixed costs			**85,227 NOK**
Variable costs of production system and equipment			
Maintenance water supply system (2% of invest)			34,000 NOK
Maintenance tractors (30 NOK p.h.; 1.584 h p.a./tractor)			237,600 NOK
Fuel (4,3 l/h; 17 NOK; 1.584 h p.a./tractor)			578,952 NOK
Maintenance trailers (0,32 NOK p.h.; 1.584 h p.a/trailer)			2,500 NOK
Maintenance compost grinder (3% of invest)			750 NOK
Electricity compost grinder (515 h; 0,7405 NOK/kWh)			7,624 NOK
Total variable costs			**861,426 NOK**
Fixed and variable costs of production system and equipment			**2,341,052 NOK**

A fully distributed costs analysis was then conducted based on defined fixed and variable costs, the required operating staff, costs for initial stocking, depreciation of equipment, machinery and licensing, rent for rooms, opportunity costs and returns based on market price estimations from SHP (*Table 3.2*; **Table 3.3**). Thereby, it was assumed that part of the smolt farm infrastructure could be co-used. This includes the pumping system for supplying the

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aquaponics farm with a mixture of 30% smolt wastewater and 70% seawater as well as the farm depot for storing part of the equipment. Further, it was assumed that U. lactuca is sold to a processor that organizes also collection of the fresh biomass for a certain withhold of the final market returns. To estimate costs, professional sources were used wherever possible (see **Annex 1**) and complemented with expert judgement from SHP.

***Table 3.3**: Cultivation details and costs for a theoretical U. lactuca decoupled aquaponics system based in Nordland, Norway in NOK per year.*

Cultivation of *Ulva lactuca*			
	days	t FM p.d.	t total
Yield	153	6.67	1020.5
	120	2.22	266.4
		Fresh biomass total	**1286.91**
Fresh biomass loss (15%)			193.0
Fresh biomass harvest volume			1093.9
Dry Matter (10%)			**109.4**
	Yield (t DM)	**Price**	**Total**
Assumed returns for processed product	109.4	140.000 NOK	15,314,229 NOK
Withhold of processor (10 % for transport, processing, resale discount)			- 1,531,423 NOK
Returns for aquaponic company (net)			13,782,806 NOK
Transport wild *U. lactuca* for initial stocking			- 3,280 NOK
Permit for coastal access to collect wild *U. lactuca*			- 1,000 NOK
Wage and non-wage costs (15,9 employees/23760 h/358 NOK)			- 8,482,320 NOK
Equipment for wild *U. lactuca* collection (2.500 NOK p. employer)			- 39,775 NOK
Hand nets for harvest (15 p.a.)			- 10,000 NOK
Total variable production costs			**- 8,536,375 NOK**
Total fixed and variable costs of production system/equipment			**- 2,341,052 NOK**
Total profit			**2,905,379 NOK**

Based on the assumptions above, three different scenarios were calculated (**Figure 3.4**, for more details Annex I). Scenario 1 is assuming a final market return of 140.000 NOK/ton dried U. lactuca and a 10% lower return for the aquaponics farm when including resale discount, collection and processing costs of the processor. Scenario 2 assumes as well a fixed withhold of 10% from the final market return by the processor, but based on the minimum final market return when applying the principle of recovery costs for the algae aquaponics farm on a long-term scale.

Scenario 3 is also applying the principle of recovery costs based on the final market value from scenario 1 in combination with the maximum possible withhold of the processor.

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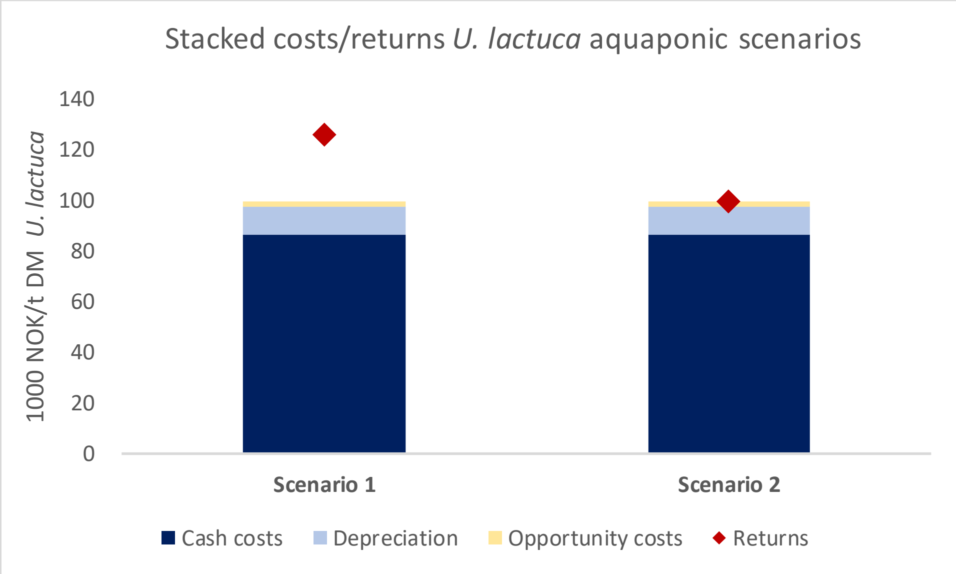

***Figure 3.4**: Stacked costs and returns for two U. lactuca aquaponics scenarios: 1) assuming final returns of 140.000 NOK/ton dried U. lactuca and a 10% withhold by the processor, 2) applying the principle of cost recovery by assuming minimum final market return with 10 % withhold by processor (2) and maximum withhold by the processor from final market returns of 140.000 NOK.*

Under scenario 1, the final returns per ton of fresh biomass would account for 2656 NOK on a long-term scale (26.560 NOK/ t dry mass). Here the algae aquaponics farm would be self-sufficient under the given assumptions, which is also illustrated by the gap between all stacked costs and the indicated returns above in **Figure 3.4**.

Scenario 2 was designed under the principle of recovery of costs without achieving profits to explore the maximum final return that is feasible for the theoretical aquaponics system. The results reveal a potential final market price volatility of 21% (scenario 2). A third scenario was calculated to represent the maximum withhold of the final market price by the processor based on the current market price resulting in a potential withhold of up to 29 % without achieving profits (see Annex I for more details).

Within the assumed production circumstances, costs and returns of the theoretical aquaponics system seems to be a promising option to connect to a smolt RAS farm. Besides potential additional returns and reducing wastewater nitrogen and phosphorus amounts, which might be required by future regulations, there could be the opportunity to increase production at the smolt farm site. In Norway, there is no precedence for increasing production by reducing the environmental loading, but it might be an option for a new facility and/or for smolt production outside of Norway.

The absolute captured nitrogen and phosphorus by *U. lactuca* is equal to 45-71 % of dissolved N and 3-6% of dissolved P within the smolt wastewater. With P being the limiting factor here, a potential production increase would be rather low and producing larger smolt might be the the best option. Besides the reduction of P and N, also a reduction of the organic load would be required to create the prerequisite for such an increased smolt production. This could be achieved by means of sludge valorisation as discussed within the section 2.3.4.

3.2.2 Valorisation of wastewater from an integrated aquaponic RAS within carp pond

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farming

An example Polish carp farm producing 26 tons during a 3 year cycle (33 months) and located in the region of Western Pommerania was defined together with the project partner ZUT and relevant stakeholders according to the typical farm approach methodology. Most of the carp farms are located in the south of Poland within the voivodeships Subcarpathia, Lesser Poland, Lublin, Silesia, Greater Poland and Opole. The farm defined within GAIN should therefore not be understood as typical carp farm for Poland (see Lasner et al. 2020 for respective farms), but as example farm that reflects the conditions of the pilot study conducted within the project.

In a second step, costs and returns were defined for a modified version of this farm including an integrated RAS system that allows shortening of the production cycle to a total of 19 months and additional production of watercress (Nasturtium officinale) within an aquaponics system. Related costs and adaptation in production practices (***Figure 3.5***) derived from the pilot RAS farm operated by ZUT, additional returns for the production of 1620 kg of watercress derived from the platform Tridge*, that systematically collects and analyses wholesale and farmgate prices* (assessed in April 2021: www.tridge.com).

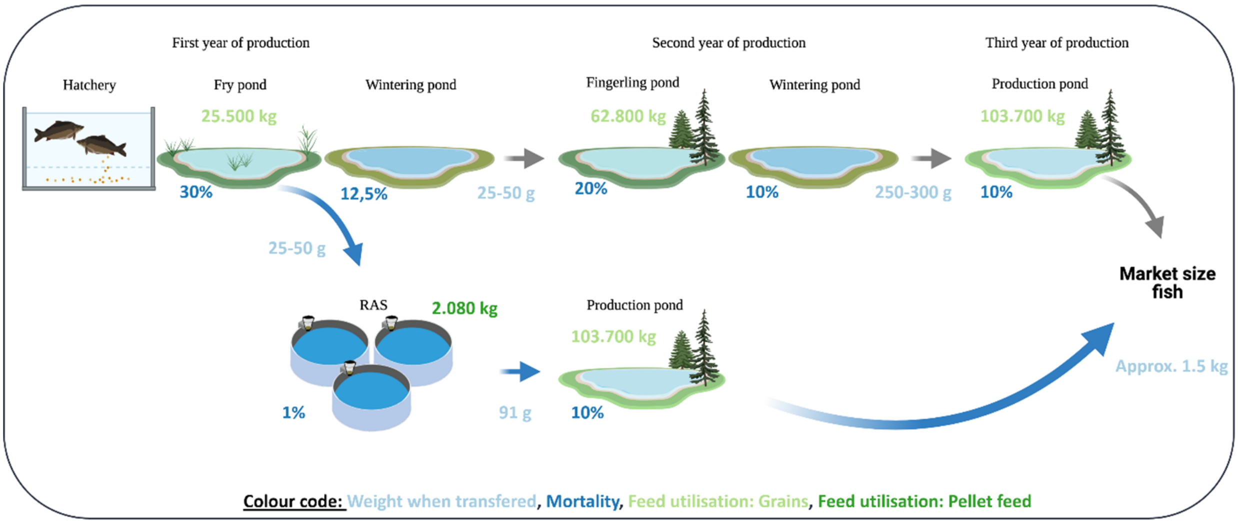

Figure 3.5: Overview of conventional pond carp production in Poland (upper panel) and shortenend cycle (lower panel) including an integrated RAS system and related fish weight when transfered (light blue), mortality in % (dark blue) and amount of feed required (grains light green; pelllet feed dark green), each for the different production steps. Production in fry ponds starts in April, transfer to RAS takes place from October-May of the same year and harvest starts in October of the following year. Data and picture material from ZUT, slightly modified.

As depicted within ***Figure 3.5***, the second year of production is replaced by a RAS system phase (October - May), reducing mortality over the whole production cycle with fish reaching the same harvest weight as in conventional pond production (1.5 kg). Further differences in production requirements and costs are presented in **Table 3.4**: Cultivation details and costs for an integrated aquaponic RAS within carp pond farming in Western Pommerania, Poland in PLN per year.**Table 3.4**, additional required equipment is listed in **Table 3.5**.

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***Table 3.4**: Cultivation details and costs for an integrated aquaponic RAS within carp pond farming in Western Pommerania, Poland in PLN per year.*

Main differences conventional pond to shortened cycle with RAS production

	unit	PL-FCP-26	PL-FCP-26 RAS
Total area (land)	m²	1,200,000	804,000
Fish area (land)	m²	900,000	603,000
Property	m²	1,200,000	804,000
Water Source		surface water	surface water plus 600 m3 rain/river or ground water
Returns grow out	PLN	299,650	307,079
Returns water cress	PLN	-	7,429
Total receipts	PLN	299,650	307,079
Maintenance machinery	PLN	35,137	35,637
Maintenance buildings and plants	PLN	6,000	4,000
Feed - variety		grains	grains + pellet feed
Feed - quantity	kg	192,000	131,280
Overall feed conversion Rate (FCR)		7.50	7.22
Overall feed - price/kg feed	PLN	0.50	0.54
Feed - total costs	PLN	96,183	106,977
Stocking total	PLN	11,074	10,039
Minor operation equipment total	PLN	-	2,950
Electricty	PLN	3,992	5,454
Permanent labour - hours	h	5,760	3,551
Permanent labour - costs	PLN	72,683	42,289
Permanent labour - non wage labour costs	PLN	40,181	23,378
Equipment replacement value	PLN	377,100	497,669
Farm system replacement value (in 10 years)	PLN	60,000	40,000

Due to the no longer required wintering ponds, the total land area can be reduced to two thirds of the originally required 120 ha. The spare land could be leased externally or would not have to be planned in for a new farm. Following the applied rent approach within the typical farm method, this saves a substantial share of opportunity costs as well as maintenance costs for the wintering ponds ("Maintenance buildings and plants"). Another substantial reduction could be achieved for operating staff hours as labour effort is reduced by 38% including already an additional 35 h to maintain watercress production. Further, there is a slight reduction in stocking costs due to lower mortality rates for the integrated RAS system production cycle compared to conventional pond production. Assuming approximately 4.6 PLN farmgate price per kg water cress (average from platform Tridge), additional returns of 7429 PLN can be achieved for the total aquaponic plant production during Oct-May.

On the other hand, additional investment into RAS associated equipment (see **Table 3.5**) including a tent as shelter for RAS production are required, increasing depreciation costs.

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Additional equipment is also associated with slightly higher maintenance costs and energy demand. When comparing cash costs, the RAS integrated system demands more minor operation equipment. The total volume of substitutional grain feed can be reduced by >50%, however 2.08 tons of comparably expensive pellet feed are required during the RAS phase of the production cycle.

***Table 3.5**: Investment for an integrated aquaponic RAS within carp pond farming in Western Pommerania, Poland in PLN per year.*

Additional investment for an integrated RAS system within a 26 t carp farm, Poland

	Device	Replacement value	Economic Lifetime (years)
Aeration	6 high blower + 48 air diffuser	22,608 PLN	20
Feeding	Feeders	29,769 PLN	20
Water analysis	Oxyguard	25,000 PLN	20
Water treatment	Mechanical filter + biological filter, sedimentation tank and pump	42,192 PLN	15
Minor equipment	Buckets and nets	1,600 PLN	5
Buildings	Tent for RAS	150,000 PLN	20

Contrasting short-, (cash costs), mid- (depreciation) and long-term costs (opportunity costs) to returns per kg liveweight for both systems and the resulting profits are depicted within **Figure 3.6a** and **Figure 3.6b**. When shortening the production cycle to 19 months by integrating a RAS system, the overall cash costs as well as opportunity costs are reduced (**Figure 3.6a**), whereas additional equipment increases depreciation costs. In combination with slightly higher returns due to marketing options for watercress this leads to very promising results for the integrated RAS system. On a short-term, a 73% higher profit can be achieved (+55 cents/kg liveweight) compared to the conventional production system and in the long term the proportional increase in profit is more than five times higher (+48 cents/kg liveweight).

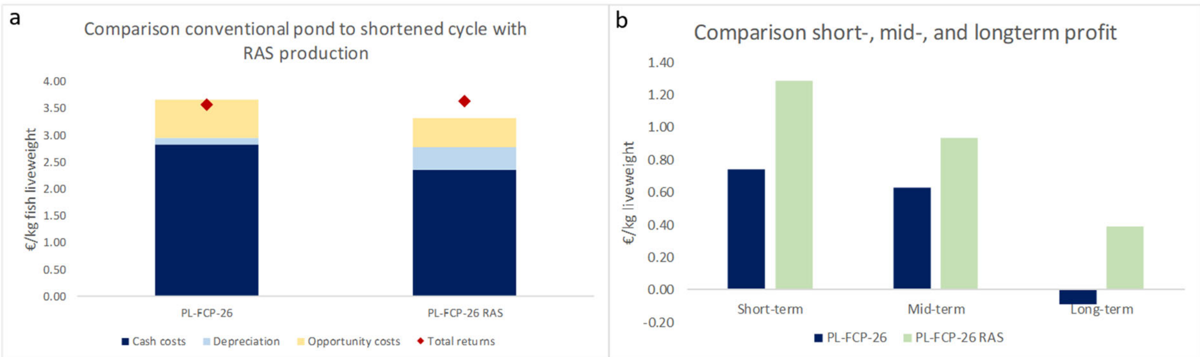

***Figure 3.6**: **a)** Stacked costs and returns for a conventional pond carp farm producing 26 tons in the region of Western Pommerania, Poland (PL-FCP-26) and an integrated pond-RAS aquaponic system (PL-FCP-26-RAS) and **b)** deriving short-, mid-, and long-term profitability for both systems; €/kg liveweight.*

Including a RAS unit to replace carp wintering ponds is very promising and could ensure long-term profitability in the case of the presented small-scale farm producing 26 tons. For this system, watercress is a self-sustainable side product with a share of 2.4 % of total returns.

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For future studies, it would be interesting to include marketing effort of aquaponic plant products within the cost-benefit analysis as well as a further exploration of culture opportunities of plant species other than watercress.

3.3 Valorisation of mortalities

The conventional method of processing mortalities and discarded fish on a fish farm is to produce a liquid fish silage with the help of formic acid. This process is associated with costs for related consumables (including formic acid), protective clothing, investment in the ensilage unit itself, its maintenance as well as costs for energy, the operating staff and disposal of silage (**Figure 3.7a**).

The innovative GAIN approach of processing mortalities and discarded fish utilizes the drying unit from Waister sanitizing fish biomass with a superheated steam drying technology (see D2.2 for more information). This process requires investment in the drying unit and additional equipment, costs for fat absorbing structure material for mortalities with a high fat content such as salmon and trout (here spent grain from breweries), costs for energy and operating staff, installation costs in the first year and annual service costs. Depending on the customer of the product, packaging and transport costs and potential additional costs such as for lab analysis may occur (**Figure 3.7b**).

These different methods for mortality processing and their associated costs as well as marketing options for the product result in varying implications for the profitability of fish farms. Therefore cost-benefit analyses considering both processes were each conducted for a typical salmon grow-out farm (producing 3200 t (gutted)) as well as an example smolt RAS farm in Norway (producing 1300 t) (Nordland).

The respective difference in long-term costs and returns for 3 scenarios for the product of dried mortalities/spent grain dry mass (mortalities have a dry mass of 25 %, spent grain of 90%, total product volume of 47 t) were compared to conventional ensilage for the typical salmon grow-out farm (**Figure 3.8)**, as well as for the example smolt RAS farm (**Figure 3.9)**. Long-term profitability describes here returns deducted by cash costs, depreciation and opportunity costs for an operating period of > 5 years (for ore detials see Kreiss and Brüning, 2020, D4.1). Information on potential returns and additional costs/transport costs where estimated by Waister in exchange with the respective industries.

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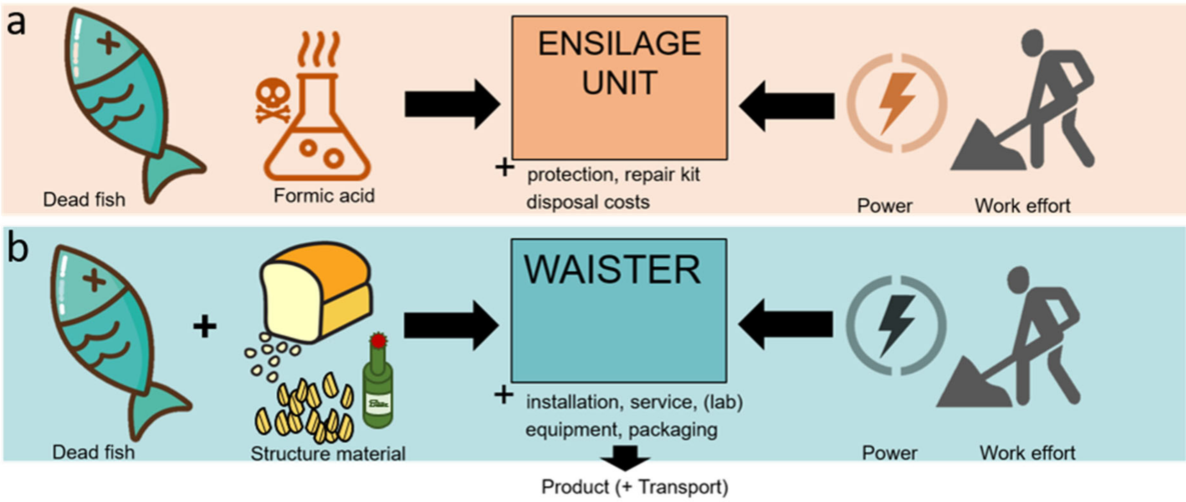

Figure 3.7: Visualization of processing mortalities through ensilage (a) and the Waister drying machine (b) and the respective associated inputs, which are related to costs for the two methods.

Scenario DM biogas (scenario 1) refers to drying mortalities and delivery at the expense of the fish farm to a biogas plant in Denmark (50 €/ton) without any returns for the product itself. Within scenario 2 (DM cement), dried mortalities are delivered and sold to the cement industry (return deducted by transport costs: 15 €/ton) and to the pet food industry in scenario 3 (DM pet food, 1315 €/ton). For scenarios 1 and 2 the value of the dried mortality product was calculated based upon the energy content of the dried mortality product relative that of coal. Scenario 3 assumes sufficient hygienic preconditions of the product to be utilized within pet food.

As presented in **Figure 3.8**, long-term profit of the typical salmon farm is about 1.5 % lower per kg gutted salmon compared to the conventional ensilage method, in case that the dried mortality product is delivered at own expense to a biogas facility without any additional return (scenario 1). A loss of about 1.4 %/kg compared to the conventional ensilage method is expected for the cement industry scenario (2), where a small return is expected to be achieved. However, for the pet food industry as customer, where a lot higher returns are expected to be achieved, the typical salmon farm could even increase its long-term profits by 0.1 %/kg gutted fish.

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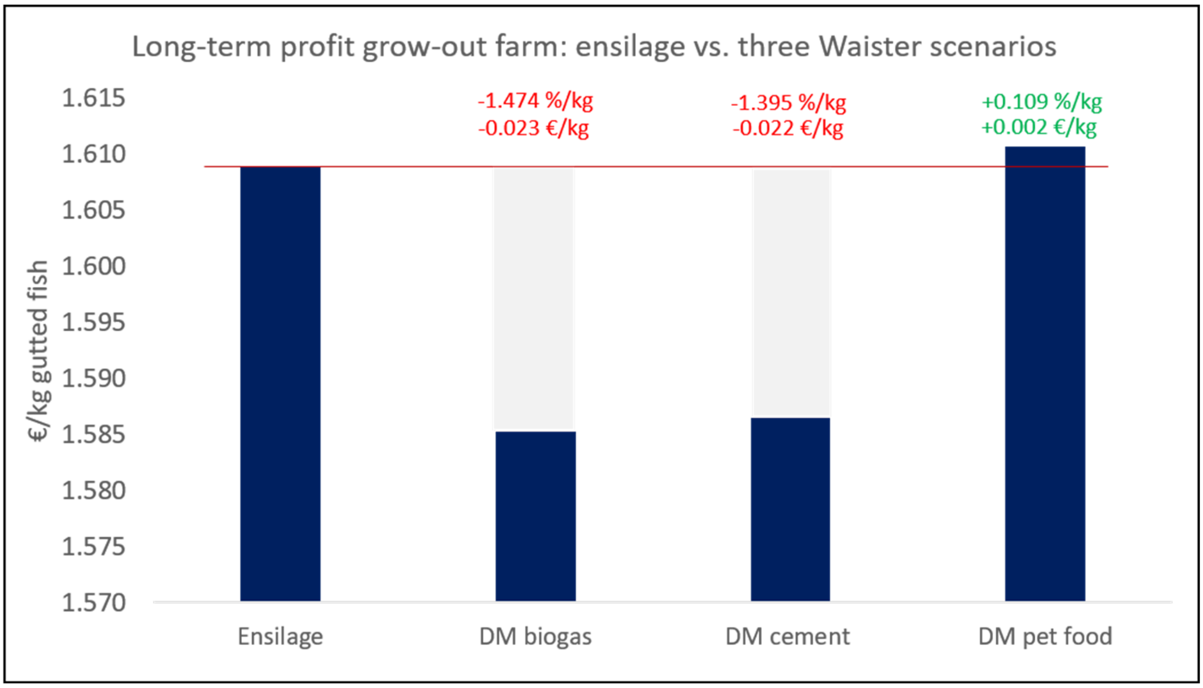

***Figure 3.8**: Required returns for a typical salmon grow-out farm in Norway in € per kg produced gutted fish using a Waister drying unit and distributing the respective product (dried fish + structure material) to achieve same profitability/achieving surplus returns compared to conventional ensilage (on long-term scale) for scenarios 1) delivered (at expense of fish farm) to a biogas plant without receiving returns 2) sold to cement industry including also transport costs, 3) sold to the pet food industry including also product analysis costs.*

For the Norwegian RAS smolt farm (**Figure 3.9**), the picture is different. Under all three scenarios that utilize a drying unit and market the resulting 11.27 t of product (to biogas, cement industry and petfood sector) increased returns can be achieved compared to processing discarded fish biomass into silage. Surplus ranges from 0.43 % (per kg fish produced) for the biogas scenario to 0.48% for the petfood industry. These results can be explained by the fact that processing morts within the drying unit is more profitable than the conventional ensilage method, balancing even the transport costs of the mixed dry product to a biogas plant in Denmark (scenario 1) and therefore achieving a significant plus in earnings for a high value sector such as the petfood industry (scenario 3). The main benefit here is related to the reduced labour effort required for the drying unit compared to producing fish silage. Compared to the typical salmon grow-out farm, that maintains an automated ensilage system including the collection and mixing of formic acid, ensilage at smolt farms is still typically a manual labour-intensive process. Further, smolt ensilage, in contrast to that of grow-out farms, requires an addition of water throughout the grinding process of mortalities, which increases the share of silage disposal costs per volume of mortalities compared to the latter.

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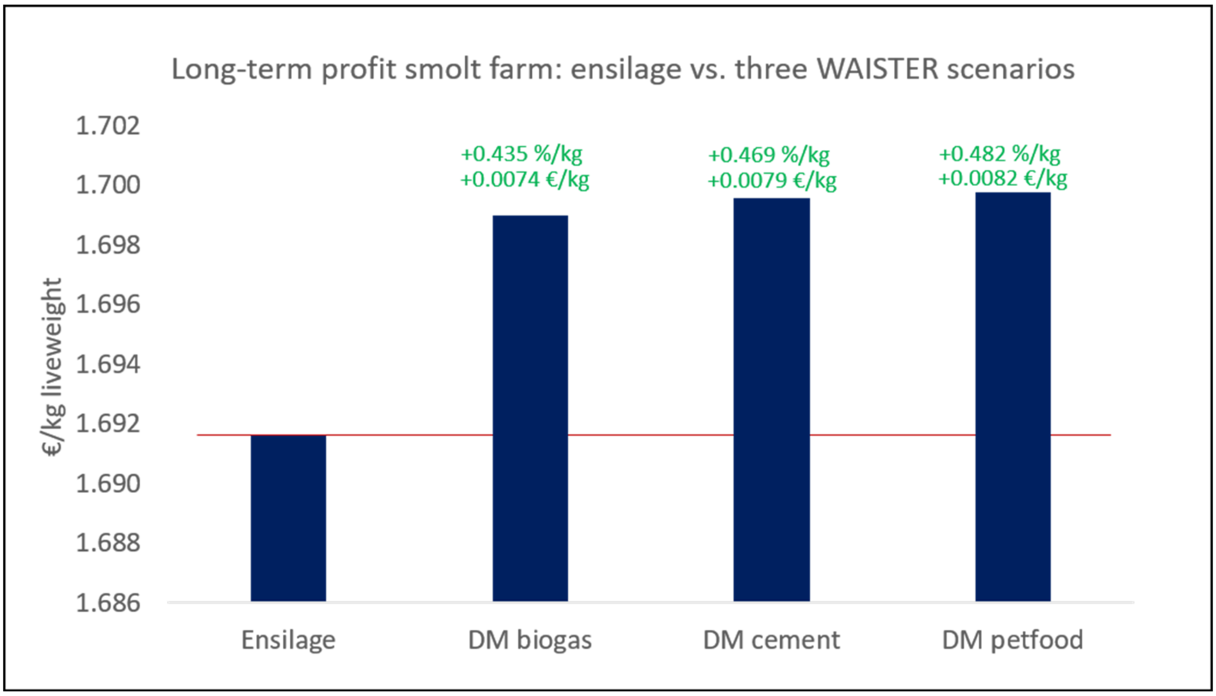

***Figure 3.9**: Surplus returns for an example smolt farm in Norway (1300 t) per kg produced fish using a Waister drying unit and distributing the respective product (dried fish + structure material) compared to conventional ensilage (on long-term scale) for scenarios 1) delivered (at expense of fish farm) to a biogas plant without receiving returns 2) sold to cement industry including also transport costs, 3) sold to the pet food industry including also product analysis costs.*

These results illustrate that dried mortalities may represent an interesting product with the potential to achieve increased returns for the typical salmon grow-out farm (scenario 3) and are very promising for a (smolt) farm with labour-intensive ensilage process (all scenarios). For customers paying no or only low prices for the product (e.g. biogas plants, cement industry), the transport distance might have a significant impact on the final costs/return opportunities, although the here presented scenarios should be only understood as examples. Commercial agreements will most likely be arranged on individual basis. Especially for the cement industry sector there might be the opportunity to achieve higher returns than assumed here when taking into account that CO_2 taxes might be levied on other substrates.

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4. Valorization of shellfish by-products

Based on the experimental work on valorisation of bivalve shells as RAS bio filter material within Task 2.3 (see Soula et al. 2019, D2.4 and Regueiero et al. 2021, D.2.8), economic considerations, based on the "typical farm" approach, described in detail in (Kreiss and Brüning, D4.1) were conducted. Thereby, EU countries that exhibit significant fish production in RAS systems as well as blue mussel production, were selected for further consideration: Denmark, the Netherlands, Germany, Spain and France (**Table 4.1**). Most important RAS species are Rainbow trout and European eel as well as sole for the Spanish sector (861 tons) and highest volumes in 2018 were achieved in Denmark and the Netherlands. On the other hand, most significant mussel production takes place in Spain and France. Consequently, for the following analysis the two examples of Denmark and Spain were chosen to include each the most important RAS and mussel producing country within the EU (**Table 4.1**).

***Table 4.1**: EU countries with fish production in RAS systems (in t per species for 2018, EUMOFA report) and blue mussel production (in t for 2018, OECD statistics and German Federal Ministry).*

Country	Denmark	Netherlands	Germany	Spain	France
Blue mussel production (tons) 2018	36450	52285	31870	347825	186450
Estimated empty shells total (40 %)	14580	20914	12748	139130	74580
Production in RAS systems species 1 (t)	Rainbow trout (11398)	African catfish (2470)	European eel (1025)	Sole (861)	Rainbow trout (3595)
Production in RAS systems species 2 (t)	Atlantic salmon (1021)	European eel (2150)	African catfish (713)	European eel (342)	Other (189)
Production in RAS systems species 3 (t)	European eel (428)	Other (351)	Other (362)	Other (86)	
Production in RAS systems species 4 (t)			Rainbow trout (40)		

Based on these two examples, a RAS production system of the prevailing RAS produced species and assumed typical size was defined (700 t rainbow trout for Denmark; 100 t eel production for Denmark; 60 t sole for Spain). For each of these systems the required bio filter material volume (plastic material and whole shells) was calculated considering various production system assumptions (e.g. FCR, protein content of feed, temperature, max. carrying capacity of system). For Atlantic salmon it was assumed that the results from trout production would be transferable. In a next step, available mussel shell material from processing facilities was compared to the theoretic demand of whole shell bio filter material for the most important RAS-produced species in Denmark and Spain (**Table 4.2**).

***Table 4.2**: Comparison of available mussel shell material from processed mussels (Fish J Stat, 2018 data; meat:shell ratios from ANFACO) and theoretic whole mussel bio filter media demand for the most important produced species in RAS systems in Denmark and Spain.*

Country	Denmark	Spain
Blue mussel production (tons) 2018	36450	347825
Estimated empty shells total (40 % of live mussels)	14580	139130
Mussel meat produced per country (t) in 2018	3362	20223
Estimated available shells from processed mussels (55 %)	4109	24717
Production in RAS systems species 1 (t)	Rainbow trout (11398)	Sole (861)
Production in RAS systems species 2 (t)	Atlantic salmon (1021)	European eel (342)
Production in RAS systems species 3 (t)	European eel (428)	Other (86)
Volume of shell biofilter required		
Rainbow trout whole shells (t)	3896.46	225.12
Salmon whole shells (t)	349.03	77.03
European Eel whole shells (t)	96.39	
Sole whole shells (t)		
Total volume shell biofilter (t)	**4341.88**	**302.15**

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While for Denmark, the demand could not be fully satisfied within one year, the amount of mussel shells would be sufficient when considering, that bio filter material is not exchanged on a yearly basis and not for all operations at once. For the Spanish sector, the volume of available empty shells is far higher than in theory required by the RAS sector when switching to mussel shell material instead of plastic material. In a next step, a rough cost-benefit analysis was conducted for two more specific examples: 1) a 700 t rainbow trout farm in Velje, Denmark, using either plastic bio filter material from a commercial source or whole mussel shells from processing facilities in the Limfjord region (**Table 4.3**), 2) a 60 t sole farm in Cervo, Spain, using either plastic bio filter material from a commercial source or whole mussel shells from processing facilities in the area of Vigo (**Table 4.4**). Thereby, a bio filter material utilization period of 3 years was assumed based on estimations from the pilot scale experiments conducted by ANFACO.

***Table 4.3**: Cost benefit analysis for plastic bio filter material and shipping; mussel shell transport costs, and disposal of both materials for a 700 t trout farm based in Velje, Denmark estimated for a bio filter running for 3 years.*

700 t Trout / DK	unit	quantity	price per unit*	costs total	cost/ton trout	cost/t; 3 years
Plastic biofilter material	t	167.51	4,330.00 €	725,313 €		
Shipping	40 FTE (63.4 m3)	28.00	1,699.00 €	47,572 €		
Adjusting pH	m³	1763.25	1.50 €	2,645 €		
Disposal	t	167.51	250.00 €	41,877 €		
				817,407 €	**1,168 €**	**389.24 €**
Whole mussel shells	t	239.30	- €	- €		
Transport Limfjord - Velje, Jutland**	km	3410	1.87 €	6,377 €		
Disposal	t	239.30	18.00 €	4,307 €		
				10,684 €	**15 €**	**5.09 €**

** 1 m³ biofilter material costs 411.27 €; 95 kg/m³ => costs per kg biofilter material 4.33 € = 4330 € je t

*estimated; 25- ton truck => 1 m³ = 1.5 t => 16.7 m³ cargo load => 21.5 tours (=22 tours), 155 km / per route

Both examples (**Table 4.3** and **Table 4.4**) reveal mussel shells to be more cost-effective than plastic material when applying for a bio filter system that runs for a period of 3 years. This is due to the assumption that mussel shells are free of costs except for their transport and that their disposal costs is assumed to be much lower compared to plastic material as well. At least in Spain, the mussel shell bio filter material could be used as soil fertilizer and only transport costs would occur here for their “disposal”. If this is also the case for Denmark is uncertain, but even here the disposal costs for natural material is assumed to be lower than for plastic material.

***Table 4.4**: Cost-benefit analysis for plastic bio filter material and shipping; mussel shell transport costs, and disposal of both materials for a 60 t sole farm based in Cervo, Spain, estimated for a bio filter running for 3 years.*

60 t Sole / ES	unit	quantity	price per unit*	costs total	cost/ton sole	cost/t; 3 years
Plastic biofilter material	t	10.98	4,330.00 €	47,552 €		
Shipping	40 FTE (63.4 m3)	2.00	1,647.00 €	3,294 €		
Adjusting pH	m³	115.60	1.50 €	173 €		
Disposal	t	10.98	250.00 €	2,746 €		
				53,765 €	**77 €**	**25.60 €**
Whole mussel shells	t	0.00	- €	- €		
*Transport Vigo - Cervo	km	284	1.87 €	531 €		
Disposal	t	0.00	18.00 €	- €		
				531 €	**1 €**	**0 €**

* 1 m³ biofilter material costs 411.27 €; 95 kg/m³ => costs per kg biofilter material 4.33 € = 4330 € je t

**estimated; 25- ton truck => 1 m³ = 1.5 t => 16.7 m³ cargo load => 21.5 tours (=22 tours), 284 km / per route

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For bio filter systems that are running for a longer time period than three years (e.g. 10 or more years), plastic would for certain be the material of choice as the benefit of a running bio filter system would not be outweighed by a more cost-efficient solution associated with risks for the production.

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5. Valorization of fish farming by-products

Fish by-products may constitute as much as 70% of fish and shellfish after industrial processing of seafood (Olsen et al. 2014). Part of these are used as low-value ingredients such as fertilizer or animal feed, but the known healthy compounds and properties associated with fish are also present in their by-products including a potential good source of bioactive compounds, with important functional properties that can be isolated or up-concentrated. The latter may give them an added value in higher end markets, as for instance the human food sector, for nutraceuticals or cosmetics (Khawli et al. 2019).

Based on the extraction protocols for each 100 kg of various fish by-products from all GAIN species and related yields of fish protein hydrolysate (FPH), gelatine, peptones and lactic acid bacteria (LAB) from CSIC (link to GAIN D2.3), we conducted a comparative economic analysis on industry scale, based on the “typical farm” approach, described in detail in (Kreiss and Brüning, D4.1). Thereby, industry insights from Bioceval (Cuxhaven, Germany) as a sector representative for fish by-product processing, expert assumptions for the scale-up of the different processes (CSIC) and industry-scale prices for the required inputs and products build the baseline for the presented economic analysis. This input-output based economic analysis was exemplarily conducted for a theoretical processing facility with a capacity of 7,000 t fish by-products being located in Northern Germany. The capacity was oriented at the yearly minimum volume for a profitable utilisation rate of the processing line according to Bioceval CUX.

For our theoretical approach, we applied industrial scale prices for chemical reagents and other fermentation inputs, water, electricity, staff costs as well as disposal costs for occurring wastewater, all referring to a located industry in Northern Germany. These input and waste costs where then contrasted to market prices based on knowledge within the project (SPAROS for FPH) or B2B marketing platforms (Alibaba.com for remaining products). Not included within the calculation are any other fixed and variable costs besides the mentioned input and disposal costs (such as insurances), depreciation costs for equipment and buildings, as well as opportunity costs (such as capital costs). Furthermore, the value of potential side products such as fish oil or fishmeal were also not taken into account within the present analysis.

For each GAIN product, two different scenarios for the purchase price of the fish by-product raw material were calculated to reflect the prevailing volatile market situation. Scenario 1 assumes an average of 100 €/ton fish by-products (stated minimum returns for unprocessed by-products by fish processors, see D 4.1) and scenario 2 assumes maximum costs of 300 €/t for fish by-products as an input (commun. Bioceval CUX). Thereby the full range and anything in between is feasible, dependent on fish species, type and quality of by-product. Further, potential costs for fish by-products and their transport are usually negotiated individually for every processor and depend also on the current market demand (commun. Bioceval CUX).

5.1 Fish gelatine

Fish gelatine is water soluble material of proteins which has a gelling property. This property leads to a wide range of application. Food producers as well as aquaculture/animal feed producers use gelatine as thickeners and food clarifier, pharmaceutical and clinical as well as

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nutraceutical producers use it for encapsulating drugs and bioactive substances, as hydrogel for tissue regeneration and as food supplement. It is further utilized by the chemical industry to produce dyes and glues (Lv et al., 2019, Vázquez et al. 2019, Milovanovic and Hayes, 2018). Commonly used gelatine is derived from porcine and bovine. Religious restrictions and disease outbreaks, such as *Bovine spongiforme Enzephalopathie (BSE)*, created the need for alternatives of mammalian sourced gelatines (Vázquez et al. 2019, Milovanovic and Hayes, 2018, Sultana et al., 2018). This includes marine gelatines e.g. sourced from fish skin bones or scales as well as vegetable alternatives. A global market analysis allocated the value of fish gelatine to approx. 18% compared to 36% deriving from porcine and 27 % deriving from bovine by-products (Market Research Report: Global Food Grade Gelatin Market 2021-2028, Dataintelo, 2019). Lv et al. (2019) reviewed novel potential applications of fish gelatine and pointed out its potential in tissue engineering and bone regeneration as well as research on antihypertensive application for this product (Valcacel et al. 2021, Vázquez et al. 2021).

The gelling capacity of gelatine is indicated in the unit bloom[1]: low bloom gelatine (50-125) is very soft and water binding capacity correlates with increasing bloom number. Medium bloom gelatine (175-225) is often used for food e.g. in frostings, cream stabilizers, marshmallows or canned hams, whereas high bloom gelatine (225-325) is e.g. used in gelatine desserts, jelly fillings, cream fillings and gelatine capsules. Gelling capacity is significantly dependent on the utilized fish species. The gel strength of cold-water fish gelatine is lower compared to that of warm-water fish gelatine hence the latter is more suitable for food gelling applications (Nitsuwat et al., 2021).

For the production of gelatine, many protocols are available (Vázquez et al., 2019a). In general, fish skin is treated with alkalis and organic acids to extract the gelatine and with a final drying step a powdered product can be obtained (e.g. García-Santiago et al. 2020). Blooms for salmonids were in the range of low bloom gelatine, whereas those of seabass, sea bream and turbot fell mostly into the category of medium bloom gelatine.

Table 5.1 depicts all gelatine-relevant input and output costs/returns included within the present analysis for scenario 1 (including raw material costs of 100 €/ton). Disposal costs for gelatine processing refer to usual sewage under the assumption that certain thresholds of COD and BOD are not surpassed and verified by regular water analysis from external laboratories (included within disposal costs).

As presented in **Table 5.1**, gelatine production from fish skins does not create a surplus for any of the examined species within GAIN, either for scenario 1 or 2. Hereby, it has to be taken into account that reliable market price estimations for fish gelatines are difficult to obtain and those applied within the present analysis derive from a Chinese B2B platform (Alibaba). However, there is already an existing large gelatine market from terrestrial animal by-products, which are usually a lot cheaper than those deriving from fish, if they come at a cost at all. Further, the inferior rheological properties of fish gelatine besides quality factors such

[1] https://www.customcollagen.com/gelatin-bloom-strength-types-and-uses/

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as colour, odour, bloom strength and viscosity might limit the use of fish gelatine compared to mammalian products (Karim and Bhat, 2009; Khawli et al. 2019).

Taking a closer look at the costs reveals that production costs for salmon, trout, sea bream and seabass are very similar and, under the assumptions described, raw material costs account for approx. 24-29% % (scenario 1) – 49-55% % (scenario 2) and those of chemicals for 37-25 % of the total costs. Within total chemical costs are the most important cost drivers. The processing of turbot skins required a lower use of chemicals, which explains the lower overall costs incurring here. The processes achieved different yields of fish gelatine and therefore the cost per ton gelatine is lowest for seabream at 6,015-8,956 € and highest for trout at 25,564-38,064 €.

***Table 5.1**: Costs for 7000 tons of salmon, trout, turbot, sea bream and seabass skins and the related chemicals, staff, energy, water and disposal required for gelatine processing in contrast to assumed total returns and per t or product.*

Processing Fish skins to Gelatine

	Unit	Salmon	Trout	Turbot	Sea bream	Seabass
Yield gelatine per 7.000 t FBP	t	**364**	**112**	**329**	**476**	**385**
Revenue per total yield	**€**	**1,641,640**	**505,120**	**1,483,790**	**2,146,760**	**1,736,350**
Scenario 1: min. raw material costs	**€**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**
Scenario 2: max. raw material costs	**€**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**
Chemicals and water total	€	1,070,040	1,070,040	798,160	1,070,040	1,070,040
Staff total	€	219,520	219,520	219,520	219,520	219,520
Electricity total*	€	4,241	4,241	4,241	4,241	4,241
Disposal total**	€	869,400	869,400	676,200	869,400	869,400
Scenario 1 - Total costs/7000 t FBP	**€**	**2,863,201**	**2,863,201**	**2,398,121**	**2,863,201**	**2,863,201**
Costs per ton Gelatine	**€**	**7,866**	**25,564**	**7,289**	**6,015**	**7,437**
Surplus / loss per ton Gelatine	**€**	**- 3,356**	**- 21,054**	**- 2,779**	**- 1,505**	**- 2,927**
Scenario 2 - Total costs/7000 t FBP	**€**	**4,263,201**	**4,263,201**	**3,798,121**	**4,263,201**	**4,263,201**
Costs per ton Gelatine	**€**	**11,712**	**38,064**	**11,544**	**8,956**	**11,073**
Surplus / loss per ton Gelatine	**€**	**- 7,202**	**- 33,554**	**- 7,034**	**- 4,446**	**- 6,563**

* industrial price, incl. basic costs
**incl. 3.500 € laboratory costs

Consequently, a market price of about approx. 4,500 – 5,800 €/t gelatine in combination with no expenses for raw fish by-product material would be required to achieve cost recovery for processing salmon, turbot, seabass and sea bream skins. In contrast, there are also estimations for fish gelatine to achieve prices of 25 €/ kg (García-Santiago et al. 2020) or up to 95 €/kg (with high bloom value) to the end consumer[2] within the European market. Especially gelatine processed from seabass skins could be suitable for the latter product category. In general, a sales value of 25 €/kg would result in a revenue of 17,563 €/t for scenario 1 and 13,927 €/ton for scenario 2, but it is unclear which product quantities could be marketed within such a price niche.

5.2 Fish protein hydrolysate (FPH)

Fish protein hydrolysate (FPH) is a further potential option to utilize fish materials remaining from processing. Enzymatic treatment of fish by-products with proteases yields a product rich

[2] [https://shop.biogenial.de/Premium-Fischgelatine.html; https://www.wuerzteufel.de/4398/Tierisch-Gelatine-Fischgelatine-GEWICHT-100-g-VERPACKUNG-DOSE

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in proteins, peptides and free amino acids (Vázquez et al., 2019), with functional properties of the peptides being partially preserved. FPH is considered to have a huge potential application as a protein source for human consumption (Petrova et al., 2018) or within animal nutrition (Hou et al. 2017), the pharmaceutical industry as well as for further industries. According to market research reports (e.g. "Global Market Insights", "Research and Markets"), the global demand for FPH is strongly increasing and was valued at nearly USD 400 Million in 2019 and is projected to surpass USD 520 Million in 2025, growing at a rate of around 4.8% between 2019 and 2025 (Globe Newswire on Research and Markets report, 2020). Despite these promising market developments, especially the dehydration process for dry FPH is costly (Petrova et al., 2018).

Proteins can by hydrolysed enzymatically, chemically or thermally. Within GAIN, the production of FPH was conducted using crushed fish heads or a mixture of trimmings and frames with a subsequent enzymatic treatment (alcalase) for hydrolysation. The final product, powdered FPH, was obtained after several separation steps and a final drying step (for more details see Vázquez et al., 2019b; GAIN D2.3).

Table 5.2 depicts all FPH-relevant input and output costs/returns included within the present analysis for scenario 1 (including raw material costs of 100 €/ton) and scenario 2 (raw material costs of 300 €/ton). Disposal costs for FPH processing refer to usual sewage as the residues within the generated "wastewater" are not considered to be significant and the occurring mineral waste from bones is expected to be of commercial interest without achieving additional returns.

***Table 5.2**: Input-Output analysis for processing fish by-products to fish protein hydrolysate (FPH). Total cost of processing 7,000 t of salmon, trout and turbot heads or a mixture of trimmings and frames (T&F) to produce FPH, including prices for raw material (scenario 1: 100 €/ton; scenario 2: 300 €/ton), chemicals, staff, energy, water and disposal and related to one tonne of product in contrast to assumed revenue per total yield and therefore to estimate the total returns per ton product.*

Processing fish heads and trimmings/frames (T&F) to Fishprotein Hydrolysate (FPH)

	Unit	Salmon heads	Salmon T&F	Trout heads	Trout T&F	Turbot heads	Turbot T&F
Yield FPH per 7.000 t FBP	t	840	980	826	770	840	1,022
Revenue per total yield	€	1,680,000	1,960,000	1,652,000	1,540,000	1,680,000	2,044,000
Scenario 1: min. raw material costs	€	700,000	700,000	700,000	700,000	700,000	700,000
Scenario 2: max raw material costs	€	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000
Chemicals and water total	€	469,965	482,058	262,060	278,989	495,359	472,384
Staff total	€	219,520	219,520	219,520	219,520	219,520	219,520
Electricity total*	€	3,364	3,364	3,319	3,319	3,341	3,341
Disposal water total**	€	25,406	25,527	24,983	25,152	25,659	25,430
Scenario 1 - Total costs/7000 t FBP	€	1,418,255	1,430,468	1,209,882	1,226,980	1,443,880	1,420,675
Costs per ton FPH	€	1,688	1,460	1,465	1,593	1,719	1,390
Surplus / loss per ton FPH	€	312	540	535	407	281	610
Scenario 2 - Total costs/7000 t FBP	€	2,818,255	2,830,468	2,609,882	2,626,980	2,843,880	2,820,675
Costs per ton FPH	€	3,355	2,888	3,160	3,412	3,386	2,760
Surplus / loss per ton FPH	€	- 1,355	- 888	- 1,160	- 1,412	- 1,386	- 760

* industrial price, incl. basic costs
** All liquids

As presented in **Table 5.2**, the costs are quite similar for processing salmon and turbot by-products and lowest for obtaining FPH from trout by-products. In contrast to salmon and turbot, only half the amount of enzyme is required to process trout by-products (reducing the

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share of chemical input from ca. 33% to 22% (s1) and ca. 17% to 10% (s2)). FPH yields from trout by-products are lowest among the three species, but due to less required chemical input, the overall costs per ton FPH are similar or even lower compared to processing salmon and turbot by-products. A surplus under scenario 1, can be achieved for all species reaching a span of 281 (turbot heads) to 610 €/t FPH (turbot t&f), whereas under scenario 2, FPH production is not profitable at all. Trimmings/frames in general achieve a higher FPH yield and thereby total market returns compared to heads, with the exception of trout trimmings/frames. Trout by-products however, require the lowest chemical input volume and are thereby most profitable when comparing on species level. Under the assumptions described, raw material costs account for 49-57 % in scenario 1 and 74-80% in scenario 2 and clearly illustrate the high cost share of the raw material input.

5.3 Peptones and Lactic Acid Bacteria (LAB)

Similar to FPH is the production process of peptones, which consist as well of a mixture of polypeptides and amino acids, but have a different target industry: microbial culture media producers. Peptones are utilized as organic nitrogen source in complex media for the cultivation of different kinds of microorganisms, e.g. bacteria like lactic acid bacteria (LAB) or yeasts (Vázquez et al., 2019a). Similar to gelatins, peptones of non-meat origin are becoming increasingly important in the light of BSE, certified free of swine flu or kosher and halal diets (Fallah et al. 2015).

Within GAIN, peptones were obtained from heads, trimmings/frames (with different weight proportions of 80-90 % trimmings and 10-20 % frames) as well as viscera from salmon, trout, turbot, sea bream and seabass. The crushed by-products were treated enzymatically, followed by several separation steps and a final drying step to obtain a powdered product (dry peptone). Since the protocols and yields for the different by-products of each fish species differed hardly, the present economic analysis was based on mean values over all fish by-products (for more details see Vázquez et al., 2020).

Table 5.3 depicts all dry peptone-relevant input and output costs/returns included within the present analysis for scenario 1 (including raw material costs of 100 €/ton) and scenario 2 (raw material costs of 300 €/ton). Disposal costs for peptone production refer to usual sewage as the residues within the generated "wastewater" were not considered to be significant and the occurring mineral waste from bones is expected to be of commercial interest without achieving additional returns.

As presented in **Table 5.3**, the costs are quite similar for salmon, turbot and seabass, but clearly lower when processing trout by-products. Similar to the processing of by-products for FPH, trout by-products required only half the amount of enzyme (reducing the share of chemical input from 27 – 28 % to 17 – 18 %) compared to those deriving from other fish species. Although the yield of peptones from trout is in the middle range compared to other fish species, the costs per ton peptone are at the lower range together with those for processing turbot by-products. The latter reached the highest yields of peptone.

A surplus for producing dry peptones under scenario 1 is achieved for the utilization of by-products from all species with a range from 17,309 € for seabass (lowest peptone yield) up to

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17,915 € for trout. In scenario 1, raw material costs account for a share of 49 - 58 % of total costs. The surplus decreases under the assumption of much higher raw material costs (scenario 2) and ranges between 15,158 – 16,325 €/ton dry peptone.

***Table 5.3**: Input-Output analysis for processing fish by-products to dry peptones. Total cost of processing 7,000 t of salmon, trout, turbot, seabream and seabass by-products to produce dry peptones, including prices for raw material (scenario 1: 100 €/ton; scenario 2: 300 €/ton), chemicals, staff, energy, water and disposal and related to one tonne of product in contrast to assumed revenue per total yield and therefore to estimate the total returns per ton product.*

Processing fish by-products (average results for heads, trimmings & frames, viscera) to Dry Peptones

	Unit	Salmon	Trout	Turbot	Sea bream	Seabass
Average Yield Dry Peptones per 7.000 t FBP#	t	**840**	**788**	**910**	**716**	**651**
Revenue per total yield	**€**	**16,338,000**	**15,330,490**	**17,699,500**	**13,928,145**	**12,661,950**
Scenario 1: Price/t	€	100	100	100	100	1,100
min. raw material costs FBP total	**€**	**700,000**	**700,000**	**700,000**	**700,000**	**7,700,000**
Scenario 2: Price/t	€	300	300	300	300	300
max. raw material costs FBP total	**€**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**
Chemicals and water total	€	469,965	262,060	495,359	424,014	445,780
Staff total	€	219,520	219,520	219,520	219,520	219,520
Electricity total**	€	3,656	3,589	3,488	3,510	3,510
Disposal total***	€	25,406	24,983	25,659	24,947	25,164
Scenario 1 - Total costs/7000 t FBP	**€**	**1,418,547**	**1,210,152**	**1,444,026**	**1,371,991**	**8,393,974**
Costs per ton Dry Peptone	**€**	**1,689**	**1,535**	**1,587**	**1,916**	**12,894**
Surplus / loss per ton Dry Peptone	**€**	**17,761**	**17,915**	**17,863**	**17,534**	**6,556**
Scenario 2 - Total costs/7000 t FBP	**€**	**2,818,547**	**2,610,152**	**2,844,026**	**2,771,991**	**2,793,974**
Costs per ton Dry Peptone	**€**	**3,355**	**3,312**	**3,125**	**3,871**	**4,292**
Surplus / loss per ton Dry Peptone	**€**	**16,095**	**16,138**	**16,325**	**15,579**	**15,158**

#Average from heads, trimmings + frames and viscera

*Industrial price, incl. basic costs

**All liquids

As mentioned above, peptones are utilized as a nitrogen source in microbial growth media in biotechnological industry including the production of lactic acid bacteria (LAB). These are one of the most relevant industrial microbes and have a wide range of applications. LAB are often used in food fermentation processes (De Vuyst and Leroy, 2007), but also within the chemical industry for the production of lactic acid and are increasingly used as probiotics as they possess interesting health promoting properties. In addition to their use as probiotics in human nutrition, LAB are also increasingly added to animal feed. Different strains of Lactobacillus have been used as probiotics in aquaculture (for a review, see *Newaj-Fyzul et al., 2014*). Within GAIN, the growth of LAB on cultivation media processed from fish by-products allows us to evaluate the cost-benefits of a potential circular utilization of fish by-products from aquaculture: 1) for liquid peptone production → 2) the subsequent use of liquid peptones as a component of the growth medium for LAB → 3) the use of LAB as probiotics in aquaculture. Further, LAB growth can serve as indicator when testing the suitability of marine peptones as media for fastidious bacteria that require complex growth factors (Vázquez et al., 2019a).

In this study, liquid peptones were produced either enzymatically (as described before) or within a thermal process. Since liquid peptones were directly used as media, the drying step was omitted. Depending on the yield of peptones, different amounts of other chemicals were

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added to achieve optimal growth conditions. The target products of this process include LAB as well as the corresponding produced lactic acid. This process was examined for by-products (heads or trimmings and frames or viscera) of salmon, trout, turbot, sea bream and seabass.

Table 5.4a presents the cost-benefit analysis of the usage of the enzymatically produced peptones. Turbot peptones achieve the highest yield of LAB, independent of the by-product type. However, viscera in general achieve less LAB compared to the related heads or trimmings in combination with frames. LAB production with peptone from turbot heads and trimmings in combination with frames require the lowest cost per ton of LAB yield. Under scenario 1, all processes achieved a surplus in the range of 25,503/ t LAB to 35,744 €/t LAB (over all species). Considering higher costs for raw material (scenario 2) the surplus decreases to 19,789 – 28,601 €/t LAB (over all species).

The yield of LAB is much lower, when peptone production takes place in a thermal process (**Table 5.4b**). However, the total costs are also lower, mainly due to the elimination of expenses for enzymes. Under scenario 1 the surplus is between 22,068 and 34,944 €/ton LAB (incl. lactic acid revenue) and under scenario 2 between 8,735 and 29,247 €/ton LAB (incl. lactic acid revenue).

Comparing the costs and surplus between enzymatic and thermal peptone extraction, there is no clear prevalence. Depending on the fish species and the by-product used, the enzymatic peptone extraction (as for seabream and seabass by-products, especially viscera), or the thermal peptone extraction (as for salmon, trout and turbot) is more profitable.

This application example shows that fish by-product peptones are well suited for the production of LAB and thus an adequate alternative to other common nitrogen sources (for more information on the suitability of the fish peptones produced in this project, see Vázquez et al., 2020).

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***Table 5.4**: **a)**: Input-Output analysis for processing fish by-products to culture LAB via Liquid Peptones obtained enzymatically and **b)** thermally. Total cost of processing 7,000 t of salmon, trout and turbot by-products to produce LAB, including two scenarios for raw material costs (scenario 1: 100 €/ton; scenario 2: 300 €/ton), chemicals, staff, energy, water and disposal and related to one ton of product in contrast to assumed revenue per total yield and therefore to estimate the total returns per ton product.*

A) Processing fish by-products into Liquid Peptones (enzymatic) to culture Lactic Acid Bacteria (LAB) and obtain lactic acid

	Unit	Salmon			Trout			Turbot			Sea bream			Seabass		
		heads	trimmings,frames	viscera	heads	trimmings,frames	viscera	heads	trimmings,frames	viscera	heads	trimmings,frames	viscera	heads	trimmings,frames	viscera
Yield LAB per 7.000 t FBP	t	315	350	245	301	315	280	455	441	420	385	364	210	350	371	196
Revenue per total yield	€	16,686,923	17,068,030	13,095,132	14,453,755	15,275,698	13,464,360	22,003,127	21,176,432	19,711,877	19,349,777	18,121,376	11,281,418	17,543,190	18,520,231	11,420,724
Scenario 1: min. raw material costs	€	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000
Scenario 2: max. raw material costs	€	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000
Chemicals and water total	€	5,466,272	5,466,272	5,466,272	4,551,466	4,551,466	4,551,466	6,663,519	6,663,519	6,663,519	6,708,556	6,119,186	3,562,720	5,725,365	6,100,311	3,143,498
Staff total	€	443,800	443,800	443,800	443,800	443,800	443,800	443,800	443,800	443,800	443,800	443,800	443,800	443,800	443,800	443,800
Electricity total	€	4,928	4,928	4,928	4,590	4,590	4,590	5,299	5,299	5,299	5,299	5,063	3,994	5,063	5,254	3,960
Disposal total****	€	231,840	231,840	231,840	198,030	198,030	198,030	284,970	284,970	284,970	292,215	265,650	145,383	246,330	261,786	123,648
Scenario 1 - Total costs/7000 t FBP	€	6,846,840	6,846,840	6,846,840	5,897,886	5,897,886	5,897,886	8,097,588	8,097,588	8,097,588	8,149,870	7,533,698	4,855,897	7,120,557	7,511,151	4,414,906
Costs per ton LAB[1)]	€	21,736	19,562	27,946	19,594	18,723	21,064	17,797	18,362	19,280	21,168	20,697	23,123	20,344	20,246	22,525
Surplus / loss per ton LAB[2)]	€	31,238	29,203	25,503	28,425	29,771	27,023	30,562	29,657	27,653	29,091	29,087	30,598	29,779	29,674	35,744
Scenario 1 - Total costs/7000 t FBP	€	8,246,840	8,246,840	8,246,840	7,297,886	7,297,886	7,297,886	9,497,588	9,497,588	9,497,588	9,549,870	8,933,698	6,255,897	8,520,557	8,911,151	5,814,906
Costs per ton LAB[1)]	€	26,180	23,562	33,661	24,245	23,168	26,064	20,874	21,536	22,613	24,805	24,543	29,790	24,344	24,019	29,668
Surplus / loss per ton LAB[2)]	€	26,794	25,203	19,789	23,774	25,326	22,023	27,485	26,483	24,320	25,454	25,241	23,931	25,779	25,900	28,601

* Average Alibaba; margin 7.570 - 41.088 €/t
** Average Alibaba; margin 3.566 - 11.508 €/t
***industrial price, incl. basic costs
**** All liquids

1) costs incl. production of lactic acid
2) Revenue LAB incl. lactic acid

B) Processing fish by-products into Liquid Peptones (thermal) to culture Lactic Acid Bacteria (LAB) and obtain lactic acid

	Unit	Salmon			Trout			Turbot			Sea bream			Seabass		
		heads	trimmings,frames	viscera	heads	trimmings,frames	viscera	heads	trimmings,frames	viscera	heads	trimmings,frames	viscera	heads	trimmings,frames	viscera
Yield LAB per 7.000 t FBP	t	245	231	175	196	210	140	420	406	224	140	140	105	119	140	105
Revenue per total yield	€	12,612,845	11,798,029	9,484,335	9,757,664	10,340,602	6,732,180	20,681,203	20,322,541	11,151,616	7,207,340	7,207,340	4,927,969	6,223,172	7,207,340	4,927,969
Scenario 1: min. raw material costs	€	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000	700,000
Scenario 2: max. raw material costs	€	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000	2,100,000
Chemical and water total	€	3,451,450	3,315,428	2,157,980	2,383,075	2,509,008	1,265,217	5,761,345	5,676,741	2,828,993	1,755,269	1,755,269	1,153,303	1,539,796	1,762,889	1,416,275
Staff total	€	406,420	406,420	406,420	406,420	406,420	406,420	406,420	406,420	406,420	406,420	406,420	406,420	406,420	406,420	406,420
Electricity total	€	3,893	3,735	3,330	3,105	3,173	2,835	4,185	4,106	3,285	2,779	2,779	2,385	2,588	2,779	2,385
Disposal total****	€	161,805	158,183	101,430	113,505	118,335	60,375	265,650	260,820	131,618	85,008	85,008	56,753	77,280	85,733	85,733
Scenario 1 - Total costs/7000 t FBP	€	4,723,568	4,583,766	3,369,160	3,606,105	3,736,936	2,434,847	7,137,601	7,048,087	4,070,316	2,949,475	2,949,475	2,318,860	2,726,083	2,957,820	2,610,812
Costs per ton LAB[1)]	€	19,280	19,843	19,252	18,398	17,795	17,392	16,994	17,360	18,171	21,068	21,068	22,084	22,908	21,127	24,865
Surplus / loss per ton LAB[2)]	€	32,201	31,231	34,944	31,386	31,446	30,695	32,247	32,696	31,613	30,413	30,413	24,849	29,387	30,354	22,068
Scenario 1 - Total costs/7000 t FBP	€	6,123,568	5,983,766	4,769,160	5,006,105	5,136,936	3,834,847	8,537,601	8,448,087	5,470,316	4,349,475	4,349,475	3,718,860	4,126,083	4,357,820	4,010,812
Costs per ton LAB[1)]	€	24,994	25,904	27,252	25,541	24,462	27,392	20,328	20,808	24,421	31,068	31,068	35,418	34,673	31,127	38,198
Surplus / loss per ton LAB[2)]	€	26,487	25,170	26,944	24,243	24,779	20,695	28,913	29,247	25,363	20,413	20,413	11,515	17,623	20,354	8,735

* Average Alibaba; margin 7.570 - 41.088 €/t
** Average Alibaba; margin 3.566 - 11.508 €/t
***industrial price, incl. basic costs
**** All liquids

1) Costs incl. production of lactic acid
2) Revenue LAB incl. lactic acid

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5.4 Conclusions

Comparing the processes examined above for economic viability, especially the utilization of fish-by products for processing of dry peptones and liquid peptones with subsequent utilization as growth media for LAC are promising. The profitability of processing FPH is depending predominantly on the by-product type (trimmings/frames most promising for tested species and by-products) and the valorization of fish by-products into gelatin did not proof to be profitable in the current input-output analysis. However, it has to be kept in mind that these conclusions only apply to the framework conditions adopted here.

On the one hand side not all expected short-, but especially mid- and long-term costs could be included within the analysis, but on the other side the potential valorisation of further by-products within the different processes was not covered as well. For example, all described products contain fish oil as a side product, although varying in volume depending on species and by-product type. Fishmeal could be another side product, but would most likely demand additional equipment and input for processing.

Further, the assumed B2B platform prices may not, or only partly, reflect the current market potential. In general, a valid estimation of potential returns for the different examined products is difficult. Publicly available price information is scarce and prices are often the result of individual negotiations. In addition, prices depend on quality/purity of the products and the offered quantity/ package sizes, and, probably most important, the demand for the specific product. Especially new products are very costly to market and niche products, to which high quality secondary products deriving from fish by-product often belong, might only be demanded in small quantities. This might result in the production line being underutilized (commun. Bioceval CUX). In general, fish by-product processing companies often have to adapt to different market requirements and thereby retain a certain flexibility in their processing line that includes an economic risk. Usually there are no binding sales volumes that are contractually stipulated with the purchasing companies, increasing the economic risk even further (commun. Bioceval CUX).

Another important point to consider is the availability and the associated cost of the fish by-product raw material. Within the conducted economic analysis, we assumed two scenarios for raw material costs/t in order to represent the potential range, knowing that prices can fluctuate strongly, e.g. between species, by-product type and quality, season, country of origin as well as demand/market for other sectors (commun. Bioceval CUX). Especially fish heads are marketed often directly as food (predominantly deriving from salmon and cod), e.g. for fish soup, achieving prices starting from 0.5 €/kg up to returns between 4 and 5 €/kg for high value by-products determined for the food industry/market (see Deliverable 4.1). Fish mince, obtained mostly from trimmings and frames, is another example for direct marketing of fish by-products (e.g. for fish fingers, fish cakes, surimi). Thereby the direct marketing of both, fish heads and mince, achieve a higher yield compared to secondary products that are processes from these by-products. On the other hand, the demand for viscera is comparably low, and this by-product will probably mostly be marketed for prices as assumed under scenario 1. In general, by-products deriving from seawater species are often marketed for higher prices compared to those from freshwater species, due to their different content in omega 3 fatty acids. However, for by-products deriving from aquaculture, this will depend on

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the feed and related omega 3 content. Single-variety by-products are more expensive than mixed products, whereas the first category seems to be increasingly valorized by the processing sector itself (e.g. Thai Union, MOWI) reducing the availability on the by-product market for external buyers.

Sector insights report about difficulties in remaining permanently solvent within the niche of (processing independent) fish by-product valorization (commun. Bioceval CUX and within GAIN) and Olsen et al. (2014) concluded that it is unlikely that by-products can be used to any large extend to produce high-priced products. Amongst other reasons, Olsen et al. (2014) mentioned a lack of existing markets as well as of high quality by-products, high costs of isolating specific components and the competition of quickly developed cheaper alternatives to interesting properties identified within fish by-products. It seems therefore crucial to establish appropriate and efficient extraction methods in order to succeed in utilizing marine resources in a responsible way (Khawli et al. 2019). Further, improving sustainability of the food production system often increases costs in the short-term, whereas revenues are uncertain. A thorough ecological assessement of fish by-product recycling and recovering as well as creating transparency to the consumer are important to justify higher market prices (see Jouvenot, 2015).

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6. Perspective exploitation of rainbow trout by products: the Italian case study

The results presented in the previous chapter indicate that the cost of production of FPH and peptones are likely to be lower for rainbow trout, compared with those pertaining salmon, turbot and seabass. In particular, the extraction of valuable secondary products from rainbow trout by-products requires in both cases only half the amount of enzyme, compared to those deriving from other fish species. Although the yield of peptones from trout is in the middle range compared to other fish species, the costs are at in the lower range, together with those for processing turbot by-products. Therefore, the surplus/ton for dry peptones is the second highest. Considering these data and the relevance of trout production in Europe, the potential exploitation of these secondary products was investigated. The analysis focused on the Italian market, as Italy is the main trout producer in the EU.

UNIVE activities aimed at shedding light on the economic viability of strategies based on the valorization of by-products, focusing on valorization pathways other than pet food. The reasons are twofold: first, the last chapter provides a comprehensive overview of the potential use of FPH in pet food, second, the focus on one single avenue for such a valorization offers the opportunity to be more precise in defining and sizing the opportunities, costs and operational transformations, while a general view on all the possible transformation would introduce too much variation and variability. Thus, working on a specific area might help in validating a first set of assumptions and models, calling for subsequent stretches to other types of markets and transformations.

The following sections summarize the results of the activities performed by UNIVE. Research and analyses aimed at: 1) understanding the potential dimensions of the market for the outcomes of these processes; 2) identifying the forces and variables that will likely influence the viability of these strategies and ensuing business models. Finally, some suggestions for the implementation of these strategies are provided.

In the light of the above-mentioned economic findings, some spin-off exploration has been carried out, aimed at preliminarily suggesting what the potential economic impact may be of valorizing selected aquaculture by-products by reusing and valorizing them according to the principles of the Circular Economy (Ellen McArthur Foundation, 2013). The present section reports the mapping of trout farming in Italy; mapping of target companies that may represent some recipients of the fish industry by-products, and some preliminary remarks about deriving market potential for the valorization of such by-products.

6.1 Trout production in EU and Italy

According to FAO, circa 680.000 tonnes of trout species were farmed in the world in 2018. The main producers are Iran, the EU and Turkey. Trout is one of the main aquaculture species in the EU: its production exceeded 156.000 tonnes in 2018. The major producing countries are Italy, France and Denmark. Rainbow trout is a highly versatile species which is reflected by its wide geographic distribution and the various culture methods applied.

Table 6.1: Rainbow trout annual productions in main EU countries

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MS	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Evol. 2018/08
Italy	35.802	35.697	34.366	35.261	35.004	31.300	30.503	34.307	34.407	32.826	-8%
France	35.152	34.545	30.806	30.627	30.818	29.347	23.489	35.674	34.906	32.593	-7%
Denmark*	25.120	22.291	17.739	19.048	19.024	19.678	19.529	20.405	19.058	19.010	-24%
Spain	18.429	17.382	16.546	16.302	15.797	15.104	16.154	17.209	16.829	16.002	-13%
Poland	14.872	14.872	10.398	10.724	10.251	13.449	12.727	13.730	13.808	14.902	0%
UK	12.309	11.988	10.996	12.515	10.502	10.798	10.161	10.092	9.559	8.496	-31%
Germany*	22.568	22.230	20.561	9.378	9.601	9.937	8.527	8.533	8.397	7.852	-65%
Sweden	3.982	5.576	7.490	7.448	6.641	6.951	7.048	9.123	8.505	6.716	69%
Others	14.761	15.624	15.368	12.154	12.327	12.451	12.939	13.709	14.195	17.666	20%
Total EU	**182.995**	**180.204**	**164.271**	**153.457**	**149.964**	**149.014**	**141.076**	**162.782**	**159.664**	**156.064**	**-15%**

*Source: EUROSTAT / National statistics for Denmark and Germany. *) the decrease of the German production is related to a modification in survey methodology in 2012.*

According to the last Italian census of aquaculture (Maiolo&al, 2020), currently there are around 310 freshwater farming companies, most of which produce rainbow trout. Recent surveys and value-chain analyses on aquaculture companies in the European Union, carried out within the GAIN project and also specifically addressing trout farms in Italy (Malcorps et al., 2021), have shown that small enterprises, including (and especially) sole-proprietorship companies are quite skeptical toward innovations and by-product reuse. However, their production volumes are of course expected to be limited, and logistic expenditures may discourage by-product transportation and sales. On the contrary, medium-size companies are considered as more promising. This is why a focus follows on the latter. Furthermore, sole-proprietorship companies are not required any public financial statements, namely income statement and balance sheet. According to data provided by API, (Associazione Piscicoltori Italiani), (A. Fabris, Personal Communication), the Italian market is populated by approximately 20 trout-processing firms whose operations are connected to trout farming. Their size, in terms of production, ranges between 20 tons per year to 2000 tons per year (processed product). The percentage of transformed trout distributed on the National market amounts to approximately 65% of total production, while 35% is exported.

6.2 Mapping of potential fish by-product recipients in Italy

<u>Pet food producers</u>

Based on data provides by the Italian Ministry of Health (Ministero della Salute, 2021), 39 pet food producers are present in Emilia Romagna, 30 in Lombardia, 24 in Veneto, and 19 in Piemonte (**Figure 6.1**). Cumulatively, 28 companies are located in north-eastern Italy, 67 (42%) in north-eastern Italy and adjacent Emilia Romagna, and 116 (73%) in the entire northern Italy.

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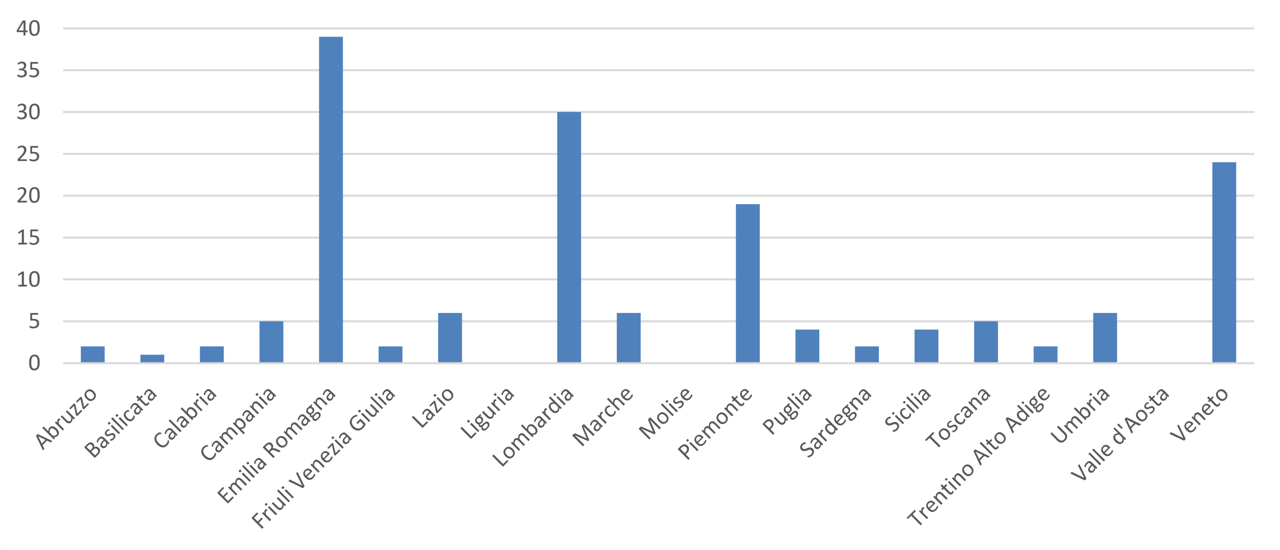

***Figure 6.1**: Italian pet food producing companies by region.*

<u>Cosmetic producers</u>

Based on the Italian official records for cosmetic producers (code 20.42 of the national economic activity classification, commonly known as ATECO)[3], 927 cosmetic producers are present in Italy (**Figure 6.2**): 72 in Veneto, 73 in Piemonte, 277 in Lombardia, 91 in Emilia Romagna, and fewer numbers in the remaining regions. Cumulatively, 189 (20%) companies are located in north-eastern Italy, 280 (30%) in north-eastern Italy and adjacent Emilia Romagna, and 653 (60%) in the entire northern Italy.

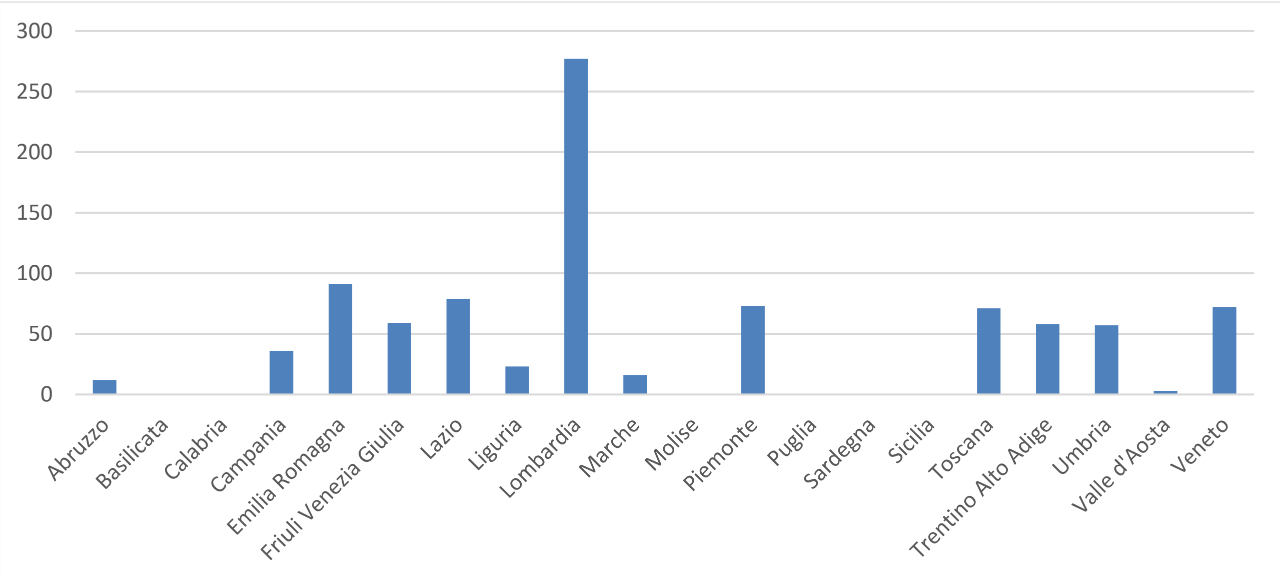

***Figure 6.2**: Italian cosmetic producing companies by region.*

[3] also accessible through platforms like Report Aziende (2021) and iCribis (2021b)

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6.3 Methods

The previous analyses were mainly based on secondary sources and interviews to experts (e.g.: associations such as API). They provide an overview of the potential for business models focused on the transformation of by-products. The viability of these strategies depends on the integration of incumbents' specific industrial processes with novel ones, and on the recognition of potential sources of friction. In other words, while the market potential exists in principle, the actual entry of actors into it depends on their ability to extend their operations in an economically sustainable fashion. This is in line with the attempt to effectively apply both the circular economy action plan (adopted by the European Commission since 2015) and the achievement of the sustainability objectives set by the 2030 Agenda. A circular economy protects companies from the increasing scarcity of resources, promotes job creation and social integration and is important in the context of contrasting and adapting to climate change. Indeed, it aims to maintain the value of products, materials and resources for as long as possible by returning them into the product cycle at the end of their use, while minimizing the generation of waste. The transition to an economy like the one defined above is recognized as fundamental for achieving ever greater environmental, social and economic sustainability. For this reason, we tried to improve our understanding of the strategic, organization- and market-related antecedents of both the actual possibility of entry in a (still potential) market and its implications. The aims of the case study were manifold:

1. understanding and framing the current competitive position of each firm, and in particular understanding the value-chain and market-related pressures they experience;
2. capturing these firms' representatives' perceptions on the evolution of the sector and on the viability (or lack thereof) of alternative business models based on the extraction of the secondary products, as described in Chapter 3;
3. gaining an in-depth view of the technical and operational implications of the entry in such segments.

These activities aimed at capturing the perceived existence of a viable break-even point by representatives of these firms. A second order of research objectives entailed the investigation of the visible and hidden (e.g.: organizational) costs of by-product disposal. Thus, we aimed at capturing the perceived entity of extraction costs and the subsequent prices that the firm might command on the market.

The cases were realized as follows. First, the team proceeded with an extensive analysis of secondary material related to the sampled firms. Two cases, representative of the production and by-product processing sector, were investigated:

- ASTRO https://www.troteastro.it/, a fish farmer cooperative which centralizes fish processing, collecting fish form 15 producers, and treats a volume of about 1,300 tonnes/year: therefore, ASTRO could be potentially interested in extracting secondary products and commercializing them.

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- Farpro (https://www.farpro.it/), one of the biggest Italian companies coneverting animal by-products into secondary products.

Financial statements of these companies were extracted from the AIDA National Database. This allowed us to develop a preliminary understanding of the current economic, financial and competitive situation of the firms. Then the firms were contacted and knowledgeable representatives were interviewed. Semi-structured interviews were focused on the main themes mentioned above. The next section presents a set of preliminary results that might orient the decisions of firms when facing the trade-offs entailed in disposing or extracting by-products.

6.4 Results of the Case Study

In this subsection we present separately the results of the financial analysis and the interview with ASTRO and FAR PRO.

6.4.1 ASTRO Products and market

ASTRO - Associazione Troticoltori Trentini is a cooperative company founded in 1987 and located in Trento, in Northern Italy. It includes 15 different partners who farm rainbow trout in 25 different locations in the Trentino-Alto Adige region. ASTRO takes care of fish collection from producers and processing, as well as of the commercialization of the final product and disposal of by-products. Every year it handles 1,300 tons of fish, 95% of which is represented by rainbow trout. Therefore, ASTRO processes bout 4% of the Italian production. In 2020 employed 32 people, between management, production and administration. The cooperative process and package fish using its own infrastructure . The processes and the quality of the product allowed the company to obtain several quality certifications. In particular, the products have the I.G.P. seal (a standard of quality and origin of the production) and are certified by “Friend of the sea”, an international association that guarantees the sustainability of the production techniques.

ASTRO produces and deliver to market a wide variety of products, fresh and packed. It offers rainbow trouts, arctic chars and carpione in different formats: whole, fillet or gutted. In addition to the fresh fish, it also produces elaborate recipes, packed to be sold in the supermarkets. The offer of the company includes smoked fish (both for rainbow trout and arctic chars), trout hamburgers, trout meatballs, trout eggs, trout in saor[4], breaded trout fillet and other specialities.

[4]Typical Venetian seasoning based on sweet and sour onions, pine nuts and sultana.

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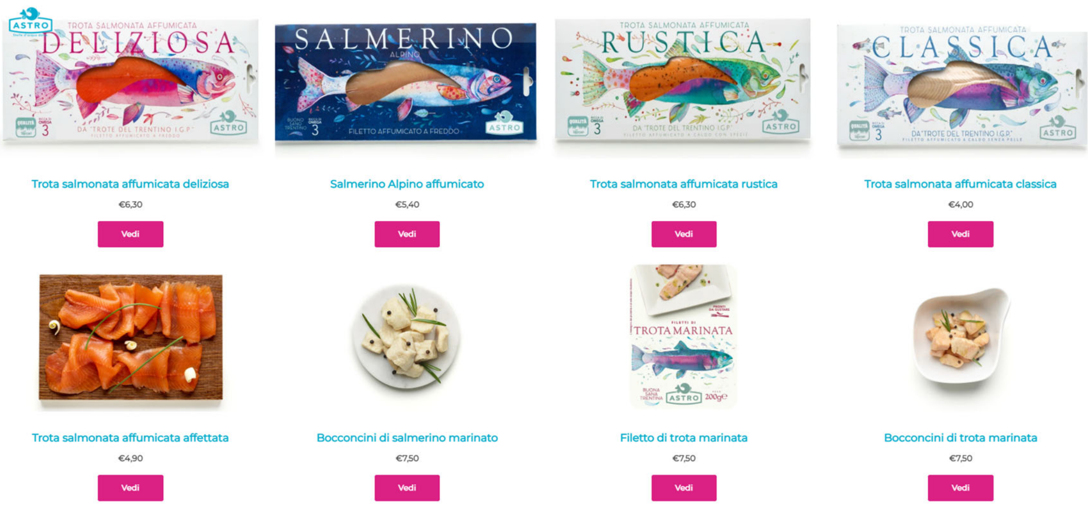

Figure 6.3: Some products of ASTRO

The output of the production is 700 tons. More than half of this is sold in fillet format (400 tons), followed by gutted fish (140 tons). The ready-to-eat products still consist of a really limited portion of the total. The quantities produced and sold to the market decreased from 2019 (-11 tons), but the level of the revenues remained similar, due to the increase of the price of the fish.

In 2020 90% of the market of the company is represented by mass retailers, the remaining part is sold through the hospitality industry (mainly hotels and restaurants of the region Trentino-Alto Adige). The COVID-19 crisis reduced this segment of the market, as for several months such activities were closed. At the same time the sales through retailers increased and the ready-to-eat products registered a significant rise of sales (+28%), even if they still don't reach a significant part of revenues. But the observable trend is remarkable and can grow even more in the next years.

In the last years Astro started a process to increase the number of customers, especially in the mass retailers segment. This decision has been taken after the volumes of sales to the main retailer sharply dropped (-56% in 10 years). Nowadays the company relies on a wider base of customers, which gives less dependency from a single big retailer. The company is also developing a direct channel to sell its products to the consumer through the physical store and the online one, but this doesn't contribute significantly to the revenues.

6.4.2 <u>ASTRO Financial analysis</u>

ASTRO - Associazione Troticoltori Trentini is a Cooperative company. The economic results of the company have been stable in the last five years. In 2016 the total revenues were 7,1 million €, while in the last available income statement (2020) they have dropped to 6,9 million €. The differences of revenues in the last five years have been relatively low. In 2019 the company was regaining shares of the market, but during 2020 the impact of the COVID-19 crisis hit the results of Astro, with a difference of -1,1% on the previous year. During 2020 the hospitality industry market channel suffered (restaurants were closed for several months throughout the pandemic) and this caused the reduction of revenues. This drop was mitigated by the increase of prices, that allowed to reduce the effect on the revenues.

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Table 6.2: Income statement of ASTRO 2016-2020.

	2016	2017	2018	2019	2020	% on revenues 2020
TOTAL REVENUES	**7.127.405**	**6.890.638**	**6.891.399**	**7.019.596**	**6.942.713**	**100,00%**
Cost of goods sold	4.569.276	4.352.235	4.524.610	4.560.563	4.565.605	65,76%
GROSS PROFIT	**2.558.129**	**2.538.403**	**2.366.789**	**2.459.033**	**2.377.108**	**34,24%**
EXPENSES						
Services	1.378.384	1.381.056	1.165.384	1.178.568	1.210.816	17,44%
Salaries and wages	948.166	954.108	940.755	986.083	970.595	13,98%
Depreciation and amortization	116.860	151.849	122.299	126.187	90.455	1,30%
Other costs	64.191	15.850	105.490	138.753	79.247	1,14%
Total expenses	2.507.601	2.502.863	2.333.928	2.429.591	2.351.113	33,86%
EBIT	**50.528**	**35.540**	**32.861**	**29.442**	**25.995**	**0,37%**
Interest expense	-38.408	-32.270	-31.042	-27.523	-23.778	-0,34%
EBT	**12.120**	**3.270**	**1.819**	**1.919**	**2.217**	**0,03%**
Income Taxes	2.000	0	0	0	500	0,01%
NET PROFIT	**10.120**	**3.270**	**1.819**	**1.919**	**1.717**	**0,02%**

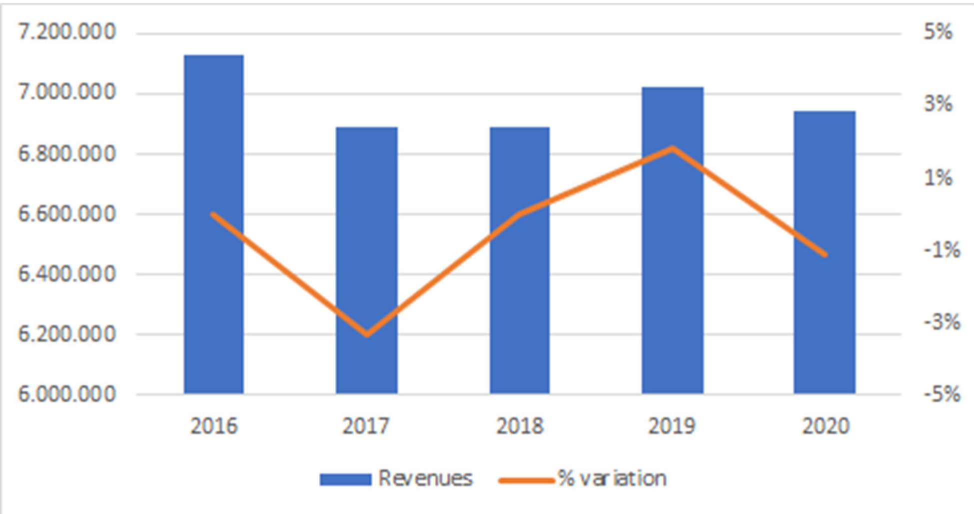

***Figure 6.4**: Revenues and variation of revenues on previous year of Astro.*

The structure of the expenses of the company remained stable during the period. In 2020 the cost of the goods sold represented almost ⅔ of the total revenues with a slow but constant growth since 2017. Services and salaries are the other two main categories of costs in the income statement of the company, representing 17% and 14% of the revenues. The EBIT (earnings before interests and taxes) index is close to zero, but positive. In the last five years Astro always registered low values in this index and the trend is descending, from 50.000€ in 2016 to 26.000€ in 2020 (-51% in the period). The final result after interest expenses and income taxes is 1.717€ in 2020, with a stable trend in the last three years.

Table 6.3: Balance sheet of Astro 2016-2020.

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	2016	2017	2018	2019	2020
ASSETS					
Intangible assets	453.910	266.880	218.765	206.368	188.192
Tangible assets	2.680.557	2.773.445	2.705.531	2.746.342	2.751.556
Financial assets	61.501	40.150	40.150	40.428	40.428
Total noncurrent assets	**3.195.968**	**3.080.475**	**2.964.446**	**2.993.138**	**2.980.176**
Inventory	188.351	281.492	345.607	243.950	314.087
Accounts receivable	912.673	919.712	954.515	947.561	1.042.374
Cash	39.721	3.182	118.718	93.960	17.752
Total current assets	**1.140.745**	**1.204.386**	**1.418.840**	**1.285.471**	**1.374.213**
Other assets	**2.278**	**10.723**	**26.141**	**19.599**	**16.016**
TOTAL ASSETS	**4.338.991**	**4.295.584**	**4.409.427**	**4.298.208**	**4.370.405**
LIABILITIES AND EQUITY					
Account payables	1.998.004	1.899.208	1.723.660	1.888.212	1.856.273
Financial debt	1.160.225	1.195.261	1.326.447	1.192.422	1.252.587
Other debts	405.703	343.088	504.572	387.911	435.674
Total debts	**3.563.932**	**3.437.557**	**3.554.679**	**3.468.545**	**3.544.534**
Equity capital	1.300	81.300	76.300	49.350	43.900
Reserves	763.639	773.457	776.629	778.394	780.254
Retained earnings	10.120	3.270	1.819	1.919	1.717
Total equity	**775.059**	**858.027**	**854.748**	**829.663**	**825.871**
TOTAL LIABILITIES AND EQUITY	**4.338.991**	**4.295.584**	**4.409.427**	**4.298.208**	**4.370.405**

On the balance sheet side, Astro presents an equilibrated structure of the assets. Noncurrent assets are the main ones and represent two thirds of the total assets: they consist of the land, the building and machinery needed for production.

The other assets are the current ones. Here the account receivables are more than 1 million euros and it has a growing trend in the last five years. A consistent part (314.000 €) is represented by the inventory, while cash is low with a decreasing trend from the last three years. Total assets amount is 4.370.405 € in 2020.

The liabilities are mainly constituted by two sources: account payables and financial debt. Account payables are higher than receivables, but it is possible to note a decreasing trend in the last five years (with the exception of 2018). Financial debts grew in 2020, due especially to the cash needs of the company during the pandemic crisis of COVID-19. Even if the worldwide situation was difficult, Astro did not need to increase the financial debt.

Equity is less than one fourth of the debts: the structure of the cooperative company involves a low capitalization (only 43.900 €), while reserves are the most consistent part of equity and

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have a growing path throughout the years, thanks to the positive economic results of the company.

Table 6.4: Main financial ratios of Astro in 2020.

FINANCIAL RATIOS	2020
EBITDA	116.450
EBITDA/Revenues	1,69
Return on assets (ROA)	0,59
Return on investment (ROI)	1,25
Return on sales (ROS)	0,37
Return on equity (ROE)	0,21

Cooperative companies' purpose is to realize the economic, cultural and social needs of the organization's members and its surrounding community and doesn’t maximize profits, but the wellbeing of the people involved in the company. This is coherent with the low-profitability, but stable results of the company in the last five years. As a consequence of the results previously analyzed, main income statement ratios are positive. Earnings before interest, taxes, depreciation and amortization (EBITDA) is 116.450€ and it is 1,69% of the total revenues. Return on sales (ROS) is 0,37, this means that for every 100€ of revenues, the company is able to generate 0,37€ of operating profit. The ratios that compare returns with balance sheet data are also low: return on assets (ROA), return on investment (ROI) and return on equity (ROE) are respectively 0,59, 1,25 and 0,21, giving a small but stable return on the invested capital and on the equity of the partners.

6.4.3 ASTRO by-products

The production of ASTRO is pretty wide and for each product there is a different level of by-products. For the whole trouts the efficiency is 100% (except for an insignificant amount of trouts discarded, due to irregularities of the fish), while for the smoked trouts only the 30% of the input is sold. As an average, the company has an efficiency of 55%, thus the 45% is by-product and consists of heads, fishbone, viscera and trims. This amount is large (1.300 x 45% = 585 tons), therefore the company had to make a choice in the past years. The cost for the disposal of the waste depends on different factors, from quantity and quality to the location. Normally the cost of disposal is between 0,10 and 0,40 € per kg. The overhead costs are not significant, as the disposal of wastes by an external company doesn’t imply particular logistics for ASTRO and administrative costs are very low in comparison with the ones of the whole company. Considering an average cost of 0,25 € per kg and an amount of by-product of 585 tons, the annual cost for disposal would be 146.250 €. This extra cost would make the company lose all its margins and obtain economical losses at the end of the year.

The solution found by ASTRO is to sell, for a low price, all the by-products to a company that produces pet food. The income is around 0,015 € per kg. This gives an extra revenue of 8.775 € per year, that barely covers the transportation and overhead costs. It is possible to assume that the sale of the byproducts to a pet food company is an operation that has an economic result of 0 €. When Astro opted to sell its by-products, it obtained a saving of almost 150.000 € per year compared to the disposal of waste.

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To take advantage of the significant quantity of by-products produced by the company, ASTRO started a research project with the University of Trento. They studied together the possibility to better reuse the by-products in terms of circular economy and guarantee the company an interesting extra income. The object of study has been the extraction and valorization of fish oil to be sold especially as nutritional supplements: as a matter of fact, fish oil is rich in Omega-3, which is a product that is increasing its market shares, especially in the last decade.

The joint study is still ongoing, but, at present, the conclusion is that the investment for the new laboratory and machinery would not be profitable for the quantities of by-products that Astro handles. At the same time, it is not feasible to get more by-products from other fish companies, because Omega-3 to be extractable needs to be taken from a fresh by-product. Considering a normal lead time from another company, it would be impossible to obtain high quality Omega-3.

The partial results of the research is confirmed by the absence of such plants in Mediterranean Europe. The extraction of fish oil for Omega-3 based products is done only in Northern Sea and Atlantic Ocean fisheries, in particular for companies that produce large quantities of salmon, as they can reach quantities of 100.000 tons of fish per year: in this case the extraction of fish oil is economically feasible.

6.4.4 Farpro Products and market

In Italy, the market for by-products is composed by 50 factories that produce meals and 3 factories that focus on frozen products. Those who produce frozen products generally freeze them as they are (whole or ground). Farpro applies specific technologies capable of separating meat from bone or meat from cartilage, and this already brings a relevant enhancement (for example meat might be used for frozen food, bones are transformed in meals). Moreover, of the 50 companies that make meals, some are specialized in chicken, bones for slaughter, butchers, etc . Farpro once focused on blood meal and decided, since they had machinery for both meal and freezing (in addition to the extraction of plasma to make hemoglobin, unique in Italy), to expand their production to protein hydrolysates. For these reasons, Farpro can be considered a hybrid company.

The firm leads the Italian market in production of different products obtained both from animals and fish by-products. Its portfolio counts more than 250 items. Operating in over 50 countries, Farpro now offers the industry’s most extensive and specialized product range.

The company processes about 150,000 tons / year, including sheep, cattle, poultry, etc.. by-products. The fish quota is around 5,000 tons / year and almost 50% is related to trout. Farpro collects 90% of the total Italian fish by-product, excluding shellfish.

In 2020 it employed 51 people and the turnover in the same year was around 45 million euros.

6.4.5 FarPro Financial analysis

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Farpro Modena S.p.a. is a public limited company and it is part of Gruppo FarPro. The economic results of the company registered an important growth in the last five years. In 2016 the total revenues were 28,3 million €, while in the last available income statement (2020) they have reached 47,4 million €, with an increase of 67,4%. The growth has been constant, except for a drop in 2019, that was recovered during the following year. During the first pandemic year after the crisis for COVID-19, the company registered good results, thanks to the capacity to produce different products and its ability to reallocate its sales to different markets.

Table 6.5: Income statement of FarPro 2016-2020

	2016	2017	2018	2019	2020	% on revenues 2020
TOTAL REVENUES	**28.330.633**	**33.730.627**	**45.026.196**	**42.817.669**	**47.429.738**	**100,00%**
Cost of goods sold	14.265.545	18.667.620	27.138.939	25.993.379	29.083.075	61,32%
GROSS PROFIT	**14.065.088**	**15.063.007**	**17.887.257**	**16.824.290**	**18.346.663**	**38,68%**
EXPENSES						
Services	9.029.268	9.655.098	11.234.998	11.450.052	11.660.548	24,58%
Salaries and wages	2.977.290	3.027.004	3.151.489	3.313.260	3.293.177	6,94%
Depreciation and amortization	1.177.045	1.173.748	1.125.819	1.642.265	1.216.888	2,57%
Other costs	456.821	596.226	356.601	380.391	463.213	0,98%
Total expenses	13.640.424	14.452.076	15.868.907	16.785.968	16.633.826	35,07%
EBIT	**424.664**	**610.931**	**2.018.350**	**38.322**	**1.712.837**	**3,61%**
Interest expense	-152.028	13.867	726.850	558.545	216.869	0,46%
EBT	**272.636**	**624.798**	**2.745.200**	**596.867**	**1.929.706**	**4,07%**
Income Taxes	93.106	165.894	424.568	89.232	147.344	0,31%
NET PROFIT	**179.530**	**458.904**	**2.320.632**	**507.635**	**1.782.362**	**3,76%**

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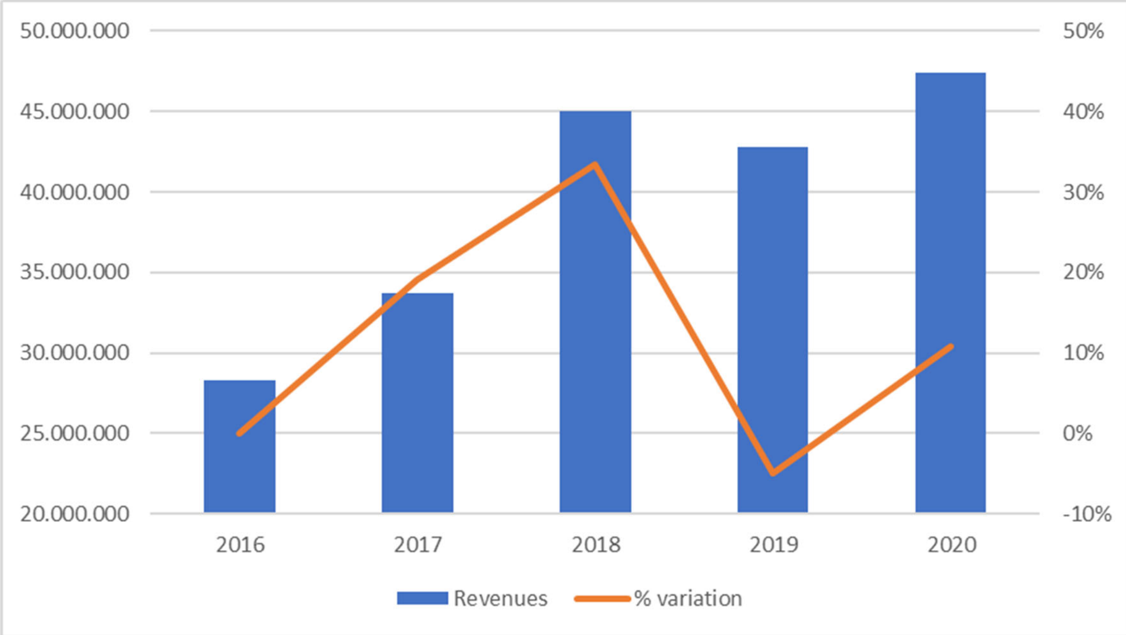

Figure 6.5: Revenues and variation of revenues on previous year of FarPro

The structure of the expenses of the company remained stable during the period. In 2020 the cost of the goods sold represented 61,3% of the total revenues with a constant growth since 2016, except for 2019 when costs followed the same trend of revenues. Services is the other important categories of costs in the income statement of the company, representing 24% of the revenues. Salaries and wages are the 7% of the revenues and this data did not follow a proportional growth with the revenues: the increase was low and in 2020 the salaries were lower than previous year. The productivity of the employees had a significant growth through the years. The EBIT (earnings before interests and taxes) index has always been positive, with two peaks in 2018 (with the highest registered value of 2 million €) and 2020. The final result after interest expenses and income taxes is 1,78 million €, with positive results in the last five years.

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Table 6.6: Balance sheet of FarPro 2016-2020

	2016	2017	2018	2019	2020
ASSETS					
Intangible assets	14.926	23.333	381.587	276.740	22.594
Tangible assets	22.233.448	21.105.634	21.937.135	23.732.300	28.367.693
Financial assets	333.148	1.487.012	1.482.847	1.369.823	1.370.347
Total noncurrent assets	**22.581.522**	**22.615.979**	**23.801.569**	**25.378.863**	**29.760.634**
Inventory	4.561.501	3.442.683	4.678.160	4.926.494	5.422.861
Accounts receivable	8.293.203	9.475.995	10.934.855	11.887.234	9.521.867
Cash	381.730	115.230	26.542	19.029	171.397
Total current assets	**13.236.434**	**13.033.908**	**15.639.557**	**16.832.757**	**15.116.125**
Other assets	**123.033**	**96.298**	**659.269**	**660.348**	**617.583**
TOTAL ASSETS	**35.940.989**	**35.746.185**	**40.100.395**	**42.871.968**	**45.494.342**
LIABILITIES AND EQUITY					
Account payables	8.663.738	8.161.648	7.124.479	8.064.932	7.803.857
Financial debt	9.673.341	8.870.189	11.339.562	13.528.448	10.569.164
Other debts	1.912.428	2.668.028	3.326.352	2.405.687	3.586.786
Total debts	**20.249.507**	**19.699.865**	**21.790.393**	**23.999.067**	**21.959.807**
Equity capital	1.770.807	1.770.807	1.770.807	1.770.807	1.770.807
Reserves	13.741.145	13.816.609	14.218.563	16.594.459	19.981.366
Retained earnings	179.530	458.904	2.320.632	507.635	1.782.362
Total equity	**15.691.482**	**16.046.320**	**18.310.002**	**18.872.901**	**23.534.535**
TOTAL LIABILITIES AND EQUITY	**35.940.989**	**35.746.185**	**40.100.395**	**42.871.968**	**45.494.342**

Farpro presents an equilibrated structure of the assets. Noncurrent assets are the main ones and represent almost two thirds of the total assets. Among these the majority consists in tangible assets, that grew up during last five years after some structural investments. A growing trend is registered also in financial assets, which are participations in other companies (especially a 50% in HariPro S.p.a., which produces animal proteins and food aromas, and a 100% in For Pet Us Inc., a subsidiary in the United States).

The other assets composing the balance sheet are the current ones. The account receivables had a variation between 8 and 11 million €. Inventories at the end of the year are consistent: in 2020 reached the maximum of 5,4 million €. Total assets amount is 45.494.342 € in 2020.

The liabilities are mainly constituted by two sources: account payables and financial debt, with a higher amount for the second one. Account payables is now lower than receivables, but in 2016 the situation was opposite. Financial debts had a growing trend between 2017 and 2019, but lowered down in 2020, thanks to the repayment of a part of the financial debt.

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After the good results of the company in previous year and the increase of reserves, in 2020 equity is higher than debts, giving to FarPro a good stability characterized by a strong capitalization.

Table 6.7: Main financial ratios of FarPro in 2020

FINANCIAL RATIOS	2020
EBITDA	2.929.725
EBITDA/Revenues	6,25
Return on assets (ROA)	3,76
Return on investment (ROI)	5,02
Return on sales (ROS)	3,65
Return on equity (ROE)	7,57

2020 has been a positive economical year for FarPro, which registered high levels of revenues and profits. As a consequence, also intermediate ratios are positive: EBITDA in 2020 was almost 3 million € and it was 6,25% of the total revenues, generating an important operative result. Return on sales (ROS) is 3,65, this means that for every 100€ of revenues, the company is able to generate 3,65€ of operating profit. The ratios that compare returns with balance sheet data are also high: return on assets (ROA), return on investment (ROI) and return on equity (ROE) are respectively 3,76, 5,02 and 7,57, giving a high level return on the invested capital and on the equity of the partners.

6.4.6 FarPRo fish by-products

As mentioned before, the fish quota transformed by the company is around 5,000 tons / year. Although Farpro is the first Italian company for processing fish by-product, compared to the rest of Europe this is a very low level. In Poland, for example, 160,000 tons / year of by-products.

Company representatives we interviewed maintain that a first important step in enhancing the by-products has been made. Previously, processors had to pay around 150 euros / ton for the disposal of the by-product; today these companies earn on average 50 euros / ton for by-product. The by-product is collected fresh and the cost varies according to the quantities involved: on limited quantities, transport costs might affect the final prices. Refrigeration would cost too much and it is not a viable way as well as importing the product, due to the transport costs.

According to Farpro representatives, in Italy, the biggest problem hindering the development of this by-product market is the scarcity of raw materials, which is due to:

- Low aquaculture production.

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- Different consumption habits: in Italy there is a higher propensity to buy the whole product instead processed product .
- High cost of processing infrastructure, which does not make profitable for SME to process by products in house.
- Great volatility of by-product prices due to different factors (trade policies, health policies, etc.).

In summary, the economic sustainability of Farpro is linked to the large portfolio of products, not only related to fish, and to the ability, thanks to the various technologies adopted, to create customized products and modify production based on new market needs.

6.5 Perspective research

Future developments of the research presented in this section of the document will focus on a detailed investigation of the costs of investing in the laboratory and the technologies needed to extract secondary products, such as Omega 3 fatty acids, and on the estimation of the break-even point. This analysis will allow fish farms to assess the economic viability of a novel circular business models.

The methodology applied in this case study could also be extended to other medium-large producers/producer cooperatives, in order to confirm the results here presented further understand the viability of these strategies, also in relation to companies producing organic trout, thus allowing to explore the implications of extracting and marketing organic-related secondary products.

Finally, interviews with firms focused on rendering would allowed to estimate the size of demand of by-products, but, unfortunately, contacts with these companies were not successful.

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7. Potential exploitation of seabass and seabream by-products in the pet food industry

The Global pet food industry reached around EUR 85 billion at the end of 2020. The European market is estimated at EUR 22.4 billion in the same period. With an average of 3% CAGR in the past few years. The pet food market is expected to continue growing in value to reach EUR 26 billion in 2025, mostly driven by one megatrend: pet humanization (FEDIAF, n.d.).

The emergence of new pet parents' generations (millennials and Generation Z) has led the pet food market to enter a phase characterized by intense innovation. Recent years have been marked by the emergence of new pet food businesses, a series of major health issues related to food and shaking the trust between the industry and consumers. In order to answer these new consumers expectations, the pet food industry is adapting. A new wave of products is emerging, focusing on providing not only nutrition but also clean and functional nutrition. Functional pet food will soon become mainstream, targeting conditions such as digestive issues, allergies or even cancer or providing wellness. The industry is also working on new ways to deliver the product and building an effective and efficient supply chain utilizing technology.

With the changes expected with the next generational cohort becoming the decision-makers in households, the pet food industry needs to address several challenges. The industry is expected to become more responsible, transparent and trustworthy, with a corporate world embracing systematic sustainable practices, including Animal Welfare, a growing topic in the industry. A lack of readiness in some key operations areas will be detrimental to some leading brands in North America and Europe, where the challenges are no longer how to market products but where to produce them and how.

One of the growing global trends in pet food diets is the increase in protein content. In addition, the focus is shifting from the protein amount to sourcing, type, function and quality of protein pets should be consuming.

Blockchain will soon allow consumers to screen instantly the entire product identity and will force brands to supply only raw materials with strong sustainability credentials. This has greatly benefited the seafood industry in Northern Europe and the Americas. The emergence of pet foods containing up to 30% of fishmeal is no longer uncommon. The rise in use of animal protein is leading to new elements of differentiation such as the use of whole fish, clear identification of the species, sustainability accreditation of the fishery, etc.

Increasing demand for fish products globally and wish to improve their competitiveness, led pet foods companies to externalize production of fish-based dog and cat food. Thailand is considered the most competitive solution to manufacture canned food containing fish. To answer the market trends, they have specialized to offer species-specific diets. Asian Sea bass (barramundi) and bream species are today widely used and claimed by the leading pet food brands globally. However, the next generation is demanding locally harvested proteins, transparency of the supply chain, safe products, animal welfare considerations and product freshness.

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The European aquaculture is extremely fragmented. The majority of these aquaculture enterprises are micro-enterprises, employing less than 10 employees. EU aquaculture production is mainly focused in 4 countries: Spain (21%), France (15%), Italy (14%) and Greece (10%), which make up 74% of the sales volume (FEAP, 2020).

The heterogeneity and fragmentation of the European aquaculture industry organization is a challenge that will need to be addressed along with the competitive landscape to effectively serve the pet food industry.

Green Aquaculture Intensification in Europe GAIN H2020 project is designed to support the ecological intensification of aquaculture in the European Union (EU) and the European Economic Area (EEA), with the dual objectives of increasing production and competitiveness of the industry, while ensuring sustainability and compliance with EU regulations on food safety and environment. The GAIN consortium has critically evaluated the types of side-streams produced and considered the different options for re-use. One of the areas identified to value the side stream is the European pet food industry.

The European bass and bream industry has many opportunities to grow in the pet food category. The already built reputation of high quality, sustainability and safety, provide a good opportunity to set a standard and to fulfil unmet needs in premium sector of the pet food industry.

Producing fishmeal can be sustainable economically, socially, environmentally, providing the volume of side stream material to process is significant, and the right product is made. An ultra-premium pet food-grade bass and bream meal would also set the European bass and bream aquaculture apart from the Asian competition. In order to increase the overall meal quality, the partial hydrolysis of the raw materials during the rendering process should be considered. Process companies like Alpha Laval or Buhler implement programs to develop such technology, combining process time and temperature with enzymes active at high temperatures.

Frozen blocks are also existing products with a possible good return on investment through the pet food industry. The product freshness is an important compound of the product mix and is widely evaluated by pet food manufacturers. Another key compound is the possibility to “customize” the offer by providing specific parts such as skins, minced flesh, heads and frame, livers, offal in frozen block form with extremely low biogenic amines. The ability to supply such material in large quantities is a significant advantage as it gives producers of palatants, hydrolysates, protein concentrates supplying the pet food industry, as well as the pet food industry itself, opportunities develop new product and allow them to answer precisely to their consumers' demands. This would be possible to achieve with freezing capabilities on the fish harvesting site and a freezing process starting at the latest four hours post-mortem.

Unfortunately, the oil produced from the fish secondary products does not have a lot of value for the pet food industry due to its low content in EPA and DHA.

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Many companies have rushed in the past 10 years on the production of hydrolysed fish proteins making this segment very crowded and not as profitable as expected. Some of these companies created after 2010, went bankrupt in early 2020.

By providing high quality frozen raw materials for the ingredient industry and pet food manufacturers, and by offering an ultra-premium – partially hydrolysed bass meal at a lower cost than fish hydrolysates, the South European bass and bream aquaculture industry has an opportunity to position itself as a unique supplier of the pet food industry. The main hurdle, at the moment, is a lack of concentration in the industry. The most realistic scenario is for existing integrated companies processing seafood and which have direct access to the side stream, to invest in a processing plant producing ultra-premium bass meal and set a collecting network of pre-sorted raw materials in frozen form.

An alternative option would be for these companies to produce themselves pet food products sold under their brand, capturing the entire profit generated in the value chain. In that case, two segments are recommended: canned food for cats and dog treats.

This deliverable presents a comprehensive market analysis of the European pet food industry, focusing on protein usage, including macro-trends, competitive landscape, industry challenges, factors limiting entry to the market and opportunities for protein suppliers to solve identified problems presented by the pet food industry. The study will specifically cover the potential of the Southern European bass and bream species as a source of nutrition and functional ingredients for the European pet food Industry and how competitive it can be depending on the type of ingredient produced.

Based on the finding and conclusion of the first part of the study, a business model was elaborated for the valuation of secondary products of the Southern European bass and bream aquaculture. The model considers the level of integration and concentration of the industry. The study details the type of investment necessary, the recommended technology to produce the ingredient(s) and highlights the key elements to achieve success.

The results include:

- Recommendation of the most suited ingredients -form, attributes, stability, pricing – generating value and profits on the pet food market including a product targeted specification.
- Recommendation of the best structure to manufacture and market the selected ingredient to the pet food industry.
- A 5-years business plan estimating the necessary investments, the costs, the go-to-market preferred strategy as well as an estimated Profit and Loss for each possible scenario pre-selected during that period.
- A business case, which could facilitate the implementation of the business plan.

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7.1 Global pet food market

The global pet products market was estimated at 106 billion Euros in 2020, with a compound annual growth rate (CAGR) of 1.3%. The low growth compared to previous years is mainly due to economic slowdown across countries owing to the COVID-19 outbreak and the measures to contain it. According to the last estimates, in 2018, the global population of dogs and cats considered as pets was at 844 million animals (FEDIAF, n.d.).

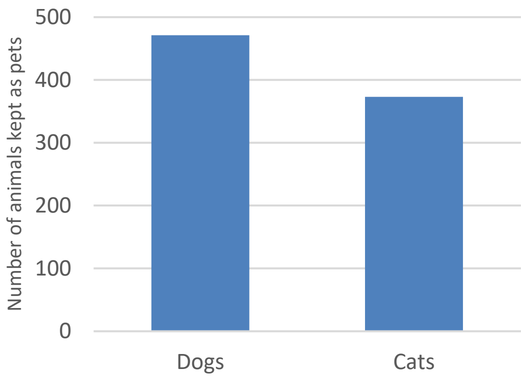

***Figure 7.1**: Global population of cats and dogs kept as pets.*

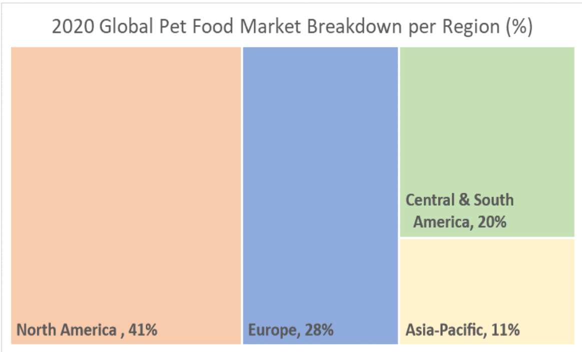

***Figure 7.2**: Regional breakdown of the global pet food market.*

The global pet food market[5], in 2020, totaled 75% of the global pet products market. This market is dominated by North America where 32 billion euros of pet food was sold in 2020 and an average CAGR between 2016-2026 is estimated at 5.7 %. In the United States, more than half of the population, about 67%, owned a pet in 2019-2020 which is equivalent to 84.9 million households (FEDIAF, n.d).

The second-largest market is Europe where 21 billion euros were sold in 2020. The average CAGR is estimated at 3%. In this region, 85 million households have a pet.

[5] The pet food segment covers food products for dogs and cats, as well as feed products for other house pets such as rodents and reptiles. It does not include feed for farm animals.

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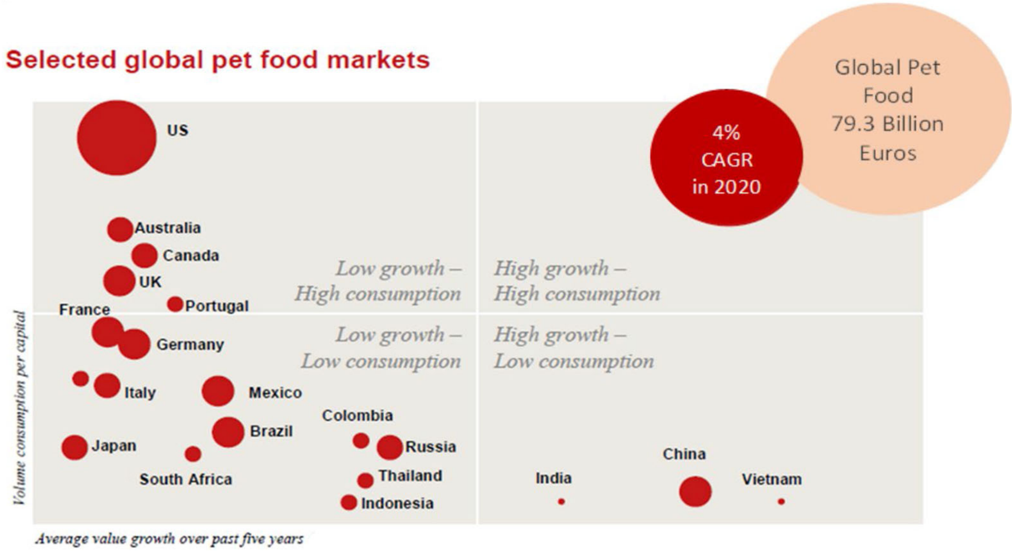

Figure 7.3: Volume consumption and average growth of global pet food markets.

7.1.1 Pet humanization

Humanization of pets implies that pet owners treat pets like family members, and thus, they are increasingly buying premium and super-premium foods, as well as, sophisticated snacks and treats for pets. Premium pet foods are typical of higher quality and safer than regular pet foods, and are also natural and organic. In 2016, about 14% of pet food launches in the USA were positioned as indulgent or premium. Buyers are looking for products, which are locally grown, or natural, or have digestive benefits. Hence, it is not a surprise that the sales of premium and specialized pet foods are higher than the sales of mid-priced products. Additionally, the pet humanization trend led to an increase in health consciousness and has generated demand for pet food free of sugars, grains, dyes, and other chemical additives. In recent years, other trends such as the following rose alongside pet humanization:

- Rise of sustainability;
- Focus in protein content;
- Strong acceleration of e-commerce;
- New pet parents, are millennials or Gen Z, are consumers with a much stronger connection with pets than other generations;
- Adoption of cats by new consumers leading pet food brands to giving more attention to the felines.

The growing popularity of smaller dog breeds has made it difficult to grow pet food volume sales. In fact, volume growth in dog and cat food has not topped 3% globally for at least a decade and a half. In this environment, rising average prices – driven by pet humanization trends – have been the foundation of industry growth.

As owners are increasingly willing to spend on premium, high-quality food to improve the health and wellbeing of their pets, trading-up has helped increase the average unit prices by nearly 24% across dog and cat food from 2013 to 2019.

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For decades, ingredients have been the primary battleground in premium pet food. Ingredients serve as a primary source of brand differentiation, and ingredient-focused messages dominate brand marketing. Ingredient trends have evolved over time. In the early 2000s, the focus was on the scientific engineering of ingredients to optimize recipes for specific life stages. Iams Premium Protection, for instance, used veterinary and nutritional science to create an optimal food for puppies.

Premium pet food saw a tidal shift in the 2010s. Upstart brands like Blue Buffalo encouraged owners to take the "True Blue Test" and examine the top five ingredients in their pet's food. Natural, meat-first and ancestral diet recipes exploded in popularity as transparency assumed new importance.

Despite this shift, ingredient composition remained at the centre of premium pet food (Shmalberg, 2013). For decades, this overarching focus on product formulation has not wavered.

7.1.2 Moving away from processed food

As the industry moves into a new decade, premium pet food is on the precipice of a transformational shift. Owners are moving beyond ingredient lists to gauge the physical appearance of pet food. In many ways, the processing method used to create pet food is becoming as important as the ingredient list.

This change is rooted in broader dietary shifts. Processed food has fallen out of favour as consumers gravitate towards chilled or refrigerated offerings that maintain a fresh or "less processed" image. Across the supermarket – from dips and ready meals to breakfast cereals and snack bars – shoppers increasingly view dry, shelf-stable and centre store categories as relatively "processed" (Barnard, 2010).

This poses a challenge to dry kibble – which represents nearly 70% of the global market in 2019. As packaging in premium dry pet food increasingly features large images of fresh meat and vegetables or wilderness scenes, there is a stark and growing disconnect with the actual dried kibble product itself.

7.1.3 The next frontier: pet food processing

Upstart brands are using new processing methods to move premium food beyond ingredient lists. Biologically appropriate raw foods (BARF) – in frozen or freeze-dried formats – and chilled/fresh foods claim to better maintain the nutritional integrity of ingredients destroyed by the high heat of extruding dry kibble. Raw foods more closely adhere to the type of food animals eat in the wild. Fresh foods also compete on physical appearance, as evidenced by the motto of The Farmer's Dog (US) – "Dog food should look like food. Not burnt brown balls."

Technology is allowing these new formats to extend their reach across markets. Historically, fresh, or frozen pet food required retailers to have dedicated refrigerated or freezer space – not an inexpensive proposition. And while some brands like Freshet (USA) or Billy + Margot (Australia) have grown by building this type of retail infrastructure, technology has allowed other brands to grow in new ways.

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E-commerce has led to an explosion of direct-to-consumer brands that ship fresh food direct to pet owner doors at regular intervals. Online-only brands like Dog Chef (Belgium), Lyka (Australia), Pet Plate (US) and Butternut Box (UK) have sprung onto the scene. Online business models also allow for customization with recipes designed for each pet's specific breed, age, activity level, allergies, among others.

Freeze-drying technology has allowed BARF to reach new heights. In freeze-dried form, raw food becomes shelf-stable and can be sold in many more retail settings. Kibble is also increasingly more commonly blended with BARF products to provide a more affordable solution to BARF feeding. Particularly prominent in North America and Australia, at present, freeze-dried raw food is also significantly more expensive than other premium pet foods (given its low weight and high price). In fact, the median unit price for freeze-dried pet food averaged across the 12 markets below is nearly ten times higher than the category average.

7.1.4 COVID-19: Impact and the future

Premium pet food has proven to be incredibly resilient under COVID-19. Pet humanization trends remain strong despite recessionary pressures, while pet ownership has jumped as people struggle with social isolation and the need for companionship. Sales of dry pet food (and processed foods generally) spiked as consumers stockpiled in early 2020 during quarantine, but this boost is likely to be temporary.

Long-term, the future of premium pet food will increasingly be defined by physical format. Dry kibble faces threats from frozen, refrigerated, freeze-dried, fresh or chilled products that look like human food, claim to be less processed, and mirror the choices pet owners are making in their own diets.

7.1.5 Top global players

Table 7.1: Major stakeholder companies in the pet food industry.

Company	Country	Annual Revenue
Mars Petcare Inc.	United States	$18,085,000,000
Nestlé Purina Pet Care	Switzerland	$15,422,000,000
J.M. Smucker	United States	$2,937,500,000
Hill's Pet Nutrition	United States	$2,525,000,000
General Mills	United States	$1,694,600,000
Diamond Pet Foods	United States	$1,500,000,000
Spectrum Brands/ United Pet Group	United States	$951,000,000
Agrolimen SA	Spain	$900,000,000

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Unicharm Corp.	Japan	$822,000,000
Simmons Pet Food	United States	$800,000,000

7.2 European pet food market

In 2020, Europe was responsible for about 27% share of the global market. The existence of advanced economies, a greater percentage of pet possession, and the inclination of the customer to additionally expand on pet care are some of the most important motivating reasons for the development of the pet food industry. The regional market is ruled by cat food products due to the greater possession of the cat.

7.2.1 European market in numbers

There are 150 pet food producers operating an estimated 200 plants across Europe. These plants directly employ approximately 100,000 and indirectly approximately 900,000 European workers.

These manufacturers produce annually an estimated 8.5 million tons of pet food and generate €21.8 billion in revenue. The European market for pet food has grown 2.8% since 2020, according to the European Pet Food Federation (FEDIAF).

It is projected to witness a CAGR of 4.8% during the forecast period, 2021-2026. The primary economies of the European continent are Germany, France, Italy, Spain, and the United Kingdom. Hence the markets of these countries play an important role in the overall market formation.

Roughly 38% of all households in the European Union own a pet today, a total of 88 million homes. Among these households live approximately 81 million cats, 71 million dogs.

7.2.2 European market mega trends

The European pet food market is supported by the following trends:

- The trend towards pet humanization has taken over the entire world, with growing ranks of European pet owners defining themselves as pet parents or treating their pets like family members
- Pet owners' desire to pamper their pets accelerated during the COVID-19 crisis, and fuelled demand for a wider variety of high-quality pet food products. This sparkled ongoing innovation in the pet food industry including, in many cases, a new source of protein.
- Premiumization of pet food products, partially encouraged by a stagnation of the pet population and a shift from ownership of medium and large size breeds to smaller size breeds.
- Increase of cat ownership.
- Concentration of the producers. The recent acquisitions of United Pet Food in Europe

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are a striking example of this concentration.

- Increase in supply-chain volatility. This trend will continue to push pet food companies to source ingredients and raw materials locally.

The commercialization of products in the past three years have followed the major trends in **Figure 7.4**. Three of the six trends are directly related to proteins in pet food.

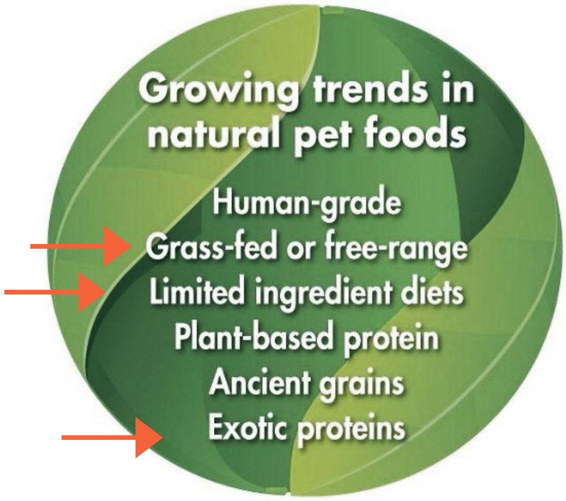

***Figure 7.4**: Growing trends in natural pet foods.*

7.2.3 The European consumer

The European pet food consumer evolved during the past 10 years, following similar lines as consumer demands in the Food & Beverage industry. The consumer demands include:

- Increased awareness of food provenance
- Concern about additives and chemicals
- A desire for traceability and organic ingredients
- An interest in high-protein, grain-free diets

7.3 Animal protein market generated by the European pet food industry

The global animal protein market is very dynamic, with new developments regularly replacing the traditional ingredients and answering consumers evolving expectations. The world's demand for animal protein is expected to reach EUR 49.5 billion in 2027 (CAGR of 5.4% between 2021 and 2027) and to double compared to the current market in 2050. The increased consumer consciousness towards health and growing awareness about the role of protein-rich foods in muscle building and weight management are the major forces driving the market. Moreover, the rise of the middle- class, change in dietary patterns and increase of per capita spending on health supplements have also contributed towards the growth of the market.

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At present, Europe dominates the animal protein market and will continue so in the next decade.

In response to the demand for variety and the protein trend in the food & Beverage industry, many petfood brands have recently increased the level of protein in their diets. Along with that increase, new sources of protein appeared, such as ocean-based proteins, plant-based proteins or exotic proteins.

However, we can wonder, first, what are the protein needs of cats and dogs. Are these needs justifying the overall increase of protein content in cat and dog diets or is it a trend generated by the humanization of pet food?

Cats are obligate carnivorous and rely heavily on protein as a source of nutrients, the ideal adult cat diet should contain 53% of protein (Salaun et al., 2016). On the other hand, dogs are carnivorous and can only assimilate small quantities of carbohydrates without experiencing any digestive problems. The ideal adult dog diet should contain 30% of protein and only 7% of carbohydrates.

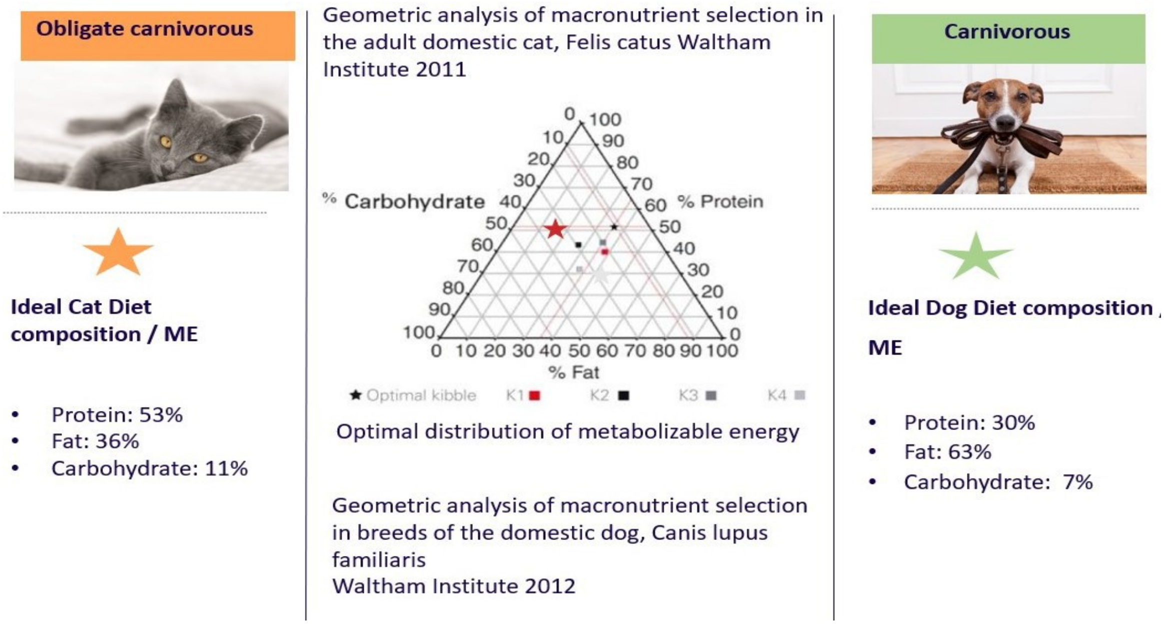

Figure 7.5: Nutritional needs of domestic cats and dogs. Adapted from "Geometric analysis of macronutrient selection in the adult domestic cat, Felis catus", by Hewson-Hughes et al. (2011). J Exp Biol 214 (6), 1039–1051. Retrieved from https://journals.biologists.com/jeb/article/214/6/1039/10664/Geometric-analysis-of-macronutrient-selection-in.

Yet, on average, today's dry dog foods contain somewhere between 46 and 74 percent carbohydrates. The readjustment the industry has undertaken is technically justified and will continue to contribute to the animal protein market growth.

In addition to the protein content increase, the pet food industry is focusing on protein functionality. A functional protein will bring benefits beyond its nutritional value.

7.3.1 The rise of exotic proteins

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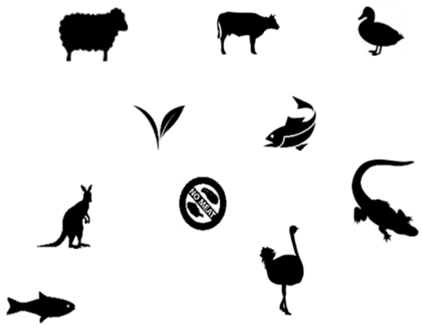
Exotic proteins like ostrich, kangaroo, wild boar, quail and alligator are becoming very popular. They are usually leaner proteins than traditional proteins like beef, pork, lamb.

Some of the other advantages provided by the use of exotic proteins are:

- Increase in variety and diversity in terms of potential protein sources
- Help in reduction of allergies and sensitivities such as skin issues, rashes, excessive itching, scratching or licking
- Provide pet's immune system a break from their battle against pathogens
- Favor a transition to a different food containing ingredients dogs and cats are more familiar with or close to "back to nature/wild diets"



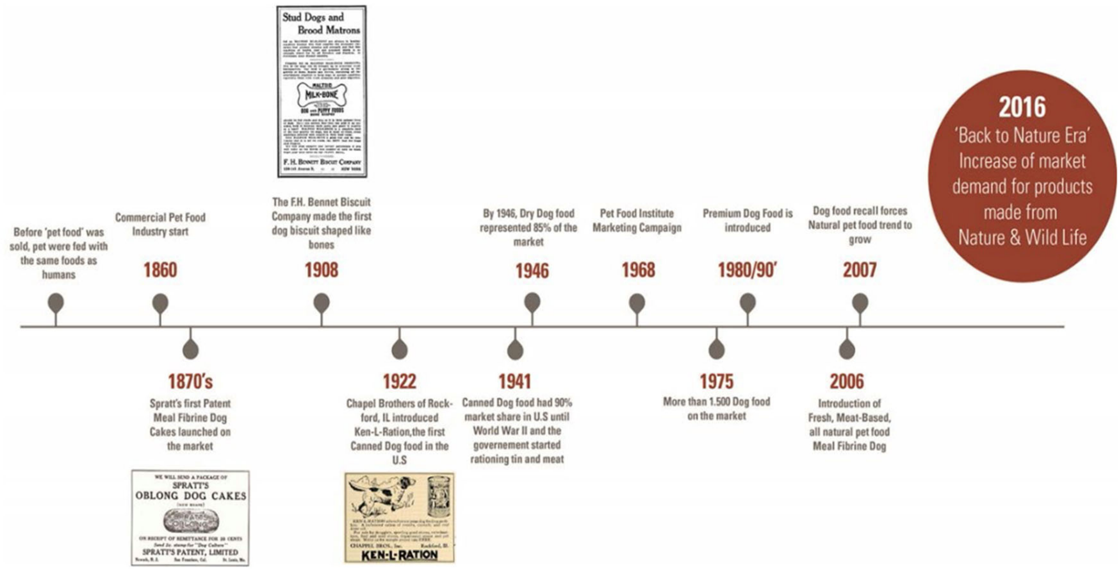


Figure 7.6: *A brief history of the pet diet: Technology developments have fostered pet food evolution.*

7.3.2 Focus on Fish proteins

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The world population will grow from 7.87 billions today to 8.55 billions in 2030. In response to that growth, the farming aquaculture must grow from 80 million tonnes to 109 million tonnes in 2030, less than 10 years from now (FAO, 2018).

Globally, a little less than 20 percent of total fish produced is currently used for fishmeal and fish oil production, and the proportion is expected to remain unchanged into 2030. Seafoodsource (2016) claimed that only 5.7 million tons of by-products are currently processed and as much as 11.7 million tons are not collected from processing plants for further utilization. The global production of fishmeal in 2030 is projected to be around 7.6million tonnes. The fraction made of aquaculture side stream should be close to 5.6 millions tonnes, which represents the vast majority of fishmeal.

The fish processing industries produce large amounts of wastes (up to 55% of body weight): muscle-trimmings (8‑17%), skin and fins (1‑3%), bones (9‑15%), heads (9‑12%), viscera (12‑18%) (Penven et al., 2013).

The global human-inedible fish by-products market is evaluated at approximately six million tons a year. The global fish protein for animal feed application market is expected to grow by 5.2% CAGR between 2019 and 2025. A few factors influencing the trend are:

1. Government mandates regarding fish waste disposal;
2. High amino acid content;
3. North America is pulling the market;
4. Increasing demand for natural and organic beauty products;
5. Europe: Growing fish protein hydrolysate demand for food applications;
6. Expansion of aquaculture industry in Asia.

Fish protein is considered by the pet food industry as a healthy source, providing all the essential amino acids with a dog or a cat need. Dog parents are looking at a variety of proteins, taste or flavours. Fish diets for dogs fall perfectly into the answers the industry provided. The fish claim grew faster than classical protein source claims such as beef, chicken, and turkey, in the last decade. In addition to being nutritionally beneficial, the utilization of fish by-products represents an environmentally and socially responsible practice, by using all the protein sources of a fish while not competing with the human food supply.

The forms of fish used in the European pet food industry are variable, depending on the species and where it is used. It can be found in a frozen form, usually pre-grounded, as a slurry. This frozen form is mostly used in the wet segment, as European producers of extruded kibbles do not utilize slurries widely.

The most common form of fish protein is fishmeal, for its convenience as it is shelf-stable.

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Fish oil is among the most used ingredients by the European pet food industry, due to its relatively high content in poly-unsaturated fatty acids EPA and DHA. The fish oil origin varies, but it is very rarely from aquaculture sources due to the lower content of omega-3 fatty acids in most farmed species compared to the wild-caught one (Lundebye et al., 2017).

7.3.3 Fish hydrolysates

Global fish protein hydrolysate for animal feed application market size is estimated at EUR 212 million in 2019 and is expected to reach over EUR 288 million by the end of 2027 (Grand View Research, 2020). At the global scale, five percent of the animal by-products and plant products for feed are used for protein hydrolysis.

Fish hydrolysates are used for several reasons, some of them being: (1) Flavour enhancers for pets through the production of glutamate; (2) Source of concentrated protein to increase protein content in pet food diets; (3) Functional ingredients due to the water and fat absorption and emulsifying and binding properties; (4) Precursors for protein synthesis which depends on the composition of free AAs (sport nutrition, sarcopenia) or it can be used to cure or prevent specific conditions (healing, wounding, cancer).

Diets containing fish hydrolysates (source: Birdstone Consulting):

- Therapeutic diets – hydrolized protein pet food;
- LID and Sensitive stomach diets;
- High protein diets;
- Functional Pet Food and treats;
- Palatants;
- Supplements.

7.3.4 Aquaculture versus wild caught

Overfishing is a key challenge facing all of us in the human and pet food sector, replacing vulnerable species with more sustainable species or alternative proteins is another change many manufacturers continue to adapt and explore (De Silva & Turchini, 2008).

Due to some logistical challenges, the products from aquaculture have not yet taken significant market share in the pet food industry. Also, the availability of wild-caught species and the strong North European fishing industries have, so far, been able to accommodate the European pet food industry (Stevens et al., 2018). But a few companies are starting to utilize aquaculture-based species. The first pet food product to carry the Best Aquaculture Practices (BAP) label is also available on the market. MacKnight Food Group's Smoked Salmon & Sweet Potato Bites are produced at the company's processing plant which obtained BAP certification in October 2017 and is capable of producing four-star BAP salmon.

7.3.5 Sustainability, fish proteins and pet food

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Approximately 25% of the 106 million metric tons of the yearly global capture fisheries production are considered forage fish[6] (FAO, 2015). These species are transformed via reduction processes into fish oil and fish meal (Pikitch et al., 2012). Over the past two decades, wild capture fisheries have been in a phase of stagnation that is thought to be the result of stock over- exploitation, weather changes related phenomena and the consequent implementation of quota to support the FAO Code of Conduct for Responsible Fisheries (FAO, 2016). Consequently, the global fishmeal production has reached a plateau at around 6 million and, as a result of the incessant demand for these commodities, the prices have increased. According to World Bank data, Peruvian fishmeal of 65% protein increased from 550 Euros per metric Ton in June 2006 to 1,262 Euros per metric Ton in November 2021.

The exploitation of forage fish by different sectors of the industry besides aquaculture feed has been completely overlooked. Aquaculture is a major consumer of wild- caught fish primarily as fishmeal and fish oil (FAO,2016). It has been estimated that the aquaculture sector consumes 56% and 87% of the total production of these commodities, respectively. So, a significant portion of the forage fish raw, processed into fishmeal, fish oil or hydrolysates is consumed by other industries (FAO, 2016). And, the pet food industry, in particular, has gone unnoticed in that regard.

Why is it so important? In 2021, only 32% of the global fishmeal production was produced from fish waste. This implies that 62% of global fishmeal production is coming from forage fish. Producing fishmeal from fish waste as a secondary activity of the fish processed for human consumption is contributing to a circular economy, especially if that fishmeal is re-integrated into the food chain. It is not the case of fishmeal produced from forage fish caught only for the purpose of producing fishmeal, not for direct human consumption.

According to Turchini & De Silva (2008), annually, 2.5 million tonnes of the caught forage fish is consumed by the global cat food industry. This number does not include the use of fishmeal in other pet foods. In comparison to the total volume caught every year, the value is low, however, it demonstrates, the model might not the most effective in the long run. Several pet food companies have already initiated sourcing programs to eradicate the use of these species.

The main challenges of fisheries in Europe are related to the circular economy transition, in particular the adaptation to climate change, and growing threats of marine debris and waste streams. Addressing these issues should be seen as an opportunity to improve things from an intensive sustainable perspective. The EU has implemented directives and regulations, as part of the answer to the environmental challenge and to avoid discards or unwanted caught fish to return to the sea. The only alternative becomes processing the discards on shore or in land. Another action is the ban of single-use plastics, increasing product life cycle and reducing the high impact of these residues on the ecosystems.

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[6] Forage fish are small to medium pelagic marine species which are preyed on by larger predators higher on the food chain.

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Figure 7.7: Example of a circular economy by valorization of food.

Aquaculture, on the other side, has several waste streams that have classically been regarded as of limited value and potentially harmful. However, there has been an enhanced focus on valorising wastes from food production systems. For example, in the seafood/aquaculture sector, solid waste from finfish production has been identified as a potential substrate for anaerobic digestion with a secondary use as a fertiliser. In 2021, there is still a need to leverage emerging natural processes to reduce operational costs and the environmental burden of food production for future sustainability and intensification of the aquaculture sector. This requires technical innovation along with a broader discussion across stakeholders.

Nutrient-enriched effluent waters are also being treated by bacteria or used to culture vegetables in integrated multitrophic aquaculture (IMTA) approach. New IMTA concepts also apply to the use of microalgae and duckweed for waste treatment using organic principles. Fish trimmings and blood waters have been proposed as a source of bio-oil, amino acids and other bio-based products such as bio inks and functional feeds. Bio-based feeds derived from insect larvae, algae and underutilized biological resources offer a means of valorising food waste, reducing nutrient emissions to the wider environment and a reduced pressure on wild fish stocks. With 53% of global fish supply coming from aquaculture and most wild fish stocks at or beyond their maximum sustainable yield, the aquaculture sector will continue to experience growth to match the growing demand for protein (FAO, 2020). It is well suited to become a leader in sustainable food production and a strong supplier of the pet food industry via the production of high-quality fishmeal participating in a circular economy effort.

7.4 Opportunities

The pet food industry will continue to use fish and fish-based ingredients as a source of protein and will expect the product quality to be overall superior to what is currently

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available. In the coming decade, there will be a slow transition to new sources of animal proteins along with the evolution between pets and humans. The limited supply of wild-caught fish species will create tensions on the market, forcing many pet food producers to look at the aquaculture alternatives.

The rise of observed health issues in pets for the past 10-15 years, particularly in dogs and cats, leads to a global trend to increase protein intake and formulate pet food with higher animal protein and a wider variety of the protein source. The new sources are called exotic proteins and have taken a significant share of the products available in Europe and address the most common health issues:

- Digestive unbalance;
- Allergies;
- Obesity.

In addition to the mainstream sources of protein like beef, chicken and lamb, pet foods formulated with duck, rabbit, goat, guinea fowl or quail are now becoming part of the classic portfolio of all the major brands.

Fish has particularly taken a significant portion of the new products in the market due to formulations with nutritional purposes, as a way to promote a healthy lifestyle. Fish are usually a good source of protein, amino acids and important unsaturated fatty acids - DHA and EPA - for both dogs and cats. They are also a source of selenium, calcium, vitamin A and D, all the essential amino acids and taurine, making this raw material very interesting and unique from a nutritional standpoint (Sidhu, 2003) .

However, managing consistently the fresh seafood supply chain can be a major challenge for many producers. The reduced form of the fish after water removal is convenient, the reason why good quality, sustainable fish meals have never been so much in demand than now, increasing prices.

The fishmeal market is aware of the possibilities the pet food industry offers and it is developing to the point of allowing fishmeal customization. Unfortunately, most companies offering these products have not fully explored the potential of the product. There is an opportunity for a customized fishmeal, specifically produced for the pet food industry and displaying the following characteristics:

Higher protein than a regular fishmeal, with a target protein level at 75%;

Lower ash content giving the ability to formulate cat food with high protein content, without the problem of high ash content;

Highly digestible and displaying low protein molecular weight for use in prescription diets.

The processes and technologies of hydrolysis provide additional health benefits to fish raw materials by breaking down fish proteins into peptides providing bioactive compounds (Mackie, I., 1982) with effect on satiety, cognition, stress, digestive tract, etc.

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Fish was not widely used in dog food until a few years ago when two studies demonstrated the positive impact of a diet rich in Omega-3 fatty acid on a puppy's development. Most brand still do not disclaim the fish species, using instead generic descriptors such as fishmeal, white fish, pelagic fish, or ocean fish. A new trend popped-up in North America to answer some consumers unmet needs and expectations of a more transparent pet food industry. Consequently, major brands reformulated their diets and began to label the fish species, using, in that case, fishmeal produced with a single species.

By-products from the processing of aquaculture are increasingly considered as a potential source of raw materials for sustainable fishmeal production. However, the quality of the processes applied to raw materials is critical to enhance their nutritional value. In this sense, enzymatic hydrolysis could improve the palatability, nutritional quality, and functional properties of the finished product.

Enzymatic hydrolysis of fish proteins results in the formation of a mixture of free amino acids, di-, tri- and oligopeptides, and enhances the occurrence of polar groups and the solubility of hydrolysate compounds. Due to the low-molecular-weight nitrogenous compounds are important for the feeding behaviour, nutrition and health of cats and dogs, therefore, partially hydrolysed fish meal would be a very valuable ingredient to formulate dog and cat's diets. However, protein hydrolysate performances could be highly dependent on the methods used for production: nutritional and functional properties are closely related to their characteristics and composition, including the abundance and diversity of different oligopeptides.

Animal by-product rendering establishments are still relevant industries worldwide.

Rendering is a joint series of operations, facilities, and machinery that can physiochemically transform animal by-products (including meat, bone, blood, hoofs, feathers, and other tissues) into high aggregate value feed ingredients. Animal by-product meal safety is paramount to protect feed, animals, and the rest of the food chain from unwanted contamination. Animal by-product meals are frequently used as input in poultry, swine, and dog food. Animal by-product rendering is envisaged not only as a revenue source but also as a means to reduce environmental pollution, as it involves waste management through composting bioreactions, water treatment, and heat recirculation (e.g., using waste heat recovery evaporators during cooking). The main useful outputs of animal by- products processing to the feed industry include meat and bone meal (MBM), bone meal, blood meal, hydrolysed feather meal, poultry by-products meal, fish meal, and fish oil.

7.5 Interviews with European producers

7.5.1 Aim and methodology

In order to validate our assumptions on the market expectation, a questionnaire containing 15 questions was mailed to 25 pet food companies located in 7 different countries. Companies had an option to answer the questionnaire in writing or could opt for a phone call.

The questionnaire sent to European pet food companies is shown below in Table 7.2.

***Table 7.2**: Questionnaire for pet food companies.*

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	Questions	Possible answers to choose from
1	Can you characterize the seafood ingredients you are using? Multiple answers are fine.	• Locally sourced • Imported from European country • Imported from other country • Buy from producer • Buy from broker/importer • Farmed • Wild caught • Do not know • It is from a non-certified source • It is from a certified fishery or farm • Please specify the certification • Frozen • Fresh • Dried • Naturally preserved • Synthetically preserved
2	How important is for your company to know and to label on your product the species used in the seafood ingredients?	• Not important, we do not label fish species on our products • Somehow important • Important for traceability and transparency reasons • Mandatory: We label the fish species on our packaging
3	What are the 2 most important attributes when looking for a new source of fishmeal?	• Sustainable label • (MSC, Monterey Bay, WWF) • Fish species for marketing claim • Palatability • Freshness
4	Why do you think aquaculture ingredients are not currently widely used in pet food products?	• Lack of availability in the market • Negative perceptions of aquaculture products by consumers • Product of overall lower perceived quality compared to wild caught ingredients • Quality of products available not satisfactory • The price of aquaculture products is too high compared to other options • Are the functional attributes targeted under expectations? • Is there not enough information on the sourcing and supply? • The material we tested so far did not reach our sustainability standards

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5	Fishmeal can be produced from fish grown in aquafarms (farmed fish) or caught in the ocean (Wild fish). Several studies pointed out perceived differences by European consumers between the two sources of fish. Do you think the perception applies also to pet food?	• Yes • No
6	If you were presented two options of fishmeal with sustainable certification (Friend of the Sea, ASC/MSC, BAP, Monterey Bay), one from aquaculture, the other one from wild fisheries, what would be your choice?	• Sustainable aquaculture • Wild fishery • I think there are no differences
7	How do you perceive your customers openness to aquaculture products?	• Reluctant. Our customer would refuse to use products from aquaculture • Curious, want to try, it seems like an interesting sustainability proposition • Very open. They demand it • They never considered it because of a lack of awareness
8	If you had the ability to do so, what is the one thing (price excluded) you would change in the fish meal you are currently using?	• Increased availability • Freshness • More transparency on its origin • Better oxidative stability • Reduced freight time • Higher protein and lower ash content • Better clarity on the fish species used • Lower heavy metals • Other • Explain
9	Existing fishmeal available on the European market typically have 65% protein, 15-19% ash and 10% fat, with a 90% digestibility. Do you see any benefit of using a fishmeal with protein level > 70%, ash content < 13%?	• Yes • Explanation • No

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10	Based on your knowledge of the fishmeal market, what price would you consider to be acceptable for a fish meal with min 70% protein, max 14% ash, low biogenic amines, stabilized with natural antioxidant and providing sustainability credentials?	• Between 1500-1800 /metric T • Between 1800 and 2000/metric T • Between 2000-2400/metric • >2,400 /metric T
11	Fish hydrolysates are used in specialty pet foods to increase product digestibility, reduce pet sensitivity to proteins (allergies) and in some cases to take advantage of the bioactive peptides to reduce stress, increase skin and hair health and reduce digestive issues. But hydrolysates price is limiting its use in pet	• Yes • No
12	If you were proposed seabass and seabream fishmeal or/and frozen block from European Origin, would you consider using it in your product?	• Yes • No • Maybe •
13	What is your perception of these species when used in pet food?	• Maybe • High Quality • Low Quality • Sustainable Clean protein • High levels of heavy metals and PCBs • Good nutritional profile • Luxury image

7.5.2 Results and interpretation

The success rate of direct contact to the 25 pet food companies was quite low, we received just six replies. The communication with the companies was done mostly via email or phone calls. The response level might have been affected by the global pandemic, COVID-19, which may have made communication within companies more difficult. Answers were provided by Neodis, Vobra, Royal Canin, The Pet Lab, Befood and United Pet food.

These companies represent the European pet food industry relatively well. The six companies who answered the questionnaire are from the UK (2), France (2), Italy (1), the Netherlands (1). Surprisingly, the companies had, overall, very similar answers. This may be due to the provided multiple choice answers. Also, the topic was well defined and specific enough to obtain a fairly good picture of the industry expectations with only a few questionnaires.

The European pet food industry tends to purchase fishmeal and fish oils from intermediaries and not directly from producers. Companies tend to have limited access to the full chain; therefore, they do not necessarily select the most sustainable option.

Both farmed and wild species are currently used in the sector and knowledge of the fish species is mandatory.

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The most important attribute pet food companies are monitoring when selecting or receiving fishmeal is the level of protein and ashes. This attribute was systematically selected. Other attributes selected by companies were freshness, palatability and price.

Regarding the low penetration of aquaculture ingredients in the pet food industry, the explanation chosen was also very homogeneous amongst the companies who answered: "perceived quality is not satisfactory and the ingredients are priced too high compared to the fishmeal made from wild-sourced species".

Wild fishmeal is overall better perceived by the industry, but not by all companies. Two companies believe this perception does not apply to pet food. Considering this, there is no reluctance to use a product containing fish from aquaculture in the future. Though, there is a lack of awareness and/or curiosity.

The 8th question directed the answers towards a better-quality product with a disregard for price and, as a result, found out that the key elements of improvement are a lower concentration of heavy metals, a higher protein content and increase the freshness of the product.

All companies see a benefit in using fishmeal with higher protein and lower ash content, The reason being the possibility to formulate diets with higher protein content – which is in line with current market trends.

7.6 European seabream and seabass market

Aquaculture production in the EU has become increasingly important and, since 1994, it has risen by 24%. In 2018, aquaculture represented about 20% of all the European fish and shellfish supply (Scientific, Technical and Economic Committee for Fisheries, 2021). Among Member States, production is rather heterogeneous and, the four EU aquaculture producers represent 74% of the total EU aquaculture production. Production is concentrated in Spain, Italy, France and Greece. The United Kingdom, before Brexit, was a major contributor to the EU aquaculture production. In 2018, it was the biggest producer of aquaculture finfish representing 26% of the total production volume of EU member states. The European seabass and gilthead seabream are some of the primary marine finfish species farmed in the EU, just surpassed by the Atlantic Salmon (Publications Office of the European Union, 2020).

The European Sea bass (Dicentrarchus labrax L.) is a marine fish of key economic and cultural importance in Europe. It is now more an aquaculture than a fisheries species (>96% of the production in 2016), although modern rearing techniques date back only from the late 1980s (Department of Marketing & Institute of Aquaculture of University of Stirling, 2004 Study). It also has high interest for evolutionary studies, as it is composed of two semi species (Atlantic and Mediterranean lineages) that have come into secondary contact following the last glaciation. Based on quantitative genetics studies of most traits of interest over the past 10–15 years, selective breeding programs are now applied to this species, which is at the beginning of its domestication process (EUMOFA, 2019).

Farming of sea bass was traditionally small-scale and based on the capture of wild juveniles, however, it is now predominantly undertaken intensively in net pens, largely in southern

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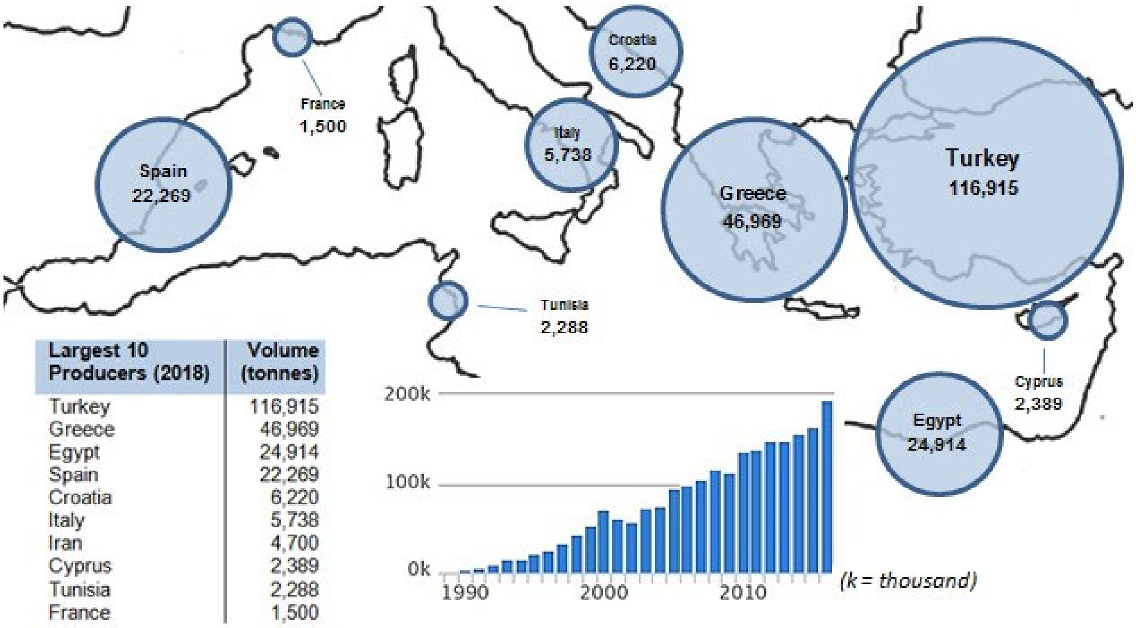
European coastal waters using hatchery-reared seed (i.e., juveniles) (EUMOFA, 2019). World production of farmed sea bass has increased steadily from around 60,000 tons in 2003 to 235,537 tons in 2018 and is valued at EUR 984 million. Turkey, Greece Egypt and Spain are the most important farming countries (**Figure 7.8**) and combined represent about 69% of the total world production (FEAP Secretariat, 2020).



Largest 10 Producers (2018)	Volume (tonnes)
Turkey	116,915
Greece	46,969
Egypt	24,914
Spain	22,269
Croatia	6,220
Italy	5,738
Iran	4,700
Cyprus	2,389
Tunisia	2,288
France	1,500

Figure 7.8*: Adapted from FAO. Global European seabass production in 2018 - key locations and volumes.*

The gilthead seabream (*Sparus aurata*) is also a high value marine fish species and, although it is not as valuable as the European Seabass, it is the fifth most valued species in the EU aquaculture sector. The aquaculture is the main source of supply of this species in the EU (97%) and its importance has been increasing since the 2000's. The global catches have been decreasing as fishing pressure increases so, EU aquaculture producers are global suppliers of seabream (EUMOFA, n.d.).

The species was traditionally farmed in an extensive rearing system which took advantage of the natural trophic migration of juveniles. These systems are still used nowadays on a much smaller scale in coastal lagoons and salt water ponds. The large-scale production of juveniles and high adaptability of the species allowed for the production volumes to increase.

The Mediterranean is the hotspot for global production of seabream. Greece is the main global supplier of the species and its production is more than half of the EU aquaculture (FEAP Secretariat, 2020).

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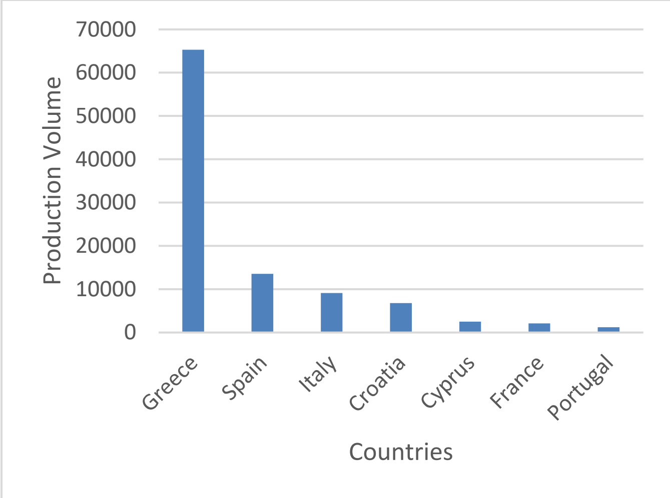

Figure 7.9*: Adapted from FEAP Secretariat. Gilthead seabream EU production in 2019.*

7.6.1 Production

EU production of farmed seabass and seabream is relatively stable, however, production in Turkey continues to rise. The EU imports of both species from Turkey are also on the rise and have increased by 15% from 2018 to 2019. At the same time, the import prices of these species have decreased on average, farmed seabass prices decreased 9% to 3,78 EUR/kg, while farmed seabream remained stable at around 3,90 EUR/kg. The primary exported product is fresh or chilled whole fish but value-added products and fish fillets are now being used to target new markets in Northern Europe (FEAP Secretariat, 2020).

The production of European seabass and gilthead seabream, follows the trend of the aquaculture sector in the EU, although there are large corporations in the industry, producers tend to be small and medium-sized enterprises supplying mainly internal markets within the operating country. There are about 15,000 companies that employ 75,000 people but, the marine finfish aquaculture industry employs the least number of workers. The majority of these micro-enterprises or small businesses are located in coastal or rural areas and employ less than ten employees (Scientific, Technical and Economic Committee for Fisheries, 2020).

The fragmentation of the industry and often lack of vertical integration in the SME leads to a disconnection between the producers and end-consumers due to the high dependence on the downstream suppliers. Preference and consumption patterns are heterogeneous across member states and while upstream suppliers could have the ability to adapt to consumer demands, the lack of awareness on market demand hinders profitability and market value of the products. In order to valorise the aquaculture sector and these products, the Aquaculture Stewardship Council (ASC) has launched in September 2018, a specific standard which incorporates sea bass, sea bream and meagre. There are already several producers across the Mediterranean mostly in Greece and Croatia.

Farmed sea bass from the Mediterranean is mostly for export, mainly to mainland Europe, particularly Italy and Spain. Greece exports around 70% of its domestic production, and exports have expanded into new markets, such as the UK, Germany, and France. Trade in sea bass seed includes not only the largest producer countries but countries such Italy, Spain and France which help supply grow-out farms across the Mediterranean (FEPA Secretariat, 2020).

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The apparent market for seabass in Europe (**Table 7.4**) amounts to 97,000 tonnes, which are mostly consumed fresh. The major markets, Italy, Spain and France, represent more than 70% of total EU consumption. The annual consumption per capita is 190 grams on average but exceeds 500 grams in a few Mediterranean countries (Italy, Spain, Portugal, Cyprus) (EUMOFA, 2019).

Producers tend to rear a range of sizes for market and, European seabass are generally harvested when an individual reaches 300-500g, which takes from a year and a half to two years, depending on water temperature. Otherwise, seabass can be sold as a large fish weighing from 800 grams up to about 1 kilogram (EUMOFA, 2019).

As the European seabass, the commercial size of seabream includes a portion size (300g-500g) and a larger fish of up to 2 kilograms. The supply of seabream is almost exclusively whole fish but fillets are also sold fresh and frozen. The average price of seabream is around EUR 5 per kg. The apparent market for seabream (**Table 7.5**), in 2015, totals 107,300 tonnes. The average annual consumption per capita is 211 grams. The countries where consumption is higher are Greece, Cyprus, Portugal and Italy (EUMOFA, 2017). These countries are also among those with highest consumption of fish per capita in the EU.

Table 7.3: Major players in the supply of European seabass and gilthead seabream.

Country	Company
Greece	Aegean Fish Afentoulis liveris Sea world SA Hellenic Fish farming SA Dias Aquaculture Group
Spain	Seamax Global Freiremar Pescanova
Croatia	Marikultura Fortica

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UK	Anglesey Aquaculture Mousehole fish Sea Delight
Cyprus	Blue Island Seaware fisheries Ltd
France	Frial Cotes et poissons
Italy	Natalino Pesca

Table 7.4: Adapted from EUMOFA,2019. Apparent market for European seabass and consumption per capita in 2016.

MS	Aquaculture (t)	Fisheries (t)	Imports (t/we)	Exports (t/we)	Apparent market (t/we)	Consumption per capita (kg)
Italy	6 800	355	26 502	2 535	31 122	0.513
Spain	23 445	580	9 440	8 175	25 290	0.545
France	1 928	2 735	6 112	1 135	9 640	0.145
Greece	42 557	348	717	35 035	8 587	0.796
United Kingdom	-	538	6 914	309	7 143	0.109
Portugal	450	408	6 324	148	7 034	0.680
Germany	-	-	3 974	2 133	1 841	0.022
Croatia	5 291	8	167	3 870	1 596	0.381
Belgium	-	23	2 326	1 722	627	0.056
Cyprus	1 442	1	153	1 051	545	0.643
Other MS	39	852	7 472	4 834	3 526	0.023
EU 28	81 952	5 848	70 101	60 947	96 954	0.190

***Table 7.5**: Adapted from FEAP Secretariat, 2020. Apparent market for gilthead seabream and consumption per capita in 2015 in the EU main national markets*

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MS	Aquaculture (t)	Fisheries (t)	Imports (t)	Exports (t)	Apparent market (t)	Consumption per capita (kg)
Italy	7 400	900	26 100	3 300	31 100	0.512
Spain	16 200	800	6 500	5 500	18 000	0.388
France	1 500	1 200	8 300	700	10 300	0.155
Greece	65 000	200	500	34 800	30 900	2.846
United Kingdom	-	-	2 500	100	2 400	0.037
Portugal	1 400	200	9 100	100	6 300	0.607
Germany	-	-	4 800	1 300	3 500	0.043
Croatia	4 500	100	-	2 900	1 700	0.402
Cyprus	3 600	-	-	3 000	600	0.708
Other MS	ε	ε	5 800	3 300	2 500	0.015
EU 28	99 600	3 400	63 600	55 000	107 300	0.211

7.6.2 Price evolution

As seabass and seabream aquaculture grew between 1990 and 2002, production costs were driven down, and products saturated the market. Prices subsequently declined rapidly by more than two-thirds; this can be attributed to the limited demand from smaller, more traditional markets for sea bass (mainly in southern Europe), the lack of diversified products, and limited focus on market development and promotion at the time. However, the drop in price subsequently opened new markets and helped expand existing ones.

Acceptable profit margins for producers should be sustained through further improvements in productivity and product diversification. In recent years, the sector has found new market opportunities which show increasing trends in sea bass consumption (e.g., Russia and the US).

Greek and Turkish seabass and sea bream production are likely to continue to dominate Mediterranean aquaculture for the foreseeable future. The outlook for the aquaculture sector on these species is cautiously positive, so long as prices are maintained at economically sustainable levels. However, this is dependent on the rate of production volume growth and the progress made towards farm cost reductions, as well as market demand. In that regard, the investment in production capabilities to transform and value the sea bass side stream in the right market will help producers and processors to increase the overall competitiveness of that industry.

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Data consisting of monthly domestic price series for fish purchased by French households from 2007 to 2012 show that the fresh fish markets for whole wild and farmed sea bream are partially integrated, yet those for whole wild and farmed sea bass are not integrated. The substantially higher price for wild sea bass relative to farmed sea bass suggests that consumers may be more sensitive to seafood production processes when it comes to higher-value species.

There is an exception in the case of frozen fish market in Germany. Bronnmann and Asche (2005) report that German consumers give a higher price premium to aquaculture products, namely €0.28 per 100 g on average.

7.7 Sustainable business model proposition(s) to generate value from seabass and seabream side stream processing by answering unmet needs of the pet food industry

7.7.1 What are the pet food industry unmet needs?

The European pet food Industry has engaged in a mutation toward higher practices regarding sustainability. These practices include a selection of suppliers capable of providing consistent, high quality and multi-functional ingredients. The continuous process of selection is supported by consumers expecting Human Food quality or grade for their pets.

Adding functionality to an ingredient can not only generate value due to the function itself, but it can also solve an existing side-viewed problem. For instance, hydrolysing a protein generates flavour compounds, taste modulators, and bioactive compounds. Moreover, it changes physical appearance, viscosity, state and particle size. Hydrolysis is a reduction operation. The agitation, by increasing the dispersion of small particles, enhances the hydrolysis and increases the homogeneity of the group of particles. The higher the homogeneity of the medium, the easier it will dry with a relatively economical drying technology available. A well-agitated hydrolysate of fish materials will tend to homogenize. Consecutive operations will be affected and will need to be adapted. The process adaptation will be simplified compared to a classical fish meal process, requiring less capital investment necessary in order to build a process line.

Hydrolysates have a high price point, among other attributes, that limits their use in pet food. However, adding the functions of hydrolysates to another ingredient, to be used in large quantities through process modification and without increasing costs would be an advantage for manufacturers. It would be creating value at a much lower cost.

Partially Hydrolysed High Protein fishmeal would solve many technical issues pet food manufacturers regularly encounter without the limiting high price point, but it is currently not available on the market.

Sustainability is another key attribute companies have identified and, through the use of fish protein from the aquaculture sector this attribute would be easier to fulfil. But, still today, companies are unable to pursue it due to a lack of suppliers.

Another important unmet need which is a key attribute in pet food, in general, is the freshness of the materials. This is not necessarily well defined by some suppliers and therefore is not properly managed.

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7.7.2 Investing in quality

To manufacture a high-quality fishmeal, it is important to have in place a program to carefully monitor the following quality criteria:

- **Freshness:** Defining and measuring fishmeal freshness can be challenging. Yet, freshness of pet food ingredients can affect the palatability, nutrition, and safety of the final product. Flavours caused by chemical or microbiological deterioration of the ingredients can result in food refusal since animals rely on their sense of smell and taste to differentiate safe, nutritious foods from those that taste bad or may contain toxic substances. Lack of freshness will be noticed by a strong “fishy” or rancid smell. At a chemical level, it can be described by two types of phenomena:

- **Spoilage due to bacterial development:** The result of this development is the production of biogenic amines such as tyramine, cadaverine, putrescine and histamine. Some other compounds will develop by decomposition of these amines into trimethylamine and ammoniac. A premium fresh fishmeal will typically display a level of histamine less than 20 ppm and total biogenic amines less than 100 ppm.

- **Lipid oxidation:** Fish meals usually contain residual fat after fat extraction (8% on average). Due to its composition and, more specifically its content in poly-unsaturated fatty acids (PUFAs), aquatic species fat is prone to oxidation, therefore it is one of the most important controls made by the pet food manufacturers. The indicators usually measured are the peroxide value and the aldehydes level in the fishmeal. Peroxide value and hexanal level should be respectively less than 10 milliequivalent of O2/Kg of fat extracted from fishmeal and less than 10-15 ppm to consider it as non-oxidized (Low, L. K., 1992).

- **High Protein and Low Ash levels:** The average level of protein in a fishmeal is between 60% and 72%. Fat content is usually well controlled due to the fat extraction during fishmeal production and so is the water content, usually around 5% (Cho, J.H. & Kim, I.H., 2010) The level of protein is therefore associated with the ash content. A low protein fishmeal will exhibit high ash content (> 20%) and on the other hand, a high protein fishmeal will be characterized by a low ash level. A high ash level will limit formulation of cat diets as well as, the possibility to develop high protein diets.

- **High Ileac digestibility:** It is expected by the pet food industry to accept only fishmeal with a level of digestibility over 85%. Protein Low molecular weight generated during a partial hydrolysis will increase ileac digestibility.

- **Palatability**: This attribute is connected to freshness, the degree of hydrolysis, fat content and species. It is not an attribute that can be easily implemented during fishmeal production or during the reception at customers. But it is integrated into the evaluation of a new fishmeal during the qualification process by the pet food Industry.

- **Contaminants:** Table 7.6 summarizes the type of contaminants and the acceptable levels for use in the pet food industry.

Table 7.6: Acceptable level of contaminants for use in the pet food industry. [*] Not Documented; [a] Kim, H. T.,

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Loftus, J. P., Mann, S., Wakshlag, J.J. (2018). Evaluation of Arsenic, Cadmium, Lead and Mercury contamination in over-the-counter available dry dog food with different animal ingredients (red meat, poultry and fish). Front Vet Sci 5, 264. https://doi.org/10.3389/fvets.2018.00264.

Contaminants	Unit	Method	Target (ppm)	Maximum suggested for pet food (ppm or mg/kg)
Arsenic[a]	ppm	ICPMS	1.4	10
Cadmium[a]	ppm	ICPMS	0.05	2
Chromium	ppm	AOAC990.08	0.4	8
Lead[a]	ppm	ICPMS	0.005	10
Mercury[a]	ppm	ICPMS	0.04	0.27
Melamine (LC/MS/MS)	ppm (mg/kg)	US FDA LIB 4421	ND*	2
Dioxine & Furan	ppm (mg/kg)	EPA 8290	ND*	1.25

7.7.3 Chemical composition of sea bass fillet and by-products

The evaluation of the chemical composition of sea bass fillet and by-products is shown in the table below. The evaluation of moisture content in the fillet and by-product of sea bass indicates that the higher moisture content ($p < 0.05$) is observed on the fillets. In the case of fat, the gut contains more lipids ($p < 0.05$) than the fillets and other by- products.

Regarding the protein content, the highest amount is obtained from the skin. Particularly for ash content, the head displays the highest content.

Table 7.7: Chemical composition of European Seabass. SEM: standard error of the mean; n.d.: not determined; n = 10. a–e Means in the same row with different letters differ significantly (p < 0.05; Dunn's or Duncan's test), by Munekata, P.E.S., Pateiro, M., Domínguez, R., Zhou, J., Barba, F.J. & Lorenzo, J.M. (2020). Nutritional Characterization of Sea Bass Processing By-Products. Biomolecules, 10(2), 232. Doi:10.3390/biom10020232

(g/100 g)	Fillet	Skin	Guts	Gills	Liver	Head	Fish
Moisture	72e	54bc	38a	62de	48ab	59cd	52b
SEM	0.4	1	2	0.4	1	0.8	1
Protein	21ef	25f	8a	16de	12ab	16cd	15bc
SEM	0.08	0.7	0.6	0.1	0.5	0.2	0.4
Fat	4a	17bc	53e	13ab	35de	14ab	19cd
SEM	0.5	1	3	0.5	2	0.6	0.6
Ash	1.3bc	3.0cd	0.78a	5.8de	1.1ab	10f	7ef
SEM	0.02	0.3	0.03	0.2	0.07	0.6	0.4

7.7.4 Regulatory context in Europe

Farmed fish should be processed according to the "fishmeal method" as outlined in regulation (EC) 1774/2002. The minimum conditions proposed for the heat treatment of aquaculture fish are 76°C /20 minutes or any other combination of time length and temperature conditions resulting in 3 LOG_{10} reductions of IPNV.

The manufacturing of fishmeal and fish oil for animal feed was formerly approved according to the regulation of March 26th, 1999, no 416 relating to Fishmeal, Fish Oils. Since October

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2007, the production is regulated by Regulation of October 27th, 2007, no 1254 relating to animal by-products not intended for human consumption which implements Regulation (EC) No1774/2002 of the European Parliament and the Council of 3rd October 2002 laying down health rules concerning animal by-products not intended for human consumption.

Annex V, Chapter III of Regulation (EC) 1774/2002 defines seven methods for treatment of animal by-products. Annex VII, Chapter II, paragraph 3 states that fishmeal must have been submitted to any of the processing methods and parameters which ensures that the product complies with the microbiological standards set in Chapter I, paragraph 10 about Salmonella and Enterobacteriaceae.

Annex VII, Chapter I, Section C states that critical control points (CCPs) that determine the extent of heat treatment must be identified for each processing method and shall include at least particle size, temperature, pressure and duration of the heat treatment process or feeding rate to a continuous system. Minimum process standards shall be specified for each CCP. Also, there are requirements to monitor the equipment, keep records and treatment of material that has not received the required heat treatment.

7.7.5 The challenges

There are several logistical challenges that need to be solved before the side stream can be used to produce high-quality fishmeal. The raw materials quality must be maintained at its best to obtain an ingredient with superior attributes. In order to control this aspect, a short distance between the location where the side stream is produced and where it is processed will be privileged.

The use of the European Seabass and Gilthead Seabream have additional challenges:

- By-products generated are of low volume
- Production is still predominately done in small-farms causing volumes to be dispersed across Europe
- There is still significant wastage because of the diffuse nature of secondary processing which does not produce enough raw material in one location to have an attractive economy of scale for by-product technologies.

To overcome these challenges, having in place the proper cold chain is a necessity. The side stream should be transported in a chilled environment, by adding directly ice to the material before loading or by transporting the containers from the side stream in a refrigerated truck. Furthermore, the side stream should be less than 18 hours old (Post-mortem) to avoid high levels of biogenic amines and/or bad smells due to the production of trimethylamine.

The volume of fish available in side stream is also important to take into consideration to size of the processing plant. In the case of the European Seabass, the primary production (seabass farming) is dispersed. Moreover, the volume of side stream material generated in one farm is not important enough to supply a fishmeal plant.

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7.7.6 Recommended model to produce High Protein – Partially Hydrolysed fish meal

Transporting a small number of materials to a processing unit from many farms will not allow the production of high-quality fishmeal. To limit the time between side stream production and processing, the processing plant needs to be next to the fish processing centre, where the fish is filleted. Seabass food processors could be good candidates to start a fishmeal activity, generating revenues from the side stream.

Plant design will need to consider that a maximum of 5,000T of side stream from the fish processing will be produced, which will translate into 1,000 T of dry solids.

Table 7.8: Unit size and Volume of finished goods produced on one location.

Working days	Shifts	Volume of whole seabass metric T/Yr.	Waste/side stream volume	Finished dry products	Capacity (Metric T/day, with 30% buffer).
240	1	10,000	5000	1000	5.5

A second option could be a stand-alone company, collecting 100% of the fish food processing plant waste at a price negotiated for several years to guarantee the raw materials cost stability. In that case, the supply chain would require additional investment in a truck fleet or a partnership with an independent trucking company providing chilled freight.

The third option is an existing by-product processor interested in capturing the side stream to complete an existing portfolio of fish meals. In that case, part of the existing infrastructure might be used to produce HPPH 75. However, it is rare to see side stream processing plants with a solid refrigeration system, and complete segregation of species. Therefore, some investment would be required.

The following information can be applied to an existing fish processing plant, an independent structure, or an existing fishmeal production plant.

7.8 What is the most adequate technology to produce the HPPH 75 fishmeal?

The aim of this chapter is to provide a general guideline on the technologies to manufacture High Protein (75%), Partially Hydrolysed fish meal (HPPH-75). In recent years, one of the most challenging topics in the fishmeal and fish oil industry has been renewability, environmental impact, use of natural resources and release of gases and wastewater. These topics should be at the centre of a fishmeal plant design, evaluating carefully the impact of each operation on the environment, deciding if spending more energy to reduce or remove water is worth the value created after selling the product.

7.8.1 Quick Review of fish meal technologies

Historically, a standard fishmeal plant was designed to effectively separate the different fractions of the waste: bones, protein, and fat. The energy costs were not the centre of concern, only the yield of each fraction was monitored. Therefore, the process used was not necessarily the most optimal from an energy consumption standpoint. The primary objective of fishmeal plants is a reduction by the removal of water. It is done by heating the material in order for the water to evaporate.

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Transforming water into steam requires a significant amount of energy, and how the energy is transferred to the water will influence the effectiveness of the drying process.

The different steps of most existing plants have not evolved in the past four decades and are the following (FAO, n.d):

I. Cooking of material into a horizontal or vertical cooker to allow tissues to separate from bones and for the fat to melt. During that step, protein coagulates, and oil and water are separated from solids. In some plants, a pre-heating step is added to optimize energy consumption. The preheater is a series of tubes in which the raw material evolves until reaching temperatures of 50-55ºC. After the first heating in a tubular structure, the materials are cooked in a second cooker, reaching a temperature between 90ºC and 95ºC. The cooking step is generally fast and the retention time in that first step is no longer than 15 minutes;

II. Separation between liquid and solids through a twin-screw press;

III. Drying of solids through a rotary dryer;

IV. Grinding to obtain the desired particle size;

V. Packing.

Other processes have more recently been developed, two of the most remarkable are:

- Hedinn process, also called Hedinn protein plant (HPP), mostly used in Iceland, having the advantage of being compact and energy cost savvy (Hedinn, 2021);
- pH Shift process, developed in Sweden in 2019, consisting of protein solubilization by low or high pH and centrifugation force.

Unfortunately, none of these designs can truly hydrolyse fish materials and remove enough bones to decrease ash content and increase protein content.

7.8.2 HPPH 75 Process description by Unit Operations

In fact, the objective is to remove water effectively without damaging the product. To produce HPPH 75 fishmeal, the removal of bones is essential, as it is the primary source of ash. A partial hydrolysis will be used to increase the qualities of the product. The enzymatic hydrolysis must take place at a temperature over 60ºC for 20 minutes. The first part of the process will therefore have three purposes:

- Heating the raw material to coagulate protein and initiating enzymatic reactions;
- Melt fat;
- Separate bones from tissues.

The plant design will be different from a standard fishmeal plant. Specialized companies in design and construction of fish processing manufactures can provide detailed information on each step of the process and these will be able to adapt it to each individual project. As an

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example, conveying of a product from one step to the next is usually done horizontally, using conveying screws, in close circuits. Nonetheless, with a vertical design, a gravity system can be implemented, saving energy during processing and contributing to lower capital investments.

A complete product line consists of the following sections (**Figure 7.10**).

- **Raw material handling or pumping and temporary cold storage:** It is advised not to grind the raw material to facilitate the filtration step and bone removal later.
- **Cooking**: The process starts with cooking the raw material in a conventional indirect steam tube or cylinder to reach a temperature at the end of the tube of 55^{o}C. The material then goes to a second tube where temperature is maintained constant, at 55^{o}C to initiate hydrolysis.
- **Mixing:** The product is transferred to an air mixer that will homogenize and retain the product at 55^{o}C for 20 minutes.
- **Cooking:** The product is transferred to a third tube cooker, where the temperature reaches 70^{o}C at the middle section of the tube and 75^{o}C at the end of the tube.
- **Separation – filtration:** The slurry obtained falls on the top of a vibrating separator containing 4 levels. Bones are extracted from the top screens, and proteins are posteriorly obtained from the remaining three screens. The bones are discarded from the main production line to a grinding step, followed by a drying step and bagging.
- **Drying:** The collected proteins are dried using a continuous thin drier to evaporate residual water left from the vibrating filtration.
- **Bagging:** The dry meal goes through a magnetic detector before bagging. At this stage, an antioxidant is added to the dry product. Once the fishmeal is dried, the antioxidant added and the final product bagged, it is ready for labelling and storage.
- **Oil extraction:** The liquid obtained from the filtration is centrifuged to separate the oil phase from the water-soluble phase.

The water-soluble phase or stick water are packed in IBCs or in cardboard bag -in- box and are stored in the refrigeration area. It is recommended not to reinject the stick water into the meal for two reasons:

- It will complexify the drying process;
- The stick water contains biogenic amines. Re-integrating it into the fishmeal process would jeopardize the fishmeal quality.

The crude oil obtained is stored in a regular tank where the antioxidant will be added.

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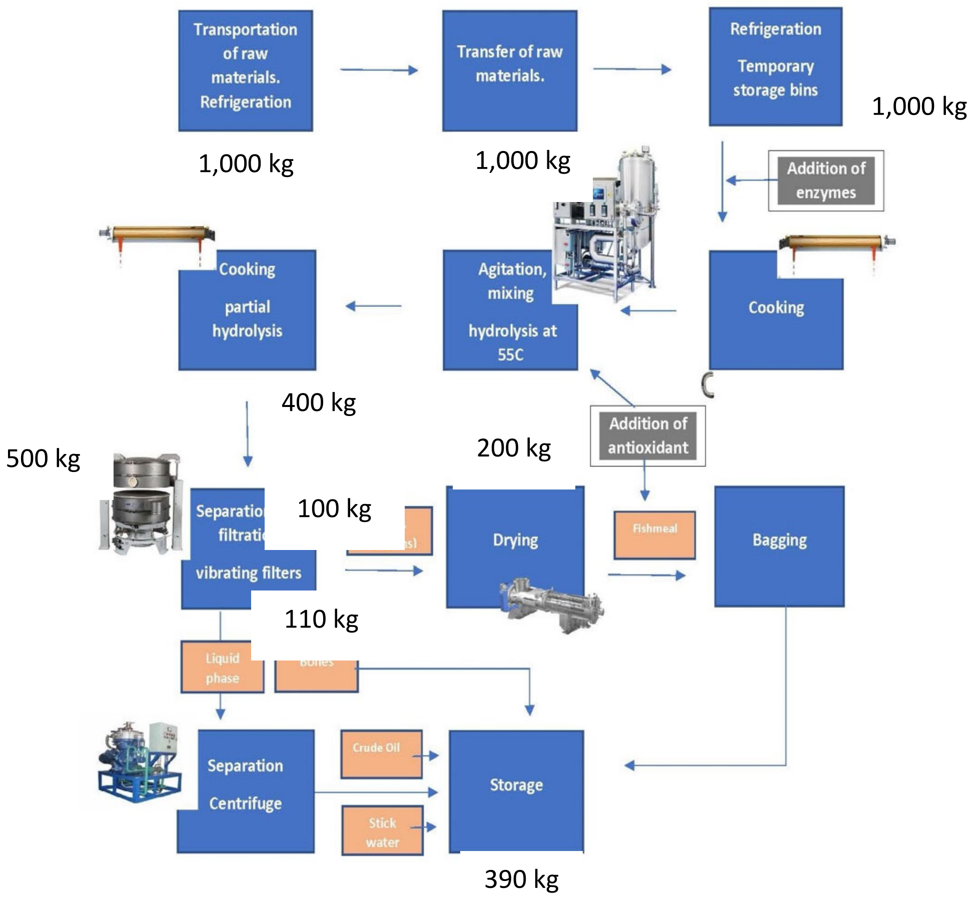

***Figure 7.10**: HPPH 75 process flow chart.*

7.8.3 Refrigeration

Refrigeration is the heart of a fish processing plant. It all starts with the use of ice from the time of harvesting until it reaches to final consumer kitchen. It is highly necessary to keep the temperature chain intact to maintain the quality of the product, whether it is fresh or frozen. Fish tend to develop, within 24 hours, a typical smell that is the consequence of protein decomposition. The ability to keep low temperature until fish products are processed will

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provide the product a strong competitive advantage. A fishmeal displaying strong freshness attributes will be preferred by the pet food industry for several reasons:

- Better perceived by the consumer
- Healthier (No biogenic amines)
- Better palatability from an animal standpoint.

In the case of a fishmeal plant, the refrigeration is limited to the reception and storage of the raw materials. A good system will require a stable energy supply, as well as a back-up energy source for emergency situations.

For the docking area, the best method to load/unload material is by using a dock leveller which bridges the gap and height between the building and the vehicle. The height and position of the dock leveller should be well suitable for refrigerated trucks and container docking. Forklifts that are suitable for container loading can minimize the loading-unloading time very effectively.

The design of the refrigeration area is very crucial for energy- efficient operation. Ammonia is a very efficient refrigerant for this application and it is safe when handled with care. The safety starts with the design, position of vessels, fabrication and testing of all vessels, selection of valves, welding of all joints, proper pressure and testing procedures, position of ammonia sensors, proper identification of pipes and proper air exhaust system for plant room and other critical areas. Proper safety equipment should also be available at the right place to handle an emergency. It is always advisable to keep the high-pressure receiver above the machine room or in a safe open place.

All standard compressors whether it is reciprocating, or screw is efficient when taken individually. However, some of the compressors have oil lifting issues. This should be cross checked before selecting the compressor. Compressors driven with 'Variable Frequency Drive' by ensuring the speed variation in line with refrigeration capacity change will certainly ensure power saving. The speed variation with compressor capacity control in larger capacity compressors is the best combination to save energy. Evaporative condensers are the best type of condenser. Most of the evaporative condensers are with coil type heat exchangers and evaporative condensers with plate type heat exchangers are yet to get tested at various conditions. Above all, it is the system design that makes the process efficient and effective. Selection of pipes, fittings, valves and controls in-line with the capacity requirement, velocity and pressure drop are very essential for a trouble-free system operation. All required safety devices and safety line components must safeguard operating equipment and human safety. Ammonia sensors with alarms and system interlock should not be avoided. The incorporation of PLC (Programmable Logic Controller) and SCADA (Supervisory Control and Data Acquisition) will give immense benefit for the plant operation by making it simple at the same time very informative.

7.8.4 Cooking and mixing

The purpose of the heating process is to liberate the oil from the fat depots of the fish, and to condition the material for the subsequent treatment in the various processing units of the

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plant. "Cooking", as this operation has traditionally been called is, therefore, a key process of the utmost importance for the whole functioning of the factory.

Until recently, the general view has been that the best results and optimum performance of the plant would be obtained at the highest possible temperature which, at atmospheric pressure, would be l00 °C. New experiments, however, have shown that the walls of the fat cells are broken down before the temperature reaches 50 °C. The oil is then free, and theoretically, it should be possible to separate it from the solid material. Another important observation from recent investigations is that coagulation of the fish protein is completed at about 75 °C and, furthermore, that the process is very rapid. This new experience leads to the conclusion that there is very little, if anything, to be gained by heating the material beyond 75 °C or by using a long heating time. The problem is primarily a question of heat transfer and temperature control to ensure a uniform, optimum temperature throughout the whole mass. Since reduction of heat load on the material, that is the combined effect of temperature and time, tends to improve the quality of the products, we may expect new technological answers to the heating problem, in line with this new knowledge. However, at the present state of technology, we must accept that optimum conditions for a particular type of raw material must largely be established through practical experience.

The cooking takes place in four stages using three separate tubular heat exchangers to control time and temperature, through which the product is conveyed continuously. Heat is transferred indirectly from a surrounding jacket. This is an improvement over the direct steam injection cooker, in which water is condensed in the mass during the process and must be removed. To effectively separate the bones later in the process, keeping them intact as much as possible is very important. Some cooking processes also tend to grind the material, breaking bones into smaller pieces making them difficult to remove during the separation phase. Also, the mass would need a very effective and gentle agitation during a period that a classical tubular conveying system does not allow. An airlift bubble column will then be installed after the second heating tube to accelerate hydrolysis and homogenize slurry without breaking bones.

Figure 7.11: Temperature during the different stages of the cooking phase.

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There are two methods to apply an enzymatic hydrolysis on raw materials. The first one is called autolysis and takes advantage of the endogenic enzymes found in the fish. The second option is to add an enzyme mixture. This method is more a convenient and consistent method than that with autolytic enzymes due to a high variation in optimal conditions for each of enzyme in the autolytic enzymatic composition.

Moreover, the enzymatic content of fish can vary with season, gender, age, etc.

The choice of the type of enzyme can be challenging. In this case, considering the product will be used by the pet food industry, one key attribute to keep in mind is the meal palatability. Enzymes tend to develop a bitter taste with an advanced degree of hydrolysis. Bitterness is usually not well accepted by dogs. Therefore, using an enzyme that does not generate bitterness will be privileged. The table below summarizes the bitterness factor of different enzymes commonly used in fish processing.

Table 7.9: Enzyme types and respective relative bitterness.

Type of enzyme	Relative bitterness
Papain and bromelain	3.4
Autolytic enzymes	3.7
Flavour enzyme	4.1
Bromelain	4.6
Protamex	4.7
Papain	4.8
Promod	5.1
Alcalase	5.5

The inactivation of enzymatic hydrolysis is typically accomplished by increasing temperatures to around 75°C for a short time. This is done by transferring the slurry from the external loop bubble column to a third heating tube. The enzymes are added at the beginning of the process, online, just before the side stream entry in the tubular heat exchanger. During the air mixing operation, citric acid in dry form, a water-soluble antioxidant, will be added. The lipid-soluble antioxidant will be added at a different unitary operation, downstream.

7.8.5 Separation and straining through a multi layers vibrating screen

The equipment in **Figure 7.12** separates solids from liquids or segregate dry materials into various sizes. Particles as fine as 37 microns can be screened, with up to four screen decks incorporated in one separator. This technology is very well adapted to the partially hydrolysed raw material: basically, the equipment is a vibratory screening device that vibrates about its centre of mass.

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***Figure 7.12**: Vibratory screening device used for separation and filtration.*

Vibration is accomplished by eccentric weights on the upper and lower ends of the motion-generator shaft. Rotation of the top weight creates vibration in the horizontal plane, which causes the material to move across the screen cloth to the periphery. The lower weight acts to tilt the machine, causing vibration in the vertical and tangential planes. The angle of lead given the lower weight, with relation to the upper weight, provides variable control of the spiral screening pattern. Speed and spiral pattern of the material travel over the screen cloth and can be set by the operator for maximum throughput and screening efficiency.

During cooking, and as a result of the partial hydrolysis, tissues progressively detach themselves from the bones and fat melts. The only parts remaining almost intact are the bones.

The hydrolysis helps disaggregate muscles into smaller pieces. The vibrating filter contributes to breaking down pieces of muscles into smaller parts. The strength added during the filtration step breaks, even more, the remaining coarse pieces into fragments and to some extent, contributing also to separate liquids and solids.

The first screen (on the top) will collect larger fishbones (head, etc.) letting the slurry go to the second screen. The fishbone collected needs to be discarded or can be sold as a source of minerals for fertilizers.

The second, third and fourth screens will progressively contain more protein and fewer bones. The fourth screen ensures most proteins have been separated from the liquid phase and should have a screen size close to 50 microns.

Posterior to this process, it is possible to create different grades of protein concentrate by keeping collected solids in different process streams. The separation of bones from the slurry allows an increase of the protein content in the new slurry and, a significant decrease in the ash content.

The liquid collected is then going to be centrifuged (**Figure 7.13**) to separate the crude oil from the stick water. Residual stick water can be either concentrated and refrigerated or sold without any other treatment to the pet food industry. Although the product is concentrated, the high content of biogenic amines and other impurities is a limiting factor to its commercialization. An alternative market to the pet food industry is the fertilizers market, where this product can gain added value.

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Figure 7.13: Centrifuge used for separation of the liquid phase.

7.8.6 Drying of the solids

The product obtained after filtration is like a paste or a product that does not flow easily. One of the advantages of the previous operations compared to a classical fishmeal line is the ability to decrease particle size effectively and homogenize the medium (no bones, no fat, homogeneous slurry). The removal of water can be done using the thin film drying technology (**Figure 7.14**), allowing fast drying and a low retention time of the product in the cylinder. Indirect thin film drying has been considered as an attractive drying technology to food companies, due to its high energy efficiency, since energy consumption is on average 40% less in comparison to spray drying.

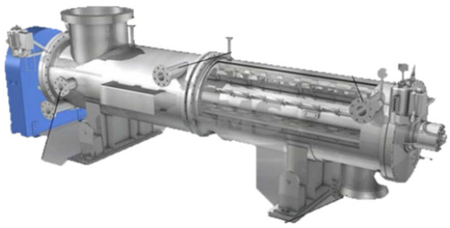

Figure 7.14: Equipment used for thin film drying technology.

The advantages of thin film drying are the following:

- Drying of products being sticky during the transition from paste to solids;
- Small product hold-up in the dryer;
- Fast start-up and shutdown;
- No residual product inside at standstill.

The technology consists of a horizontally arranged heated shell with end covers and a rotor with bolted-on blades. The wet product fed through the inlet nozzle is picked up by the rotor blades, applied on the hot wall and is simultaneously conveyed towards the outlet nozzle at the opposite end of the body.

The generated vapours stream counter-currently to the product flow and the dryer close to the feed nozzle. Evaporation and conveying capacity are adapted by the arrangement of the rotor blade. Entrained particles from the dry zone are removed in the wet zone. During this process, moisture levels of less than 1 % can be achieved and the residence time of the product is typically between 5 to 15 minutes.

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Temperature reaches its highest value during this step of the process, reaching a temperature superior to 90ºC. Therefore, it should be considered the CCP of the line of the process.

7.8.7 Effluents

To provide a sustainable model, management of effluents is an area that should not be overlooked.

The origin of effluents is multiple and need to be characterized to identify the best solution possible. A major source is the wastewater obtained after extraction of the oil from the liquid filtrate. It represents roughly 390 kg/metric Ton of raw material treated or 2,000 T per year for a plant treating 5,000T of side stream per year.

The second source of effluent is the water from cleaning. That volume will depend on the cleaning frequency and should be around 500 T per year.

Another factor that will determine the method used to treat wastewater is the outcome of the water after treatment. Ideally, it should be re-used in the plant for cleaning purpose. A circular water model which allows the water to be re-used for cleaning purposes is suggested in this report.

The proven technology most effective to separate water from solids and contaminants is a Membrane Bioreactor (MBR) (a high-performance solution for wastewater reuse) (Santos et al., 2011). MBR can be difficult to implement when the membrane is not properly fit and might break easily. This usually happens when backwashing. This step is essential for reliable membrane operation, however nearly impossible in most submerged membrane systems. Due to this, a submerged membrane is not recommended for this application.

Flat sheet membranes are especially prone to immediate damage when backwashed, rendering this short but very effective hydraulic cleaning method useless. The solution is the use of an unbreakable layer of flat sheets. The patented technology is a thin envelope of two polymeric ultrafiltration membranes, 4 mm thick, with an integrated permeate channel (IPC) in the middle. The two layers are physically integrated into the 3D spacer fabric, making the membrane unbreakable.

The membrane bioreactor equipped with an IPC membrane is probably the most effective technology to implement circular water and decrease to its minimum the capital investment necessary for water treatment.

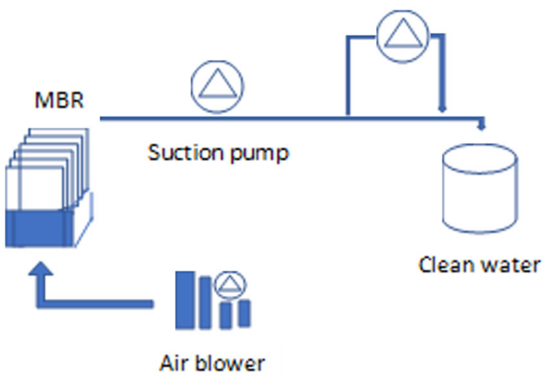

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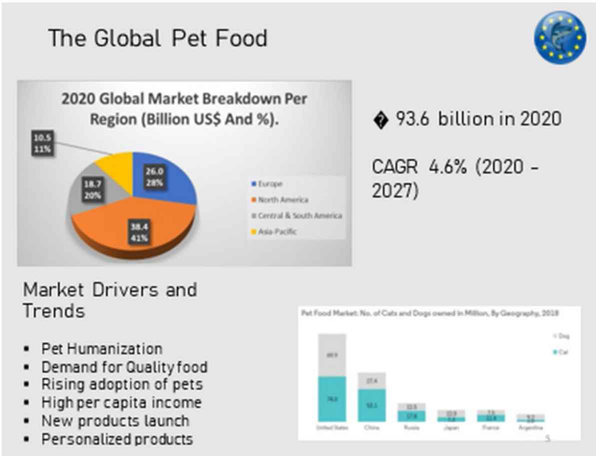
Figure 7.15: Membrane bioreactor principle.

7.9 Business plan for a new production unit



Opportunities

Animal Protein will continue to grow. New origins will be integrated in pet diets, such as insects, lab meat as well as new vegetable protein sources.

With limited supply, the effects of rarity should be translated into "luxury" or ultra-premium image and quality.
The premiumization and the humanization trends can only accelerate the success of a high end and customized approach. The concept can be applied to anything, including fishmeal.

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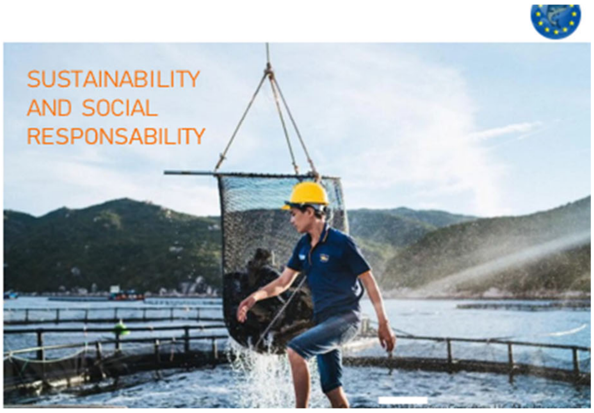

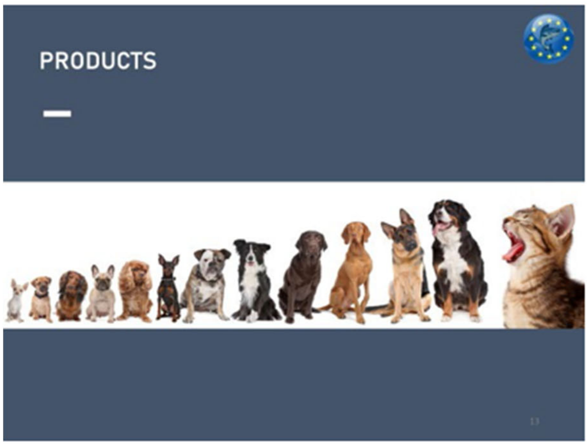

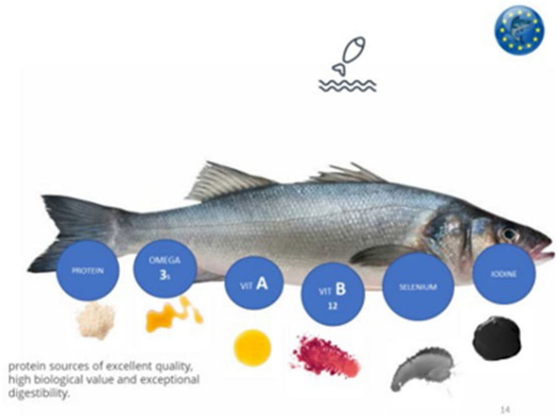

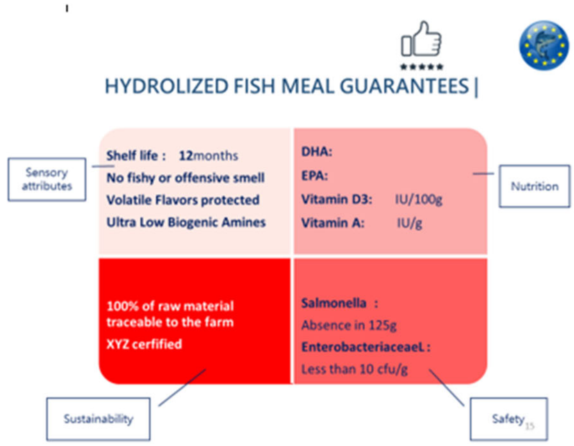

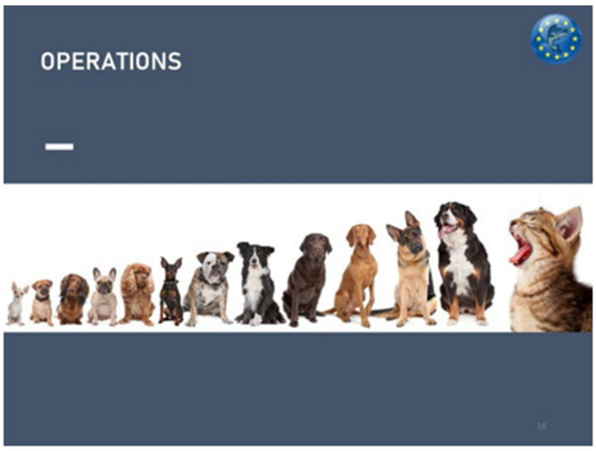

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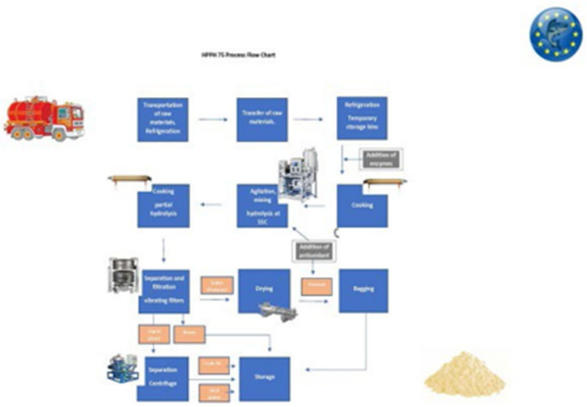

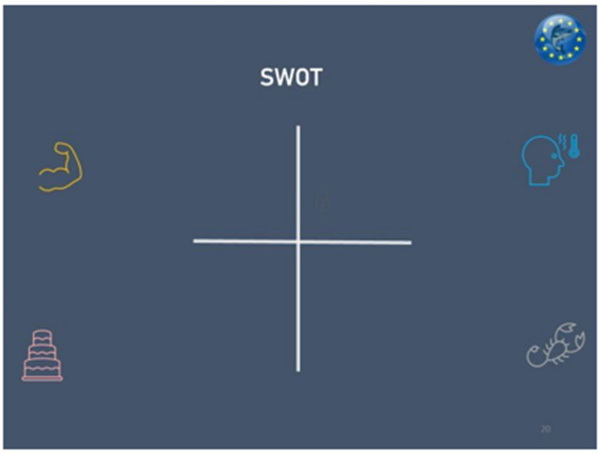

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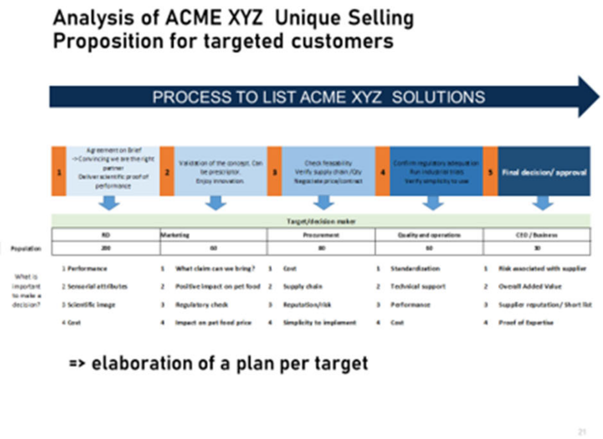

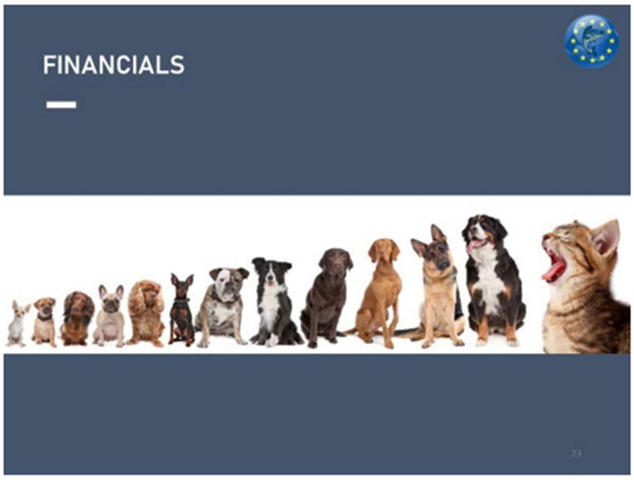

7.10 Financials

The proposed Profit and Loss document was built on some assumptions listed below.

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7.10.1 Price of HPPH 75

HPPH75 is, by nature, a premium ingredient and an important part of cats and dogs' speciality products nutritional base. Due to the higher protein and lower ash content, it can be used in some prescription diets, where other fishmeal cannot be used.

Therefore, it enters in the pet food market with much less competition.

A 70% protein fishmeal providing good freshness standards is valued at 1600-1800 Euros per metric ton, to which a natural antioxidant needs to be added that usually has a cost of 30 euros per metric ton (Probst et al., 2015).

Pricing the HPPH 75 at 2000 euros per metric ton or more removes it from the fishmeal category, closing many opportunities to be sold. A price of 1800 euros per metric ton seems to be the maximum companies are willing to pay for good quality, 70% protein fish meal, based on the questionnaire answers and other price sources. If valued per point of protein, the price of HPPH75 should be at 1930 euros per metric ton (Ex-factory price) or less.

7.10.2 Raw material price

It will depend on the option chosen. A company already processing seabass may want to define the price of raw material as zero, since it is a by-product otherwise discarded. As a stand-alone activity, the raw material should be purchased at a price negotiated with suppliers for a few years in order to stabilize the activity. In this study, the price was arbitrarily chosen at 50 euros per metric ton, representing almost 30% of the total production costs. This price takes into consideration the discard cost the supplier would have to pay if the product was not upcycled into the food chain.

Based on the existing farmed seabass volume produced in Europe, as well as the market growth projections in the next 5 years, the volume available at one point of collection will probably plateau at a maximum of 5,000 metric tons of size stream per year (Table 7.8). This volume would generate 1,000 metric T of HPPH fishmeal per year.

7.10.3 Investments

The investment will depend on the option chosen: 1) Stand-alone plant; 2) Use an existing rendering facility; 3) Addition of a processing unit at an existing seabass processor. The building costs have not been included in the calculations. Instead, a fixed annual cost for a rented building and office have been considered of about 60,000 Euros/year. The additional capital investment for a building and office would be around 200,000 euros. Amortized over five years, the annual cost would be 40,000 Euros per year.

7.10.4 Equipment Capital investment

The simplicity of the line allows a low capex compared to a typical fishmeal line, partially due to the relatively low volume of raw materials processed per day. The total capital investment needed for the line is described in **Table 7.10**.

Table 7.10: *Description of capital investment needed for investment. Prices sourced from multiple enterprises including Alfa Laval.*

Description	Cost (Euros)	Amortization /year (Euros)
Refrigeration system	60,000	19,200

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Air compressor	10,000	3,200
Silos reception	50,000	16,000
Transfer to tubular system	20,000	6,400
Tubular cooker	85,000	27,200
Vibrating filtration	35,000	11,200
Pumps	18,000	5,760
Dryer	125,000	40,000
Grinding	65,000	20,800
Packaging station	35,000	11,200
Metal detector	15,000	4,800
Panels, electric cables, pipes, valves, cocks, electric and pipe installation	125,000	40,000
Boiler room	100,000	32,000
Total	**743,000**	**237,760**

7.10.5 Annual Production cost of fishmeal (per metric Ton)

The yearly production costs of producing fishmeal including fixed and variable costs are enumerated in **Table 7.11**.

Table 7.11*: Yearly production cost of fishmeal (per metric Ton). [a] considering 240 working days per year. [b] Labour costs consider a team of 6 people located in Southern Europe with an average monthly salary of EUR 1,400. [c] Calculations made for Year 1 with a starting quantity of 2,000 metric tons of raw material per year. [d] Calculations made for the maximum of 5,000 metric tons of raw material per year.*

	Cost (Euros)	Raw material 5,000 metric tons per year 21T per day[a]
Annual fixed plant cost		
Amortization (depreciation and interest in equal annual amounts)	237,000	
Insurance: 2% investment costs	14,860	
Maintenance and repairs: 5% of investment costs	37,150	
Management	80,000	
Supervision and permanent labour	100,000[b]	
Interest on working capital	10,000	
Lease/rent	60,000	560,000
Variable costs		
Cost of raw material at EUR 50/ton	100,000[c]	250,000[d]
Plant costs per ton of raw material		
Gas: 400KWh/T of raw material x EUR 0.028/KWh	11.2	

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Electricity: 40 kWh × EUR 0.12 × 24 h/ 100	1.15	
Bags: 4 at EUR 0.30 each	1.20	
Labour	3.00	
Water	0.40	
Total plant costs/ton of raw material	**16.95**	**84,750**
Total annual production costs		**894,750**
Per ton of meal		**894**

7.10.6 Profit and Loss statement

***Table 7.12**: Profit and Loss statement.*

		Year 1	Year 2	Year 3	Year 4	Year 5
Quantities Sold		400	600	800	1,000	1,000
Selling Price per metric ton		**1,930**	**1,930**	**1,930**	**1,930**	**1,930**
Total Revenue (Sales)		**772,000**	**1,158,000**	**1,544,000**	**1,930,000**	**1,930,000**
Cost of sales	Quantity of raw material/year (metric ton)	2,000	3,000	4,000	5,000	5,000
	Raw materials	100,000	150,000	200,000	250,000	250,000
	Repairs and maintenance (5% investment)	35,000	35,000	35,000	35,000	35,000
	Rent & related costs	60,000	60,000	60,000	60,000	60,000
	Utilities	28,000	43,000	59,000	76,000	79,000
	Amortization (depreciation and interest)	237,000	237,000	237,000	237,000	237,000
	Salary (supervision and permanent labour cost)	100,000	110,000	120,000	130,000	140,000
Total Cost of Sales		**560,000**	**635,000**	**711,000**	**788,000**	**801,000**
Gross Profit		**212,000**	**515,000**	**833,000**	**1,142,000**	**1,129,000**
Expenses						
Selling, General & Administrative	Salary & Payroll (Management)	80,000	82,000	85,000	87,000	90,000
	Payroll expensed (payroll externalized)	5,000	5,000	5,000	5,500	5,500
	Other outside services	10,000	10,000	10,000	10,000	10,000
	Supplies (office and operating)	7,000	8,000	9,000	10,000	11,000
	Accounting and legal	8,500	8,500	9,000	9,000	9,500
	IT	4,000	4,000	5,000	5,000	5,000

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	Insurance (2% of investment costs)	14,000	14,000	14,000	14,000	14,000
Total SG&A		**128,500**	**131,500**	**137,000**	**140,500**	**145,000**
Marketing and Advertising		12,000	13,000	14,000	15,000	16,000
Interests on working capital		10,000	10,000	10,000	10,000	10,000
Taxes (real estate, etc)		45,000	55,000	60,000	63,000	65,000
Total expenses		**195,500**	**209,500**	**221,000**	**228,500**	**236,000**
Net Operating Income		**16,500**	**305,500**	**612,000**	**913,500**	**893,000**
%		**2%**	**26%**	**40%**	**47%**	**46%**

At the end of year 1, the company will achieve a break-even result due to the weight of fixed costs compared to the revenues (

Table 7.12). Some costs could even be cut that year in order to generate profit. The budget allocated for maintenance in the first year could be lower since the equipment would be under warranty. However, savings in that category might be difficult as, in order to have in place a solid management programme, replacement parts should be inventory from the start.

Another option which decreases costs in the first year, would be to index the building lease on sales, therefore decreasing rent at the start of the rental period and increasing it in the following years.

Labour costs were divided into two sections (i) the team working actively on the plant and (ii) the management team. The team working on plant would be small due to the heavy equipment with a maximum of about 8 workers needed. The average monthly salary would be approximately EUR 1,400 which is adjusted yearly for inflation and according to the production volume.

Utility costs include plant costs such as gas, electricity, water and bags. The calculated cost per ton of raw materials was calculated to be EUR 13.95 given the current values practice in the Southern Europe. Each year this value is updated to accommodate inflation which was set as 3%.

Selling, general and administrative expenses which are third-party companies as accounting and IT were calculated based on current rates and length of contracts.

At the end of the second year, operating costs already reach 26%, which is satisfactory for a new activity. It will then plateau at 47-46% at full capacity.

8. Conclusion

This deliverable summarizes the results of a comprehensive techno-economic analysis, aimed at assessing the potential exploitation of GAIN innovative circular processes, developed and tested in GAIN WP2. These processes concerned the cost-effective disposal and, whenever possible, reuse and valorization of:

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- Aquafarming side-streams, namely: 1) **fish sludge** from RAS, Recirculating Aquaculture Systems, 2) **waste waters** from RAS; 3) **mortalities**.
- By products from fish and shellfish processing, namely heads, frames, trims, viscera.

They main results are summarized below.

Novel feeds, including as ingredients also Fish Protein Hydrolisates (FPH) extracted from by-products of farmed fish, were tested on Atlantic salmon, rainbow trout, seabass, seabream and turbot. The results of the feed trials showed that the growth performances, were, in general, comparable with those of commercial formulations, including higher pecentages of fish meal and fish oil derived from fishery. These innovative formulations, however, were in general more expensive and, at present, unsustainable from the economic point of view. Nevertheless, these feeds may become attractive for the industry in the near future, as, on the one hand, prices of fish meal and fish oil from fishery are likely to increase and, on the other, the demand for feeds with reduced or no such ingredients is increasing.

Fish sludge. Two processes for drying and sanitizing fish sludge were developed up to TRL 8 in GAIN. The first one combines a conventional filtering system and an energy efficient dryer, the second one is based on a standalone filtration/drying unit. In both cases, the final product is a sanitized powder, rich in organic matter, nitrogen and phosphrous, of high caloric content. The results of the economic analysis show that both systems are very promising options for sludge valorisation for a RAS smolt farm in Norway. Further arrangements, also with potential kickback opportunities when selling the final product to the biofertilisier industry, are conceivable. Considering the positive results of the environmental assessment of the two sludge valorisation methods (Christiano et al. 2021, D4.4), these methods might present valuable opportunities for enhancing RAS circularity.

Waste waters: open pond aquaponics. The results of the techno-economic analysis applied to a theoretical decoupled aquaponics system capturing dissolved nutrients from wastewater discharged by a smolt RAS in Nordland (Norway) showed that costs and returns of the theoretical aquaponics system seems to be a promising option. Besides potential additional returns and reducing wastewater nitrogen and phosphorus amounts, which might be required by future regulations, there could be the opportunity to increase production at the smolt farm site. In Norway, there is no precedence for increasing production by reducing the environmental loading, but it might be an option for a new facility and/or for smolt production outside Norway.

Waste waters: integrating carp pond farming and aquaponics. Including a RAS unit to replace carp wintering ponds is very promising and could ensure long-term profitability in the case of small-scale farms, such as the one investigated in the GAIN pilot case studies, which produces 26 tons/year. For this system, watercress is a self-sustainable co-product, with a share of 2.4 % of total returns. For future studies, it would be interesting to include marketing effort of aquaponic plant products within the cost-benefit analysis as well as a further exploration of culture opportunities of plant species other than watercress.

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Mortalities. The innovative GAIN approach of processing mortalities and discarded fish utilizes the drying unit from Waister, sanitizing fish biomass with a superheated steam drying technology. The results of the economic analysis indicate that this process has the potential to to turn dried mortalities into an interesting product, which could increase returns for the typical salmon grow-out farm taken as case study. They also suggest that conomic returns could be very promising for a (smolt) farm with labour-intensive ensilage process. The application of the process to other species would be straightforward.

Shellfish by-products: shells as RAS biofilter filling media. GAIN tested he use of shells as filler for RAS biofilters. Even though this innovation achieved an intermediate TRL of 5, a preliminary economic analysis suggest that mussel shells could be a cost-effective alternative to plastic material. This is due to the assumption that mussel shells are free of costs except for their transport and that their disposal costs are assumed to be much lower compared to plastic material as well. At least in Spain, the mussel shell bio filter material could be used as soil fertilizer and only transport costs would occur here for their "disposal". If this is also the case for Denmark is uncertain, but even here the disposal costs for natural material are assumed to be lower than for plastic material.

Fish by-products. In general, the processes tested in GAIN for extracting valuable secondary products from fish processing by-products turned out to be viable form the economic point of view. Of particular interest is the utilization of dry peptones and liquid peptones as growth media for LAC. The profitability of processing FPH is depending predominantly on the by-product type (trimmings/frames most promising for tested species and by-products). The valorization of fish by-products into gelatin did not proof to be profitable in the current input-output analysis, under the assumption adopted in the economic analysis carried out in GAIN. The supplementary analysis carried out for assessing the potential market of secondary products deriving from the processing of rainbow trout in Italy confirmed that farmers are interested in these innovations, but extraction processes require a minimum volume to become remunerative. Therefore, it is likely that only farmer OP /cooperatives with centralize processing plants, could undertake these circular valorization pathways.

Adding value to FPH as pet-food ingredients. The results of a comprehensive study indicates that the pet food sector is demanding high quality, sustainable ingredients and is shifting towards higher protein content feeds. A modified process for producing High Protein Partial Hydrolisates from seabass and seabream by-products is outlined. The results of an "a priori" financial analysis and a 5-year business plan estimating the necessary investments, the costs, the go-to-market strategy, as well as an estimated profit and loss, show that this process could become profitable for a rendering plant treating 5000 metric tons of product per year. High quality- partially hydrolysed and sustainable fish meal has wide applications in European pet-foods and will obtain for these purposes a price premium over a conventional meal, but to benefit from this the control of raw fish quality and of processing conditions must be very strict. Special types of fishmeal have proved beneficial in many applications, there is little doubt that, in future, a wider differentiation in the fishmeal products will be part of a sustainable aquaculture model.

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Annex 1

I) Profits under three return scenarios for decoupled open aquaponic system *U. lactuca*

Scenarios per NOK/ton dry matter	**Scenario 1**	**Scenario 2**	**Scenario 3**
	Current returns & 10% withhold processor **(NOK/t DM)**	Min. returns for cost recovery **(NOK/t DM)**	Max. withhold processor for cost recovery **(NOK/ t DM)**
Assumed returns for processed product	140,000 NOK	110,488 NOK	140,000 NOK
Withhold of processor (for transport, processing, resale discount)	- 14,000 NOK	- 11,049 NOK	- 40,561 NOK
Returns for aquaponic company (net)	126,000 NOK	99,439 NOK	99,439 NOK
Transport wild *U. lactuca* for initial stocking	- 30 NOK	- 30 NOK	- 30 NOK
Permit for coastal access to collect wild *U. lactuca*	- 9 NOK	- 9 NOK	- 9 NOK
Wage and non-wage costs (15,9 employees/23760 h/358 NOK)	- 77,544 NOK	- 77,544 NOK	- 77,544 NOK
Equipment for wild *U. lactuca* collection (2.500 NOK p. employer)	- 364 NOK	- 364 NOK	- 364 NOK
Hand nets for harvest (15 p.a.)	- 91 NOK	- 91 NOK	- 91 NOK
Variable production costs	**- 78,038 NOK**	**- 78,038 NOK**	**- 78,038 NOK**
Fixed and variable costs of production system/equipment	**- 21,401 NOK**	**- 21,401 NOK**	**- 21,401 NOK**
Profit	**26,560 NOK**	**- 0 NOK**	**- 0 NOK**

II) Processing fish heads and trimmings/frames (T&F) to Fishprotein Hydrolysate (FPH)

		Unit	Salmon heads	Salmon T&F	Trout heads	Trout T&F	Turbot heads	Turbot T&F
Yield FPH per ton fish by-product (FBP)		kg	120	140	118	110	120	146
Yield FPH per 7.000 t FBP		**t**	**840**	**980**	**826**	**770**	**840**	**1,022**
Revenue per t FPH		€	2,000	2,000	2,000	2,000	2,000	2,000
Revenue per total yield		**€**	**1,680,000**	**1,960,000**	**1,652,000**	**1,540,000**	**1,680,000**	**2,044,000**
Scenario 1:	Price/t	€	100	100	100	100	100	100
min. raw material costs	**FBP total**	**€**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**
Scenario 2:	Price/t	€	300	300	300	300	300	300
max. raw material cost	**FBP total**	**€**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**
Chemicals	Alcalase®2.4	l	14,000	14,000	7,000	7,000	14,000	14,000
	Price/l	€	24	24	24	24	24	24
	Alcalase®2.4 total	**€**	**336,000**	**336,000**	**168,000**	**168,000**	**336,000**	**336,000**
	NaOH (20%)	l	350,000	385,000	234,500	283,500	423,500	357,000
	Price/l	€	0.35	0.35	0.35	0.35	0.35	0.35
	NaOH total	**€**	**120,925**	**133,018**	**81,020**	**97,949**	**146,319**	**123,344**
	Water	m^3	7,000	7,000	7,000	7,000	7,000	7,000
	Price/m^3	€	1.50	1.50	1.50	1.50	1.50	1.50
	Water total*/m^3	**€**	**13,040**	**13,040**	**13,040**	**13,040**	**13,040**	**13,040**
Staff	Foreman	€	70,000	70,000	70,000	70,000	70,000	70,000
	4 Operators à 37.380 € p	€	149,520.00	149,520.00	149,520.00	149,520.00	149,520.00	149,520.00
	Staff total	€	**219,520**	**219,520**	**219,520**	**219,520**	**219,520**	**219,520**
Electricity	Requirement	kW	14,651	14,651	14,455	14,455	14,553	14,553
	Price/ kW*	€	0.23	0.23	0.23	0.23	0.23	0.23
	Electricity total	€	**3,364**	**3,364**	**3,319**	**3,319**	**3,341**	**3,341**
Disposal water**	Volume water	m^3	7,364	7,399	7,242	7,291	7,438	7,371
	Price/m^3	€	3.45	3.45	3.45	3.45	3.45	3.45
	Disposal total	€	**25,406**	**25,527**	**24,983**	**25,152**	**25,659**	**25,430**
Scenario 1 -	**Total costs/7000 t FBP**	**€**	**1,418,255**	**1,430,468**	**1,209,882**	**1,226,980**	**1,443,880**	**1,420,675**
	Costs per ton FPH	**€**	**1,688**	**1,460**	**1,465**	**1,593**	**1,719**	**1,390**
	Surplus / loss per ton FPH	**€**	**312**	**540**	**535**	**407**	**281**	**610**
Scenario 2 -	**Total costs/7000 t FBP**	**€**	**2,818,255**	**2,830,468**	**2,609,882**	**2,626,980**	**2,843,880**	**2,820,675**
	Costs per ton FPH	**€**	**3,355**	**2,888**	**3,160**	**3,412**	**3,386**	**2,760**
	Surplus / loss per ton FPH	**€**	**- 1,355**	**- 888**	**- 1,160**	**- 1,412**	**- 1,386**	**- 760**

* industrial price, incl. basic costs

** All liquids

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III) Processing fish by-products (average results for heads, trimmings & frames, viscera) to Dry Peptones

		Unit	Salmon	Trout	Turbot	Sea bream	Seabass
Average Yield Dry Peptones per ton fish by-product (FBP)[#]		kg	120	113	130	102	93
Average Yield Dry Peptones per 7.000 t FBP		**t**	**840**	**788**	**910**	**716**	**651**
Revenue per t Dry Peptone*		€	19,450	19,450	19,450	19,450	19,450
Revenue per total yield		**€**	**16,338,000**	**15,330,490**	**17,699,500**	**13,928,145**	**12,661,950**
Scenario 1:	Price/t	€	100	100	100	100	1,100
min. raw material costs	**FBP total**	**€**	**700,000**	**700,000**	**700,000**	**700,000**	**7,700,000**
Scenario 2:	Price/t	€	300	300	300	300	300
max. raw material costs	**FBP total**	**€**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**
Chemicals	Alcalase®2.4	l	14,000	7,000	14,000	14,000	14,000
	Price/kg	€	24	24	24	24	24
	Alcalase®2.4 total	**€**	**336,000**	**168,000**	**336,000**	**336,000**	**336,000**
	NaOH (20%)	l	350,000	234,500	423,500	217,000	280,000
	Price/kg	€	0.35	0.35	0.35	0.35	0.35
	NaOH total	**€**	**120,925**	**81,020**	**146,319**	**74,974**	**96,740**
	Water	m^3	7,000	7,000	7,000	7,000	7,000
	Price/m^3	€	1.50	1.50	1.50	1.50	1.50
	Water total/m^3**	**€**	**13,040**	**13,040**	**13,040**	**13,040**	**13,040**
Staff	Foreman	€	70,000	70,000	70,000	70,000	70,000
	4 Operators à 37.380 € p.a.	€	149,520	149,520	149,520	149,520	149,520
	Staff total	€	**219,520**	**219,520**	**219,520**	**219,520**	**219,520**
Electricity	Requirement	kW	15,925	15,631	15,190	15,288	15,288
	Price/ kW**	€	0.23	0.23	0.23	0.23	0.23
	Electricity total	€	**3,656**	**3,589**	**3,488**	**3,510**	**3,510**
Disposal water* **	Volume water	m^3	7,364	7,242	7,438	7,231	7,294
	Price/m^3	€	3.45	3.45	3.45	3.45	3.45
	Disposal total	€	**25,406**	**24,983**	**25,659**	**24,947**	**25,164**
Scenario 1 - Total costs/7000 t FBP		**€**	**1,418,547**	**1,210,152**	**1,444,026**	**1,371,991**	**8,393,974**
Costs per ton Dry Peptone		**€**	**1,689**	**1,535**	**1,587**	**1,916**	**12,894**
Surplus / loss per ton Dry Peptone		**€**	**17,761**	**17,915**	**17,863**	**17,534**	**6,556**
Scenario 2 - Total costs/7000 t FBP		**€**	**2,818,547**	**2,610,152**	**2,844,026**	**2,771,991**	**2,793,974**
Costs per ton Dry Peptone		**€**	**3,355**	**3,312**	**3,125**	**3,871**	**4,292**
Surplus / loss per ton Dry Peptone		**€**	**16,095**	**16,138**	**16,325**	**15,579**	**15,158**

[#]Average from heads, trimmings + frames and viscera

* Average Alibaba; margin 8.240 - 30.670 €/t

**industrial price, incl. basic costs

*** All liquids

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IV) Processing fish by-products into Liquid Peptones (enzymatic) to culture Lactic Acid Bacteria (LAB) and obtain lactic acid

		Unit	Salmon			Trout			Turbot			Sea bream			Seabass		
			Heads	Trimming, Frames	Viscera	Heads	Trimming, Frames	Viscera	Heads	Trimming, Frames	Viscera	Heads	Trimming, Frames	Viscera	Heads	Trimming, Frames	Viscera
Yield LAB per ton fish by-product (FBP)		kg	45	50	35	43	45	40	65	63	60	55	52	30	50	53	28
Yield LAB per 7.000 t FBP		t	**315**	**350**	**245**	**301**	**315**	**280**	**455**	**441**	**420**	**385**	**364**	**210**	**350**	**371**	**196**
Yield lactic acid per ton LAB (as by-product)		t	4.22	3.60	4.29	3.49	3.56	3.50	3.54	3.49	3.33	3.82	3.75	4.33	3.80	3.77	5.00
Revenue per t LAB*		€	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329
Revenue per t lactic acid**		€	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788
Revenue per t LAB (incl. by-product)		€	52,974	48,766	53,450	48,019	48,494	48,087	48,359	48,019	46,933	50,259	49,784	53,721	50,123	49,920	58,269
Revenue per total yield		€	**16,686,923**	**17,068,030**	**13,095,132**	**14,453,755**	**15,275,698**	**13,464,360**	**22,003,127**	**21,176,432**	**19,711,877**	**19,349,777**	**18,121,376**	**11,281,418**	**17,543,190**	**18,520,231**	**11,420,724**
Scenario 1:	Price/t	€	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
min. raw material costs	**FBP total**	€	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**
Scenario 2:	Price/t	€	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
max. raw material costs	**FBP total**	€	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**
Chemicals	Glucose	t	1,806	1,806	1,806	1,575	1,575	1,575	2,205	2,205	2,205	2,240	2,030	1,190	1,890	2,030	1,050
	Price/t	€	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00	1,148.00
	Glucose total	€	**2,073,288**	**2,073,288**	**2,073,288**	**1,808,100**	**1,808,100**	**1,808,100**	**2,531,340**	**2,531,340**	**2,531,340**	**2,571,520**	**2,330,440**	**1,366,120**	**2,169,720**	**2,330,440**	**1,205,400**
	Alcalase®(2.4)	l	14,000	14,000	14,000	7,000	7,000	7,000	14,000	14,000	14,000	14,000	14,000	14,000	14,000	14,000	14,000
	Price/l	€	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
	Alcalase®2.4 total	€	**336,000**	**336,000**	**336,000**	**168,000**	**168,000**	**168,000**	**336,000**	**336,000**	**336,000**	**336,000**	**336,000**	**336,000**	**336,000**	**336,000**	**336,000**
	Yeast	t	287	287	287	252	252	252	350	350	350	350	322	189	301	322	168
	Price/t	€	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00	2,460.00
	Yeast total	€	**706,020**	**706,020**	**706,020**	**619,920**	**619,920**	**619,920**	**861,000**	**861,000**	**861,000**	**861,000**	**792,120**	**464,940**	**740,460**	**792,120**	**413,280**
	NaOH (20%)	l	350,000	350,000	350,000	234,500	234,500	234,500	423,500	423,500	423,500	217,000	217,000	217,000	280,000	280,000	280,000
	Price/l	€	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	NaOH total	€	**120,925**	**120,925**	**120,925**	**81,020**	**81,020**	**81,020**	**146,319**	**146,319**	**146,319**	**74,974**	**74,974**	**74,974**	**96,740**	**96,740**	**96,740**
	Sodium Acetate	t	334	334	334	285	285	285	411	411	411	422	383	209	355	378	177
	Price/t	€	976	976	976	976	976	976	976	976	976	976	976	976	976	976	976
	Sodium Acetate total	€	**326,061**	**326,061**	**326,061**	**278,261**	**278,261**	**278,261**	**401,174**	**401,174**	**401,174**	**411,417**	**373,860**	**203,831**	**346,546**	**368,398**	**173,102**
	Ammoniumcitrate	t	120	120	120	101	101	101	151	151	151	155	140	70	129	138	58
	Price/t	€	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460
	Ammoniumcitrate total	€	**296,184**	**296,184**	**296,184**	**247,968**	**247,968**	**247,968**	**371,952**	**371,952**	**371,952**	**382,284**	**344,400**	**172,889**	**316,848**	**338,890**	**141,893**
	Tween 80	t	60	60	60	50	50	50	76	76	76	78	70	35	64	69	29
	Price/t	€	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541
	Tween 80 total	€	**1,236,568**	**1,236,568**	**1,236,568**	**1,035,266**	**1,035,266**	**1,035,266**	**1,552,900**	**1,552,900**	**1,552,900**	**1,596,036**	**1,437,870**	**721,811**	**1,322,840**	**1,414,864**	**592,402**
	K_2HPO_4	t	120	120	120	101	101	101	151	151	151	155	140	70	129	138	58
	Price/t	€	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050
	K_2HPO_4 total	€	**246,820**	**246,820**	**246,820**	**206,640**	**206,640**	**206,640**	**309,960**	**309,960**	**309,960**	**318,570**	**287,000**	**144,074**	**264,040**	**282,408**	**118,244**
	$MgSO_4$	t	12	12	12	10	10	10	15	15	15	16	14	7	13	14	6
	Price/t	€	288	288	288	288	288	288	288	288	288	288	288	288	288	288	288
	$MgSO_4$ total	€	**3,462**	**3,462**	**3,462**	**2,898**	**2,898**	**2,898**	**4,347**	**4,347**	**4,347**	**4,468**	**4,025**	**2,021**	**3,703**	**3,961**	**1,658**
	$MnSO_4$	t	3.01	3.01	3.01	2.52	2.52	2.52	3.78	3.78	3.78	3.89	3.50	1.76	3.22	3.44	1.44
	Price/t	€	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821
	$MnSO_4$ total	€	**17,520**	**17,520**	**17,520**	**14,668**	**14,668**	**14,668**	**22,001**	**22,001**	**22,001**	**22,613**	**20,372**	**10,227**	**18,742**	**20,046**	**8,393**
	Lactobacilli; freeze-dried vial		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Price/vial	€	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
	Lactobacilli total	€	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**
	Water	m³	67,200	67,200	67,200	57,400	57,400	57,400	82,600	82,600	82,600	84,700	77,000	42,140	71,400	75,880	35,840
	Price/m³	€	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
	Water total*/m³**	€	**103,340**	**103,340**	**103,340**	**88,640**	**88,640**	**88,640**	**126,440**	**126,440**	**126,440**	**129,590**	**118,040**	**65,750**	**109,640**	**116,360**	**56,300**
Staff	Foreman	€	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000
	10 Operators à 37.380 € p.a.	€	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800
	Staff total	€	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**
Electricity	Requirement	kW	21,462	21,462	21,462	19,992	19,992	19,992	23,079	23,079	23,079	23,079	22,050	17,395	22,050	22,883	17,248
	Price/ kW***	€	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296	0.2296
	Electricity total	€	**4,928**	**4,928**	**4,928**	**4,590**	**4,590**	**4,590**	**5,299**	**5,299**	**5,299**	**5,299**	**5,063**	**3,994**	**5,063**	**5,254**	**3,960**
Disposal water**	Volume water	m³	67,200	67,200	67,200	57,400	57,400	57,400	82,600	82,600	82,600	84,700	77,000	42,140	71,400	75,880	35,840
	Price/m³	€	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45
	Disposal total	€	**231,840**	**231,840**	**231,840**	**198,030**	**198,030**	**198,030**	**284,970**	**284,970**	**284,970**	**292,215**	**265,650**	**145,383**	**246,330**	**261,786**	**123,648**
Scenario 1 - Total costs/7000 t FBP		€	**6,846,840**	**6,846,840**	**6,846,840**	**5,897,886**	**5,897,886**	**5,897,886**	**8,097,588**	**8,097,588**	**8,097,588**	**8,149,870**	**7,533,698**	**4,855,897**	**7,120,557**	**7,511,151**	**4,414,906**
Costs per ton LAB[1)]		€	**21,736**	**19,562**	**27,946**	**19,594**	**18,723**	**21,064**	**17,797**	**18,362**	**19,280**	**21,168**	**20,697**	**23,123**	**20,344**	**20,246**	**22,525**
Surplus / loss per ton LAB[2)]		€	**31,238**	**29,203**	**25,503**	**28,425**	**29,771**	**27,023**	**30,562**	**29,657**	**27,653**	**29,091**	**29,087**	**30,598**	**29,779**	**29,674**	**35,744**
Scenario 1 - Total costs/7000 t FBP		€	**8,246,840**	**8,246,840**	**8,246,840**	**7,297,886**	**7,297,886**	**7,297,886**	**9,497,588**	**9,497,588**	**9,497,588**	**9,549,870**	**8,933,698**	**6,255,897**	**8,520,557**	**8,911,151**	**5,814,906**
Costs per ton LAB[1)]		€	**26,180**	**23,562**	**33,661**	**24,245**	**23,168**	**26,064**	**20,874**	**21,536**	**22,613**	**24,805**	**24,543**	**29,790**	**24,344**	**24,019**	**29,668**
Surplus / loss per ton LAB[2)]		€	**26,794**	**25,203**	**19,789**	**23,774**	**25,326**	**22,023**	**27,485**	**26,483**	**24,320**	**25,454**	**25,241**	**23,931**	**25,779**	**25,900**	**28,601**

* Average Alibaba; margin 7.570 - 41.088 €/t

** Average Alibaba; margin 3.566 - 11.508 €/t

***industrial price, incl. basic costs

**** All liquids

1) costs incl. production of lactic acid

2) Revenue LAB incl. lactic acid

V) Processing fish by-products into Liquid Peptones (thermal) to culture Lactic Acid Bacteria (LAB) and obtain lactic acid

		Unit	Salmon			Trout			Turbot			Sea bream			Seabass		
			Heads	Trimming, Frames	Viscera	Heads	Trimming, Frames	Viscera	Heads	Trimming, Frames	Viscera	Heads	Trimming, Frames	Viscera	Heads	Trimming, Frames	Viscera
Yield LAB per ton fish by-product (FBP)		kg	35	33	25	28	30	20	60	58	32	20	20	15	17	20	15
Yield LAB per 7.000 t FBP		t	**245**	**231**	**175**	**196**	**210**	**140**	**420**	**406**	**224**	**140**	**140**	**105**	**119**	**140**	**105**
Yield lactic acid per ton LAB (as by-product)		t	4.00	3.94	4.40	3.75	3.67	3.50	3.67	3.79	3.75	4.00	4.00	3.33	4.12	4.00	3.33
Revenue per t LAB*		€	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329	24,329
Revenue per t lactic acid**		€	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788	6,788
Revenue per t LAB (incl. by-product)		€	51,481	51,074	54,196	49,784	49,241	48,087	49,241	50,056	49,784	51,481	51,481	46,933	52,296	51,481	46,933
Revenue per total yield		€	**12,612,845**	**11,798,029**	**9,484,335**	**9,757,664**	**10,340,602**	**6,732,180**	**20,681,203**	**20,322,541**	**11,151,616**	**7,207,340**	**7,207,340**	**4,927,969**	**6,223,172**	**7,207,340**	**4,927,969**
Scenario 1:	Price/t	€	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
min. raw material costs	**FBP total**	€	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**	**700,000**
Scenario 2:	Price/t	€	300	30	300	300	300	300	300	300	300	300	300	300	300	300	300
max. raw material costs	**FBP total**	€	**2,100,000**	**210,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**	**2,100,000**
Chemicals	Glucose	kg	1,260	1,190	840	910	945	546	2,044	2,030	1,071	686	686	497	630	686	476
	Price/t	€	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148
	Glucose total	€	**1,446,480**	**1,366,120**	**964,320**	**1,044,680**	**1,084,860**	**626,808**	**2,346,512**	**2,330,440**	**1,229,508**	**787,528**	**787,528**	**570,556**	**723,240**	**787,528**	**546,448**
	Yeast	t	203	196	133	140	154	84	329	322	168	112	112	77	84	112	70
	Price/t	€	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460
	Yeast total	€	**499,380**	**482,160**	**327,180**	**344,400**	**378,840**	**206,640**	**809,340**	**792,120**	**413,280**	**275,520**	**275,520**	**189,420**	**206,640**	**275,520**	**172,200**
	Sodium Acetate	t	233	228	145	163	170	86	383	376	189	121	121	81	110	123	123
	Price/t	€	976	976	976	976	976	976	976	976	976	976	976	976	976	976	976
	Sodium Acetate total	€	**227,048**	**221,926**	**141,691**	**158,763**	**165,591**	**83,649**	**373,860**	**367,032**	**184,370**	**118,474**	**118,474**	**78,528**	**107,549**	**119,499**	**119,499**
	Ammoniumcitrate	t	79.8	77.7	44.8	51.8	54.6	21.0	140.0	137.2	62.3	35.3	35.3	18.9	30.8	35.7	35.7
	Price/t	€	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460
	Ammoniumcitrate total	€	**196,308**	**191,142**	**110,208**	**127,428**	**134,316**	**51,660**	**344,400**	**337,512**	**153,258**	**86,789**	**86,789**	**46,494**	**75,768**	**87,822**	**87,822**
	Tween 80	t	39.9	38.9	22.4	25.9	27.3	10.5	70.0	68.6	31.2	17.6	17.6	9.5	15.4	17.9	17.9
	Price/t	€	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541	20,541
	Tween 80 total	€	**819,586**	**798,018**	**460,118**	**532,012**	**560,769**	**215,681**	**1,437,870**	**1,409,113**	**639,852**	**362,343**	**362,343**	**194,112**	**316,331**	**366,657**	**366,657**
	K_2HPO_4	t	79.8	77.7	44.8	51.8	54.6	21.0	140.0	137.2	62.3	35.3	35.3	18.9	30.8	35.7	35.7
	Price/t	€	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050
	K_2HPO_4 total	€	**163,590**	**159,285**	**91,840**	**106,190**	**111,930**	**43,050**	**287,000**	**281,260**	**127,715**	**72,324**	**72,324**	**38,745**	**63,140**	**73,185**	**73,185**
	$MgSO_4$	t	8.0	7.8	4.5	5.2	5.5	2.1	14.0	13.7	6.2	3.5	3.5	1.9	3.1	3.6	3.57
	Price/t	€	288	288	288	288	288	288	288	288	288	288	288	288	288	288	288
	$MgSO_4$ total	€	**2,294**	**2,234**	**1,288**	**1,489**	**1,570**	**604**	**4,025**	**3,945**	**1,791**	**1,014**	**1,014**	**543**	**886**	**1,026**	**1,026**
	$MnSO_4$	t	2.0	1.9	1.1	1.3	1.4	0.5	3.5	3.4	1.6	0.9	0.9	0.5	0.8	0.9	0.9
	Price/t	€	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821	5,821
	$MnSO_4$ total	€	**11,612**	**11,306**	**6,519**	**7,538**	**7,945**	**3,056**	**20,372**	**19,964**	**9,065**	**5,134**	**5,134**	**2,750**	**4,482**	**5,195**	**5,195**
	Lactobacilli; freeze-dried vial		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Price/vial	€	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
	Lactobacilli total	€	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**	**85**
	Water	m³	46,900	45,850	29,400	32,900	34,300	17,500	77,000	75,600	38,150	24,640	24,640	16,450	22,400	24,850	24,850
	Price/m³	€	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
	Water total*/m³**	€	**72,890**	**71,315**	**46,640**	**51,890**	**53,990**	**28,790**	**118,040**	**115,940**	**59,765**	**39,500**	**39,500**	**27,215**	**36,140**	**39,815**	**39,815**
Staff	Foreman	€	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000
	10 Operators à 37.380 € p.a.	€	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800	373,800
	Staff total	€	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**	**443,800**
Electricity	Requirement	kW	16,954	16,268	14,504	13,524	13,818	12,348	18,228	17,885	14,308	12,103	12,103	10,388	11,270	12,103	10,388
	Price/ kW***	€	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
	Electricity total	€	**3,893**	**3,735**	**3,330**	**3,105**	**3,173**	**2,835**	**4,185**	**4,106**	**3,285**	**2,779**	**2,779**	**2,385**	**2,588**	**2,779**	**2,385**
Disposal water**	Volume water	m³	46,900	45,850	29,400	32,900	34,300	17,500	77,000	75,600	38,150	24,640	24,640	16,450	22,400	24,850	24,850
	Price/m³	€	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45
	Disposal total	€	**161,805**	**158,183**	**101,430**	**113,505**	**118,335**	**60,375**	**265,650**	**260,820**	**131,618**	**85,008**	**85,008**	**56,753**	**77,280**	**85,733**	**85,733**
Scenario 1 - Total costs/7000 t FBP		€	**4,748,770**	**4,609,309**	**3,398,450**	**3,634,884**	**3,765,204**	**2,467,032**	**7,155,139**	**7,066,137**	**4,097,392**	**2,980,298**	**2,980,298**	**2,351,386**	**2,757,928**	**2,988,643**	**2,643,849**
Costs per ton LAB[1]		€	**19,383**	**19,954**	**19,420**	**18,545**	**17,930**	**17,622**	**17,036**	**17,404**	**18,292**	**21,288**	**21,288**	**22,394**	**23,176**	**21,347**	**25,180**
Surplus / loss per ton LAB[2]		€	**32,098**	**31,120**	**34,776**	**31,239**	**31,311**	**30,465**	**32,205**	**32,651**	**31,492**	**30,193**	**30,193**	**24,539**	**29,120**	**30,134**	**21,754**
Scenario 1 - Total costs/7000 t FBP		€	**6,148,770**	**4,119,309**	**4,798,450**	**5,034,884**	**5,165,204**	**3,867,032**	**8,555,139**	**8,466,137**	**5,497,392**	**4,380,298**	**4,380,298**	**3,751,386**	**4,157,928**	**4,388,643**	**4,043,849**
Costs per ton LAB[1]		€	**25,097**	**17,833**	**27,420**	**25,688**	**24,596**	**27,622**	**20,369**	**20,853**	**24,542**	**31,288**	**31,288**	**35,727**	**34,941**	**31,347**	**38,513**
Surplus / loss per ton LAB[2]		€	**26,384**	**33,241**	**26,776**	**24,096**	**24,645**	**20,465**	**28,872**	**29,203**	**25,242**	**20,193**	**20,193**	**11,206**	**17,355**	**20,134**	**8,420**

* Average Alibaba; margin 7.570 - 41.088 €/t
** Average Alibaba; margin 3.566 - 11.508 €/t
***industrial price, incl. basic costs
**** All liquids

[1] Costs incl. production of lactic acid
[2] Revenue LAB incl. lactic acid

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Annex 2

GAIN PET FOOD PROJECT

ABOUT GAIN

GAIN (Green Aquaculture Intensification in Europe) is a European Union Horizon 2020 research project led by the University of Venice (IT). The partnership includes the Alfred Wegener Institute (DE), IBM (IE), University of Stirling (UK), Longline Environment (IE), Wageningen University (NL), SPAROS (PT), NOAA (USA), Dalhousie University (CA), Consejo Superior de Investigaciones Cientificas (ES), and Salten Havbrukspark (NO).

GAIN started on May 1st, 2018, runs for 42 months, and is designed to support the ecological intensification of aquaculture in the European Union (EU) and European Economic Area (EEA), with the dual objectives of increasing production and competitiveness of the industry, while ensuring sustainability and compliance with EU regulations on food safety and environment.

The eco-intensification of EU and EEA aquaculture is the only way to satisfy the increasing demand for high quality aquatic products and decrease dependence on imports, which, in the EU 28, reached 65% by volume in 2008-2012.Successful eco-intensification of European aquaculture requires the integration of scientific and technical innovations, new policies and economic instruments, and the mitigation of social constraints.

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GAIN focuses on three broad themes

Production and Environment

design of novel finfish feeds, making healthier and better fish; and (ii) application of precision aquaculture, using sensors and Big Data for real-time feedback to farmers and managers on both production and environmental quality.

Secondary outputs

There is substantial waste in finfish and shellfish farming, with respect to mortalities, re - use of side-streams, and use of by-products. Innovative actions in GAIN include: (i) obtaining renewable products from mortalities, and feed ingredients from by -products of fish and shellfish; (iii) production of algae from fish farms.

Policy and Markets

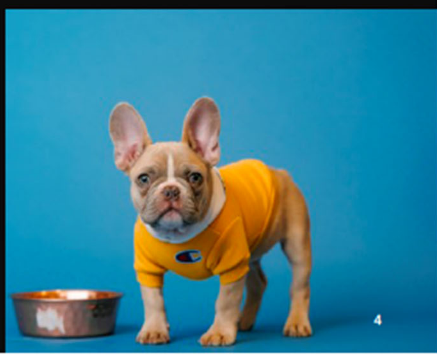
There are policy and market barriers to the implementation of the circular economy. GAIN will propose solutions by reviewing legislation and suggesting improvements; analyzing the balance between fish supply and demand, where serious inconsistencies have been flagged, and impacts in Europe of changes in global markets; evaluating consumer acceptance.

3

ABOUT THE PROJECT

OBJECTIVES

- **Provide guidance** to the Sustainable European aquaculture on the use of some of their product by the Pet Food industry
- **Take action** for the Sustainable Development Goals (SDGs).



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READY? LET'S GO

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Survey to The European Pet Food Industry on Seafood, Seabass and Seabream.

Definitions

Seafood ingredients in the following survey refer to 3 products: fishmeals, fish oils and fish hydrolysates.

Seafood raw materials are any uncooked part of the fish, usually presented in the form of frozen blocks.

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1 Can you characterize the seafood ingredients you are using?

Multiple answers are fine.

- ❑ locally sourced
- ❑ Imported from European country
- ❑ Imported from other country

- ❑ Farmed
- ❑ Wild caught
- ❑ Don't know

- ❑ Naturally preserved
- ❑ Synthe�cally preserved

- ❑ From a cer�fied fishery or farm
- ❑ From a noncer�fied sourcing

- ❑ Buy from producer
- ❑ Buy from broker/importer

What type of cer�fica�on does the product display

2 How important is for your company to know and to label on your product the species used in the seafood ingredients:

- ❑ Not important, we do not label fish species on our products
- ❑ Somehow important
- ❑ Important for traceability and transparency reasons

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3 What are the 2 most important attribute(s) when looking for a new source of fishmeal

- ❑ Sustainable label (MSC, Monterey Bay, WWF)
- ❑ Fish species for marketing claim
- ❑ Palatability
- ❑ Freshness
- ❑ Price
- ❑ Protein and ash content
- ❑ Locally sourced
- ❑ Other. Explain

10

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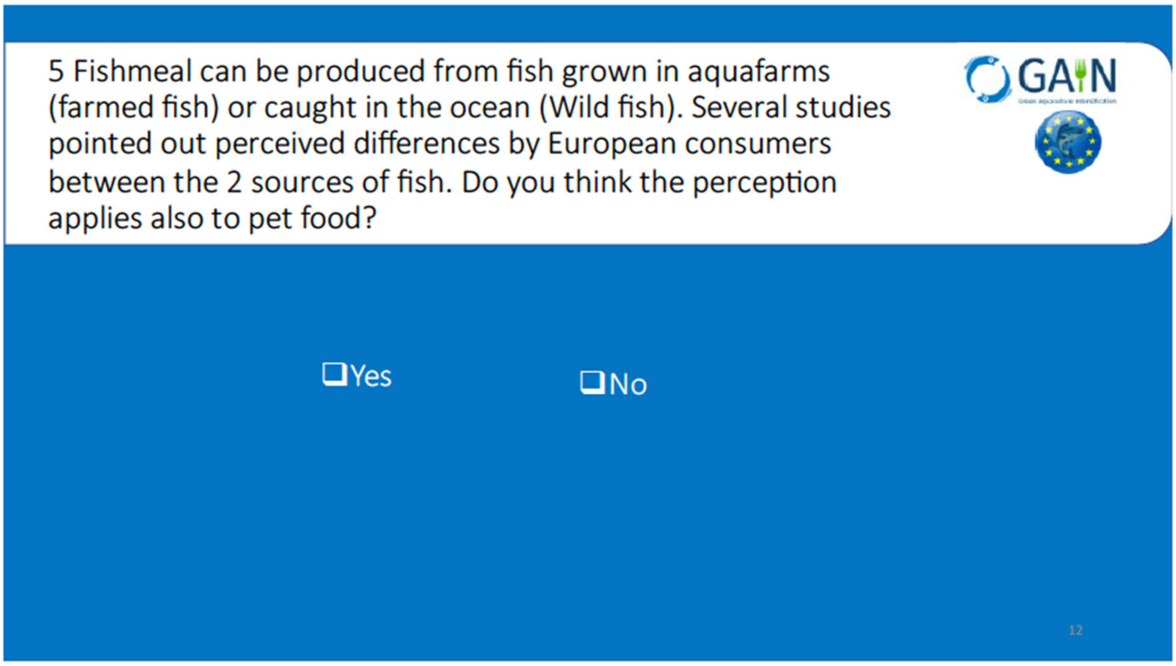

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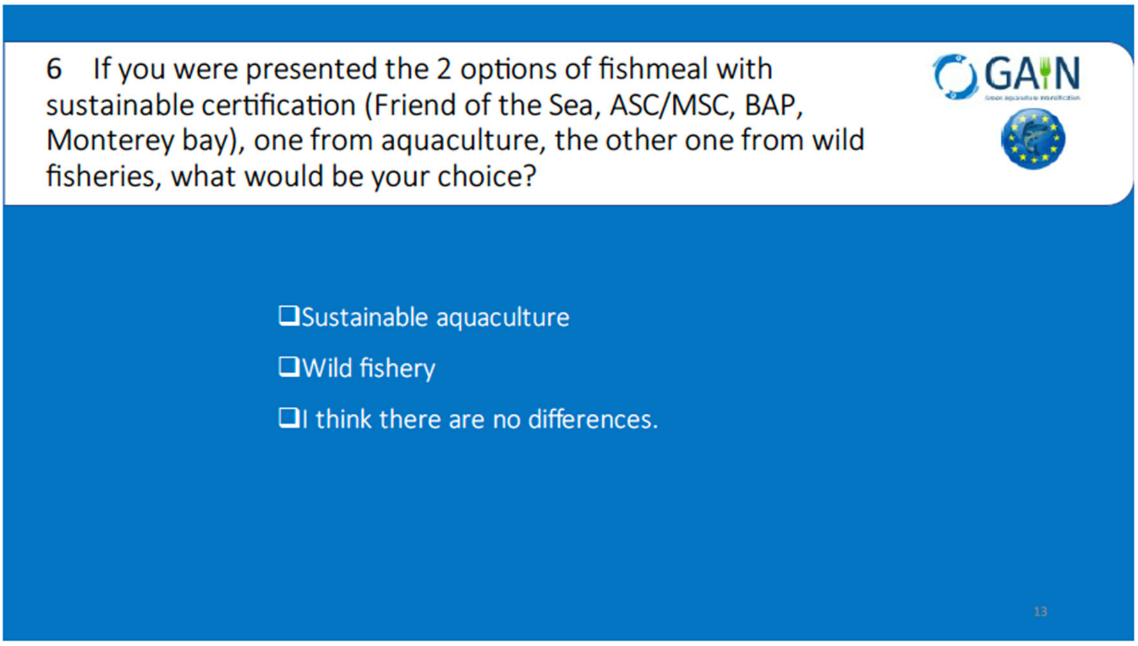

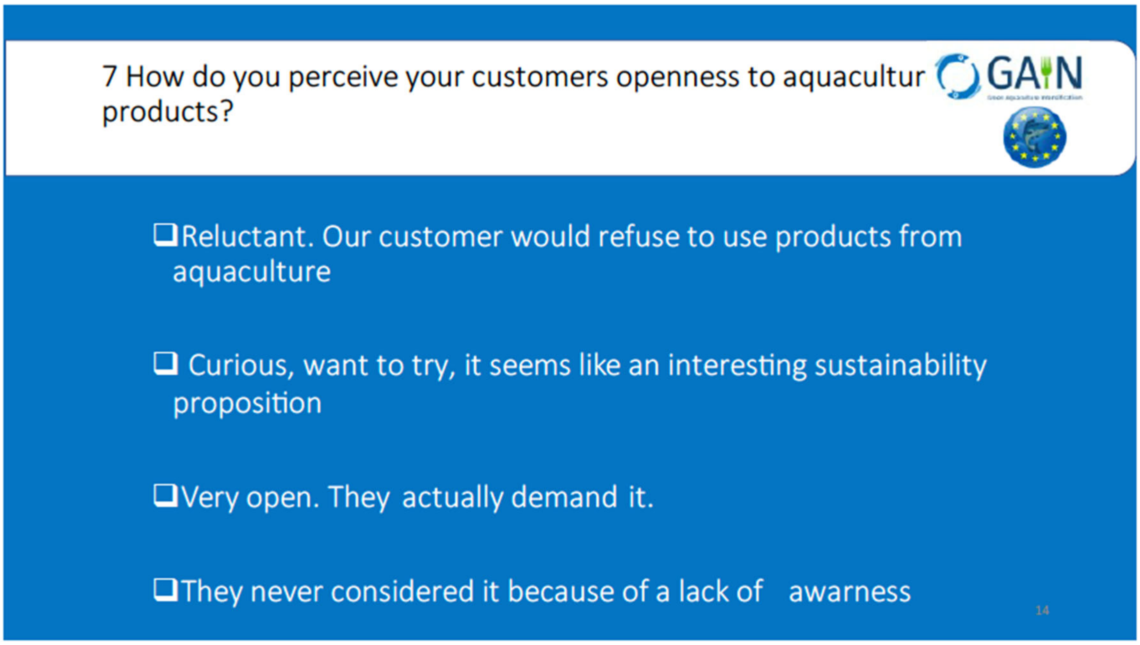

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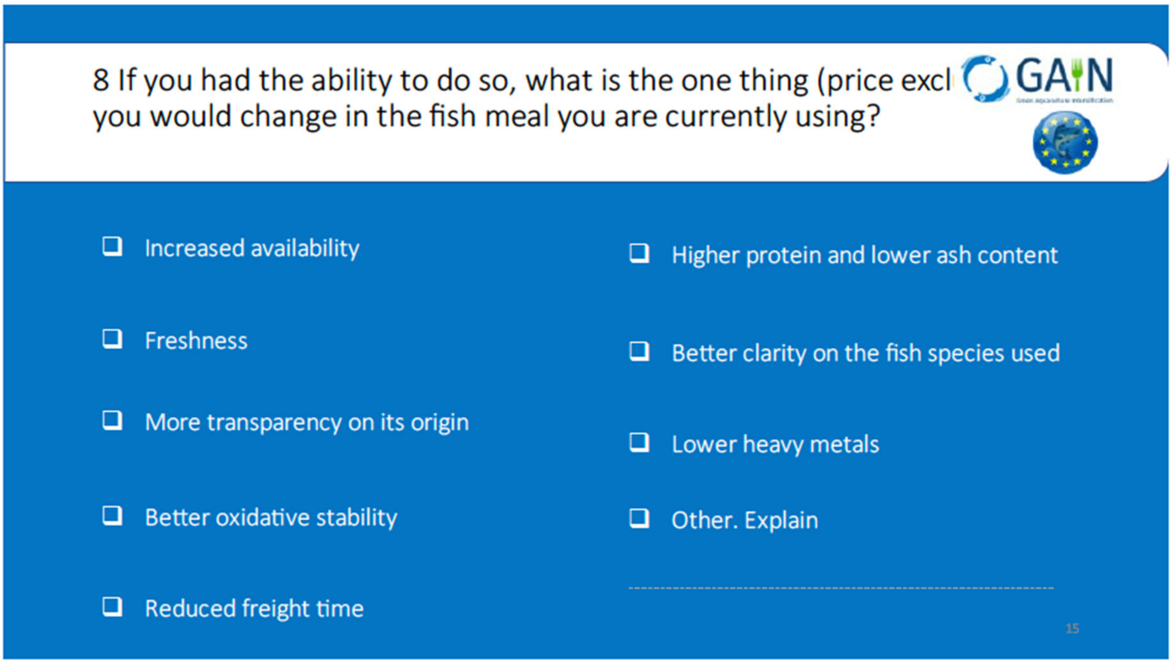

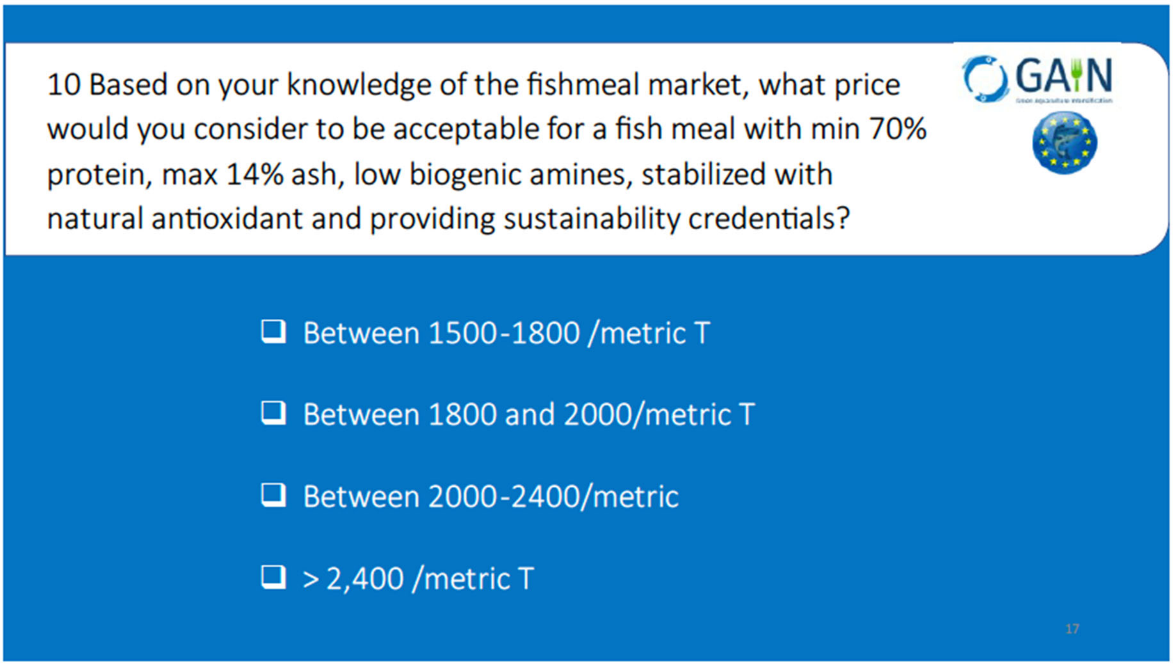

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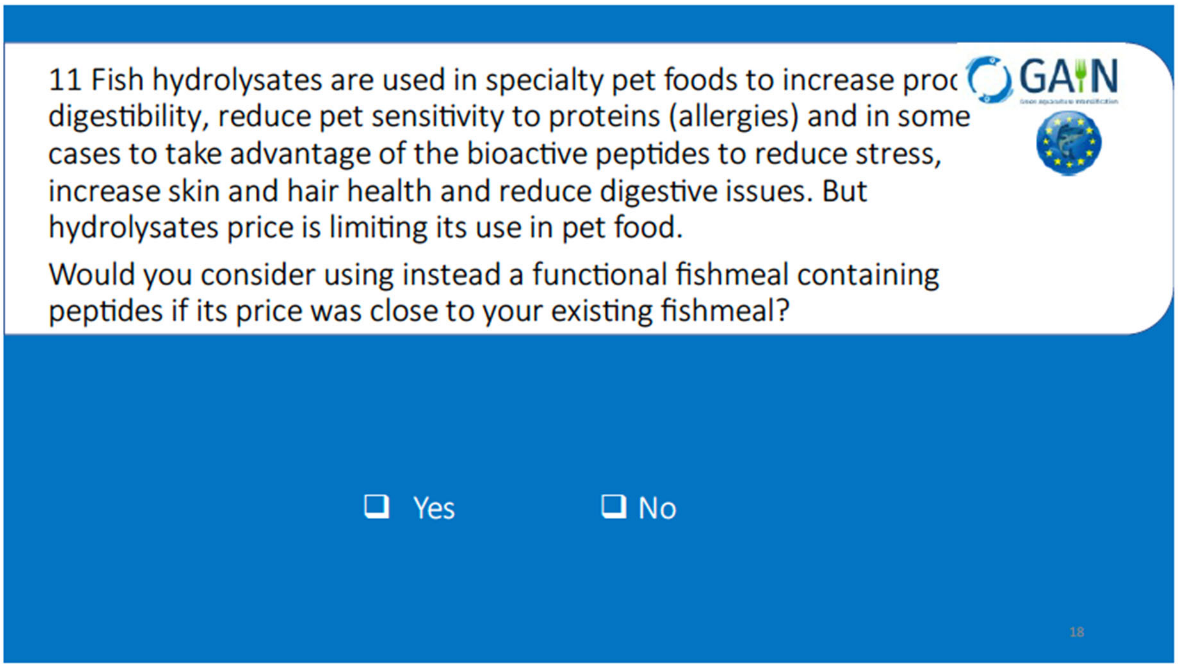

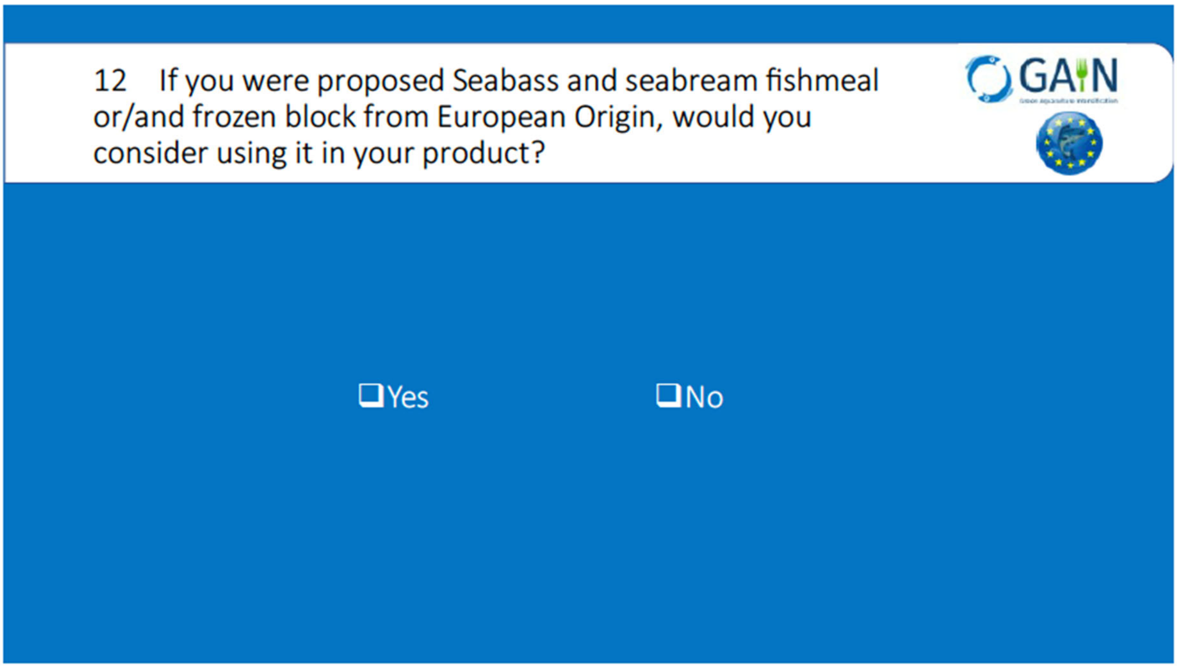

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13 What is your perception of these species when used in pet food?

- ❑ High quality
- ❑ Low quality
- ❑ High level of heavy metals and PCBs
- ❑ High quality
- ❑ Clean protein
- ❑ Good nutritional profile
- ❑ Sustainable
- ❑ Luxury image

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Thank You For Your Time

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Mackerel Recipe with Sea Bream	almo nature	Cat	Wet Food	HQS - High Quality Sourced. Complete and balance cat food made with the finest fresh ingredients. With added vitamins and minerals. Complete and Balance - Feed your HQS Complete 3 cans per day for every 8 lbs of bodyweight. Adjust as necessary for less active or more active cats. (70g can)	Mackerel, Water Sufficient For Cooking, Seabream, Sunflower Oil, Tapioca Starch, Calcium Sulfate, Potassium Chloride, Guar Gum, Magnesium Sulfate, Minerals (Zinc Oxide, Reduced Iron, Sodium Selenite, Manganese Sulfate Monohydrate, Copper Glycine Complex, Potassium Iodide), Taurine, Vitamins (Vitamin E Supplement, Niacin Supplement, Vitamin A Supplement, Vitamin B12 Supplement, Vitamin D3 Supplement, Calcium Pantothenate, Riboflavin Supplement, Pyridoxine Hydrochloride, Biotin, Folic Acid, Menadione Sodium Bisulfite Complex (Source Of Vitamin K Activity)).	
Mackerel with Seabream in Jelly	Applaws Natural Pet Food	Cat	Complementary Wet Food	Applaws Cat tins in jelly contain the same great ingredients you would expect from Applaws, but are gently cooked in a soft natural jelly made from human grade carrageenan (extracted from seaweed). Two oily fish are found in this mackerel with seabreem recipe making it an excellent source of natural Omega oils.	Mackerel 56%, Seabream 4%, Vegetable gelling agent	

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				(70g can)		
Chicken & Seabream Fish (Premium Plus Series	YI.HU Aristo-Cats (QIAN HU corporation Limited)	Cat	Wet Food	Japan Best Selling Formula Rich in DHA, Anti-odour & Taking care of Intestines Made in Thailand (80g can)	Chicken, Seabream, Polysaccharide Gum, Taurine, Vitamin E, Fructo Oligosaccharide, Water	
Seabream Pouch (Super Premium)	Brit Care	Cat	Complem entary	For beauty, health and vitality. Brit Care is made of natural, hypo-allergenic and highly digestible ingredients that do not overstress the organism, and prevents against food intolerances. Brit Care improves your cat's quality of life. Made in Czech Republic (80g pouch)	Seabream 46 %, Rice, Food Starch Modified, Tuna Crude Oil, Water	
Tuna with Seabream in Broth	Applaws Natural Pet Food	Cat	Complementary Wet Food	Applaws Cat Pouches are a convenient way to give your cat the highest quality meat protein. Two tasty fish are found in this Tuna with seabream recipe which can make it an excellent source of natural Omega oils (70g pouch)	Tuna Fillet 70%, Fish Broth 24%, Sea Bream 5%, Brown Rice 1%	

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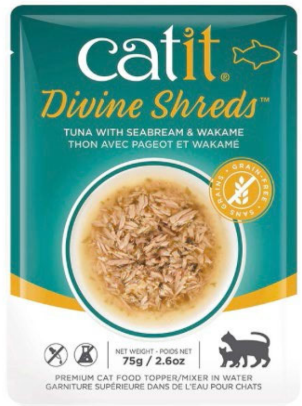
Tuna With Seabream & Wakame in Water	catit	Cat	Complementary Food	Premium cat food topper/mixer with tuna Natural, clean feeding with only 4 ingredients Rich in protein, low in calories Hydrating supplementary wet food No grains, additives, preservatives or by-products (75g pouch)	Water Sufficient for Processing, Tuna, Seabream, Dried Kelp	
Chicken Shavings With Rosy Seabass Cat Treats	Cattyman	Cat	Treats	Combination of Japanese famous chicken "Hakata-jidori" and high grade "Nodoguro" fish. Contains no preservatives or coloring agent. (30g)	Meat (chicken & chicken breast), flour, cornstarch, chicken fat, seared tuna, sorbitol, glycerin, minerals (calcium), phosphate (sodium).	

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Skipjack Tuna White & Chicken With Sea Bream	Daily Delight	Cat	Wet Food	The best white-meat fish from the Western Pacific Ocean! High in palatability and a healthy substitute for red meat! Offers a considerable amount of Vitamin B9, B12 and Calcium	Skipjack Tuna, Chicken, Seabream, Water, Rice, Lysine, Taurine and Vitamin E	
Mackerel With Tuna Fillet And Sea Bream In Broth Pouch	encore	Cat	Complementary pet food	75% Fish | Rich in Taurine | 100% Natural When you want to spoil your cat serve Encore – you can see the difference. Each pouch is filled with 100% natural ingredients and no artificial flavours or additives. This product is only available as part of a multipack. (70g pouch)	Mackerel 45%, Fish Broth, Tuna Fillet 20%, Seabream 10%, Rice	
Chicken Breast & Seabass	Grandorf	Cat		A completely natural wet food from selective meat fillet, gently cooked in its own broth. Ideal for cats with a sensitive digestion. Only meat and nothing superfluous – an excellent supplement to dry foods for a varied diet. (Multipack 6x70g)	65% chicken fillet, 10% seabass fillet, 24% own broth, 1% potato	

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Jelly Yellowfin Tuna With Seabream	Monge	Cat	Complementary Wet Food	It's a line totally dedicated to the natural feeding, only natural ingredients highly selected, very high quality, complementary food for cats with delicious tuna, product of Italy, with all the typical features of the high quality products: high palatability from freshness and good quality ingredients, with high nutritional content, rich in Omega 3, rich in proteins, with low fat content. These products are totally natural, in jelly, without preservatives and colorants, gluten free. Good for helping the cat to keep smart healthy shape, energetic, fresh all the time. Produced in Thailand (80g can)	Tuna (Thunnus Albacares) 47,5%, seabream (Nemipterus spp.) 5%, rice, F.O.S. (Fructo oligosaccharides)	
Sea Bass, Sardine & Shrimp	N&D Ocean/ Farmina	Cat	Wet Food	N&D Ocean Cat Sea Bass, Sardine & Shrimp Recipe is formulated to meet the nutritional levels established by the AAFCO Cat Food Nutrient Profiles for maintenance. 100% Satisfaction Guaranteed. Adult	Seabass, sardine, cod, sweet potatoes, shrimp, herring oil, fructooligosaccharide, calcium carbonate, potassium chloride, vitamin A supplement, vitamin D3 supplement, vitamin E supplement, menadione sodium bisulfite complex, choline chloride, zinc methionine hydroxy analogue chelate, manganese methionine hydroxy	

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				12x2.816oz	analogue chelate, ferrous glycine complex, copper methionine hydroxy analogue chelate, DL- methionine, taurine, L-Carnitine	
Fancy Feast® Natural Seabass & Shrimp Wet Cat Food In A Delicate Broth	Purina	Cat	Wet Food	A purely savory combination of natural seabass and shrimp, served in a delicate broth. Complete and balanced with vitamins and minerals for adult cats. Never any by-products or fillers. Product of Thailand	Fish broth, seabass, tuna, shrimp, sunflower seed oil, calcium lactate, tricalcium phosphate, guar gum, celery powder, choline chloride, salt, xanthan gum, taurine, MINERALS [zinc sulfate, ferrous sulfate, magnesium sulfate, copper sulfate, manganese sulfate, potassium iodide], VITAMINS [thiamine mononitrate (Vitamin B-1), Vitamin E supplement, niacin (Vitamin B-3), calcium pantothenate (Vitamin B-5), Vitamin A supplement, riboflavin supplement (Vitamin B-2), pyridoxine hydrochloride (Vitamin B-6), folic acid (Vitamin B-9), menadione sodium bisulfite complex (Vitamin K), biotin (Vitamin B-7), Vitamin B-12 supplement]. E-6401	

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Muse Creatables Natural Seafood Chowder Cat Food Complement	Purina	Cat	Food Complement	With Muse Creatables, you can mix and match a new favorite for your cat every day. Mix all three to make a meal or add any one to complement your cat's current wet or dry food. Made with real fish. Product of Thailand	Fish broth, seabass, scallops, sweet potato, milk powder, xanthan gum, guar gum. A-3784	
Tuna Fillet With Seabream in Broth	Reveal	Cat	Complementary Wet Food	The natural ingredients in a Reveal can make your cat really happy. Every portion is made with real protein and no artificial flavors or additives. (70g can)	Tuna Fillet, Seabream, Fish Broth.	
Savory Seafood Purrfect Broths	Rachael Ray Nutrish (The J.M. Smucker)	Cat	Wet Food	Savory Seafood Recipe with real flaked seabass, shrimp & veggies in a delicious broth. (1.4 oz pouch)	Fish Broth, Tuna, Seabass, Shrimp, Carrots, Pumpkin, Fish Extract (Natural Flavor), Guar Gum, Xanthan Gum.	

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Tuna With Seabass	Schesir	Cat	Wet Food	The top of natural quality, in tasty jelly. Only the best parts of the fish, steamed and processed by hand, with preparation in tasty jelly. Adult, Short Coat (85g can)	Tuna 51%, Seabass 6% Rice 1.5%	
Tuna With Seabass	Schesir	Cat	Wet Food	Top quality food for adult cats in soft jelly: with 100% natural ingredients, free from added colorings and preservatives. Careful selection of the very best parts of the fish, steam-cooked and hand-processed. Adult, Short Coat (50g pouch; 100g pouch, Multipack 6x50g)	Tuna 57% Seabass 5% Rice 1.5%	
Tuna with Seabass in natural gravy	Schesir	Cat	Wet Food	Top quality food for adult cats in natural gravy, enriched with tapioca starch: with 100% natural ingredients, free from added colorings and preservatives. Careful selection of the very best parts of the meat, steam-cooked and hand- processed. Adult, Short Coat (70g can)	Fish (tuna 57.4%, Seabass 5.7%) Tapioca starch 1.4%	

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Tuna With Seabream	Schesir	Cat	Wet Food	The top of natural quality, in natural jelly. Only the best parts of the fish, steamed and processed by hand, with preparation in tasty jelly. Adult, Short coat (85g can)	Tuna 51% Seabream 6%,Rice 1.5%	
Tuna With Seabream In Natural Gravy	Schesir	Cat	Wet Food	Top quality food for adult cats in natural gravy, enriched with tapioca starch: with 100% natural ingredients, free from added colorings and preservatives. Careful selection of the very best parts of the meat, steam-cooked and hand- processed. Adult, Short Coat	Fish (tuna 57.4%, seabream 5.7%) Tapioca starch 1.5%	
Tuna With Seabream	Schesir	Cat	Wet Food	Top quality food for adult cats made with 100% natural ingredients, free from added colorings and preservatives. Careful selection of the very best parts of the meat and the fish, steam-cooked and hand-processed. In broth. Adult, Short Coat (70 g can or	Fish (tuna 70.5%, seabream 4.2%) rice 1.4%	

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				70g pouch)	Fish (tuna 56%, seabream 4%), Rice 3%	
Tuna With Seabream	Schesir	Cat	Wet Food	Top quality food for adult cats in the convenience format 50g pouch: careful selection of the very best parts of the fish, steam- cooked and hand-processed, in soft jelly. With 100% natural ingredients, free from added colorings and preservatives. Adult, Short Coat (50 g pouch; 100g pouch; Multipack 6x50g)	Fish (tuna 55%, seabream 4%), Rice 1,5%	

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Tuna With Seabream	Schesir	Cat	Wet Food	Top quality food for adult cats made with 100% natural ingredients, free from added colorings and preservatives. Careful selection of the very best parts of the meat and the fish, steam-cooked and hand-processed. In broth. Adult, Short Coat (70g can)	Chicken fillets 70.6% Fish broth 23.8% Seabream 4.2% Rice 1.4%	
Chicken Fillets With Seabass	Schesir	Cat	Wet Food	Top quality food for adult cats in the convenience format 50g pouch: careful selection of the very best parts of the fish and of the Chicken, steam-cooked and hand-processed, in soft jelly. With 100% natural ingredients, free from added colorings and preservatives. Adult, Short Coat (50g pouch or 100g pouch)	Chicken fillets 75% Seabass 4% Rice 1.5%	

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Bonito Tuna & Seabream Recipe In A Savory Broth	SA-SHI Simply 4 ingredients	Cat	Wet Food	Fish is the First Ingredient, Not Water 10% of Our Profits are Donated to Service Animals NO Xanthan Gum NO Guar Gum NO Carrageenan Gum Dolphin & Turtle Safe Grain Free (50g pouch)	Bonito Tuna, Fish Broth, Seabream, Tapioca Starch	
Tuna & Seabass with Shrimp Recipe in Broth	Simply Nourish	Cat	Complementary Food	Simply Nourish Tuna & Seabass with Shrimp Recipe in Broth Grain Free Meal Topper is made with real seafood, and is the perfect complement for your cat's food. Your kitty will love the great taste of this topper and its ability to make an already tasty meal simply delicious. Adult (56 g pouch)	Tuna Broth, Tuna, Seabass, Shrimp, Tapioca Starch, Sunflower Oil, salt, Guar Gum	

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Five Oceans Seabream & Tuna Recipe in Gravy	Solid Gold	Cat	Wet Food	A holistic food with natural ingredients, vitamins, minerals and amino acids your cat is sure to go crazy over! Grain and gluten free, this wet cat food is crafted with a carefully balanced combination of ingredients including seabream, tuna, and tapioca and served in a gravy your cat will love. This seabream and tuna recipe is a nutritionally complete and balanced meal, perfect for adult cats and growing kittens. May also be served as an accompaniment to dry food or as a tasty treat. Your cat will be ready to explore the five oceans as they unleash their inner gold! (170g can)	Water Sufficient for Processing, Seabream, Tuna, Tapioca, Canola Oil, Tricalcium Phosphate, Xanthan Gum, Taurine, Choline Chloride, Vitamin E Supplement, Zinc Oxide, Thiamine Mononitrate, Manganese Sulfate, Vitamin A Supplement, Menadione Sodium Bisulfate Complex (Source of Vitamin K), Riboflavin Supplement, Pyridoxine Hydrochloride, Folic Acid, Vitamin D3 Supplement.	
Oahu Luau Seabass	Tiki Cat	Cat	Wet Food	Flaked seabass with olive oil, rich in essential fatty acids, in a savory consommé	eabass broth, seabass, mackerel, sunflower seed oil, dicalcium phosphate, olive oil, calcium lactate, potassium chloride, taurine, salt, choline chloride, magnesium sulfate, ferrous sulfate, thiamine mononitrate (vitamin B1), vitamin E supplement, niacin (vitamin B3), zinc oxide, vitamin A supplement, biotin, vitamin B12 supplement, copper amino	

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					acid chelate, manganous oxide, calcium pantothenate, riboflavin supplement (vitamin B2), sodium selenite, pyridoxine hydrochloride (vitamin B6), folic acid, menadione sodium bisulfite complex (source of vitamin K activity), potassium iodide, vitamin D3 supplement.	
Poesie Colours Chicken & Sweetcorn with Seabream in Gravy	Vitakraft	Cat	Wet Food	Taste that melts in the mouth – deliciously tender, bite by bite: fluffy, whisked mousse in enticing flavours. A balanced diet is one of the most important factors for a cat to lead a healthy life. Poésie® not only perfectly meets the needs of adult cats, the delicious varieties also indulge your kitty with irresistibly good taste. A poem for every cat! Your cat will sense that you've chosen the very best for it – bite by bite. Poésie – just the right portion of love and affection, every day. For a loving relationship that lasts a cat's lifetime. (70g can)	Water. Chicken. Sweet corn. Seabream. Modified Tapioca starch. Sunflower oil. Mineral(Dicalcium phosphate. potassium chloride. sodium chloride. magnesium sulphate). Xanthan gum. Vitamin mix (Vitamin C. Thiamine mononitrate. Vitamin E. Niacin. Pantothenic acid. Riboflavin. Pyridoxin hydrochloride. Folic acid. D.biotin. Vitamin B12 [Cyanocobalamine]. Vitamin A [Retinyl acetate]. Vitamin D3 [Cholecalciferol]. Zinc.Chelate. Iron.Chelate. Manganese Chelate. Calcium Iodate. Sodium Selenite). Choline chloride. Taurine. Sodium EDTA. Copper Proteinate	

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N&D Ocean Seabass & Squid	Farmina Pet Foods	Dog	Wet Food	N&D Ocean Dog Sea Bass & Squid Recipe is formulated to meet the nutritional levels established by the AAFCO Dog Food Nutrient Profiles for maintenance. 100% Satisfaction Guaranteed. (285g can)	Seabass, cod, herring, squid, sweet potatoes, herring oil, shrimp, fructooligosaccharide, calcium carbonate, potassium chloride, chondroitin sulfate, glucosamine hydrochloride, vitamin A supplement, vitamin D3 supplement, vitamin E supplement, choline chloride, zinc methionine hydroxy analogue chelate, manganese methionine hydroxy analogue chelate, ferrous glycine complex, copper methionine hydroxy analogue chelate, selenium yeast, DL- methionine, taurine, L- Carnitine	
Tuna With Seabass	Schesir	Dog	Wet Food	All the high Schesir quality, with 100% natural ingredients, no preservatives or colourings and only the very best parts of meat of the same quality as those used for human consumption in the 4x85g small doses format: for small breed dogs and for dogs loving taste small doses of different flavors. Adult (Multipack 4x85g)	Fish (tuna 48%, seabass 4%) Rice 1.3%	

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100% Pure Seabass Snax Stix	Akela	Dog	Treats	Grain& Gluten-Free, Low Fat; High in Fish Oil; Hypoallergenic 100g	100% Seabass	
Seabass With Wildrice Bakes	Dog gone fishin’	Dog	Treats	Wholesome baked treats made with nutritious Seabass and Wild Rice. Healthy low calorie snack, reward or training treat dogs just love.	Seabass 45%, white fish, dried potato startch, wild rice 4%, dried potato fibre, dried herb powder	
Pure Seabass Sticks	JR PET PRODUCTS	Dog	Treats	JR’s 100% natural pure seabass fish sticks for dogs are not only a delicious treat but they’re healthy too. Ideal for dogs of all breeds and sizes, they’re a great source of protein and essential Omega-3 fatty acids. 50g	100% Seabass	

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Pure Seabass Training Treats	JR Pet Products	Dog	Treats	JR's pure range of training treats for dogs now includes Seabass. Naturally healthy and totally irresistible, they're very popular thanks to the fact they're all 100% pure fish. JR's pure training treats come in handy bite size pieces and are perfect for any size dog. Claims to be hypoallergenic	100% Seabass	
Chicken With Seabass	Canagan	Cat	Wet Food	Chicken with seabass is for all lifestages. Tender shredded Chicken with Seabass, simply cooked in its own natural gravy. Canagan is a highly nutritious complete food for cats that can also be used to accompany dry food. We use chicken breast meat without the skin for all our wet chicken foods	Chicken Breast (58%), Chicken Broth (31%), Seabass (5%), Sunflower Oil, Thickening Agent (Tapioca) and Minerals.	

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