UNIVERSIDADE DO ALGARVE
FACULDADE DE CIÊNCIAS E TECNOLOGIA

Marine by-products in Portugal: sources, actual processing and alternative valorisation

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Dissertation for the obtainment of the master´s degree in Marine Biology

Supervisors: Professor Doutor Paulo Vaz-Pires

Abel Salazar Institute for the Biomedical Sciences

University of Porto - Portugal

Professora Doutora Teresa Modesto

Faculty of Sciences and Technology

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Declaração de autoria de trabalho

"Declaro ser a autora deste trabalho que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída"

Snapne'pi nitya jagatam ashesam
srashta cha hanta vibhura prabheyaha
trata tvam eka strividho vibinnaha
tam tvam nrisimham satatam nato'smi

I offer my obeisance unto Lord Nrisimha who is the creator, the maintainer and the destroyer of the entire universe. Although You perform all of these three acts simultaneously, You are completely beyond these activities. You are the all-pervading, unlimited supreme spirit.

(Lord Ramacandra's Nrisimha-Panchamrita)

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Well, the elaboration of this thesis witnessed several scenarios of my life: living in 4 different cities of 3 different countries, learning one new language, starting to learn another one, being possible only due to the kind help of:

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Engineer Irineu Batista, for his precious and always ready help and knowledge and….for the light meal moments in which the “team of fish eaters” (they know who they are!) was trying to convert me! (Unsuccessfully though….!),

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RESUMO

A produção de alimento de origem aquática em 2010 foi de 148.5 milhões de t de peixe (a pesca contribuiu com 88.6 milhões de t, cerca de 60% da produção total e a aquacultura com 59.9 milhões de t, cerca de 40% da produção total; destes, 128 milhões de t (86.5%) foram canalizados para a alimentação humana e os restantes 20 milhões de t (13.5%) utilizados para a produção de farinha e óleo de peixe. O pescado fornece 20% do aporte de proteína animal a cerca de 30 milhões de pessoas a nível mundial.

O fornecimento mundial de pescado tem aumentado significativamente devido ao crescimento sustentável da sua produção e à melhoria dos canais de distribuição nas últimas 5 décadas (taxa média de 3.2%/ano no período de 1961-2009), ultrapassando o aumento do crescimento populacional (1.7%/ano). Como consequência, o fornecimento mundial de pescado per capita aumentou de 9.9 kg (média do peso vivo equivalente) nos anos 60 para 18.4 kg em 2009.

A percentagem crescente de *stocks* pesqueiros sobre-explorados, a diminuição da pesca de espécies marinhas e a decrescente proporção de espécies que não estão completamente exploradas a nível global nos últimos anos são indícios de que o estado da pesca marinha mundial está a piorar e tem um impacto negativo na produção de pescado. A sobre-exploração tem um impacto negativo não só a nível ecológico mas também ao nível da produção pesqueira dado esta estar reduzida, conduzindo a futuros impactos sociais e económicos negativos.

Em relação à aquacultura, a sua produção aumentou cerca de 12 vezes entre 1980 e 2010, com uma taxa média anual de 8.8%, continuando a crescer a partir daí apesar de a uma taxa mais baixa. Em 2010 a aquacultura atingiu o seu máximo com 60 milhões de t de produção, correspondente a um valor estimado em 125 mil milhões de dólares (valores excluindo plantas aquáticas e produtos não alimentares).

Atualmente, na pesca, os indivíduos de tamanho abaixo do mínimo legal, com valor comercial baixo ou as espécies sem quota piscatória são normalmente devolvidos ao mar – as chamadas devoluções ao mar. A percentagem de devoluções ao mar varia dentro das frotas pesqueiras dado depender da seletividade dos mecanismos de pesca. As devoluções ao mar estão estimadas em 7.3 milhões de t/ano (cerca de 8% da captura total de pescado) para o período entre 1992 e 2001. Estas devoluções são um desperdício de recursos biológicos, sendo em parte responsáveis pela

depleção das populações de espécies aquáticas. A frota de arrasto tem um papel muito importante na captura e dispersão de biomassa, dada a significativa porção de capturas na frota de arrasto ser de espécies não-alvo, sendo portanto devolvidas ao mar já mortas. Vários autores consideram que a grande quantidade de peixes , crustáceos e moluscos mortos devolvidos ao mar em áreas pesqueiras tem potenciais repercussões ao nível das comunidades biológicas da superfície, coluna de água e sedimento. Para além das devoluções ao mar, outra fonte de sub-produtos marinhos é o processamento a bordo, principalmente a evisceração e a consequente limpeza, gerando quantidades consideráveis (por vezes cerca de 80% do indivíduo) de desperdícios como cabeças, espinhas, vísceras, pele, etc. Para além dos efeitos adversos na cadeia trófica, esta evisceração a bordo contribui para a acumulação de poluentes como PCBs, dioxinas e metais pesados e a dispersão, nas áreas de pesca, dos parasitas existentes nas vísceras. Para além da FAO, a Comissão Europeia também tomou várias ações para a implementação das políticas de "zero-desperdícios" e "não devoluções ao mar" salientando assim a importância da valorização dos sub-produtos marinhos como medida de redução do desperdício. Os sub-produtos marinhos também podem ter origem nos portos e lotas onde ocorre a primeira venda de pescado, que pode ser rejeitado por inspeção sanitária ou retirado por não ser vendido. Outra fonte de sub-produtos de origem marinha é a indústria transformadora do pescado, por exemplo as indústrias de salga e seca de bacalhau, de conservas e de congelação de pescado. Neste trabalho foi efetuada uma sondagem com uma abordagem multimetódica com o objetivo de avaliar as quantidades de subprodutos marinhos produzidos em Portugal e as suas principais utilizações.

Esta pesquisa foi efetuada, dependendo da situação, através de questionários enviados por fax ou email às empresas da indústria marinha, entrevistas com os responsáveis pelas empresas e consulta de registos relacionados com o tema, obtidos das entidades competentes. Efetuou-se também uma pesquisa bibliográfica sobre as atuais valorizações de subprodutos de origem marinha e potenciais utilizações. Da pesquisa biliográfica aos trabalhos do grupo ICES concluíu-se que em Portugal as devoluções ao mar variam entre cerca de 1000 t/ano no caso da cavala (*Scomber colias*) e 8 t/ano no caso do Pimpim (*Capros aper*). Em relação aos valores de retiradas e rejeições os valores situam-se entre cerca de 3000 t/ano e 700 t/ano, respectivamente.

Do total de respostas aos questionários (cerca de 17%) concluiu-se que a indústria que mais significativamente contribui para a geração de subprodutos é a conserveira, principalmente nos Açores, atingindo valores de cerca de 3,000 t/ano. Em Portugal continental as indústrias que produzem mais subprodutos são a salga e seca de bacalhau na zona da ria de Aveiro, com cerca de 1,300 t/ano e a conserveira no Algarve, com cerca de 1,200 t/ano. De salientar que a percentagem de respostas da zona Norte foi relativamente menor, não refletindo assim a realidade regional em termos de indústria marinha. Das entrevistas às fábricas de farinha de peixe e consulta de registos, concluiu-se que as 4 fábricas existentes em Portugal processam cerca de 135,000 t/ano; cerca de 900 t/ano são recolhidas em Portugal e processadas no Norte de Espanha e cerca de 500 t/ano são geradas na Andaluzia e processadas em Portugal. Na ilha da Madeira todos os resíduos atualmente têm como destino o aterro sanitário, por inexistência de soluções alternativas. Para além da produção de farinha e óleo de peixe, outras utilizações dos subprodutos marinhos incluem a extracção de quitosano para aplicações diversas como suplementos alimentares, e a extração de várias enzimas ativas a baixas temperaturas como a tripsina, elastase e colagenases serinas, com diversas aplicações que têm em conta a sua especificidade em relação à temperatura em que se encontram ativas.

TERMOS CHAVE: Pesca em Portugal, valorização alternativa de subprodutos marinhos.

ABSTRACT

The total production of aquatic food, in 2010, was estimated in 148.5 million t of fish (fish capture contributed with 60% and aquaculture with 40%) from which 86.5% were directed to human consumption with the remaining 13.5% used mainly for the production of fish meal and oil. Nowadays fish discards are estimated in 8% of the total fish catch with important ecological and economic impacts. The marine processing industry also generates large quantities of "waste". Due to the new European Commission policies of "no-discard" and "zero-waste" several research projects have been created to valorise marine by-products, MARMED project (within which this thesis was made) being one of them. In this study a multi-method survey was conducted to inquire about the quantities and types of marine by-products and discards generated and processed in Portugal. These included three types of methods: written questionnaires to the fish processing industries, interviews with the managers and records consultation. From around 17% total replies it was visible that in Portugal the industry that more contributes to the generation of marine by-products is the canning industry, particularly in the Açores with values of 3,000 t/year approximately, followed by the cod salting and drying industry in the central region of the continental Portugal with 1,300 t/year approximately. The information gathered from the four fish meal factories existing in Portugal showed that in total they process around 135,000 t/year of marine by-products, around 900 t/year are produced in Portugal but processed in Spain, and around 500 t/year are produced in Andalucia and processed in Portugal. In Madeira all by-products go to landfill due to the lack of other valorization solutions. Besides the production of fish meal and fish oil, other utilizations of marine by-products include the extraction of chitosan for several applications like food supplements, the extraction of several enzymes active at low temperatures like tripsine, elastase and others.

KEYWORDS: Marine by-products; Portuguese fisheries; Alternative valorisation of marine by-products

Host Institutions and conditions

Abel Salazar Institute for the Biomedical Sciences of the University of Porto (Institution where the work was done) and the Faculty of Sciences and Technology of the University of Algarve (Institution that confers the degree). This work was developed in the frame of the Project MARMED: Development of innovating biomedical products from marine resources valorisation (2011-1/164), funded from the European Regional Development Fund through the Atlantic Area Transnational Cooperation Program.

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1. LITERATURE REVIEW

1.1 Importance of marine products, fisheries and aquaculture in the world

Fishing, as an ancient activity, was always an important part of many human societies. Nevertheless it was during the 20th century that the fishing activity had a dramatic change due to several factors: the freezing technology invention, the fishing effort increase due to the introduction of steam trawling and all the improvements in fishing tackle/equipment (Blanco *et al.*, 2007). In 1885, the concerns about the decrease of specific fish stocks in coastal waters started (Kreuzer, 1974). By then, the idea of the inexhaustibility of the sea was considered erroneous in the McIntosh´s book "Resources of the Sea", thus implying the need for the conservation of fish stocks (Blanco *et al.*, 2007).

The potential of fisheries has been estimated through several institutions being FAO (Food and Agriculture Organization of the United Nations) Fishery Resources division one of them.

Since the 1960's, FAO has been monitoring the state of capture fisheries. The results of this monitoring show that the total world marine capture fish production increased at a rate of 6% per year since 1950 (19.3 million t) to 1970 (around 60 million t). The estimation of maximum potential of the traditionally exploited marine species (excluding cephalopods) was 80-100 million t/year. This estimation was further confirmed by later studies. In 1989 and 2002 this amount was surpassed with more than 100 million t and 134 million t, respectively (Blanco *et* al., 2007).

Marine captures contributed around 86% to this production, even though this contribution has diminished in the last decades due to the faster expansion of marine and inland water aquaculture (FAO, 2005).

In terms of total production of aquatic food in 2010, for instance, it was estimated in 148.5 million t of fish (fish capture contributed with 88.6 million t, around 60% of the total production, and aquaculture with 59.9 million t, around 40% of the total production) (Table 1.1 and Fig. 1.1) from which 128 million t (86.5%) were canalized for human consumption with the remaining 13.5% (20 million t) utilized mainly for the production of fish meal and oil. Estimated numbers point to an increase in 2011 (154 and 131 million t, respectively) (Fig. 1.2) (FAO, 2012).

Table 1.1 - World capture fisheries and aquaculture production and utilization (FAO, 2012).

	2006	2007	2008	2009	2010	2011
			(Million tonnes)			
PRODUCTION						
Capture						
Inland	9.8	10.0	10.2	10.4	11.2	11.5
Marine	80.2	80.4	79.5	79.2	77.4	78.9
Total capture	**90.0**	**90.3**	**89.7**	**89.6**	**88.6**	**90.4**
Aquaculture						
Inland	31.3	33.4	36.0	38.1	41.7	44.3
Marine	16.0	16.6	16.9	17.6	18.1	19.3
Total aquaculture	**47.3**	**49.9**	**52.9**	**55.7**	**59.9**	**63.6**
TOTAL WORLD FISHERIES	**137.3**	**140.2**	**142.6**	**145.3**	**148.5**	**154.0**
UTILIZATION						
Human consumption	114.3	117.3	119.7	123.6	128.3	130.8
Non-food uses	23.0	23.0	22.9	21.8	20.2	23.2
Population (*billions*)	6.6	6.7	6.7	6.8	6.9	7.0
Per capita food fish supply (*kg*)	17.4	17.6	17.8	18.1	18.6	18.8

Notes: Excluding aquatic plants. Totals may not match due to rounding. Data for 2011 are provisional estimates.

World fish food supply has increased significantly, due to sustained growth in fish production and the improvement in the distribution channels, in the last five decades (average rate 3.2%/year in the period of 1961-2009) surpassing the increase in the world population (1.7 %/year). As a consequence, the world *per capita* food fish supply increased from 9.9 kg (average live weight equivalent) in the 1960s to 18.4 kg in 2009 indicating a further increase in fish consumption to 18.6 kg (FAO, 2012).

Regarding the contribution of fish to the human protein intake, several studies have been made namely by FAO. These studies state that the protein from fish origin was 16.6 % of the world´s population intake of animal protein and 6.5 % of the total protein intake in 2009. Fish provides around 3.0 billion people worldwide with 20% of their intake of animal protein and 4.3 billion people with 15% of this type of protein.

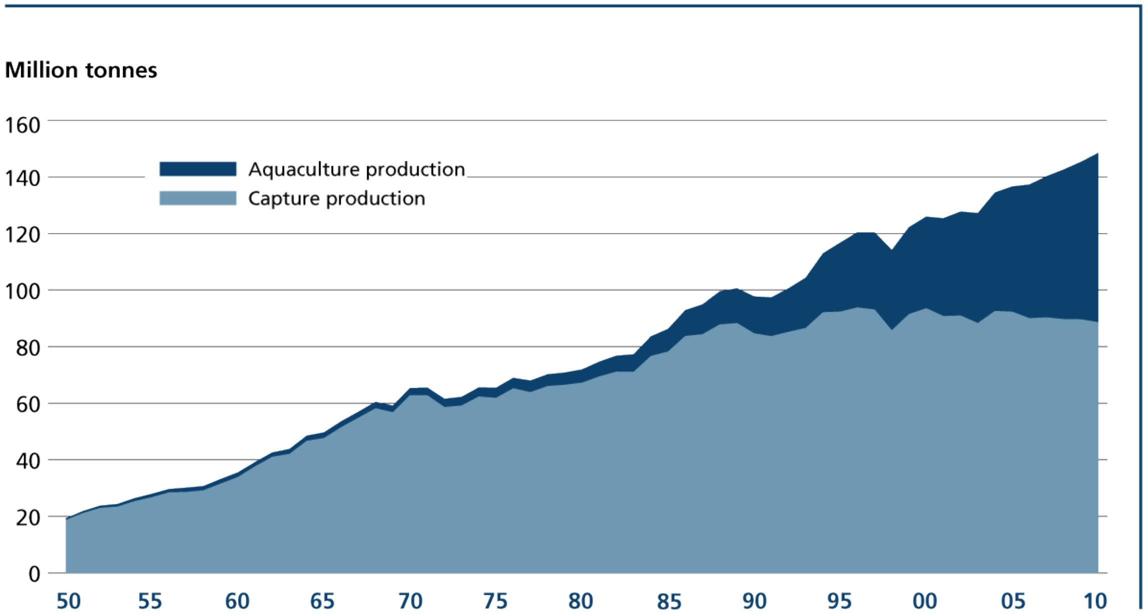

Figure 1.1 - World capture fisheries and aquaculture production (FAO, 2012).

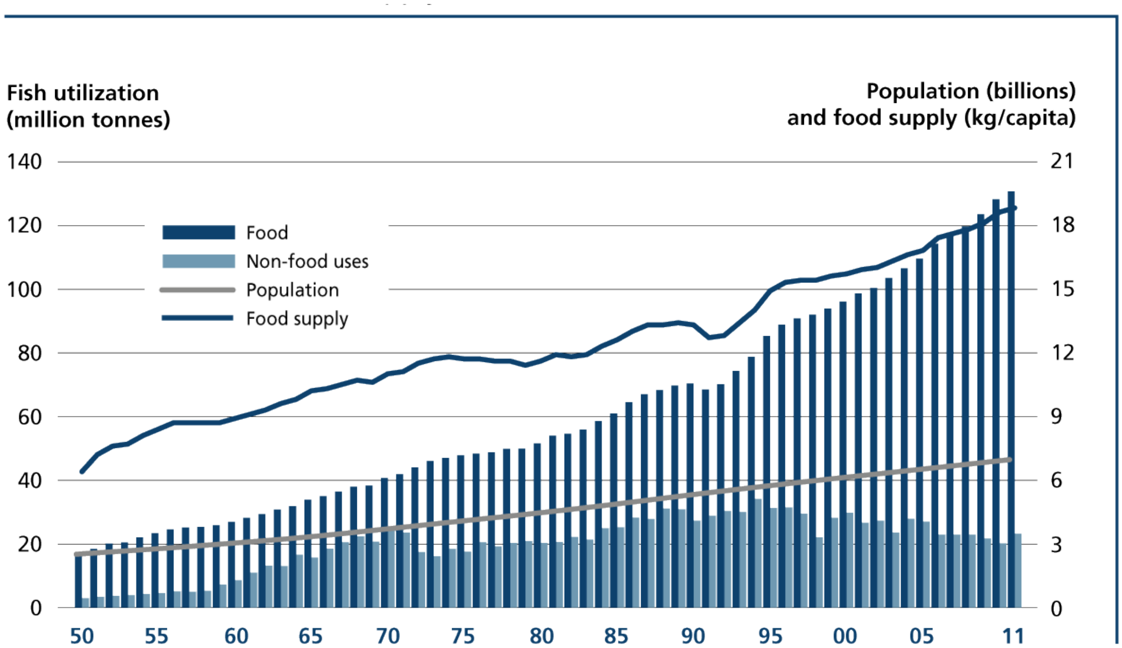

Figure 1.2 - World fish use and supply (FAO, 2012).

There is a visible difference between developed and developing countries regarding the contribution of fish to animal protein intake. In developing countries, although the values are low, they can reach 19.2 % and 24.0% in Low-Income, Food-Deficit Countries (LIFDC). Both in developing and developed countries this percentage has decreased slightly in recent years due to the rapid growth of other animal proteins (FAO, 2012).

Concerning the overall global capture fisheries production, in general it is stable at about 90 million t, despite the visible changes in catch trends depending on the countries, fishing area and species. Landings of all marine species, except anchoveta, ranged from 72.1 million to 73.3 million t between 2004-2010. On the other hand, the most visible changes were in anchoveta landings in the Southeast Pacific that decreased from 10.7 million t in 2004 to 4.2 million t in 2010. Inland water capture production had a continuous growth, with an overall increase of 2.6 million t between 2004-2010 (Fig. 1.3). Regarding inland waters, its total global capture production has increased significantly since the mid-2000s with an estimated production reported of 11.2 million t in 2010 and an increase of 30 % since 2004, even though there may be significant underestimations in some regions (FAO, 2012).

Fisheries and aquaculture provide numerous jobs, besides the primary production sector, like in ancillary activities such as processing, packaging, marketing and distribution, manufacturing of fish-processing equipment, net and gear making, ice production and supply, boat construction and maintenance, research and administration. This employment (together with dependents) is estimated to support the livelihoods of 660-820 million people: 10-12% of the world´s population (FAO, 2012).

Regarding the world total number of fishing vessels, it was estimated in 2010 in 4.36 million, from which 74% (3.23 million) vessels were considered to operate in marine waters and the remaining 1.13 million operating in inland waters (FAO, 2012).

Nowadays one major concern is focused on the exploited fish stocks. In this regard, studies by FAO show that the world´s marine fisheries have increased significantly between 1950 and 1996 from 16.8 million t to 86.4 million t, respectively, after which there was a decrease before stabilization at about 80 million t. In 2010 there was a global record production of 77.4 million t. The proportion of non-fully exploited stocks has been decreasing gradually since 1974, date of the first FAO assessment. On the other hand, the percentage of the overexploited stocks has been increasing, markedly in late 1970s and 1980s from 10% in 1974 to 26% in 1989 (Fig. 1.5).

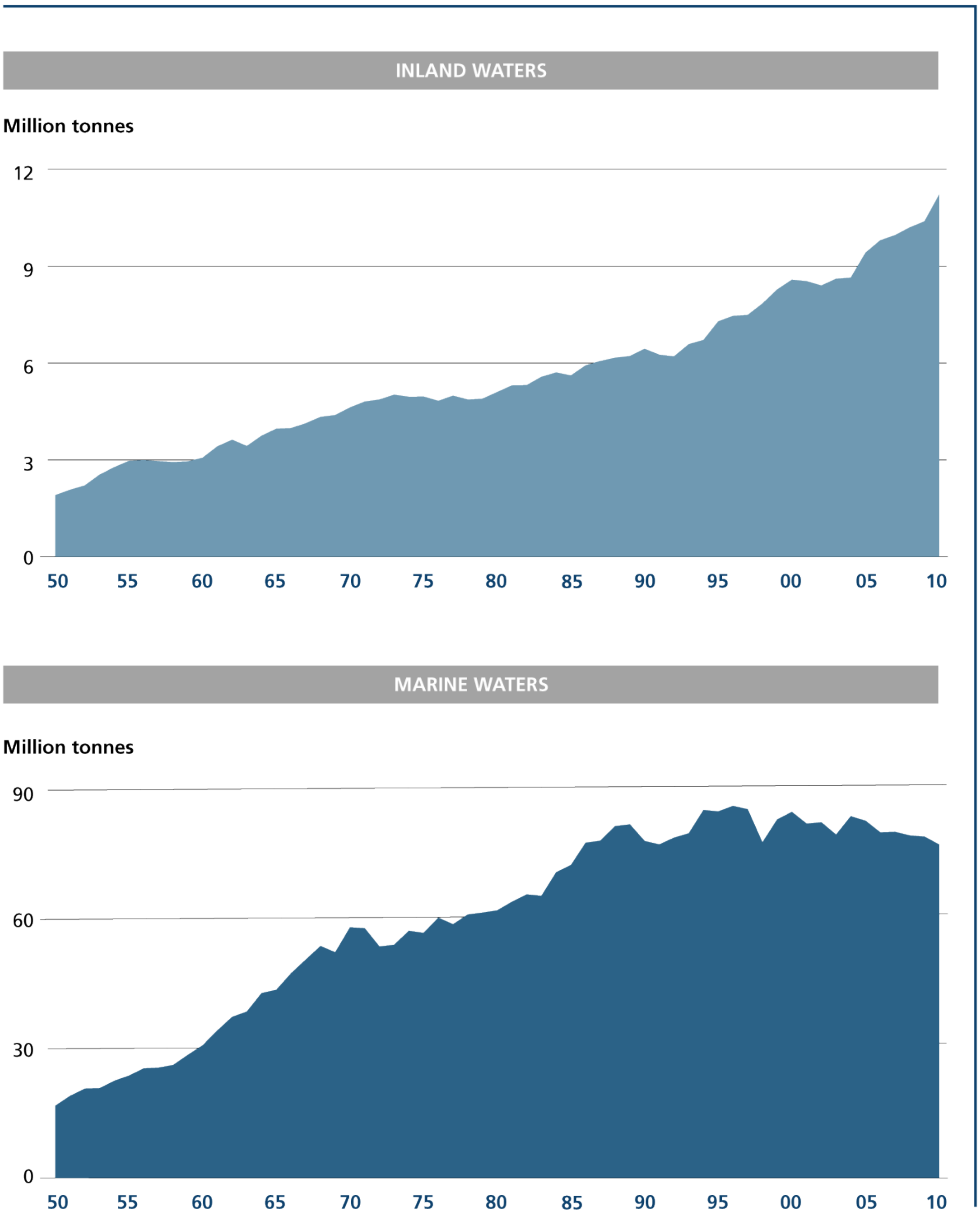

Figure 1.3 - World capture fisheries production (inland and marine waters) (FAO, 2012).

The number of overexploited stocks continued to increase, after the 1990s but at a slower rate. Figure 1.4 shows the impact of overfishing on the ecosystem.

If the plans to rebuild the overexploited stocks are put in place, then it is possible to have higher production even from these stocks. Regarding the fraction of fully exploited stocks, producing catches reaching their maximum sustainable production and with no room for further expansion,

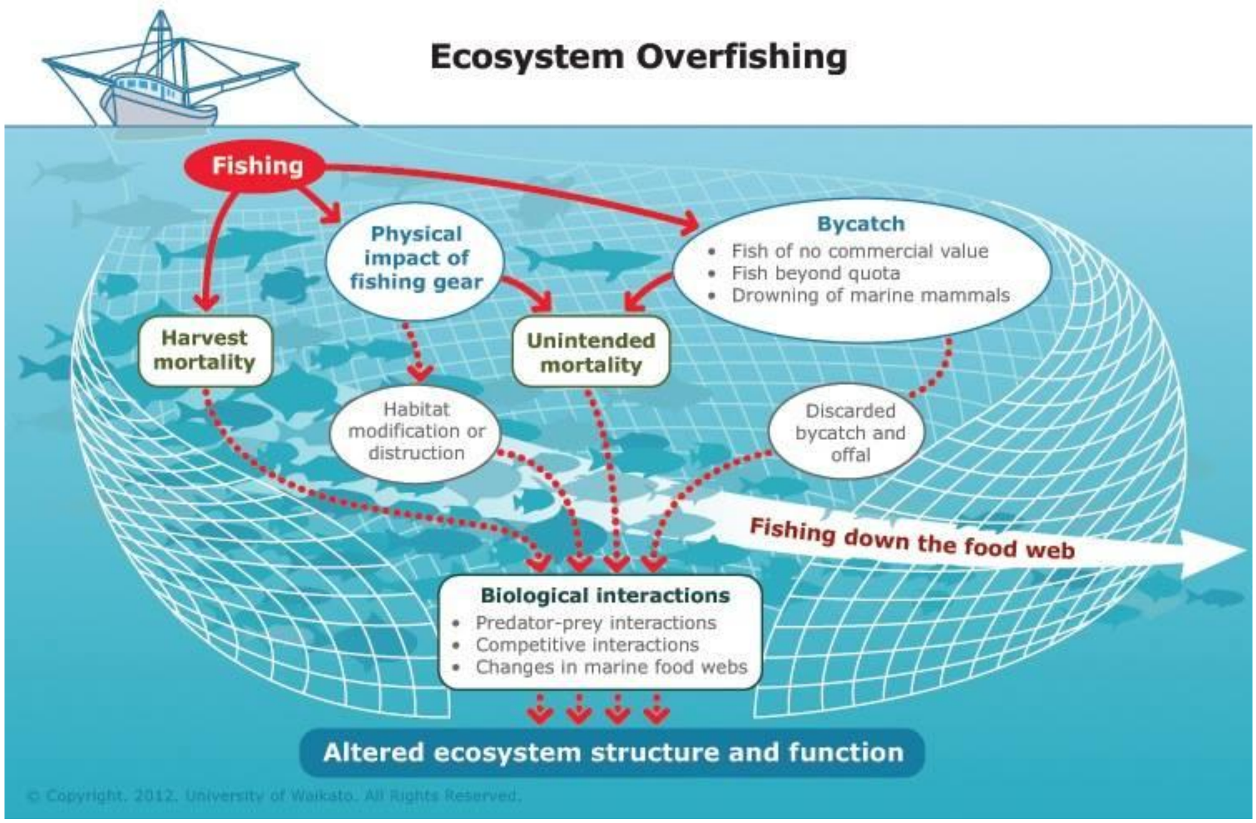

Figure 1.4 - Overfishing ecosystem impact (University of Waikato, 2012).

thus requiring effective management in order to avoid decline, it had minimal changes over the time: from 1974 to 1985, around 50%, in 1989 it decreased to 43% and in 2009 it increased to 57%. Around 29.9% of the stocks are classified as overexploited: they produce yields lower than their biological and ecological potential thus requiring a strict management planning to restore their full and sustainable productivity, according to the Johannesburg Plan of Implementation, outcome from the World Summit on Sustainable Development (United Nations, 2004), demanding all overexploited stocks to be restored to the level of maximum sustainable yield by

2015, an objective questionable to be achieved as planned. In 2009, 12.7% of the stocks were non-fully exploited and are still under relatively low fishing pressure, with potential to increase their production (even though their potential production is very often low) and requiring adequate management plans to make sure that any possible increase in the exploitation rate will not result in overfishing in the future (FAO, 2012).

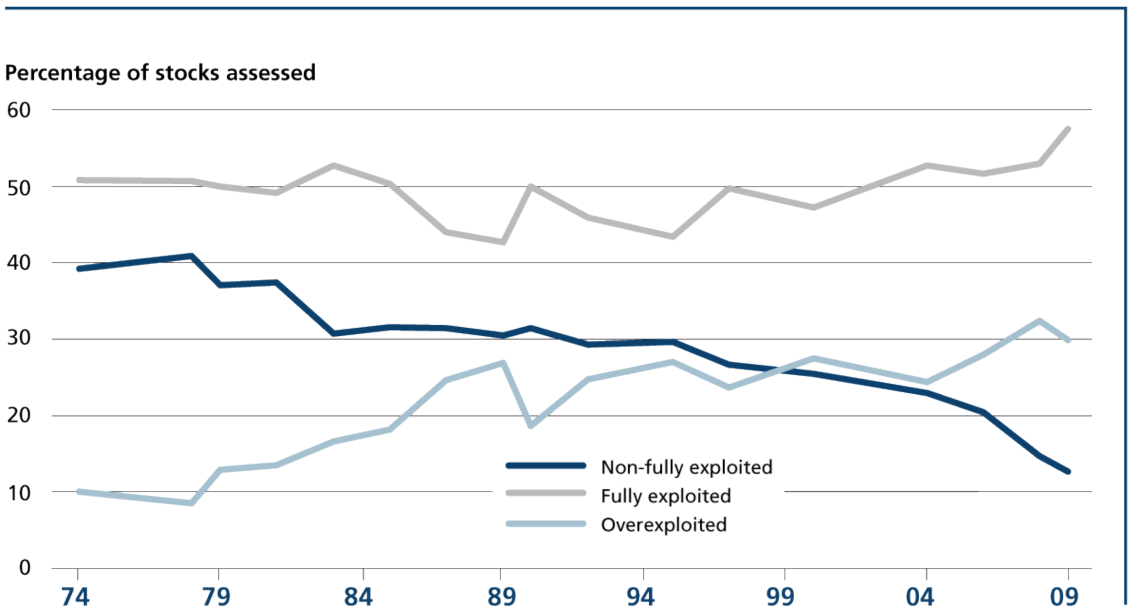

Figure 1.5 - Global trends in the state of world marine fish stocks (FAO, 2012).

On the other hand, 30% of world marine capture fisheries production are accounted by top ten species which stocks are fully exploited and have no potential for increases in the production, whereas some stocks are overexploited but it is possible to increase their production by putting in place effective rebuilding plans. Examples of fully exploited stocks are: the two main stocks of anchoveta in the Southeast Pacific, Alaska Pollock in the North Pacific, blue whiting in the Atlantic, Atlantic herring in both Northeast and Northwest Atlantic and chub mackerel in the Eastern and Northwest Pacific. Examples of overexploited stocks are Japanese anchovy in the Northwest Pacific and Chilean jack mackerel in the Southeast Pacific. In 2009, there were estimations for the overexploitation of the stock of largehead hairtail in the main fishing area in the Northwest Pacific. Still in 2009 one-third of the seven principal tuna species were estimated to be overexploited, 37.5% were already fully exploited and 29% were non-fully exploited. Unless significant improvements in the management of tuna species are implemented, the status of tuna stocks (and catches as a consequence) may further deteriorate in the long term. This is due to the significant tuna demand and the tuna fishing fleets overcapacity (FAO, 2012).

The increased percentage of overexploited fish stocks, the declining of global marine catch and the decreased proportion of non-fully exploited species around the world, in the last few years, are signs that the state of world marine fisheries is worsening and is having a negative impact on fishery production. Overexploitation has a negative impact not only on the ecological aspect but also on the level of fish production since it is reduced leading to further negative social and economic consequences. Effective management plans must be put in place in order to increase the contribution of marine fisheries to the food security, economies and well-being of the coastal communities. For some highly migratory, straddling and other fish resources that are exploited only or partially in the high seas, the situation is more critical. In 2001, the United Nations Fish Stocks Agreement was put in practice and should be used as a legal basis for management measures of the high seas fisheries (FAO, 2012).

However, despite the serious global situation of marine capture fisheries, there has been made good progress in reducing exploitation rates and in restoring overexploited fish stocks and marine ecosystems by the effective management actions in some areas. 67% of stocks the United States of America are being sustainable harvested, with only 17% being overexploited. Also in New Zealand 69% of the stocks are above management targets, thus urging for mandatory rebuilding plans for all fisheries below target thresholds. Australia also reported overfishing for only 12% of the stocks in 2009. The Newfoundland-Labrador Shelf, the Northeast United States Shelf, the Southern Australian Shelf and California Current ecosystems have shown since the 1990s significant decreases in fishing pressure, so they are now at or below the modelled exploitation rate that gives the multispecies maximum sustainable yield of the ecosystem. These successful examples support the effective management of fisheries (FAO, 2012).

Regarding the form in which the catch is utilized in the year 2010, 40.5% of the world's fish production (60.2 million t) was in live, fresh or chilled forms, 45.9% (68.1 million t) was processed in frozen, cured or otherwise prepared forms for direct human consumption and 13.6% as destined for non-food uses (Fig. 1.6). There has been an increase in the proportion of fisheries production used for direct human consumption instead of other uses, since the early 1990s. On the other hand, in the 1980s around 68% of the fish produced was used for human consumption, having this share increased to more than 86% in 2010 (128.3 million t), and 20.2 million t were used to non-food purposes, from which 75% (15 million t) was destined to fish meal and fish oil and the remaining 5.1 million t used as fish for ornamental purposes, for culture (fingerlings, fry, etc.), for bait, for pharmaceutical uses and also as direct feed in aquaculture, for livestock and for fur animals (FAO, 2012).

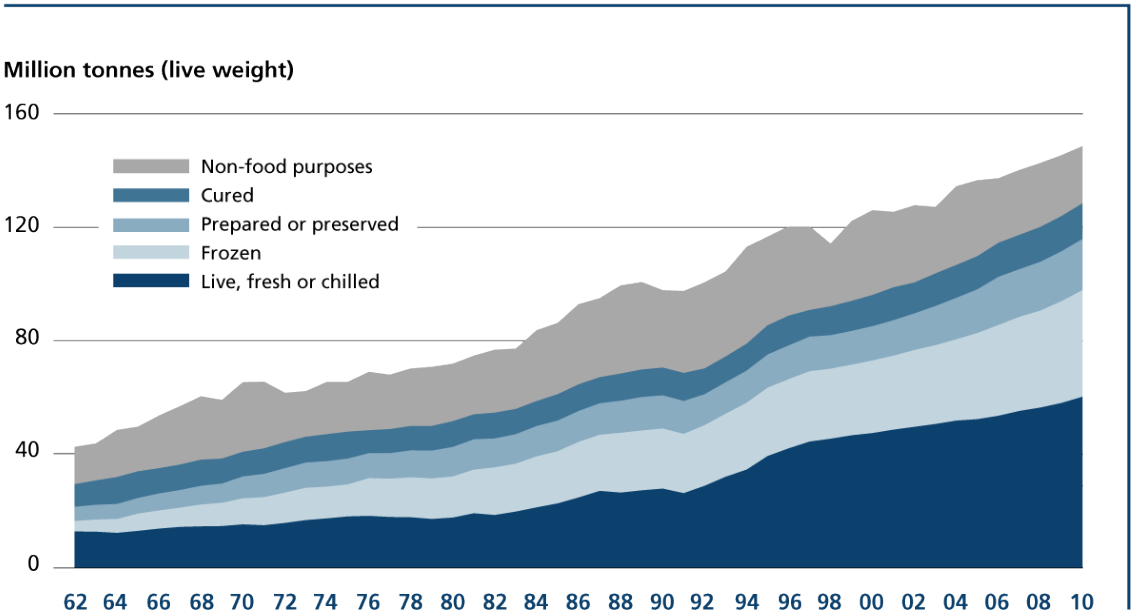

Figure 1.6 - Utilization of world fisheries production (FAO, 2012).

Regarding aquaculture, its production has increased by almost 12 times between 1980-2010, with an average annual rate of 8.8%. Aquaculture continues to grow, despite at a slower rate than in the 1980s and 1990s. In 2010, world aquaculture reached a peak of 60 million t with an estimated $ 125 billion in the U. S. (excluding aquatic plants and non-food products). If farmed aquatic plants and non-food products are included in the statistics, then the value of aquaculture production in 2010 reaches 79 million t, worth US $ 125 billion. Nowadays, about 190 countries raise around 600 aquatic species in farming systems of different intensities and technological sophistication, including hatcheries that produce seeds for stocking to the wild, especially in inland waters (FAO, 2012).

Aquaculture production is distributed unevenly throughout the regions and countries of different economic development levels. The top ten producing countries contributed for 87.6% of the quantity and 81.9% of the value of the world´s farmed food fish, in 2010. In this year, Asia alone contributed for 89% of the volume of world aquaculture production, being China the biggest contributor which accounted for more than 60% of world aquaculture production volume. Other

Asiatic big producers were: India, Vietnam, Indonesia, Bangladesh, Thailand, Myanmar, Philippines and Japan. The Asian share of freshwater aquaculture has increasing gradually from around 60% in the 1990s until 65.6 % in 2010 (FAO, 2012).

Global aquaculture production is dominated by freshwater fishes 56.4%, 33.7 million t), followed by molluscs (23.6%, 14.2 million t), crustaceans (9.6%, 5.7 million t), diadromous fishes (6.0%, 3.6 million t), marine fishes (3.1%, 1.8 million t) and other aquatic animals (1.4 million t, 814 300 t). Even though feed is generally considered a limiting factor in aquaculture development, one-third of all farmed food fish production (20 million t) is achieved without artificial feeding like bivalves and filter-feeding carps (Fig. 1.7). Nevertheless, the percentage of non-fed species in the global aquatic production has decreased from more than 50% in 1980 to 33.3% nowadays, showing the faster body-growth rates obtained in the cultivation of fed species and the growing demand of the consumer for higher trophic-level species of fishes and crustaceans (FAO, 2012).

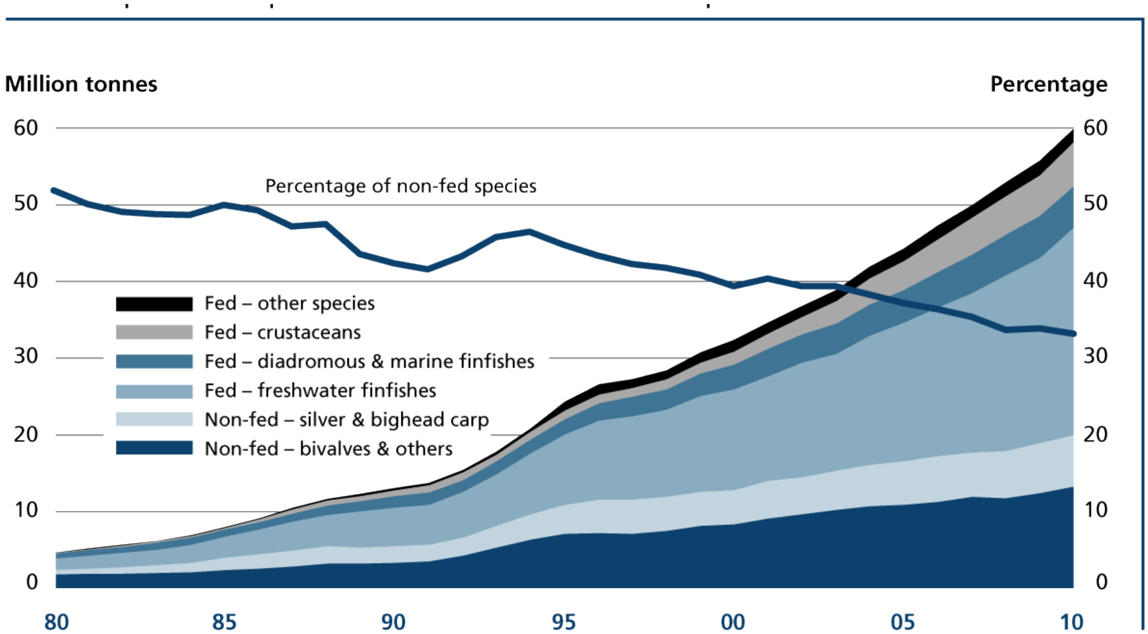

Figure 1.7 - World aquaculture production of non-fed and fed species (FAO, 2012).

Aquaculture has been the engine driving growth in total fish production, while global capture production has been stable, increasing its contribution to world total fish production from 20.9% in 1995 to 32.4% in 2005 and 40.3% in 2010. On the other hand, regarding world food fish production, aquaculture has increased its contribution from 9% in 1980 to 47% in 2010. Regarding freshwater production, it increased from less than 50% before 1990 to almost 62% in

2010, while the share of marine aquaculture production decreased from more than 40% to just above 30% (FAO, 2012).

1.2 Marine industry in Portugal

1.2.1 Fisheries

In Portugal, fisheries employed in 2011 approximately 0.3% (13,156 out of 4,361,187) of the working population with 16,797 registered fishermen in 2013 (INE, 2014).

The total amount of fish landed by the Portuguese fleet was 193,211 t in 2013, where 162,258 t was fresh fish and 30,953 t frozen fish (16% of total landed fish). Most of this fish was for human consumption and the major part of landed fresh fish was whole fish (95.5 %), but in the case of frozen fish only 22.3 % was whole fish (INE, 2014).

In the Portuguese auctions, the total amount of fresh or refrigerated fish sold was 144,654 t and its value was about 253 million Euros in 2013. The distribution was the following: 123,907 t (marine and freshwater fish), 1,097 t (crustaceans) and 19,646 t (bivalves and cephalopods). The main species of fresh fish sold in auction (Table 1.2) were Atlantic chub mackerel (*Scomber colias*), sardine (*Sardina pilchardus)*, horse mackerel (*Trachurus trachurus*), tuna (*Thunnus* spp.) and similar, black scabbard fish (*Aphanopus carbo*), blue jack mackerel (*Trachurus picturatus*), hake (*Merluccius merluccius)*, blue whiting (*Micromesistius poutassou*) and octopus (*Octopus* sp.) (INE, 2014).

Table 1.2 – Main landings in the Portuguese auctions in 2013 (INE, 2014).

Landings in auctions (fresh fish) in 2013	
Species	Amount (tons)
Atlantic chub mackerel (*Scomber colias*)	37,309
Sardine (*Sardina pilchardus*)	27,669
Horse mackerel (*Trachurus trachurus*)	15,337
Tuna (*Thunnus* spp.) and similar	11,502
Black scabbard fish (*Aphanopus carbo*)	4,093
Blue jack mackerel (*Trachurus picturatus*)	3,497
Hake (*Merluccius merluccius*)	2,745
Blue whiting (*Micromesistius poutassou*)	1,996
Octopus (*Octopus* sp.)	12,934

1.2.2 Aquaculture

The total sales of aquaculture products in 2011 were around 53 million Euros. In Portugal there are 1,492 aquaculture registered companies, from which 1472 are of salt and brackish water and only 20 of fresh water. The total area of aquaculture land is of 1,583 ha (INE, 2014).

The best year for production was 2012 with a total of 10,500 t, from which 4,300 were turbot (Aquaculture Portugal, 2014). In 2013 there was a general decrease in the aquatic production due to the decrease of turbot production on one of the major Portuguese aquacultures of the sector. This particular aquaculture influences all Portuguese aquaculture statistics since it produces significant quantities of turbot. In 2014, after this incident, aquaculture is expected to increase again (Pedro, 2015 oral communication). The exception to this tendency was blue mussel (*Mytilus* spp.) which increased, particularly in the Algarve region, to approximated values of 1,500 tons in 2013. The quantities of other species produced during 2013 were: grooved carpet shell (*Ruditapes* spp.) 2,500-3,000 t; oyster (*Crassostrea* sp.) 700-800 t; trout (*Oncorhynchus mykiss*) 1,000 t; sea bream (*Sparus aurata*) 400-500 t (in Madeira Island), flounder (*Platichthys* spp.*)* 35 t (Aquaculture Portugal, 2014).

1.2.3 Fish processing industry

The latest published data shows that in Portugal the fish processing industry was composed of 180 companies, from which 163 were in continental Portugal in 2012. The total number of employed people in this type of industry was 6823 in 2012. Regarding production, in 2012, there was a total of 105,892 t of frozen products composed by: 14,823 t of aquatic invertebrates (squids, octopus, cuttlefish, molluscs and others); 7,477 t of hake; 3,731 t of fillets; 7, 669 t of sardine; 27, 161 t of codfish and 4,029 t of redfish. Dried and salted products account for 61,411 t with salted codfish contributing with 50,049 t. The contribution of the canning industry was 44,700 t in total distributed by: sardine canning in olive oil 4,549 t; sardine canning in other vegetable oils 5,458 t; sardine canning in tomato sauce 2,802 t; tuna canning in olive oil 3,003 t; tuna canning in other vegetable oils 10,467 t; mackerel, horse mackerel and others in olive oil 1,814 t; mackerel, horse mackerel and others in other vegetable oils 763 t (INE, 2014).

In terms of value, in 2012, the industry of frozen fish sold 329,949,000 Euros corresponding to 85,602 t; the industry of dried and salted fish contributed with 258,951 Euros (47,406 t) and the canning industry with 194,725 Euros (42,808 t).

1.3 Definitions

In order to clarify terms and expressions commonly used within this area, some of the most frequently used were chosen and the most adequate definitions found are as follows:

Waste is any substance or object which the holder discards or intends or is required to discard (EC, 1998).

Bio-waste means biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants (EC, 1998).

Discards or **discarded catch** is that portion of the total organic material of animal origin in the catch, which is thrown away or dumped at sea for whatever reason. It does not include plant materials and post-harvest waste such as offal. The discards may be dead or alive (Kelleher, 2005, adapted from FAO, 1996).

By-catch is the total catch of non-target animals during fisheries. Discards are not a subset of by-catch since the target species are often discarded (Kelleher, 2005).

Rejections in the auction are seafood that didn´t pass the veterinary sanitary inspection in the auction (this data is sent to the Portuguese National Institute of Statistics (INE) by the General Directorate of Veterinary - DGAV) or that was impossible to commercialize (this data is sent to INE by the General Directorate of Natural Resources, Security and Maritime Services - DGRM - part of the Ministry of Agriculture, Sea, Environment and Territory Management) (INE, 2014).

Withdrawals from the auction

Seafood that did not reach the minimum selling price or that was not sold by any other reason (no buyer interested, for example).

Disposal means any operation which is not recovery even where the operation has, as a secondary consequence, the reclamation of substances or energy (EC, 1998).

Animal by-products are entire bodies or parts of animals, products of animal origin or other products obtained from animals, which are not intended for human consumption, including oocytes, embryos and semen (EU, 2009). Animal by-products including processed products that are destined for incineration, land filling or use in a biogas or composting plant are still under the scope of EC (1998).

Derived products are products obtained from one or more treatments, transformations or steps of processing of animal by-products (EU, 2009).

Another definition of **by-products** found in this study is **fish waste**: discarded during processing for human consumption; also called fish scrap, fish offal, filleted offal, gurry (USA), trash fish or industrial fish (OECD, 2002).

For the purpose of data collection for this work, marine animal by-products produced or processed in Portugal were searched under both regulations - waste and animal by-product –

since their final destinations (disposal or valorisation) determine the institutions where data is collected and available.

There is an interesting proposal, recommending that by-products that are used in food should be called **co-products,** in order to avoid the eventually bad image of by-products in consumers' minds (Olsen, 2013). With the same concern, another term - **rest raw materials** - has been recently introduced for by-products (Rustad *et al.*, 2011).

By-products and derived products searched in this study are of category 2 (fish caused by mortality in aquaculture) and 3 (aquatic animals without signs of communicable disease to humans or animals, aquatic animal by-products originating from plants manufacturing products for human consumption, shells from shellfish with soft tissue or flesh (…) originating from animals which did not show any signs of communicable disease through that material to humans or animals) (EU, 2009).

Fish by-products can be divided in two large groups regarding spoilage and degradation levels: a) easily degradable by-products with high concentration of different endogenous enzymes (by-products containing viscera or blood) and b) relatively stable by-products (heads, skin and bones) (Rustad *et al.*, 2011).

Regarding "Fishery Products" several definitions appear in the literature as exemplified afterwards. In this work the definition of Gousset *et al.* (2001) will be considered, which includes the major part of aquatic animals. However, to perform this study the legal frame has to be considered (namely EU, 2004) that includes a different definition, excluding bivalve molluscs, live echinoderms, live tunicates, live marine gastropods, mammals, reptiles and frogs.

Fishery products all the animals or part of the animals, marine or from freshwater, from fisheries or aquaculture, destined to human consumption. This very broad definition includes fishes, crustaceans, marine molluscs (cephalopods, bivalves, marine gastropods) and tunicates present in the living state, fresh, refrigerated, frozen, whole, prepared or transformed (Gousset *et al.*, 2001).

Another definition of **fishery products** is all seawater or freshwater animals (except for live bivalve molluscs, live echinoderms, live tunicates and live marine gastropods, and all mammals, reptiles and frogs) whether wild or farmed and including all edible forms, parts and products of such animals (EU, 2004).

This definition is complemented with the next one – products of animal origin. The reason for this categorization is the different sanitary demands of each category: in the first case – fishery products – the animals are sold dead to the consumer and in the second – products of animal origin – they are intended to be supplied alive to the consumer, thus increasing their sanitary standards.

Products of animal origin "– food of animal origin, including honey and blood;– live bivalve molluscs, live echinoderms, live tunicates and live marine gastropods intended for human consumption; and – other animals destined to be prepared with a view to being supplied live to the final consumer" (EU, 2004).

Seafood includes finfish, shellfish and molluscs. The term shellfish covers the bivalve molluscs (oysters, cockles, clams and mussels), the gastropods (periwinkles, sea-snails) and the crustaceans (crab, lobster, shrimp) (Huss, 1994).

For the purpose of this study seaweeds were included in the category of seafood thus distinguishing it from fishery products.

The definition of Fishery products by Gousset *et al.* (2001) seems more complete and intuitive regarding its meaning.

1.4 Characteristics of marine by-products

Different fish species have specific processing yields and, consequently, generate different proportions of by-products, as shown in table 1.3.

Marine by-products are remarkable source of proteins, lipids, enzymes, pigments, minerals, vitamins and others, as summarized in table 1.4.

The fraction of by-products that is protein-rich are the cut-offs, backbones, heads, skin, roe, milt, stomachs, viscera and blood. Information on the available quantities, chemical composition and properties of both protein and lipid fraction, depending on the species, season and fishing ground, is very important for the industry in order to optimise the use of by-products. By-product protein content varies according to the by-product fraction (table 1.5). Protein content is generally expressed as crude protein, Nx6.25, which includes also the NPN (non-protein-nitrogen). The meat of white fish has an NPN value between 9 and 15% of the total N. NPN is composed in about 95% of free amino acids, dipeptides, trimethylamine oxide (TMAO) and degradation products like urea, guanidine, nucleotides and their degradation products (Rustad, 2007).

Table 1.3– Amount of different by-products fractions (Rustad, 2007).

Species	By-product fraction amount of total fish weight (%)						
	Head	Backbone/frames	Cut-offs	Skin	Roe	Milt	Viscera
Cod	20.2	9.7	8.2	4.2	0.7	1.3	5.6
Saithe	15.3	9.9	8.8	4.8	0.3	0.2	7.2
Haddock	18.9	10.6	9.3	4.5	0.7	0.1	6.2
Tusk	17.9	8.4	21.2	6.4	2.0	0.0	9.9
Ling	18.6	-	-	-	1.7	-	3.3
Atlantic Salmon	10.0	10.0	-	5.0	-	-	14.0
Carp, wild	21-25	-	5-9	6-8	-	-	3-4
Carp, cultured	20-21	-	6-8	8-11	-	-	4-5

Fish roe is a protein rich fraction of by-products (16-30%). On the other hand, backbone is responsible for around one-third of the dry weight and is composed mainly of minerals (60-70%) and proteins (30%) (Rustad, 2007).

Table 1.4– Constituents of by-products (Shahidi, 2007).

Ingredient	Application area
Proteins/biopeptides	Nutraceuticals, immune-enhancers
Minerals/calcium	Food, nutraceuticals
Chitosan, glucosamine	Nutraceuticals, agriculture, food, water purification
Omega-3 oils	Nutraceuticals, dietary supplements, food
Carotenoids/xanthophylls	Nutraceuticals, fish feed
Chordprotein sulphate	Supplements, arthritic pain relief
Squalene	Skin care
Specialty chemicals	Miscellaneous

The proteins of marine by-products are of high quality due to their high digestibility and amino acid composition. Their recovery from the by-products can be done in different ways utilizing mechanical separation from frames, alkaline or acid extraction or hydrolysis. When proteins are hydrolysed by fish endogenous enzymes, before or during the primary processing, quality deterioration may occur; on the other hand, under controlled conditions, this same hydrolysis may produce fish sauces or fish silage.

Table 1.5– Protein content in different by-product fractions (Rustad, 2007).

Species	Protein content % of wet weight					
	Head	Backbone/frames	Cut-offs	Skin	Milt	Viscera
Cod	-	-	13-23	-	-	9-13
Saithe	-	-	15-19	-	-	12-19
Haddock	-	-	15-18	-	-	7-11
Tusk	-	-	17-23	-	-	3-12
Ling	-	-	13-23	-	-	8-12
Carp, wild	-	-	14-22	-	14-27	15-23
Carp, cultured	-	-	12-17	-	19-25	26
Atlantic Salmon	11-13	10-15	-	8-12 [1]	-	5-7
Herring	13.1	-	-	-	18.0	-

[1-] Includes bellyflap

Furthermore, commercially available proteases can be added to fish by-products to produce protein hydrolysates with several applications namely situations where water solubility, water and lipid holding capacity and rheological properties are important (Shahidi, 2007). Protein hydrolysates can stimulate the immunologic activity, have anti-oxidant capacity and inhibit the activity of the angiotensine converting enzyme (ACE) (Je *et al.* 2004). Despite these important functional properties, fish proteins are not optimally utilized in the growing protein ingredient and health markets due to the challenges in the purification process that generate a loss of protein functionality (Rustad, 2007).

The quantity and chemical composition of different by-product fractions have seasonal variations. Falch *et al* (2007) found a higher proportion of viscera during the seasons of autumn and spring. Other examples are the highest proportion of gonads of Gadidae species that spawn during the months of January to June in the Northern Hemisphere. On the other hand, roe proportions are higher in autumn and spring, reaching 2.2% of the round weight of fish on average during the spawning season (Rustad, 2007).

Rustad (2007) points out to the importance of treating the by-products in the same way as the main products (fillets, for example) in order to obtain the maximum quality. This author stresses the importance of not freezing the raw material since this process leads to the loss of both water-holding capacity and gel forming ability, especially in the case of mince. Also the time of freezing and the thawing conditions can reduce the functional properties of the by-products.

Other important points in the maintenance of by-products quality are the handling on-board and sorting, especially regarding the reduction of enzymatic rate of degradation and microbial spoilage (Rustad, 2007).

In the case of fish protein hydrolysates (FPH), minced and surimi-based products preparation or extraction of lipids, enzymes and/or other bioactive compounds is very important to control the endogenous enzymes in the raw material and also to know how these activities are influenced by temperature (Rustad, 2007).

Another component of interest of marine by-products is the lipid fraction. Recent studies on the beneficial health impact of long chain polyunsaturated omega-3 fatty acids, specifically eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), have increased the interest in seafood consumption thus stressing the importance in fish lipids especially those from the under-utilized by-product landing. The group of lipids includes fatty acids, fats, oils, waxes, phospholipids, glycolipids, steroids and a few vitamins. Fatty acids are the monobasic aliphatic carboxylic acid and can be divided in three categories: saturated, unsaturated (monounsaturated – MUFA and polyunsaturated – PUFA). Polyunsaturated fatty acids, that include: linoleic acid (also known as α-linoleic acid), the essential omega-6 fatty acid, from which it is possible to synthesise other omega-6 like fatty acids arachidonic acid; linolenic acid, the corresponding essential omega-3 fatty acid that gives origin to other omega-3 fatty acids like EPA and DHA (Kerry, 2007).

The concentration of fatty acids in fish tissue varies with diet, size, species, age, reproductive condition, geographical location and season (Ackman, 1989). Lipids are prone to oxidation and this process interferes with the nutritional quality, wholesomeness, safety, colour, flavour and texture of fish. This oxidation occurs particularly after death, when the antioxidants ingested by the fish are no longer present, and is mostly due to enzymatic hydrolysis. Oily fish are more prone to lipid oxidation and spoilage because of their high concentration of PUFA in the lipids. Lipid oxidation (rancidity) is also dependent on the levels of endogenous antioxidants, endogenous oxidative catalysts and external facts like heat, light, processing procedures, preservation and handling. For example, freezing practices when applied properly can reduce rancidity during storage because of a reduction on the ice crystal damage on the lipids membrane (where lipid oxidation occurs in the first place). If the freezing process is rapid, the formation and distribution of small ice crystals can reduce this initial damage related to freezing. Regarding frozen fish, vacuum packing and modified atmosphere packing (MAP) are processes to extend its shelf-life by reducing or eliminating the access to oxygen.

In order to diminish off-flavour production due to the formation of volatile compounds it is necessary to stop or slow down the oxidation process. The most common methods are the direct application of antioxidants (Kerry, 2007). The main limitation for shelf-life of marine oil is lipid oxidation, therefore this has to be considered in the production of marine lipids (Falch *et al*, 2007).

Kerry (2007) stresses the importance of research on the extracting methods of lipids from by-products in order to use them as potential functional ingredients. There is a growing interest not only on the extraction processes but also at the level of concentration and stability of fish oil.

Besides reactions catalyzed by enzymes, microbial activity is another factor inducing fish spoilage since it is a good substrate for microbial growth. While fish muscle is sterile, intestines and gills have large amounts of bacteria, therefore it is necessary to separate these fractions from those less contaminated. Another source of pathogens present in raw material and processed products is their contact with fish handlers equipments or other environmental conditions. Bacterial activity can produce enzymatic degradation (for example of lipases, proteases, peptidases and reductases) thus causing the spoilage of by-products. Therefore, it is very important to produce by-products hygienically right after the careful handling of the fish.

However, the limited space on-board can be a limiting factor regarding the handling and further utilization of by-products.

1.5 Sources of marine by-products

1.5.1 On-board: discards, by-catch and on-board fish processing industry

The current on-board discards are constituted by low commercial value fish species, non-targeted species (by-catch) or undersized targeted species. The percentage of discards varies within the fishing methods (trawlers, long-liners etc.) since it depends on the selectivity of the fishing gears employed (Alonso *et al.*, 2010).

Previously FAO (Alverson *et al.*, 1994) estimated discards as being of around 27 million t per year (near one third of the total fish captures), however, Kelleher (2005) estimated the amount of discards in 7.3 million t per year during the period from 1992 to 2001 (around 8% of the total fish catch).

Discards are a purposeless waste of valuable living resources, responsible for the depletion of fish populations (Alonso *et al.*, 2010). Fish trawler fleet is very important in catching and dispersing biomass since a significant portion of trawl catches is composed by non-target species, thus being returned to the sea. This input of discarded species to the foodweb is an important result of fishing practices (Bozzano and Sardà, 2002).

In fish trawlers fleet, great part of the fish (about half the non-commercial crustaceans and 98% of non-comercial cephalopods) is dead when discarded (Hill and Wassenberg, 1990). This low survival rate of discarded non-commercial invertebrates was also confirmed by Bergman and van Santbrink (2000).

Bozzano and Sardà (2002) consider the large quantities of dead fish, crustaceans and molluscs discarded in fishing areas to have potential repercussions on the surface, midwater and benthic communities of the affected areas.

The mass of discards that reach the bottom is regulated by the scavenging activity of seabirds (Camphuysen *et al.*, 1995; Oro and Ruiz, 1997). In the water column some authors (Hill and Wassenberg, 1990) report significant rates of bait loss, while other authors (Castro *et al.*, 1999) consider this activity reduced off the coast of southern Portugal. Thus, the demersal community of the continental shelf, varying with the study area, receives a regular supply of organic matter in the form of fishery discards with its ecological impact for the benthic species and their energy supply to the community (Bozzano and Sardà, 2002).

Discards can change trophic links within communities due to the strong non-selective predation and the input of significant quantities of energy (Bozzano and Sardà, 2002). These energy inputs cause a greater abundance of consumers when compared to their feed only by *in situ* resources (Polis and Strong, 1996). Another aspect of continuous discards in the same area (North Sea) may emphasize secondary production because of the feeding activity of scavenger communities, thus allowing faster transfer of organic matter into the food web (Groenewold and Fonds, 2000).

Discard amounts and composition vary greatly with the target species, the fishing season (Bozzano and Sardà, 2002) and the fishing area. For instance, in shallower fishing areas of the Catalan Sea discards can reach 50% of the total catch whereas in deeper water it may reach only 20% of the total catch (Carbonell *et al.*, 1997).

Discards are done during fishing vessel movement thus being spread over large areas and becoming available to large numbers of scavengers. Little information is available, worldwide, on the possible effects of discards on the life cycles of many marine species (Bozzano ans Sardà, 2002). Nevertheless, various studies have shown the importance of benthic scavengers in consuming fishery discards and dispersing surface-derived organic carbon (Hill and Wassenberg, 1990; Ramsay *et al.*, 1997; Bergman and van Santbrink, 2000; Fonds and Groenewold, 2000; Legezynska *et al.*, 2000).

On the other hand, discarding juvenile fish, fish of little or no economic interest or fish that is over-quota is known to compromise future yields; while discarding mature fish is a waste of resources in short term and a reduction of the amount of adult fish that would otherwise support productivity (Jensen *et al.*, 1988).

Generally, to reduce the level of discards aimed by national and European administrations, reflected in the reform of Common Fisheries Policy (CFP) a change is needed in the perception/attitude of the actors participating in the extractive sector towards the concept of keeping in the holds the whole catch (target species, by-catch and other marine organisms that cannot be returned alive to the sea). The reform of CFP allows fishermen to actively participate in the process of designing measures to avoid by-catch in the first place and to land all commercial species that are caught. However difficulties are expected in the implementation of this objective (Pazo *et al*., 2014).

Discards are a key point of the Ecosystem Approach to Fisheries Management (EAFM), and a complex issue. Discarding practices relate to the core of fishing operations, from an economic, legal and biological view point. Nevertheless, besides all these challenges, there is a common agreement (among citizens, NGOs, the fishing sector, policymakers, scientists, etc.) that understands discards as being very negative endeavours for the implementation of effective solutions for this problem (Pazo *et al*., 2014).

FAO (2010) has recently developed, in a report, a technical consultation to set international guidelines on by-catch management and discard reduction (Pazo *et al*., 2014). These guidelines are intended to support states and Regional Fisheries Management Organizations or Arrangements (RFMO/As) in managing by-catch and reducing discards in conformity with FAO Code of Conduct for Responsible Fisheries (FAO, 1995). The scope of the guidelines, in this report, is global, covering all fishing activities in all seas, oceans and inland waters. Further, in the same report (FAO, 2010) and regarding the By-catch Management Planning (BMP), it is mentioned that states and RFMO/As should make sure BMP take in consideration both best practices and a reduction in discards developed in cooperation with relevant stakeholders (Pazo *et al*., 2014). Best practices include the development of measures to meet these objectives, adapted to the characteristics of each fishery in which by-catch and discard problems need to be addressed (Pazo *et al*., 2014).

Pazo *et al.* (2014) summarise the main FAO (2010) guidelines on by-catch management and reduction of discards:

- To minimise potential by-catch through spatial and/or temporal measures;

- To minimise by-catch through modifications of fishing gears and practices;

- To maximise the release of alive by-catch while ensuring the safety of the fishing crew;

- To make the best use of unavoidable by-catch according to FAO code (1995)

Besides discards, another source of marine by-products (biomass loss) is on-board fish processing industries. Especially fish evisceration and cleaning generates a considerable amount of waste like heads, bones, guts, skins etc. Normally, demersal species (*e.g.* monkfish, cod, conger, haddock, ling, etc) and some cartilaginous species like sharks are gutted on board, producing variable amounts of fish waste (mainly viscera) that are dumped at the sea (Alonso *et al.*, 2010).

Besides the adverse effect on the trophic chain, on-board evisceration contributes to the accumulation of pollutants as PCBs, dioxins and heavy metals and the dispersion of parasites existent in the viscera (like *Anisakis*) in the fishing areas (Blanco *et al.*, 2007). The percentage of marine by-products generated on-board varies according to the target species (for example, most fatty fish is processed on-board but most lean fish species are landed as whole fish), and according to the fishing areas (fishing fleets working in coastal waters tend to land the whole volume of captured fish to be processed in-land). However, estimations of average waste amounts vary between 15 and 30% of the total catch, but in some cases (skate fish) could reach 80% (Alonso *et al.*, 2010).

In this regard, and to promote the responsible and sustainable management of the European fishing activity, the European Commission took several actions for the implementation of "no-discard" and "zero-waste" policies to be followed by the European fishing fleets in the near future. Some of these policies are: "to reduce unwanted by-catches and eliminate discards in European fisheries" (EC, 2007). As a result, non-target species or fish above quota (or below minimum market size) will no longer be discarded, but kept on board to be brought ashore (Alonso *et al.*, 2010). These policies and their implementation were discussed with the Member States in 2007 and were approved by the EU parliament in 2008 (Alonso *et al.*, 2010). Later, the European Commission (EU, 2013) established as objectives for the CFP, to: "gradually eliminate discards, on a case-by-case basis, taking into account the best available scientific advice, by avoiding and reducing, as far as possible, unwanted catches and by gradually ensuring that catches are landed"; "where necessary, make the best use of unwanted catches, without creating a market for such of those catches that are below the minimum conservation reference size"; "provide conditions for economically viable and competitive fishing capture and processing industry and land-based fishing related activity". It was also agreed that Member States should produce a "discard atlas" with the level of discards in each fishery (EU, 2013).

In the European Atlantic area, the amount of marine by-products generated in fishing vessels is difficult to estimate due to the lack of records of the amount of discarded species. While on board it is difficult to estimate the quantities of by-products since it depends on the different processes and on the species (Sotelo *et al.*, 2011).

Generally, the catch is landed by the coast fleet having had refrigeration on-board or not and the fish can be gutted or round, according to the species, statutory regulations, temperature, season and if the by-products are utilized or not. Recently the landing of round fish, fresh and frozen, became a source of interest concerning the possibility of on-shore processing.This being the case, the raw material of several vessels could be processed in the same facilities, optimizing the process in economic terms. In the case of ocean trawlers, normally, the catch is frozen either round or gutted, but some of the vessels process the catch for fish filleting mainly. Fig. 1.8 shows the generation of by-products produced during filleting operation and presents a preservation technology (Falch et al, 2007).

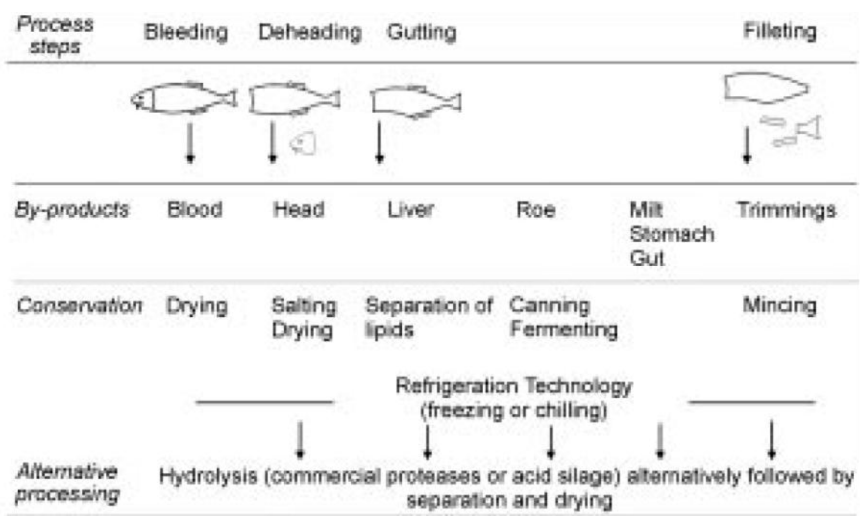

Figure 1.8 - By-products generated during filleting of gadiform species with suggested methods of preservation and bulk production (Falch et al, 2007).

1.5.2 In-land

1.5.2.1 Auctions: rejections and withdrawals

Together with by-catch and aquaculture mortality, fishing ports and auctions contribute to the generation of by-products in the form of whole aquatic animals as opposed to the fish processing industry that contributes with parts of animals.
At the fishing ports and auctions in the Atlantic area, usually the marine by-products are stored in containers and further collected by transporters (or directly by the fish meal producers) to the fish meal factories (Sotelo *et al.*, 2011).

1.5.2.2 Fish processing industry: Fresh and frozen, cod salting and drying, canning

There has been a rapid progress in the technological development of food processing and packaging with processors of traditional products losing market share due to the long-term shifts in consumer preferences, processing and general fisheries industries. The processing industry became more intensive, concentrated in geographic areas, vertically integrated and connected with global supply chains. This is a reflection of the increasing globalization of the fisheries value chain, where the large retailers control the growth of international distribution channels. Another growing tendency is the outsourcing processing on a regional and world scale although outsourcing of production to developing countries maybe not be increasing significantly because of the restrictions on the sanitary and hygiene requirements that are a challenge to meet in developing countries as well as the recent growing labour costs. Another tendency is for processors to become more integrated with producers, particularly for groundfish, the Asian being an example, in which major processors have their own fleet of fishing vessels. Also large producers of farmed salmon, catfish and shrimp have their own advanced centralized processing plants. On the other hand, processors without purchasing or sourcing power of strong brands have difficulties due to the scarcity of domestic raw material, being forced to import fish to continue their business (FAO, 2012).

In 2010, 46.9% of the fish destined for human consumption was in live, fresh or chilled form, 29.3% frozen, 14.0% prepared or preserved and 9.8% cured. 55.2% of the total processed fish for human consumption was frozen accounting for 25.3% of the total fish production. Frozen proportion fish grew from 33.2% of the total production for human consumption in 1970 to a record of 52.1% in 2010. On the other hand, the share of prepared and preserved forms was stable during this period, reaching only 26.9% in 2010. The share of frozen products increased in developing countries from 18.9% in 2000 to 24.1% in 2010, while the share of prepared or preserved forms grew from 7.8% in 2000 to 11% in 2010. Because of the deficiencies in the infrastructure of processing facilities, as well as the consumer habits in developing countries, 56% of the fish destined for human consumption was mostly in live or fresh form, soon after landing or harvesting, in 2010. In these countries, there is still a tradition for retailing and consuming fish in cured forms (dried, smoked or fermented) although this share has decreased from 10.9% in 2000 to 8.9% in 2010. On the other hand, the bulk of production destined for human consumption, in developed countries is commercialized frozen or in prepared or preserved forms (FAO, 2012).

Regarding trade, and due to their high perishability, 90% of trade in quantity (live weight equivalent) in fish and fishery products is made of processed products. The tendency to trade frozen fish is increasing from 25% of the total quantity in 1980 to 39% in 2010. The share of prepared and preserved fish of the total quantity has almost doubled from 9% in 1980 to 16% in 2010. On the other hand, traded fish in live, fresh and chilled forms increased from 7% in 1980 to 10% in 2010, thus showing an improvement in the logistics and an increase in the demand of unprocessed fish (FAO, 2012).

Industrial processing is only responsible for a waste of 50% (Guérard *et al.*, 2005 in Rustad *et al.*, 2011) and the total of seafood processing discards and by-products may reach 75% of the total weight of the catch (Shahidi, 1994 in Rustad *et al.*, 2011).

From previous studies (Sotelo *et al.*, 2011), it is clear that, in Portugal, the canning and frozen fish industries are the ones that produce the major part of marine by-products. Estimated amounts of by-products generated by the sardine and mackerel canning industries were around 19,600 t/year (being the contribution of whole sardine around 1,485 t). In Azores, the value of marine by-products from the tuna canning industry, stated by the producer, was around 3,720 t in 2009. Regarding the frozen fish industry, the by-products estimated from its production were around 11,970 t. These by-products are valorised for the production of fish meal/oil (Sotelo *et al.*, 2011).

1.6 Main utilizations of marine by-products

As previously stated, marine by-products can be in the form of whole fish (generated from by-catch, discards, aquaculture mortality and auctions rejections and withdrawals or parts of fish that are generally not used for human consumption - trimmings, frames, heads, tails, bones, viscera, fins, skin, shells and a small percentage of muscle associated and normally difficult to separate from these parts; leftover carcasses after the extraction of roe and the male counterparts carcasses (Shahidi, 2007), shells of crustaceans and shellfish from marine bioprocessing plants (Kim and Mendis, 2006). These can be obtained on board, while performing processing operations, or from all aquatic food processing industries, including some farmed fish companies. Fig. 1.9 summarizes the possible utilizations of fish by-products.

The destination of by-products may differ according to its origin: a land-based operation or an offshore processing. In the first case, the supplies are made either by small boats, in which the fishing trip may last only a few hours or a whole day, or by oceangoing trawlers where the trips last from a few hours to a week or more. In smaller boats the fish is brought ashore, sometimes ungutted thus improving the total utilization of the whole fish compared to longer trips where the fish is gutted at the sea, thus depending on the crew if the guts are kept or discarded in the ocean. On the other hand, on oceangoing trawlers equipped with on-board freezing, with fishing trips lasting up to one month, the utilization depends on the vessels with some only keeping the fillets and others having their own fish meal plants on board, thus utilizing all the harvested fish. Parts of the fish should be considered raw material instead of waste and thought of as alternative product streams. The authors' opinion is that the scientific knowledge of proteins and fish oil chemistry, in the future, will imply that some of the so-called by-products can be turned into more valuable products than the main flesh of fish fillets (Kristbergsson and Arason, 2007).

In the United Kingdom, on-board generated by-products are sold for an insignificant amount compared to the whole fish (fig. 1.10).

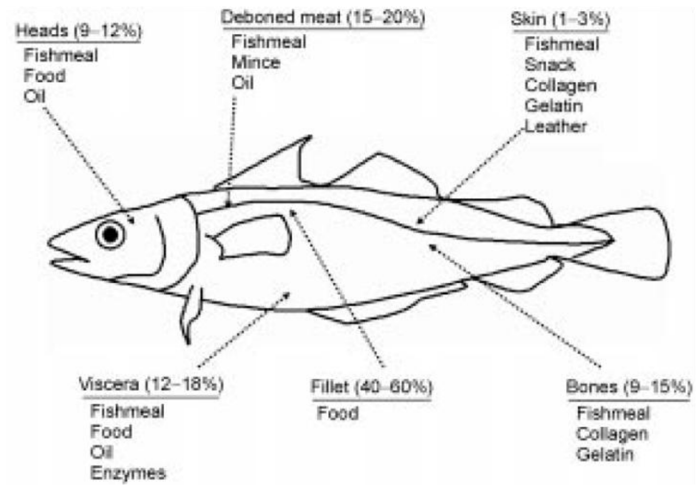

Figure 1.9 - Fish by-products and their possible uses (compiled from Andrieux,2004; Gildberg et al., 2002; Guérard et al., 2004; Liaset et al., 2003 in Guérard, 2007).

Regarding fish viscera (also referred to as guts), its constitution is both the liver and roes (or milt), representing 10 to 25% of the net weight of round fish, according to the maturity and season. Roes and liver are utilized in human consumption, either directly or indirectly since long time.

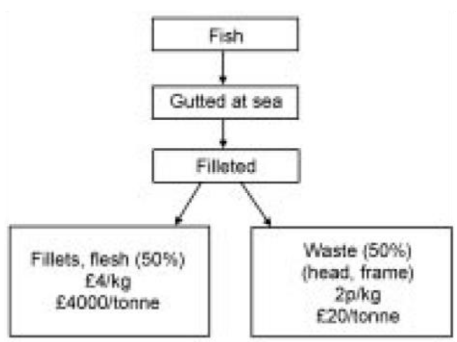

Figure 1.10 - Price for fish and fish waste (Taylor and Himonides, 2007).

On the other hand, other parts of the guts such as the pyloric caeca are usually not used in human consumption but rather used as sources of bioactive compounds such as enzymes with multiple applications (Kristbergsson and Arason, 2007).

Another marine by-product with potential added value is fish roe. It is a seasonal product since the roes are only collected during the fish spawning season (Kristbergsson and Arason, 2007) and its quality depends on the maturity state of the roes in the moment of harvest (Katsiadaki and Taylor, 1999) affecting the quality of roe derived products like caviar and various spreads (Kristbergsson and Arason, 2007).

Caviar designates only the roe from species that belong to the Acipenseriformes (that includes sturgeons) while the roe of other fish are named “caviar substitute” (Catarci, 2004). While world trade in sturgeon caviar has decreased with the breakup of the Soviet Union, the market in caviar substitutes and other fish roe has increased (Catarci, 2004). An example of caviar substitute is lumpfish roe, exported by Iceland, although it is not considered a by-product because roes are the reason for catching lumpfish (Kristbergsson and Arason, 2007).

Capelin roe is another example of caviar substitute made from by-products. Even though smaller in diameter when compared to the sturgeon and lumpfish roes, they are used for the popular traditional Japanese sushi dish named Masago, where the roes are cured and processed following the Japanese tradition. Although capelin roes’ market was mostly in Japan, now there are some producers making caviar substitute products and spreads to be sold in the European market. In 2003 Iceland exported 4,913 t of capelin roe and 9,505 t in 2004, but it should be noted that only 5% of the capelin is used for human consumption with 1% in the form of frozen roes. Capelin roe price is about 30 times higher than the capelin muscle, thus there is even a special automated processing machine developed for the extraction, separation, cleaning, weighing, packing and preserving of capelin roe commercially available and made by Traust Technologies (http://www.traust.is) (Kristbergsson and Arason, 2007).

Cod, haddock and saithe roes are also demanded frozen and salted for smoking, canning and to produce various kinds of Scandinavian popular spreads. Bringing fish ashore already gutted, in the cases of fishing trips longer than 24 h, is considered a good practice in terms of fish quality but a reduction in the availability of roes and other viscera for processing, since normally the guts have been discarded at sea, thus only the roe from fish brought ashore ungutted, especially for salting or freezing, is available to be processed. However the increase in the roe price has changed this situation and nowadays roe from the major part of the harvested ground fish are collected and thus utilized. Cod roes are normally collected and stored with salt in insulated plastic tubs undergoing curing during storage or frozen. Later on, roes are desalted, have their membranes removed, are mixed with additives (colour and preservatives), packed and pasteurized in consumer-size containers or further mixed and mashed in the case of the production of spread type products, or special undergone curing techniques and maturing processes like in the case of Masago (Kristbergsson and Arason, 2007).

Regarding fish heads, it is a by-product often discarded or used to produce bonemeal or animal feed (Kristbergsson and Arason, 2007). The different parts of cod head are: tongue (1-4%), cheeks (5-15%), collar or nape (15-20%) and upper head meat (5-15%) (Kristbergsson and Arason, 2007). From tongues and cheeks are considered as delicacies in some specific markets (Kristbergsson and Arason, 2007). The processing of tongues and cheeks evolved from being exclusively manually made (labour intensive, thus expensive) to recent mechanical solutions to automatically cut out the fish these parts from head (Sigurdsson, 1993) and for tearing out gills and further splitting of the cod heads (Kristbergsson and Arason, 2007). Afterwards these products are salted to be sold in the salt fish markets in Portugal and Spain (Kristbergsson and Arason, 2007). One third of heads from round fish is utilized for the processing of the tongue or cheek and the other two thirds are utilized for drying (Kristbergsson and Arason., 2007). In the past 25 years, indoor drying techniques (Fig. 1.11) for fish have been developed thus increasing the production of dried cod heads from 1,000 t to 15,000 t (Kristbergsson and Arason, 2007).

Figure 1.11 - Modern computer-controlled drying facility for cod heads: heads processing, racks transport, racks in the primary drying chamber and control board (Kristbergsson and Arason, 2007).

Regarding the protein fraction of marine by-products, there has been research over the last 25 years on isolation, purification and characterization of enzymes from fish intestines made it possible its applications in different industries such as food, natural skin care products, cosmetics and pharmaceuticals (Kristbergsson and Arason , 2007). Particularly the hydrolytic enzymes such as cod serine proteases as trypsin (Ágeirsson *et al*., 1989), chymotrypsins (Ásgeirsson and Bjarnason, 1991), elastase (Ásgeirsson and Bjarnason, 1993) and serine collagenases (Kristjansson *et al.*, 1995). Because these cold-active or psychrophilic enzymes are more active at low temperatures than the correspondent mammalian or bacterial enzymes and plus have higher catalytic efficiency, higher sensitivity to heat and low pH and higher activity towards native proteins (Kristbergsson and Arason, 2007), they can be beneficial in industrial processes, medical, pharmaceutical, hygienic and cosmetic processes (Bjarnason, 2001), because of the smaller concentrations needed due their higher catalytic efficiency (Kristbergsson *et al.*, 2007). Other advantages are the need of milder conditions for the destruction of residual enzyme activity because of their sensitivity to temperature and the ability to penetrate human skin, thus being used in commercial skin formulas (Penzym, commercialized by Zymetech Inc.).

Another application of cold-active marine enzymes is the production of protein hydrolysates that can be used as all natural seafood flavours to be used on soups, surimi, pet food applications (Kristbergsson *et al.*, 2007), preparation of minimally treated fruit and vegetable beverages and hydrolysis of various food proteins like gelatine, vegetable proteins and collagens (Aranson, 2003). An example of the utilization of cold-active proteinases is a mixture of trypsin, chymotrypsin, elastases and collagenases commercialized with the name Cryotin, said to have several potential uses in industry, medicine and research, particularly, in food processing applications requiring low temperature hydrolysis, inactivation with mild conditions or native collagen digestion (Gudbjarnason, 1999). Nowadays, Cryotin is utilized in a patented process for the preparation of high-quality all-natural flavourings for the industry of food processing and innovative cooking commercially available as Northtaste® by NorthIce Inc (Kristbergsson *et al.*, 2007). There is research being made by several groups, worldwide, on bioactive proteins from fish to be utilized in nutraceuticals (Alasalvar and Taylor, 2002).

Nowadays the main utilization of marine by-products is silage, fish meal and oil. For example in Iceland, fish meal plants are the ultimate factory for these by-products since it is there that all raw material ends when there is no other previous utilization (as an example, even bones are processed into bone meal in fish meal plants (Kristbergsson and Arason, 2007). The production of fish meal is made from whole fish or fish by-products remaining from processing, being the major contributors small pelagic species, especially anchoveta (FAO, 2012), capelin, menhaden and herring (Kristbergsson and Arason, 2007). Normally fish processing occurs at on-shore facilities since the on-board processing has decreased in the last decades. This is due to the recent decrease of on-board fish meal and fish-oil processing units. Fig. 1.12 shows three of the most important bulk processes for by-products processing: fish silage, cod liver oil and fish protein hydrolysate (Falch *et al*, 2007).

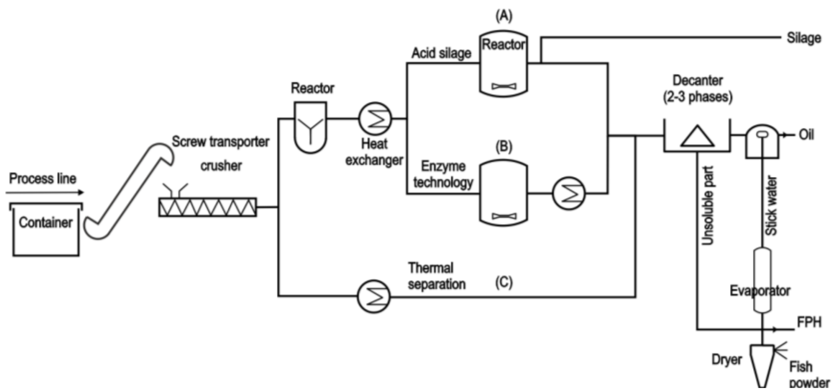

Figure 1.12 - Illustration of three alternative production lines for on-board processing of by-products (A) Silage, (B) Controlled enzymatic hydrolysis with production of FPH and fish oil and (C) Production of cod liver oil (Falch et al, 2007).

Regarding farmed products, in general, aquaculture waste is not permitted for the manufacture of aquaculture feed and must be processed in completely separated facilities (Gill, 2000).

Lately herring has been processed mostly for human consumption for salting or freezing but 95% of the harvested capelin has been used for fish meal and oil production, being the major source of fish oil in Iceland (Kristbergsson and Arason, 2007).

There has been an increase in the quality of fish meal in the last 20 years. Previously, fish meal was dried in drum dryers with oil for the generation of heating. The solid fraction was in direct contact with the heating surface thus causing high degree of denaturation of the heat-labile fish proteins. Aquaculture was a driver for higher quality fish meal (better functionality and bioactivity) since cultured fish is more sensitive to the quality of proteins than domestic animals (Kristbergsson and Arason, 2007).

The latest advances in fish meal plants utilize steam dryers and indirect air drying systems such as the Dyn-Jet dryers (Atlas-Stord A/S, Denmark) in which the flue gas from the burner doesn't contact directly with the air that dries the material (Kristbergsson and Arason, 2007). Gunnarson (2003) considers that the method of indirect drying produces fish meal with higher functional properties in relation to old drying techniques.

On the other hand, fish silage is made by adding acid to fish by-products (offal and guts) utilizing an organic acid like formic acid in order to reduce the pH approximately to 4 thus preventing microbial growth but allowing the endogenous enzymes to achieve conditions that are optimal for protein hydrolysis and thereby liquefying the by-products. In this process lipid oxidation can be prevented through the utilization of antioxidants together with the acid (Falch *et al*, 2007).

Another utilization of marine by-products is to produce fish protein hydrolysates (FPH) that are made with the addition of commercial enzymes (proteases) to the by-products under controlled conditions (Falch *et al*, 2007).

Regarding cold water fish gelatine, it has lower gelling and melting temperatures when compared with the traditional bovine gelatines even though with similar gel strengths (Gudmundsson, 2002). At least one Icelandic fish processing company exports fish skin to Canada and Spain to be utilized for gelatine production (Kristbergsson and Arason, 2007). Other uses for fish gelatine are food formulations like in kosher and halal foods and as a safe alternative without the risk of bovine spongiform encephalopathy (BSE) (Kristbergsson and Arason, 2007).

Marine by-products like fish frames, napes and trimmings can also be utilized for instance to produce minced fish also named minced fish meat, minced meat, fish mince, mince, and consisting of the fish flesh separated from the skin and bone in a mechanical separator, normally constituted by a perforated drum and a squeezing belt (Kristbergsson and Arason, 2007). The device is fed with trimmings from fillets, for example, from a hopper being pressed between moving, flexible belt and the outer part of counterrotating, perforated, stainless steel drum (Kristbergsson and Arason, 2007). The flesh squeezed through the perforated drum is afterwards removed from the inside by a fixed screw (Kristbergsson and Arason, 2007). The diameter of the drum perforations, varying between 1 to 10 mm, the pressure applied into the squeezing belt and ultimately the raw material utilized determine the coarseness and texture of the mince, the colour of the product and the yield of the flesh (Kristbergsson and Arason, 2007). Whittle and Howgate

(2000) recommend the continuous removal of skin and bones remaining outside of the drum by a fixed scraping blade to be used later in the production of bonemeal.

There are considerable quantities of flesh remaining on the frames and napes after the filleting of round fish such as cod but, in the case of Iceland, mince is produced mainly from trimmings resultant from boneless fillets production. Mince produced from nape and frames is darker and of poorer quality than that obtained from the trimmings or cut-offs. In the case of frame mince, its dark to reddish colour is due to the kidney, localized under the spinal cord or backbone, being mixed with the flesh under abrasive handling conditions of the frame. Therefore another process used to clean the flesh off the bones is water jet, which preserves the kidney (Kristbergsson and Arason, 2007)

Wendel *et al*. (2002) concluded that water jet technology results in lower yields but high quality surimi when compared to the traditional mechanical deboning of Pacific whiting frames. The yield reduction may be originated from the protein loss in the water phase, possibly being rectified by better protein recovery filtration techniques or through the new process utilized in surimi production that includes acid or alkaline protein solubilization (Undeland *et al*., 2002; Liang and Hultin, 2005; Kristinsson *et al*., 2005) initially developed for surimi production from fatty dark flesh fish like herring or capelin (Kristbergsson *et al.*, 2007). This water jet technology could also be utilized in the production of bioactive or functional foods (Kristbergsson *et al.*, 2007). In the case of Iceland, its production of mince from round fish has increased showing a better use of the raw material (Kristbergsson *et al.*, 2007).

As a rough estimation, one tonne of gutted cod gives around 100-180 kg of mince from various parts of the fish, being 3-4% from the trimmings, 4-5% from the nape, 3-4% from the head, 3-4% from the belly flap and 4-5% from the frame in a total of 15-18% of the fish (Kristbergsson and Arason, 2007).

Figure 1.13 represents a machinery to scrap flesh from the backbones, and cutting swim bladders and belly flaps from backbones after the butterfly splitting or filleting of the cod (Sigurdsson, 1992) thus allowing the better utilization, exportation and value adding of the products on the salted fish markets (Kristbergsson and Arason, 2007).

Another example of adding value to by-products is presented in the work by Mei *et al.* (2003) where is developed a methodology to transform low-value fish cut-offs and trimmings into fillet like products, similar in texture to intact fish flesh.

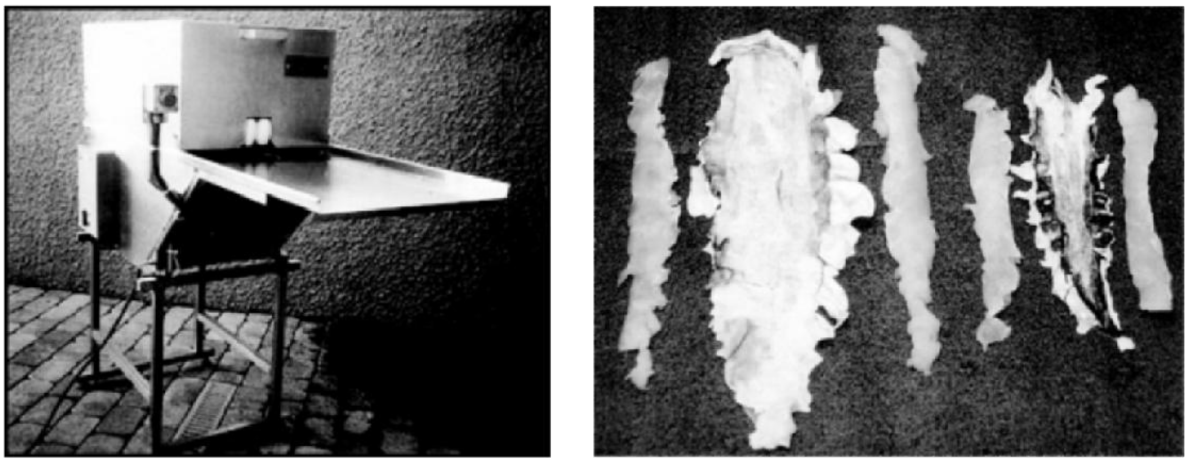

Figure 1.13 - The MESA 850 cod backbone processor, and recovered meat and swim bladder (Kristbergsson and Arason, 2007).

Regarding the lipid fraction of marine by-products, their main utilization is fish oils and concentrates of polyunsaturated fatty acids.

After the processes of extraction and separation in the fish meal plant (fig. 1.14), the fish oil is further purified in refineries in the same way as vegetable oils with alkali refining, degumming, bleaching, deodorization, fractionation and low-molecular-weight distillation for highly purified supplements, or even further steps like hydrogenation and inter-esterification, according to the end use of the oil (Kristbergsson and Arason, 2007).

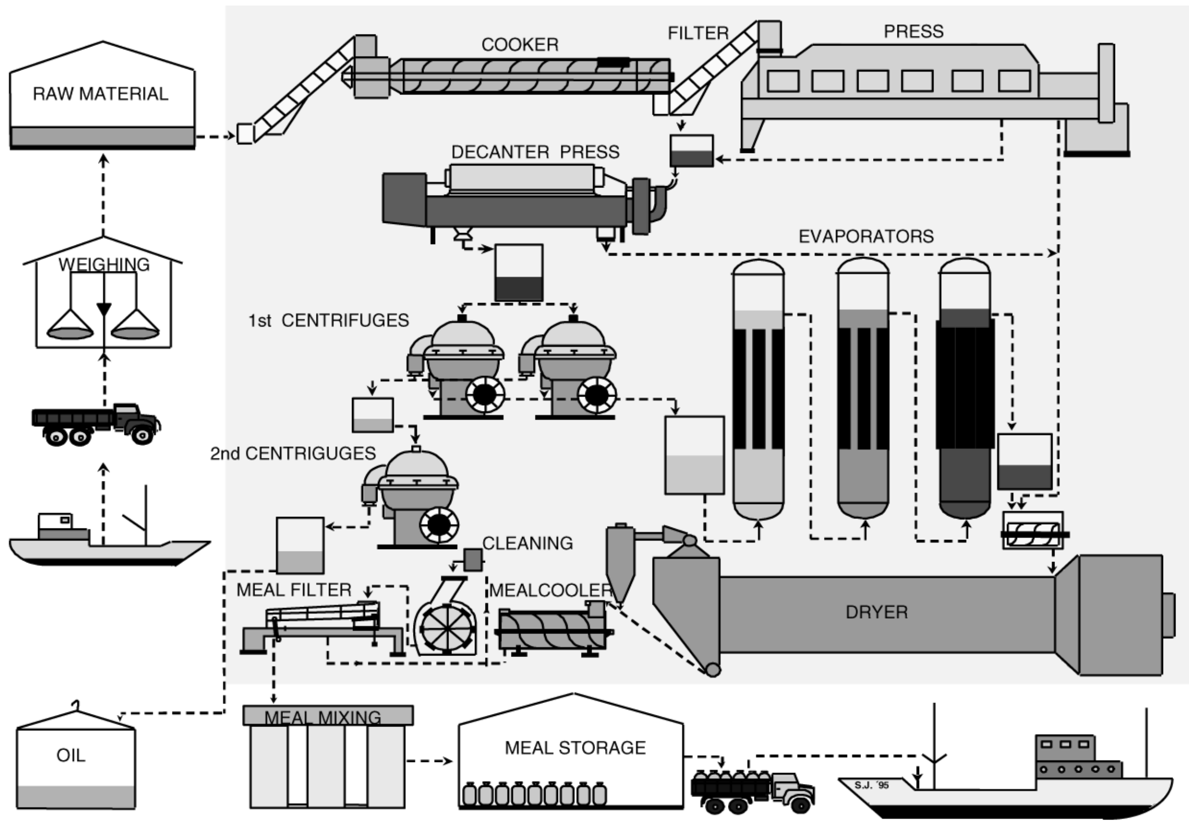

Figure 1.14 - Fish meal plant with fish meal and oil streams (Kristbergsson and Arason, 2007)

Fish body oils are so called because they are made from the processing of the whole fish of pelagic fishes. In general, fish oil is utilized in animal feed but not in direct human consumption. Fish oil primary processing results from fish meal plants in which the fish is cooked, pressed and the oil separated from the solid component and water, with three-phase centrifuges (Kristbergsson and Arason, 2007).

Because fish oils are highly unsaturated with long-chain fatty acids, they are very prone to oxidation. Some fish oils are less sensitive due to natural antioxidants present in the oil or to the difference in or lack of pro-oxidants. It has been shown (Bragadóttir *et al.*, 2002, 2004) that the quality of fish meal and oil from capelin is high and even better than from other species. Recently, research has been made to direct the capelin oil to human consumption (Kristbergsson and Arason, 2007).

This recent interest in polyunsaturated fatty acids for human consumption started with the observations of Bang and Dyerberger (1981) on how heart failure rate was low in the Inuit's (Greenland), even though there was a high-fat diet, and the author´s correlation to the polyunsaturated fatty acids in the population diet (Kristbergsson and Arason, 2007). Afterwards Kinsella (1986) documented the beneficial effects of fish oils and omega-3 fatty acids on the cardiovascular system, topic that is still subject to research worldwide (Kristbergsson and Arason, 2007).

Regarding cod, its liver is around 10% on the ungutted cod and the bulk of cod liver oil is utilized for direct human consumption, consumed as a dietary supplement as capsules or liquid (Kristbergsson and Arason, 2007). Falch *et al.* (2006) estimated that the production of 10,000 kg of cod fillets (gadoid species) generates by-products with more than 1,000 kg of marine lipids from which more than 30% are omega-3 fatty acids. Nowadays the research for the production of fish oils and concentrates with additional omega-3 content has been emphasized, with special focus on the content and ratio of eicosapentaenoic acid (EPA) to docosahexaenoic acid (DHA) (Kristbergsson and Arason, 2007). Another study that increased the interest on cod liver oil and other fish oil was made by Bourre *et al.* (1993) and Makrides *et al.* (1995) linking the infant brain development and function to fatty acids from fish oils (Kristbergsson and Arason, 2007).

Even though all the cod liver brought ashore is being utilized, mostly for the production of dietary supplements, still significant quantities of round fish liver are discarded at sea in Iceland. An alternative utilization for cod liver is in canned form, although its production (around 200 t in Iceland) is small due to the lack of raw material (Kristbergsson and Arason, 2007).

Although the health benefits of LCPUFA in fish oil have been emphasized recently, there are other interesting compounds in the fish liver oil of some shark species such a squalene. On the other hand, some ether-type fish oils like shark liver oil have specific characteristic such as being fully saturated and thus not prone to oxidation but still at liquid form at room temperature. These ether oils have high potential for unique industrial applications due to their characteristics. Fish oils are expected to be even more important in the pharmaceutical and health food industry in the future provided there is improved separation techniques and more gentle processing methods (Kristbergsson and Arason, 2007).

Another marine by-product with potential added value is fish skin. The scales of fish skin can be used as raw material for pearl essence – the shimmery product utilized in cosmetics (Anon, 2006). Mostly it is made of herring scales imported from the United States of America (USA) (Kristbergsson and Arason., 2007).

Fish skin can also be tanned for processing as leather. For example, Atlantic Leather Inc. (http://www.atlanticleather.is/) is expanding their products from simple items for the tourist industry to more conventional goods, signing contracts with Nike for footware and Dior for fashion items (Kristbergsson and Arason, 2007).

Regarding crustaceans, the production of shrimp (either from capture or culture) has increased to 4.2 million t in 2002 (FAOSTAT, 2004), thus leading to a major concern regarding the shrimp and prawn industry since the processing of peeled shrimps produces large quantities of "waste" (40% of the original mass) (Joesen and Villadsen, 1994). Kristbergsson and Arason (2007) consider that the processing of North Atlantic shrimp produces 30-40% of peeled shrimp with an estimation of 65% to 70% offal, in which 20-30% are soluble material consisted of small particle matter and 30-40% of solids (shell material). The growth of this shrimp and prawn processing industry, leading to the increase in the overall quantity of waste, together with the low degradation kinetics of the shell, caused the reinforcement of the environmental restrictions from several governments (Goosen, 1997).

This has increased the interest in alternative use of shrimp and prawn waste as raw material for highly profitable processes since it contains proteins, chitin and astaxanthin (colouring agent needed in salmon feed) (Kristbergsson and Arason, 2007). Veigarsson (1999) estimated the composition of the shell from North Atlantic shrimp as: around 34% calcium carbonate, 28% chitin and 38% protein, agreeing with the estimations of Shahidi and Synowiecki (1991): chitin content in crab and shrimp shells is 32% and 17% respectively, on dry weight basis. Kristbergsson and Arason (2007) concluded that the percentage of chitin depends on the species varying from 8 to 17% on a dry weight basis. Shrimp shells are a significant source of chitin, the second-most abundant biopolymer in nature after cellulose, which can be deacetylated to chitosan (Kristbergsson *et al.*, 2007).

Chitin polymers are embedded in a protein structure that can be calcified with salts forming the hard-shell structure. This biopolymer is constituted by *N*-acetyl-*D*-glucosamine (GlcNAc) units that are biodegradable but insoluble in water. By enzymatic or chemical hydrolysis in caustic soda, at elevated temperatures, the acetyl group connected to the amine group in the C2 position on the glucan ring can be removed and a deacetylated form is exposed. When this deacetylation is as high as 55% the polymer formed is called chitosan that acts like a polycationic electrolyte in acidic aqueous media. Because of its cationic nature (while other polymers are anionic under similar conditions), chitosan has many applications like in agriculture, foods and cosmetics with its properties being studied for medical and pharmaceutical applications (Kristbergsson and Arason, 2007).

Muzzarelli and Muzzarelli (2005) reported the special interest in medical applications, namely wound-healing properties of the oligomers produced by chitosan hydrolysis. It is also used as bone regenerator, water purifier by flocculation, dietary supplement with lipid binding and hypocholesterolemic properties (fig. 1.15).

Figure 1.15 - Example of a chitosan dietary supplement commercially available on Italian supermarkets.

To obtain chitin from shrimp shells it is needed to remove the mineral and protein matrix embedding the chitin by grinding the dried shells, followed by washes in concentrated acids and alkali in conditions and processes in order varying according to individual processors. After the drying and grinding of shells, astaxanthin can be salvaged with organic solvents. Recent collaborative works between the University of Tennessee and Massachusetts in the USA and the laboratories of the Iceland University, in cooperation with Primex INC, which is the main producer of chitin and chitosan in Europe, have led to the optimization of chitin and chitosan processing with ultrasound (Kristbergsson and Arason, 2007). Sachindra and Mahendrakar (2005) have optimized the extraction of astaxanthin utilizing vegetable oils but Kristbergsson *and Arason.* (2007) report that it is possible also with fish oil.

Other utilizations of aquatic by-products are the production of human food ingredients like surimi (Shahidi, 2007) or functional foods.

Presently, research is being made on the field of utilizing marine by-products for the production of 3D scaffolds for the replacement, repair and regeneration of several human tissues in regenerative medicine (Rodríguez-Valencia *et al*., 2014).

As a summary, fig. 1.16 is a schematic representation of the possible utilizations of fish-products for human consumption.

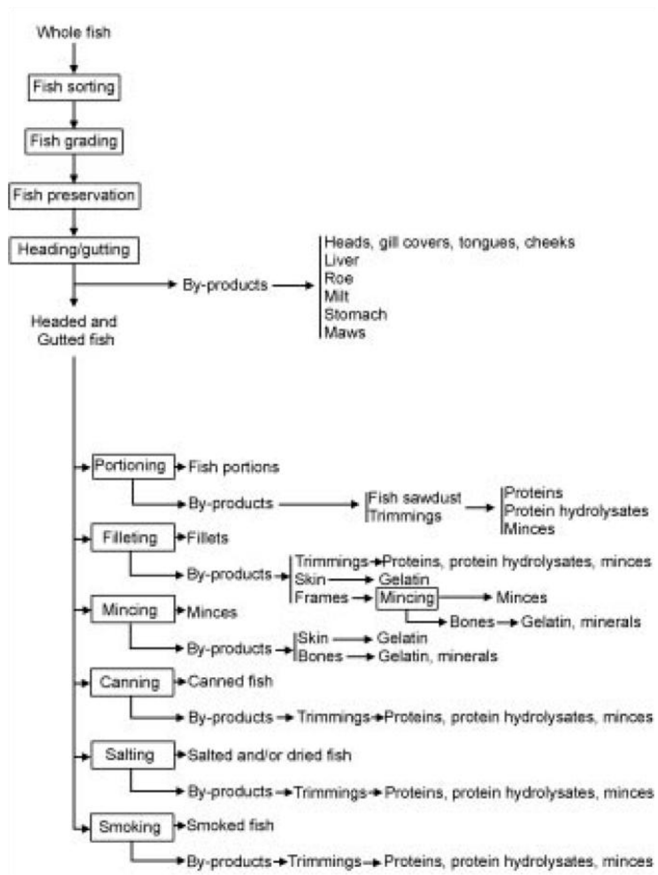

Figure 1.16 - Scheme for the utilization of fish by-products for human consumption in general (Batista, 2007).

1.7 Other initiatives to reduce waste and add value to marine by-products

In the context of "zero-waste" EU and FAO policies, one of the projects created to provide support to these actions was the BEFAIR initiative (Benign and Environmentally Friendly fish processing practices to provide Added value and Innovative solutions for a Responsible and sustainable management of fisheries in which France, Spain and Portugal were participating. This project aimed for the contribution to the minimization of the adverse ecological and environmental impact of fishing activities (both on board and on shore), by supporting fleets to comply with the "zero-waste" production on board. For this purpose several state of the art technologies to upgrade wastes and discards in order to obtain added value products were explored at a pre-industrial scale, mainly in the food industry but also in other sectors, like pharmaceutical. In this project, an user-friendly dynamic and multipurpose visual interface for simulating food and biotechnology processing plants (Taboada *et al.*, 2003; Vilas *et al.*, 2008) was developed (Alonso *et al.*, 2010).

Another initiative with the aim to minimize the discards and to optimize the valorisation of inevitable unwanted biomass was the FAROS Life +. The authors of this work analysed the most important discarded species in the selected *métiers* of interest, for the possibility of valorisation options in a variety of sectors, including food products for human consumption. Protocols were established to determine the most suitable valorisation strategies for each of them. For this, the authors analysed several factors like the status of stocks in the environment, the valorisation potential of each species or by-product and the amounts discarded by each *métier*. The aim of this valorisation work was to produce protein hydrolysates, peptones, enzymatic mixtures, fish oil with a high content of polyunsaturated fatty acids (PUFA) and other added-value biocompounds or high quality fish meal. These products are of interest for sectors like aquaculture or food (Pazo *et al.*, 2014).

BIOTECMAR (BIOTEChnological exploitation of MARine products and by-products) was another project in this line. In this project, the partners involved (Spain, Ireland, Portugal and France) obtained quantitative and qualitative data for the main unused marine biomasses in their respective countries. This permitted the proposal of new approaches for the valorisation or production of compounds. A summary is given in table 1.6 (Sotelo *et al.*, 2011).

Table 1.6- Proposed value chains for marine by-products
(BIOTECMAR project, Sotelo *et al.*, 2011).

By-product and its origin	Component of the by-product to be valorised	Applications
Swimming crab from fleet discards	Chitin/Chitosan	Many
	Proteins	Food industry
	Crab flavor	Food industry
Whole fishes from auctions withdrawals and rejections	Fish meal	Feeds
	Protein hydrolysates	Feeds / Food industry
	Oil	Feeds / Food industry
	Enzymes	Industry / Feed ingredients
Fresh or frozen sardine by-products from the canning industry: rejected fish, heads, viscera, tails, cut offs	Protein hydrolysates	Feeds for aquaculture Foods
	Oil	Feeds / Food
	Enzymes	Industry / Feed ingredients
By-products from the frozen fish industry: fish "sawdust", cut offs	Protein hydrolysates	Feeds for aquaculture Foods
	Native proteins	Food industry
	Oil	Feeds / Food
Cod by-products: skin, bones, livers, effluents	Antifreeze proteins	Food / Medicine
	Colagen/gelatin	Food industry / Cosmetics
	Oil	Feeds / Food
	Free aminoacids: taurine and creatine	Dietetics

Another research on this area was the "Fish Value" - a Portuguese project in which a canning factory and several academic institutions made a consortium to add value to marine by-products.

The results , presented on the seminar “Fish Value” in 2013, show that it is possible to produce biodiesel from fish oil although the car engine would have to be adapted to a less viscous diesel (Dias, 2013 oral communication). Another utilization was the protein hydrolysates of the fish boiling water from which the insoluble fraction could be used for incorporation in foodstuffs and the soluble fraction as a protein substitute in foods (Carvalho, 2013 oral communication). From the scales, collagen and gelatine can be extracted. Collagen can be used in cosmetics due to its water retaining properties; in biomedics, in bone implants, recuperation of soft tissues and as haemostatic, among other utilizations (Ferraro *et al*, 2013). Another component extracted from the scales was hydroxyapatite. Besides its orthopaedic and dental applications, hydroxyapatite can also be used as a biomaterial to remove heavy metal molecules from the aquatic environment (Piccirillo *et al*, 2013).

Given the importance and the various fields of applications of marine by-products, it is necessary to evaluate their quantity and type in order to utilize this resource fully. This study aims to evaluate the situation in Portugal regarding marine by-products.

2 MARMED PROJECT AND STUDY AIMS

The MARMED project - Development of innovating biomedical products from marine resources valorisation (2011-1/164), funded from the European Regional Development Fund through the Atlantic Area Transnational Cooperation Program, is a project with several partners within the Atlantic area that aimed at the development of innovative biomedical products from marine by-products.

The objective of this work, developed in the frame of this project, was the characterization of the sources, quantity, main utilizations and valorisation of marine by-products in Portugal and the assessment of potential utilizations to add value to marine by-products in Portugal.

3 DATA SOURCES AND METHODOLOGY

In order to analyse a group of Portuguese fish farmers and enterprises of the fisheries sector, a descriptive survey utilizing a multi-method approach was used in order to evaluate the variables "quantity of marine by-products produced/available in Portugal" and "quality (type) of marine by-products produced/available in Portugal". The several data collection instruments utilized were: 1- questionnaires sent out by email or fax, 2- standardized interviews and 3- documental analysis.

1- Questionnaires (see appendix) with quantitative, open questions were sent by email or fax (according to the contact available) to the Portuguese industries related with marine by-products and registered with veterinary control number available at DGAV in 2013. As the study was progressing, several other companies were contacted and it became evident that they were working without veterinary control number; therefore, the questionnaire was also sent to those companies. Some of the companies contacted were unable to receive the questionnaire sent by email or fax, by several unidentified reasons; therefore, for this study, only those questionnaires that were successfully delivered were considered, in a total of 237. The distribution of the successful sent out questionnaires by industry category is summarized in table 3.1.
As a method of approach to respondents (Oppenheim, 1992), the purpose of the research was stated in the introduction of the questionnaire as well as the length and duration of it.
From the replies received the total quantity of marine by-products per region was calculated by summing the quantities of marine by-products generated or processed, declared on each questionnaire. This type of data aggregation was a choice to maintain the replying companies confidential and also to give a regional characterization of Portugal in terms of available marine by-products.

2- Standardized telephone interviews were scheduled with 30 companies distributed by several industry categories as summarized in table 3.1. This methodology was utilized when the contact person of a certain company was known, thus facilitating the communication or when the companies to whom the questionnaire was sent replied stating their preference for telephone interview rather than questionnaire reply. The responses were noted down during the telephone conversation and the data obtained was aggregated by region.

Table 3.1 - Distribution of successful sent out questionnaires and invitations for interviews by industry categories.

	Questionnaires sent successfully:				Invitations for interviews	Total
Industry type	By email	By fax	On the company's website form	Total questionnaires		
Codfish salting	42	8	-	50	-	50
Fresh and frozen fish	109	49	1	161	4	165
Fish canning	1	11	-	12	2	14
Macro algae production	1	-	-	1	-	1
Microalgae production	-	-	-	-	1	1
Bivalve purification centre	-	2	-	2	-	2
Biogas plant	8	-	-	8	-	8
Auction	-	1	-	1	-	1
Distribution (hypermarkets, distribution centres, municipal markets)	-	1	-	1	10	11
Aquaculture	3	-	-	1	-	3
Shellfish	-		-	-	1	1
Fish meal plants					6	6
Caviar production					1	1
By-product operators (transportation, other valorisation than fish meal)					4	1
Scientific centre for marine research					1	1
Total	164	72	1	237	30	267

3- Official sources (content analysis of records)

Several official sources were consulted namely: the General Directorate of Veterinary (DGAV), the Regional Directorates of Veterinary Services – North and Tagus Valley, the Portuguese Agency for the Environment (APA), the Institute of Financing Agriculture and Fisheries (IFAP), the National Institute of Statistics (INE) and the General Directorate of Natural Resources, Security and Maritime Services (DGRM) that belong to the Ministry of Agriculture, Sea, Environment and Territory Management. This research brought to light the daily reports on marine by-products received by one of the four Portuguese fish meal plants. These reports were analysed and the total quantity of by-products per region was calculated again keeping the confidentiality of the companies involved.

4 RESULTS

From table 4.1 one can see that the percentage of replies to questionnaires was low (less than 9%) as opposed to the interviews (more than 80%).

Table 4.1- Summary of the replies to surveys and standardized interviews in number and percentage.

Type of data collection instrument	Number of replies	Percentage of replies (%)
Questionnaires	21	9
Interviews	25	83
Total replies	45	17

In Portugal, the major part of fish discards occurs in trawlers. In the other segments of the fishing fleet, discards are not significant. Data on discards is not available on board so the estimations presented in this report are based on official and technical published reports for some segments of the trawling fleet or specific fisheries. The most discarded species was Atlantic chub mackerel (*Scomber colias*) and the least discarded was boarfish (*Capros aper*) (table 4.2).

When data from the same industry came from different sources the criteria of selection was: first, the reply to the questionnaire; second, the reply to the interview and third, the analysis of records. The reason why only 3 questionnaires were sent to aquacultures lies in the difficulty in obtaining information about working aquaculture companies in Portugal. Therefore only the contact of those 3 that have also processing factory and thus have a veterinary control number was available. During this project we also sent one informative flyer about the project, after which we had the reply of one company.

The Portuguese fish auctions registered two types of by-products: withdrawals and rejections. Withdrawals correspond to fish not sold in the auction due to the low price attained or absence of buyer, and rejections refer to spoiled fish that was not approved by the veterinary control. The total amount of withdrawals was 3,150 t and the total rejections in auctions of continental Portugal, Madeira and Azores was 764 t (INE, 2014) (table 4.3). The species that had more withdrawals was Atlantic chub mackerel (*Scomber colias),* followed by Atlantic mackerel (*Scomber scombrus*) and the one with fewer withdrawals was anchovy (*Engraulis encrasicholus*).

Table 4.2 - Discards by species in Portuguese ICES (International Council for the Exploration of the Sea) Division IXa.

Species	Quantity (t/year)	Data year	Reference
Atlantic chub mackerel (*Scomber colias*)	1006	2011	Prista and Fernandes, 2012b
Chub mackerel (*Scomber japonicus*)	739	2011	Prista and Fernandes, 2012b
Blue whiting (*Micromesistius poutassou*)	690	2011	Prista and Fernandes, 2012b
Boarfish (*Capros aper*)	8	2011	Prista and Fernandes, 2012b
Hake (*Merluccius merluccius*)	452	2013	Prista *et al.*, 2014
Sardine (*Sardina pilchardus*)	119	2011	Prista *et al.*, 2012c
Sharks	111	2011	Prista and Fernandes, 2012a

Figure 4.1 shows the evolution of rejections and withdrawals from 2005 to 2012. It is possible to see (corroborated by the results on table 4.3) that withdrawals are always in bigger quantity than veterinary rejections. It is also visible one maximum peak of withdrawals in 2009, corresponding to approximately 8500 t, followed by a significant decrease in the next years. The species that contributed the most for this peak was sardine. In the following years, the sardine capture and landings diminished greatly thus increasing the auction prices. Therefore sardine was not withdrawed anymore from the auctions and sold to the fish meal factories because the selling

price was superior to the compensation benefit the European Union gives when the fish selling price is under a certain limit (Batista, personal communication, 8th December, 2015).

On the other hand, rejections increased drastically from 2009 to 2012, reaching approximately 100 t in 2012.

Table 4.3 - Withdrawals of whole fish at the national fish auctions (INE, 2014).

Withdrawals and rejections (2013)	
Withdrawals by species	Amount (t)
Anchovy (*Engraulis encrasicolus*)	1
Horse mackerel (*Trachurus trachurus*)	310
Atlantic chub mackerel (*Scomber colias*)	1284
European conger (*Conger conger*)	6
Pout (*Trisopterus luscus*)	35
Hake (*Merluccius merluccius)*	31
Monk fish (*Lophius piscatorius*)	20
Atlantic mackerel (*Scomber scombrus*)	899
Sardine (*Sardina pilchardus*)	564
Withdrawals in fish auctions	3150
Rejections in fish auctions	764
Total withdrawals and rejections	3914

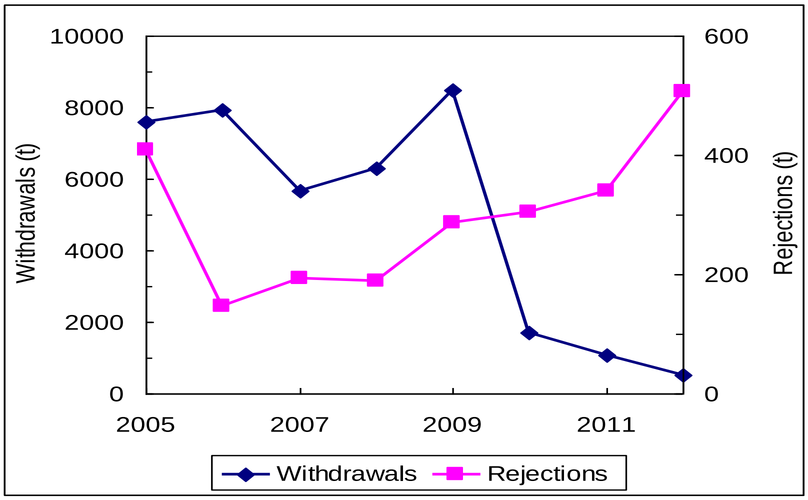

Figure 4.1- Evolution of auction rejections and withdrawals (Batista, 2013 oral communication).

As it can be seen in fig. 4.2 fish canning industry is the major producer of marine by-products, particularly in Azores. According to the replies to the survey, in continental Portugal the main producers of marine by-products are the cod salting industry in the central region of the country, where the factories are mostly located in the “Ria de Aveiro” region. This result may indicate a bias, since this central area of Portugal was where we got the major part of the replies. The production of marine by-products by the fresh and frozen industry was also higher in the central area of the country.

Given the reduced percentage of replies (45 in total) this mapping of the available marine by-products in Portugal is simply indicative.

Regarding fish meal plants, fig. 4.3 shows their location in continental Portugal and in Pico, Azores. Interesting to notice that there are marine by-products generated in Spain (namely Andaluzia, (fig. 4.2) that are processed in Portugal and by-products generated in Portugal that are processed in Spain. In S. Miguel island, Azores, marine by-products are dumped in landfill while others are incinerated in biogas plants due to the absence of fish meal plants or other marine by-products processing techniques. In Madeira island, the by-products are mainly dumped to landfill.

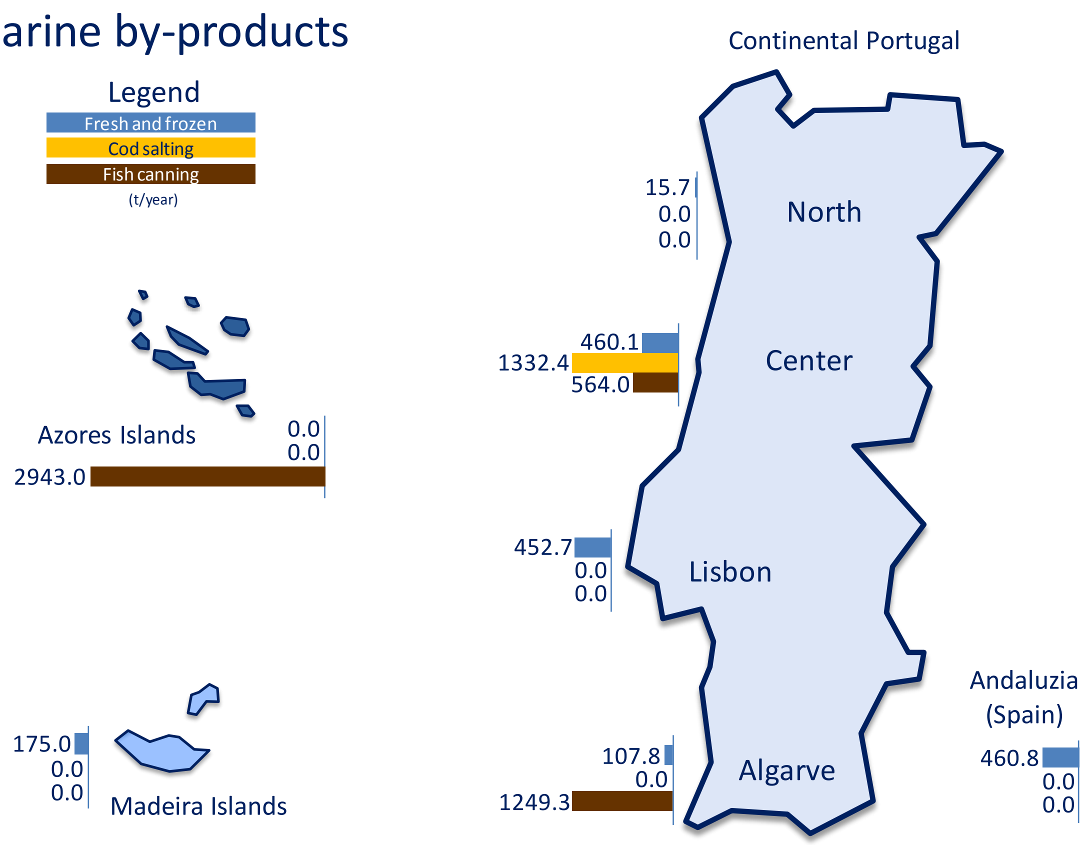

Figure 4.2 - Regional distribution of marine by-products available in Portugal.

also because of the inexistence of other processing alternatives. Based on the information collected from the fish meal plants it is possible to estimate the yearly quantity of marine by-products processed in Portugal as approximately 135,000 t/year. There are also around 150 t of marine by-products processed together with cattle meat.

Figure 4.4 shows the available data from one fish meal plant, based on the daily reports of the quantities of marine by-products received by this plant and delivered to General Directorate of Veterinary. Some months have no information due to the absence of reports. From this graph it is evident that the by-products from cod fish salting industry are higher in the months of October to December. Fish canning by-products, on the other hand, are higher in the months of January and March, while marine by-products from the fresh and frozen industry had its peak in May.

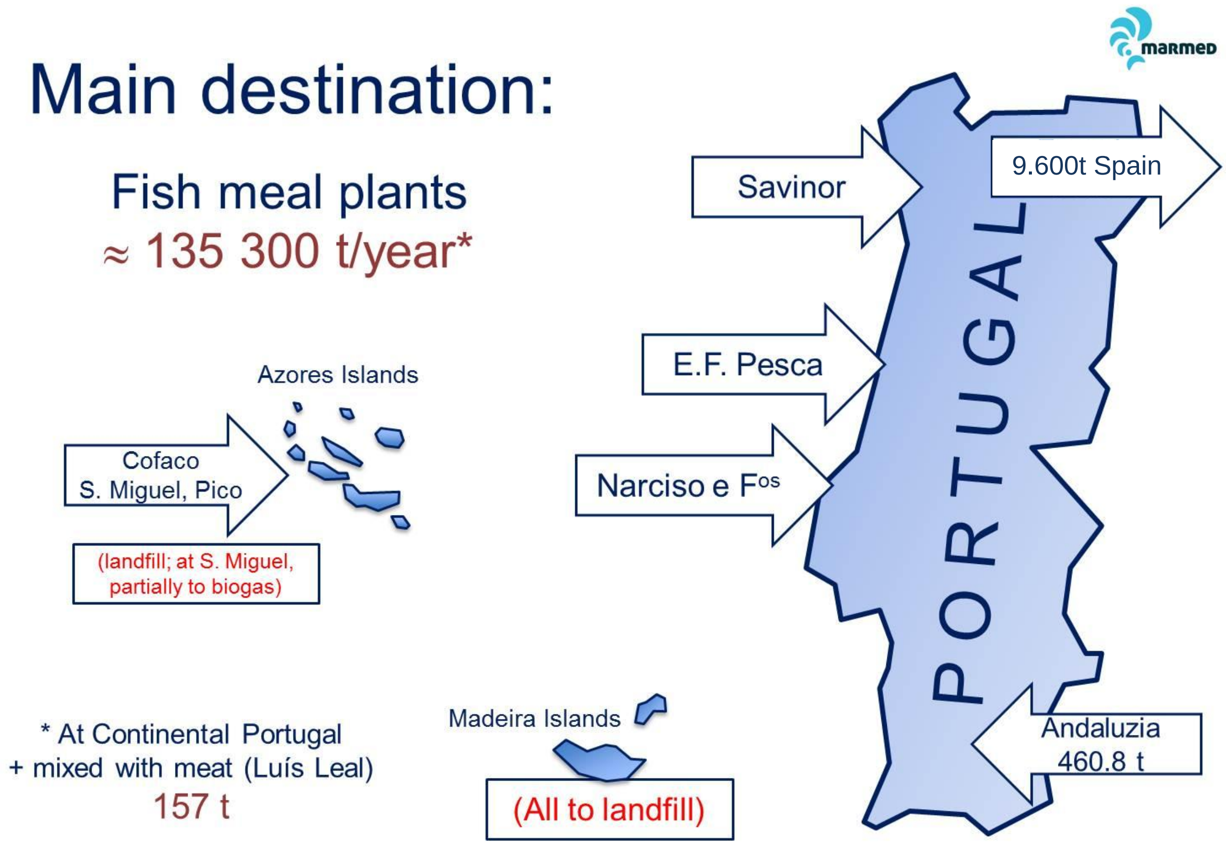

Figure 4.3 - Main destination of marine by-products available in Portugal.

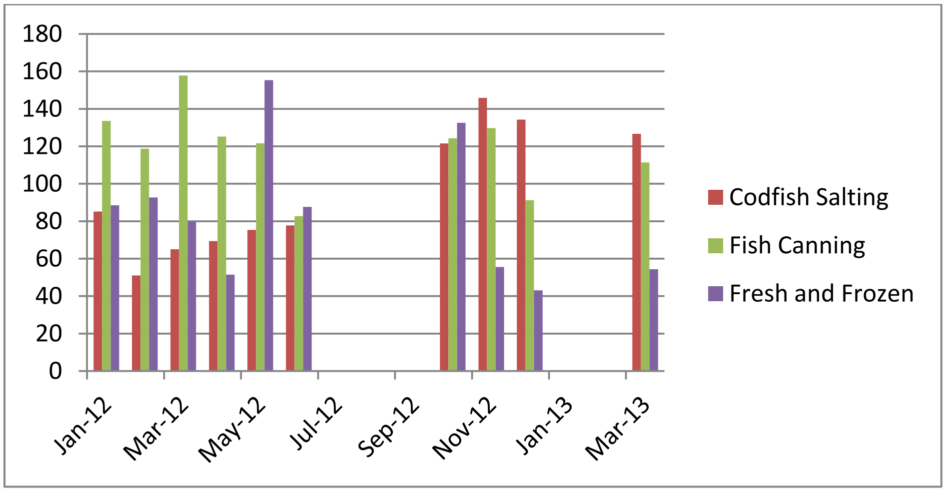

Figure 4.4 - Monthly evolution of marine by-products received by a fish meal plant in continental Portugal.

5 DISCUSSION OF RESULTS

As the replies to the multimethod approach survey sent to the Portuguese marine industries were received, several situations became clear. The interviews (83% of replies) were much more successful than the questionnaires (9% replies), making a total of approximately 17% replies. One reason could be that the questionnaires were not anonymous thus potentially causing some type of threat (fear of crossed information with the finances department or other reasons) for the companies.

One suggestion for future works in this area would be the creation of a web platform for the questionnaire filling, to keep the anonymity of the companies like in previous studies (Martins, 2011). In this case the questionnaires would need to be reformulated to ask at least the geographic information, number of employees and other relevant information of the company in order to classify and map the national distribution of marine by-products available.

In general, the gathering of information in this work was difficult due to several reasons like the economic crisis making the companies fearful of communication, the company's challenges in drawing long term strategies, narrow mentality of the industrials not valuing the importance of available data for scientific research, lack of workers to reply to emails and lack of crossed information. During the MARMED project an explanatory flyer was made, so when it was available it was sent to all the marine industries in Portugal as a source of information. After this, one more company replied to the questionnaire saying that the work was very interesting and they would like to establish a partnership with the academia for the utilization of their by-products. This example shows that information and education is needed to change mentalities and improve the communication and relationships between the academia and the industry. Although a long term project, this investment in the education, may improve the mentalities and the communication between the academia and the industry.

Another action to improve these relationships could be the involvement of the industry in the decision making phase regarding scientific projects, thus giving them the opportunity to be involved since the beginning and therefore improving their participation in the projects/consortiums as a major interested partner.

Another challenge faced during this work was the lack of an organization or institution centralizing all the information on fisheries, marine industries, quantity of marine by-products generated and other relevant topics as it happens in other countries of the Atlantic area, like the United Kingdom, where the Seafish organization does this work of centralizing all relevant information (http://www.seafish.org/). In Portugal it is clear that the state is lacking the means to gather this information and make it available for the academia or the public in general.

On the other hand, the Portuguese state should improve its management system, since it was clear, as the study was proceeding, that many companies were working without veterinary control number. Among other important and obvious consequences, this makes it impossible to trace or contact them. This type of information should be regularly updated because throughout this work many of the companies were already closed, fact that was not registered in the site of the General Directorate of Veterinary, but became clear due to the returned to sender of some flyers received with the post message stating that the company was no longer working. On the other hand, 3 out of 4 of the fish meal plants, obliged by law to send their daily reports of the by-products received, do not do it, thus increasing the difficulty on the information collection.

Regarding discards, there is no information about some of the on-board activities. Therefore, the number of discards is based on reports of the ICES group, unfortunately not available for all fishing activities. However, these reports contain very important information, namely on the types of by-products. The reason why this information is vital is that the researchers and industrials involved in the utilization of the by-products need to know the species producing them in order to manage the systems according to the raw materials available. This information of the by-products generating species is absent in other areas of the marine industry, like the transformation industry.

About rejections and withdrawals in Portugal, it is clear that the withdrawals have much more impact than the rejections, being the latter almost negligible (around 700 t/year). The increase in veterinary rejections before auctions since 2006 (fig. 4.1) may indicate more efficacy in veterinary control at the auction level.

The industry that produces more marine by-products is the fish canning (fig. 4.2). This is also found in previous studies (Sotelo *et al.*, 2011). It is also interesting to notice that there are around

400 t/year of undifferentiated marine by-products generated in Andaluzia that are actually processed in Portugal and around 10,000 t/year of by-products generated in Portugal that are processed in the North of Spain (fig. 4.3). Fig. 4.2 shows the fish canning factory in Azores as the biggest producer of marine by-products, while in continental Portugal the major contributions are the cod and salting industries in the central region of the country and the fish canning industry in the South. This study, particularly this mapping of the available by-products in Portugal, may contribute to the information needed for future researchers and later on industrials interested in marine by-product valorisation, since the knowledge of type of raw material and where and when it is available are basic requirements to a business plan. Together with fig. 4.3, fig. 4.2 gives a valuable insight for researchers and future industrials where the marine by-products are available in Portugal and where they are already being used by fish meal plants.

The flow of by-products (from Spain to Portugal and vice-versa) is managed by financial market conditions and not necessarily by practical reasons like the by-products being processed in the nearest processing plant. These may lead to a decrease in the quality of by-products, depending on the conditions in which they are transported, being vital to ensure they are transported frozen (or by using other long-term preservation method) to preserve their quality. One of the biggest challenges in the management of marine by-products processing plants is the unpredictable quantities of raw material received (daily and monthly) (fig. 4.4). This variation is due, not only to the seasonal variations in the amounts and types of species caught in the fisheries or harvested in aquaculture, but also on the market laws and competition for the by-products that presently are not enough for the 4 fish meal plants existing in Portugal.

One possible improvement for this situation would be to create small valorisation plants throughout the country, near marine by-products producing units thus reducing the transport distance of the by-products and improving their quality on the arrival. This would increase their added value since they could be utilized in more profitable ways like protein hydrolysates, for example.

Also to improve the quality of marine by-products, in general, Rustad (2007) suggests bringing the catch on-shore ungutted to be properly processed, under controlled circumstances. A study in Norway showed that cod could be gutted on-shore up to 12 hours after the catch with no negative effects on the quality of the fish or even the by-products. When the cod is spawning, thus with low filling in the stomach/intestines it can wait 48 hours to be ungutted, on the other hand cod that was heavily fed should not be kept for more than 12 hours for gutting. The author stresses the importance to develop methods with the aim to preserve the different by-products fractions. These methods (for example chilling, freezing, drying, fermentation and use of preservatives like antioxidants) should be specific for each application of the by-product.

Another field that needs more research are the extraction methods of interesting fractions/biomolecules. All these processes should take in consideration the variations due to season, habitat and species, and be optimized regarding yield, product quality and processing costs. To achieve this optimal utilization the characterization of the raw material in terms of chemical composition and enzymatic activity is needed. Marine by-products are only profitable if there is market interest to make them economically viable and for that this knowledge about their composition is a necessity. Environmental restrictions to the waste of marine by-products and underutilized species and economic incentives to their valorisation are also ways to promote their utilization thus increasing their viability (Rustad, 2007).

Another crucial point in the improvement of the quality of marine by-products is the handling of the catch. With the new techniques that allow gentle automatic processing of fish for the removal of viscera, it is possible to increase the yield and preserve the different fractions of the by-products, thus allowing an increased price for the most valuable parts. This automatic process for the utilization of individual by-products has to follow three stages: 1- viscera gentle removal thus allowing the undamaged preservation of each fraction, 2- automatic recognition and separation of specific fractions and 3- automatically sorting of the separate fractions. The process of gentle handling on-board retains the biological membranes that act as a physical barrier to biochemical deterioration increasing the preservation of the by-products (Falch *et al*, 2007).

Not only is important the gentle handling of the catch but also the hygienic conditions in which they are handled and processed to reduce microbial development and unwanted enzymatic activity.

For the improvement of by-products quality it is also important the preservation method. For example, chilled sea water is preferred to the use of ice because the catch is cooled more rapidly, there is less effort to stow and unload, less possibilities for the fish to be crushed or lose weight and the possibility of reducing the temperature of sea water to -1ºC not freezing the fish inside it (Falch *et al*, 2007).

Another strategy to preserve the by-products is the addition of acid, immediately after processing to reduce the pH and liquefy the by-products (Falch *et al*, 2007). The author also suggests drying raw material on-board as another solution for the improvement of by-products quality because dry matter is lighter than wet matter (thus reducing the weight of the vessel and as a consequence the fuel costs) and also because it occupies less space/volume on-board. Other possibilities to optimize the by-product management are the immediate use of cut-offs and trimmings from the processing of white fish on-board to produce fish mince or wash them to produce surimi.

Other challenges in by-product management include the handle, store and transport of bulk products, thus being limiting factors for the processing and utilisation.

Studies on the quantity and quality (chemical composition, etc.) on by-products are extremely important. Fishbase (www.fishbase.org) has a comprehensive database that includes a processing table for each species showing information on the weight distribution of by-products and also some information on the composition.

Falch *et a,l* (2007) stresses the importance of having predictable quantities and raw material with potential to produce standardized (as much as possible) products that are able to satisfy customers.

In order to analyse the profitability of by-products processing and to choose where to process them, on-board or on-shore, a program was developed - MaxFish - to help to calculate the possible output and profitability of a given catch (fig. 5.1). Until now cod species data (weights and fractions) are the basic information of the program's database. To increase the usefulness of the program is needed more information on chemical composition and their variation on cod species and also more information of other species of interest (Falch *et al*, 2007).

Studies on the viability of extracting molecules or fractions of interest from marine by-products were also executed on the BIOTECMAR project, namely on the extraction of asthaxanthin from crustacean by-products and the recovery of marine aromas from mussel juice. This viability analysis for all fractions or molecules of interest should include the following:

1- Identification of the raw material: product description; origin and industrial processes related to the generation of this raw material

2- Quantification of the available raw material in its different sources

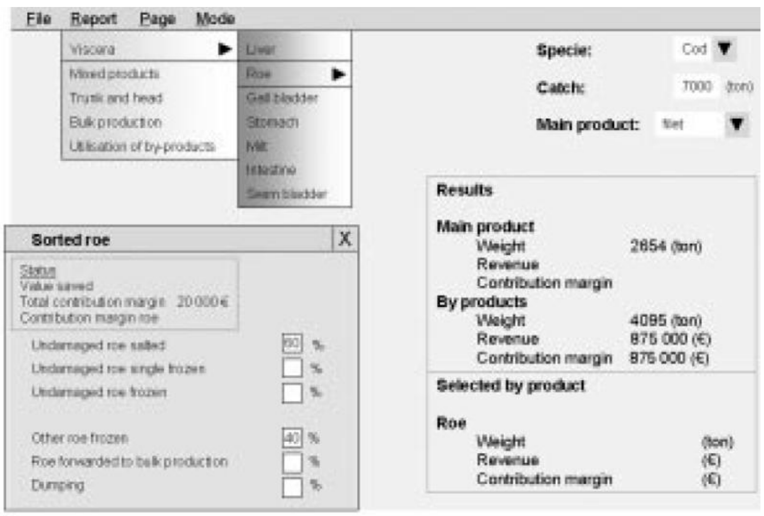

Figure 5.1 - An example showing applications for the MaxFish program to plan the utilisation of by-products (Falch *et al*, 2007).

3- Logistic: examples: temporality of supply, quality control and transport as obstacles for the compound of interest?

4- Legislation (namely European Legislation on marine by-products)

5- Costs analysis: several potential scenarios, analysis of raw material costs in specific sources

6- Costs of the extraction and transformation: extraction methods, search of the patents already existent

7- Economic viability: calculation of the cost per kg of the fraction or molecule of interest

8- Market analysis: competition analysis (competitors, price of the compound from synthetic origin or other natural sources, search for products rich in the compound, 9- Demand analysis: market segments, competitors

10- Diagnosis of the situation: SWOT analysis (strengths, weaknesses, opportunities, threats).

Since there are no perspectives for the catch from marine fisheries to rise in the future, the increase in the quantity of fish has to come from aquaculture. This will demand more feed that will necessarily come from agriculture, lower trophic levels (namely krill and plankton) and marine by-products (especially regarding marine oil). This increase in aquaculture will in turn generate more by-products with the possibility of being processed under controlled conditions and thus being utilized for added-value products or for products for human consumption (Rustad, 2007).

Nowadays the utilization of by-products is mainly for feed (fish meal and oil, and fish silage). Human consumption would be the potential for value addition to the by-products, namely as food ingredients or as nutraceuticals, thus requiring the raw material to be treated as valuable already on-board the fishing vessel or at the processing plant, with rapid sorting, storage and preservation or later processing into bulk products. Another measure needed for the improvement of the utilisation of by-products would be the implementation of stronger regulations regarding the waste of raw material by national and international authorities. Regarding the utilization of enzymes or other bioactive molecules found in marine by-products, they will always be found in very low concentrations and therefore their production will probably be made through genetic modified organisms (Rustad, 2007).

Regarding the valorisation of by-products for the production of functional foods or foods in general it is clear that the consumers, particularly in Portugal, where the traditional thought may create resistance to innovation, need to be educated and informed that the foodstuff produced from by-products contain the same properties than the original marine products, for the success of this type of valorisation.

On the other hand, with the implementation of marine products (either molecules of medical or other interest, functional foods, cosmetics, etc.) from the valorisation of by-products including non-target endangered species that will not be discarded, it will appear in the market products or active principles of these species thus making it difficult for a later management and tracing back the origin of these products. This may induce illegal catch of these species for the trade of their by-products or derived compounds, since their by-products will be already allowed in the market, so there will be a need for more effective systems of control and tracing back the origin of these compounds.

6 CONCLUSIONS

There is a need to educate, inform and motivate the marine industry managers regarding the importance of facilitating information to scientific researchers on a confidential basis, clarifying that there is no interference with their finances and taxes situation.

It would be helpful if all the information regarding marine by-products would be centralized in only one institution, like it happens in some other countries, in order to facilitate researchers to access and make good use of this information.

Another point to inform the marine industry managers is about other options (already being made in other countries like Spain, France and Scandinavian countries) to valorise the marine by-products in order to achieve successful consortiums in the future.

In Portugal the main utilization of marine by-products is fish meal and oil. To increase the quality of marine by-products for their improved valorisation, several measures can be taken: gentle handling of the catch to avoid unwanted enzymatic activity and microbial spoilage; choice of the appropriate preservation method, taking in consideration the further use of the by-products; when possible on-board processing of the by-products either by addition of acid or a drying process; appropriate choice of the place for gutting or processing the fish, on-board or on-shore depending on the maximum profit possible; use of software (like MaxFish) to help in the choosing of the best choice; appropriate store and transport of by-products, treating them as the catch itself. Another measure to improve marine by-products quality would be the construction of valorisation units near the by-products generating plants, thus reducing the time of transport, or implement measures to support the by-product treatment within the same facilities that generate them to avoid the need for new and expensive spaces and equipments only for by-product treatment. The advantaged in terms of proximity, and consequently in less degradation, would be maximised in this last case, thus reducing the time of transport.

Other options for the optimized processing of by-products would be their processing, or at least pre-processing, already inside the generating by-products units facilities. This would spare the construction of new facilities with increased costs and would allow the immediate utilization of the by-products with all the advantages on the level of quality improvement. All these solutions would need to take in consideration the economic viability.

For the viability analysis of marine by-products, several steps are to be taken in order to check the profitability of the resultant product. -

It is very important to perform research on the chemical composition and quantity of marine by-products available for the industrials to properly process them, in order to have products the most standardized as possible. Fishbase already has a database with some information on this topic.

7 REFERENCES

Ackman, R. (1989). Nutritional composition of fats in seafoods. *Progress in Food and Nutrition Science, 13*, 161-241.

Alasalvar, C.; Taylor, T. (2002). *Seafoods: technology, quality and nutraceutical applications.* New York, LLC: Springer-Verlag. pp. 17-31

Alonso, A.; Antelo, L.; Otero, I.; Perez, R. (2010). Contributing to fisheries sustainability by making the best possible use of their resources: the BEFAIR initiative. *Trends in Food Science and Technology, 21*, 569-578.

Alverson, D.; Freeberg, M.; Murawski, S.; Pope, J. (1994). *A global assessment of fisheries by-catch and discards.* FAO Fisheries Technical Paper No 339, Rome, FAO 233p.

Anonymous. (2006). Cosmetics. Retrieved February 2015, from http://en.wikipedia.org/wiki/Cosmetics

Aquaculture Portugal online magazine - Aquacultura em Portugal e no mundo, com especial destaque para os países lusófonos. (n.d.). Retrieved December 2014, from http://omeva.tumblr.com/

Arason, S. (2003). Utilization of fish by-products in Iceland. In P. Bechtel (Ed.), *Advances in seafood by-products 2002* Conference Proceedings, pp. 43-62. Fairbanks: Alaska sea grant college program, University of Alaska Fairbanks 566 pp.

Árgeirsson, B.; Bjarnason , JB. (1993). Properties of elastase from Atlantic cod, a cold-adapted proteinase. *Biochimica et Biophysica Acta, 1164(1)*, 91-100.

Ásgeirsson, B.; Bjarnason, JB. (1991). Structural and kinetic-properties of chymotrypsin from Atlantic cod (*Gadus morhua*) - comparison with bovine chymotrypsin. *Comparative Biochemistry and Physiology, 99(2)*, 327-335.

Ásgeirsson, B.; Fox, JW.; Bjarnason, JB. (1989). Purification and characterization of trypsin from the poikilotherm *Gadus morhua*. *European Journal of Biochemistry, 3*, 696-704.

Bang, H.; Dyerberg, J. (1981). The lipid metabolism in Greenlanders. *Meddelelser om Gronland, Man & Society, 2*, 18.

Batista, I. (2007). Chapter 8: By-catch, underutilized species and underutilized fish parts as food ingredients, pp. 71-195, In F. Shahidi (Ed.), *Maximising the value of marine by-products.* Cambridge: Woodhead Publishing in Food Science, Technology and Nutrition 532 pp.

Bergman, M.; van Santbrink, J. (2000). Mortality in megafauna benthic population caused by trawl fishereies on the Dutch continental shelf in the Notth North Sea in 1994. *ICES Journal of Marine Sciences, 57*, 1321-1332.

Bjarnason, J. (2001). Biotechnological applications of fish offal in Iceland. *Verdiskaping av marine biprodukter etter a˚r 2000.* Trondheim. Retrieved Jan 2015, from http://www.rubin.no/files/projects/attach/jonbragibjarnason.doc

Blanco, M.; Sotelo, C.; Chapela, M.; Perez-Martin, R. (2007). Towards sustainable and efficient use of fisheries resources: present and future trends. *Trends Food Science & Technology, 18(1)*, 29-36.

Bourre, J.; Bonneil, M.; Clement, M.; Dumont, O.; Durand, g.; Lafront, H.; Nalbone, G.; Piciotti, M. (1993). Function of dietary polyunsaturated fatty acids in the nervous system. *Prostaglandins, Leukotrienes and Essential Fatty Acids, 48*, 5-15.

Bozzano, A.; Sardà, F. (2002). Fishery discards consumption rate and scavenging activity in the northwestern Mediterranean Sea. *ICES Journal of Marine Science, 59*, 15-28.

Bragadóttir M.; Palmadóttir, H.; Kristbergsson, K. (2004). Composition and chemical changes during storage of fish meal from capelin (*Mallotus villosus*). *Journal of Agriculture and Food Chemistry, 11(3/4)*, 1572-1580.

Bragadóttir, M.; Palmadóttir, H.; Kristbergsson, K. (2002). Seasonal changes in chemical composition and quality parameters of capellin (*Mallotus villosus*). *Journal of Aquatic Food Product Technology, 11(3)*, 87-103.

Camphuysen, C.; Calvo, B.; Durinck , J; Ensor, K.; follestad, A.; Furness, R.; Garthe, S.; Leaper, G.; Skov, H.; Tasker, M.; Winter, C. (1995). *Consumption of discards by seabirds in the*

North sea. Final Report of EC DG XIV Research Contract BIOECO/93/10. NIOZ-Report 1995-5, Netherlands Institute for Sea Research, Texel 202 pp.

Carbonell, A.; De Ranieri, S.; Martín, P. (1997). *Discards of the western Mediterranean trawl fleets.* European Commission 142 pp.

Castro, M.; Araújo, A.; Erzini, K.; Monteiro, P.; Bozzano, A., Cartes, J.; Juliá, A.; Rotlland, G.; Sardà, F. (1999). *Methodologies to study the impact of discards in trawl fisheries.* Final report to the European Commission, DGXIV-Project 96-063. 83 pp.

Catarci, C. (2004). *World markets and industry of selected commercially-exploited aquatic species with an internaitional conservation profile.* FAO Fisheries. Retrieved from http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/006/Y5261E/y5261e06.htm

EC (1998). *Directive 2008 on waste and repealing certain directives.* Retrieved March 2013, from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF

EC (2007, 03 28). Communication from the commission to the council and the European parliament. *COM (2007) 132 final* .

EU (2004). *Regulation 853 laying down specific hygiene rules for the hygiene of foodstuffs.* Retrieved March 2013, from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:139:0055:0205:EN:PDF

EU (2009). *Regulation 1069 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing regulation (EC) Nº 1774/2002 (Animal by-products regulation).* Retrieved March 2013, from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:300:0001:0033:EN:PDF

EU (2013). Regulation 1380/2013 of the European Parliament and the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No

2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC. Retrieved March 2013, from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:354:0022:0061:EN:PDF

Falch, E.; Sandbakk, M.; Aursand, M. (2007). Chapter 3: On-board handling of marine by-products to prevent microbial spoilage, enzymatic reactions and lipid oxidation, pp 47-64 In F. Shahidi (Ed.), *Maximising the value of marine by-products.* Cambridge: Woodhead Publishing in Food Science, Technology and Nutrition 532 pp.

Falch, E.; Rustad, T.; Auursand, M. (2006). By-products from gadoids species as raw material for production of marine lipids as ingredients in food or feed. *Process Biochemistry, 41(3)*, 666-674.

FAO (1995). *Code of conduct for responsible fisheries.* Rome: FAO 41 pp.

FAO (2005). *Review of the state of world marine fishery resources.* FAO, FAO Fisheries. Rome: FAO Fisheries 14 pp.

FAO (2010). *Report of the technical consultation to develop international guidelines on bycatch management and reduction of discards.* FAO Fisheries and Aquaculture. Rome: FAO Fisheries and Aquaculture 32 pp.

FAO (2012). The state of world fisheries and aquaculture (SOFIA). Rome 209 pp.

FAOSTAT (2004). *Amount of shrimp and prawn harvested 2002.* Rome: FAO Statistical Databases.

Ferraro, V.; Carvalho, A.; Piccirillo, C.; Santos, M.; Castro, P.; Pintado, M. (2013). Extraction of high added value biological compounds from sardine, sardine-type fish and mackerel canning residues - a review. Materials Science and Engineering, C 33, 3111-3120.

Fishbase (08/2015). Retrieved March 2015, from http://www.fishbase.org/

Fonds, M.; Groenewold, S. (2000). Food subsidies generated by the beam-trawl fishery in the southern North Sea. In M. Kaiser, & S. Groot (Eds.), *Effects of Fishing on Non-target Species and Habitats* (pp. 130-150 pp). UK, UK: Blackwell Science.

Gill, T. (2000). *Waste from processing aquatic animals and animal products: implications on aquatic animal pathogen transfer.* FAO. Rome: FAO 26 pp.

Goosen, M. (1997). *Application of chitin and chitosan.* Lancaster: Technomic Publishing Company Inc 336 pp.

Gousset, J.; Tixerant, G.; Roblot, M.; Holvoet, C.; Jamet, J.; Schaan, M. A.; Auber, P.; Lagoin, Y.; Montassier, C.; Allemeersch, C.; Perre, D.;. (2001). *Les produits de la Pêche: poissons, custacés, Molllusques - Identification des principal espèces; qualité des produits.* Paris: Informations Services Vétérinaires français.

Groenewold, S.; fonds, M. (2000). Effects on benthic scavengers of discards and damaged benthos produced by the beam-trawl fishery in the southern North Sea. *ICES Journal of Marine Science, 57*, 1395-1406.

Gudbjarnason, S. (1999). Bioactive marine natural products. *Rit Fiskideildar, 16*, 107-110. Retrieved from http://www.hafro.is/Bokasafn/Greinar/Rit-fisk/rit_fisk_16–107.pdf

Gudmundsson, R. (2002). Rheological properties of fish gelatins. *Journal of Food Science, 67(6)*, 2172-2176.

Guérard, F. (2007). Chapter 6: Enzymatic method for marine by-products recovery, pp 107-143. In F. Shaidhi (Ed.), *Maximising the value of marine by-products.* Cambridge: Woodhead Publishing in Food Science, Technology and Nutrition 532 pp.

Gunnarsson, J. (2003). The functional properties of fishmeal; the effects of dryers. University of Iceland . Reykjavik, Iceland: University of Iceland library 143 pp

Hill, B.; Wassenberg, T. (1990). Fate of discards from prawn trawlers in Torres Strait. *Australian Journal of Marine and Freshwater Research, 41*, 53-64.

Huss, H. (1994). *Assurance of seafood quality.* FAO Fisheries. Rome: FAO.

INE, I. N. (2014). *Estatísticas da Pesca.* INE. Lisbon: INE.

Je, J.; Park, P.; Kwen, J.; Kim, S. (2004). A novel angiotensin converting enzyme inhibitory peptide form Alaska pollack (*Theragra chalcogramma*) frame protein hydrolysate. *Journal of Agriculture and Food Chemistry, 52*, 7842-7845.

Jensen, A.; Reider, R.; Kovalak, W. (1988). Estimation of production forgone. *North American Journal of Fisheries Management, 8*, 191-198.

Joensen, O.; Villadsen, A. (1994). Ecological sustainable production of chitin and chitosan. In Z. Karnicki, M. Brzeski, P. Bykowski, & A. Woitasz-Pajak (Eds.), *Chitin world* (pp. 38-47). Bremenhaven: Wirtschaftsverlag NW.

Katsiadaki, L.; Taylor, K. (1999). Assessment of quality of cod roes and relationships between quality and maturity stage. *Journal of the Science of Food and Agriculture, 79(10)*, 1249-1259.

Kelleher, K. (2005). *Discards in the world´s marine fisheries. An update.* FAO, FAO Fisheries. Rome: FAO 131 pp.

Kerry, J. (2007). Chapter 2: Physical and chemical properties of lipid by-products from seafood waste, 22-46 pp. In F. Shahidi (Ed.), *Maximising the value of marine by-products.* Cambridge: Woodhead Publishing in Food Science, Technology and Nutrition 532 pp.

Kim, S-K.; Mendis, E. (2006). Bioactive compounds from marine processing by-products - a review. *Food research Research international, 39*, 383-393.

Kinsella, J. (1986). Food components with potential therapeutic benefits - the n-3-polyunsaturated fatty-acids of fish oils. *Food Technology, 40(2)*, 89.

Kreuzer, R. (1974). Fish and its place in culture. In R. Kruzer (Ed.), *Fishery products.* west Byfleet, England: Fishing News Books Ltd.

Kristbergsson, K.; Arason, S. (2007). Utilization of by-products in the fish industry. In V. Oreopoulou, & W. Russ (Eds.), *Utilization of by-products and treatment of waste in the food industry* (Vol. 3, pp. 233-258). United States of America: Springer US.

Kristinsson, H.; Theodore, A.; Demir, N.; Ingadóttir, B. (2005). A comparative study between acid- and alkali-aided processing and surimi processing for the recovery of proteins from channel catfish muscle. *Journal of Food Science, 70(4),* C2698-C306.

Kristjansson, M.; Gudmundsdóttir, S.; Fox, JW.; Bjarnason, J. (1995). Characterization of a collagenolytic serine proteinase from the Atlantic cod (*Gadus morhua*). *Comparative Biochemistry and Physiology, 110(4)*, 707-717.

Legezynska, J.; Weslawski, J.; Presler, P. (2000). Benthic scavengers collected by baited traps in the high Arctic. *Polar Biology, 23*, 539-544.

Liang, Y.; Hultin, H. (2005). Effect of pH on sedimentatiton of cod (*Gadus morhua*) muscle membranes. *Journal of Food Science, 70(2)*, C164-C172.

Makrides, M.; Neumann, M.; Simmer, K,; Pater, J.; Gibson, R. (1995). Are long-chain polyunsaturated fatty-acids essential nutrients in infancy. *Lancet, 345(8963),* 1463-1468.

Martins, W. (2011). *Inquérito exploratório referente à geração, armazenamento, transporte e descarte de resíduos em indústrias de pesca do Brasil.* School of Agriculture "Luiz de Queiroz". Piracicaba: University of São Paulo 99 pp.

Mei, M.; Gudmundsdóttir, G.; Thorkelsson, G.; Arason, S.; Kristbergsson, K. (2003). Reforming fish cut-offs into fillets with texture resembling intact fish flesh. *IFT Annual Meeting Book of Abstracts* (pp. 40-9). Chicago: Institute of Food Technologists.

Muzzarelli, R.; Muzzarelli, C. (2005). Chitosan chemistry: relevance to the biomedical sciences. *Advances in Polymer Science, 186*, 151-209.

Nations, U. (2004). *Johannesburg Plan of Implementation IV. Protecting and managing the natural resource base of economic and social development.* Retrieved April 2015, from UN Department of Economic and Social Affaris, Division for sustainable Sustainable development Development (online): www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/POIChapter4.htm

OECD (2002). *Multilingual dictionary of fish and fish products* (5th ed). Paris: Wiley-Blackwell.

Olsen, R. (2013). *Keynote speech.* Tromso: Western European Fish Technologists Association (WEFTA).

Oppenheim, A. N. (1992). *Questionnaire design, interviewing and attitude measurement* (2nd ed.). New York: Continuum 303 pp.

Oro, D.; Ruiz, X. (1997). Exploitation of trawler discards by breeding seabirds in the north-western Mediterranean: differences between the Ebro Delta and the Balearic Islands areas. *ICES Journal of Marine Sciences*, *54*, 695-707.

Pazo, T.; Antelo, L.; Franco-Uría, A.; Pérez-Martin, R.; Sotelo, C.; Alonso, A. (2014). Fish discards management in selected Spanish and Portuguese *métiers*: identification and potential valorisation. *Trends in Food Science and Technology, 36*, 29-43. Retrieved from http://dx.doi.org/10.1016/j.tifs.2013.12.006

Piccirillo, C.; Silva, M.; Pullar, R.; Braga da Cruz, I.; Jorge, R.; Pintado, M.; Castro, P. (2013). Extraction and characterisation of apatite- and ticalcium phosphate-based materials from cod fish bones. Materials Science Engineering, C 33, 103-110.

Polis, G.; Strong, D. (1996). Food web complexity and community dynamics. *The American Naturalist*, *147*, 813-846.

Prista, N.; Fernandes, A. C.; Martins, M. M.; Gonçalves, P. (2012c). Discards of boarfish, atlantic Atlantic mackerel, chub mackerel and blue whiting by the Portuguese bottom otter trawl fleet operaiting in the Portuguese ICES division IXa. *Working document for the ICES working group on widely distributed stocks (WGWIDE).* Lowestoft: ICES.

Prista, N.; Fernandes, A. (2012a). *Update on Portuguese bottom otter trawl discard data (WGHMM species).* Workign Document for the ICES Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM2012), Copenhagen.

Prista, N.; Fernandes, A. C. (2012b). Elasmobranchs discarded by the portuguese bottom otter trawl fleet. *Working document for the ICES working group on elasmobranch fishes (WGEF).* Lisbon: ICES.

Prista, N.; Fernandes, A. C.; Pereira, C.; Alpoim, R.; Borges, F. (2014). Discards of WGBIE species by the portuguese bottom otter trawl operating in the ICES division XIa (2004-2013). *Working group for the Bay of Biscay and the Iberic Waters Ecoregion (WGBIE 2014)*. Lisbon: ICES.

Ramsay, K.; Kaiser, M.; Moore, P.; Hughes, R. (1997). Consumption of fishery discards by benthic scavengers: utilization of energy subsidies in different marine habitats. *Journal of Animal Ecology, 39*, 884-896.

Rodríguez-Valencia, C.; Chiussi, S.; López-Álvarez, M.; Serra, J.; Stefanov, S.; González, P. (2014). Biomineralization of marine-patterned C-scaffolds. *Bioinspired, Biomimetic and Nanobiomaterials, 3*(BBN2), 1-9.

Rustad, T. (2007). Chapter 1: Physical and chemical properties of protein seafood by-products, 3-21 pp. In F. Shahidi (Ed.), *Maximising the value of marine by-products.* Cambridge: Woodhead Publishing in Food Science, Technology and Nutrition 532 pp.

Rustad, T.; Storro, I.; Slizyte, R. (2011). Possibilities for the utilisation of marine by-products. *International Journal of Food Science and Technology, 46*, 2001-2014.

Sachindra, N.; Mahendrakar, N. (2005). Process optimization for extraction of carotenoids from shrimp waste with vegetable oils. *Bioresource Technology, 96(10)*, 1195-1200.

SEAFISH (2015). Retrieved from Seafish: http://www.seafish.org/

Shahidi, F. (2007). Maximising the value of marine by-products: an overview, XXI-XXV pp. In F. Shahidi (Ed.), *Maximising the value of marine by-products.* Cambridge: Woodhead Publishing in Food Science, Technology and Nutrition 532 pp.

Shahidi, F.; Synowiecki, J. (1991). Isolation and characterization of nutrients and value-added products from snow crab (*Chinoecetes opilio*) and shrimp (*Pandalus borealis*) processingn discards. *Journal of Agriculture and Food Chemistry, 39(8)*, 1527-1532.

Sigurdsson, A. (1992). *Patent No. 1491*. Iceland.

Sigurdsson, A. (1993). *Patent No. 5,226,848.* United States of America.

Sotelo, C.; Maguire, J.; Batista, I.; Borseau, P.; Guérard, F.; Floch-Laizet, C. (2011). *Marine Bbiomasses of the Atlantic Region.* BIOTECMAR.

Taboada, L.; Villafin, M.; Banga, J.; Alonso, A. (2003). Virtual interface for developing SCADA tools for chemical process. *II Ecosimpro user´s workshop.* Madrid: II Ecosimpro user´s workshop. Retrieved from www.ecosimpro

Taylor, K.; Himonides, A. (2007). Chapter 6: Increased processed flesh yield by recovery from marine by-products, 91-106 pp. In F. Shahidi (Ed.), *Maximising the value of marine by-products.* Cambridge: Woodhead Publishing in Food Science, Technology and Nutrition 532 pp.

Undeland, I.; Kelleher, S.; Hultin, H. (2002). Recovery of functional proteins from herring (*Clupea harengus*) light muscle by an acid or alkaline solubilization process. *Journal of Agriculture and Food Chemistry, 50(25)*, 7371-7379.

Veigarsson, H. (1999). Water management in Northern Shrimp muscle (*Pandalus borealis*) with emphasis on processing. University of Iceland. Reykjavík: University Library.

Vilas, C.; García, M.; Villafín, M.; Banga, J.; Alonso, A. (2008). Desarollo de una librería de componentes en ECOSIMPro para la operación de plantas de procesamiento térmico de alimentos. *Revista Iberoamericana de Automática e Informática Industrial, 5 (1)*, 51-65.

Waikato, U. o. (2012). *The Univeristy of Waikato*. Retrieved from http://www.waikato.ac.nz/

Wendel, A.; Park, J.; Kristbergsson, K. (2002). Recovered meat from Pacific whiting frame. Journal of *Aquatic Food Product Technology*, *11(1)*, 5-18.

Whittle, K.; Howgate, P. (2000). *Glossary of fish technology terms.* Rome: FAO.

8. Appendix

Questionnaire sent to the marine industries

Exmos. Senhores:

No momento atual torna-se mais importante ainda a correta gestão de todos os desperdícios da indústria alimentar, sobretudo na área do pescado, um alimento considerado cada vez mais importante na dieta humana actual.

Neste sentido, o Instituto de Ciências Biomédicas Abel Salazar (ICBAS) da Universidade do Porto é um dos parceiros do projeto MARMED: Desenvolvimento de produtos biomédicos inovadores a partir da valorização de recursos marinhos, no âmbito do Programa de Cooperação Transnacional da Área Atlântica
http://www.marmedproject.eu/

Na atividade 1 deste projeto prevê-se o levantamento das quantidades e tipos de materiais rejeitados pela indústria do pescado em Portugal, para constituir uma base de dados o mais completa e atual possível. Neste sentido, consideramos vital a colaboração da vossa empresa e pedimos o favor de preencher o pequeno questionário que surge abaixo neste email, bastando para isso responder, acrescentando a resposta a seguir a cada pergunta. Nas respostas numéricas bastam valores aproximados.

Por favor preencha a Parte II individualmente para os dois principais produtos fabricados. Prevê-se que o preenchimento demore cerca de 5 min. Por favor responda, quando adequado, tendo em consideração os dados relativos ao ano de 2012 ou, na sua falta, ao ano mais recente disponível.

Em caso de qualquer dúvida não hesite em nos contactar

Muito obrigada e os nossos melhores cumprimentos
Raquel Coimbra
Técnica Superior do Projeto MARMED
telefone: +351220428311

QUESTIONÁRIO:
Nome da empresa:
Descrição:

Parte I
Gerente:
Diretor comercial:
Diretor de Marketing:
Diretor de produção:
Controlo de Qualidade:
Morada:

Telefone:
Fax:
Email:
Sítio / Web site:
Nº de controlo veterinário:
Número de colaboradores:
Marcas Comerciais:

Parte II - Produto 1
Produto:
Produção anual (Peso total (t):
Valor de vendas anual (€):
Tipo de desperdícios (resíduos, sub-produtos e produtos derivados):
Destino actual dos desperdícios:
Entidade responsável pelo transporte dos desperdícios:
Entidade responsável pela eliminação ou valorização dos desperdícios:
Quantidade de desperdícios produzida (por cada tipo ou total (t):
Valor obtido com a eventual venda dos desperdícios (€ ou €/kg):

Parte II – Produto 2
Produto:
Produção anual (Peso total (t):
Valor de vendas anual (€):
Tipo de desperdícios (resíduos, sub-produtos e produtos derivados):
Destino actual dos desperdícios:
Entidade responsável pelo transporte dos desperdícios:
Entidade responsável pela eliminação ou valorização dos desperdícios:
Quantidade de desperdícios produzida (por cada tipo ou total (t):
Valor obtido com a eventual venda dos desperdícios (€ ou €/kg):

Informação adicional:
Se assim o entender faça um comentário sobre este questionário e/ou os objectivos deste projecto.

Nome da pessoa que respondeu ao questionário:

Muito obrigada pela sua colaboração!