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Innovative uses of fisheries by-products

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Innovative uses of fisheries by-products

by

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This report looks at the generation and management of fish by-products resulting from the primary production process that is undertaken by the fish processing industry. Different by-products are generated in different countries and some specific cases are highlighted, in particular, in Norway, Mexico, France and China, among others. A consideration of the utilization and marketing of processed by-products generated by the seafood industry forms the core of the report and covers the range of options from waste disposal to the production of value-added products that present income-generating market opportunities. Market opportunities for specific resources, such as those generated from tilapia, shrimp and other crustaceans, catfish and mussels are detailed. Future trends include the identification and utilization of a variety of compounds such as oils, proteins, pigments and minerals that could be used as fertilizers, nutraceuticals and various food ingredients. Finally, the regulation of by-products, their usage and disposal is addressed.

Layout: Gloria Loriente
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FOREWORD

Numerous persons and institutions, too many to be named individually, contributed their valuable time and knowledge towards the successful completion of this report. Nevertheless, the support given by Michaela Archer from Seafish (UK), Xiaoshuan Zhang from China Agriculture University and Audun Lem from FAO should be pointed out.

As fisheries and aquaculture by-products are generated all around the world, it is impossible to make a compilation without the inclusion of the work of many professionals who have been studying these products in order to have a better understanding of them and to foresee higher returns from their processing. So, with the proper quotation their work has been included, trying to keep the original meaning.

The report does not claim to be exhaustive, nor does it claim to cover all relevant products and specifications available on the market. While steps have been taken to ensure accuracy, the author cannot accept responsibility or be held liable to any person for any loss or damage arising out of or in connection with this information being inaccurate, incomplete or misleading. It is the responsibility of the potential user of a material or product to consult with the supplier or manufacturer and ascertain whether a particular product will satisfy their specific requirements. The listing or featuring of a particular product or company does not constitute an endorsement by the author who cannot guarantee the performance of individual products or materials.

1. INTRODUCTION

1.1. CONCEPTS

There is a wide range of names for the secondary products in the fish processing industry: for example, if the main aim is to produce fillets, then the rest of the fish such as the head, guts, skin, internal organs, bones, gills, and others are regarded as the secondary products, which also could be named co-products, by-products, waste, offal and so on. These names are related more to the process being undertaken than to the actual quality, because in general, if the fish is in good condition, the whole fish is edible. In other words, it is during processing that these parts are converted to non-human consumption or other quality reduction products. If the processor keeps and treats the secondary product in the same way as the main one, it will retain its edible and premium quality condition. Tradition has also played a role and many times all the secondary products are listed as non-edible.

There is, however, confusion in the way different authors and agents deal in and name these products, so for the purposes of this publication, co-product and by-product are used with the same meaning, that is, secondary products that could be used for human consumption. Nevertheless there are some that are not intended for food such as mussel shells, or fish skin. The word ‘waste’ is normally used for non-human consumption, however, in this publication the meaning could be used for edible products as well, depending on the terms used by the primary processor.

By-products information in terms of quality, quantities and prices is not readily available and has been gathered from many sources that emphasise different aspects such as origin, the market place, the final product, research done to obtain it, among others. In order to make the information clearer and more accessible, it has been presented case by case according to resource, country or region or final product, whichever is the more relevant, while not repeating the data.

1.2. PRICES

When discussing prices of by-products prices in the development of a new business it is quite difficult to calculate a realistic figure. Often the primary processor has to pay for transport and landfill to get rid of what for him is an undesirable by-product. Thus, if he has the opportunity to pass this product on to a secondary processor, he may not make a charge for it. However, if the primary processor perceives that the additional value given to the by-product by the secondary processor is leading to a viable business opportunity he may consider charging for the by-product and therefore an agreed price may be reached. This final price is very difficult to predict at the beginning when it is a cost for the primary processor and the success or failure of the added value process cannot be determined.

1.3. TRADE

In general, exports from developing countries are usually in the form of frozen products. This may be a result of the nature of the exported product but in some cases increased customs taxes in developed countries have inhibited the growth of more value-added products in the developing countries (Kurien, 2005).

1.4. WATER

As processing plants use water in significant quantities, mainly for cleaning and cooking operations, the effluents might be important sources of organic material that could be further utilized. However, a survey done in the UK (WRAP), where indicative results for water usage were obtained for specific areas of seafood processing, notably white fish, crab and scallop processing, showed a high level of variability and further work would be required to establish the real quantities utilized. The high variability observed has prevented an estimation of quantities and the economic implications of liquid effluents for the industry in general and the focus is on the more quantifiable solid ones. The exception is the amount of research undertaken on the effluent from surimi, where the water utilized is around 25 times the amount of surimi produced.

Other operations involved in fish processing, such as washing, thawing and cooking generate aqueous effluents that are normally discarded. Wastewaters produced by the industry may have a very high organic load as a result of proteins, oils and suspended solids (0.5–20 g/l). Therefore, they should be discharged with proper treatment, preventing negative impacts and allowing the recovery of high added value products (Bergé, 2009).

1.5. BY-PRODUCTS ON LAND

Fish processing companies employ raw fish as raw material to be processed in order to obtain a final product with higher commercial value. Several operations are involved in fish processing such as heading, gutting, filleting, removing tails and peeling. These operations generate many by-products, including heads, viscera, tails, skins, shells and fins that are not put on market because of their low acceptance by consumers or because sanitary regulations prohibit their use in human foods.

1.6. DISCARDS

From a study conducted in 2005, it has been estimated by the Food and Agriculture Organisation (FAO) that around 7.3 million tonnes of whole fish (around 8 percent by volume of the global catch) is discarded worldwide every year in commercial fisheries. Based on previous FAO studies, current estimates suggest a reduction in discards and discard rates at the global level (Kelleher, 2005). As these discards are normally not landed, they are not considered in the present report.

1.7. SUPPLY OPPORTUNITY

The main commercial fisheries and aquaculture products have specific seasons and the food market place is accustomed to them. For example, farmed coho salmon is harvested in Chile in spring and summer, so the market is supplied from November to March. The consumer is aware that in any other period of the year the product has been stored for a longer time.

If coho by-products are transformed into a raw material for the cosmetic industry, collagen for example, the process should be done in the harvesting season, but the material must be available for the cosmetic industry time schedule, which might be completely different from the time of harvesting, thereby requiring the by-product industry to cover these opportunity differences by keeping additional stock of final or intermediate products, which in turn could affect their economic feasibility.

1.8. ADDITIONAL ECONOMIC IMPLICATIONS

When a farmer is considering moving or increasing farming and processing areas for economic reasons, by-products utilization should be considered too, among other variables such as labour, water temperature and site licenses, which are more directly related and inherent to aquaculture. This is apparent for the case of Spanish mussel growing companies moving their growing and canning operations to Chile, where the cooking juices process is still to be developed on the required scale. In this case these by-products represent more an environmental issue rather than a market opportunity.

1.9. DEMAND ORIENTATION

In the last 20 years the use of fishmeal and fish oil has gone through a dramatic change resulting from the many adjustments that the market and industry have had to face:

- Supply restrictions. As wild catch seems to have reached a plateau and there is increased pressure to use it for direct human consumption, the direct production of fishmeal and oil out of round fish seems to have reached a maximum, and will probably decline in the future.
- Process limitations. The traditional oil hydrogenation to increase its melting point and allow its use for margarine production has been reduced to a minimum because of the generation of trans fats, which have a detrimental effect on cardiovascular health.
- Flavour. When fishmeal was the cheapest high quality protein available for animal feeds, growers used it extensively, which affected the taste and flavour of the final products, mainly poultry and pork. This was intensified when the meal (FAQ) was produced using direct combustion gases for drying.

1.10. TRADE CONDITIONS

Trade conditions have a paramount importance for by-products industry development. For example, the Norwegian salmon industry, not being in the European Union, has been restricted by EU trade regulations when exporting headed and gutted (HG) or just gutted salmon to the EU, because of concerns for its own fish processing industry. For this reason and also because the quantities of by-products are small, the industry has developed more sophisticated applications compared with fishmeal, such as salmon hydrolysates.

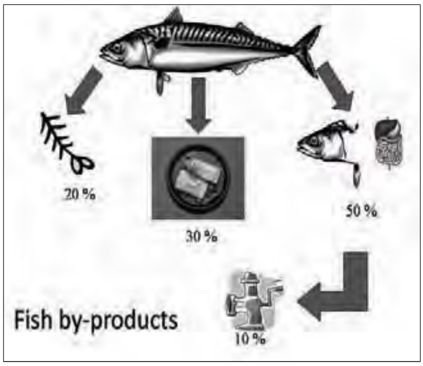
In contrast, the Chilean salmon industry, forced by the distance to its main market, the USA, has reduced shipment weights, which have a direct influence on fresh salmon airfreight transport costs. This reduction has been made possible by the development of the edible part (just the fillets) market. This meant that huge quantities of by-products were left behind that had to be been dealt with as salmon meal and oil production. This might not be the best economical solution, but is the most practical way to handle volumes similar to the volumes being exported.

2. BY-PRODUCTS GENERATION AND MANAGEMENT

2.1. INTRODUCTION

Figures 1a and 1b. By-products generation

Source: Archer, 2001.



Source: Roy, 2001.

As is true for all edible animal species, the whole fish contains a high quantity of non-edible content in relation to the quality and amount that is presented to the final consumer. For cod in Norway it could be 58 percent, but molluscs, crustacean and shellfish in general have a much higher proportion, for example, 88 percent for scallops. The removal of the part not suitable for consumption should be done at some point in the supply chain. The process industry depends largely on the kind of raw material it handles, where round fish may imply huge quantities of by-products, while fillets may generate a minimum or insignificant amount of waste (James, 2011).

Primary or secondary processors are very different from each other, which makes it extremely difficult to obtain a global standard for the whole industry. Even for a single processor it is difficult to ascertain which quantities correspond to which raw material. Only one species processor was able to provide reliable information that could be adopted for the whole industry, but this is not common and in general the information should be considered as an aggregate (James, 2011).

There is wide variability in terms of producing countries or regions. For example, Thailand and Viet Nam are the second and third largest exporters in Asia. Thailand has established itself as a processing centre of excellence largely dependent on imported raw material, whereas Viet Nam has a growing domestic resource base and imports only limited, albeit growing, volumes of raw material. In both countries, the processing industry contributes significantly to the domestic economy through job creation and trade.

2.1.1. Processing at sea

Most species of white fish undergo some processing at sea. Seafish's 2001 waste study (Archer, 2001) provided estimates on the ratio of gutting waste according to the species. For cod, it can vary between 8 and 22 percent of the whole weight of the fish, but it is typically around 16 percent. There are no published ratios for other white fish species, so the figure for cod is generally applied to all white fish. Nevertheless, these by-products, being easily perishable, need to be stabilized immediately by freezing. Only livers and eggs from some species, such as sharks and monkfish, have enough commercial value to be sold on land. Therefore, most of the wastage generated on board is discarded to the sea (Bergé, 2009).

Pelagic and shellfish generally do not receive any processing at sea apart from a proportion of the nephrops catch, which typically have their head and claws removed to be discarded at sea. In the case of Argentina though, scallops are shelled at sea and the shells returned to it to allow for spat collection (J. Torre, personal communication, 2012).

2.1.2. By-products generation control

The industry is keen to obtain the maximum edible yield, without compromising quality, but in certain cases different processes are applied for specific purposes, for example, with salmon fillets where the amount of fat is recognised in the trim denomination. Trim E, for example, is skinned and has no fat whereas trim A is the opposite, with a much higher yield from the whole fish. In other forms of control, retailers train staff to handle fish, avoiding the raw material falling on the floor, and using lower quality fish in alternative products (James, 2011).

Retailers also handle by-products generation through market strategies such as special offers on a certain days (Friday for fish), or discounts to members of staff. Other mechanisms include good logistics by having proper control of stock ordering, optimising the way in which the products are displayed to the clients and having frequent and complete monitoring of warehouse and display temperatures (James, 2011).

2.1.3. CONVERSION FACTORS

It is possible to estimate the by-products generated by a specific resource utilising conversion factors. The Coordinating Working Party on Fishery Statistics, with advice from FAO, has developed a set of conversion factors, which appear in the Handbook of Fishery Statistical Standards (CWP, 2002) indicating the relationship between the final product and original live fish weight, information that could be used to determine by-products quantities as a whole. There is more specific information in the conversion factors developed by Ofimer in France, which indicate the proportion of each by-product, including guts, heads, liver, bones, skin and fins, and for certain species giving even a relationship with size (Andrieux, 2001).

2.2. BY-PRODUCTS FROM SPECIFIC COUNTRIES

2.2.1. Norway

Norway is a special case with regard to by-products because it has an institution called RUBIN, which is a foundation established in 1992, working for increased and more profitable utilization of by-products from the fisheries and fish farming in that country. The data indicated here are mainly from their web site (www.rubin.no).

By-products from Norwegian fisheries, included fish farming consist of viscera (liver, roe, stomachs, etc.), heads, backbones, cuts and rejected fish from processing. The by-products are generated when the fish is gutted, headed and further processed - either on-board fishing vessels or in processing plants on shore. The Norwegian fisheries produce about 800 000 tonnes of by-products annually (2009), which is 24 percent of all the fish caught and farmed in Norway. Today most of the by-products are used as raw materials for feed production, such as fishmeal and silage. About 180 000 tonnes are still dumped into the sea, mainly by the fishing fleet. The total value represents between NOK 1.5 and 2.0 billion.

Table 1. Utilized resources (by-products) in 2011 (tonnes/year)

Resource	Cod	Pelagic	Farmed fish	Shrimp	Crab	Total
Utilized	108 000	231 000	275 000	5 500	500	620 000
Dumped	181 000	7 000	-	4 500	4 000	196 500
Rounded sum	289 000	238 000	275 000	10 000	4 500	816 500

Source: Rubin, 2011.

The by-products (620 000 tonnes in 2011) produced in Norway are utilized in different uses and applications:

Table 1. By-products applications in Norway, 2011 (tonnes/year)

Applications	Cod	Pelagic	Farmed fish	Shrimp	Crab	Total
Meal	26 000	143 000		1 000		170 000
Silage	10 000	84 500	155 000			249 500
Raw silage for fur animals			500			500
Frozen or fresh silage for fur animals	22 000	500	1 000			23 500
Fresh Oil			75 000			75 000
Human Consumption	50 400	3 000	14 000		500	67 600
Hydrolysate and oil			30 000			30 000
Chitin, Chitosan				3 000		3 000
Diverse				1 500	1 500	
Rounded sum	108 400	230 800	275 000	5 500	500	620 200

Source: Rubin, 2011.

2.2.2. Argentina

The main fisheries in Argentina that generate by-products are langoustine (Argentine red shrimp), squid, hubbsi hake and hoki hake. The first one has been relatively stable in quantities, although prices have suffered an increase as a result of market variations, but by-products have been stable. For squid there has been a small reduction because the market is receiving more whole mollusc than tube; the opposite has been true for hake where the market prefers fillets over H&G (Dirección de Economía Pesquera, 2011).

Fishing boats in Argentina land fresh and frozen products. The first ones are processed on land, giving the by-products to one of the three fishmeal plants available, two private and the third one a cooperative. The main species is hake, plus a few quantities from other species. The fishmeal plants do not pay for the raw material and even the primary processors have to pay for transport. Langoustine by-products were processed in the past, but now go to landfills; probably this is due to uneven supply (J. Torre, personal communication, 2012).

In 2009 exports of fishmeal and fish oil were 37 487 and 1 015 tonnes, respectively, coming from white fish, mainly hake, by-products processing (Dirección de Economía Pesquera, 2011).

2.2.3. Mexico

In Mexico logistics play a central role. Tuna plants send most of their offal to fishmeal plants, whereas for the rest of the industry, their location on the coast makes it very difficult to assemble the wide variety of by-products for further processing. Away from coastal areas, artisanal articles are made from tilapia skins and shark skin is used for shoes and belts, and there is some interesting research being undertaken on collagen from giant squid (*Dosidicus gigas*) (Torres-Arreola, 2008).

In the case of shellfish, shrimp heads, the main by-product, are converted into meals for human or animal consumption, while the oyster shells are ground and returned to the sea to increase calcium levels.

Studies done in the North West, where most of the fishing takes place, have concluded that, although further processing could be promising, the quantities are not sufficient to make the cost of transporting them worthwhile. If processing takes place on the boats it normally means that the by-products end up in the sea, and the plants cannot gather enough material to justify further processing (M.T. Viana, personal communication, 2012).

Official statistics show that the raw material coming from by-products for fishmeal production amounted to 75 771 tonnes in 2008 (CONAPESCA, 2008).

2.2.4. France

The producers of by-products are wholesale fish merchants, smokers and canners and in 2002 they produced 150 000 tonnes of internal organs, heads, bones and skins, starting from 320 000 tonnes of fish. A first estimation of the quantities of by-products generated in Metropolitan France by the fisheries sector was initiated using data from the output of primary processing and transformation of twenty-nine fish species used in France, namely 14 white fish species (including cod, plaice, whiting and haddock), six blue fish (herring, mackerel, sardine, tuna,), two salmonids (salmon and trout) and seven cartilaginous fish (including dogfish and shark).

The results were extrapolated to include all fish species subjected to primary processing or transformation in France and French territories. The gross tonnage of fish giving rise to by-products was estimated at 320 000 tonnes in 2002. The tonnage corresponding to by-products was estimated at 150 000 tonnes, that is to say 47 percent of the gross tonnage. There are three major producers of by-products: wholesale fish merchants, smokers and canners. The wholesalers and primary processors, which work mainly white fish (120 000 tonnes) and cartilaginous fish (25 000 tonnes), generate more than 50 percent of by-products from the gross products that are used. The smokers primarily use salmonids (44 000 tonnes) while the canning facility focus on blue fish (61 000 tonnes). These two respectively generate 31 percent and 48 percent of by-products from the gross products that are used (Andrieux, 2004).

The work done in 2002 by Ofimer, was updated in 2005 by Ifremer. These results are shown in the following table:

Table 3. French fish procesing by-products 2005

Group	Raw Material	Heads	Viscera	Fishbones	Skin	Fins	Total by-products
White Fish	73 183	20 099	6 096	15 587	2 394	0	44 176
Cartilaginous	16 803	1 966	2 671	2 288	543	2 717	10 185
Salmonids	90 129	8 618	12 182	16 299	5 581	0	42 680
Pelagic	249 935	53 982	33 651	24 612	5 581	0	117 826
Total	430 050	8 4665	54 600	58 786	14 099	2 717	214 867

Source: Bergé, 2009.

For the same year that the by-products were calculated (2002) where the fish processed was 320 000 tonnes generating 150 000 tonnes of by-products, the final destinations were:

- 80 000 tonnes for reduction to 15 000 tonnes of fishmeal and 5 000 tonnes of fish oil.
- 30 000 tonnes for hydrolysis, giving 6 000 tonnes of hydrolysate.
- 33 000 tonnes for fish mince.
- 2 200 tonnes transformed into aromatic products.
- 4 800 tonnes used for gelatine, chondroitin sulphate, chitin, chitosan, collagen, leather, etc (Andrieux, 2004).

The main constraint on a stronger incorporation in dietary and nutraceutical markets is due to French Food Regulations, which are more restrictive than those of other European countries (Bergé, 2009).

2.2.5. Spain

It seems that the well- established tradition of buying whole or only gutted fish has prevented the development of waste management solutions, and it is most likely that mortalities from farms are dumped or used for tuna ranching and bait for other species. In the case of seabass and seabream from aquaculture, these are sold round or whole, so the waste is generated by the retailers or by the final clients (Mack *et al.,* 2004).

2.2.6. China

Aquatic product processing in China can generate a considerable quantity of waste, depending on the general eating habits and processing methods of aquatic products. These technologies not only waste resources but also cause pollution of the environment. In order to improve the resource utilization, it is important to strengthen research and development on aquatic product waste. The main by-products, made up of fish head, bones, skin, fins, internal organs and scale, shrimp head, shrimp skin, the shrimp, shells, are shown in the following table (X. Zhang, personal communication, 2012):

Table 4. Aquatic products output of 2010 in China

Kinds	Annual production (ten thousand tonnes)	Inedible rate (percent)	Waste quantity (ten thousand tonnes)
Fish	3 132	40	1 252
Prawn and crab	558	50	279
Shellfish	1 223	73	892

Source: X. Zhang, personal communication, 2012.

Fish by-products are used to produce fish oil and fishmeal. Fish oil is mainly used for replacement of mineral oil or to treat diabetes, high blood pressure and other diseases. Fishmeal is mainly used for high protein feed.

Fish skin is used for making leather and is regarded as an important leather raw material. Fishbone is used to manufacture bone meal. Bone meal is mainly used for feed additives. Fish internal organs are used to extract protease. This enzyme, which is one of the digestive enzymes in fish, can be widely used in the manufacture of cleaners to remove plaques and dirt, and in food processing and biological research.

Fish scale is used for processing fish silver. Fish silver's appearance is pure silver white with high gloss and is used for raw materials of medicine, biochemical drugs and paint manufacturing. Shells can be processed into pearl powder and shell powder. Pearl powder is used for medicine and cosmetics manufacturing and shell powder is used for feed processing.

Shrimp shells are used for making chitosan. Chitosan is used in medicine, wastewater treatment, as a food antistaling agent, in cigarette adhesives and as a plant growth regulator (X. Zhang, personal communication, 2012).

2.2.7. Chile

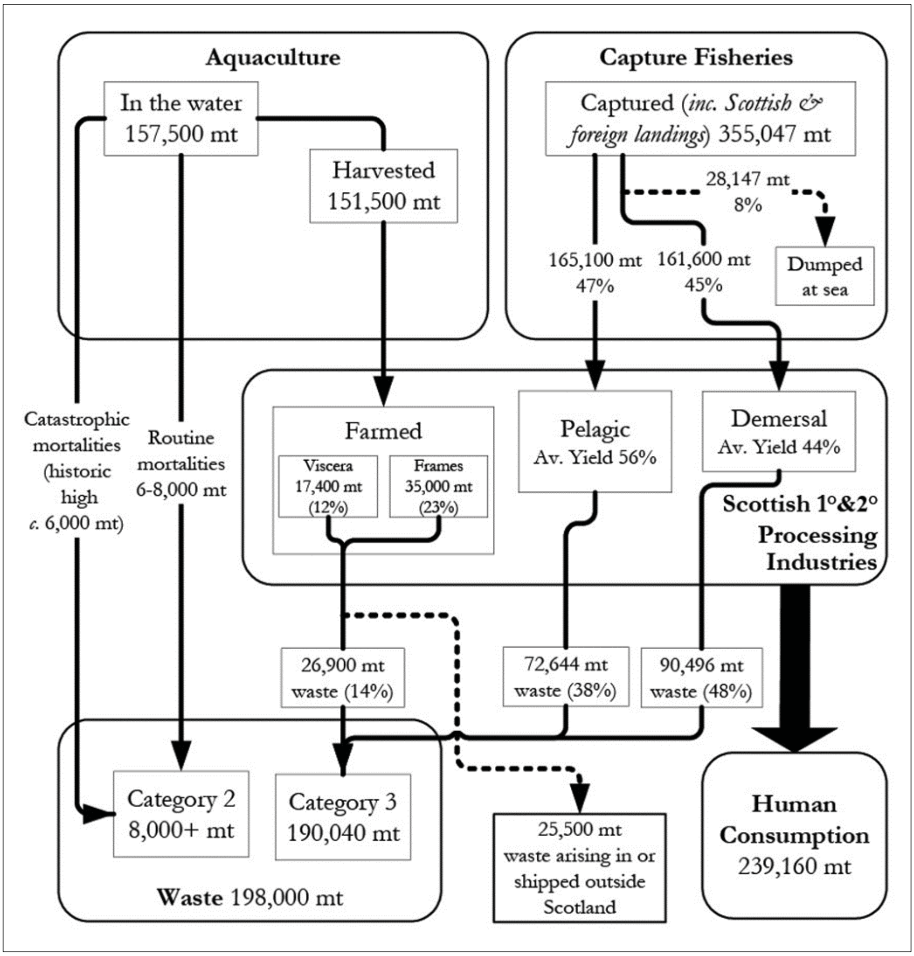
The main by-product operation conducted in Chile is related to the salmon industry located in the Southern part of the country. Before the Infectious Salmon Anaemia (ISA) crisis affected the industry between July 2007 and 2010, there were two main processors, namely Pesquera Pacific Star and Salmonoil. These companies merged during the raw material shortage and now are Fiordo Austral (www.fiordoaustral.cl) with 5 fishmeal plants, gathering salmon by-products from 50 processing plants using 15 well equipped trucks plus boats for the remote areas. The salmon meals produced have a protein content ranging from 60–63 percent for standard quality and up to 67 percent for the premium quality. The oils placed in the market go from crude salmon oil quality for any use up to deodorised ones for petfoods. The next processor in size, Pesquera La Portada, manages only 10 percent of the by-products volume.

Eighty percent of these products go to the markets of China, Japan, Taiwan Province of China, the Republic of Korea, USA, Brazil, Argentina, EU and others. The average FOB price for the total exported in 2011 of 33 913 tonnes of salmon meal was USD 1 261/tonne, whereas the meal from pelagic species was USD 1 462. For oil the situation was similar: for total salmon oil exports of 38 234 tonnes, the FOB price was USD 1 332/tonne, compared with USD 1 682/tonne for pelagic species oil (R. Zamora, personal communication, 2012).

2.2.8. Scotland

The work developed within the Poseidon Project covered fish by-products from aquaculture as well as capture fisheries and is shown in the following flow sheet:

Figure 2. By-product flow sheet



Source: Mack *et al*., 2004.

2.3. BY-PRODUCTS FROM SPECIFIC RESOURCES

2.3.1. Salmon

The salmon farming industry has grown enormously both in Norway, Chile and in other parts of the world during recent years. Much of the salmon is sold to the customer as gutted, whole salmon, but significant amounts also are sold as fillets. In a typical automated filleting line, the fillets make up approximately 59/63 percent of the total wet weight in a salmon with body weight of 5/6 kg. Other products from the filleting line are salmon frame (9/15 percent), head (10/12 percent) and trimmings (1/2 percent) (Liaset, 2003).

Figure 3. Salmon frames

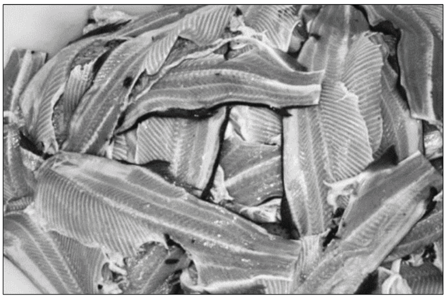


Figure 4. Salmon heads

2.3.2. Tilapia

As the filleting yield of tilapia is only around 30 percent, there is an important throughput of by-products, with its corresponding environmental impact plus the cost of handling and disposal. If these by-products could be utilized for other purposes the industry costs would be reduced, with value added to its products. Minced fish (MF) is an interesting alternative for this purpose, taking into account that other species are suitable for this application as well, for example in the production of frankfurters. However, the heme pigments present give to a darker colour in the MF, which might be put off consumers (Campagnoli de Oliveira Filho, 2008).

Figure 5. Fresh Tilapia

2.3.3. Shellfish

Shellfish on average generates 50 to 60 percent of solid waste, which it is mainly derived from the exoskeleton. Depending on the species the protein content could be between 25 and 40 percent, the chitin content between 15 and 25 percent and calcium carbonate between 40 and 50 percent. Because protein is not very high, this by-product is normally not considered suitable for animal feed, although it may be more useful as a fertiliser because of the nitrogen content (6 percent), phosphorous (2 percent), potassium (1 percent) and organic matter (ADAS UK Ltd., 2006).

2.3.3.1. Shrimp

Shrimp processing industries are generating more waste material every year. As there has not been any important development in the technology to handle this biomaterial, problems related to waste collection, disposal and pollution have arisen. The present method of processing this material to generate chitin and chitosan has resulted in the contamination of aquatic ecosystems with hydrochloric acid, acetic acid and sodium hydroxide with the corresponding negative effect on flora and fauna (Kandra, 2012).

Total world shrimp production is over 6 million tonnes, divided almost equally between fisheries and aquaculture. Shrimp is produced all over the world but the highest volume comes from Asia. Two thirds of world production is concentrated in ten countries: China, India, Indonesia, Thailand, Viet Nam, Canada, USA, Greenland, Malaysia and Mexico. China alone generates about one third of the world production. The main countries for warmwater shrimp are India, USA and Thailand, whereas Greenland, Norway and Iceland are the most important for coldwater shrimp (Huong, 2009).

Figure 6. Shrimp

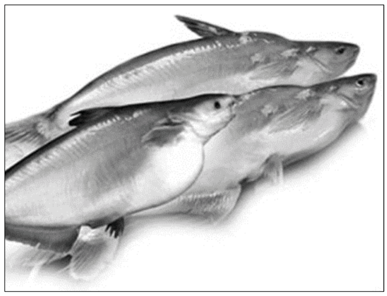
The shrimp packaging and processing industry is the main source of non-utilized oils and proteins of marine origin, which is included in the heads. These are separated near the landings or at the packaging plants. The normal form of export is frozen shrimp without exoskeleton. Depending on the species considered, between 45 and 48 percent of shrimp as raw material is disposed of as by-product.

A different situation is found in small production facilities in the live crustacean producing centres in Galicia, where by-products generation from different crustaceans is considered to be only about 330 tonnes/year. It originates from species such as edible crab (*Cancer pagurus*), chestnut crab (*Necora puber*), spinous spider crab (*Maja squinado*), Norway lobster (*Nephrops norvegicus*), european lobster (*Homarus gammarus*), common prawn (*Palaemon serratus*) and common spiny lobster (*Palinurus elephas*). At these live crustacean centres, by-products accumulate in small quantities each day. However, problems with getting rid of or storing these products make trying to add value not worthwhile The way in which the industry handles them, as products not intended for human consumption means that the food or neutraceutical market would not be able to take them (Maroto, October 2011).

2.3.4. Catfish

According to the export processing companies, the proportion of fillets is only between 32 and 36 percent depending on the rearing conditions. Accordingly, the by-products are over 60 percent of the live fish, with huge economic, disposal and environmental concerns.

Figures 7a and 7b. Pangasius



Source: McGee, 2010.

2.3.4.1. Pangasius

There are around ten large processing companies in Viet Nam, plus many small companies dedicated to tra and basa catfish trade, which in general are found in the Mekong Delta. Catfish is exported to more than 33 countries in the world, with only shrimp more important in value terms, compared with catfish fillets.

In a survey done in 2005, considering the farms to be 3 250 ha, and harvesting 326 000 tonnes of catfish, the by-products were 212 000 tonnes, of which 53 percent went to dry fishmeal, 42 percent to wet fishmeal and 5 percent for human consumption (Thuy, 2007). These quantities have increased dramatically and catfish production in the Delta was over 1 million tonnes in 2009, increasing to 1.5 million tonnes in 2010 (Thuy, 2011).

Figure 8. Pangasius fillets

Source: Safe Seafood, 2013.

2.3.4.2. Channel Catfish

For a market-size channel catfish (680–1 135 g), the head remnants account for 24 percent of the fish whole weight, the bones 13.6 percent, the guts 10.8 percent, the skin 4.7 percent, and cuts and pieces 3.7 percent. These percentages mean that an average of 56.8 percent of the whole fish is to be discarded. Assuming the total production to be 300 000 tonnes (2006) the quantity of by-products would be 140 000 discounting a small amount for process losses (Menghe *et al.*, 2007). Currently, the production in the USA has dropped to 151 700 tonnes in 2011, and therefore by-products could be estimated at 71 000 tonnes, from which fishmeal and fish oil can be produced (NASS, 2012).

3. FISH BY-PRODUCTS MARKETS AND UTILIZATION

3.1. INTRODUCTION

3.1.1. Industry Strategy

"There are many options for utilizing the by-products (wastes) generated by the seafood industry. Options that might work in one location or area will not be economical in another area. Generally, the options span the range from disposal of the seafood waste with no added value achieved (and perhaps involving a disposal and hauling cost) all the way to the development of high valued biochemical products. The tendency throughout the global seafood industry has always been to select the options with the least investment and least penalties or consequences. Thus the conversion of seafood waste to by-products or co-products normally does not take on a high priority until the penalties or consequences of disposal outweigh the benefits. In many areas the disposal of fish waste is a breakeven venture with the sales of any products balancing out the costs. In those areas, disposal has a defined cost which seems to increase each year. When there is sufficient waste in defined areas, the production of fishmeal and oil makes sense because there are existing markets for these products and demand continues to increase". This quotation is from a study by A. Bimbo (2008) for the industry in Alaska and is probably true for many other places.

3.2. MARKETS FOR PROCESSED BY-PRODUCTS

3.2.2. Fishmeal

There are two main sources of raw materials for fishmeal and oil plants. About 75 percent originates from fish species that have only a limited or no demand for human consumption, and the rest comes from primary processors by-products, in that way avoiding the environmental and financial costs of handling them.

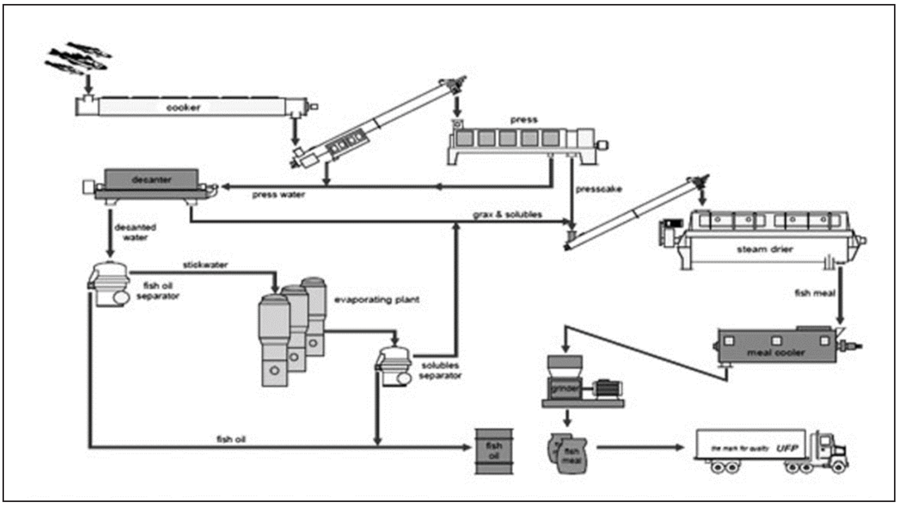
The process to obtain the meal and oil involves reception and storage of fresh raw fish and fish trimmings, continuous cooking, pressing to separate water and oil, drying and milling to the proper particle size. The meal obtained has a light brown colour depending on the thermal treatment utilized. There are at least four different meals recognised in the market, with the corresponding price variations:

- High quality: normally for small and refined aquaculture operations for trout or marine fish.
- LT (low temperature) meal: because of its low temperature treatment it is quite easy to digest and used for small pigs and salmon.
- Prime: having high protein content.
- FAQ (fair average quality): low in protein content and utilized as an ingredient for pig and poultry feeds (Green, 2011).

The other price consideration, besides the process variables, is the protein content, and this represents the main difference for the by-product meal because compared with whole fish meal it has less protein. The other disadvantage of fishmeal coming from aquaculture by-products is its location as it should be utilized in feeds for species different from the original, thus adding a transport cost. For example Chilean salmon meal is exported to the Chinese market mainly for fresh water aquaculture (H. Bacigalupo, personal communication, 2012).

In general fishmeal is used as a high protein (60–72 percent protein content) ingredient in feed for farmed land animals and farmed fish. The fishmeal proportion in the feeds for land animals could range between 1 and 5 percent, e.g. for weaned pigs as a special diet. However, for farmed salmon the amount may be much higher, 20–30 percent, as there are no flavour restrictions in the final product (Green, 2011).

Figure 9. Schematic fishmeal and fish oil production flow sheet



Source: Green, 2011.

This plant at the centre of the UK fish processing industry is fundamental for its development because of the by-products handling and disposal. It works with 170 suppliers where they gather the raw material, keeping its freshness to guarantee the quality of the meal (Hryckowian, 2012).

Trimmings from processing industries in Europe represent 33 percent of the raw material supply to the fishmeal processing industry. However, there is a huge variation among the different countries: for example, in Denmark about 80 percent of the fish processing trimmings go the fishmeal plants, whereas in Spain it is only 10 percent. The situation in other countries such as the UK, France and Germany is between 33 to 55 percent of trimmings going to the meal industry (University of Newcastle, 2003).

Table 5. Global fishmeal usage by species in aquaculture (2000–2020)

Species *Tonnes*	**Tot FM used**	**Mean % FM**	**Tot FM used**	**Mean % FM**	**Tot FM used**	**Mean % FM**	**Tot FM used**	**Mean % FM**	**Tot FM used**	**Mean % FM**
	2000		**2005**		**2010**		**2015**		**2020**	
Carp	541	9	649	8	316	3	279	2	182	1
Tilapia	199	11	268	9	148	3	158	2	126	1
Shrimp	476	25	1 044	24	860	12	790	8	616	5
Salmon	530	40	628	35	400	18	340	12	290	8
Marine fish	476	44	700	36	671	24	675	16	455	8
Trout	239	36	253	34	182	18	155	12	132	8
Catfish	61	8	220	12	192	6	148	3	107	2
Milkfish	31	10	23	5	11	2	14	2		
Eels	239	62	218	60	179	45	145	35	108	25

Source: Green, 2011.

Table 6. Fish trimmings used for fishmeal and oil production

Species	**Country**
Catfish	USA, Vietnam
Tuna sp.	Thailand, Japan, USA, Australia, South Korea, China, France, Ecuador, Maldive Islands and Others
Salmon	Norway, USA- Alaska (wild), UK, Ireland, Canada, Chile, Japan (wild)
Sardine/Pilchard	Peru, Chile, South Africa, Namibia, Japan, Spain, Mexico
White Fish sp.	UK, USA-Alaska, Canada, Chile
Dogfish	Canada, USA
Horse Mackerel	Ireland, Norway, Denmark, Spain
Atlantic Herring	Iceland, Norway, Denmark, UK, Faeroe Islands, Sweden, Ireland, Canada
Mackerel sp.	Mackerel sp.
Hoki (Blue Grenadier)	Australia, New Zealand

Source: Bimbo, 2008.

IFFO has made an estimation in 2008 of the proportion of raw material coming from fish trimmings, which is shown in the following table:

Table 7. By-products in fishmeal production (2008)

Production in thousand tonnes	Fishmeal	By-product Coefficient %	By-product FM Production
Thailand	468	60	280.8
Japan	202.9	90	182.6
Chile	673.3	14	94.3
USA	216.2	25	54.1
Mexico	105.8	50	52.9
Iceland	140.9	32	45.1
Russian Fed.	71	50	35.5
Denmark	161.3	20	32.3
Canada	31.2	100	31.2
Norway	135	22	29.7
TOTAL 10	**2 205.6**	**38**	**838.4**
OTHERS	**2 612.4**	**15**	**389.5**
TOTAL WORLD	**4 818**	**25%**	**1 227.9**

Source: Chamberlain, IFFO, 2011.

The IFFO has also given an estimate that by 2020, instead of 25 percent coming from trimmings, the amount would increase to 50 percent (Jackson, 2011). This is based on the fact that aquaculture is increasing whereas capture fisheries remain stable.

Consumption of fishmeal is increasingly concentrated in Asia with China continuing to be the most important single market, but most relevant is the change in the use of fishmeal: in 1980 only 10 percent went to aquaculture, but now it is over 60 percent. This is split four ways between salmon and trout, marine fish species, crustaceans and others (mainly fresh water) (Jackson, 2011).

3.2.3. Fish Oil

As indicated in the schematic flow sheet shown above, fish oil is produced in parallel with fishmeal, and it has the same implication for fish trimmings.

The change in fish oil consumption has been even more dramatic than the case of fishmeal because of the negative impact of hydrogenated products for human consumption as a result of the generation of trans fats and their impact in cardiovascular diseases.

Table 8. Fish Oil use (percent)

Use/Year	1970	1990	2010
Industrial, leather tanning	20	20	7
Hydrogenation, margarine	80	59	1
Refined edible		5	12
Aquaculture		16	80

Source: Jackson, 2011.

The increased oil production from South America has been the main cause of the 34 percent more oil supply in the first half of 2011, in spite of reduced exports from Chile because of the recovery of the salmon industry, which is the major fish oil consumer in the country. However, increased production in Peru balanced this reduction in exports. In general, annual fish oil production dropped below one million tonnes in 2009 and prices have also been driven up by the growing demand for nutraceutical supplements to improve cardiovascular health (COFI, 2012).

Oils from by-products may have interesting markets, particularly if they are processed by molecular distillation and enzymatic processes in combination with specially developed methods to purify the final products. Proper deodorization, at the beginning or end of the process is essential, as well as obtaining concentrated omega-3's, which are among the most important ingredients for the nutraceutical industry. DHA and EPA have proven to be valuable supplements that support health and wellbeing in a wide range of medical conditions. Concentrated EPA and DHA allow the industry to formulate products with fewer calories and no fish flavour, but with all the benefits of their chemical composition that has been shown to be important to the heart, brain, eye, joints, and for prenatal development.

The production of highly concentrated omega-3's has the disadvantage of generating saturated fats as by-products, and at least one company is trying to use these oils as fuels to generate steam for their processing plants. Compared with fossil fuels there is the advantage of CO2 neutrality and there is no sulphur contamination (Rieber Oils, 2011).

The classification of crude fish oil plants and vessels is in relation to the new EU health directive for human consumption to ensure the quality of raw materials. Fish oil intended for human consumption must meet the requirements for fishery products found in the hygiene regulations. This means that the raw materials and the fish oil must come from establishments, including vessels, registered or approved pursuant to the hygiene regulations and be derived from products that are fit for human consumption and are handled throughout the food chain as such. Animal by-products and fishery products not fit for human consumption cannot be used as raw material for fish oil for human consumption (Rieber Oils, 2011).

3.2.4. Silage

Silage is a well-known process, initially utilized in hay farms, where decomposition is prevented by pH reduction, because of the fermentation of carbohydrates. This principle could also be applied to fish by-products, but the industry has developed a more direct process by adding formic acid, the sole supplementary ingredient in the process. When compared with fishmeal, the main advantage of silage is related to size. Very small units could work economically, and be used by remote processors, controlling the main by-products problem such as environmental and handling issues. The development of this technology found its initial applications in white fish waste utilization in Scandanavia, long before the salmon farming industry was established (Mack *et al.,* 2004).

The size of the ensiling tanks can vary between 250 and 2 000 litres, although the smaller sizes are more common. As mentioned before, it does not require the infrastructure of fishmeal plants and could be conducted by local farms and processors. Most of the ensilers are situated on fish farm land sites to take care of normal mortalities and minor disease events. As ensilers could be located close to the source of the material, it is not necessary to resort to costly transport systems including refrigeration and temperature control, for example. As ensiling works with the natural enzymes present in the raw material, it is best to have the freshest possible material, which is facilitated by locating the units close to the farms.

Figure 10. Ensiling unit

Source: Scanbio, 2013.

Bad quality fish reduces the speed of the ensiling process. The final product is easy to handle, needing only sealed containers, which can vary in size according to the final transport requirements, from 50 litre drums up to 30 tonne tanks or silos (Mack *et al.*, 2004).

The process is relatively simple and has few stages. In the first one the raw material is macerated, reducing its size and allowing an increase in surface area, which facilitates the action of the enzymes from the viscera. When no viscera are included the process takes longer. Afterwards, the macerated raw material is mixed 3.5 percent of formic acid, the pH is reduced below 4, preventing any further spoilage and giving time for natural autolysis. Finally the product is pumped into the storage container, normally large tanks for processing waste or drums for mortalities (Mack *et al.,* 2004)

In Scandinavia, Poland, Denmark and the Netherlands well established markets for silage from fish waste can be found. As it is a highly nutritious feed for pigs, fur animals, and poultry it can be included as an ingredient in their diets. Silage from white fish is used, as an alternative to LT fishmeal and sells at a lower price on an equivalent dry weight basis (Mack *et al.,* 2004).

In tropical climates, sometimes the original hay silage process is applied by adding sugars like molasses and a culture of lactic acid bacteria, which generates lactic acid out of the sugars, reducing the pH and keeping the quality of the by-product. This acidity prevents the growth of spoilage bacteria that produce off-flavours and toxins like trimethylamine and histamine, if left at neutral pH (Gill, 2000).

Besides land animal feeding, silage has been used in aquaculture as well, for example, shrimp silage, which has a positive colour content as well as protein content, and has also been used for famed salmon. The process, including carbohydrate addition, has been used successfully for offal coming from salmon, shrimp and tilapia aquaculture and used subsequently for different farmed species. In tropical countries, where cane sugar is produced, the low cost availability of sugar molasses could make this process more economical than using formic acid. Compared with fishmeal, silage in general has the advantage of no heat denaturation and the proteins are more available for the aquaculture species. One exception is a process developed in Norway, where the silage is heat treated to destroy any remaining pathogens, and control the spread of disease (Gill, 2000).

Silage could be used as an ingredient in feeds formulation, supplying protein and water for the formulation, which is extruded afterwards to obtain the proper density and stability required to be used in aquaculture farms. The extruder process applies high pressure and temperature, cooking all the ingredients when in a thermoplastic state and then, with a sudden pressure decrease, the expansion and the desired final low density. Water is evaporated to a certain degree during this process, which is normally finished by hot air drying to avoid spoilage before being used (Gill, 2000).

3.2.5. Compost

The process to generate compost requires that the fish by-product, which is rich in proteins, ha the particle size reduced and is mixed, normally with a vegetal material, rich in carbon, in a ratio of about 40:1. The mix is then aerated and the bacteria present allowed to break down the organic material (fibres, fats and proteins), generating enough heat to increase the temperature to 50–70 °C and destroying the harmful bacteria and viruses present in the raw material. The result is a fine humus suitable for improving soil quality as a result of its high organic and nitrogen content. Nevertheless, the inactivation of pathogens has not yet been fully proven and requires further development (Mack *et al.,* 2004).

According to "lets recycle" (http://www.letsrecycle.com) the price for green compost could be around GPB 8 per cubic meter.

Figure 11. Oly Mountain compost

One such process was developed in Norway and has recently gone into production. The process was developed through research funded by the RUBIN Foundation (see By-Products from Specific Countries) in Trondheim, Norway, and involves the mixing of problem wastes such as animal manure, municipal sewage and aquaculture mortalities. Liquid compost is formed by aerobic fermentation at 60 °C. The equipment for the compost manufacture was supplied by Alpha Laval and a description of the RUBIN composting process may be found in RUBIN (1998). The compost produced in the Norwegian process is currently used as an agricultural organic fertilizer. The Rubin Foundation claims that although the process is capable of destroying *Aeromonas salmonicida* and infectious salmon anaemia, thermophilic fermentation was not able to remove antibiotic residues sometimes found in aquaculture waste.

Thermo Tech Technologies in Langley, British Columbia, Canada, developed another commercial composting process. The process involves aerobic fermentation with thermophilic bacteria at approximately 70 °C. The process has been used to compost many different raw material wastes including fish products. Thermo Tech claims that the process eliminates human bacterial and viral pathogens and destroys many different antibiotics found in municipal sewage sludges such as chlortetracycline, sulphamethazine and penicillin. Therefore it might be possible that this process could be used to destroy fish pathogens (Gill, 2000).

3.2.6. FISH PROTEIN HYDROLYSATE (FPH)

Fish protein hydrolysate is a fine powder or protein concentrate produced by the use of enzymes to break fish proteins down into their component amino acids. The process requires very fresh material and so would be ideal for salmon process waste from filleting and is also used for viscera with an oil removal unit included. The fish is minced and mixed with water. Enzymes are then added in a sealed or continuous reactor. Process variables of time, temperature and pressure plus the amount of enzymes depend on the raw material being used. Any undigested material such as bones and skin are sieved out (and then usually added to an adjacent fishmeal stream). Finally the liquor is concentrated, pasteurised and dried (Ramírez, 2007).

Rossyew Salmon Pro is a salmon protein hydrolysate that is vacuum evaporated at low temperature to 45 percent dry matter to produce a stable savoury brown liquid. Low temperature concentration preserves valuable peptides. This fish hydrolysate is used as a nutritious ingredient in pig feeds, palatable pet foods and as an attractant in aquaculture diets (http://www.rossyew.co.uk/salmon_pro.htm).

The increasing number of products on the market made with FPH shows the many possible industrial applications of FPH. These include biotechnology (because of the ability to feed microorganisms), the food and feed industry, (because of protein content and functionality), agriculture, cosmetics and biomedical sectors. It has both of nutritional and biological advantages. It is particularly useful in foods and feeds because FPH has good nutritional value, an excellent amino acid balance, coupled with high digestibility and quick uptake. High water solubility is another advantage. As with other peptides, FPH presents some particular biological activities that are valuable for biomedical applications.

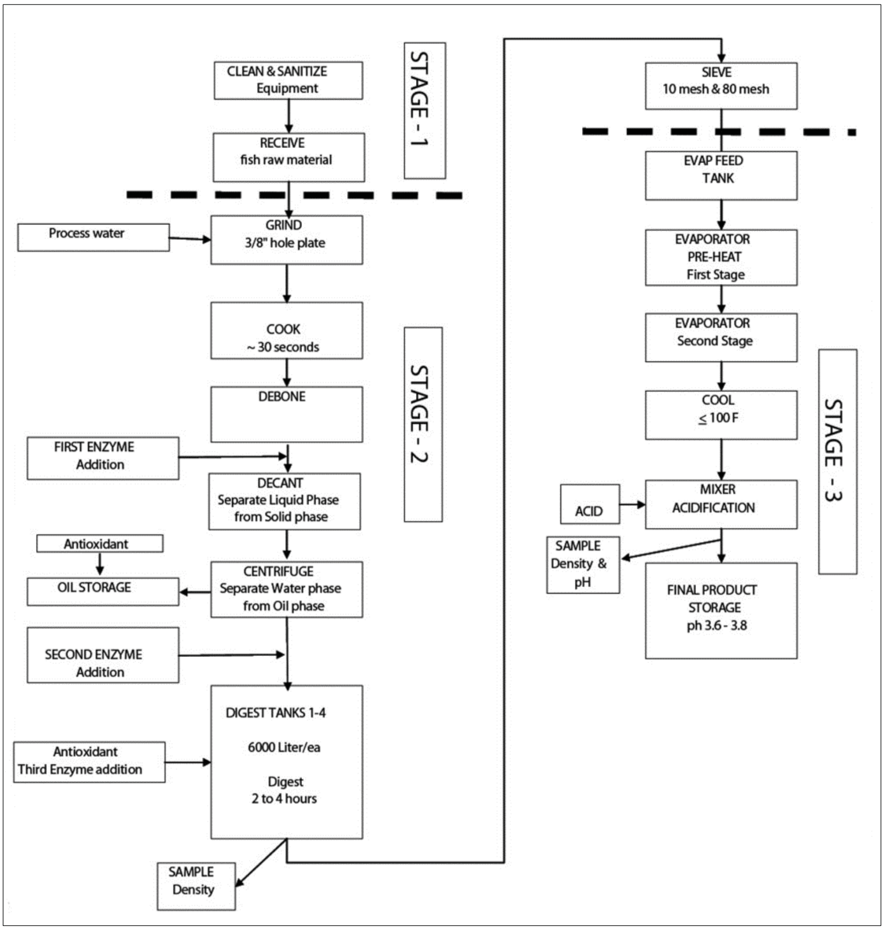
The utilization of FPH in food systems has been effective in:

- The enrichment of the protein value of cereals, legume products and beverages;
- The increase of the water holding capacity of fish and animal proteins (marinating);
- Preventing protein breakdown in jellified products and dried proteins;
- Avoiding lipid degradation as a result of the antioxidant capacity of FPH.

The peptides present in FPH give an additional benefit when used in feeds, because of their immunostimulant activity, which is very important for fish larvae whose defensive system is not fully developed. In other applications, FPH peptides can provide plants with easily available nitrogen, and this availability also makes them suitable as a growth media for various microorganisms (Batista, 2011).

The process to produce hydrolysate could vary from batch to continous; the figure below shows the process developed by Alaska Protein Recovery.

Figure 12. Enzymatic by-products hydrolysis



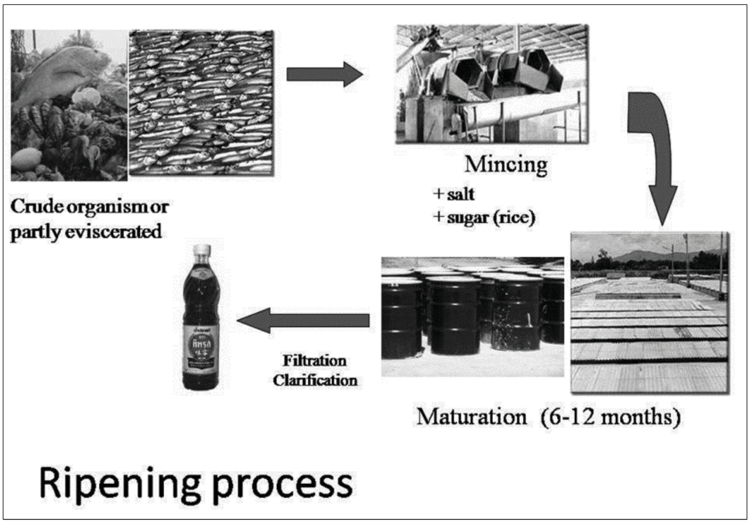
Source: Alaska Protein Recovery, 2013.

3.2.7. Fish Sauce

Fish sauce is an essential condiment in Southeast Asian cooking (especially Thai and Vietnamese), just as salt is to the West and soy sauce is to China. The sauce is a fermented product based on fish proteins and composed mainly of water, salt and soluble nitrogenous compounds (Huong, 2009).

The process is simple: the fish or fish by-product is mixed with salt and kept in a tank or other closed container, submerged in the brine mixture. There is no further processing or need for temperature regulation. For small pieces or small fish the fermentation time is quite short, but for large ones it could extend from 6 to 12 months (Huong, 2009).

Figure 13. Sauce process



Source: Roy, 2011.

Figure 14. Fish sauce products

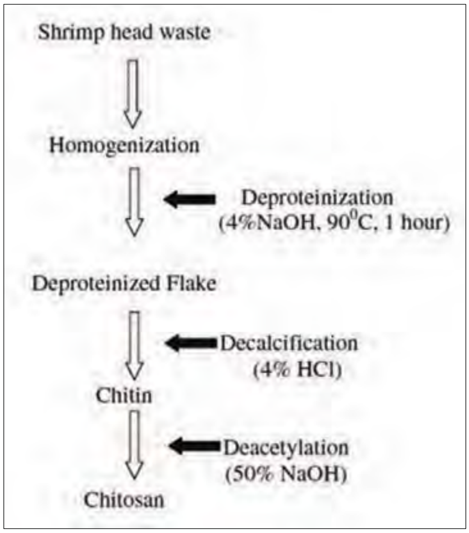
Source: Houng, 2009.

Although many consumers appreciate the sauce made from a specific fish, there are examples of sauces made from by-products, such as those traded in the Republic of Korea and made out of cod gills. Traditionally, the sauce is made by mixing one part of salt with three parts of fish, and leaving it at room temperature. The fish to salt ratio depends on the country. During the fermentation process, proteolysis is achieved by the enzymes present in the muscle and the digestive organs plus the proteases produced by the halophilic bacteria (Huong, 2009).

3.2.8. Chitin and Chitosan

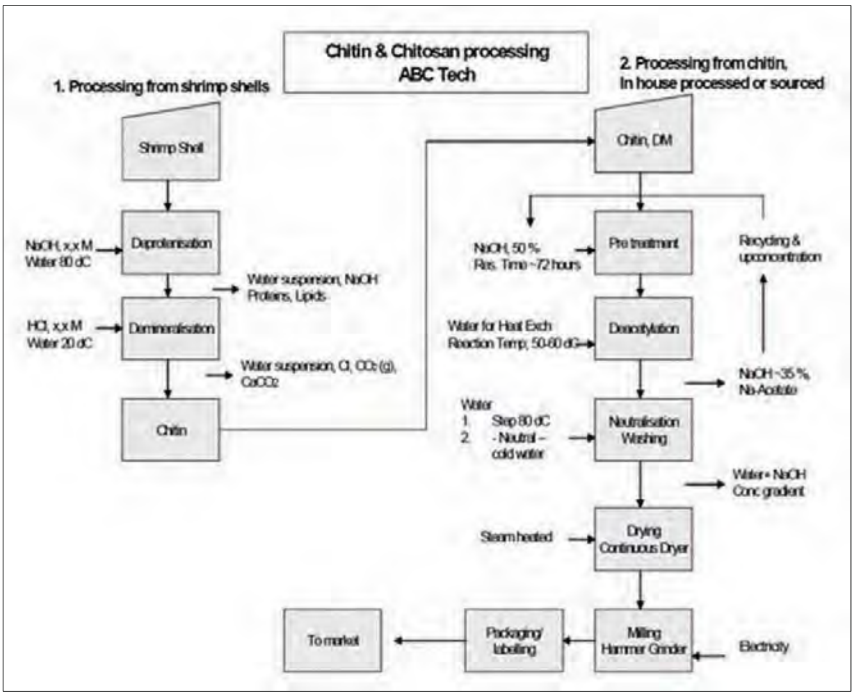
The production of chitin and chitosan from crustaceans is achieved by the process indicated on the right, which has environmental complications because of the use of NaOH and HCl. There is important research, though, related to milder processing utilising enzymes, which allow the recovery of proteins and peptides. However the cost is still quite high compared with the chemical process. The process includes deproteinisation using NaOH, decalcification using HCl to obtain chitin and then diacetylation to obtain chitosan (Kandra *et al.*, 2012).

Figure 15. Chitin and Chitosan process



Source: Kandra, 2012.

Figure 16. Chitin and Chitosan flow sheet

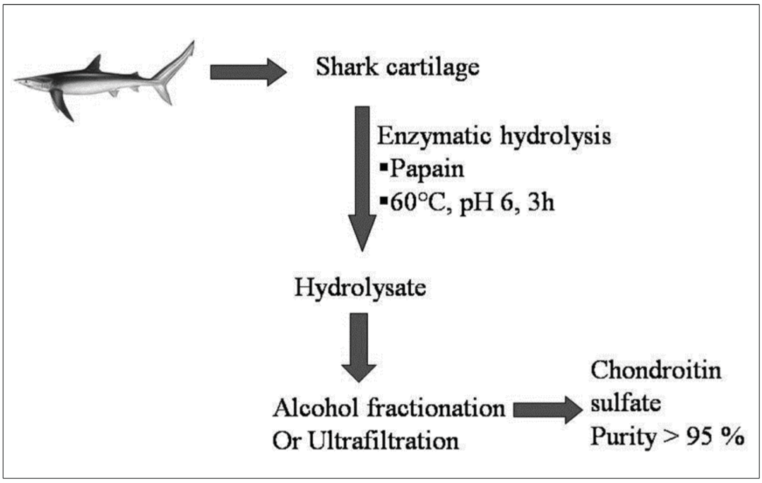


Source: Rubin, 2008.

3.2.9. Chondroitine Sulphate

This is a glycoprotein found in the cartilage of structural tissues. The marine sources are the cartilages of rays and sharks. Presently, chondroitin is utilized as a food supplement to reduce joint pain, improve joint performance and to help with structural protection for the patients with arthritis (Huong, 2009). A schematic production flow sheet is shown on the left (Roy, 2001).

Figure 17. Chondroitin Sulphate process



Source: Roy, 2011.

3.2.10. Collagen and Gelatine

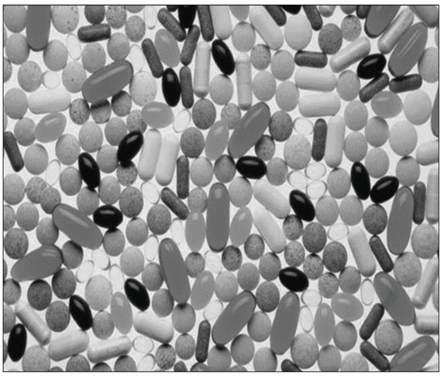
Many years ago a type of glue was produced from fish skins and bones. The product was similar to gelatine and could be used for technical applications only. Now, however, the production of fish gelatine is only a small fraction, between 1 and 1.5 percent of the world annual production, which is in the order of 250 000-300 000 tonnes. Nevertheless, there is a market for no-cow and pork raw materials, which lends new interest to using materials from fish origin for these applications. There are many studies showing the characteristics of fish gelatine. Of particular interest is the relation between fish habitat temperature and the gelatine melting point, which means that the gelatine coming from low temperature fish, salmon for example, is not suitable for jelly desserts, because it would melt at ambient temperatures in many parts of the world (Gildberg and Arnesen, 2007).

The production workflows of many companies in the fish collagen manufacture include the following activities (Maroto, September 2011):

1. Extract
2. Filtrate and refine (First)
3. Enzymatic hydrolysis
4. Filtrate and refine (Second)
5. Concentrate
6. Sterilisation
7. Dehydration

Although not suitable for use as gelatine at room temperatures, other uses for fish gelatine from cold water species include the prevention of syneresis and also to improve the texture of foods. Another use is in foods that are consumed quickly after taking them from refrigeration. The manufacturers of dry products are already using them for micro-encapsulation of vitamins and pharmaceutical ingredients (Karim and Bhat, 2009).

Figure 18. Gelatin Capsules



Source: Compass, 2013.

Figure 19. Gelatin

Source: Compass, 2013.

In South America and in Northern Europe farmed Atlantic salmon has become a very large fish resource, with by-products readily available. Up to 2007 salmon skin in Norway was not produced in large quantities, because the fish was exported whole, but now, as the market for fish processed without skin is being developed, there are considerable quantities of salmon skin available. The skin represents 5 percent of the fish and could be used as raw material for gelatine production. Although research has been carried out on salmon collagen, much more research is still required on salmon gelatine (Gildberg and Arnesen, 2007).

Although fish gelatine/collagen is a small market there are interesting possibilities for different applications. The price paid for collagen of fish origin seems to depend on how it will be used. For example, the food industry is now paying between EUR 8 and EUR 12/kg for collagen to be used as a traditional ingredient such as binders, stabilisers, emulsifiers and film-formers, as well as some new applications as fat replacers, while the food supplement industry pays between

EUR 10 and EUR 12/kg for collagen to be used as a bone lubricator and stimulator to generate body collagen in people at risk of osteoarthritis and osteoporosis. For cosmetic applications, collagen fetches between EUR 20 and EUR 25/kg and its high water retention capability is used in spreads to give skin a smoother look and reduce wrinkles. Similarly, Chinese producers are offering cosmetic collagen in a price range of EUR 10 to EUR 40/kg for functional products that relate to skin care beauty (Rubin, 2012).

Global production of marine gelatine is close to 3 000 tonnes. Average prices seem to be higher compared with prices for animal based gelatine.

Table 9. Present producers of marine collagen/gelatine

Country	**Producers**
France	Rousselot, Copalis, Weishardt Group
Spain	Junca Gelatines,
Canada	Norland Products, US & Canada,
Italy	Lapi Gelatine
Japan	YSK, Nitta Gelatin,
Taiwan/Japan	Jellice (from fish scales)
Korea	Amicogen, Geltech Co
Norway	Seagarden
China	Over 20 small producers

Source: Rubin, 2012.

3.2.11. Disposal

Although disposal is not considered a market or an opportunity, it is a realty that the fish processor faces when there are no processing alternatives for its by-products. In the UK specific regulations apply to disposing of waste material and the following table shows the disposal alternatives for crustacean by-products.

Table 10. Disposal alternatives

Waste treatment option	Range of costs (per tonne) to the producer (2007 costs)
Aerobic digestion Anaerobic digestion Composting Landfill	GBP 40–GBP 60 plus transport costs
Alkaline hydrolysis Autoclaving Crustacea meal Mechanical and biological treatment	No data available
Ensiling (excluding heat treatment)	GBP 25 excluding transport and off-site treatment
Direct animal feeding (bait)	From free (for bait) to GBP 40
Incineration	GBP 100–GBP 160 plus transport
Land spreading (including initial treatment)	GBP 10–GBP 200 depending on extent of initial treatment and including licensing and transport costs
Rendering	GBP 60–GBP 100 plus transport

Source: Seafish, 2008a.

3.3. MARKETS BY RESOURCE

3.3.1. Tilapia

The tilapia processing industry generates a number of different by-products, but the most relevant is the skin of tilapia, which has three very different markets. In Brazil an industry has developed that produces shirts, wallets, briefcases etc. out of fine skin strips, which are treated and dyed at the primary processing plants. In Asia, tilapia skins without scales are used as a food product and are cut into stripes and deep-fried. These are very popular appetisers in Thailand and Philippines. The third market is the collagen/gelatine industry, where the gelatine from tilapia has wider applications because it is a tropical species and does not have the cold water limitation, while at the same time having the benefit of being non-bovine (Fitzsimmons, 2004).

Figure 20. Tilapia leather articles

Figure 21. Tilapia leather

Trimmings and heads are other by-products, where heads sometimes receive the traditional use as a soup ingredient, and trimmings could be included in raw preparations as "ceviche". Flesh recovered by mincing machines could also be included in food preparations such as sausages, fish balls or other more sophisticated products. These by-products could also be used as animal feeds, mainly for pigs (Fitzsimmons, 2004).

3.3.2. Shrimp and Crustaceans

Crustacean by-products can be of value without further processing, as they can be used directly for feeds in veterinary practice and aquaculture. There are processing units of different sizes prepared to dry them and mix them with other agricultural wastes or raw materials to generate animal feeds. Typically, shrimp heads and other by-products are sun dried, which allows only for an animal consumption product because of poor hygiene. Other ways of disposing of shrimp waste is in landfill, soil dumping or even returning it to the sea, which leads to an important environmental problem. Another possibility is to make silage out of shrimp heads by adding sugar molasses and utilising *Lactobacillus plantarum* for the fermentation, followed by drying and the addition of 15 percent feather meal. This silage could be used as a partial replacement for fishmeal in tilapia and African catfish diets (Kandra *et al.*, 2012).

Another possible use of shrimp and crustacean by-products is the production of pigments like astaxanthin, but yield and costs involved do not allow for a feasible operation. Thus, most astaxanthin marketed for the production of feed for the aquaculture industry is of synthetic origin. Natural astaxanthin has market potential in the nutraceutical industry, but crustacean pigments cannot compete with the pigments obtained from microorganisms such as the alga

Haematococcus pluvialis or the yeast *Phaffia rhodozyma*. The pigment yield from crustaceans is very low (Maroto, 2011a).

From a competitive point of view, it seems to be much more profitable to generate enzymatic hydrolysates without further separation, because all the components have an important nutritional value, and further processing means only additional cost. The nutrients involved include polypeptides and polyunsaturated fatty acids as well as astaxanthin. A crustacean meal, rich in astaxanthin, is the way some companies obtain value out of this crustacean waste (Maroto, October 2011a).

3.3.2.1. The USA situation for crab by-products

In the past, in the USA crab by-product (scrap) was dehydrated with a grain/alfalfa dryer, reduced with a hammer mill and sold as crab meal for use in animal feed. However, that practice is hardly economical and is now seldom seen. Most scrap is land applied under agreements with farmers, or taken to landfills. Sometimes it is composted with agricultural residues and sold to nurseries or homeowners as a soil supplement,.but this is only a small niche market at present. There is interest in better utilizing fish processing waste, which is mostly land filled now, but these projects have also made little progress. The costs associated with transporting the materials, processing, storing and distribution often exceed the value of the finished product (T.E. Rippen, personal communication, 2012).

3.3.3. Catfish

3.3.3.1. Pangasius

Fishmeal processors capture most catfish by-products generated by the primary processors in Viet Nam, but there are some small quantities going to restaurants because better prices can be obtained. These by-products include livers, stomachs and swimming bladders. The material destined for fishmeal is delivered whole or separated as stipulated by the contract according to the chemical composition and its corresponding price. A further channel involves other fish farmers who buy the different by-products and mix them with low value capture fish to make aquaculture feeds (Thuy, 2007).

There is considerable variation in the by-products that go into the meal, as well as in the production process itself and hence the quality of the meal coming from different factories will also vary. This is a concern for the final animal grower because of the uncertain quality of the supply in terms of crude protein, amino acid and fatty acid contents, which in turn affects animal growth, flesh quality and economics (Thuy, 2011).

“In Viet Nam the processing of catfish by-product is only a little different between provinces. Firstly, the by-products are finely ground, cooked and then separated into three fractions. Oil floats on the surface and is removed by bucket and further refined before being transported to storage tanks. The middle level is liquor (waste water) which is high in protein, and also is a cause of environmental pollution, because of the unpleasant odours that develop after being stored for some days. Sometime it is used together with sea fish to produce fish sauce for human consumption. In An Giang and Dong Thap provinces cassava root meal is added to the waste water and sold as condensed fish meal to fish producers, either as wet feed or after sun-drying or drying by machine to produce dry fish meal for animal feed (Can Tho). The lowest fraction is waste material, which is used to produce fish meal, after being pressed and dried by machine (Can Tho), sun-dried (An Giang) or dried on trays (Dong Thap). The final step is dry grinding with an antioxidant substance added. Drying by machine is most popular in most provinces, as it is less labour intensive than drying by tray, and sun-drying is only applied in some small-scale factories. However, fish meals that are produced by the different drying methods do not differ substantially in quality" (Thuy *et al.,* 2007).

3.3.3.2. Channel Catfish

In the US, the amount of round catfish received in 2011 by processing plants was 151 700 tonnes, paying an average price to the grower of USD 2.75 per kg (NASS, 2012). The by-products are sent to fishmeal plants or are size reduced and cooled to be sent to pet food canners. This is an advantage to the industry as it does not incur in disposal costs (Silva and Dean, 2001).

However, revenues for catfish offal are very low and just cover transport cost to the rendering plants. If it is considered that 13.6 percent of the fish live weight is frames and approximately 25 to 50 percent of the frames weight could be recovered as flesh, depending on the process, then mince might be considered an interesting alternative market (Hoke, 2000).

3.3.3.3. Catfish Mince

Catfish mince has been made from deboned meat and trimmings. Catfish mince is normally prepared by washing, draining and deboning the frames. The slurry produced is washed several times, pressed through a screen and dewatered with a screw press. Washing is required to increase stability and improve the colour, which is obtained by taking out bones, fat and blood. Although washing is done up to three times, one wash and drain cycle is enough to obtain a good quality product. This process reduces fat and the risk of rancidity, increasing protein and iron content. The addition of cryoprotectants has been shown to keep the quality of the stored mince. Surimi made out of mince is another possibility with prices in the range of USD 0.60 to 2.93/kg, considering the frames costs between USD 0 and 0.33/kg, with a mince recovery of 15–20 percent (Silva *et al.,* 2009).

3.3.4. Shellfish by-products markets

Situation in the UK

As the normal supply to the processors is whole shellfish, the amount of waste, which includes shell and non-edible sift parts such as the viscera, is huge. These quantities are especially relevant for species like nephrops, crab and scallop.

Thus, disposal could be a big problem for the processors, which historically was readily disposed of by a variety of mechanisms including returning it to the sea, as with scallops in the Southern Atlantic.

However, the current regulations in Europe (Animal By-products Regulation, ABPR) classify the shells as Category 3 ABP and should be disposed according to that denomination. Complying with this regulation has been costly to the industry who thinks that this legislation should not be applied to shellfish shell.

The main controversy is related to the term "free-of-flesh", because there is no clear definition of this, and therefore, the Seafish Industry Authority in the UK is carrying out research to define the standards for shell treatment. This might allow the industry to find more profitable ways of disposal.

Although it might be a trade-off in the quality of the meat obtained, machines could be used to separate meat from shells, resulting in very low quantities of edible flesh being discarded. However, some processors still prefer hand picking because the meat quality obtained is better (James, 2011).

If the shells could be rendered completely clean, they might be considered as a co-product and used in several applications such as aggregates for roads and decorative purposes, giving the processor an additional income. As it is not often possible to obtain a perfectly clean shell, processors normally have to dispose of the flesh "contaminated" shell and incur costs in doing this.

There are other alternatives for waste treatment, but the most common are landfill and composting, where the first one involves a cost in the UK between GPB 50 and GPB 100 per tonne. Other possibilities include incineration and usage as bait, but these are minor by comparison. Although the ABPR regulations do not allow the direct landfill of shellfish waste, this is permitted in areas where there is no alternative (James, 2011).

3.3.5. Bait

As the disposal costs are so high, the production of bait from shellfish could be beneficial for the processors as well as for the fishers, who have seen an increase in costs of about 20 percent in recent years. Nevertheless, it is difficult to have a low price bait that fishes well, so simpler production methods are preferred, which avoid the use of binders.

"From reviewing different bait systems a basic cost analysis indicates that following an investment of GPB 35K (subject to existing flesh separation) a flesh waste facility with a capacity to process 5 tonnes per week could produce just over half a million 0.5 kg bait sticks a year at a profit of around GPB 12K/yr (15 percent margin), whilst producing bait sticks for sale at GPB 0.15/stick. This would be in addition to savings of around GPB 15K/yr on waste disposal" (Seafish, 2008b).

3.3.6. Mussel Cooking Juices

It is estimated that about half the mussel production goes into processing, generating mussel cooking water, which could be transformed into a mussel juice product. However, it has not developed well because there is not a very high demand. Nevertheless, it could be always included in the range of products offered by a processor. The most likely buyers could be the readymeals manufacturers who produce a wide variety of products that could benefit from a natural marine taste such as paellas, risottos and Asian soups. Large mussel producing countries are likely to enter these markets with prices related to quality and degree of concentration (Maguire *et al.,* 2011).

At present the liquid mussel extract in the market is mainly from the New Zealand green mussel (*Perna canaliculus*), which is considered to have health-giving properties. In 2005 this market was worth about NZD 209 million, on sales of the order of 95 000 tonnes. The exports of the same product in powder form were valued at NZD 20 million. The volume of *Mytilus edulis* extract produced is not available in terms of quantities, but the extract could be bought on line at a price of between GPB 21 and GPB 30 per litre.

It could be assumed that for each kilogram of mussels cooked in water that the amount of cooking juice would be 2 litres, and if this is concentrated, reducing the volume by a factor of ten, possible production of concentrated juice might be estimated to be in the range of one tenth of the total mussel production. There is also an important proportion of the production undertaken using direct steam, and in that case only 0.2 litres of juice are produced per kg of mussels. Taking all these into consideration, the cost to produce one litre of concentrated mussel juice could be between EUR 3 and EUR 4. The concentration of the extract would be the main factor determining the price, which would be driven by customer demand (Maguire *et al.,* 2011).

3.3.7. Mussel shell grit

The grit is made of 100 percent mussel shell and contains different minerals, but specially 36 percent of calcium, which is an excellent feed supplement for poultry. Normally the grit size is adjusted to the feeding habits. The process includes heating to 135 °C for 32 minutes, to guarantee the microbiologic quality, cooled and ground to the requisite size (www.abonomar.com).

Figure 22. Mussel Shells

Source: Abonamar, 2013.

4. BY-PRODUCTS UTILISATION TRENDS

4.1. GENERAL VIEW

Fish by-products contain many different valuable compounds including oils, proteins, pigments and minerals that could be used in a variety of industries such as fertilisers, nutraceuticals, and ingredients for foods, aquaculture and agriculture. Among them the hydrolysates or silage produced in Norway are clear examples of use in pet and livestock feed. Another interesting development is the production of chitin and chitosan, which have many applications in water treatments and pest control, for example. Besides this, the nature of marine by-products allows the generation of organic fertilisers and composts with advantages over chemical fertilisers. Other alternatives exist to obtain benefits from fish by-products, but there are still some restrictions to be overcome before the actual applications could be developed (Mack *et al.*, 2004).

Research has provided many interesting molecules and products from marine origin. However, the costs of extracting them or the effect on the environment may prevent the development of the process from marine products, and industry prefers to generate them either synthetically or using modified microorganisms (FAO, 2010).

Figure 23. Chondroitin sulphates in the market

Seafish has prepared a matrix for the different by-products and their possible future uses, giving a qualitative assessment in terms of capital and research requirements, which is shown below.

Table 11. By-products utilization matrix

Waste management option		Is it legal	Costs		End uses		Minimum throughput or scale of facility required	Minimum scope of facility	Estimated timescale to establish this option
			Capital cost	Cost per tonne	Produces a marketabl e product?	Readily available markets?			
		yes or no	low, med, high		yes, no, needs investigation, niche (requires special process approach)		small, medium, large	local, regional, national	0-1, 1-2, 2-3, 3+ years
Reduce	**Heads, tongues, cheeks, fins**	Yes	Low	Low	Yes	Niche	Small	Local	0-1
	Mince	Yes	Low	Low	Yes	Niche	Small	Local	0-1
	Roe & milt	Yes	Low	Med	Yes	Niche	Medium	Local	0-1
	Soup, stocks, sauces	Yes	Low	Med	Yes	Niche	Medium	Loc-Reg	1-2
Recycle All Seafood	**Fishmeal and oil**	Yes	High	High	High	Yes	Yes	National	1-2
	Ensiling (excluding heat treatment)	Yes	Med	Low	No	No	Small	Regional	0-1
	Rendering	Yes	High	High	Needs Investigation	Needs Investigation	Large	Regional	2-3
	Composting	Yes	Med-High	Med	Yes	Yes	Medium	Regional	2-3
	Aerobic digestion	Yes	High	High	Yes	Yes	Medium	Regional	2-3
	Mechanical and biological treatment	Yes	High	High	Needs Investigation	Needs Investigation	Medium	Loc-Reg	2-3
	Autoclaving	Yes	High	High	Needs Investigation	Needs Investigation	Small	Loc-Reg	1-2
	Alkaline hydrolysis	Yes	High	High	Needs Investigation	Needs Investigation	Large	Reg-Nat	3+
	Direct animal feeding (bait)	Yes	Low	Low	Yes	Yes	Small	Local	0-1
	Fertilisers and soil conditioners	Yes	High	High	Yes	Yes	Large	Regional	2-3

Table 11. By-products utilization matrix (continued)

Waste management option		Is it legal	Costs		End uses		Minimum throughput or scale of facility required	Minimum scope of facility	Availability of this option
			Capital	Cost per tonne	Produces a marketable product?	Readily available markets?			
		yes or no	low, med, high		yes, no, needs investigation		small, medium, large	local, regional, national	0-1, 1-2, 2-3, 3+ years
	Landspreading (excluding initial treatment)	Yes	Low	Low	Yes	Yes	small	Local	0-1
	Pharmaceuticals & cosmetics	Yes	High	High	Yes	Needs investigation	Large	National	3+
Recycle Finfish only	**Fish bones**	Yes	Low	Low-med	Yes	Yes	Medium	Regional	1-2
	Collagen & gelatine	Yes	High	High	Yes	Needs Investigation	Large	National	2-3
	Fish protein concentrates	Yes	High	High	Yes	Needs Investigation	Large	National	3+
	Fish protein hydrolysates	Yes	High	High	Yes	Needs Investigation	Large	National	3+
	Enzymes	Yes	High	High	Yes	Needs Investigation	Large	National	3+
	Leather	Yes	Med-High	High	Yes	Yes	Large	Reg-Nat	2-3
Recycle Shellfish only	**Crustacea based derivatives**	Yes	High	High	Yes	Yes	Large	Reg-Nat	3+
	Mollusc shell based products	Yes	Low	Med	Yes	Yes	Small	Loc-Reg	0-1
	Cultch	Yes	Low	Low	No	No	Small	Local	0-1
Energy recovery from waste	**Anaerobic digestion**	Yes	High	Med	Yes	Yes	Large	Reg-Nat	3+
	Incineration with energy recovery	Yes	High	High	Yes	Yes	Large	Reg-Nat	3+
	Biofuels	Yes	High	High	Yes	Yes	Large	Reg-Nat	3+
Disposal	**Disposal at sea**	Yes	Medium	Low	No	No	Small	Loc-Reg	0-1
	Incineration	Yes	High	High	No	No	Large	Reg-Nat	3+

Source: Archer *et al.*, 2005)

4.2. NUTRACEUTICALS AND FUNCTIONAL FOODS

It is considered that a nutraceutical is a "food, or part of food, that provides medical or health benefits, including the prevention and treatment of disease"; and that a functional food is a "food that provides health benefits beyond basic nutrition" (Alpine). Processors marketing these products are stressing the proved health benefits or the already recognised ones of these food supplements. The table below shows some products available in the market that contain fish hydrolysates. The Japanese authorities have approved Katsuobushi oligopeptide made from dried bonito; in Japan it is known as PEPIDE ACE 3000, in the USA as Vasotensin® and PeptACE™, and in Canada as Levenorm™. Another product approved in Japan is obtained from the hydrolysis of sardines and is called SP100N. In the USA a white fish hydrolysate, known as Secure®, has been on the market since 1994 (Thorkelsson, March 2009).

Table 12. Nutraceuticals

Collagen peptides	Claims	References
Hydrolysed dried bonito bowels		
Peptide ACE 3000	Blood pressure reduction	www.nippon-sapuri.com/english/
Vasotensin®	Blood pressure reduction	www.metagenics.com
PeptACE™	Blood pressure reduction	http://us.naturalfactors.com/
Levenorm™	Blood pressure reduction	www.onc.ca/
Peptides from sardines		
Lapis Support	Blood pressure reduction	http://www.tokiwayakuhin.jp/
Collagen peptides		
Bifidus & Collagen	Skin improvement	http://www.kagome.co.jp/
Hydrolysed whitefish		
Seacure	Gastrointestinal health	http://www.propernutrition.com
Protizen	Anti-stress	http://www.copalis.fr/
AntiSress 24	Anti-stress	www.fortepharma.com/fr/index.html
Fortidium	Anti-oxidative stress	www.biothalassol.com/
Nutripeptin	Glycaemia reduction	www.nutrimarine.com

Source: Thorkelsson, March 2009.

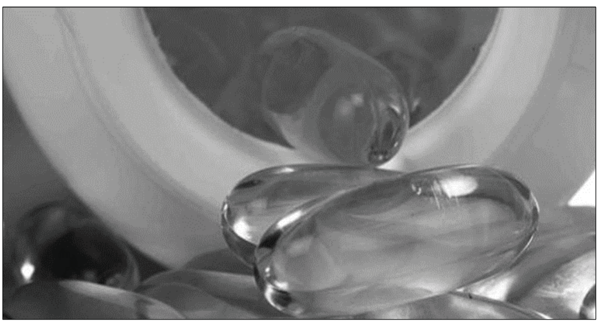
4.3. REFINED FISH OIL

There is ample research work to justify the premise that long chain poly unsaturated fatty acids (PUFAs) in the diet reduce the risk of cardiovascular diseases. Much work has been done to enrich common foods and preparations with healthy PUFAs, in order to increase the consumption of eicosapentaenoic acid (EPA) and docosahexaenoic (DHA), but in spite of the increasing number of these products, consumer acceptance is still limited because of the short shelf life and the appearance of unpleasant fishy flavours when rancidity appears (Sorenson, 2012).

Fish oil in the market could be roughly classified into 4 types or grades according to the concentration of PUFAs:

1. Cod liver oil. It has a low concentration of long-chain omega-3 fatty acids and may contain high levels of contaminants (organic mercury, PCB's, and DDT), but it has been a supplement for many years. Although it is an inexpensive way of obtaining the unsaturated fatty acids, it is unlikely that the market would sustain it because of the disagreeable taste.
2. Food grade fish oils. These are normally obtained from fish body oils. When the label indicates which fish it has been produced from, it normally means that the raw material utilized refers to a food grade fish oil intended for health purposes. The oil is offered in soft gel capsules in order to suppress the poor taste. A more purified type could be obtained by controlled molecular distillation that removes the cholesterol.
3. Fish Oil Concentrate. A normal process applied in the oil industry, known as winterisation to separate saturated fats, could be applied in a more controlled way to separate ethyl esters from fish oil, concentrating the PUFAs over the other more saturated ones.
4. Pharmaceutical fish oil. When a molecular distillation is applied, which means a much more costly process, PUFAs could be very well separated even from the monounsaturated fatty acids, which may cause some gastric problems (Alpine, 2004).

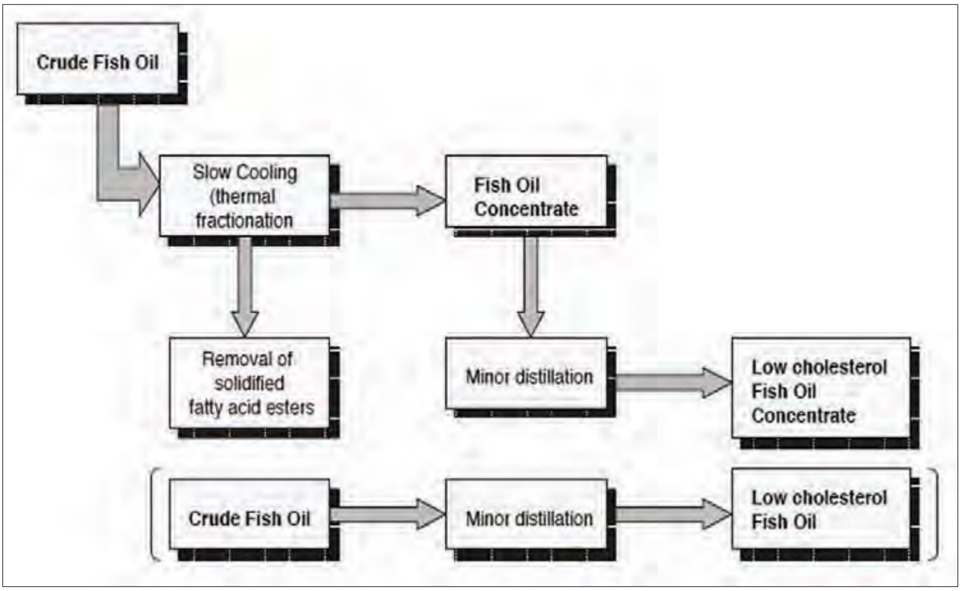
Figure 24. Oil capsules



Source: Pronova, 2013.

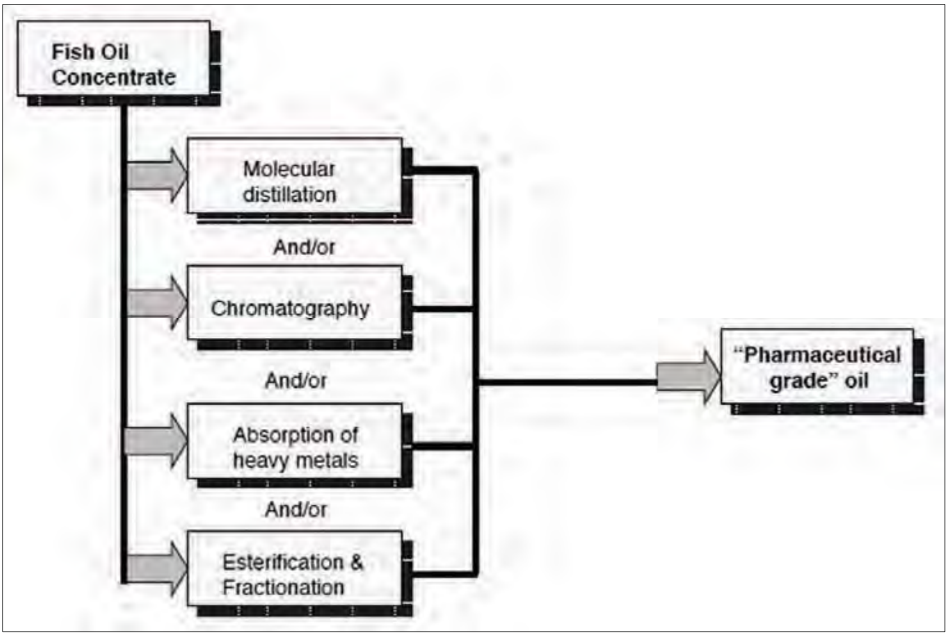
The perception that the nutraceutical industry has of the omega-3 oils becomes daily more important as science has repeatedly demonstrated that EPA and DHA are valuable in the support of health and wellness in many different conditions and ages. Considering the flavour and functional effect in foods, innovation has been focused on the production of concentrates that allow the nutraceutical industry to provide their customers with significant amounts of EPA and DHA without impairing flavour or taste of the final products and with the proper quantities to achieve the desired health effect (Dillingham, 2012). Schematic flow sheets for these concentrates are shown below:

Figure 25. Health-food grade fish oil



Source: Alpine, 2004.

Figure 26. Pharmaceutical grade fish oil



Source: Alpine, 2004.

The production of these concentrates has a drawback in generating a highly saturated by-product, which has been tackled, at least in one industry, by an old use of fish oil – that of producing biodiesel for power generation (Dillingham, 2012).

4.4. ENZYMES

As fish silage was developed in the 1970s, the possibility of fractionation to recover pepsins and peptides was recognised. The pepsins are used for processing some fishery products and the peptides could find applications in immunology. In vitro and in vivo studies have shown that certain peptide fractions in fish protein hydrolysates may stimulate the non-specific immune defence system. Both fish sauce and fish silage are protein hydrolysates with immune stimulating properties. By minor modifications of the technology to produce them, crude fish pepsins might be recovered and by ultrafiltration or a different separation process; the low molecular weight peptone fraction could be recovered too (Gildberg, 2004).

Pepsins from cold water species may be used in caviar production as well as for descaling fish. It is known that certain fish peptides have a stimulating effect on the fish non-specific immune defence system, and it may have similar effects on other animals and even humans. It seems that fish sauce may have similar peptides and become an interesting new nutraceutical food (Gildberg, 2004).

4.4.1. Enzymatic processing

Besides the products mentioned above there are other possibilities of enzyme processing, which are shown in the following table:

Table 13. By-products enzymatic processing

Raw material	Enzyme	Product	Application examples
Fish, Viscera, filleting by-products	Proteases	Peptides, amino-acids, nucleotides.	Animal feed Human nutrition (flavour) Nutraceuticals Cosmetics
Liver, eyes, flesh	Proteases, lipases	Oils Free fatty acids	Human nutrition Animal feed
Oyster Cooker effluent	Amylase, Protease	Peptides, amino acids, alcohols, IMP	Aroma
Shrimp heads and shells	Proteases	Chitin Carotenoids	Cosmetics Food and feed
Fish cartilage	Proteases	Chondroitin sulfate	Nutraceuticals Pharmaceuticals Cosmetics

Source: Roy, 2001.

4.5. CRUSTACEANS

As mentioned for chitin and chitosan the enzymatic process is rather expensive, but one way to balance this additional cost is to discover other products with extra value. Among them, for example in shrimp, there are bioactive compounds with antimicrobial activity, natural pigments such as astaxanthin and β-carotene, with their remarkable antioxidant capacity, polyunsaturated fatty acids, manufactured glucosamine derived by hydrolysing chitin, glycosoaminoglycans and amino acids (Kandra *et al.*, 2012).

5. REGULATIONS FOR BY-PRODUCTS USAGE AND DISPOSAL

The processors of fish by-products intended for human consumption must place only safe products on the market. The regulations that apply directly to the indication of chemical and microbial limits are: Regulation (EC No 2073/2005; Recommendation 2004/705/EC; Regulation (EC) No 178/2002. These regulations give the applicable limits and also give guidance and recommendations for processing and market distribution, including the corresponding criteria for the HACCP and hygiene keeping systems (Thorkelsson, 2009b).

The Animal By-Products Regulation or EC Regulation 1774/2002 came into force in May 2003. The aim of the legislation is to prevent any risk to public or animal health from animal by-products. The Regulation controls the collection, transport, storage, handling, processing and use or disposal of animal by-products.

The implementation of the Regulation throughout EU Member States was reviewed in 2004 and changes were recommended to increase the flexibility of the controls proportionate to the risk. Regulation 1774/2002 was replaced by Regulation (EC) No 1069/2009. This change came into force in 2011.

5.1. WASTE PRODUCTS REGULATION IN THE UK

The Regulation 1774/2002 (ABPR) determines that animal by-products not for human consumption should be disposed of utilizing the proper channels to do this. There are three types of by-products, ranked according to their risk. The first one implies a higher risk and the third means the lowest risk, and each one has its own storage, handling and disposal requirements. See table below (Archer *et al.*, 2005).

Table 14. Waste products classification in the UK

Category	Type of raw material included	Storage and disposal requirements
1	• All body parts affected by TSE, pet/zoo/circus animals, experimental animals • Wild animals suspected of being infected with disease communicable to humans or animals, • Animals containing residues of environmental contaminants • Animal material collected when treating waste water from Category 1 processing plants and • Mixtures of Category 1 material with either Categories 2 or 3 materials or both	• Incineration • Processing in an approved Category 1 processing plants (rendering) • Rendering followed by incineration • Rendering followed by landfill
2	• Mortalities • Animal by-products containing digestive tract or manure components • Animal material collected from treating waste water from slaughter houses or Category 2 processing plants • Products containing residues of veterinary drugs and contaminants listed in Group B(1) and (2) of Annex I to Directive 96/23/EC • Non-Category 1 by-products from non-member States. • Animals or parts of animals that have been slaughtered for human consumption, inc those killed to eradicate an epizootic disease • Mixtures of Category 2 material with Category 3 material	• Incineration • Processing in an approved Category 2 processing plants (rendering) • Rendering followed by incineration in approved plants • Rendering followed by landfill in approved plants • Certain marked material may be (i) used as an organic fertiliser, (ii) transformed in a biogas plant or (iii) buried in approved landfill sites • For material of fish origin, may be ensiled or composted (subject to approval).
3	• Parts of slaughtered animals for human consumption • Fish or other sea animals (exc. sea mammals) caught in the open sea for the purpose of reduction to fish meal • Fresh fish by-products from plants manufacturing fish products for human consumption.	• Incineration • Processing in an approved Category 3 processing plants • Rendering followed by incineration in approved plants • Rendering followed by landfill • Transformed into technical products at approved plants • Used as a raw material in pet foods & animal feeds • Transformed in a biogas or composting plant • For material of fish origin, ensiled or composted • Where authorised, used as a feed for zoo, circus, fur animal, hounds, maggot/ worm (as bait)

Source: Archer *et al.*, 2005.

The waste coming from seafood processing is normally in Category 3, but in some cases shellfish may contain algal toxins, meaning it will fall into Category 1 and when the shellfish has died before arriving the plant it is normally classified as Category 2.

The regulations (ABPR) indicate the conditions to further process the fish by-products, including requirements for storage, cleaning, treatment, transport etc. In the UK, plants that wish to process fish by-products normally require the approval of the Veterinary Service, and the proper environmental controls.

After the outbreak of the transmissible spongiform encephalopathies (TSE's) there are important restrictions to the use of animal proteins in animal feed. Council Decision 2000/766/EC does not allow feeding farmed animals intended for food with processed animal proteins with the exception of fishmeal utilized for non-ruminant diets.

With the TSE outbreak the aquaculture industry voluntarily banned the use of fishmeal for feeds to same fish species, a concept that has been included in the Commission Regulation 811/2003/EC, which covers also the burial and burning of by-products and additional clarification of the ABPR. The Regulation allows the utilization of wild fish and by-products to be used as fish feed.

5.1.1. Disposal on Land

The fact that waste might be a vector for the transmission of microbial or viral illnesses has been included in the Environmental Protection Act 1990, which does not allow disposal on land unless a proper license on waste management has been granted. The Act indicates also the transport conditions that the processor must fulfil, besides the documentation requirements.

The reduction of landfill has been included in the EU Landfill Directive, which requires that the quantities of waste being disposed of to landfill be reduced only to 35 percent of 1995 levels by 2020. Therefore industry should find new ways to take care of waste in order to comply with the regulation, which is another incentive for finding new value added applications (Archer *et al.*, 2005).

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